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# Numerical Simulation and Sizing of Salt Gradient Solar Pond for Power Generation

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**Abstract:** ***The author in this paper is investigating the performance on the basis of numerical simulation of Salt Gradient Solar Pond (SGSP) sizing for power generation. The simulation was carried out for various salts used in the SGSP and they are NaCl, $NaHCO_3$, $MgCl_2$ and $BaCl_2$. The thermal efficiency considered as 5% to numerical simulation and sizing of SGSP for power generation. The simulated results obtained for thermal power plant, Cross sectional area of Pond, flow rate and velocity for the salts NaCl, $NaHCO_3$, $MgCl_2$ and $BaCl_2$. The various simulated results were compared and it was found that the best result suited for the salt and $BaCl_2$ and least suited for the salt NaCl.***

**Keywords:** Salt Gradient Solar Pond (SGSP), Salts like NaCl, $NaHCO_3$, $MgCl_2$ and $BaCl_2$, Thermal Efficiency, Simulation and Sizing of SGSP

## 1. Introduction

Salt Gradient Solar Ponds (SGSPs) are basically large reservoirs of saline water and salinity varies from top to bottom. It is most important characteristic of SGSP is that it is a type of solar collector which provides an inexpensive means for collecting and storing solar energy as investigated by [1 REVERA]. The performance of SGSP mainly depends upon its thermal storage capacity, mechanical or electrical power may be generated by direct conversion of solar energy either by PV cells or via thermo-electric power system. Among the above mentioned two ways of converting solar energy, at present the thermo-electric system is most promising, as the technology and economics for the other way are still far away from the acceptable limits. A SGSP consists of three distinct zones as shown in Fig. 1. The upper convective zone (UCZ) or surface convective zone (SCZ) of thickness varying between 0.15 to 0.2m which has very low and nearly like the fresh water. Beneath the UCZ, the Non-Convective Zone (NCZ) or Gradient Zone (GZ) [2, 3, 4] of thicknesh that varies between 1.0 to 1.2m with the salt concentration increasing downward [5, 6] and is therefore an important zone of variable properties. The lowest zone is the Lower Convective Zone (LCZ) or Storage Zone (SZ) which has the a thickness between 1.0m to 2.0m with nearly uniformly very high concentration brine or like saturated brine. Due to convective mixing with the NCZ and salt diffusion from bottom to surface, the salinity of UCZ increases and estimated to be 20 to 30 kg/m$^3$/year for the warm NaClsolar ponds as reported by [6]. Generally, it has been reported earlier by many researchers that the temperature developed in the storage zone was up to 80$^0$C but it is overcome and the temperature developed by replacing flat bottom by corrugated and reach more than 90$^0$C [7]. Sun radiated, total solar radiation is about 3.9x10$^{23}$ kW/m$^2$but only 1.72x10$^{14}$ kW/m$^2$ received by the Earth's surface. The radiation received by the Earth is very much but a part of itis sufficient to full fill the total energy crisis of the World. The solar heat flux striking the outermost atmosphere is generally 1380W/m$^2$. When the solar radiation penetrates atmosphere then some of the solar radiation absorbed by the atmosphere so that the heatflux reaches the Earth's surface is about 990 W/m$^2$ as reported [8]. The modeling and simulation of SGSP for study the effects system and operating parameters on the performance was reported [9, 15].Several researchers were carried out {10, 11, 12] the work for ground heat losses for large solar ponds and it has been observed that the negligible ground losses. The thermal performance of the SGSPs is basically depends upon the transparency of the pond's brine to the insolation. It has been reported [13] for impairment of transparency arises from the dissolved colored substances, suspended particles, bacteria and algae. There are so many solar thermal electrical power plants in operation in the world wide at present. It has been reported [14] that the effects of system and operating parameters on the performance of salt gradient solar pond. There are so many researchers were studied about the design, development and modeling of salt gradient solar pond and one of them reported [16], obtained the simulated results for the cross-sectional area, flow rate, velocity, thermal and electrical power. The results obtained were in good agreement with the other researchers.

### 1.1 Consideration of Main Design Parameters

- The Power Plant has an output of 40MWe
- Thermal efficiency to be 5%
- A binary isobutene fluid close Rankine Cycle is considered
- Heat losses to the ground is negligible
- Maximum salt concentration in the storage zone is 20-25% by weight
- All surfaces of the SGSP made completely isolated by using the liners to prevent the leakage and ensure good heat absorption in solar pond.

### 1.2 Pond Size Calculations

The average annual insolation in Jamshedpur was taken as follows:

The winter months were considered to be only three months like November, December and January. The average insolation for winter months was 350Cal/cm$^2$.day. The summer months were therefore become nine months like

February, March, April, May, June, July, August, September and October. The average insolation for summer months was 580Cal/cm$^2$.day.

The average annual insolation can be obtained as below:
Average Annual Insolation= [(3x350+9x580)/12]=7982.55 MJ/m$^2$.year
Now, the capacity of thermal power plant required for 40 MWe with 5% thermal efficiency can be calculated as below:

Thermal capacity = 40/0.05=800MWt

Therefore,
800MWt=(800MWx365day/yearx24/day)=120.14x10$^9$ MJ/year

Therefore, cross sectional area of SGSP can be obtained as below:

The ratio of electrical energy of the plant per year and thermal energy of the plant per year gives the cross sectional area (C/S area) of the SGSP.

Hence,
Cross sectional area of the SGSP =(120.14x10$^9$ MJ/year)/(7982.55 MJ/m$^2$.year) =15050328m$^2$

### 1.3 Extraction of Thermal Power

40MWe Electrical power plant was considered for design of solar pond and a temperature difference of 25$^0$C. The density of NaCl is 1.2g/cm$^3$ and its specific heat is 0.86Cal/g$^0$C.

Now, the electrical power 40MWe=40x14.3x10$^6$Cal/min=572x10$^6$Cal/min.

Therefore, flow rate can be simulated as follows:
Flow rate=(572x10$^6$Cal/min.)/(25x0.86Cal/g$^0$Cx1.2g/cm$^3$)=22.17x 10$^6$cm$^3$/min.

This flow rate should be quite linear so that the storage zone would not get disturbed with the pond width of 3879.48m and the flow rate 22.17x10$^6$cm$^3$/min.The velocity of 20cm thick UCZ would be given as below:

Velocity=Volumetric flow rate/Cross sectional area =(22.17x10$^6$cm$^3$/min)/( 3879.48mx100cmx10cm) =5.71cm/min.

The velocity calculated here is quite low which ensures that the flow between layers without any disturbance.

Now, for the remaining capacity of electrical power plants like 35MWe, 30MWe, 25MWe, 20MWe, 15MWe and 10MWe, the results were simulated and written in tabular form as in Table-I.

Now, the simulation was carried out for the salts $NaHCO_3$, $NaHCO_3$, $MgCl_2$ and $BaCl_2$ written in tabular form as Table-II, Table-II and Table-IV respectively.

## 2. Results and Discussions

**Table 1:** SGSP with NaCl salt with Density=1.2g/cm$^3$ and Specific Heat=0.86Cal/g$^0$C

| Sl. No. | Velocity (cm/min) | Cross-sectional Area of SGSP (m$^2$) | Flow Rate (cm$^3$/min) | Thermal Power (MWt) | Electrical Power (MWe) |
|---|---|---|---|---|---|
| 1. | 5.71 | 15050328 | 22.17x10$^6$ | 800 | 40 |
| 2. | 5.34 | 13168624 | 19.4x10$^6$ | 700 | 35 |
| 3. | 4.95 | 11287190 | 16.63x10$^6$ | 600 | 30 |
| 4. | 4.52 | 9405574 | 13.86x10$^6$ | 500 | 25 |
| 5. | 4.03 | 7523958 | 11.09x10$^6$ | 400 | 20 |
| 6. | 3.50 | 5643595 | 8.32x10$^6$ | 300 | 15 |
| 7. | 2.86 | 3758221 | 5.55x10$^6$ | 200 | 10 |

**Table 2:** SGSP with $NaHCO_3$ salt with Density=2.2g/cm$^3$ and Specific Heat=0.022Cal/g$^0$C

| Sl. No. | Velocity (cm/min) | Cross-sectional Area of SGSP (m$^2$) | Flow Rate (cm$^3$/min) | Thermal Power (MWt) | Electrical Power (MWe) |
|---|---|---|---|---|---|
| 1. | 10.47 | 15050328 | 40.65x10$^6$ | 800 | 40 |
| 2. | 9.8 | 13168624 | 35.57x10$^6$ | 700 | 35 |
| 3. | 9.07 | 11287190 | 30.49x10$^6$ | 600 | 30 |
| 4. | 8.28 | 9405574 | 25.41x10$^6$ | 500 | 25 |
| 5. | 7.41 | 7523958 | 20.33x10$^6$ | 400 | 20 |
| 6. | 6.42 | 5643595 | 15.25x10$^6$ | 300 | 15 |
| 7. | 5.25 | 3758221 | 10.17x10$^6$ | 200 | 10 |

**Table 3:** SGSP with $MgCl_2$ salt with Density=2.32g/cm$^3$and Specific Heat= 0.017Cal/g$^0$C

| Sl. No. | Velocity (cm/min) | Cross-sectional Area of SGSP (m$^2$) | Flow Rate (cm$^3$/min) | Thermal Power (MWt) | Electrical Power (MWe) |
|---|---|---|---|---|---|
| 1. | 11.05 | 15050328 | 42.87x10$^6$ | 800 | 40 |
| 2. | 10.34 | 13168624 | 37.51x10$^6$ | 700 | 35 |
| 3. | 9.57 | 11287190 | 32.15x10$^6$ | 600 | 30 |
| 4. | 8.74 | 9405574 | 26.80x10$^6$ | 500 | 25 |
| 5. | 7.81 | 7523958 | 21.44x10$^6$ | 400 | 20 |
| 6. | 6.77 | 5643595 | 16.08x10$^6$ | 300 | 15 |
| 7. | 5.34 | 3758221 | 10.73x10$^6$ | 200 | 10 |

**Table 4:** SGSP with $BaCl_2$ salt with Density=3.86g/cm$^3$and Specific Heat= 0.0055Cal/g$^0$C

| SL. No. | Velocity (cm/min) | Cross-sectional Area of SGSP (m$^2$) | Flow Rate (cm$^3$/min) | Thermal Power MWt | Electrical Power MWe |
|---|---|---|---|---|---|
| 1. | 18.38 | 15050328 | 71.3x10$^6$ | 800 | 40 |
| 2. | 17.19 | 13168624 | 62.4x10$^6$ | 700 | 35 |
| 3. | 15.92 | 11287190 | 53.49x10$^6$ | 600 | 30 |
| 4. | 14.42 | 9405574 | 44.24x10$^6$ | 500 | 25 |
| 5. | 13.00 | 7523958 | 35.67x10$^6$ | 400 | 20 |
| 6. | 11.26 | 5643595 | 26.76x10$^6$ | 300 | 15 |
| 7. | 09.21 | 3758221 | 17.85x10$^6$ | 200 | 10 |

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