Thermal modeling Of Solar Pond in Matlab

Mr. Md. Irfan Ali, Ms. S. Madhu, Mr. R. Yuvaraj

Abstract— Solar pond technology has made substantial progress in the recent years. This paper presents the mathematical and thermal modeling of the bottom layer of the solar pond, which is also known as lower convective zone(LCZ), where heat is stored. A solar pond of height 0.95m and diameter 1.25m was built at SRM University, LCZ was maintained at the salinity of 50 g/Kg for the experiment work. Nine k-type thermocouples were used for measuring the temperature of pond at various zones. Simulink tool-box from matlab is used for simulation of LCZ. Simulated results are validated with experimental results.

Index Terms— solar pond, renewable energy, solar energy, k-type thermocouples, matlab, M-file coding, simulation in simulink.

1 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. Solar energy can be collected and stored effectively as sensible heat in a solar pond containing dissolved salt (NaCl), the latter helping to create a stable density-gradient. The storage capacity depends on the ponds depth: the salt concentration increasing with depth in the solar pond. It has been realized recently that solar ponds can be an economically-viable source of heat. The use of solar energy in India has been very limited. This is because solar energy is a dilute energy source, and hence energy must be collected over large areas resulting in initial capital investment, moreover it is also an intermittent energy source. Hence solar energy systems must incorporate storage in order to take care of energy needs during nights and on cloudy days. This results in further increase in the capital cost of such systems. One way to overcome these problems is to use a large body of water for the collection and storage of solar energy. Another useful way is to build a physical model of solar pond in simulink using thermal library and giving real working inputs and getting the simulated results. By analysing the simulated results we can construct the real working practical model, which saves both money and the time.

2 MATHEMATICAL MODELING

In salt-gradient solar-pond there are three zones, 1) upper convective zone (UCZ), it consists of fresh water, 2) non-convective zone (NCZ) the salinity gradually increases, 3) lower convective zone (LCZ) the salinity is maintained at 50g/Kg for the experimental analysis. In this paper only the LCZ is considered where the sensible energy is stored.

A salt-gradient solar-pond collects and stores solar-insolation as heat in single unit. The stability of the solar-pond is normally maintained by the presence of the salt when exposed to solar insolation for heating.

Following assumptions were made, both the UCZ and LCZ strata have uniform and constant temperatures and salt concentrations, whereas the temperature and the salt-concentration increase with depth in the NCZ layer. In the pseudo steady-state :
Rate of heat input = Rate of heat stored in the LCZ + rate of heat losses,

i.e. $Q_{in} = Q_{stored} + Q_{lost}$ (1)

The temperature of the stored zone (LCZ) at the end of the period, T_{t+dt} is

$$T_{t+dt} = \{ A_s [h_{(z)} I_g + (k_w T_a / d_{ncz})] + [m C_p T_t / dt] \} / \{[m C_p / dt] + [A_s k_w / d_{ncz}] \} \quad (2)$$

Where

- A_s surface area, m^2
- c_p specific heat of stored water, J / Kg K
- d_{ncz} lower vertical zone vertical extent, m
- dt time intervals, (sec)
- $h_{(z)}$ fraction of solar insolation penetrating to LCZ
- I_g hourly insolation incident on a horizontal surface, W/m^2
- k_w stored-water thermal conductivity, W / m K
- m mass of the water in the store, Kg
- T_a ambient temperature, ^oC
- T_t temperature of the pond at time 't', ^oC
- Q_{in} rate of energy input to the pond, W
- Q_{lost} rate of energy lost from the LCZ to environment, W
- Q_{stored} rate of energy stored in the LCZ, W

The fraction of solar radiation penetrating to the depth 'z' in the pond is taken as 0.7. Specific heat of the saline water, C_{pw} is calculated from[5] :

$$C_{pw} = a_1 + a_2 T_w + a_3 T_w^2 + a_4 T_w^3 \quad (3)$$

and

$$a_1 = 4.206 - 6.6197 s + 1.2288 * 10^{-2} s^2 \quad (4)$$

$$a_2 = -1.1262 + 5.4178 * 10^{-2} s - 2.2719 * 10^{-4} s^2 \quad (5)$$

$$a_3 = 1.2026*10^{-2} - 5.5366*10^{-4} s + 1.8906*10^{-6} s^2 \quad (6)$$

- *Md Irfan Ali is currently pursuing masters degree program in Energy Engineering in SRM University, India, E-mail: irfanalimech@gmail.com*
- *S. Madhu is currently pursuing masters degree program in Information Technology in SRM University, India, E-mail: madhuit.1506@gmail.com*
- *Mr.R. Yuvaraj is currently working as an assistant professor in dept. Of Mechanical Engineering, SRM University, India.*

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$$a_4 = 6.8774*10^{-7} + 1.517*10^{-6}\, s - 4.4268*10^{-9}\, s^2 \quad (7)$$

where 's' is the salinity of the LCZ in g/Kg.

The effectiveness of the copper heat exchanger is taken as 0.9. The vertical distant (d_{ncz}) of the NCZ is 0.9. The water passing through the copper heat exchanger gets heated up due to the heat stored in the LCZ. For every time interval dt, the change in saline water temperature is taken as the sum of initial temperature (ambient temperature in the case of first iteration) and the temperature difference obtained from Eq.(1). Like that every time interval the change in temperature is calculated.

2.1 PONDS EFFICIENCY

The thermal effectiveness, $\eta_{p,}$ of solar pond can be defined as the ratio of the useful energy stored to the amount of insolation transmitted to the LCZ of the pond, both in the same period, dt.

$$\eta_P = [(m\, C_p / dt) * (T_{t+dt} - T_t)] / [A_s\, I_g\, h_{(z)}] \quad (8)$$

Fig. 2. Arrangement of K-type thermocouples to measure the temperature of various zones of solar-pond.

3 EXPERIMENTAL SET-UP

In fig. 1 you can see the experimental set-up of solar-pond installed in SRM University. It is made-up of mild steel and mounted on a concrete slab. The height of the pond is 0.95m and its diameter is 1.25m. The surface area exposed to the solar insolation is 1.23m^2. In fig.2 you can see the arrangement of k-type thermocouples to measure the temperature of various zones of the solar-pond.

Fig. 1. Experimental set-up of solar-pond in SRM University

In fig.2. you can see the arrangement of 9 k-type thermocouples adopted to measure the temperature of the solar pond at various zones.

Experiments were conducted with 50 g/Kg salinity concentration in LCZ and the results obtained were compared with simulated results. The results from simulation were supporting the experimental results, there was not much variation.

4 SIMULATION IN MATLAB

The above discussed mathematical model was coded in M-file to generate the temperature readings of the LCZ of the solar-pond at consecutive time intervals 'dt', the code also generates the efficiency of the solar-pond at consecutive time intervals. With the help of M-file code we can find the temperatures of the LCZ and the thermal efficiency of the pond at consecutive time intervals for any solar pond of given dimensions. A physical model of LCZ of the solar-pond was built in simulink assuming the pond is perfectly insulated and only loss is because of the convection current created at the interphase of LCZ and NCZ. In fig.3 you can see the physical model of pond in simulink.

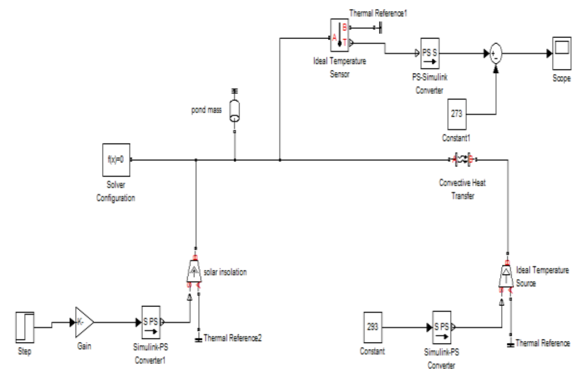

Fig. 3. Physical model of solar-pond in simulink.

5 RESULTS AND DISCUSSIONS

The simulated results of solar-pond are for surface area 1.2m², And d_{ncz}= 0.32m. Salt concentrations of 40g/Kg, 50g/Kg, 60g/Kg, and 70g/Kg were considered for the simulation. As the salinity increases the temperature of the LCZ increases. But 50g/Kg salt concentration was found to be most optimal for the above pond. As the concentration of LCZ increases there are chances of choking of pipes. The maximum experimental temperature obtained was 45 °C between 12 noon to 2PM. The experimental values were little bit deviating from the simulated values obtained in matlab. Following are the simulated results obtained from the matlab.

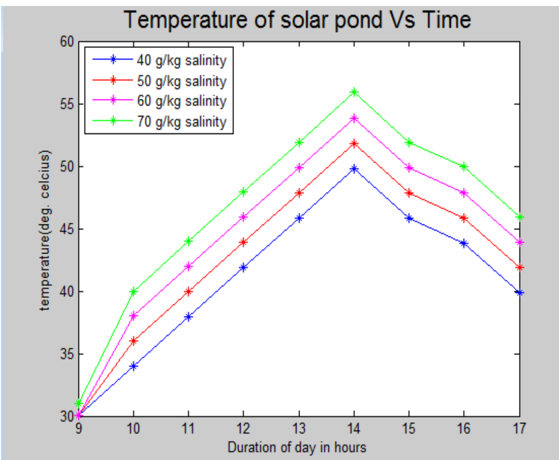

Fig. 4. Variation of temperature in LCZ for different salinities with duration of day. As the salinity increases the temperature of the LCZ increases.

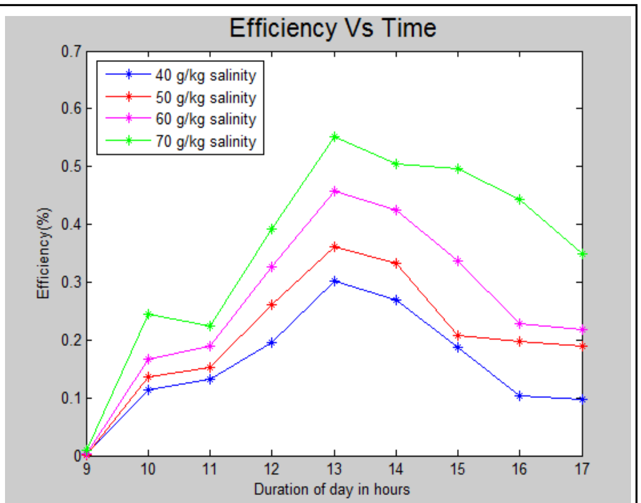

Fig. 5. Variation of efficiency of solar pond vs duration of day in hours. Efficiency of the pond increases for higher salinity. The efficiency of the pond is higher between 12 noon to 2 PM.

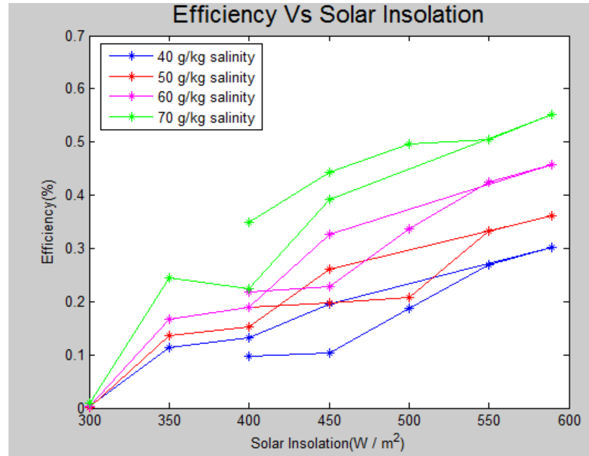

Fig. 6. Efficiency of the pond vs solar insolation, you can see as the insolation increases the efficiency increases, and as the insolation decreases the efficiency decreases. Higher efficiency can be obtained for higher salt concentration.

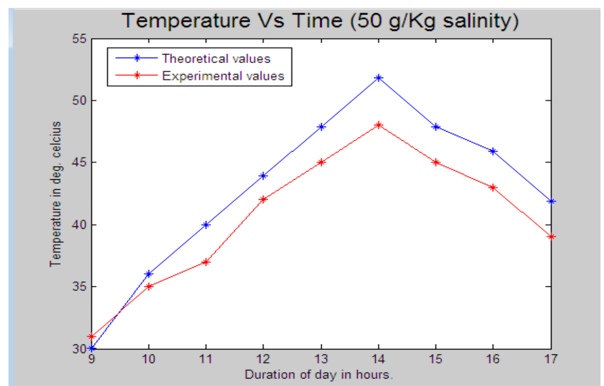

Fig. 7. Comparision of theoretical and practical values of LCZ temperatures with respect to time are shown here. 5 deg. Celcius difference was found between the theoretical and experimental values at the peak temperatures.

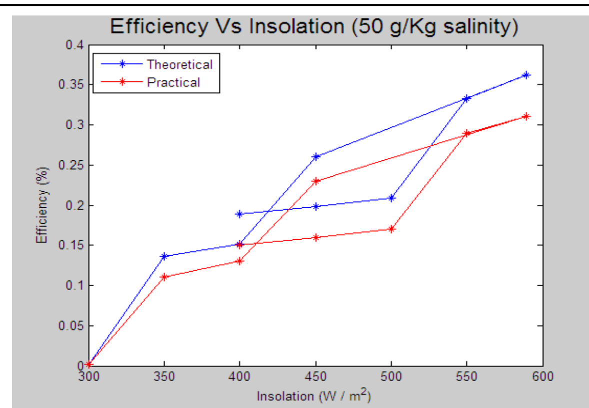

Fig. 8. Theoretical and experimental efficiencies of the pond at 50 g/Kg salinity are compared with respect to time. 0.05% difference in the efficiencies was found at the peak insolation level.

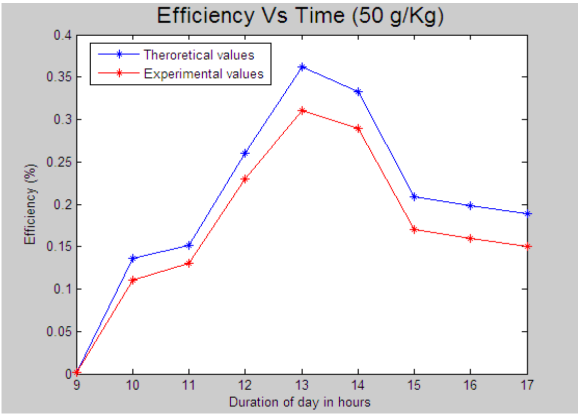

Fig. 9. Experimental and theoretical efficiencies of pond at 50 g/Kg salinity were compared with respect to time. 0.05 % difference was found between the theoretical and experimental values at the peak efficiencies.

6 CONCLUSION

With respect to the size of the solar-pond the above results were obtained. It was found that, as the salinity of the LCZ increases, the temperature of the LCZ and efficiency of the pond increases. But higher salt concentration in the LCZ may choke the pipe-lines. So from the simulated results in matlab ,we find that 50 g/Kg is the optimal salinity for the LCZ for our pond. The simulated results were not much deviating with the experimental results. Reliable results were obtained from the thermal modeling of pond in simulink. The solar-pond can be used as a pre-heater. Solar-pond can be integrated to still for increasing the efficiency of the still. Many pre-heating applications of solar-pond and its portability, low space-requirement and its environmental friendliness make it more advantageous.

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