CHAPTER VIII

SALT GRADIENT SOLAR POND : EXPERIMENTAL STUDY

8.1 INTRODUCTION:

The classical flat plate solar collector constructed of metal and other fabricated materials is limited in size to a few square meters. Large collecting areas are only possible by connecting an assembly of these units. Solar energy can be collected on a large area by constructing a solar pond.

A solar pond basically consists of a large containment volume, a salinity-stratified solution contained there in and associated equipment. In some respects the solar pond has much in common with a water retention pond and hence well established technologies can be employed for the construction. The important desirable thing for the construction of the solar pond is site selection. The following essential requirements are necessary to construct a solar pond such as high insolation, low wind speed, moving water table not too close, absence of wind-borne debris, relatively flat site and soil with good cohesion for walls. The basic consideration in any pond design are area, shape of surface, depth of each zone and slope of side walls. In 1984 A. Akbarzadeh has studied the effect of sloping walls on the salt concentration. In 1991, M.A. Hassab and et al., analyzed that the shading effect due to side walls affect the collection and storage of solar energy. In this chapter construction of the laboratory model salt gradient solar ponds and their performance are explained.

8.2 SALT GRADIENT SOLAR POND I (SGSP I)

CONSTRUCTION DETAILS

8.2.1 EXCAVATION

The earth selected to remove the soil is sketched in fig (8.1). The center area of 0.71m x 0.85m is dug to a depth of 1.5m. Then the slope is made from a distance 0.85m towards the bottom along east west direction. Similarly, the slope is made from
Fig (8.1) Excavation
Fig (8.2) Volume of the Pit.
distance 0.76m towards the bottom facing north - south direction. Thus the earth excavation is done for a volume of 4.737 m³. The entire volume of the pit is shown in fig (8.2). The bottom of the pit and sloped side surfaces of the pit are smoothened and sharp stones or gravel, tree roots or other protrusions are removed.

8.2.2 INSULATION BEFORE WALL CONSTRUCTION

The sloped side walls of the pit is splashed by water and then a layer of clay is applied. A 2cm thick clay is pasted uniformly over the entire sloped surface area of the pit. It is allowed to dry for a day. The bottom of the pit is insulated for 30 cm with dry sand and clay. A small trench is made at its bottom perimeter to build a toe - wall. A layer of black polyethylene sheet is laid on the sand and clay, another sand layer of thickness 20cm was laid over the polyethylene sheet. Finally, a black polyethylene sheet is laid over entire area of the pond. This is used to reduce the permeability.

8.2.3 WALL CONSTRUCTION:

A toe-wall is constructed at the bottom trench along the perimeter of the pond. Then the sloped surface is constructed using bricks and cement mortar from the toe walls. This wall construction is done over the black polyethylene sheet. During the wall construction at the slope surface a sand layer is maintained in between the polyethylene sheet and clay liner. Again, this wall construction is extended vertically to a height of 55 cm at all the sides of the pond from the surface of the earth using bricks.

8.2.4 INSULATION AFTER WALL CONSTRUCTION:

To achieve good storage capacity the bottom of the pond and side walls of the pond are insulated using saw dust. The insulation thickness at the bottom is 60 cm and the thickness over the walls of the pond is 25 cm.
Saw dust insulation in salt gradient solar pond (SGSP I)
Fig. (8.5) Filling process of the salt gradient solar pond I (SGSP I)
A view of salt gradient solar pond I (SGSP I) and salt gradient solar pond II (SGSP II)
Heat Exchanger for salt gradient solar pond (SGSP)
Fig.(8.9) Salt replenishment
Fig. (8.10) Surface washing
Heat extraction
Fig.(8.13) Filling the Salt gradient solar pond II (SGSP II)
Fig.(8.6) Surface cleaning of the pond
Fig (8.3) Cross Section View of the Salt Gradient Solar Pond I with Insulation

1. Liner
2. Saw dust
3. Brick wall
4. Liner
5. Sieved sand
6. Sand and clay
7. Liner
8. Clay liner
1. Stand
2. Pulley
3. Iron rope
4. Pointer
5. Iron rod
6. Copper tube
7. Thermocouple
8. Grooved GI pipe
9. Handle
10. Scale

Fig (8.4) Density and Temperature measuring Arrangement.
8.2.5 SHEET LAYING :

A white low density polyethylene sheet (LDPE) of 100 micron thickness is laid over the saw dust. It covers the entire surface area of the pond and also it acts as a safety liner. Then a black low density polyethylene sheet of 100 micron thickness is laid over the entire surface area of the pond and exposed to sunlight. This exposed liner at the bottom helps to increase absorptivity. Fig(8.3) shows the cross sectional view of the pond insulation and wall construction. The total depth of this experimental pond is 0.95m.

8.2.6 THERMOCOUPLE ARRANGEMENTS :

Unijunction Cu-Constantan thermocouples are placed at the bottom of the insulation (TC3), middle of the insulation (TC2) and at the top surface of the insulation (TC1). By using these thermocouples the bottom thermal loss can be measured. The thermocouples are also placed at the side walls.

8.2.7 TEMPERATURE AND DENSITY MEASURING ARRANGEMENT OF A SGSP I :

A GI pipe of 3/4 inch diameter is chosen and a groove is made along the length of the pipe. A 1/2 inch diameter iron rod of length 1.3m easily moves inside the pipe. A pointer is attached at top of the rod so as to slide through the groove over a marked scale attached adjacent to the GI pipe. A copper pipe of 1/4 inch diameter is bent as shown in fig (8.4) and attached at the bottom of the iron rod.

Two small pulleys are attached on the GI pipe, one at the top of the GI pipe and the other at the middle of grooved GI pipe. This entire arrangement is joined using a GI pipe of 0.25 inch diameter as shown in fig (8.4) with the GI pipe of 1.5 inch diameter. This GI pipe acts as a stand and its bottom is bolted to the ground. An iron wire is connected to the top of the iron rod and a handle is attached to the stand. This iron wire is passing through two pulleys. A thermocouple is fixed at the bottom of
the movable iron rod to measure the temperature of the pond at various depths. A copper tube is also fixed at the bottom of the movable iron rod. A small pump connected to the copper tube through flexible rubber tube, is used to collect the NaCl solution at various depths for density measurements.

**8.2.8 FILLING THE POND SGSP I**

Solar ponds are generally filled in layered sections with small saline differences between adjacent layers. The pond filling is done by two methods. One as forward method, i.e., the bottom layer of higher concentration filled first and successively lighter layers floated upon the lower denser layers. At Pondicherry a 500 m² pond was filled by high concentration solution with the injection diffuser pumping of fresh water in to the brine starting from top of the LCZ, so that it mixes with the pond fluid (fresh water) and change its density as desirable density is based on the forward filling method. According to this method this pond is filled from the bottom with successively denser layers. The lighter layers are lifted. They float upon the denser layers. In our laboratory model, the pond is filled by the following procedures. The salt is mixed with water for the required concentration in the adjacent mixing tank and it is transferred to the passage tank through the motor. The salt solution from the passage tank is passed to the pond bottom under natural flow using a plastic tube 0.25 inch diameter. The time taken to pass the salt solution and raise in water level in the pond at each layer of filling are measured. Then the velocity of the raise of water level in the pond during the filling process is calculated and as shown in Table(8.1).

**Table (8.1) : SGSP I**

<table>
<thead>
<tr>
<th>S.No</th>
<th>Concentration (%)</th>
<th>Depth (m)</th>
<th>Velocity m s⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>3</td>
<td>0.2</td>
<td>$5.01 \times 10^{-5}$</td>
</tr>
<tr>
<td>2.</td>
<td>5</td>
<td>0.3</td>
<td>$4.589 \times 10^{-5}$</td>
</tr>
<tr>
<td>3.</td>
<td>8</td>
<td>0.4</td>
<td>$3.857 \times 10^{-5}$</td>
</tr>
<tr>
<td>4.</td>
<td>11</td>
<td>0.5</td>
<td>$3.421 \times 10^{-5}$</td>
</tr>
<tr>
<td>5.</td>
<td>14</td>
<td>0.6</td>
<td>$2.211 \times 10^{-5}$</td>
</tr>
<tr>
<td>6.</td>
<td>17</td>
<td>0.7</td>
<td>$1.731 \times 10^{-5}$</td>
</tr>
<tr>
<td>7.</td>
<td>20</td>
<td>0.9</td>
<td>$1.341 \times 10^{-5}$</td>
</tr>
</tbody>
</table>
8.2.9 GRADIENT ESTABLISHMENT OF SGSP I:

The laboratory SGSP I is filled with fresh water before establishing the gradient. The bottom and side wall insulation is settled by the weight of the fresh water and after settlement of the insulation, the fresh water is drained out.

This pond consists of three zones, they are upper convective zone (UCZ), non convective zone (NCZ) and lower convective zone (LCZ). The thickness is maintained in the pond as follows: The lower convective zone is 0.2 m, non convective zone is 0.6 m and upper convective zone is 0.1 m.

The fresh water is filled initially in the pond and it acts as the UCZ. Then the layer of lesser concentration of 3% NaCl solution is introduced at the bottom of the pond. Similarly, 5%, 8%, 11%, 14% and 17% are introduced one by one at the bottom of the pond towards increasing order of concentration. There are six such layers are setup in the pond and that it act as NCZ. Finally, 20% concentration layer is introduced at the bottom and it acts as the lower convective zone (LCZ). In this case all low density layers are floating on the high density layers. (8.5) shows the pond filling process.

8.2.9(a) Upper Convective Zone (UCZ) of SGSP I

This zone is maintained by using fresh water. The volume of water in this zone of about 500 liters. Its thickness is 10 cm and floats over the Non Convective Zone (NCZ).

8.2.9(b) Non Convective Zone (NCZ) of SGSP I

This zone consists of 6 layers of equal thickness of 10 cm. It floats over the lower convective zone (LCZ). The quantity of water and the salt requirement used to establish the layers in NCZ of the pond is given in the following table (8.2).
Table (8. 2):

<table>
<thead>
<tr>
<th>No of layers</th>
<th>Volume (liters)</th>
<th>Sodium chloride NaCl (kg)</th>
<th>Percentage of concentration (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UCZ</td>
<td>500.0</td>
<td>0.000</td>
<td>0</td>
</tr>
<tr>
<td>NCZ 1</td>
<td>500.0</td>
<td>15.000</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>500.0</td>
<td>25.000</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>500.0</td>
<td>40.000</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>437.5</td>
<td>48.125</td>
<td>11</td>
</tr>
<tr>
<td>5</td>
<td>312.5</td>
<td>43.750</td>
<td>14</td>
</tr>
<tr>
<td>6</td>
<td>150.0</td>
<td>25.500</td>
<td>17</td>
</tr>
<tr>
<td>LCZ</td>
<td>225.0</td>
<td>45.000</td>
<td>20</td>
</tr>
</tbody>
</table>

8.2.9(c) Lower Convective Zone (LCZ) of SGSP I

This storage zone lies at the bottom of the pond. The thickness of this zone is 20 cm and the volume occupied in this zone is 225 liters. The sodium chloride solution of 20% concentration is used and the salt requirement to maintain for this zone is 45 kg.

8.3 MAINTENANCE OF THE SGSP I

8.3.1 BIOLOGICAL GROWTH AND DUST CONTROL:

The growth of algae is potentially a serious problem in SGSP I as it is exposed to absorb the sunlight. A standard procedure for controlling various organisms (such as Blue green algae or Cyano Bacteria, Biamentous or Colonial forms) is to add copper sulphate. The better procedure for algae control is to add copper sulphate of 100 gms, while filling each layer of the pond. Further growth of algae can be controlled by introducing additional copper sulphate (CuSO₄) at regular intervals. The clarity of solution can be maintained by spraying aluminum sulphate [Al₂(SO₄)₂ ⋅ H₂O] or alum over the surface. The precipitate of dust formed at the bottom due to aluminium sulphate can be removed easily. Dust particles, insects etc. floating at the surface of the pond are removed by using skimming net. Fig (8.6) shows the surface cleaning of the pond.
Fig. (8.7) Heat Exchanger Design
8.4 HEAT EXCHANGER DESIGN:

Heat energy is extracted from or supplied to the lower convective zone of the SGSP using a submerged heat exchanger. This exchanger is made up of copper because it has good thermal conductivity and high tolerance of corrosion in salt solution. The dimensions of the heat exchanger are outer diameter $1.2 \times 10^{-2} \text{m}$, inner diameter of $1.1 \times 10^{-2} \text{m}$, and thickness of $0.5 \text{mm}$.

The design of the heat exchanger is shown in Fig (8.7). The total length of copper tube used in this heat exchanger is $10 \text{m}$. This tube is bent in the form of squares having $(0.8 \text{m} \times 0.8 \text{m})$ dimensions at the outer side of the square. The size of the squares are diminishing inwards having $10 \text{cm}$ gap between the each squares. The outlet and inlet extended from the same copper tube are bent vertically upwards to a height of $1 \text{m}$ and $1.25 \text{m}$ respectively.

8.5 HEAT EXCHANGER WITH INSULATION:

The heat energy is extracted from the LCZ as its temperature is higher than that of other layers. The NCZ keeps the temperature gradient in a stair case form. The inlet and outlet to the heat exchanger, if not properly insulated, will disturb the temperature gradient zone. So they are well insulated with glass wool.

The inlet and outlet of the copper tube with glass wool are put inside PVC tube. The bottom end at exchanger region is closed tightly using cups (dummies). The gap between the PVC tube and copper tube is packed tightly with glass wool. The water penetration through the gap is sealed by M-seal. Similarly the top of the PVC tube is covered by using the cups (dummies).
Fig.(8.8) : Variation of solubility of NaCl with temperature (°C)
8.6 SALT TESTING:

8.6.1 SALT SELECTION

Salt constitutes a major cost of the solar pond, therefore the economic feasibility of a solar pond will be the salt selection. The salt should fulfill the following requirements.

1. It is inexpensive and easily available
2. Less moisture content
3. It has high value of solubility and solubility should not vary with temperature.

In this present work the sodium chloride salt is found to be a suitable one. The analysis of NaCl salt is presented as follows.

8.6.2 SOLUBILITY TEST

The saturated solution (0.034kg in 100ml) of NaCl is taken at room temperature and it was heated to 40°C, then five milligrams of salt was added to maintain its saturation, the same process was repeated up to 80°C. The amount of salt requirement at every 10°C of temperature was noted. The variation of solubility of NaCl with temperature is shown in figure (8.8). This figure shows that at higher temperatures more salt is required to maintain its saturation.

8.7 EXPERIMENTAL STUDY OF THE SALT GRADIENT SOLAR POND I

8.7.1 MEASUREMENT OF TEMPERATURE VARIATIONS OF THE POND

The total solar radiation which is the combination of beam and diffuse radiation on the horizontal surface is measured using a pyranometer. The ambient temperature is also recorded. The hourly rise in the temperature of the SGSP I is recorded using digital thermometer. The temperature of the pond is measured every 5cm from the bottom to the surface level of the pond. The bottom losses are also recorded.
using the thermocouples placed at the bottom of the pond. The thermocouples are \( T_{b1} \), \( T_{b2} \) and \( T_{b3} \). \( T_{b1} \) shows the temperature of insulation material just below the LCZ, \( T_{b2} \) shows the temperature of insulation material at the middle of the insulation region and \( T_{b3} \) shows the temperature rise at the bottom of the insulation material. The ambient temperature is measured using a mercury thermometer. The hourly variation in ambient temperature is recorded along with the temperature variation in the pond.

### 8.8 EVAPORATION STUDY:

The upper convective zone is maintained by using fresh water. The evaporation from the surface is studied by a scale permanently fixed at the surface of the water level which is immersed in the water. The water level of the pond is measured at 9 A.M. and at 4 P.M. daily. The decrease in water level is recorded. It is found that water level decreases by 0.5 cm due to evaporation during the days of clear sky and 0.3 cm during the normal sunny days. During the clear sky days surface evaporation of the pond is 21.808 lit day \(^{-1}\), it is 5.452 lit day \(^{-1}\) on the cloudy days and 10.904 lit day \(^{-1}\) on the normal sunny days.

### 8.9 SALINITY MEASUREMENT:

The sample solution is taken at every 5 cm depth from their respective layers. 50 ml solution is sucked from each layer of the pond and only 10 ml is pipetted out and weighed. The density \( \rho \) is calculated using mass/volume ratios,

\[
\text{Density}(\rho) = \frac{\text{mass}}{\text{volume}} = \frac{M}{V} \quad (8.1)
\]

This relation is used to determine the density of the collected sample solutions from various layers. This calculated densities form a density profile. It is converted into concentration and obtained the concentration profile of the SGSP. This sample solution is collected at 4.00 P.M. daily and the salinity is studied.
Fig.(8.11) Physical arrangement of the open loop setup for heat extraction in SGSP.
8.10 SALT REPLENISHMENT:

The salinity of the lower convective zone decreases gradually due to salt diffusion towards the upper surface. The quantity of salt diffusion is calculated from the change in the density of the LCZ. The diffused quantity of salt is introduced at the bottom of the pond frequently once in 15 days. A PVC pipe of 7.8 cm diameter is inserted into the pond and salt is introduced through this pipe with the help of funnel in different places at the bottom of the pond. This arrangement is shown in fig(8.9).

8.11 SURFACE WASHING:

The upper level or surface level of the pond decreases due to evaporation. The concentration of the UCZ also increases due to the diffusion of salt from the LCZ. This surface water level is maintained by filling up water at the surface. During this process the water is allowed to over flow on the surface zone for 15 minutes. It is very helpful to wash the salt content present at the surface. The very small dust particles and debris floating at the surface level are also cleaned. The insects and other dust particles are also removed using skimming net. This surface washing and surface cleaning are shown in fig(8.10).

8.12 HEAT EXTRACTION FROM SGSP I

The heat extraction is done in the SGSP I. A physical arrangement for the open loop setup for heat extraction is shown in fig(8.11). A water storage tank is placed at a height of 1m from the ground level and outlet of the tank is connected to the inlet of exchanger through a pump. This pump is controlled by a regulator arrangement. The outlet of the heat exchanger is connected to a sump. In this sump, the hot water is collected. During the heat extraction the flow rate is measured at every 10 minutes interval by using the measuring jar. The water level in the storage tank is maintained constant throughout the extraction.
Fig.(8.12): Cross section view of Laboratory model of SGSP II

1. Liner
2. Fiber glass tank
3. Sawdust
4. Cardboard
5. Thermocouple arrangement
During the extraction process, the inlet temperature $T_{in}$, outlet temperature $T_{out}$ and lower convective zone temperature are recorded at every 10 minutes interval. The temperature profile of the pond, before extraction and after extraction, are also recorded. These observations are continued up to the uniformity of LCZ temperature after the extraction.

8.13 SALT GRADIENT SOLAR POND II (SGSP II)

8.13.1 CONSTRUCTION OF SGSP II

A fiber glass tank of dimension (1m x 1m x 1m) is chosen for the construction of laboratory model SGSP II. The volume of the fiber glass tank is $1m^3$. As the conductivity of the fiber glass tank is poor, the tank is insulated externally with the help of card board. The material used for insulation is saw dust. An insulation material of thickness 10 cm is packed along the sides of the tank and 40 cm at its bottom. Inside the fiber glass tank is lined by using LDPE liner of 100 micron thickness and black polyethylene liner. It protects from any leakage or avoids the permeability of water through fiber glass tank. Similarly outside of the insulated tank is also covered by the LDPE liner and it gives protection to the insulation from rainfall. The cross section of this laboratory model SGSP II is shown in fig (8.12).

8.13.2 GRADIENT ESTABLISHMENT OF SGSP II

The method adopted for filling this pond is same as that of laboratory model SGSP I. The velocity of the rise in water during the filling up this pond is given in the table. It also consists of three zones and they are UCZ, NCZ and LCZ. The filling of SGSP II under the formation of following zones are shown in fig (8.13). The velocity of the rise of water level in the SGSP II during the filling process is shown in table (8.3).
Table (8.3): SGSP II

<table>
<thead>
<tr>
<th>S.No</th>
<th>Concentration (%)</th>
<th>Depth (m)</th>
<th>Velocity ( m/s )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>3</td>
<td>0.2</td>
<td>( 1.489 \times 10^{-4} )</td>
</tr>
<tr>
<td>2.</td>
<td>5</td>
<td>0.3</td>
<td>( 1.339 \times 10^{-4} )</td>
</tr>
<tr>
<td>3.</td>
<td>8</td>
<td>0.4</td>
<td>( 1.302 \times 10^{-4} )</td>
</tr>
<tr>
<td>4.</td>
<td>11</td>
<td>0.5</td>
<td>( 1.264 \times 10^{-4} )</td>
</tr>
<tr>
<td>5.</td>
<td>14</td>
<td>0.6</td>
<td>( 1.195 \times 10^{-4} )</td>
</tr>
<tr>
<td>6.</td>
<td>17</td>
<td>0.7</td>
<td>( 1.125 \times 10^{-4} )</td>
</tr>
<tr>
<td>7.</td>
<td>20</td>
<td>0.9</td>
<td>( 0.7795 \times 10^{-4} )</td>
</tr>
</tbody>
</table>

8.13.2(a) Upper convective zone (UCZ) of SGSP II

The fresh water is used to occupy a volume of 100 liters on this layer. Its thickness of about 10 cm and lies over the NCZ.

8.13.2(b) Non convective zone (NCZ) of SGSP II

Similar to the SGSP I, non convective zone is separated into 6 layers of equal thickness and it is of 10 cm. It floats on the surface of the LCZ. The quantity of water and salt required for each layer is shown in table (8.4).

Table (8.4):

<table>
<thead>
<tr>
<th>No of layers</th>
<th>Volume (liter)</th>
<th>Sodium chloride NaCl (Kg)</th>
<th>Percentage concentration (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UCZ</td>
<td>100.0</td>
<td>0.000</td>
<td>0</td>
</tr>
<tr>
<td>NCZ 1</td>
<td>100.0</td>
<td>3.000</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>100.0</td>
<td>5.000</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>100.0</td>
<td>8.000</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>100.0</td>
<td>11.000</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>100.0</td>
<td>14.000</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>100.0</td>
<td>17.000</td>
<td>17</td>
</tr>
<tr>
<td>LCZ</td>
<td>200.0</td>
<td>40.000</td>
<td>20</td>
</tr>
</tbody>
</table>

8.13.2(c) Lower convective zone of SGSP II

In the SGSP II, the lower convective zone thickness is 20 cm and volume of water in this zone is 200 liter. Sodium chloride solution of 20 % concentration is used and salt required for this zone formation is 40 kg. The maintenance of the SGSP II
such as algae control, salt replenishment and surface washing are done similar to the SGSP I

8.14 THERMOCOUPLE ARRANGEMENT OF SGSP II

A 1m scale is drilled at equal distance of 10cm at 10 places. Thermocouples are inserted into the holes and placed the scale with thermocouple inside the pond. All the thermocouples are connected to the selector switch to record the temperature of each layer using digital thermometer. Similarly thermocouple are placed at the bottom and sides of this SGSP II.

8.15 EXPERIMENTAL STUDY OF SALT GRADIENT SOLAR POND II

The pond filling is done as in the above mentioned procedure. When pond filling is over, the pond is allowed to receive solar radiation by opening the surface of the pond. The experimental work is carried out in the following manner.

The thermal performance of the pond is studied by measuring the following parameters. They are, the hourly ambient temperature, the hourly total radiation, the temperature profile of the pond, the pond evaporation etc. The rise of temperature in the pond is recorded at the interval of every one hour. These readings are recorded from 9 A.M. to 4 P.M. daily.

The bottom loss of the pond is studied by using the thermocouples $T_{b1}$, $T_{b2}$ and $T_{b3}$. The thermocouple $T_{b1}$ is used to measure the bottom temperature at the top of the insulation region and just below LCZ. $T_{b2}$ is used to measure the temperature at the middle of the insulation region. And $T_{b3}$ is used to measure the temperature at the bottom of the insulation region.
The temperature profile of the pond is measured by using the thermocouples. These thermocouples are fixed in 10 cm distance in the wooden frame of 1 m length. These are connected to the selector switch and immersed into the pond to measure the temperature of each layer.

8.16 DENSITY MEASUREMENT IN SGSP II:
A specially prepared 50 ml pipette is used to take the NaCl sample solution from the pond. This sample solution is taken at each 5 cm depth of water. This sample solution is weighed and the density ($\rho$) is calculated by mass / volume ratio.

8.16.1 SURFACE WASHING:
The upper convective zone thickness decreases due to evaporation. The fresh water is flushed at the surface of the pond and the level is maintained. Similarly, the salt replenishment is also done as it is done in the case of SGSP I.

8.17 THERMAL LOSSES OF THE SGSP I AND SGSP II
The $\alpha \tau$ product for SGSP I and SGSP II
According to C.F. Kooi (1979), the absorbance transmittance product is determined in the following equation.

$$\alpha \tau = a + b - b \left[ \frac{x_2 \ln x_2 - x_1 \ln x_1}{x_2 - x_1} \right]$$ (8.2)

where $a = 0.36$ and $b = 0.08$. The other losses such as convection, evaporation and radiation are calculated by using the equation (7.14) from previous chapter VII.

8.18 EFFICIENCY FOR SGSP I AND SGSP II:
The concept of efficiency has proved to be a very useful on in the aspects of science and engineering. It has two important functions.
1) It gives an easy method of comparison between the two different engineering devices performing the same function.

2) It indicates the scope for improvement in a device performing the same function. In addition to these, efficiency is often useful in engineering design calculations. The average efficiency of the heat collection in salt gradient solar pond is studied as,

$$\eta = (\alpha \gamma - U_1) \frac{\Delta T}{1} \quad \Delta T = T_{LCZ} - T_{umb}$$  \hspace{1cm} (8.3)

where

$$U_1 = U_{NCZ} + U_b = \frac{K' \Delta T}{X_2 - X_1} + \frac{K_{sd} \Delta T}{X_{sd}}$$  \hspace{1cm} (8.4)

8.19 RESULTS AND DISCUSSION:

**SGSP I:**

Fig(8.14) shows the development of the temperature profile in SGSP I when the pond is exposed to radiation. This fig shows that the temperature of upper layer is higher than that of bottom layers of the pond in the first day. The temperature of the UCZ is 31.5 °C and the temperature of the adjacent layer in NCZ is 39 °C at the depth of 60 cm. The temperature of the LCZ is 36.4 °C at 4 P.M. in the first day. In the II day at 9 AM, LCZ temperature is 36.8 °C and the temperature of the adjacent layer in NCZ at the 60 cm depth decreases to 38 °C. This 1 °C is lost due to the conduction towards bottom and top. At 4 P.M the temperature at 60 cm depth raises to 41.8 °C and at 50 cm depth the temperature raises to 42.8 °C and in the LCZ it is 41.6 °C.

In the III day at 9:00 AM the temperature at 50 cm and 60 cm depth are 37 °C and 35 °C respectively. And the LCZ temperature is 38.6 °C. At 4:00 P.M the temperature raises to 43.4 °C and 44 °C at 50 cm and 60 cm depths respectively. The LCZ temperature rises to 45 °C. In this case the rise of LCZ temperature is higher than that of the previous days temperature. Thus the steady state of the temperature profile is reached.
In the IV day at 9 AM, the temperature at 50 cm and 60 cm depth are 40 °C and 42.2 °C respectively and LCZ temperature is 43.6 °C. At 4 pm, the LCZ temperature rises to 48.2 °C and temperature at all depths increase correspondingly. In the V day at 9 00 AM, the stabilized temperature profile is obtained with LCZ temperature of 47.2 °C and the UCZ temperature of 28.6 °C. At 4.00 PM, LCZ temperature rises to 51.4 °C with UCZ temperature of 31 °C.

Fig (8.15). shows the temperature profile during rise: in temperature at the LCZ. The maximum temperature is obtained after elapse of 408 hours as 57.5 °C and it is shown in figure (8.16). Fig. (8.17) shows the variations of daily collection efficiency with respect to the number of days. The maximum daily collection efficiency of the SGSP I is 37.98 %. Fig. (8.18) shows the variation of lower convective zone temperature and upper convective zone temperature with respect to the number of days. A continuous record of readings in the SGSP I is done for 125 days. Fig (8.19) shows the variation of concentration with respect to the depth. The initial concentration is 18.8% during the period of filling in LCZ. The decrease in concentration at LCZ is noted as 17.2 % and this is studied for 15 days Fig (8.20)(a) and Fig (8.20)(b) show the variation of LCZ temperature, outlet temperature, inlet temperature, ambient temperature and effectiveness during heat extraction with respect to time at the flow rate of 33 ml s⁻¹ during the heat extraction. The overall loss factor \( (U_L) \) determined for the SGSP I system is 25.733 W m⁻². The \( αt \) product is 0.4416. The heat removal factor for the sgsp is calculated as 0.6154.

The retention capacity per day of the SGSP during night is calculated by

\[
Z = \frac{\text{Amount of energy collected - night loss}}{\text{Amount of energy collected}}
\]

\[
Z = \frac{\text{\( MC_p T_{max} - Mcp \Delta T \)}}{\text{\( MC_p T_{max} \)}} \quad (8.5)
\]

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Where $\Delta T = T_{\text{max}} - T_{\text{min}}$.

So the retention capacity per day of the SGSP I is determined as 92.98%.

Fig (8.21)(a) shows the rate of evaporation of the water at the surface. The curve shows the variation of evaporation per second with number of days and (8.21)(b) shows the variation of daily mean average solar radiation received at the surface for number of days. The evaporation rate of $5.52362 \times 10^{-5}$ lit sec$^{-1}$ m$^{-2}$ on clear sky days and of $4.4189 \times 10^{-5}$ lit sec$^{-1}$ m$^{-2}$ on the normal sky days are studied. The evaporation rate increases due to intensity of solar radiation and fluctuates accordingly.

The variation of temperature profile of the SGSP I due to extraction is shown in fig (8.22). The temperature in the LCZ nearer to the heat exchanger decreases more than that of the other regions. The stability of the LCZ temperature in the pond due to the extraction is studied and time taken to reach the stability after the supply is noted. The time taken to attain this stability at LCZ is 4 hours 45 minutes. Similarly fig. (8.23) shows the daily variation radiation received at the surface of the pond.

**SGSP II.**

The overall loss co-efficient for this system is 35.6 Wm$^{-2}$ and $\alpha \tau$ product is 0.4416. The maximum efficiency of this system is 30.57%. The fig.(8.24) shows the development of temperature profile in SGSP II and it takes five days to reach stability. The minimum temperature at 9 AM is 40º C. The maximum temperature at 4 PM is 44º C. The fig.(8.25) shows the raise in temperature up to its maximum. The maximum temperature obtained in this system is 50.7 ºC. The heat removal factor $F_R$ for the SGSP II is given as 0.5234. Fig.(8.26),(8.27) and Fig.(8.28) show the variation of efficiency, LCZ temperature, UCZ temperature and radiation with respect to number of days. This study is analyzed for 65 days. Fig.(8.29) shows the concentration profile of the SGSP II system. Similarly fig 8.30(a) and 8.30(b) shows the heat extraction curves for the same system. The retention capacity per day of the SGSP II is calculated as 88.75%.
While comparing SGSP I and SGSP II the maximum rise in temperature, collection capacity and loss during night in SGSP I are very less than that of SGSP II. For SGSP I is located at ground but SGSP II is located at the open terrace and the influence of the convection losses are more at the sides. In the case of SGSP I the influence of ambient temperature is only at the surface. This is main factor to obtain low efficiency in the SGSP I.

8.20 COMPARISON OF SGSP I AND SGSP II

The results predicted from the SGSP I and SGSP II are compared. The performance of the SGSP I is better than the SGSP II. The maximum rise in storage temperature of SGSP I is more than that of SGSP II and it is of 57 °C. The maximum storage temperature of the SGSP I is 50.7 °C. The collection efficiency of the SGSP I is 37.9% and the collection efficiency of the SGSP II is 30.57%. The efficiency of the SGSP II is less because the overall loss is more for this system. The retention capacity of SGSP I is more than that of SGSP II. The 92.98% of energy is stored from the energy collected by the SGSP I but in the case of SGSP II the retention capacity is lesser than the SGSP II because this system lies at the ground. The comparison between SGSP I and SGSP II is also given in the Table (8.5).

CONCLUSION:

The two salt gradient solar ponds (SGSP I & SGSP II) are studied. The performance of both the ponds are analyzed. The effect due to shadows from the vertical walls are very much affected during the energy collection. The performance of SGSP I is found to be better one than that of SGSP II. It is so because of the location of SGSP I in the ground. So it is clear that the ground is the suitable place for constructing solar ponds.
Fig. (8.14) Development of temperature profile in SGSP I
Fig (8 15) Temperature profile in SGSP I
Fig.(8.16): Temperature profile in SGSP1
Fig. (8.17) Variation of daily collection efficiency in SGSP I
Fig (8.18) Variation of LCZ temperature and UCZ temperature in SGSP 1
Fig (8.19) Concentration profile in SGSP I
Fig. 8 (a) Variation of LCZ temperature, outlet temperature, ambient temperature and inlet temperature in SGSP 1.
Fig 8.20(b) - Variation of Effectiveness in SGSP II
Fig. (8.21) (a) Variation of evaporation rate
Fig. 8 21(b) Variation of Irradiation during the period of evaporation
Fig. (8.22) Temperature profile during heat extraction
Fig (8.23) Daily variation of radiation received at the surface of SGSP I.
Fig (8.24) Development of temperature profile in SGSP II
Fig (8.25). Temperature profile in SGSP II
Fig. (8.26) Variation of daily collection efficiency in SGSP II.
Fig (8.28): Daily variation of radiation received at the surface of SGSP II
Fig. (8.29) Concentration profile in SGSP II
Fig. 8.30 (a): Variation of LCZ temperature, outlet temperature, ambient temperature and inlet temperature in SGSP II.
Fig. 8.30 (b) Variation of Effectiveness in SGSP II
Table (8.5):  

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Parameters</th>
<th>SGSP I</th>
<th>SGSP II</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Area</td>
<td>5.712 m²</td>
<td>1 m²</td>
</tr>
<tr>
<td>2.</td>
<td>Depth</td>
<td>0.9 m</td>
<td>1 m</td>
</tr>
<tr>
<td>3.</td>
<td>Pond site</td>
<td>Ground</td>
<td>Open terrace</td>
</tr>
<tr>
<td>4.</td>
<td>Construction Materials</td>
<td>Cement, Bricks</td>
<td>Fiber Glass</td>
</tr>
<tr>
<td>5.</td>
<td>Liner</td>
<td>LDPE</td>
<td>LDPE</td>
</tr>
<tr>
<td>6.</td>
<td>Materials</td>
<td>Sand, clay and</td>
<td>Saw Dust</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Saw Dust</td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>Salt</td>
<td>NaCl</td>
<td>NaCl</td>
</tr>
<tr>
<td>8.</td>
<td>LCZ Concentration</td>
<td>19 %</td>
<td>19.5 %</td>
</tr>
<tr>
<td>9.</td>
<td>Thickness of Zones</td>
<td>UCZ = 0.1 m</td>
<td>UCZ = 0.1 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LCZ = 0.2 m</td>
<td>LCZ = 0.2 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NCZ = 0.6 m</td>
<td>NCZ = 0.6 m</td>
</tr>
<tr>
<td>10.</td>
<td>Temperature measurement</td>
<td>Thermocouples</td>
<td>Thermocouples</td>
</tr>
<tr>
<td>11.</td>
<td>Maximum Temperature</td>
<td>57 °C</td>
<td>50.7 °C</td>
</tr>
<tr>
<td>12.</td>
<td>Storage Capacity</td>
<td>88.13 %</td>
<td>72.46 %</td>
</tr>
<tr>
<td>13.</td>
<td>Efficiency</td>
<td>37.9%</td>
<td>30.57%</td>
</tr>
<tr>
<td>14.</td>
<td>Overall loss</td>
<td>25.733 w.m⁻²</td>
<td>35.6 w.m⁻²</td>
</tr>
<tr>
<td>15.</td>
<td>Retention capacity/day</td>
<td>92.98%</td>
<td>88.75%</td>
</tr>
<tr>
<td>16.</td>
<td>Heat removal factor</td>
<td>0.6154</td>
<td>0.5234</td>
</tr>
</tbody>
</table>