International Academic Institute for Science and Technology

International Academic Journal of Science and Engineering
Vol. 1, No. 1, 2014, pp. 73-81.
ISSN 2454-3896

International Academic Journal of Science and Engineering

www.iaiest.com

Net Heat Absorbed or Lost by the Lower Convective Zone of a Solar Pond

Rasool Jahromy

Department of Mechanical Engineering, Vali-e-Asr University of Rafsanjan, Iran.

Abstract

Net heat absorbed or lost by the lower convective layer of an experimental solar pond in different days and months was studied during the period of 126 days in 1999. Internal energy level of lower convective layer increases via absorbing solar energy, and decreases due to heat loss into the ground and the walls of the pond. In order to estimate net heat absorbed in that layer, initially internal energy difference was calculated in the layer during consecutive days in the whole period. The general trend obtained for the daily changes of net heat absorbed or lost by the lower convective layer was identical in per unit mass and per unit area of the pond. Because intensity effects of temperature variations in lower convective layer over time were more important than the effects of changes in lower convective layer elevation, density and specific heat of the layer on the total trend of heat absorbed per unit area. During the study period, net heat absorption occurred for 60 days; net heat loss happened for 56 days and there was no net heat absorption or loss for 10 days or its value was very insignificant. The maximum values of net heat absorbed per unit mass and per unit surface area, were corresponded to the 1th May and were 3.41 kJ/kg and 0.51 MJ/m^2 respectively. The maximum values of net heat lost per unit mass and per unit surface area, were attributed to the 20th May and were equal to 8.50 kJ/kg and 1.44 MJ/m^2 respectively. The average daily values for the duration of heat absorption were close to the average daily values of heat loss per unit mass and per unit surface area and thus, the average daily values for the total period were positive and equal to 0.130 kJ/kg and 0.017 MJ/m^2 but insignificant. It was observed that monthly value of the net heat was positive (net heat absorption) in May and June but negative (net heat loss) in July and August as well as the amounts of average daily net heat were equal to 0.20 MJ/m^2 and -0.16 MJ/m^2 in June and July respectively.

Keywords: Solar Pond, Lower Convective Zone, Heat Absorption, Heat Loss

Introduction:

A salinity gradient solar pond is composed of a shallow pond, containing salt water whose temperature and salinity change with depth in its layers. Three different layers can be recognized in a solar pond, namely, the upper convective zone (UCZ) or the top layer, the non-convective zone (NCZ) or the gradient layer, and the lower convective zone (LCZ) or the bottom layer. The temperature and salinity in the top and bottom layers are approximately uniform, but almost linearly in the gradient layer. The gradient layer acts as an insulator layer in a solar pond, in spite of other layers. The elevation of lower convective layer changes with time, because of heat and mass diffusion in this layer. The convective heat transfer in the top and bottom layers and the conductive heat transfer in the lower convective layer make one to believe that the solar pond performs as a heat storage source. Solar ponds can be used for heating, desalination and electricity generation. Figure 1 shows the schematic diagram of a solar pond and its layers.

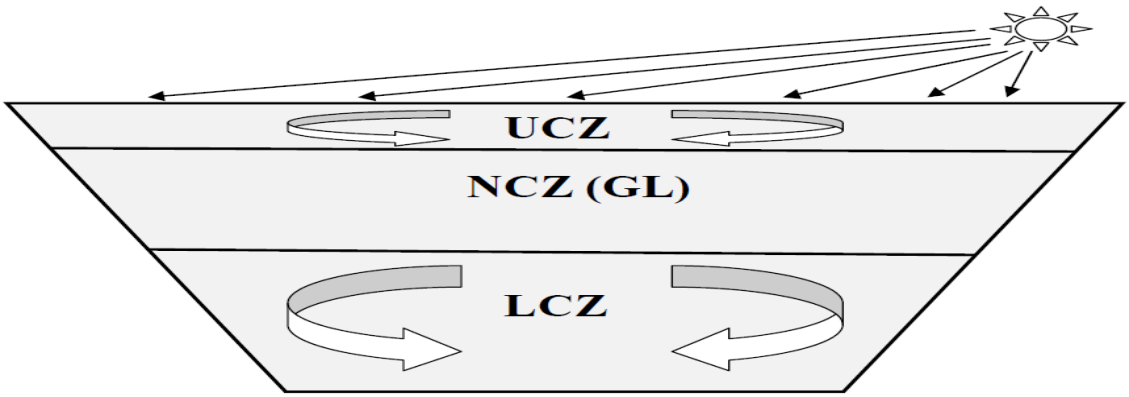


Figure 1: Schematic diagram of a salinity gradient solar pond

Weinberger (1964) investigated the physics of a solar pond for the first time. He solved the energy equation to find the transient temperature distribution, assuming the thickness of top and bottom layers is ignorable. The performance of a small solar pond in laboratory scale with salinity gradient was investigated by Jaefarzadeh (2000). The pond was in outdoor air; the history of temperature and salinity distributions, and the top and bottom layer depths were reported at different weather conditions. The numerical study of transient heat and mass transfer and stability in a salinity gradient solar pond was also performed by Mansour et al. (2004) using Fluent Software. They used 3D-model with all properties variable as function of temperature and salt concentration.

Busquets et al. (2012) experimentally investigated the thermal analysis and measurement of a solar pond prototype. They studied the non-convective zone salt gradient stability with various salinity gradients based on the Stability Margin Number (SMN) criterion. An experimental research of the energetic performance of two various solar ponds with square and circular cross sections, was carried out by Dehghan et al. (2013). They observed that the salt-water temperature in the lower convective layer of the circular solar pond reaches to a higher value in comparison with the square one. Bozkurt and Karakilcik (2015) investigated the energetic performance of a solar pond integrated with four flat plate solar collectors. They developed an energy model to study the energetic performance of the integrated solar pond. They also compared the energy performance for the zones of the salinity gradient solar pond.

This study is going to talk about net heat absorbed or lost with respect to intensity of temperature changes, elevation, specific heat and density of the lower convective layer over time in different days and months.

Net heat absorbed by the LCZ in a solar pond

According to Figure 2, part of the incoming radiant energy (Q_R) was absorbed by the lower convective layer after passing through other layers and increases its internal energy level. The level of mentioned internal energy is reduced by heat energy loss into the gradient layer (Q_{GL}), ground and side walls of the pond (Q_G); this loss is greater at night, specifically. So the net heat absorbed by the lower convective layer within a specified time will be:

$$Q_{Net} = Q_R - Q_{GL} - Q_G \tag{1}$$

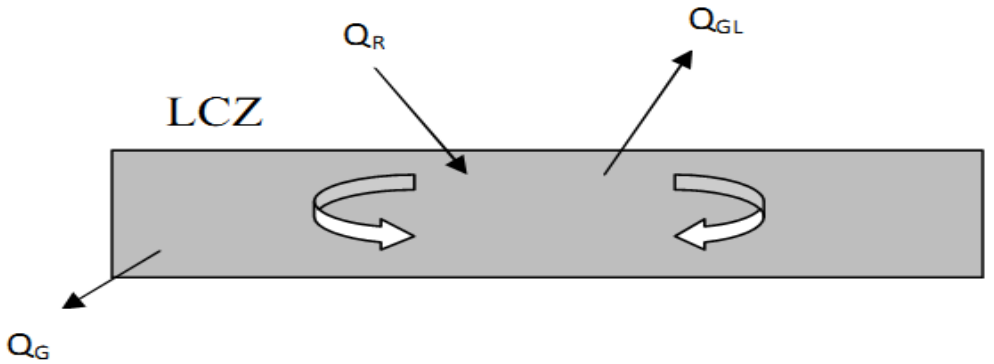


Figure 2: The incoming radiant energy into the LCZ and the heat loss into the gradient layer, ground and side walls of the pond

We want to calculate the net heat absorbed by the lower convective layer during 24 hours a day. So we must find the differences in the mentioned layer's internal energy within two consecutive days. Since the specific volume of fluids is very low; enthalpy changes are almost equal to the internal energy changes. The First Law of Thermodynamics with regardless of the changes in kinetic and potential energy, for the net heat absorbed by the lower convective layer, will be as follows:

$$q_{Net} = \bar{c}_p (T_{i+1} - T_i)_{LCZ} \tag{2}$$

$$Q_{Net} = \bar{\rho} A h_{LCZ} \bar{c}_p (T_{i+1} - T_i)_{LCZ} \tag{3}$$

q_{Net} and Q_{Net} in the above relations are the net heat absorbed or lost per unit mass and per unit surface area respectively. Furthermore, A is surface area of the pond, c_p is specific heat, ρ is density, h_{LCZ} is the elevation of lower convective layer, T_i and T_{i+1} are temperature of that layer on consecutive days.

Variations of density and specific heat with temperature and salinity for the brine

The density and specific heat for the salt-water solution are given by (Kaufmann, 1960):

$$\rho = 998 + 0.65C - 0.4(T - 20) = \frac{998 - 0.4(T - 20)}{1 - 0.0065S} \quad (4)$$

$$c_P = 4180 - 4.396C + 0.0048C^2 \quad (5)$$

In these equations, S is the salinity in wt% (S=100C/ρ), T is in $^{\circ}$C, ρ and C (salt concentration of salt water) is in kg/m^3.

Variations of the temperature, salinity and elevation in the LCZ

A small and shallow solar pond was constructed in Ferdowsi University of Mashhad and was studied for a few years. By creating a appropriate concentration gradient, the pond could have heat absorption. According to Figure 3, the beginning of the study period was the first day of May 1999, and the period continued until September lasting for 126 days. During this time, the pond with a surface area of 4m^2 and depth of 1.08m had been operating constantly. All the experimental data related to this solar pond, are taken from reference (Rahimpour, 1999). Variations of the temperature and salinity over time in the lower convective layer of the solar pond are shown in Figure 3 and Figure 4 respectively. Furthermore, Figure 5, shows the recorded variations in the elevation of the lower convective layer.

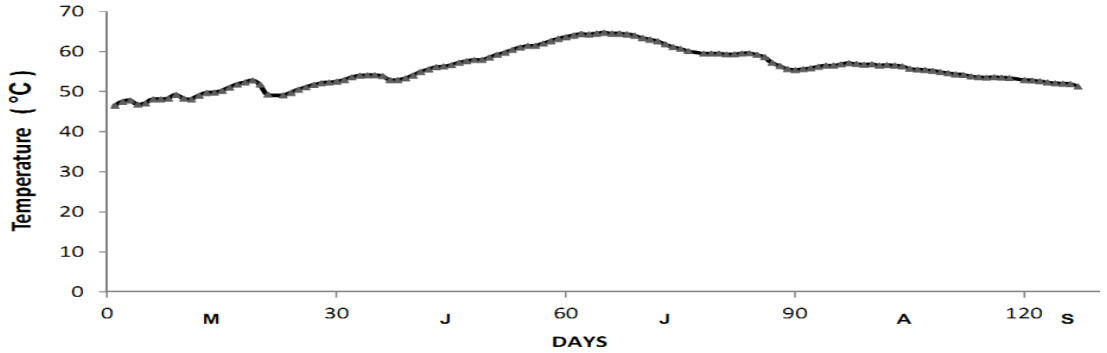


Figure 3: Variations of the temperature in the lower convective layer over time

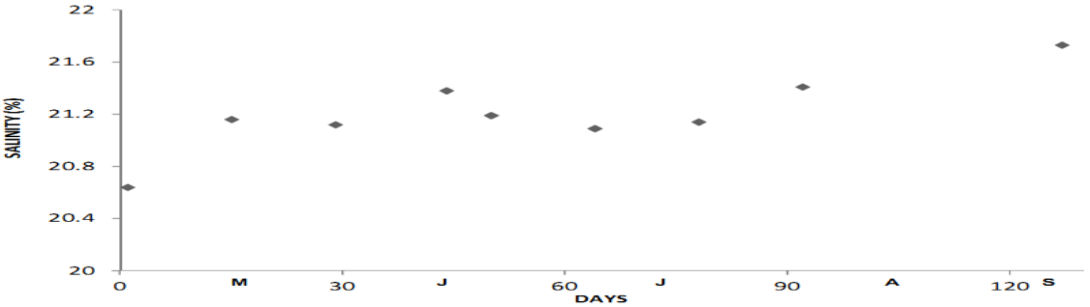


Figure 4: Variations of the salinity in the lower convective layer over time

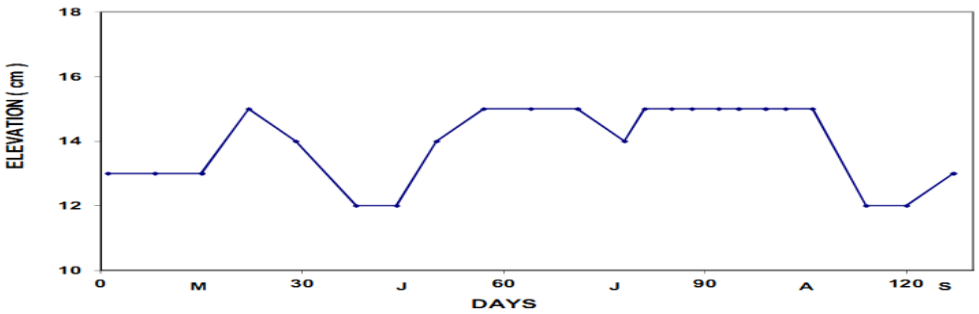


Figure 5: Variations in the elevation of the lower convective layer over time

Net heat absorbed or lost by the LCZ in different days and months

We intend to investigate the net heat absorbed or lost by lower convective layer with respect to rate of temperature variations, elevation of the lower convective, specific heat and density of the concentrated solution over time. Net heat absorbed by the lower convective layer in different days has been shown in terms of kJ/kg (kilojoules per kilogram of brine) in Figure 6. A fluctuating trend, with ups and downs is observed during the entire period under study. Positive values show net heat absorbed, and negative values indicate net heat lost on that day. The highest values of heat absorption and loss is attributed to May and June, and the maximum value of heat absorbed per unit mass is on the first day of May and equal to 3.41 kJ/kg. In other days also the values are relatively significant, and the maximum heat lost is on the Twentieth of May and equal to 8.50 kJ/kg.

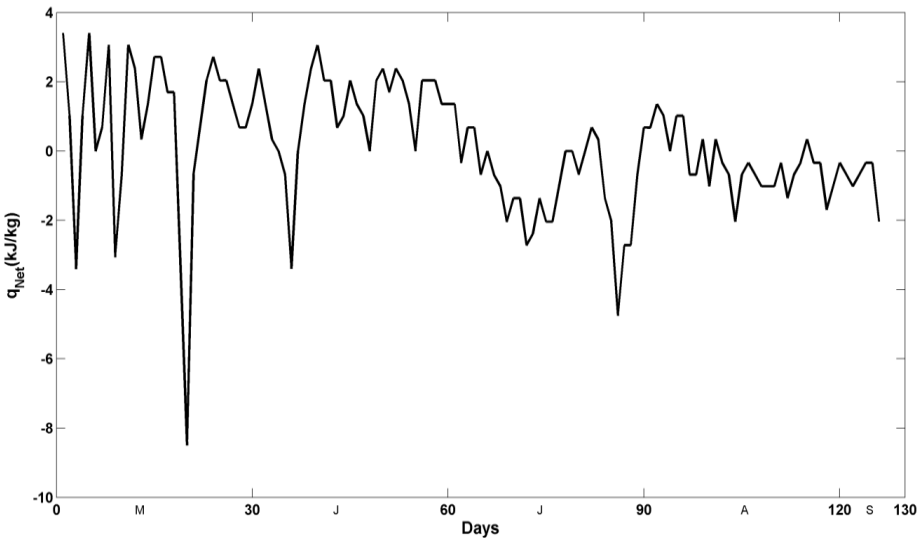


Figure 6: Net heat absorbed by the lower convective layer in different days in terms of kJ/kg

Net heat absorbed or lost by the LCZ in different days has been shown in Figure 7 in terms of MJ per square meter in the cross-section of the solar pond. The effect of different temperatures in consecutive days has the greatest impact on the overall trend. Furthermore, the changes in density, specific heat and elevation of the lower convective layer are not so much from one day to another day that could change the trend; although they have theirs impacts on the final values, but the previous trend can be observed with some changes during the period as in Figure 6. The highest heat absorbed and lost is observed in May and June, and the maximum amount of heat absorbed per unit surface area of the pond was 0.51 MJ/m^2 on the first day of May. The values obtained on other days are fairly important, and the maximum heat lost per area unit was 1.44 MJ/m^2 on the Twentieth of May. The relative maximum values in the second half of June in Figure 7 compared with Figure 6 have a relative increase than the relative maximum values in the first half of the month due to the lower convective layer growth (according to Figure 5) from mid-June onwards.

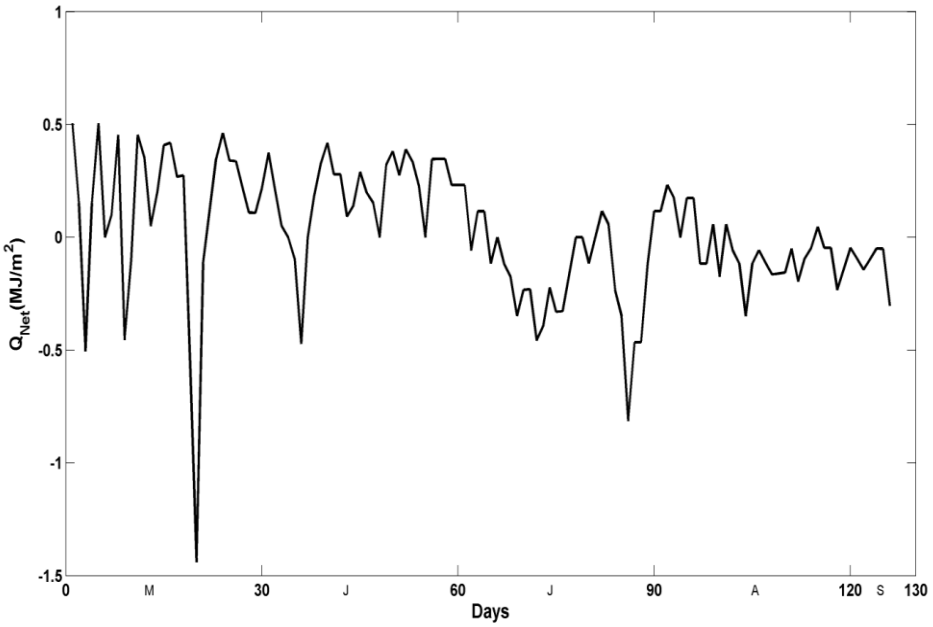


Figure 7: Net heat absorbed by the lower convective layer in different days in terms of MJ/m^2

In the entire period during the 126 days that we observed net heat absorption or loss from day to day, net heat absorption occurred in 60 days, net heat loss happened in 56 days and there was no absorption or loss for 10 days due to the net heat absorbed or lost was zero or very close to it. Table 1 demonstrates the maximum amounts in the entire period and average daily values of net heat absorption and loss for 60 and 56 days respectively, as well as average daily values of net absorption in the whole duration per unit area and per unit mass. The average daily values of the total duration (0.130 kJ/kg and 0.017 MJ/m^2) are positive but insignificant.

Table 1: The maximum amounts, and average daily net heat for 60, 56 and 126 days (whole period)

	q_{Net}(kJ/kg)	Q_{Net}(MJ/m^2)
Maximum net heat absorbed	3.41	0.51
Maximum net heat lost	-8.50	-1.44
Average daily net heat absorbed for 60 days	1.56	0.24
Average daily net heat lost for 56 days	-1.38	-0.22
Average daily net heat absorbed for 126 days (The whole period)	0.130	0.017

Currently, we want to study heat absorbed or lost by the LCZ in different months. Figure 8 shows the heat absorption and loss as well as net heat absorption or loss for various months. It can be seen that the net heat is positive (net heat absorption) in May and June but negative (net heat loss) in July and August. The net amount of heat absorption in June (5.87 MJ/m^2) is more than in May (3.27 MJ/m^2); however, the amounts of heat absorption were extremely close to in two months. The net amount of heat loss in July (-4.69 MJ/m^2) is more than in August (-1.78 MJ/m2) due to the maximum heat loss in July. Average daily net heat absorbed or lost by the LCZ in different months has been shown in Figure 9. It is observed that the amounts of average daily net heat are equal to 0.2 MJ/m^2 and -0.16 MJ/m^2 in June and July respectively.

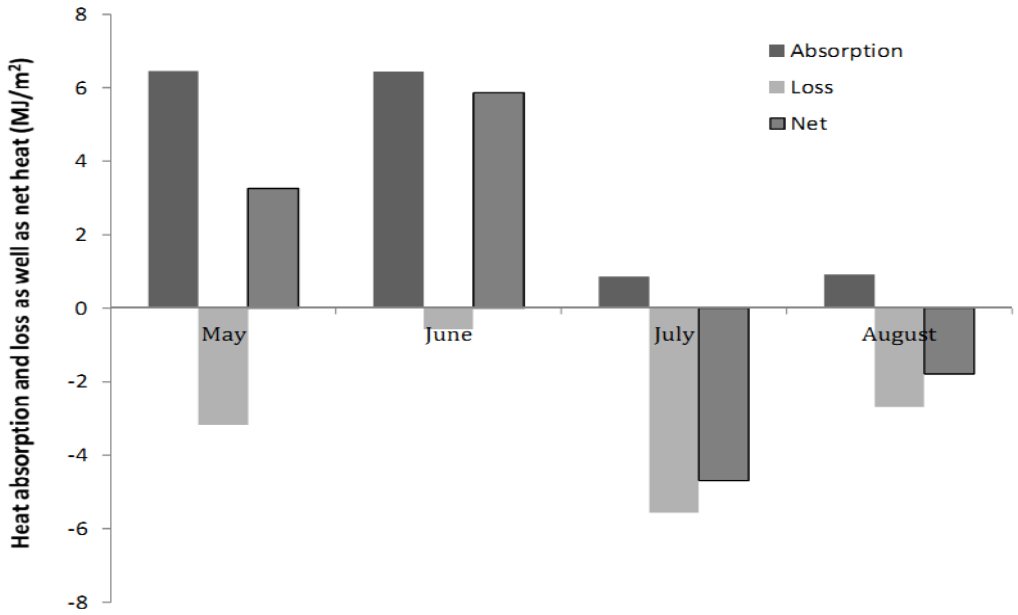


Figure 8: Heat absorption and loss as well as net heat absorption or loss in various months

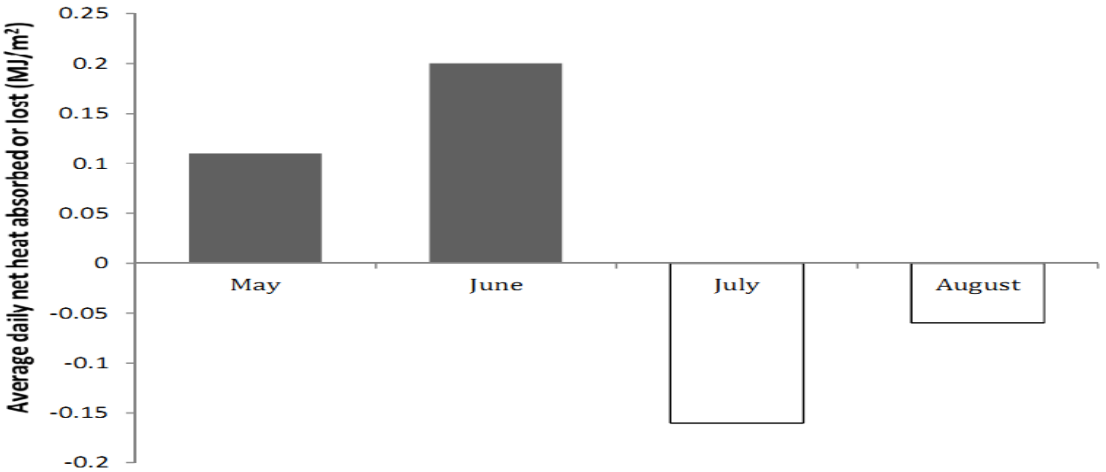


Figure 9: Average daily net heat absorbed or lost by the LCZ in different months

Conclusion:

In this study, the net heat absorbed or net heat lost by the lower convective layer in various days in the solar pond was investigated in 1999 during the period of 126 days. Internal energy level in lower convective layer increases by absorbing solar heat energy and it also decreases due to heat losses into the ground and side walls of pond. In order to obtain the net heat absorbed in lower convective layer of the solar pond; internal energy difference was calculated in that layer during consecutive days in the entire period.

The general trend obtained for the daily changes of heat absorbed or lost by the LCZ per unit mass and per unit surface area of the pond was the identical. The effects of temperature variations in the LCZ were more important than the effects of changes in elevation, density and specific heat of the lower convective layer on heat absorbed or lost per unit area. Increasing elevation of the lower convective layer in the second half of June affected the trend of net heat absorbed per unit area. During the study period, net heat absorption and loss existed in 60 and 56 days respectively; and there was no absorption or loss in 10 days.

The maximum amounts of heat absorption were attributed to May and June, and the maximum amounts of heat absorbed per unit mass were 3.41 kJ/kg and 0.51 MJ/m^2 respectively on the first day of May. In the other days also the values are relatively significant, and the maximum values of net heat lost were 8.50 kJ/kg and 1.44 MJ/m^2 on the nineteenth of May respectively. The average amounts of heat absorption were close to the average values of heat loss per unit mass and per unit area unit and thus The average daily values of the whole period (0.130 kJ/kg and 0.017 MJ/m^2) were positive, but insignificant. It was observed that monthly value of the net heat was positive in May and June but negative in July and August as well as the values of average daily net heat were equal to 0.20 MJ/m^2 and -0.16 MJ/m^2 in June and July respectively.

References:

Bozkurt, I., & Karakilcik, M. (2015). Exergy analysis of a solar pond integrated with solar collector. *Solar Energy*, *112*, 282-289.

Busquets, E., Kumar, V., Motta, J., Chacon, R., & Lu, H. (2012). Thermal analysis and measurement of a solar pond prototype to study the non-convective zone salt gradient stability. *Solar Energy*, *86*(5), 1366-1377.

Dehghan, A. A., Movahedi, A., & Mazidi, M. (2013). Experimental investigation of energy and exergy performance of square and circular solar ponds. *Solar Energy*, *97*, 273-284.

Hull, J. R., & Nielsen, C. E. (1989). Steady-state analysis of the rising solar pond. *Solar energy*, *42*(5), 365-377.

Jaefarzadeh, M. R. (2000). On the performance of a salt gradient solar pond. *Applied thermal engineering*, *20*(3), 243-252.

Kaufmann, D. W. (1960). Sodium Chloride Reinhold. *New York*, 611-620.

Mansour, R. B., Nguyen, C. T., & Galanis, N. (2004). Numerical study of transient heat and mass transfer and stability in a salt-gradient solar pond. *International Journal of Thermal Sciences*, *43*(8), 779-790.

Rahimpour, M. (1999). Study of gradient layer thickness in solar ponds. *M. S. thesis*, School of Engineering, Ferdowsi University of Mashhad.

Weinberger, H. (1964). The physics of the solar pond. Solar Energy, 8(2), 45-56.