Impact of Non-convective Zone and Lower Convective Zone Thickness on the Performance Characteristics of Salinity Gradient Solar Pond

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Abstract. A solar pond technology employs a layer of salinity gradient to prevent heat loss due to convection from the lower convective zone. Thus, the energy received from solar radiation is stored in a lower convective zone. The thickness of various zones significantly affects the behaviour of solar pond temperature. In this present study, a transient numerical investigation is conducted to evaluate the impact of depths of different zones on the performance characteristics of solar pond. The variation in maximum temperature and maturation period under the influence of non-convective zone and lower convective zone thickness is discussed. The energy obtained from a solar pond significantly depends on various losses associated with the zones. Thus, an assessment of conduction and ground heat loss is presented for the variation in thickness of zones. An attempt is also made to study the effect of thickness of zones on the temperature of the lower convective zone. It is found that the configuration of a smaller thickness of LCZ and a higher thickness of NCZ yields maximum LCZ temperature.

Keywords: Salinity Gradient Solar Pond, Conduction heat loss, Ground heat loss, Maturation time.

1. Introduction

A need to explore solar energy technology arises from the concern of energy security and environmental issues. The various zones of salinity gradient solar pond (SGSP) are shown in Figure 1. In a non-convective zone (NCZ), a salinity gradient layer is established to prevent convection heat loss from the lower convective zone (LCZ). Thus, the thermal energy gets accumulated in LCZ and can be utilized for various applications (1). Recently, a number of applications of salinity gradient solar pond have been reported for desalination, power generation, and mineral processing (2–8).
In the past few years, researchers have shown an increased interest in solar pond technology. Kumar et al. (5,9) determined the optimum thickness of zones for thermoelectric power generation application and also carried out investigations of peripheral heat conduction in solar pond. Verma and Das (10) studied the effect of wall profiles. Chakrabarty et al. (11) discussed the significance of ground conditions on the performance of salinity gradient solar pond. Ganguly et al. (12) examined the impact of bottom insulation thickness. The work carried out by the researcher shows the significance of studying the various operational parameters of a solar pond. Thus, the objective of the present work is to examine the impact of depths of different zone on the heat loss characteristics and temperature of salinity gradient solar pond.

2. Numerical model

A transient model described by [10] is used to assess the behaviour of the SGSP. The energy balance of UCZ and LCZ is expressed as Eq. (1) and Eq. (2) respectively.

\[
\rho_{UCZ}C_{p,UCZ}t_{UCZ}A_{UCZ} \left( \frac{dT_{UCZ}}{dT} \right) = Q_{sr,UCZ} + Q_{cond} - Q_{losses,UCZ} \quad (1)
\]

\[
\rho_{LCZ}C_{p,LCZ}t_{LCZ}A_{LCZ} \left( \frac{dT_{LCZ}}{dT} \right) = Q_{sr,LCZ} - Q_{cond} - Q_{load} - Q_{ground} \quad (2)
\]

Where, \( \rho \) is the fluid density in kg/m\(^3\) and \( C_p \) is the fluid specific heat in J/kg\(^\circ\)C. The pond has an area \( A \) in m\(^2\) with the zone thickness \( t \) in meters. The pond temperature \( T \) is in degree Celsius at time \( t \) in hours. The amount of solar energy collected in the respective zone, \( Q_{sr} \) is the difference between the amount of radiation entering and leaving the zone. Thus, the solar radiation absorbed by UCZ and LCZ can be described as Eq. (3) and Eq. (4) respectively.

\[
Q_{sr,UCZ} = Q_{sr,in,UCZ} - Q_{sr,out,UCZ} \quad (3)
\]

\[
Q_{sr,LCZ} = Q_{sr,in,LCZ} - Q_{sr,out,LCZ} \quad (4)
\]

The heat loss that occurs due to conduction from LCZ to UCZ is denoted by \( Q_{cond} \). The surface losses from UCZ are expressed as \( Q_{losses,UCZ} \). \( Q_{load} \) is the amount of heat removed from LCZ in W/m\(^2\) and \( Q_{ground} \) is heat loss to the ground. The wall losses are neglected in the present study. To assess the impact of various zone thicknesses on various operational parameters of solar pond, all the terms involved in Eq. (1) and Eq. (2) are
determined according to the assumptions and procedure used by (13) under the metrological conditions of Nagpur city.

3. Result and Discussion

A numerical model is employed to solve Eq. (1) and Eq. (2) by using a finite difference method in MATLAB. Figure 2(a and b) shows the different meteorological input parameters of Nagpur city for the numerical model, which are obtained from “NASA,” 2019 (14). The influence of NCZ and LCZ depth on conduction heat loss, ground heat loss, and temperature of LCZ are discussed in the subsequent sections.

![Figure 2. Meteorological conditions of Nagpur city, (a) ambient temperature and solar radiation; (b) wind speed and relative humidity](image)

3.1. Influence of LCZ and NCZ thickness on the maximum temperature of LCZ and maturation time

The impact of both NCZ thickness and LCZ thickness on maximum LCZ temperature and maturation time is shown in Figure 3(a and b). In the present analysis, NCZ thickness is considered from 0.5 m to 4.0 m and LCZ thickness is kept as 0.5 m, 1.0 m, and 1.5 m. Figure 3(a) exhibits the development of maximum LCZ temperature for variation in LCZ thickness. It can be seen that for a given LCZ thickness, the temperature of LCZ rises with an increase in the thickness of NCZ up to a certain limit. Furthermore, an increase in NCZ thickness results in the reduction of LCZ temperature. This phenomenon occurs due to a reduction in conduction loss and attenuation of solar radiation.

It can also be noticed that after the attainment of peak point, the drop in temperature is considerably large for the higher thickness of LCZ. The increase in LCZ thickness leads to a reduction in the peak temperature of LCZ. The peak temperatures are found to be 121.8 °C, 109.5 °C, and 98.5 °C for LCZ thicknesses of 0.5 m, 1.0 m, and 1.5 m respectively. The value of peak temperature reaches so high due to the absence of heat extraction process.

In Figure 3(a) the peak temperature occurs at NCZ thickness of 2.5 m, 2.0 m, and 2.0 m for LCZ thickness of 0.5 m, 1.0 m, and 1.5 m respectively, based on the given conditions. However, the variation in temperature between NCZ thicknesses of 1.5 to 2.0 m is found to be marginal for LCZ thickness of 1.0 m and 1.5 m. Thus, the selection of NCZ thickness of about 2.0 m will not provide appreciable output. Moreover, it will increase the financial investment. According to Hussain et al. (15) maturation period should also be considered for the selection of different zone thicknesses.
Figure 3. Effect of variation of LCZ thickness on (a) maximum LCZ temperature; (b) maturation time.

Figure 3(b) illustrates the maturation time for different thicknesses of LCZ. It can be seen that a longer maturation time is required with the increase in NCZ thickness owing to the attenuation of radiation intensity. The higher thickness of LCZ corresponds to a larger thermal mass of the solar pond, which also leads to a longer maturation period. A significant rise in maturation time is observed for higher NCZ and LCZ thickness. Thus, maximum temperature and maturation period should be taken into consideration to achieve the required parameters for the application.

3.2. Influence of NCZ thickness on conduction heat loss and ground heat loss

The performance of solar pond is significantly influenced by conduction and ground loss. To investigate the effect of NCZ thickness on conduction and ground loss from LCZ, a ratio of respective heat loss to solar radiation received in LCZ is employed as shown in Figure 4. The thickness of LCZ is considered as 1.0 m. In Figure 4 two peaks in conduction and ground heat loss profiles are observed due to the behaviour of solar radiation for the present location.

Figure 4. Impact of NCZ thickness on the heat loss (a) conduction; (b) ground.
For consecutive increase in NCZ thickness, it is found that the difference in the corresponding average percentage of conduction heat loss diminishes. A similar characteristic is observed for the ground heat loss profile. A reduction in conduction heat loss will enhance the accumulation of heat in LCZ which leads to an increase in ground heat loss. In a numerical study, Ganguly et al. (16) reported that the ground heat can be extracted and utilized to improve the output of the pond. Whereas, in Figure 4(b) it can be seen that ground heat loss is influenced by NCZ thickness. Hence, NCZ thickness should be taken into account while considering heat extraction from the ground.

The comparison of conduction and ground loss for NCZ thickness of 0.5 m, 1.0 m, 1.5 m, and 2.0 m is presented in Figure 5. The LCZ thickness is kept constant as 1.0 m. The conduction loss is found to be higher than ground heat loss for the NCZ thickness of 0.5 m and 1.0 m. whereas, further increase in NCZ thickness results in lower conduction loss than ground loss under the given set of conditions. The difference in conduction loss and ground loss is found to be lower for NCZ thickness of 1.0 m and 1.5 m than 0.5 m and 2.0 m.

Figure 5. Comparison of conduction and ground heat loss under the influence of NCZ thickness (a) NCZ thickness = 0.5 m; (b) NCZ thickness = 1.0 m; (c) NCZ thickness = 1.5 m; (d) NCZ thickness = 2.0 m.
3.3. Influence of LCZ and NCZ thickness on conduction heat loss and ground heat loss

In order to understand the impact of both LCZ thickness and NCZ thickness on conduction and ground loss Figure 6 is presented. The LCZ thickness is considered as 0.5 m, 1.0 m, and 1.5 m. Figure 6(a, c, and e) shows the conduction heat loss for NCZ thickness of 0.5 m, 1.0 m, and 1.5 m respectively, and Figure 6(b, d, and f) exhibits the ground heat loss for NCZ thickness of 0.5 m, 1.0 m, and 1.5 m respectively.

It is found that for the higher thickness of NCZ, the conduction loss decreases, and ground loss increases. The conduction loss is noticed to be increased with the rise in LCZ thickness from 0.5 m, 1.0 m, and 1.5 m while considering NCZ thickness of 0.5 m. However, the impact of LCZ thickness on conduction loss is seen to be negligible for NCZ thicknesses of 1.0 m and 1.5 m after initial warm-up. The impact of LCZ thickness on ground heat loss is also found to be marginal for all the considered sizes of NCZ after initial warm-up.
Figure 6. Variation of conduction and ground heat loss under the influence of LCZ and NCZ thickness, (a) Conduction heat loss (NCZ thickness = 0.5 m); (b) Ground heat loss (NCZ thickness = 0.5 m); (c) Conduction heat loss (NCZ thickness = 1.0 m); (d) Ground heat loss (NCZ thickness = 1.0 m); (e) Conduction heat loss (NCZ thickness = 1.5 m); (f) Ground heat loss (NCZ thickness = 1.5 m).

3.4. Influence of LCZ and NCZ thickness on LCZ temperature

Figure 7. Variation of LCZ temperature under the influence of LCZ and NCZ thickness, (a) NCZ thickness = 1.0 m; (b) LCZ thickness = 1.0 m.

Figure 7(a) shows the variation of LCZ temperature by assuming constant NCZ thickness. It can be noticed that LCZ temperature decreases with the increase in LCZ thickness. However, the variation in temperature after the peak point is insignificant. It can be seen that a maximum temperature of about 109.9 °C can be obtained for LCZ thickness of 0.5 m. However, it also produces a higher fluctuation of temperature of about 37 °C. For LCZ depth of 1.5 m, the variation in temperature is observed to be depreciated by 20 °C than LCZ depth of 0.5 m. Such a variation between the highest and lowest temperature may inhibit the temperature required for the application. The impact of variation of NCZ thickness on the behaviour of LCZ temperature is shown in Figure 7(b) by considering the same thickness of LCZ. Enhancement in LCZ temperature is seen with the rise of NCZ thickness. Figure
7(b) exhibits a maximum LCZ temperature of 108.3 °C and 87.7 °C for NCZ thickness of 1.5 m and 0.5 m respectively. It can be seen that the configuration of a smaller thickness of LCZ and a higher thickness of NCZ yields maximum LCZ temperature. The LCZ temperature profiles are seen to be uniform for given NCZ thickness. Thus, NCZ thickness has a negligible effect on the variation of temperature.

4. Conclusion

In this present work, a transient investigation is carried out to examine the impact of thicknesses of the different zone on various operational parameters of solar pond. It is found that the maximum LCZ temperature and maturation time should be taken into the consideration for the selection of the suitable thickness of zones. For higher NCZ and LCZ thickness, a longer maturation time is required. For a higher thickness of NCZ, it is seen that the conduction loss decreases, and ground loss increases. The influence of LCZ thickness on conduction and ground heat loss is found to be marginal. The configuration of a smaller thickness of LCZ and a higher thickness of NCZ yields maximum LCZ temperature. For LCZ depth of 1.5 m, the variation in temperature is observed to be depreciated by 20 °C than LCZ depth of 0.5 m. The impact of LCZ thickness is found to be significant on the fluctuation of LCZ temperature; whereas, NCZ thickness has a negligible effect on the variation of temperature.

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