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ENHANCEMENT OF SOLAR POND EFFECTIVENESS THROUGH ADDITION OF PCM TO LOW CONVECTIVE ZONE

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ABSTRACT

This research focuses on the development of solar ponds for efficient storage of solar energy. The influence of phase change material in the solar storage capability of solar ponds has been studied in the present wok. A comparison in the temperature fluctuations of a typical solar pond is made with its counterpart provided with phase change material. Readings have been taken during the sunshine hours in a day, and extended to seventy-five days. The solar pond exhibited identical fluctuations in average temperature irrespective of the presence of phase change material. The results revealed that during the sunshine hours, i.e., 08:00 to 17:00 for one month the average lower convective zone temperature increased by 11 ^{o}C. However, the solar still containing the phase change material during the month exhibited an average lower convective zone temperature fluctuation of approximately 3 ^{o}C. There was rapid fluctuation in the lower convective zone temperature per day when a typical solar pond was used. However, the same exhibited very little fluctuations after incorporating the phase change material in the solar pond. This is because the. phase change material absorbed heat energy from the solar radiation and replenished the heat storage capability in all three zones of the solar pond while the sun shine was interrupted by passing clouds. The monthly average temperature difference in the solar pond containing phase change material was observed to reduce by 55 % during the sunshine hours and after that it reduced by 62 %. It is concluded that the adding phase change material to the solar still is beneficial, since it helps to control the fluctuations in temperature in the three zones of the solar pond, despite the intermittent availability of the solar radiation.

Keywords: *Solar Pond, Heat Loss, Lower Convective Zone, Paraffin Wax, Convection, Salinity*

1. INTRODUCTION

The non-conventional source of energy which is available adequate in nature is the Solar energy. The solar radiation received annually in India can compensate the consumption of electrical energy by 20,000 times. Even though, the solar energy incident on the ground is more (5 kWh/m^2 day) but its usage has been limited. The reason for the limited usage is because of the unavailability of collector and storage devices as they require quite large capital investment at initial stage. Other reason for the restricted usage of the solar energy in a large scale is because it is an intermittent source of energy during cloudy days and at night times. This became the essential criteria to have a storage system to decrease the restricted usage of solar energy. Solar pond is one of the alternative ways to capture and store the solar energy for uninterrupted usage (Jose Amigo & Suárez, 2017; Batty, Riley, & Panahi, 1987; Kaushik, 1982).

Solar radiation of about 30 ^{o}C arrives at a profundity of 2 m in a transparent natural pond. This sun powered radiation is ingested at the lower part of the lake. The water at the base gets heated up and lighter and consequently ascends to the upper layer. Here the heat is lost to the ambient and, subsequently, there will be no accomplishment of temperatures greater than the surrounding in the normal pond. In the event that some system can be concocted to forestall the blending of water between the upper and lower zones of a pond, at that point the lower zone temperature will be greater than of the upper zone. The above said system can be accomplished severally. The least difficult technique is to add salt in the lower zone there by creating a density difference in the lower and upper zone. The salt utilized is by and large sodium chloride or magnesium chloride due to their minimal effort. Ponds utilizing salts to strengthen the lower layers are called 'saltiness slope ponds'. There are other alternate approaches to forestall blending of water between the upper and lower zones of a pond. The utilization of a clear honeycomb structure is considered to be one among them as it traps still air and thus gives great glassiness to sunlight-based radiation as the heat loss chops down (Aramesh, Pourfayaz, & Kasaeian, 2017; Hull, 1980; Monjezi & Campbell, 2016; Montalà, Cortina, Akbarzadeh, & Valderrama, 2019; Njoku, Agashi, & Onyegegbu, 2017).

The saltiness slope solar pond was examined in this survey as this innovation has gained enormous headway over the most recent fifteen years. The variation of the salinity level at three zones of the solar pond are appeared in Figure 1. It was found that the solar pond comprises of three particular zones. The Lower Convective Zone (LCZ) has the most elevated temperature and thickness and is the area where sun-oriented radiation is ingested and put away. The Upper Convective Zone (UCZ) has the most minimal temperature and thickness. This zone is blended by surface breezes, evaporating and night-time cooling. The zone in middle of upper and lower layer is known as the Non-Convective Zone (NCZ) (or) the salt gradient zone in light of the fact that convection never happens here. The level of salinity declines from the base to the top of the NCZ, and it goes about as a glassy non-conductor. It grants sunlight-based radiation to go through and the heat loss diminishes from the LCZ

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which is hot to the UCZ which is cool. The mode of heat transfer from LCZ to UCZ is by conduction. The thicknesses of UCZ, NCZ and LCZ are typically around 0.5 m, 1m and 1 m, separately (Akbarzadeh & Ahmadi, 1980; Al-Juwayhel & El-Refaee, 1998; Khalilian, 2017; Reza, Basirat, Parvar, & Kavoosi, 2017; Sayer, Al-hussaini, & Campbell, 2016).

The distribution of different mathematical and trial examinations of the solar pond along with the consideration of ideal operational conditions and financial plausibility has been performed (Kurt, Ozkaymak, & Binark, 2006). A consistent model of solar pond with salinity gradient has been created to foresee the temperature appropriation along the wall of pond vertically. The results observed shows that the temperature in the UCZ is in acceptance with that of values observed at LCZ and the NCZ temperature was thought to be near the surrounding temperature (Noel, Glouannec, & Velly, 1996). In an examination, numerical demonstration of a hydroponics pond was performed by discretization at nodes to understand its thermal behaviour and some of the formulae related to calculate the temperature at water-air interface was also utilised and the temperature has been finalized (Giestas, Milhazes, & Pina, 2014). A transient mathematical model of one dimension was created for a non-variant salt-slope solar pond to analyse its response with the estimated temperatures of ambient and ground level. The thermal behaviour of the coupled storage system for different stone material and bed math was also analyzed (José Amigo, Meza, & Suárez, 2017).

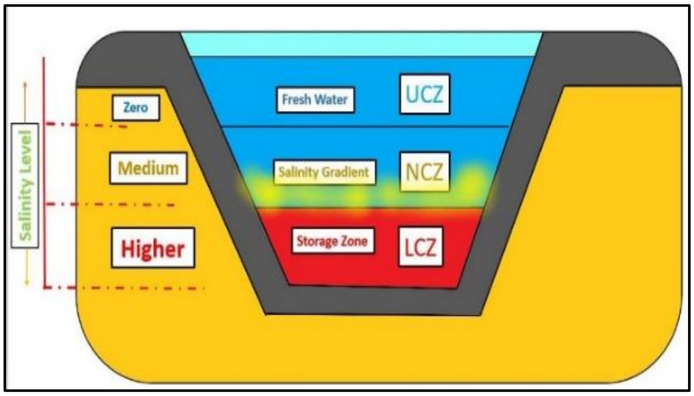


Fig. 1 Salinity gradient of Solar Pond

2. EXPERIMENTAL SET UP

The sketch of the solar pond has been depicted in the image as shown in Figure 2. A tapered tub made of black pigmented polymer sheet 6 mm thick and 2.5 m height was used as the basin for the solar pond. The saline water for the solar pond was made by mixing 3.5 % volume of sodium chloride to distilled water. The solution thus prepared was filled to the brim of the solar pond. A partially opened lid was placed on the top of the solar pond to prevent spillages. Acrylic sheets 5 mm thick were constructed in the form of square pyramid that fitted over the top of the solar still. This arrangement enabled transfer of solar energy to the saline water in the solar still. Six capsules were made using polymers to contain the phase changing materials. Each capsule had a dimension of 250 X 500 X 1000 mm, capable of containing 650 g of the phase changing material (paraffin wax, melting point = 56 ºC).

Six thermocouples (K-type) were used to read the temperature in the three different zones of the solar pond. The thermocouples were placed at various heights on the solar pond. Two additional thermocouple was used to read the atmospheric temperature as well as the wall temperature of the solar pond. An eight-bin indicator was used to display the readings from the thermocouples as shown in Figure 3. Temperature readings were recorded daily for a duration of 24 h at an interval of 30 min. The readings were extended for a period of 75 days during the research.

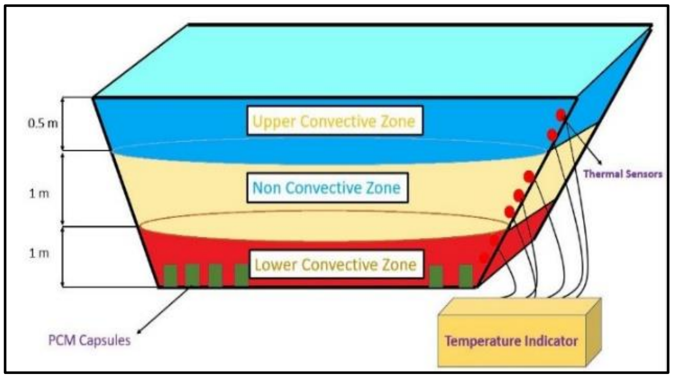


Fig. 2 Solar Pond Experimental Model

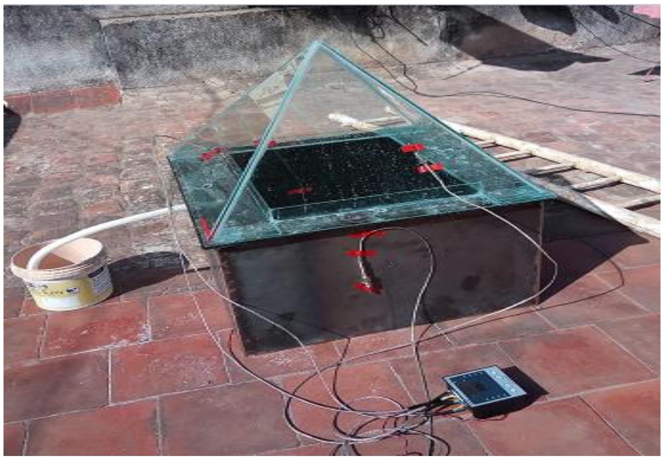


Fig. 3 Solar Pond-Experimental Setup

3. RESULTS AND DISCUSSION

3.1 Variation of Solar radiation over the experimental model on daily basis

The variation of the mean temperature of LCZ of the solar pond with and without Phase Changing Material (PCM) along with the total daily radiation has been plotted in the graph as shown in Figure 4. Readings were obtained from the experimental observation made for seventy-five consecutive days from 5th March to 17th May, 2020. The total solar radiation received everyday by the solar pond varied. The plot shows a temperature variation due to the heat transfer process in the solar pond. The temperature of the solar pond with and without PCM shows a fluctuation that is corresponding to the solar radiation for the corresponding day.

The results shows that maximum temperature attained by the solar pond without any PCM is 44.8ºC on the 55th day and while using PCM it was 48.1ºC on the 15th day. These maximum average temperatures were not recorded on the same day. The plot reveals that with the increase in number of days the average temperature absorbed by solar pond with PCM diminished even though there was abundance of solar radiation. Similar trend was observed in solar pond without PCM. It can be inferred that the repeated heating and cooling in the solar ponds with the day night cycle resulted in change in properties of the NaCl dissolved in the water and also the PCM. Interestingly the solar pond with PCM exhibited greater capability to store the heat energy which resulted in greater average temperature compared to its counterpart without PCM.

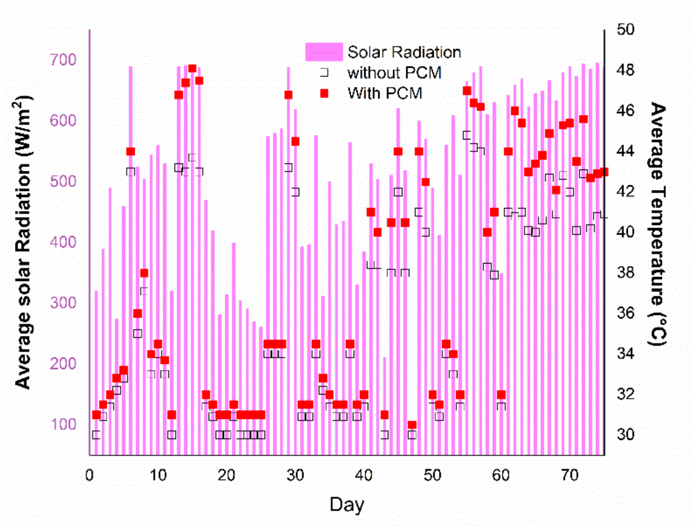


Fig. 4 Average Solar Radiation per day

3.2 Experimental temperature observation of the pond's LCZ-Hour Basis

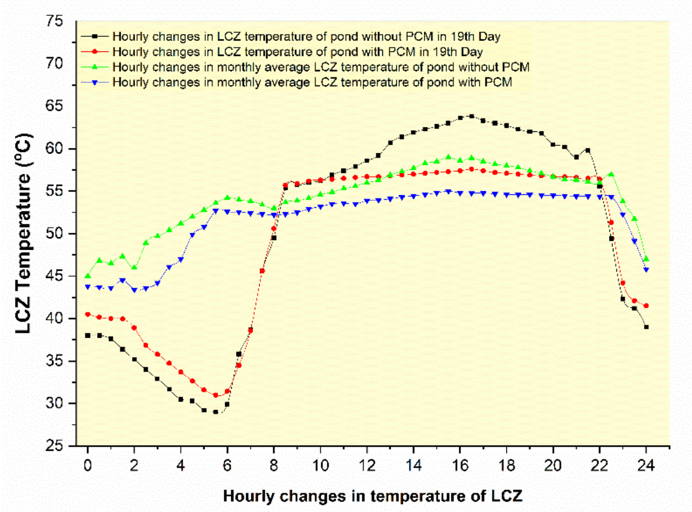


Fig. 5 LCZ Temperature-Hourly Change

During the study conducted for the seventy-five days, the intensity of the solar radiation fluctuated because of the presence of clouds. It was especially cloudy on 48th day. So, the solar intensity was very low, i.e., 98 W/m^2 as shown in Figure 4. Such a low value was not suitable to be considered for the study. Hence, it was decided to observed the readings on 19th day, when the solar intensity was normal. The temperature variation of LCZ with and without PCM during every hour of a day has been observed on the 19th day. The average value of the temperature was determined for the month as shown in Figure 5. The results observed indicates that the LCZ temperature varies drastically if the solar pond is without PCM. The temperature reached the peak value of 64°C at the 16th hour of a day and 59°C during the month. The solar pond with PCM shows minimal variation in the LCZ temperature. The initial temperature of the LCZ is 56°C and 54°C on the 19th day and as well as for a month. The final temperature of the pond has been recorded as 55.5°C and 53.9°C during the night hours.

The drastic difference in the temperature of LCZ of the solar pond with PCM and without PCM is due to the convection losses occurring between the surface of solar pond and the air moving over the pond surface. When the PCM is added to the LCZ of the pond, the sun's rays reaching the LCZ transfers its maximum amount of heat to the PCM and during night time, when the pond is cooled, the heat in the PCM is transferred to the pond. The addition of PCM reduces the convection losses and thereby the temperature of the LCZ is sustained for the entire day without any drastic variation in the temperature.

Compared to the readings obtained on the 19th day, the variation in the average temperature of solar pond for a month with PCM was 3^{0}C and without PCM was 7°C. The temperature difference is too large in the night time and is small during day time. This is due to the convection losses occurring during the breeze flow over the pond surface. Since most of the solar energy stored in PCM, the temperature difference recorded at the night time for the solar pond with PCM was low. The temperature reduction of 55 % occurred during the day time and 62 % reduction occurred during the night time for the solar pond with PCM for a month and a day respectively.

3.3 Experimental temperature observation of the pond's LCZ -Weekly Basis

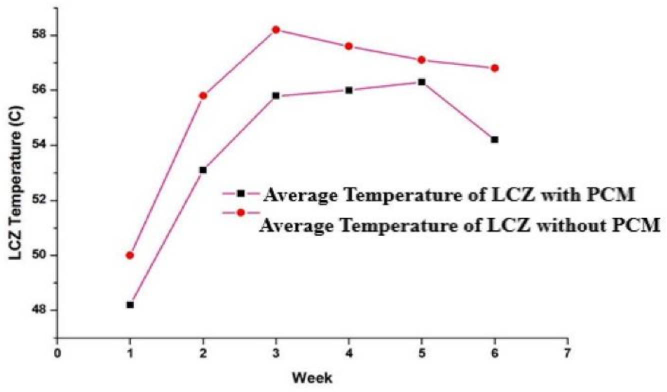


Fig. 6 Comparison of LCZ Temperature with and without PCM

The average temperature of the pond with and without PCM for 7 weeks has been plotted in the Figure 6. It is evident that the temperature of LCZ of the solar pond with PCM is low compared to the solar pond without PCM. The temperature of the pond without PCM on the 3rd week is recorded as 58°C. This difference in the temperature of LCZ is caused due to the property of PCM. The PCM usually stores the heat when it receives radiation and it transfers heat to the surrounding when it cools (or) undergoes phase change. It can be seen that the temperature of the pond can be maintained at a steady temperature by using PCM and the water in the pond can be used for various applications such as power plants without intermittent supply of hot water from the pond.

3.4 Experimental temperature observation of the pond's LCZ -Daily Basis

The variation in the average LCZ temperature of the solar pond per day is plotted in the graph as shown in Figure 7. The graph represents the difference in the temperature of LCZ in the solar pond with and without PCM. Due to the change in environmental conditions such as accumulation of local dust (or) wind flow over the surface of pond, the solar pond without PCM shows a drastic change in the temperature of LCZ. However, in the solar pond with PCM, the temperature variation in LCZ is stable. Sudden rise (or) falls in the temperature per day did not occur. The stable temperature in the solar pond with PCM is because of the increase in the salinity of LCZ. As the salinity level in LCZ becomes stable, the thermal stability of the pond also increases. In turn, it helps in continuous absorption of solar energy and continuous usage of solar energy for various applications. In this way, solar pond with PCM acts a storage device for solar energy.

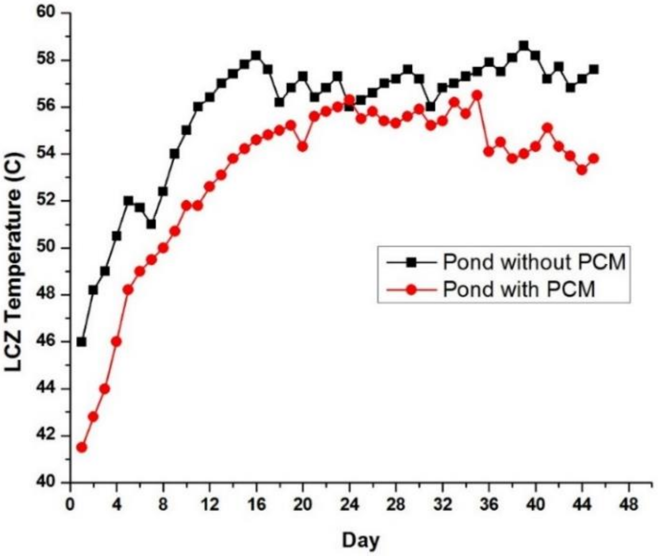


Fig. 7 Comparison of LCZ Temperature per day with and without PCM

3.5 Variation in pond temperature along with its depth

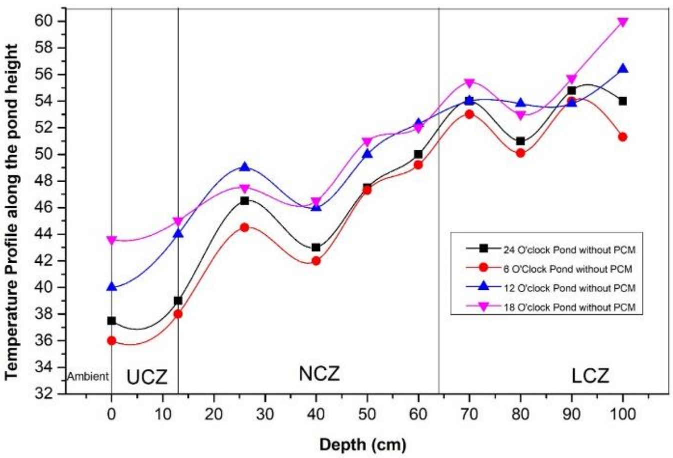
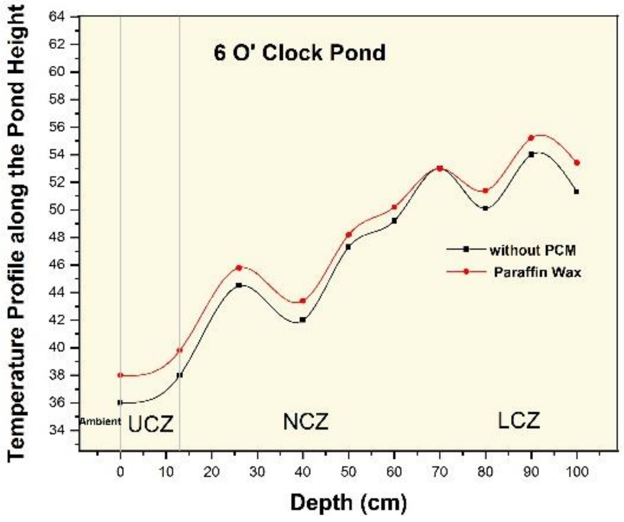


Fig. 8 Temperature profile along the pond height without PCM



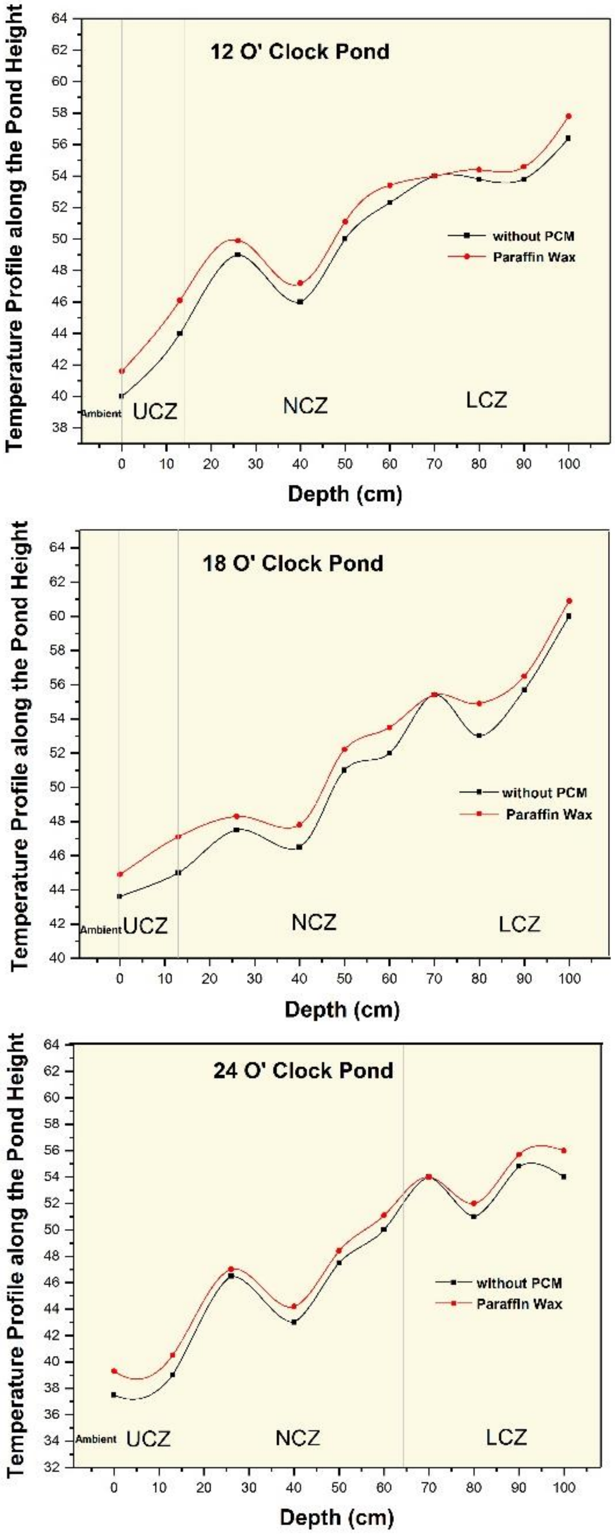


Fig. 9 Temperature profile along the pond height with PCM

The variation of solar pond temperature at its three zones i.e., UCZ, NCZ and LCZ along with its depth for a day at different hours has been projected for without and with paraffin wax in the form of graph as shown in Figure 8 and 9 respectively. The height (or) the depth of the pond is classified into three zones based on the height of each zone. The variation of temperature is recorded every 6 h in a day i.e., from morning 6 O'clock up to night 12 O'clock. It is noted from the recorded data that the temperature at various depth changed drastically in the solar pond without PCM.

It is observed that the temperature recorded in LCZ is much higher than in NCZ and UCZ. During the absence of sunshine, especially during 6 O'clock and 24 O'clock, the temperature at LCZ and NCZ are 50^{o}C and 42^{o}C respectively. But during 12 O'clock and 18 O'clock, the LCZ and NCZ temperature recorded was 60^{o}C and 46^{o}C. The sudden variation is due to the convection heat losses occurring over the zones of solar pond. The profile of temperature variation along with depth is recorded as upward parabolic with maximum temperature recorded at the higher depth in LCZ during daytime from noon to evening. From night to morning, the zones temperature variation is recorded as downward parabolic with maximum temperature recorded at depth of 45 m to 50 m in the NCZ. The PCM absorbed the solar radiation during the day and released the heat energy after sunset, resulting in stable temperature along the zones of solar pond with PCM.

4. CONCLUSIONS

A model of solar pond has been experimentally observed with and without PCM. The temperatures at the three zones of the pond is experimentally observed. The thermal behaviour of the solar pond is predicted based on the observed temperature values of UCZ, NCZ and LCZ. The experimental data is observed on monthly, weekly, daily and hourly basis. The maximum temperature of 63^{o}C was noted in the solar pond without PCM and with paraffin wax stretched around 59^{o}C during early days of the study. The performance diminished here after due to the change in the characteristics of dissolved salt in the saline water in the solar still. The variation in the average temperature of solar pond during day and night for a month with PCM was 3^{o}C and without PCM was 7^{o}C. The temperature difference of 55 % reduction during the day and 62 % reduction during the night was observed in the solar pond with PCM for a month and a day respectively. It is observed from all the results that the solar pond with PCM capsules can efficiently storage the solar energy in the solar pond. This is because the convection loss for the solar pond with PCM is low compared to the pond without PCM.

NOMENCLATURE

C	heat capacity (J/m^3·K)
c_p	specific heat (J/kg·K)
h	latent heat of phase change (J/kg)
k	thermal conductivity (W/m·K)
M	molar mass (kg/kmol)
q''	heat flux (W/m^2)
R	reflectivity
R_g	specific gas constant (J/kg·K)
t	time (s)
T	temperature (K)
u	interfacial velocity (m/s)
x	coordinate (m)

Greek Symbols

δ	optical penetration depth (m)
ε	total emissivity
ρ	density (kg/m^3)
σ	Stefan-Boltzmann constant (W/m^2 ·K^4)

Superscripts

0	last time step

Subscripts

0	initial condition
e	electron
l	lattice
∞	ambient environment

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