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Experimental Study on a Portable Mini Salt Gradient Solar Pond

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Abstract

The mini salt gradient solar pond is an innovative and novel concept which overcomes many of the difficulties of the conventional salt gradient solar pond. An experiment was carried out to analyses the performance of the mini salt gradient solar pond of surface area 2.02 m^2 at Bhavnagar, India. Experimental investigation has been carried out during the month of June 2014. The maximum storage temperature was found to be 72°C. The outcome of the experimental investigations has been reported in this paper.

Keywords: *Solar Energy, Salt Gradient Solar Pond, Storage temperature*

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INTRODUCTION

Solar energy is an abundant and renewable energy source. The annual solar energy incident at the ground in India is about 20,000 times the current electrical energy consumption. The use of solar energy in India has been very limited. In India, Gujarat and Tamil Nadu are the two states where common salt is produced on a large scale. These two states have arid regions where the land is unsuitable for agriculture and have more than 300 clear days a year. Also they constitute 10% of India's area. If 4% of the land in these two states were used as solar pond power plants, they can generate about 200 billion kilowatt hours of electrical energy. Therefore, solar ponds play an important role in meeting the future energy needs of India using a locally available and renewable energy source [1]. Gujarat receives second largest amount of solar radiation in India about 5.5 to 6 Kwh/sq.m/day with 300 sunny days/year. Most locations in Gujarat receive an annual Direct Normal Incidence (DNI) in between 1,800 – 2,000 Kwh/m^2. Waste land of about 14.40 million acres is receiving largest amount of solar radiation. Northern part of Gujarat receives highest solar radiation. The locations connected by the Rann of Kachchh region of Gujarat receive the maximum DNI in the state [2].

Solar Pond Technology

A solar pond is a large-area collector of solar energy resembling a pond that stores heat, which is then available to use for practical purposes. There are different kinds of solar ponds such as; saltwater ponds, shallow ponds with covers, gel ponds, deep ponds with glass or plastic containment devices. The characteristics of these ponds are to store the thermal energy from the incoming solar radiation in the heated layers of the pond, and to suppress the convection currents that otherwise become lead to heat loss to the atmosphere.

The most common form of solar pond is a salt gradient solar pond (Figure 1). Salt water ponds exist naturally in a variety of locations, the first ponds being discovered in Eastern Europe at the beginning of the 20th century at a natural salt lake in Transylvania. Most of the salt water ponds operated today has to take benefits of engineering technologies and application for practical purposes. Ponds can be operated seasonally or continuously, and at low, medium or high temperatures.

The characteristics of a salt water solar pond are that it has increasing amounts of salts dissolved in the water with depth. The density of each layer of the pond thus increases with depth, so it is called a salt stabilized or salinity gradient solar ponds. Below this salinity gradient zone there is a heat storage zone which contains saturated salt solution, and above it there is surface zone having a thin layer of fresh or low salinity water. Most of the incoming solar radiation reaches the heat storage zone at the bottom of the pond where it heats up the concentrated salt solution there. Upwards heat loss in the pond from the storage zone is prevented because natural convection currents in the gradient zones are suppressed. This suppression and hence insulating effect occurs because of the density gradient present. As a particular layer of solution is heated from below its density is slightly reduced, but remains higher than that of the layer above. The normal method of establishing the different gradient zone is by injection of fresh water. This method is more suitable and therefore, it has been adopted in most solar pond development in the world [3]. The erosion of the gradient zone depends upon the density and temperature gradients at the gradient zone – storage zone interface. The density of the surface layer increases as diffusion of the salt from bottom and because of evaporation. Therefore the surface layer flushed regularly with fresh water to keep the density below 5% by weight [4].

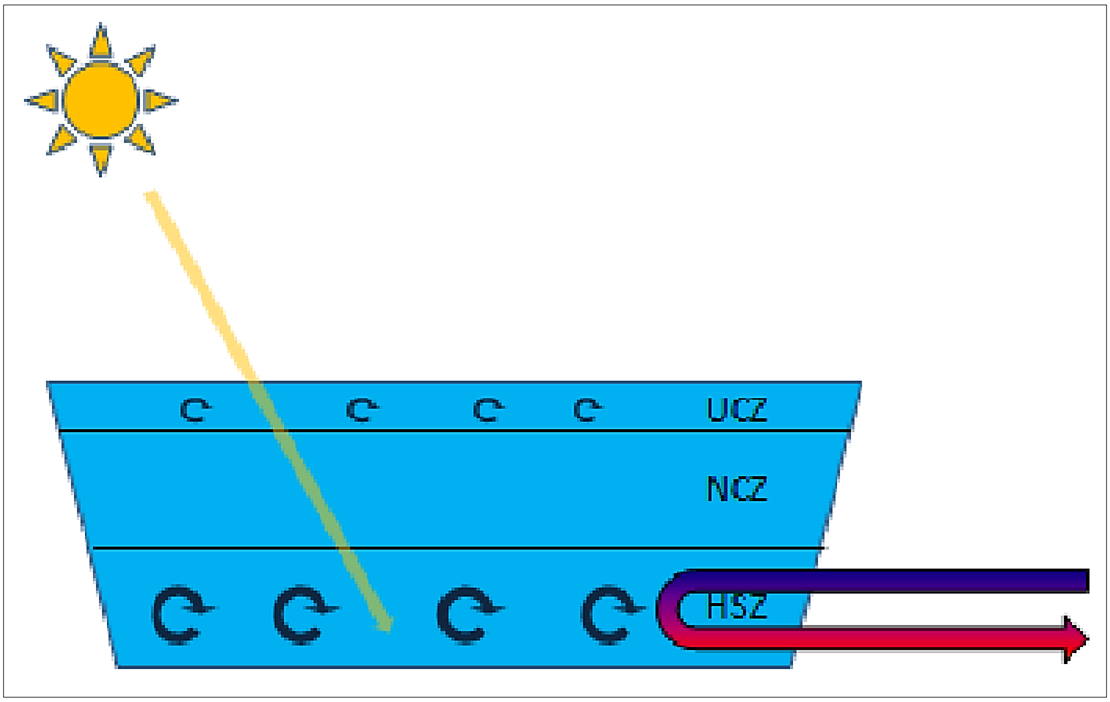

Fig. 1: *Schematic of a Salt-gradient Solar Pond.*

The thermal efficiency of a solar pond is dependent upon the clarity of the pond, which is reduced by the presence of algae or dust. Dust and debris much heavier than water will sink to the bottom. It has been observed that the dust accumulating at the bottom of the pond does not have adverse effect the absorption of solar radiation at the bottom of the pond [5]. The performance of mini solar pond is affected by its size, the effectiveness of its thermal insulation and the thickness of the three different zones. A mini solar pond can be used to store large amount of energy while operating a relatively low temperatures [6]. The behavior of the portable salt gradient solar pond mainly depends on the amount of solar radiation incident that reaches the surface of the solar pond, density gradient inside the solar pond and total thickness of the solar pond as well as the thickness of the three different zones like upper convective zone, nonconvective zone and heat storage zone [7].

Design of Mini Solar Pond

The mini salt gradient solar pond was constructed from galvanized steel sheet of 1.44 mm thickness (Figure 2). The pond width at the top and bottom are 900 and 100 mm, respectively. The height of the solar pond is 450 mm inclined at an angle of 45° to facilitate more insolation capture with relatively little shading. The bottom and sides of the pond were insulated with glass wool to reduce the heat loss through the walls. The inner surfaces of the wall were painted with matt-black to increase the rate of solar radiation absorbed.

A calculated amount of salt (NaCl) was placed on the base of the pond and then fresh water added until the pond is half full. Mixing was carried out in order to make a solution become homogeneous. The pond was then filled continuously with fresh water. In order to maintain the required stable gradient in the mini solar pond, it was necessary to inject brine periodically into the upper and lower convective layers and wash the upper zone with fresh water. The existence of a salt gradient in the pond is desirable because it gives the pond thermal stability and therefore, improves its performance. To measure the density profile, known–volume samples were taken from the different depth of the ponds and then measured by analytical electronic balance.

The concentration gradient existing in salt gradient solar pond leads to steady diffusion of salt from higher to lower concentration, that is, from bottom to top through the gradient zone. Stability is to be maintained by introducing salt at the bottom while the top is frequently washed with fresh water. When solar radiation falls on the pond, the part which is transmitted to the bottom, heats the lower layer and as a result inverse temperature gradient are set in. These are temperature gradients that are reversed from the normal. Inverse temperature gradients are maintained to eliminate convection currents that occur due to temperature difference during normal temperature gradient.

Fig. 2: *Photograph of a Salt Gradient Solar Pond.*

MATERIAL AND METHOD

In this experimental study, an insulated salt gradient solar pond having a truncated square pyramid shape with a size of 90x90 cm at the top and 10x10 cm at the bottom with 45 cm height was fabricated. The heat storage zone has 12 cm high from the bottom of the pond having 1250 kg/m^3 brine density. The nonconvective zone or the insulation zone with gradually decreasing brine density having a thickness of about 28 cm from the storage zone. Finally, the upper convective zone or surface zone with approximately 5 cm depth from the insulation zone having almost fresh water. The heat storage zone has throughout high density brine of about 1250 kg/m^3, above which there is a gradually decreasing brine density up to about 920 kg/m^3. Total thickness of the wall with glass wool used for heat insulation is about 2.5 cm. Thermal energy obtained from this pond can be stored below the boiling point of the brine. Stored energy in the form of heat can be taken out from the storage zone for practical application.

Increase of temperature in the heat storage zone is possible with the insulation of the zones surrounding the pond. Upper convective zone is one of the zones where the most heat loss takes place due to effects of wind, evaporation, rainfall, ambience etc. The temperature of the pond at different depths and at different intervals was measured by K-type thermocouple. The density at three different zones was measured by weight balance method. Throughout the experiment we assume that there is no movement in the boundary of the three different zones and no heat extraction from the pond. Specifications of the mini salt gradient solar pond for the experiment purpose are shown in Table 1. Also Mean Monthly Global Solar Radiant Exposure for Bhavnagar City (21°76´N, 72°15´E), Gujarat, India is shown in Table 2.

Table 1: *Specification of Mini Salt Gradient Solar Pond.*

Component	Description	Dimensions
Material of solar pond	Galvanized Iron Sheet	1.44 mm thick
Size of solar pond	45° inclined with base	Top 90X90 cm Base 10X10 cm Height 45 cm.
Insulation	Glass-wool	2.5 cm thick
Salt	Sodium Chloride (NaCl)	25% Maximum concentration (HSZ)
Water depth/Salinity	Upper convective zone	5 cm/920 kg/m³
	Nonconvective zone	28 cm/ 1025 kg/m³
	Heat storage zone	12 cm/1250 kg/m³
Volume of water	-------	136.5 lit
Temp. Indicator	Temp. Measuring instrument With K-type thermocouple	-------

Table 2: *Mean Monthly Global Solar Radiant Exposure for Bhavnagar City (21°76´N, 72°15´E).*

Sr. No.	Month	Insolation H (MJ/m^2/day)
1	January	17.92
2	February	20.92
3	March	24.16
4	April	26.23
5	May	26.54
6	June	22.31
7	July	16.28
8	August	16.26
9	September	19.91
10	October	21.06
11	November	18.33
12	December	16.55

RESULTS AND DISCUSSION

The concentration gradient existing in salt gradient solar pond leads to steady diffusion of salt from higher to lower concentration, that is, from bottom to top through the gradient zone (Figure 3). First the storage layer is formed with high concentration brine solution mixed in bottom. Then layers of decreasing salinity stacked on top of the storage layer using horizontal diffuser. Lastly fresh water is the final layer pumped on the surfaces. The relation between the variation of storage temperature with time and depth shows that the ambient temperature increase until it reaches the maximum value at about 14:00 pm and then it will decrease until it reaches its minimum value at 18:00 pm (Figures 4 to 6). The storage temperature at different depths increase until it reaches its maximum temperature at 16:00 pm. The maximum temperature occurs in the bottom of the pond which clearly indicates that the solar radiation penetrates into the heat storage zone and there is no heat convection due to high salinity of the water. The temperature is gradually decreasing from the HSZ to NCZ and ultimately to the UCZ which has almost fresh water layers.

The temperature difference throughout the day between heat storage zone and upper convective zone is maximum about 42°C in hot shiny day, while in case of cloudy atmosphere it becomes 31°C. Thus, even if the less solar insolation in rainy season or in the cloudy atmosphere, the temperature in the heat storage zone is high compared to the atmospheric temperature (Table 3).

In general operating salt gradient solar pond under climatic condition of Bhavnagar city (21°76´N, 72°15´E) is encouraging due to good levels of solar radiation incident and availability of salts.

Table 3: *Sample Calculations.*

Quantity	Without energy loss	With energy loss
$Q_L = U_L (T_s - T_a)$ $[W/m^2]$	0	2.14*(72−44) = 59.92
$Q_{abs} = I\alpha\tau$ $[W/m^2]$	242 * 0.45 = 108.9	242 * 0.45 = 108.9
$Q_u = Q_{abs} - Q_L$ $[W/m^2]$	108.9 – 0 = 108.9	108.9 – 59.92 = 48.98
$\eta_p = Q_u / I$ x 100%	108.9 / 242 x 100 = 45%	48.98 / 242 x 100 = 20.23%

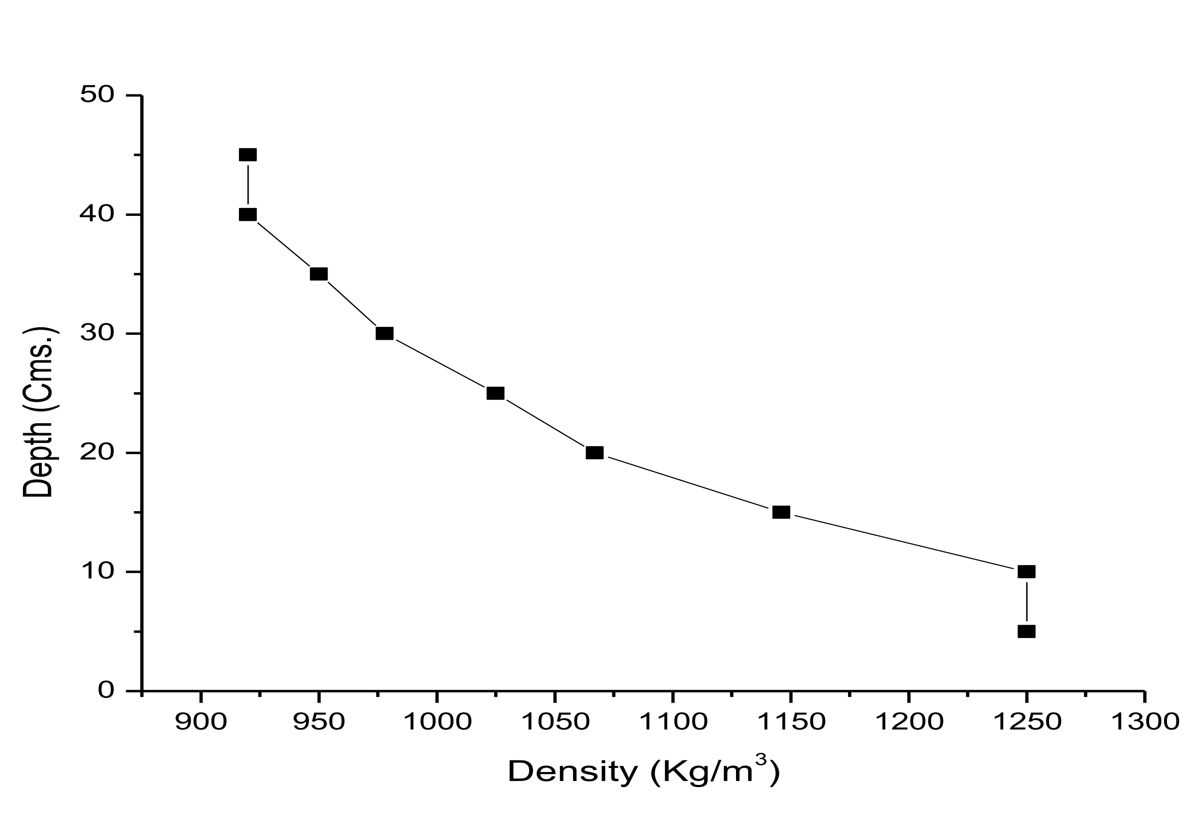

Fig. 3: *Salinity Gradient of a Mini Solar Pond.*

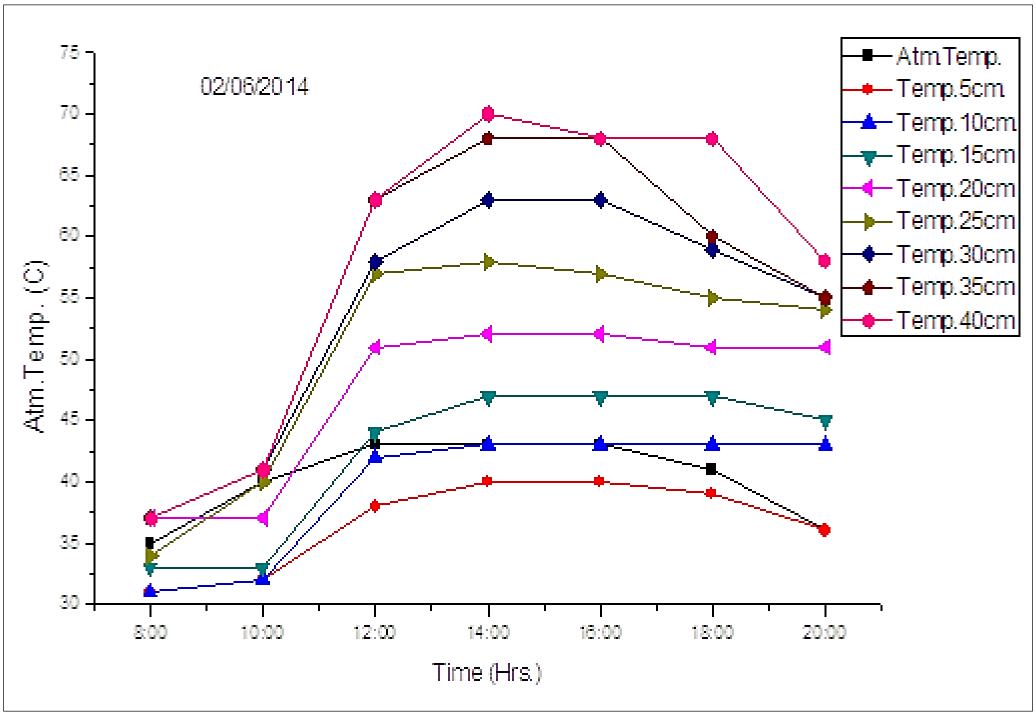

Fig. 4: *Temperature Profile at Various Time and Depth.*

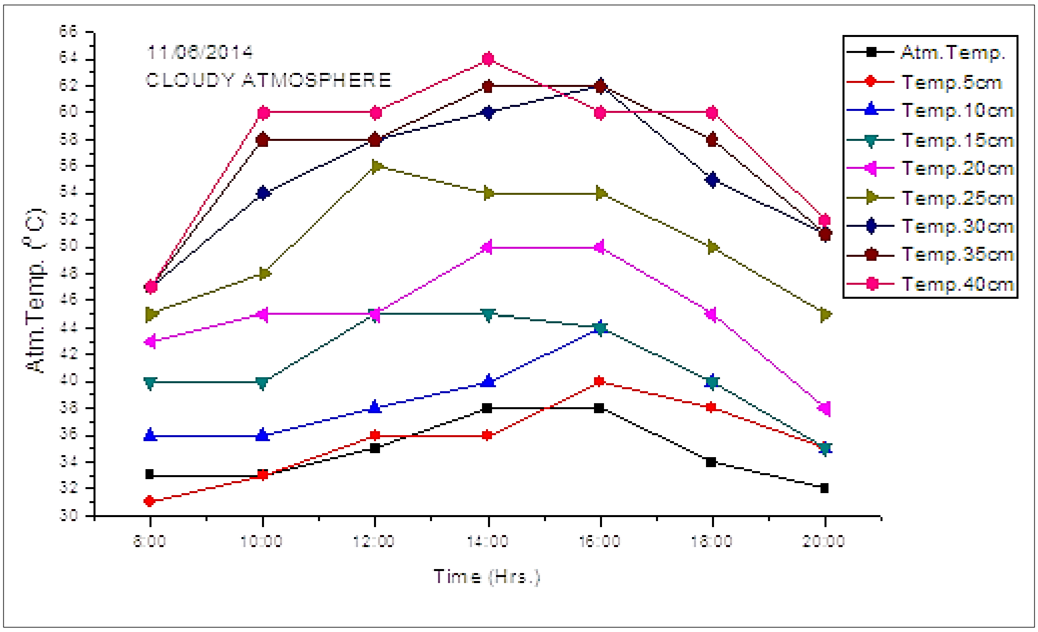

Fig. 5: *Temperature Profile at Various Time and Depth on a Cloudy Day.*

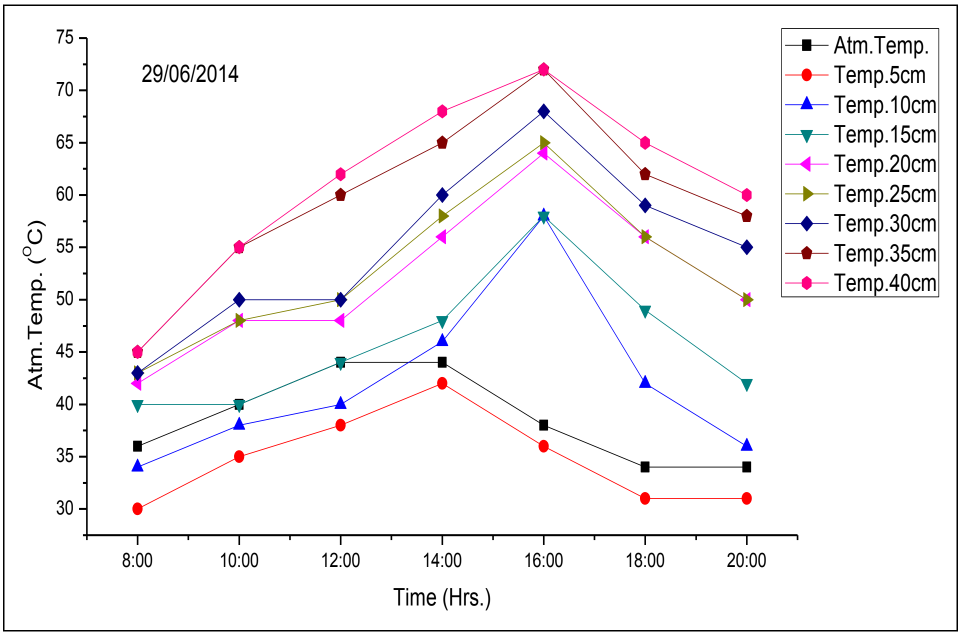

Fig. 6: *Temperature Profile at Various Time and Depth.*

CONCLUSION

A portable mini salt gradient solar pond can be used to store large amounts of heat at relatively low temperatures. The performance of the domestic salt gradient solar pond in Bhavnagar is encouraging primarily due to the high levels of radiation experienced there as shown in Table 2 [8]. So it can be economically viable. Other advantages of the portable mini solar pond are its flexibility, easy to handle, low space requirement and eco-friendly energy sources.

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