沙漠研究 **19**-1, 13- 16 (2009 )
Journal of Arid Land Studies

"Desert Technology IX "
Refereed Paper

# Increasing Energy Efficiency of Inorganic Salt Gradient Solar Pond in Thar Desert by Inclusion of Complementary Support System

Rajan JAYAPRAKASH [1] , Karuthiappan PERUMAL[1], Sanjay KUMAR[2,*], Syed MUMTAZUDDIN[3]

**Abstract**: Complementary Solar Pond System (CSP) combines the advantages of high storage efficiency of the salt gradient solar pond (SGSP) and maximum collection efficiency of shallow solar pond (SSP). The system was analyzed by a computer simulation model of thermal processes involved. SSP (1.92×1×0.3 $m^3$) and SGSP (2.41×2.41×0.9$m^3$) combination was used for experimental investigation and validation of model. In this paper, the thermal performance of the CSP system is presented under constant flow rate but with variation in quantity of salt flux at the LCZ. Results show that the system achieves high storage efficiency of 5.268% in and can be exploited commercially.

**Keywords:** Complementary solar pond (CSP), Efficiency, Energy, Solar thermal, Storage

## 1. Introduction

Solar pond is an important concept for utilization of solar energy during night or cloudy days. In the Great Indian Desert, temperature dips to 2-3 ˚C during winters. Energy from these ponds can be well utilized for space heating, aquaculture, distillation, drying and electricity production. The stability and other dynamical processes of the solar pond was comprehensively discussed by Xu (1990) while its transient behavior in a closed loop has been investigated and analyzed by Alagao (1996). It explains the behavior of solar pond with a complete salt recycling system using natural evaporation of brine in an evaporation pond. Later, Subhakar and Srinivasamurthy (1994) conducted parametric studies on saturated solar pond. Other works worth mentioning are those of Schaefer and Lowrey (1993) and Tsilingris (1988). A computer mode of the thermal performance of a floating honey comb pond cover was developed and the cost of building honey comb solar ponds and salt gradient ponds was compared by Schaefer *et al*. (1993).

## 2. Materials and Methods

CSP is an integrated design combining the advantages of the salt gradient solar pond and shallow solar pond. The salt gradient solar pond has maximum collection efficiency. The shallow solar pond has a maximum collection. The solar energy collected by shallow solar pond and transferred to the adjacent salt gradient solar pond in the evening for storage. This storage thermal energy is transferred by using heat exchanger system. The energy extracted from shallow solar pond during day time is directly used after thermal saturation of SGSP. The energy from the salt gradient solar pond is extracted during night time. At first, a simulation model of the CSP was developed using finite difference method to solve energy balance equations and compared with experimental investigation. The system is shown in **Fig. 1**.

The energy stored in the SSP is transferred to the LCZ of the SGSP. At the same time, the SGSP also gains a small amount of energy from solar radiation. This creates small increase in temperature at SGSP, which is the initial temperature of the CSP model. In CSP**,** energy from the SSP is supplied to the SGSP at each state of stability of the temperature profile. The physical model of CSP consists of three zones, Upper Convective Zone (UCZ), Lower Convective Zone (LCZ) and Non convective Zone (NCZ) with total depth of the pond D. The thickness of the upper convective zone is $X_{UCZ}$ and the thickness of the lower convective zone is $X_{LCZ}$. Non convective zone (NCZ) is divided into N grids of thickness $\Delta x$ and total thickness of $X_{NCZ}$. The bottom of the pond is well insulated and it acts as an isothermal layer of thickness $x_g$. x = 0 indicates the surface of the pond, x = $x_1$ separating the UCZ from the NCZ, x = $x_2$ separating the NCZ from the LCZ and x = $D$ separating the LCZ and Ground.

[1]Dept. of Physics, Sri Ramakrishna Mission Vidyalaya, College of Arts and Sc., Coimbatore, T.N., India
[2]Centre for Appropriate Technonology, Chandragupta Institute of Management, Patna – 800001 & Centre for Renewable Energy & Environmental Research, PO Box - 5, Muzaffarpur - 842001, Bihar, India; Ph. - +91-9431239820, E-mail: creer@sancharnet.in
[3]University Department of Chemistry, B.R.Ambedkar Bihar University, Muzaffarpur-842001, Bihar, India

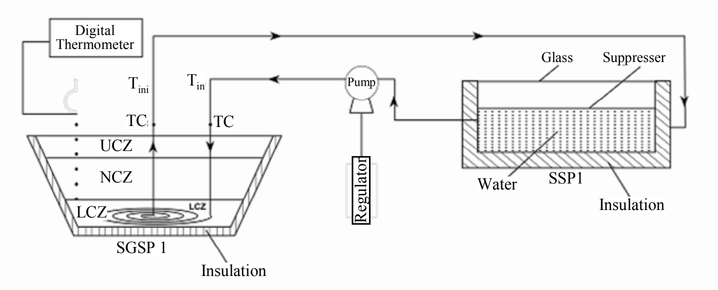


**Fig. 1. Schematic diagram of the proposed Complementary Solar Pond (CSP).**

The pond performance is analyzed by one dimensional model. All sides and bottom of the pond are well insulated. There is no shadow effect at the bottom due to side walls. The transmittance of the salt solution is assumed to be the same that of water. Energy balance is carried out per unit area of the pond. The increase in temperature due to variation of mass (concentration) is minimum during the period of supply of energy. So it is assumed as a constant. The heat transfer factor of the complementary solar ponds depends upon the effectiveness of the exchanger. The thermal expansion of the solution and heat sink term show the very small variation in the rise in temperature so it is neglected in the energy balance equation. Even though salt concentration is varying, pond thermal properties such as K, ρ and Cp are considered as constant. The energy is gained at the LCZ uniform throughout the entire zone. The initial temperature of all the systems is considered as equal to ambient temperature (30 ˚C).

## 3. Thermal Energy Balance of the Complementary Solar Pond

At first, a thermal model of the CSP system was developed to predict its performance under various climatic conditions. The energy balance equation of different parts of the system was set up and solved. Energy balance for NCZ for complementary solar pond may be written as,

$$\rho\, C_p \frac{\partial T}{\partial t} = K \frac{\partial^2 T}{\partial x^2} \tag{1}$$

The boundary conditions are,

$$T\big|_{x=X1} = T\big|_{UCZ}\ ;\ \ T\big|_{x=X2} = T\big|_{LCZ}$$

An energy balance equation of UCZ and LCZ for Complementary solar pond can be written as,

$$\rho\, C_p\, X_{UCZ} \frac{\partial T}{\partial t} = K \frac{\partial T}{\partial x} - U_{TSGSP} \tag{2}$$

$$\rho C_p x_{LCZ} \frac{\partial T}{\partial t} = -K \frac{\partial T}{\partial t}\bigg|_{x=x2} + K_g \frac{\partial T}{\partial x}\bigg|_{x=D} + Q_{trans} - Q_{pipe} \tag{3}$$

An energy balance over the LCZ with heat removal yields,

$$\rho C_p x_{LCZ} \frac{\partial T}{\partial t} = -K \frac{\partial T}{\partial x}\big| x = x2 + K_g \frac{\partial T}{\partial x}\bigg|_{x=D} - Q_{ext} \tag{4}$$

$$U_{top} = \left[ \frac{1}{h_{c1-c2} + h_{r,c1-c2}} + \frac{1}{h_c + h_{r,c2-amb}} \right]^{-1} \tag{5}$$

Thermal losses through the bottom and the sides of the SSP are given by,

$$U_g = K_g \left[ \frac{(T_w - T_g)}{x_g} \right];\quad U_s = K_s \left[ \frac{(T_w - T_g)}{x_s} \right] \tag{6}$$

Overall loss coefficient ($U_{SSP}$) is the sum of the top ($U_{top}$), bottom ($U_g$) and side loss coefficients ($U_s$). Thermal loss over the top per unit area is given by,

$$Q_{ssp} = U_{top} + U_g + U_s \tag{7}$$

where, $T_g$ = 0.83 ($T_{amb}$ + 3.7). The measured outlet temperature of shallow solar pond and LCZ temperature with the effectiveness of the heat exchanger provides the outlet temperature of the heat exchanger in the CSP system. The outlet temperature ($T_{out, trans}$) during heat transfer is given by,

$$T_{out,trans} = T_{out,SSP} - E(T_{out,SSP} - T_{LCZ}) \text{ and } E = \left[1 - \exp\left(\frac{U_{he}\, A_{tube}}{\dot{C}}\right)\right] \quad (8)$$

The overall loss of the CSP system ($U_{CSP}$) is predicted by following equation,

$$Q_{CSP} = Q_{SSP} + Q_{SGSP} + Q_{pipe} \quad (9)$$

where, $A_{tube}$ - area ($m^2$ ), $C_p$ - specific heat (J $Kg^{-1}$ $°C^{-1}$), D- depth (m), x – thickness(m), Δx- thickness of grids, $\dot{m}$ - mass flow rate (lit $s^{-1}$), t - time (s), h - heat transfer coefficient ($Wm^{-2}$ °C), T - temperature (°C), K - thermal conductivity ($Wm^{-1}$ $°C^{-1}$ ), $K_g$- thermal conductivity of ground ($Wm^{-1}$ $°C^{-1}$ ), $Q_{TSGSP}$ - quantity of heat flux ($Wm^{-2}$ ), $Q_{pipe}$-amount of heat loss in pipe, $Q_{trans}$- the amount of heat transferred,$Q_{ext}$- amount of heat extracted ($Wm^{-2}$ ), $x_1$ - boundary between UCZ and LCZ, $x_2$ - boundary between NCZ and LCZ, $Q_{SGSP}$ ($Q_{LSSP}$) - overall loss coefficient ($Wm^{-2}$) in SSP (SGSP), $QT_{SGSP}$ - loss coefficient at top of the SGSP, $h_{c1-c2}$ - heat transfer coefficient from cover 2 to cover 1 ($Wm^{-2}$ $°C^{-1}$ ), $h_{rc1-c2}$ - the radiative heat transfer coefficient from cover 2 to cover 1($Wm^{-2}$ $°C^{-1}$ ), $h_{rc2-amb}$ - the radiative heat transfer coefficient from cover 2 to ambient ($Wm^{-1}$ $°C^{-1}$), $T_w$- water temperature (°C), $T_g$- glass temperature (°C), $x_g x_s$ - thickness of the bottom of the insulation side, $K_s$ - thermal conductivity, E - effictiveness, $T_{out, ssp}$- the outlet temperature of the shallow solar pond (°C), $T_{LCZ}$ - temperature of the lower convective zone (°C), $U_{he}$ - the overall loss factor of the heat exchanger ($Wm^{-2}$), C - solution concentration (weight percentage), $A_{tube}$ - area of the tube ($m^2$), υ - Kinematics viscosity, ρ - density.

## 4. Results and Discussion

The overall efficiency of the system mainly depends on two systems. They are the performance of the SSP and the performance of SGSP. The overall efficiency is the product of the efficiency of the salt gradient solar pond and the efficiency of the shallow solar pond ($\eta_{CSP} = \eta_{SSP} \times \eta_{SGSP}$). The overall efficiency ($\eta_{CSP}$) of CSP, outlet temperature, heat storage duration etc. of the proposed complementary solarpond (CSP) were numerically predicted by solving energy balance equations in one-dimensional physical model. Energy balance equations are solved with the boundary conditions, $T|_{x=x1} = T_{UCZ}$ and $T|_{x=x2} = T_{LCZ}$. Using initial conditions, $T|_{ini,CSP} = T|_{min,SGSP}$ with different mass flow rates, energy transfer rates are given in **Table 1**.

**Table 1. Variation of energy transfer rate and outlet temperature with flow rate**

| Flow rate (lit $s^{-1}$) | Energy Transfer (kW) | Energy Extracted (kW) | Outlet Temperature during heat extraction (°C) |
|---|---|---|---|
| 0.1 | 5.5 | 9.4 | 58.2 |
| 0.25 | 7.2 | 12.5 | 47 |
| 0.5 | 7.9 | 13.6 | 41.6 |

**Table 2. Parameters and overall Thermal Performance of Experimental CSP**

| Parameters | CSP |
|---|---|
| Area of SGSP | 5.712 $m^2$ |
| Area of SSP | 1.92 $m^2$ |
| Materials | Glass, LDPE (Black), Bricks, Black stone, Saw dust, Cement |
| Pond site | Ground |
| Maximum Temperature | 59.6 °C |
| Storage Capacity | 88.46% |
| Efficiency | 5.268% - 6.026 % |
| Overall loss | 41.87 $wm^{-2}$ |
| Energy gained from SSP | 14466.82 kJ |
| Quantity of salt flux | 1.1596 x $10^{-6}$kg $m^{-2}$s |
| Energy drained from SSP | 31.78%-51.61 % |

Variation of hourly mean radiation was considered for the mathematical model and an initial temperature of the SSP ($T_{ini,SSP}$) was considered to be at 30 °C. The overall loss coefficient $U_L$ is 10.0 $Wm^{-2}$ for shallow solar pond and 25.7 $Wm^{-2}$ for salt gradient solar pond. These losses are predicted with respect to temperature. The depth and flow rate are do not change the overall loss coefficient. The maximum temperature rise in SSP was calculated to be 80 °C. **Fig. 2** shows the temperature profile of CSP of depth 1.2 m with the flow rate 0.100 (lit $s^{-1}$). The time elapsed to reach maximum temperature 67 °C is 5895 min. The calculated quantity of energy supplied at each flow rates is given in the Table 1. **Fig. 3** shows the temperature profile at pond depth of 0.9m. However, the maximum rise in temperature was observed at 67 °C. The thermal stability is reached after the energy is supplied thrice. In thermal stability, the amount of energy is transferred from shallow solar pond to salt gradient solar pond until the temperature at the UCZ and SSP are equal. The total time elapsed during these supply is 4335 min. **Figure 4** shows the salt concentration profile of the SGSP system on all the supplies of energy and attained maximum temperature. A constant flow rate of 0.100 (lit $s^{-1}$) supplied energy of 5.364 kW and temperature rose to 72.5˚C due to supply of energy.

The temperature decreased until the next day morning and reached the temperature of 61 ˚C. The time taken to reach this temperature was 1545 min. The time taken for the second supply was 1460 min and for III supply was 1460 min and reached the temperature 66.5 ˚C. So the total time taken to reach this stability was 4465min. The overall loss was predicted numerically by computer simulation in CSP system as 41.87 W/$m^2$ for 5 cm of water depth in SSP. The overall efficiency of the CSP system is 5.268%. **Table 2** shows the thermal parameters which used and predicted in experimental performance study of CSP.

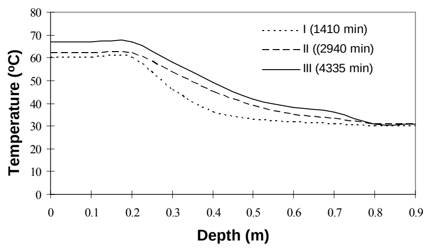


**Fig. 2. Temperature Profile in CSP System with water depth.**

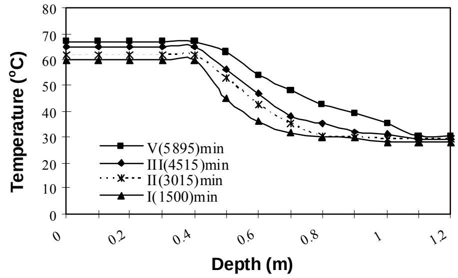


**Fig. 3. Temperature profile at pond depth of 0.9 m.**

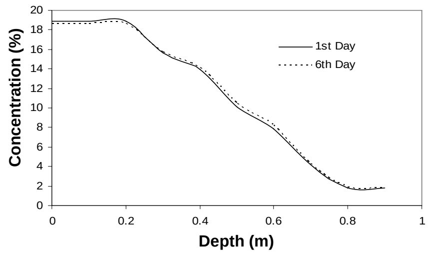


**Fig. 4. Salt Concentration pofile of the CSP for attaining Maximum temperature.**

## 5. Conclusion

In this paper, a new concept of Complementary Solar Pond System (CSP) has been introduced. It combines the advantages of high storage efficiency of the salt gradient solar pond (SGSP) and maximum collection efficiency of shallow solar pond (SSP). The rise in temperature of salt gradient solar pond in CSP system was increased by transferring the heat energy gained from SSP. Computer simulation model was also developed for optimization of process under various boundary conditions. The greatest advantage of the system is reduction in time taken to reach maximum warming period of the LCZ and quick stability.

## Acknowledgement

Authors are greatful to Nalanda Open University, Bihal for partial financial for support in carrying out the research work.

## References

Alagao F.B. (1996): Simulation of the transient behavior of a closed cycle salt gradient solar pond. *Solar Energy*, **56**: 245-260.

Schaefer R., Lowrey P. (1993): The optimum design of honey comb solar ponds and a comparison with salt gradient ponds. *Solar Energy*, **48**: 69-78.

Subhakar D., Srinivasamurthy S. (1994): Saturated solar ponds 3. Experimental verification. *Solar Energy*, **53**: 469-472.

Subhakar D., Srinivasamurthy S. (1993): Saturated solar ponds 1. Simulation procedure. *Solar Energy*, **50**: 275-282.

Tisilingiris P.T. (1988): Computer simulation modeling, Thermal Performance and Design optimization for solar ponds in Greece. *Solar and wind Technology*, **5**: 645-652.

Xu H. (1990): *Laboratory studies on dynamical process in salinity gradient solar pond*, Ph.D. Thesis, Ohio state Univ., USA.