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Research Article

DESIGN AND DEVELOPMENT OF SOLAR POND MODEL FOR POWER GENERATION

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ABSTRACT

A Salt Gradient Solar Pond (SGSP) is a large reservoir of saline water, with the difference that a specific salinity profile is artificially created and maintained. SGSP receives thermal energy by incident solar radiation. The area of SGSP depends upon the design capacity of thermal/electrical power generation. The depth of SGSP is generally ranging from 2 to 5m and area 2 to 12 km^2. In this paper the simulation carried out for the electrical power 5 to 20 MWe. To reduce the heat transfer loss by the convection, the saline water is used $MgCl_2$, $NaHCO_3$ and NaCl respectively. The salinity of the different zones maintained as 0-5% in Surface Convective Zone/Upper Convective Zone (SCZ/UCZ), 5-20% in Non-Convective Zone/Gradient Zone (NCZ/GZ) and the concentration is almost like a saturated solution in the Lower Convective Zone/Storage Zone (LCZ/SZ). Due to different salinity in the SGSP, a temperature gradient and heat storage developed in the NCZ and LCZ respectively. The temperature developed in the storage zone will reach up to 100^0C using the corrugated bottom surface.

INTRODUCTION

SGSPs have always been an important technique for storage of solar energy and appear to have significant potential for solar thermal energy storage. The performance of SGSP is mainly depend upon its thermal energy storage capacity and on its construction and maintenance costs [1, 2]. Basically Sun is radiating solar energy are at a rate of $3.85x10^{23}$kW/m^2 with the earth intercepting only about $1.72x10^{14}$kW/m^2 of the total solar radiation i.e. only $2.08x10^9$th of the total solar radiation received by the earth's surface. The solar heat flux which striking the outermost atmosphere is about 1380W/m^2.

When solar radiation penetrates the atmosphere, some of it is absorbed by the atmosphere, so that the heat flux reaches the earth's surface is only about 990W/m^2 as studied by Lunde, 1980 [3]. The calculations were carried out for solar thermal power received from the Sun in India is $2.86x10^9$kW/m^2, which is much more than the total power consumption of the country. Actually the construction of proper device for collection and storage of solar thermal energy is very difficult task. The SGSP is a more economical and effective means for both the collection and storage of solar energy for power generation. Several researchers have been carried out the experimental and theoretical. SGSP shown in Fig. 1, constructed large body of water having three different layers and 3m deep which can collect solar radiation and store it in the form thermal energy [4, 5]. The basic salt which is dissolved in high concentration (i. e. saturated solution) in the LCZ and the thickness of this zone is around 1.2m as studied by [6]. The UCZ is a layer which is almost free from salt (i. e. 5%) whose thickness is very less as 10cm. In between the UCZ and LCZ, a zone which is named as Non-convective zone in which salt concentration is varying with depth from 5-25% and thickness of this zone is 1.7m. The natural convection process is mostly prevented due to increasing salt concentration in NCZ and completely prevented in LCZ since this zone is formed by saturated salt solution. SGSP has been analysed by Tabor, H. 1980 [7] and Tabor, 1980 [8], Rabi and Neilsen, 1975 [9], Weinberger, 1964 [10], Akbarzadeh and Ahmadi 1979 [11] and Hawaldar and Brinkwork, 1981 [12] among others.

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Fig. 2 shows the Salt Gradient Solar Pond with temperature profile in the left side and salinity profile in the right side. Temperature in upper convective zone (UCZ) is uniform and constant same as in lower convective zone (LCZ). Also, the temperature in UCZ is as the temperature of atmosphere (26.2^{0}C) and in the LCZ, the developed temperature i.e. 90^{0}C. But variation of temperature in the non-convective Zone (NCZ) is varying between atmospheric temperature (26.2C) and the temperature of LCZ (90^{0}C).

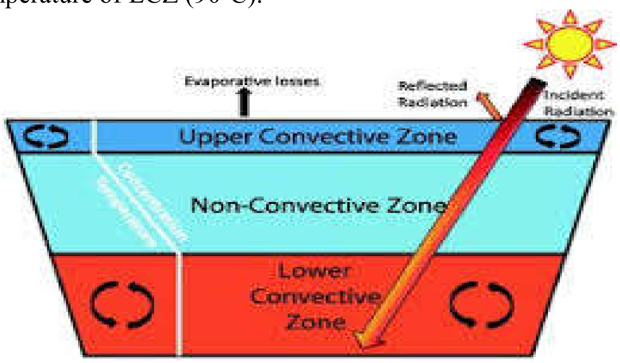

Fig 1 Salt Gradient Solar Pond

In the right side figure of salinity profile, the salinity increases with depth and it is lowest in UCZ and highest in LCZ but in NCZ, the salinity rapidly varies between UCZ and LCZ as shown in Fig. 2.

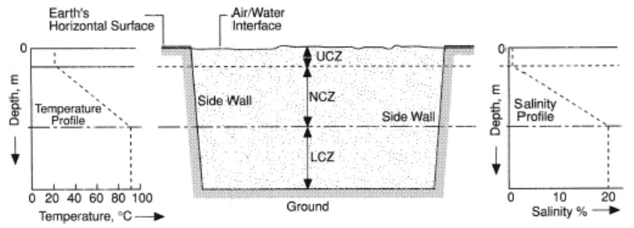

Fig 2 Salt Gradient Solar pond with Temperature Profile and Salinity Profile

The several researchers like Ravi (1975) [13], Weinberger (1964) [14] and Akabarzadeh (1979) [15] were carried out the work for the ground heat losses for large solar pond and it has been found out the ground losses was negligible.

The thermal performance of SGSPs mainly depends on the high transparency of the pond's brine to incident solar radiation. Hull, 1990 [16], analysed for impairment of transparency arise from the dissolved coloured substances, suspended particles or algae and bacteria. Solar thermal electrical power plants that could found worldwide and operate on the solar pond concepts are the following:

- 5MW plant in Dead Sea area of Palestine with 250000m^2 developed by Sargent, 1983[17]
- 70MW plant in the University of Texas at El Paso (www.solarpond.com) [18]
- 2kWplant in Alice Spring of Australia by Jabri,1996 [19]
- 20kW plant in Bhavnagar in INDIA by Jabri, 1996 [20]

Consideration of Main Design Parameters

The following are the main parameters considered for the simulation:

- The power plant has an output of 20MWe
- A binary fluid isobutene closed Rankine cycle is used
- Heat losses to the ground is negligible as analysed by Rabi, 1975 [9], Weinberger, 1964[14] and Akabarzadeh,1979[11]
- The maximum slat concentration in the storage zone is 25% by weight
- To prevent the leakage and ensure good heat absorption, all the surfaces of the pond should be completely isolated by using liners

Pond Size Calculation

The average annual insulation in India was taken as follows:

The winter months were considered to be only four months like November, December, January and February. The average insolation were 300Cal/cm^2.day. The summer months were therefore become eight months remaining with an average insolation of 510Cal/cm^2.day.

The average annual insolation can be obtained as below
[(4x300+8x510)/12] = 440Cal/cm^2.day=18.42MJ/m^2.day.
This figure is checked against the data of Al-Jubouri and Ziyada, 1997 [21] which was given as 19.054MJ/m^2.day.
Now,
18.42MJ/m^2.day=18.42MJ/m^2.365year=6723.32MJ/m^2.year.
I can estimate the thermal efficiency to be 4% therefore I need (20/0.04)=500MW thermal power plant for solar pond.
Therefore,
[500MWx365day/yearx24/day]=75.086x10^{9}MJ/year
Therefore, the area of SGSP can be obtained as below:
[75.086x10^{9}MJ/year]/[6723.32MJ/m^2.year]=11168000m^2

Thermal Heat Extraction

The power plant was chosen as 20MWe and a temperature difference of 20^{0}C comes from (100^{0}C output from the pond and 80^{0}C inlet). The density of the brine (NaCl) is 1.2g/cm^3 and its specific heat is 0.86Cal/g ^{0}C.

The electrical power 20MWe=20x14.3x 10^{6}Cal/min. = 286x10^6 Cal/min.

Now, the flow rate can be simulated by the relation an below
Flow rate =[286x10^{6}Cal/min./0.86Cal/g ^{0}Cx1.2g/cm^{3}x20^{0}C]= 13.86x10^6 cm^3/min.

This flow rate should be quite laminar so that storage zone would not get disturbed with the pond width 3341.86m and flow rate of 13.86x10^6 cm^3/min. The velocity of a 10cm thick UCZ layer would be,
Velocity = volumetric flow rate/cross sectional area
Or, Velocity = (13.86x10^{6}cm^3/min.)/(3341.86x10^2 cm^{2}x10 cm) = 4.147cm/min.

This velocity is quite low which ensures that the layered flow without any disturbance.

Power Plant

Wright, 1982 [22] considered a system of binary fluid cycle using a volatile pentene. The other has used thermal system using the fuel utilized by Kendoush, 2000[23] and Rasheed,1999[24]. In Fig. 3, the power plant working with binary fluid cycle. Fig. 2 shows the binary fluid cycle power plant.

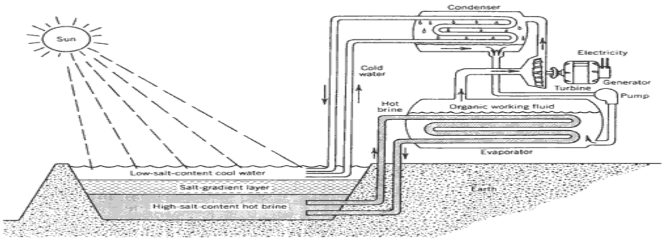

Fig 3 Solar Pond of Binary Fluid Cycle Power Plant

RESULTS AND DISCUSSIONS

In this work, the author design a mathematical model for electrical power generation. The results were simulated by using the three salts NaCl, Mg Cl_2 and $NaHCO_3$ respectively.

Variation of Electrical Power Generation (MWe) against Solar Thermal Power (MWt)

Fig. 4 shows the relationship between the solar pond thermal powers with electricity production. The electricity production is directly related to solar thermal power production.

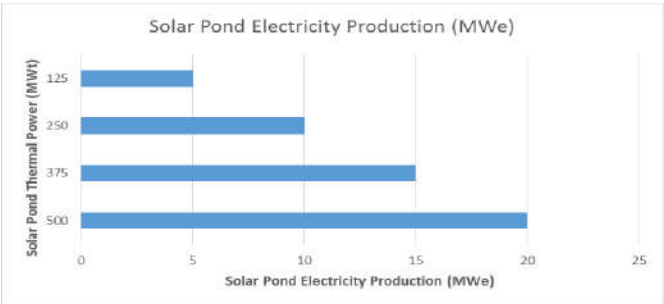

Fig 4 Variation of Electrical Power Generation (MWe) against Solar Thermal Power (MWt)

Variation of flow rate of NaCl, $MgCl_2$ and $NaHCO_3$ against Elect. Power Generation (MWe)

Fig. 5 explains clearly the relationships between flow rate of the circulated fluid with electricity production with using the different salts like NaCl, $NaHCO_3$ and $MgCl_2$ respectively. It has been found that the increase in flow rate will increase the electricity production and the largest value of flow rate obtained for the salt $MgCl_2$ and the lowest value of the flow rate for the salt NaCl. In between these two values of largest and lowest values of flow rate, the flow rate value of $NaHCO_3$ belongs.

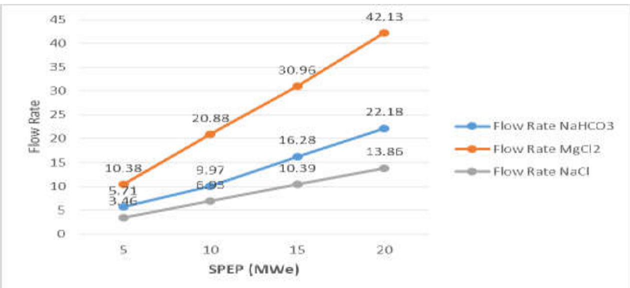

Fig 5 Effect of flow rate of NaCl, $MgCl_2$ and $NaHCO_3$ against Elect. Power Generation (MWe)

Effect of Area enhancement factor on the temperature of Salt Gradient Solar Pond

Fig. 6 shows the effect of area enhancement factor on the temperature of solar pond. From the figure it has been found that the temperature in the solar pond increases with increase in area enhancement factor. In flat bottom surface, the temperature developed in the storage zone of solar pond was 80^0C but in case of corrugated bottom surface it will increase up to 90^0C. This may also increase by the use of fluid like nano-fluids.

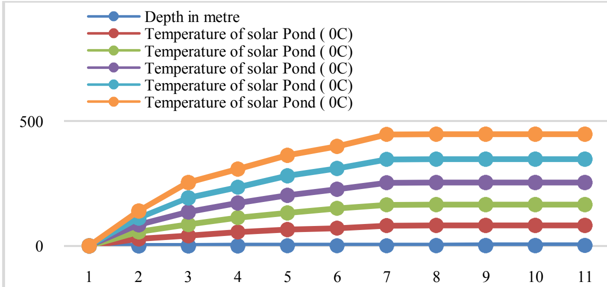

Fig.6: Effect of area enhancement factor on the temperature of Solar Pond with depth

CONCLUSIONS

On the basis of simulation carried out in this paper for design and mathematical model of SGSP, the following conclusions are drawn:

- The increase in thermal power produced in SGSP will increase the electricity production. The production of thermal power directly related to flow rate and C/S area of the SGSP.
- It has been observed that the flow rate is lowest for NaCl and largest for $MgCl_2$. The flow rate of $NaHCO_3$ is in between NaCl and $MgCl_2$.
- The effect of area enhancement factor (β) mainly affect the rise in temperature of SGSP.
- If β increases, means the area of the bottom surface of SGSP increases then temperature of SGSP increases rapidly.
- The Coefficient of the conductivity of the ground affect the temperature of the SGSP. The increase and decrease of the coefficient of the conductivity of the ground will decrease and increase the temperature of SGSP respectively. It means that the variation of temperature of SGSP inversely depends upon the coefficient of the conductivity of the ground.

Table I SGSP with NaCl salt (Density=1.2g/cm^3)

Sl. No.	Area of Solar Pond (m^2)	Flow Rate (cm^3/min.)	Thermal Power (MWt)	Electrical Power (MWe)
1.	11168000	$13.86x10^6$	500	20
2.	6700796	$10.39x10^6$	375	15
3.	5583997	$6.93x10^6$	250	10
4.	2791998	$3.46x10^6$	125	5

Table II SGSP with $MgCl_2$ salt (Density=2.32g/cm^3)

Sl. No.	Area of Solar Pond (m^2)	Flow Rate (cm^3/min.)	Thermal Power (MWt)	Electrical Power (MWe)
1.	11168000	$42.13x10^6$	500	20
2.	6700796	$30.96x10^6$	375	15
3.	5583997	$20.88x10^6$	250	10
4.	2791998	$10.38x10^6$	125	5

Table III SGSP with $NaHCO_3$ salt (Density=2.20 g/cm^3)

Sl. No.	Area of Solar Pond (m^2)	Flow Rate (cm^3/min.)	Thermal Power (MWt)	Electrical Power (MWe)
1.	11168000	$22.18x10^6$	500	20
2.	6700796	$16.28x10^6$	375	15
3.	5583997	$9.97x10^6$	250	10
4.	2791998	$5.71x10^6$	125	5

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