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A study on passive and active solar thermal input performance of Shallow Evaporation Pond (SEP)

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ABSTRACT

The passive and active solar-thermal input performance of a Shallow Evaporation Pond (SEP) has been studied. The performance of the SEP in evaporating water molecules due to the direct exposure solar radiation has been estimated from the periodic measurement of the solution specific gravity, salt concentration and the temperature of the brine solution. Active solar-thermal heating of the SEP has been achieved by collecting hot water from a domestic solar water heating system (SWH) and circulating it through a fabricated heat exchanger submerged inside the brine solution of SEP. The heat exchanging efficiency of the heat exchanger has also been reported. Recording and interpretation of data for the passive solar heating has been performed on SEP for six days. The climatic parameters such as solar insolation, ambient air temperature, air velocity, relative humidity, and saturated vapor pressure have been taken for performance prediction. Modeling calculations have been made to predict the temperature and the performance of SEP for the above mentioned mode of operation and the predicted results have been compared with the observed experimental values.

Key words: shallow solar pond, heat exchanger, evaporation, pond temperature

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INTRODUCTION

Solar pond is a body of water dissolved with NaCl salt and stacked in some definite order which is capable of collecting and storing solar energy. There are two type of solar ponds, which are of non convecting type, and convecting type. Generally the convecting ponds are of shallow depth filled with fresh water with a transparent polyethylene film made to float over the surface of the pond. A transparent glass plate placed over the shallow pond is capable of collecting solar energy and as a result water gets heated.

In the present study the shallow pond has been used to undergo forced evaporation due to solar thermal heating in order to make salt faster by allowing heat loss mechanism to take place to the air predominantly through convective and evaporative process. The conduction losses are reduced to a minimum by providing thermal insulation along the bottom and side walls of the SEP.

A shallow evaporation pond collects solar radiation and evaporate the water molecules in a slow process. Generally an open pan type of evaporation would experience an evaporation loss which would result with a decrease in its depth of 3 mm to 5 mm per day. Here in order to enhance the evaporation rate an active solar thermal input facility has been obtained from a 500 LPD solar water heater and the resulting performance of the SEP under passive and active condition has been studied. Weinberger [1] 1964, has analysed the Physics of the solar pond, by solving the heat conduction and salt diffusion equations analytically for the transcient temperature distribution, using one dimensional equation. A computer model for solar ponds, using the method of finite differences was proposed by Tybout[2], as a simple alternative approach to Weinberger's model [1]. Tybout has incorporated periodic observations of solar radiation, ambient temperature and other variables without explicitly describing them as functions of time. Subhakar and Srinivasamurthy [3] have developed a simulation procedure in which a set of non linear partial differential equations of mass and energy balances of UCZ, NCZ and LCZ have been solved numerically, by the weighted average finite difference technique to predict the transient thermal performance of a saturated solar pond.

Rubin and Benedict [4] have developed a mathematical model, applying finite difference implicit method so as to investigate the interaction among physical variables represented by various dimensionless parameters. In the present study modeling calculations have been made to predict the performance of the SEP. The thermal storage capabilities of the SEP due to passive solar absorption and active solar thermal addition obtained from a solar water heating system has been analysed and the temperature have been predicted loss of water molecules due to evaporation has been related to the concentration variation of the solution of the Shallow Evaporation Pond.

2. Theory: Heat balance equation for shallow evaporation ponds
[Heat stored in shallow evaporation pond] = [(Forced solar thermal input given to the SEP + Total solar radiation absorbed by the SEP) **-** (Heat output taken from the SEP + Heat loss in SEP)]

$$Q_{stor} = (Q_{in} + Q_{sol}) - (Q_{out} + Q_{loss}) \quad (1)$$

Total heat loss in the evaporation pond is the sum of all individual types of heat losses from the pond, viz. loss in the form of conduction, convection, evaporation and radiation. The conduction losses take place from the bottom of the pond to the ground and from pond through its sides. Suppose if the shallow evaporation pond has been made on the ground floor then the predicted heat loss to a water table with an infinite flow is given by.

$$Q_{loss} = (Q_{gr} + Q_{side}) + Q_{conv} + Q_{evap} + Q_{rad} \quad (2)$$

The heat transfer from SEP to the ground by conduction is

$$Q_{gr} = k_{gr} A (T_p - T_{gr})/D_{gr} \quad (3)$$

Here, D_{gr} is the ground depth below the pond bottom; the ground temperature has been estimated using the empirical relation [6] of

$$T_{gr} = 0.83\, T_a + 3.7$$

Heat balance equation of the shallow evaporation pond could be obtained as reported here.

$$\rho\, A\, C_p\, (dT/dt)\, D = \dot{m} C_p (T_{f,in} - T_a) + I\, A\, (1-\gamma) - \dot{m} C_p (T_{f,out} - T_a) - (k_{gr} A (T_p - T_{gr})/D_{gr} - (D \times P)\, k_{gr} (T_p - T_{gr})/ D_{gr}) - h\, A\, (T_p - T_a) - 0.0144(A_1 - A_2) [T_U - T_a + T_U'(A_1 - A_2)/(268900 - A_1)]^{0.33} - \sigma\, \varepsilon\, A\, (T'^4_p - T'^4_{sky}) \quad (4)$$

Rearranging the above equation, the rate of rise of temperature of the SEP is given as

$$dT/dt = \dot{m} C_p (T_{f,in} - T_{f,out}) + I\, A\, (1-\gamma) + T_p(-K_{gr}A - DPK_{gr}) + T_{gr}(K_{gr}A + DPK_{gr}) - h\, A\, (T_p - T_a) - 0.0144(A_1 - A_2)\{T_U - T_a + T_U'(A_1 - A_2)/(268900 - A_1)\}^{0.33} - \sigma\, \varepsilon\, A\, (T'^4_p - T'^4_{sky})/\rho\, A\, C_p\, D \quad (5)$$

The left hand side of the above equation, the expected temperature of the SEP could be estimated at any desired time of a day. The first and second term on the right hand side represents the useful thermal energy obtained from the active thermal and passive solar input to the SEP. The third and fourth terms represents the energy losses through the side, ground of the SEP. The last three terms represents the convection, evaporation and radiation respectively.

MATERIALS AND METHODS

A schematic diagram of the shallow evaporation pond with passive solar and active solar thermal addition arrangement has been shown in fig. 1. The laboratory model SEP has been designed and fabricated in the form of a rectangular tub made of cement concrete and is of dimension (0.56x0.44x0.22) m with a wall thickness of 0.03 m. In order to reduce the heat loss through bottom and side walls, all the sides and bottom of the pond have been insulated with thermocole sheet to a thickness of 0.04 m. The rectangular tank which was already insulated inside with the thermocole sheet was lined with a polyvinylchloride (PVC) sheet of thickness 400 micrometer over and above the insulation so as to hold the SEP brine solution.

In order to provide thermal input to SEP brine solution a heat exchanger has been designed and fabricated indigenously. The heat exchanger consists of two header pipes and riser pipes with inlet and outlet provision. The heat exchanger arrangement is made of G.I pipes of 0.05 m diameter which formed the necessary header pipes of two numbers and the eight numbers of 0.025 m diameter GI pipes have been used as raiser pipes. Header pipes were provided with inlet and outlet openings for the hot water inlet from the SWH system and the residual cold water outlet. The Heat exchanger has been laid inside the shallow evaporation tank brine solution as a submerged structure.

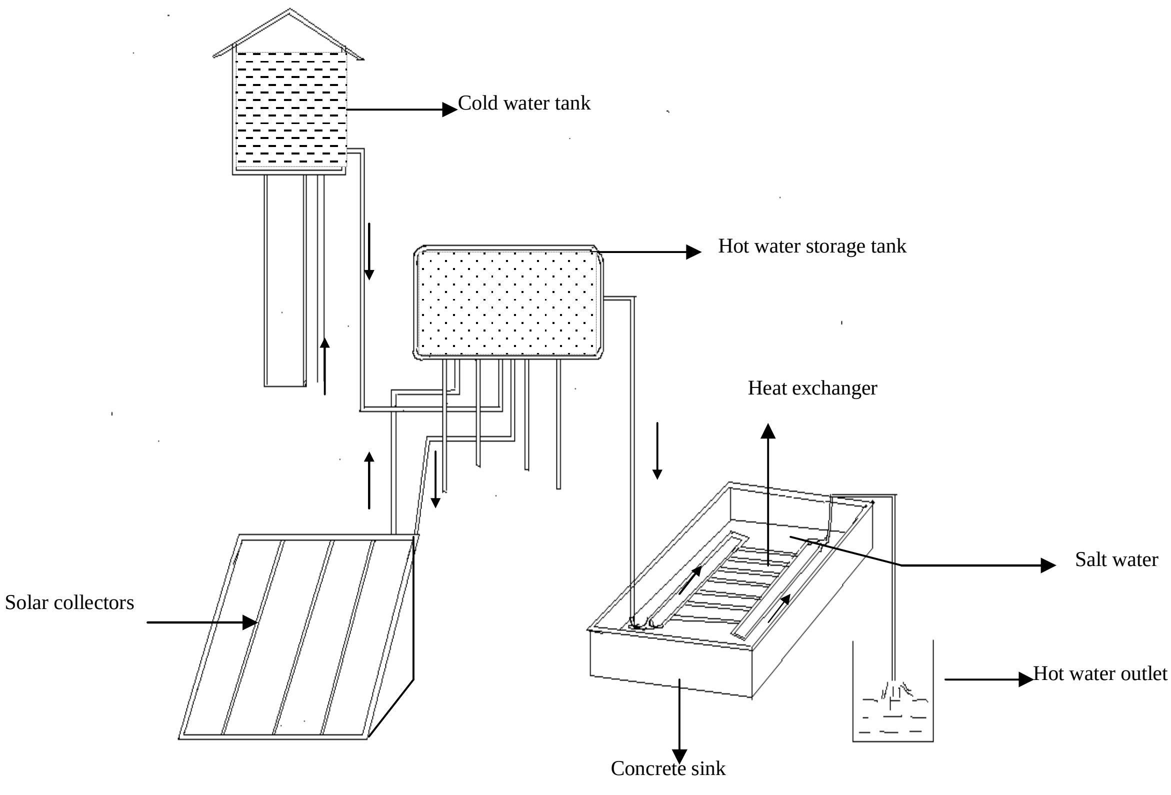

Fig.1 A schematic diagram of shallow evaporation pond

The maximum storage volume of the SEP is estimated as of 54.2 $x10^{-3}$ m^3 so that brine solution could be filled for a total depth of 0.22 m. The ambient temperature and the temperature of the salt solution have been made with mercury in glass thermometer of 0.1°C accuracy. The specific gravity of the salt solution was measured periodically using hydrometers with an accuracy of 0.001. Wind velocity was recorded with an analog integrating anemometer. The relative humidity of the ambient air has been measured directly with a Hygrometer.

Salt solution of volume 20 x $10^{-3}m^3$ with an initial specific gravity value of 1.125 was filled to a depth of 0.08 m inside the SEP. The SEP has been exposed to collect direct solar radiation and also to get heated thermally from the hot water obtained from a solar water heating system of 500 LPD storage capacities as shown in the figure 1. The flow rate and the duration of injection of thermal energy along with the absorbed direct solar energy have been recorded. The hourly temperature development in the salt solution has been observed and the values are compared with the results of the modeling studies.

RESULTS AND DISCUSSION

Passive heating of SEP is considered as the heating achieved due to solar insolation and active heating of the SEP has been performed through a heat exchanger by circulating hot water collected from the storage tank of a solar water heating system installed at Gandhigram. An optimum hot water flow rate of 0.020 kg/sec has been chosen on trial basis and administered into the SEP through the heat exchanger, so as to transfer the heat to the SEP. The heat energy exchanged with the SEP brine solution has been estimated using the relation[5].

$$Q_{in} = \dot{m} C_p \Delta T \qquad (6)$$

ΔT is the difference in temperature [7] between the fluid temperature at the inlet and outlet portion of the heat exchanger assembly, here $\Delta T = T_{f,out} - T_{f,in}$

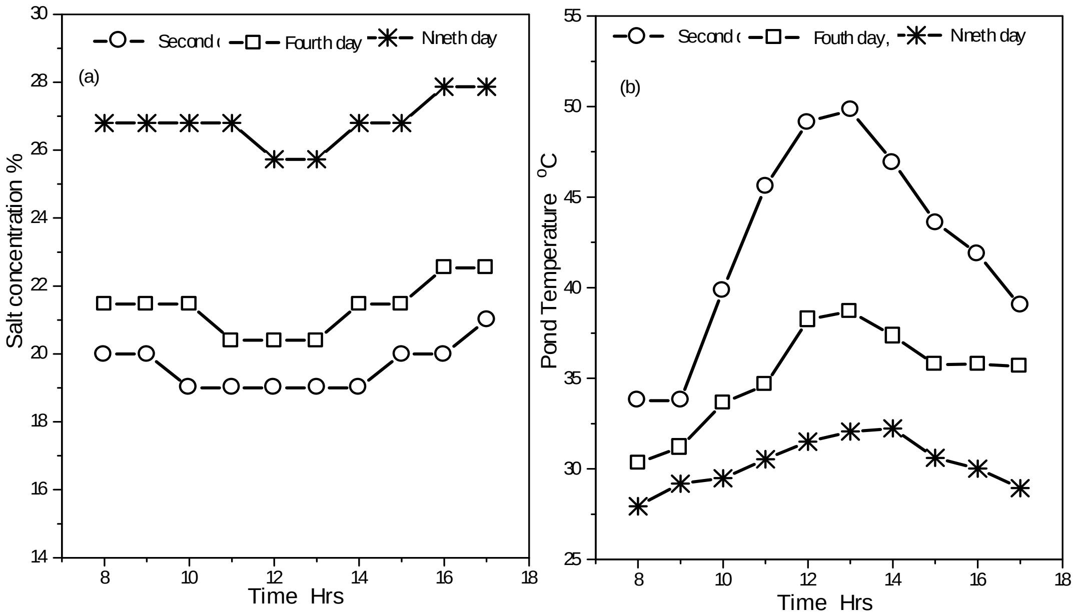

Fig.2(a) represent the hourly variation of salt concentration in % and (b) pond temperature in °C on 2nd,4th and 9th day of observation

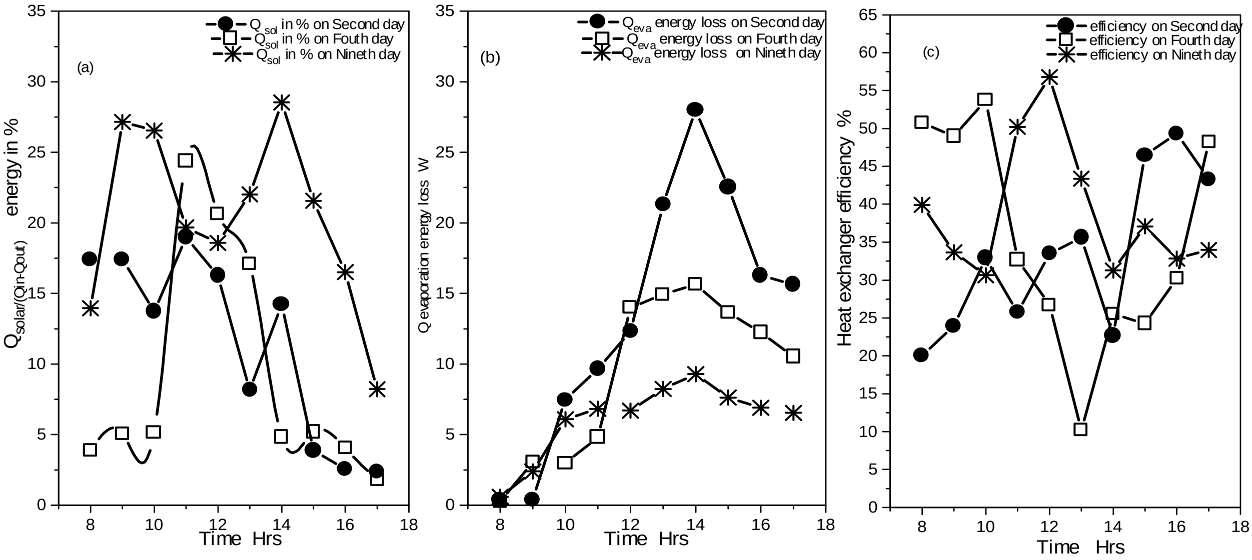

Fig. 3 Hourly variation of energy losses in % (a) Q_{sol}/Q_{in}-Q_{out} % (b) Q $_{eva}$ energy loss in W (c) Heat exchanger efficiency in %

The periodic variation of solution concentration for the second, fourth and eighth day of observation due to passive and active solar thermal input performance has been represented in figure 2(a). Active heating of the SEP has been performed on the second, fourth and on the ninth day of the observation only. On all other remaining days the SEP brine was subjected to passive heating by direct solar insolation only. It has been observed from the figure 2(a) that there is a net daily rise of 1% increase in the salt concentration on all these three occasions. However, the concentration of the SEP brine had a decrease of 1% during the morning session and had an increase of 2% during the after noon session with a net rise of 1% in the concentration of the SEP brine solution. Concentration variation remains constant for duration of 4 hours, 2 hours and 1 hour respectively on the second, fourth and ninth day of observation. The SEP brine solution was subjected to passive solar insolation alone during the period from fourth day evening to eighth day evening. This passive solar exposure has caused a daily rate of increase of salt concentration of 0.8%. There has been a gradual decline in the maximum temperature attained by the pond brine from the first day to ninth day. This could have been due to the gradual increase in the reflectivity of the bottom of the SEP due to the formation of micro size salt crystallization process.

The hourly variation of the solar pond temperature has been presented in figure 2(b). During the observation period the pond solution was having a maximum temperature of 50.5°C, 38.6°C and 34°C respectively on the 2^{nd}, 4th and 9^{th} day measurement. The last day the pond has achieved maximum ratio of solar insolation to active solar thermal input of 20.3%. The SEP could not have a rise in the pond temperature because of the solar radiation got reflected due to white bottom surface developed due to the crystallization of NaCl salt. The hourly variation of evaporation energy losses has been presented in figure 3(b).

The hourly variation in the ratio of solar energy incident to the net thermal energy supplied on to the SEP has been presented in figure 3(a). The mean value of the ratio of passive solar energy to the active solar energy provided by hot water circulation has been estimated to be 10.84%, 9.5% and 20.3 % on the 2^{nd}, 4^{th} and 9^{th} day observation.
Hourly variation of energy losses due to evaporation of water molecules from the SEP has been presented in figure 3(b). The evaporation loss was found to have a gradual increase during the morning hours and at 14 hrs on all three observed occasions the evaporation loss was having a maximum after which it declined sharply. There is a time lag

of 2 hrs between the maximum estimated solar insolation and the maximum evaporation energy. The maximum evaporation energy had a gradual fall from the first day to 9th day of observation.

The efficiency of the heat exchanger has been estimated. The hourly variation of heat exchanger efficiency has been presented in the figure 3(c). The mean heat exchanger efficiency has been estimated to be 34.8 %, 37.4 % and 40.9 % on the 2nd, 4th and 9th day of active heating of the SEP.

Table 1 Effect of the combined Passive Solar and Active heating On the evaporation volume of the SEP solution. Aperture Area of the SEP (A) = 0.246 m^2

Solar Insolation $kW/m^2/day$	No. of days	Heating Mode	Initial Specific Gravity	Depth of brine solution in the SEP		Loss of water level(h) $X10^{-2}$ m	Evaporation volume $x10^{-3}m^3$ (A x h)
				Initial level x 10^{-2}m	Final level x 10^{-2}m		
4.23	first	passive	1.125	8.0	7.5	0.5	1.23
4.10	second	passive+active	1.142	7.5	6.5	1.0	2.46
4.40	third	passive	1.150	6.5	6.0	0.5	1.23
2.62	fourth	passive +active	1.160	6.0	5.3	0.7	1.72
4.10	fifth	passive	1.168	5.3	4.8	0.5	1.23
3.96	sixth	passive	1.175	4.8	4.3	0.5	1.23
3.56	seventh	passive	1.180	4.3	3.9	0.4	0.98
3.72	eighth	passive	1.186	3.9	3.5	0.4	0.98
3.39	nineth	passive +active	1.195	3.5	2.8	0.7	1.72

Total volume of water evaporated = 12.78 x $10^{-3}m^3$

Table 1 represent the details about the mode of providing solar passive and solar thermal active heating of the SEP. The initial and final brine solution depth has been monitored everyday and the difference in values gives the loss of water level. The decrease in depth (h) has been used to estimate the volume of evaporated water molecule from the SEP. It is obtained by multiplying the (h) with the aperture area (A) of the SEP and has been reported in the last column of Table 1.

A domestic solar water heater of 500 LPD capacity has been utilized to provide a continuous whole day supply of active solar thermal heating for the SEP solution, only on three occasions during the study period. In between days have been utilized by the SWH to get itself warmed up by solar thermal heating so as to provide hot water in the temperature range from 60 ^oC to 65 ^oC. From the above experimentation a total of 12.78 x 10^{-3} m^3 of water molecules have been evaporated during the observation period. This has resulted with an average evaporation of 1.42 x 10^{-3} m^3 per day for the given SEP of 0.246 m^2 area. This result provides an estimated evaporation volume of 5.772 x 10^{-3} m^3 /m^2 day of the given type of shallow evaporation pond for the combined action of active solar thermal and passive solar heating of SEP. Conventional open pan evaporation accounts for an evaporation volume in the range of 3 to 5 x $10^{-3}m^3/m^2$ per day, for one full year of operation encompassing all seasons. The observation period is November which is a winter period for the location of study. This would have resulted with an evaporation volume in the range of 3 to 4 x $10^{-3}m^3/m^2$/day only. The higher rate of evaporation volume reported in the study could be attributed to the combined action of addition of solar energy and thermal energy obtained from a domestic solar water heating system.

CONCLUSION

An attempt has been made to study the thermal performance of a laboratory model solar evaporation pond with the objective of making salt and clean water from the brine solution. It's performance has been reported for the combined mode of operation of directly heating the SEP using solar energy and also by thermally heating the SEP by utilizing the stored thermal energy obtained from a domestic solar water heating system. Modeling results on the predicted temperature development of SEP brine has been obtained. The predicted results are found to have a close agreement with the experimental results. Enhanced rate of evaporation of water in the SEP could be attributed to the combined operation of direct solar heating and active thermal heating of the SEP solution.

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REFERENCES

[1] Weinberger H. *Solar Energy* (**1964**) **8**, 45-46.
[2] Tybout R.A. *Solar Energy* (**1967**) **11**,109-111.
[3] Subhakar D. and Srinivasamurthy S. *Solar Energy* (**1993**) 50**,** 275-282.
[4] Rubin H. and Benedict B.A. *Solar Energy* (**1984**)**32,** 771-778.
[5] McAdams W.H. Heat transmission, (**1954**) 3rd ed., McGraw-Hill, New York
[6] Cooper P.I. *Solar Energy Col*. (**1973**) **15**, 205-217.
[7] ASHRAE, Psychrometrics, ASHRAE (**1981**) Fundamentals, Chapter **5**.

Nomenclature
A pond surface area, m^2
A_1 coefficient values
A_2 coefficient values
C_p solution specific heat, $J/kg/^0C$
D depth of pond, m
h convective heat transfer coefficient, $W/m^2/^0C$
I incident solar radiation on horizontal surface, W/m^2
k thermal conductivity, $W/m/^0C$
$\dot{m}$ mass flow rate of fluid into the pond, kg/sec
P pond perimeter, m
P_{sat} saturated vapor pressure, Pa
Q heat, W
Rh relative humidity %
T temperature, ^0C
T' temperature , K
SWH solar water heating
SEP shallow evaporation pond
t time, sec
U upper surface of pond
V ambient air velocity, m/sec

Greek symbols
γ reflectivity
ε emissivity of pond surface
ρ solution density, kg/m^3
σ Stephan-Boltzman constant, $W/m^2/K^4$