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THERMAL ANALYSIS OF A SALT GRADIENT SOLAR POND PROTOTYPE

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Abstract

Solar ponds combine solar energy collection with long-term storage and can provide reliable thermal energy at temperature ranges from 50 to 90 ^{0}C. A solar pond consists of three main zones. The first zone, which is located at the top of the pond and contains the less dense saltwater mixture, is the absorption and transmission region, also known as the upper convective zone (UCZ). The second zone is the gradient zone or non-convective zone (NCZ) which contains a variation of saltwater densities increasing with depth. The last zone is the storage zone or lower convective zone (LCZ),where density is uniform and near saturation. The stability of a solar pond prototype was experimentally performed in a mild steel tank of height 1.2m, width and length of 1m with black coating on the inner sides and the exteriors were insulated with 0.2m of polystyrene sheets at the sides and bottom. The effects of the solar-pond's depth and its water's salinity on the store's temperature distributions were determined experimentally and compared with theoretical predictions.

Keywords: Thermal efficiency; Performance analysis; Heat storage; solar pond; solar energy

1. Introduction

A solar pond collects and stores solar energy in the form of hot high-density salt water. It consists mainly of three layers (see Fig. 1). The top layer called upper convective zone, UCZ, is cold, close to the atmospheric temperature, and has low salt concentration. The bottom layer called lower convective zone, LCZ is hot, 70–100^{0}C, and very salty (typically, close to saturation). These two layers are characterized by almost homogeneous temperature and concentration due to convection. Separating these two layers is the important gradient zone (non-convective zone, NCZ), where salt content increases with depth. Despite the simplicity of its working mechanism, the large number of physical phenomena involved in its operation makes the full description of the system a very difficult problem from both the physical and the mathematical points of view. In fact, although the physics of each phenomenon is quite well known, the coupling between the phenomena needs further investigations.

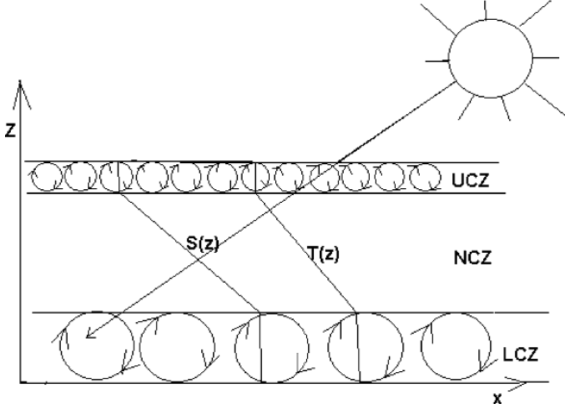

Fig.1 Schematic of solar pond

2. Experimental apparatus and procedure

In general, NCZ is the key to the working of a solar pond. It allows solar an extensive amount of work on solar pond as a radiation to penetrate into the storage zone while cost-effective method of collecting and storing prohibiting the propagation of long wave radiation solar energy on large scale is available in the because water is opaque to infrared radiation. Considerable part of the solar energy is absorbed and stored by this bottom region. LCZ has the highest temperature, and hence, the strongest thermal interaction occurs between this zone and the insulated bottom wall (IBW) and insulated side walls (ISW) surrounding it. For the experimental works, a solar pond with a surface area of 1 m X 1 m, and a depth of 1.2 m was built in Kumaraguru college of technology and used to measure temperature variations. It was built on the iron steel base to 0.5 m height from the ground and insulated by 20 mm polystyrene sheet thickness from the steel base. Inner and out sides of the pond were painted with anti-corrosion paint to avoid corrosion. Fig. 2 illustrates the inner zones of the solar pond and the measurement points. Inner zones consist of the salty water layers with various densities. The experimental temperature distributions were measured using 5 heat sensors, which were placed into the inner zones and the insulated walls of the pond. Hence the temperature distribution profiles of these regions at any time were experimentally obtained by a data acquisition system. To measure the temperature distributions of various regions, the temperature sensors were placed into the inner zones, starting from the top at0.05, 0.30, 0.55, 0.70, 0.80, 1.05 m heights. The data acquisition system was connected to a computer for data recording, monitoring and processing. The inner and wall temperatures of the pond were measured on hourly basis throughout the day. The temperatures at the inner zones and insulated side wall of the pond were measured by the sensors with a range of 0 to +155^{0}C, and with a measurement accuracy of ±1^{0}C for the temperature range of 0–120^{0}C.

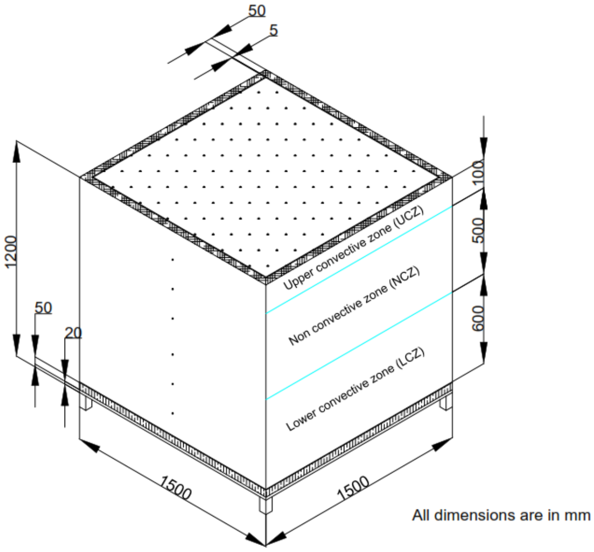

Fig.2a Constructed solar pond prototype

Fig.2b Constructed solar pond prototype

3. Performance analysis

The UCZ, NCZ and HSZ thicknesses are assigned with X_1,X_2–$X_1$and X_3–X_2, respectively. The working solution in the UCZ has uniform and low salinity (like seawater), while the working solution in the LCZ is stratified due to its high salinity and different density. In the NCZ, both concentration and temperature increase linearly with increasing pond depth. Part of the solar radiation incident on the solar pond is absorbed, part is reflected at the surface and the remaining part is transmitted, as illustrated in Figs. 3–5.InFigs. 3 and 4, most of the incident ray is transmitted through the layers and part of the transmitted ray which reaches the HSZ (Fig. 5) is converted into heat and stored in the HSZ.

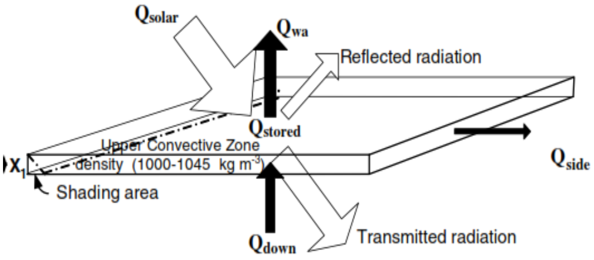

Fig. 3. Schematic of the UCZ layer.

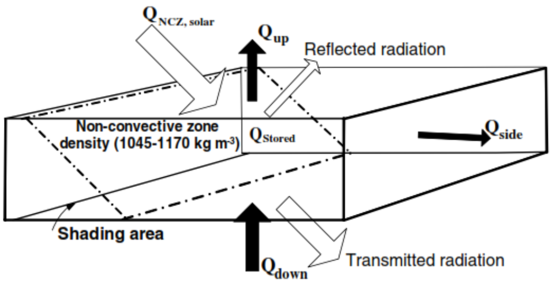

Fig. 4. Schematic of the NCZ layer.

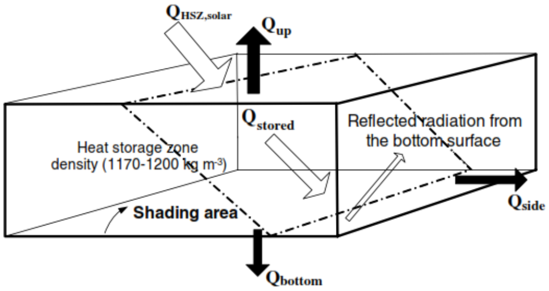

Fig. 5. Schematic of the HSZ layer.

3.1*Temperature distribution in upper convective zone (UCZ)*

In Fig. 3, energy flows for the horizontal surface upper convective zone of the pond are illustrated. Part of the incident solar radiation is reflected from the UCZ surface to air and lost. Part of the incident solar radiation is transmitted from the UCZ to the NCZ and rest of the incident solar radiation is absorbed in the zone, heating it. The thermal (energy) efficiency for the upper convective zone (UCZ) can generally be expressed as

Rate of change of energy contained in the upper convective zone of thickness l1

= (Rate at which heat is conducted in from NCZ) + (Solar radiation absorbed in the thickness l1) – (Rate at which heat is lost from the top surface by convection, evaporation and radiation)

i.e.

$$\rho l_1 C_p\left(\frac{dT_1}{dt}\right)_{x=l_1}=k\left(\frac{\partial T_{II}}{\partial x}\right)_{x=l_1}+\left[(I)_{x=0}-(I)_{x=l_1}\right]-\frac{1}{A_p}\left(q_c+q_e+q_r\right)$$

3.2*Temperature distribution in non-convective zone*

The non-convective zone (NCZ) is much thicker and occupies almost half of the solar pond. Both the concentration and temperature increase with the depth in this zone. It serves principally as insulating layer and reduces heat losses is the upward direction as shown in fig 4Assuming that the lateral dimensions of the pond are large compared to its depth L (so that the temperature varies only in the vertical direction) and that the properties are constant, the differential equation for the non-convective zone is the heat conduction equation of the form

$$\rho C_p\frac{\partial T_{II}}{\partial t}=k\frac{\partial^2 T_{II}}{\partial x^2}-\frac{dI}{dx}$$

$$where\rightarrow I=I_b\tau_{rb}\tau_{ab}+I_d\tau_{rd}\tau_{ad}$$

The term (-dI/dx) accounts for the solar radiation absorbed in the pond.

3.3*Temperature distribution in lower convective zone*

The lower convective zone (LCZ) is comparable in thickness with the non-convective zone (NCZ). Both the concentration and the temperature are nearly constant in this zone. It serves as the main heat-collection as well as thermal-storage medium as shown in the figure 5

Rate of change of energy contained in the lower convective zone of thickness (L - l2)

= (Rate at which heat is conducted in from the non-convective zone) + (Solar radiation absorbed in the thickness l2) – (Rate at which heat is conducted out to the ground underneath) – (Rate of useful heat extraction)

$$\rho(L-l_2)C_p\left(\frac{\partial T_{III}}{\partial x}\right)_{x=l_2}+(I)_{x=l_2}-\left[-k_g\left(\frac{\partial T_g}{\partial x}\right)_{x=L}\right]-\frac{q_{load}}{A_p}$$

4. **Results and discussions**

The energy flows in the inner zones of the pond are illustrated in Figs. 3–5. The performance of the solar pond depends on not only the thermal energy flows(e.g., heat losses and heat gains in the zones), but also the incident solar radiation flows (accounting for reflection, transmission and absorption). Also, shading decreases the performance of the zones. In Fig. 3, it is shown that part of the incident solar radiation is reflected on the surface; some is absorbed by the layer and part (often most) of the incident solar radiation is transmitted through the UCZ to the NCZ. The net average solar radiation incident on the sunny area of UCZ is calculated for January, May and August as439.42, 2076.88 and 2042.00 MJ, respectively. The greatest part of the incident solar radiation in Fig. 4 is transmitted to the NCZ from the UCZ. Part of the incident solar radiation is absorbed by the NCZ layers. The incident solar radiation transmitted from the NCZ to the HSZ is significant and little incident solar radiation is reflected from the NCZ to the UCZ. The net average solar radiation to reach on the sunny area of the NCZ is calculated for January, May and August as 351.54,1661.50 and 1634.05 MJ, respectively. A significant part of the incident radiation in Fig. 5reaches the HSZ from the NCZ. This transmitted solar radiation from the NCZ is absorbed in the HSZ, while little of the incident solar radiation is reflected from the HSZ to the upper zones. The net average solar radiation incident on the sunny area of the HSZ is calculated for January, May and August as 193.34, 913.83 and898.73 MJ, respectively. The primary reason for differences during different months is likely the higher temperature in summer. This change is mainly attributable to the thermo physical property of the salty water, heat losses from the pond to the air, and the absorption and reflection of incident solar radiation on the surface. The reason for the fluctuations in the saline density in the upper convective and non-convective zones is the increase in saline density of these zones due to the evaporation of the water at the upper region. These changes can be reduced by continuously adding fresh water to the top of the pond. Due to not using one of the salt gradient protection systems for cleaning purposes in a month, significant changes occurred in the non-convective region and upper convective region.

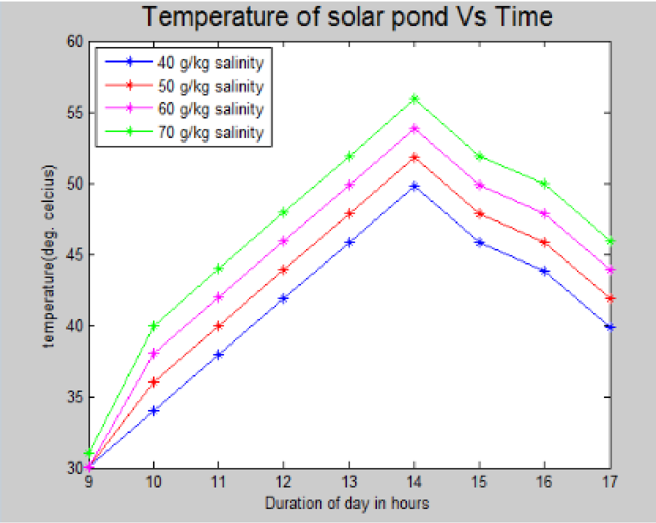

Fig.6 Variation of temperature in LCZ for different salinities with duration of day. As the salinity increases the temperature of the LCZ increases

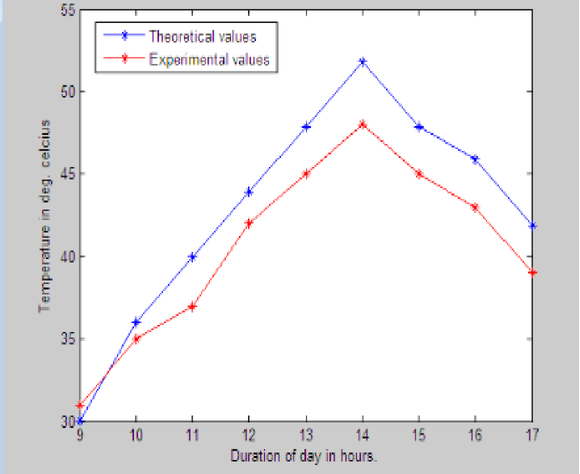

Fig.7Comparision of theoretical and practical values of LCZtemperatures with respect to time are shown here

5. Conclusions

- The thermal performance of an insulated salt gradient solar pond has been investigated. The results show that pond performance is affected strongly by the temperature of the LCZ and the temperature profile with pond depth. Due to the presence of insulation, heat losses from the sides and bottom of the pond are negligibly small. Here, we carried out efficiency calculations of zones of solar pond in order to demonstrate the effect of each zone on the performance of the insulated solar pond.

- The temperature of each layer of the inner zones depends on the incident radiation, zone thicknesses, shading areas of the zones and overall heat losses. So, to increase pond performance, the zone thicknesses should be modified to achieve higher efficiency and stability of the pond.
- Through careful design parameter modifications, pond performance can be maintained even if the incoming solar radiation reaching the zones is increased. Several parameters for the upper convective zone and non-convective zone having influences on the thermal performance are discussed.

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