Experimental Analysis of Salt Gradient Solar Pond with and without Using a Transparent Separator (Glass) Above Lower Convective Zone

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Abstract

Solar pond is use to store the heat by creating a gradient of salt. The major problem in salt gradient solar pond is continuous diffusion of salt from LCZ to UCZ. The continuous erosion of salt from high concentration zone to low concentration zone cause of decrease in energy storage efficiency with time. Two experiments were performed on a salt gradient solar pond: one with separator in lower convective zone and other one on conventional solar pond. Both the solar pond has same surface area 0.7m x 0.45m and a depth of 0.4 m. The main purpose of experiment was to compare the performance parameters (salt-concentration, maximum LCZ temperature) with and without using the glass as transparent separator. Experimental data was collected for 15 days period for each setup. On the basis of analysis of experimental data it was found that there is completely elimination of mass diffusion from LCZ i.e. salt concentration of LCZ remains same throughout period of time but on the other hand maximum LCZ temperature achieving time increases due to small decrease in transmittance.

Keywords - *Solar pond, Diffusion, Transparent separator, LCZ, Salt gradient*

I. INTRODUCTION

A salt gradient solar pond is a modified form of ordinary solar pond by creating gradient of salt to suppressing the convection current. It is a cheaper method for utilizing the solar energy without creating any pollution. There are three zone in a salt gradient solar pond as lower convecting zone (LCZ), non convecting one (NCZ), and upper convecting zone (UCZ). LCZ is the lower zone of solar pond with highest concentration and used to store the heat energy from solar radiation. NCZ is the heart of solar pond because it suppresses the convection current due to the existence of the density gradient and helps out to store thermal energy. UCZ is consisting of very small salt concentration or fresh water. UCZ covers the NCZ and protect from external disturbance such as wind, dust, raindrop etc[1].

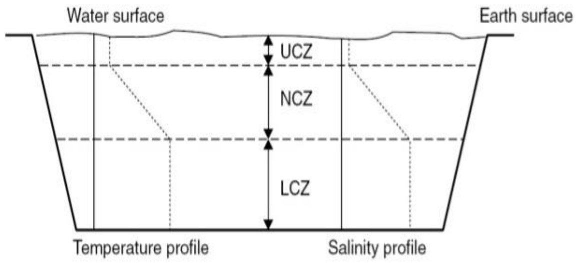

Fig: 1 Solar Pond

Solar pond efficiency to store the heat depends on stability of gradient zone. Maintaining the salt gradient zone is a major challenge because erosion of salt leads to reduce the thickness of NCZ and thus pond is destroyed. Heat is stored in the LCZ and useful heat can be extracted by using the different types of heat exchanger. Heat can be used in different applications such as milk process industry, agriculture industry, heating and refrigeration of building and industry, power production using Rankine cycle etc.

Nomenclature

C	Salt concentration
C_1	Salt concentration at top of solar pond
C_2	Salt concentration at bottom of solar pond
D	Diffusivity of salt in water
x	Depth from top
T	Temperature
T_1	Temperature of top layer of water
T_2	Temperature of bottom layer of water
ρ	Density
ρ_1	density of top layer of water
ρ_2	density of bottom layer of water
α	Thermal diffusivity
ν	kinematic viscosity
LCZ	Lower convective zone
NCZ	Non convective zone
UCZ	Upper convective zone

II.PRINCIPLE OF WORKING

The principle of working of a solar pond can be explained with reference to fig.1. Consider a pond of depth L having salts dissolved in water. By Assuming that the concentration at top (C_1) is less than that at bottom (C_2) and that a concentration gradient exists from the top to the bottom. The variation of density with temperature for the two concentrations is shown. Let $T_1$and ρ_1 be the temperature and density of top layer of water indicated by point A, and T_2 and ρ_2 be the temperature and density of bottom layer of water indicated by point B. similar points are located for the intermediate layers and the curve AB is drawn showing the variation of density as one moves downwards in the pond. It is obvious that no convection will occur so long as the slope of the curve AB is positive.[2]

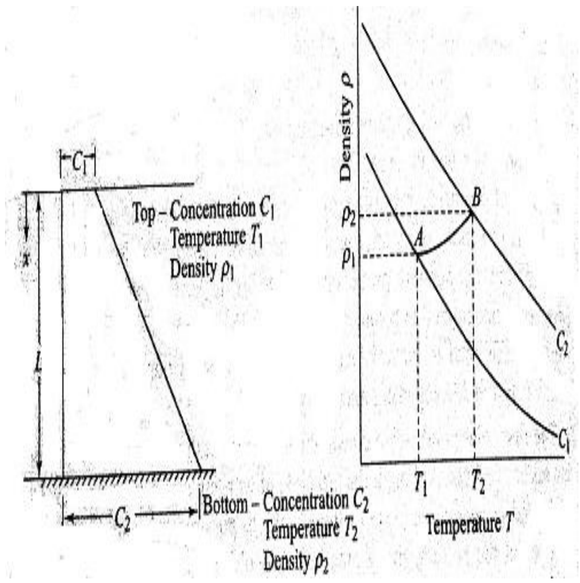

Fig.2: Variation Of Concentration And Temp

Mathematically, the condition that the lower layers remain denser than those above is given by

$$\frac{d\rho}{dx} > 0$$

Since, ρ=ρ(C,T), it follows that the condition for stability is

$$\left[\frac{\partial \rho}{\partial C}\right]_T \left[\frac{\partial C}{\partial x}\right] + \left[\frac{\partial \rho}{\partial T}\right]_C \left[\frac{\partial T}{\partial x}\right] > 0 \qquad ...(1)$$

$$\frac{\partial C}{\partial x} > -\left\{\left(\frac{\partial \rho}{\partial T}\right)_C \left(\frac{\partial T}{\partial x}\right) \Big/ \left(\frac{\partial \rho}{\partial C}\right)_T\right\} \qquad ...(2)$$

From a slightly more sophisticated analysis which considers the effect of small perturbations, it can be shown that

$$\frac{\partial C}{\partial x} > -\left\{\frac{\nu+\alpha}{\nu+D}\right\}\left\{\left(\frac{\partial \rho}{\partial T}\right)_C \left(\frac{\partial T}{\partial x}\right) \Big/ \left(\frac{\partial \rho}{\partial C}\right)_T\right\} \qquad ...(3)$$

Where, ν= kinematic viscosity,

α= thermal diffusivity,

D= diffusivity of salt in water

For the solution of salt in water under the conditions encountered in solar ponds, the value of the term $(\nu+\alpha)/(\nu+D)$ is about 1.15. Thus the criterion for stability given by equation (2) is little more stringent than the criterion given by equation (3). Equation (2) or (3) can be used for calculating the minimum concentration gradient required for maintaining a given temperature gradient at a particular level in a solar pond. In actual practice, a certain margin of safety is recommended and the concentration gradient is maintained at about twice the value given by equation [3].

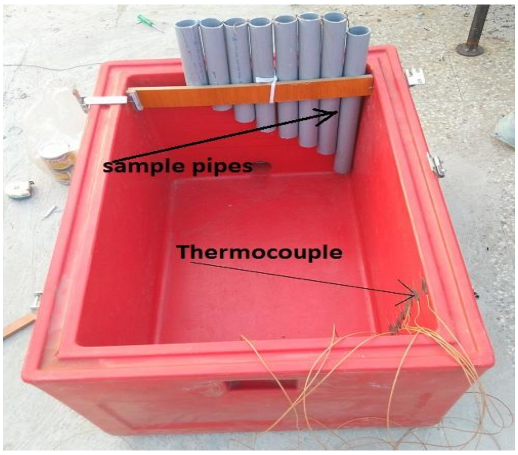

Fig.3: Solar Pond Without Using Glass

III. EXPERIMENTAL SETUP

A rooftop solar pond is used to find out the effect of transparent separator on salt diffusion and other performance parameter. Experimental setup of rooftop solar pond was established in Jaipur city. Solar pond body is constructed with a box of plastic wall (2 cm) with sandwich foam insulation. Experimental solar pond without using glass is shown in fig.2

The dimension of solar pond was 0.8m by 0.5m in cross-section and 0.4m in deep. PVC pipe of 1.5inch in diameter was used at different height (5cm gap between each pipe height) for taking the sample of salty water at different layer. The salty water sample is used to determine salt specific gravity with the help of hydrometer. Specific gravity is use to determine salt concentration at different layer. To find out temperature at different height (thermocouples were set from bottom 40 cm to top with interval of 5 cm), T-type thermocouples at wall of solar pond were used.

The experimental pond was formed using salt solution (Nacl) with concentration 20 % to 0 % (weight percentage). LCZ was formed up to height 10 cm with a uniform salt concentration of 20 %. NCZ was formed with the help of diffuser (fig.4) up to height of 35 from bottom (25 cm thickness above LCZ). Salt solution was filled with variation ΔC =3 % with depth variation ΔX = 3 cm. The main purpose of using diffuser was to eliminate the erosion of layers by jet of water. After NCZ formation, UCZ was form with a small salt concentration followed by fresh water up to top (5 cm thickness) of solar pond. Temperature and salinity data reading was collected daily for 8 hours (10 am to 5 pm) up to 15 days.

By completing the experiment on without using the glass, the setup of salt gradient solar pond with glass above lower convective zone was prepared. Glass is supported by different clip support and the thickness of glass (transparent) was 5 mm.

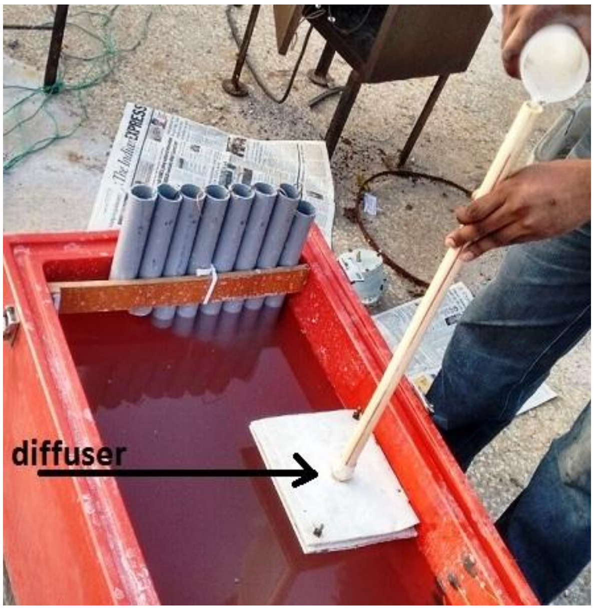

Fig. 4: Formation of NCZ using diffuser

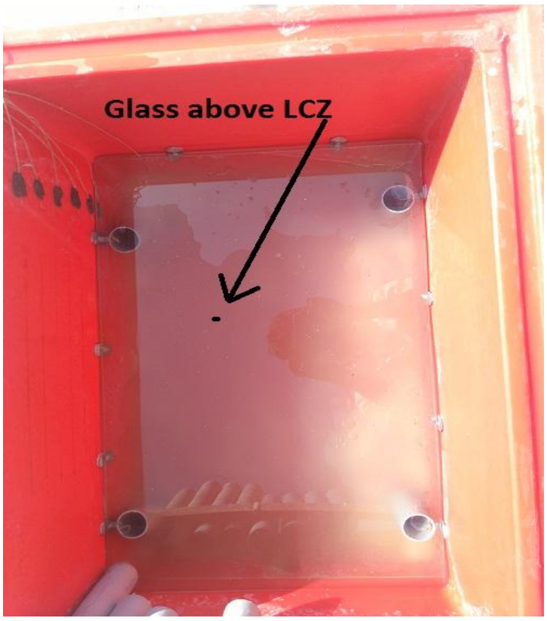

Fig. 5: Solar Pond with Glass above LCZ

IV. RESULT AND DISCUSSION

A. Salinity observation

Experiment was performed first 15 days without using any transparent glass and then after that 15 days experiment was performed with using a transparent glass above lower convecting zone. The salinity was measured each day in morning and the temperature was measure till morning 10AM to 5 PM, 8 hours every day. The variation of salinity was high due to high concentration in lower convective zone (LCZ) and very low concentration of salt in upper convective zone (UCZ) on first day. High concentration potential causes high rate of mass diffusion from lower convective zone (LCZ) to upper convective zone (UCZ) in starting days. But as the time increases, the concentration potential decreases i.e. the salt concentration of lower convective zone starts decrease and salt concentration of upper convective zone starts increase. Due to the diffusion of salt, the salt gradient start diminishing and convection current tends to increase. Convection current cause increase in useful heat transfer from lower LCZ to UCZ i.e. starts decreasing the performance of solar pond

Table 1: variation of salinity with depth for day 1 and day 15 without and with using glass

	Salinity without glass		Salinity with glass	
Depth	**Day1**	**Day15**	**Day1**	**Day15**
0	1.01	1.08	1.01	1.04
5	1.05	1.12	1.04	1.07
10	1.08	1.14	1.07	1.10
15	1.11	1.15	1.10	1.12
20	1.14	1.15	1.15	1.14
25	1.17	1.15	1.17	1.15
30	1.19	1.15	1.20	1.19
35	1.20	1.16	1.20	1.19
40	1.20	1.17	1.20	1.19

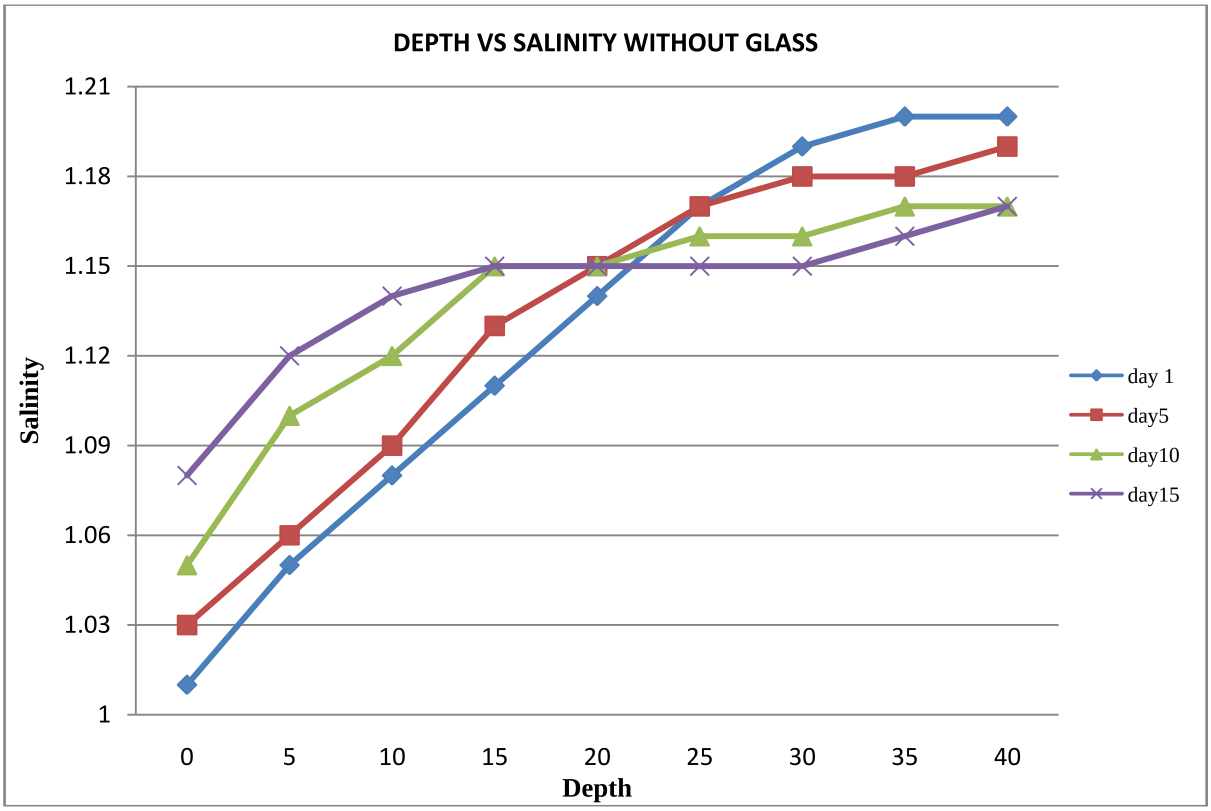

Fig. 6: Variation of salinity V/s depth without using glass above LCZ

The main purpose of using glass is to lock the diffusion of salt from lower convecting zone and maintain the salinity gradient for longer period of time. By maintaining the salinity gradient the performance of the solar pond can be maintain and store the heat for longer period. Using glass above lower convective zone separates the concentration potential between lower convecting zone and upper convective zone so that the rate of mass diffusion was very less in compare to without using a glass above LCZ.

At the day of starting experiment, the salt concentration was 1% in UCZ in both cases (with and without using glass above LCZ). But after 15 days the salt concentration in case of without using glass above LCZ, was 8 % while using glass above LCZ, it was only 4%.

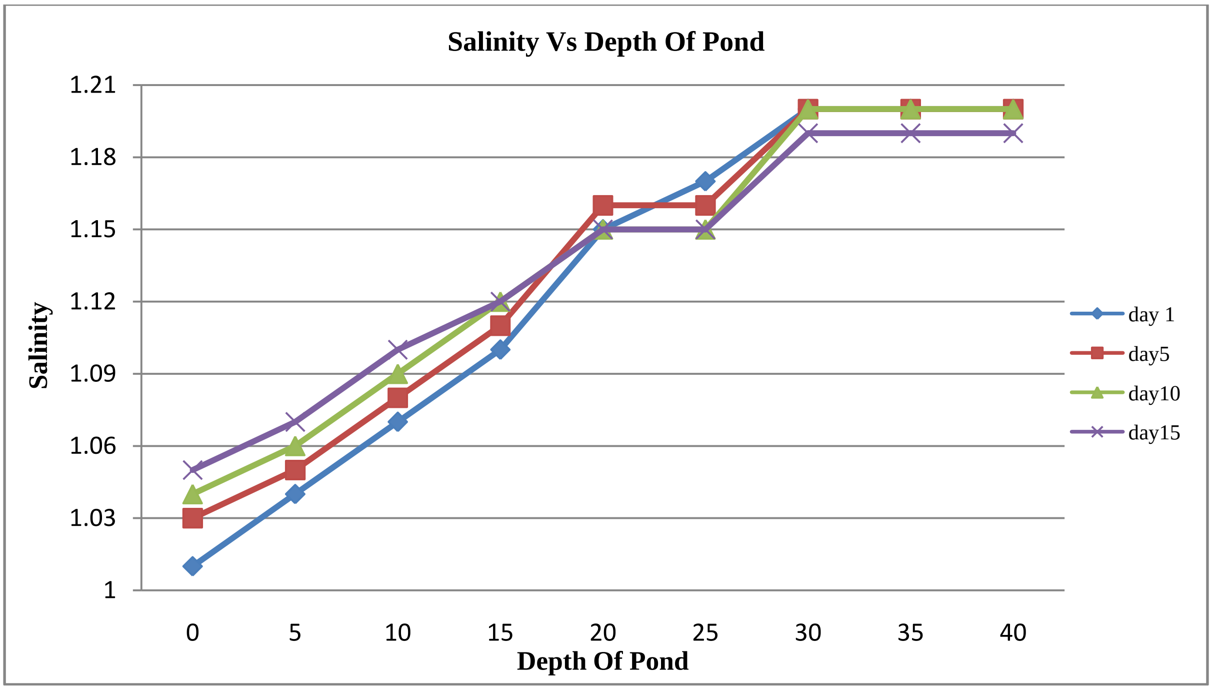

Fig.7: variation of salinity v/s depth with using glass above LCZ

B. Temperature observations:

Temperature in solar pond increase with increase in depth because as the depth of solar pond increase the density of salty water increase continuously up to LCZ and heat loss decrease. It is observed that temperature of storage zone in case of without using glass increases sharply up to 7-8 days and then start decrease because after the one week salt gradient start diminishing and due to which convection losses starts increases.

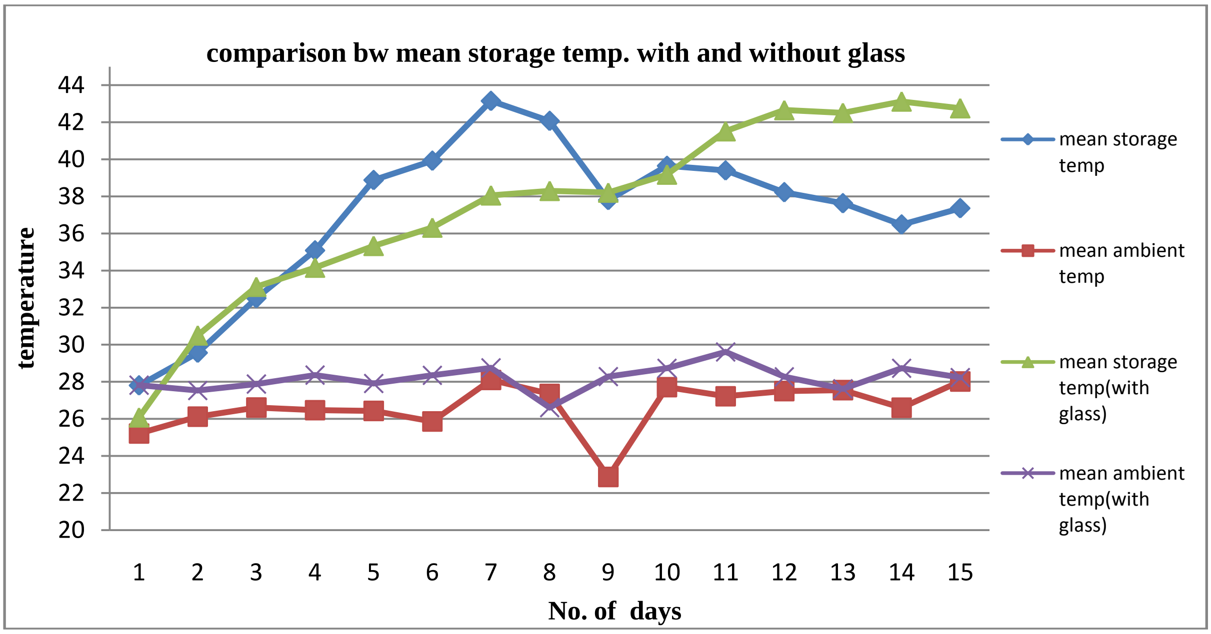

Fig 8: Mean storage temperature vs. No. of days

The maximum temperature reaches on 7th day of experiment which was 50.8 ^{0}C in LCZ without using the glass while the maximum temperature reaches on 14th day which was 47.6 ^{0}C in LCZ with using the glass. Higher temperature achieved in without using a glass but rate of increasing as well as decreasing the temperature was faster in this case due to less stability of gradient zone i.e. unable to store the heat for a longer period of time. The temperature was little lesser in case of using glass but the stability of gradient zone was more so the rate of increasing and decreasing the temperature of storage zone was less i.e. we can store the heat for a longer period of time.

But in case of using glass above LCZ, the rate of increase in temperature of storage zone was less in comparison of without using glass. There were some losses of solar radiation with using glass due to deposition of some salt and dust particle which affects the transmissivity of glass. After one week the temperature of storage zone continued increasing instead of decreasing because of stability of the salt gradient and maximum temperature achieved on 14th day. In LCZ low wavelength radiation permitted to pass through the glass but high wavelength radiation was not coming out and entrapped in LCZ ,due to this LCZ temperature was not decreasing in evening time and heat losses decreases.

V. CONCLUSION

This paper has experimentally studied the effect of a transparent separator (glass) above LCZ which decreases the diffusion of salt from LCZ to NCZ and maintain the stability of salt gradient for a longer period of time. When there was no glass above LCZ then the gradient of salt start diminishing after one week and heat loss start increasing rapidly due to convection current. But if using a transparent 5 mm glass above LCZ than rate of diminishing salt gradient was very less and temperature maintain for a longer period of time. There were some losses of solar radiation due to decrease in transmissivity (deposition of dust particles) by using glass, due to which achieving the same storage temperature, more number of days was required. The salt concentration in top of UCZ due to salt diffusion after 15 day was 8 % without using glass and 4% with using glass. So this is a significant difference in salinity by using a glass above LCZ for maintaining the salt gradient for longer period of time.

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