Pak. J. Biotechnol. Vol. 13 (special issue on Innovations in information Embedded and Communication Systems) Pp. 15 - 20 (2016)

EXPERIMENTAL AND THEORETICAL STUDY ON EFFICIENCY OF PORTABLE MINI SOLAR POND USING DISSIMILAR SALTS

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ABSTRACT

Solar energy was used from the ancient period itself. Solar energy can be entrapped by a number of ways but most prominent way by using solar pond. Solar pond has four types this paper deals with non convective salinity gradient solar pond. Solar thermal energy generated by a salinity gradient solar pond (SGSP) is one of the significant promising techniques for providing heat for desalination and other applications. Most commonly used salt is sodium chloride, but in this research, table salt which is having the similar properties like sodium chloride is used. A pond was located at 11°N walls were inclined at 45° to the horizontal. The pond was built of mild steel (1.6 mm thick) with a trapezoid surface area and with total depth of 1.7 m^2 and 500 mm. The pond was insulated by 20 mm, 2mm thick of thermo styrene and High Density Polyethylene sheet.

I. INTRODUCTION

Sun is the largest and most stable source of energy, and this energy is abundantly available all over the earth. Solar thermal energy could offer the most sustainable source of energy to power thermal desalination techniques. A solar pond is a non-natural pond that entraps solar energy and to affords desired thermal energy when needed. Convection mode in its gradient zone is suppressed by establishing a salinity gradient through the pond depth. It uses a lot of saline water with increasing density gradient from top to bottom [1]. The solar pond technology has been used in Israel (Tabor and Doron, 1990) and USA (Swift et al., 1987; Xu et al., 1993) for power generation and low-temperature process heat applications.

A. Salinity Gradient Solar Pond (SGSP)

A non-convective solar pond is simple in design and can be constructed at the reasonable cost. A unique salt gradient solar pond consists of three main zones.

B. The Upper Convecting Zone (UCZ)

Upper layer is sometimes called the surface layer. This zone has salt content in a very low way and the temperature will be very near to atmosphere temperature it consumes less cost [3]. The thickness of this zone should be kept as thin as possible. It is constructed and operated by using the low salt content water such as sea or brackish water, pure water and the expenditure to build the surface zone is usually neglected. Natural effects like the wind, falling dust, evaporation are being suppressed by the UCZ layer [4].

C. The Non-Convecting Zone (NCZ)

Middle layer can be also called the gradient zone. The position of this zone is between the top and the bottom of the pond. In this zone, the salt content and the temperature distribution will vary with depth and this is not consistent. When the salt concentration was high it exhibits a convection phenomenon [5].

D. Lower Convecting Zone (LCZ)

Lower layer can be also called the storage zone. In this the salt content and temperature will be very high when compared to other two zones and this is a homogeneous layer. The temperature will be stored and by using heat exchangers like internal or external we can extract the heat out of the pond. With the depth increase, the heat stored will get increased and the temperature difference will get decreased. When the molecular diffusivity is very low the movement of the molecules will not migrate in a faster way so that the convection phenomenon exhibits. The gradient zone consists of a several layers and each sub-layer is heavy and hot than the ones above it. By this way, the middle acts as insulator layer to reduce the lower zone upward heat loss significantly.

II. EXPERIMENTAL SETUP

Solar pond is constructed with trapezoid cross sections, with the surface area of 1.7m^2 and depth of 0.5m as shown in Figure 1. The pond is fabricated with 1.6mm mild steel iron-sheet and it is thermally insulated by 20mm thickness of thermo styrene and 2mm thickness of High Density Polyethylene sheet.

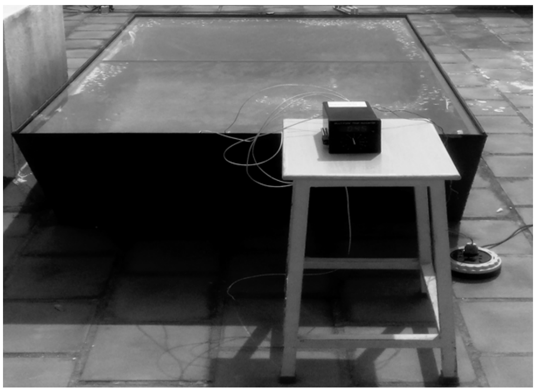

Figure1 0.85m^3 Experimental Salt Gradients Solar Pond

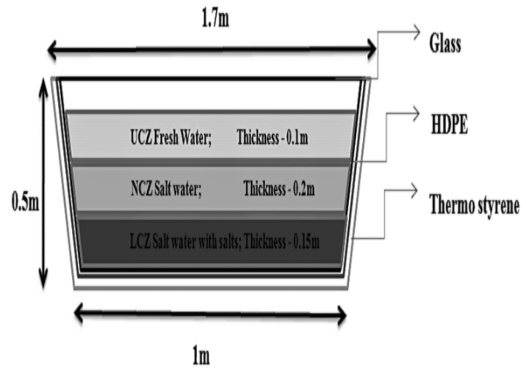

Figure2 Design and Construction of Pond

A dark color anti-corrosion paint was painted on the ponds' exterior surface. To minimize turbidity, the pond was covered with a 4mm thickness of the glass. A K-type washer type thermocouple sensor with a temperature range of 0°C to 100°C with 0.1°C accuracy is placed at 6 points spaced 5cm apart inside the pond vertically to find out the temperature variation. Another sensor is used to measure the solar radiation. The brine was prepared by dissolving a calculated amount of NaCl and table salt into salt water in a separate manner. In order to provide the salinity gradient along the height of the ponds, a small container fitted with a valve is placed outside of pond. To form LCZ salt is dissolved into salt water and taken into the container; fill the brine in the tertiary region of the pond 0.15m thickness. To form NCZ only the salt water taken into the container and fill into the second region of the pond 0.2m thickness. Finally to form UCZ fresh water was taken into the container and fills into the primary region 0.1m thickness. In this experiment, the tube was initially at the height z = 0.05 m measured from the base the brine was filled up to the level of z = 0.1m, which determine the thickness of the storage zone, the tube was raised for each 0.01m of the water surface a constant salinity distribution was obtained. Then salt water was injected when the water surface reached the level of the z = 0.35m. The thickness of the gradient zone was 0.2m in which a varying salinity gradient was through the region. After the establishment of the gradient zone, the fresh water was added to set up the surface zone. In this experiment, a period of 8 h per day was chosen [7] [8]. The charging period of the ponds were commenced from the first of December 2015. However, the values are collected between the mid of December 2015 and mid of January 2016.

III. Performance Analysis

A. Thermal Energy Efficiency

η - Efficiency

$$\eta = Q_{net} / Q_{in}$$

B. Upper Convective Zone (UCZ)

Solar energy streams through the horizontal surface of upper convective zone of the pond. Some fraction of the incident solar radiation transmitted from the UCZ to the NCZ. Some part is reflected from the UCZ surface to atmosphere and lost. The remaining rays are absorbed in the zone, for heating it [10].

$$Q_{net} = Q_{in}-Q_{out} = (Q_{solar}+ Q_{down})-(Q_{up}+ Q_{side}) \quad (1)$$

$$\eta_{ucz} = 1-(Q_{up} + Q_{side} / Q_{solar} + Q_{down})$$

$$Q_{up} = U_{up}A_{ucz} (T_{ucz} - T_{amb})$$

$$Q_{side} = U_{side}A_{side} (T_{ucz} - T_{side})$$

$$Q_{down} = K\, A_{ucz} ((T_{down} - T_{ucz})/X_1)$$

$$Q_{solar} = ßA_{ucz}\, h_1$$

C. Non Convective Zone (NCZ)

Solar energy streams through the gradient zone of the pond. Solar radiation falls on the surface of the gradient zone, this is fraction of the incident solar radiation on surface of the pond, is transmitted from the surface zone. A small fraction of the incident solar radiation on the gradient zone is reflected from the gradient zone to the surface zone. The solar radiation that is reflected from the gradient zone increases the surface zone efficiency. And some fraction of the incident solar radiation is transmitted to the storage zone while part of the incident solar radiation is absorbed by the gradient zone. A part of the incident solar radiation is absorbed by storage zone and transmitted into the gradient zone, and part of the absorbed radiation is stored in the LCZ. So, the gradient zone is heated and the zones temperature increases. Thus, a temperature gradient occurs in this zone.

$$Q_{net} = Q_{in}-Q_{out} = (Q_{solar}+ Q_{down})-(Q_{up}+ Q_{side}) \quad (2)$$

$$\eta_{ucz} = 1-(Q_{up} + Q_{side} / Q_{solar} + Q_{down})$$

$$Q_{up} = U_{up}A_{ncz} (T_{ncz} - T_{amb})$$

$$Q_{side} = U_{side}A_{side} (T_{ncz} - T_{side})$$

$$Q_{down} = K\, A_{ncz} ((T_{down} - T_{ncz})/X_1)$$

$$Q_{solar} = ßA_{ncz}\, h_1$$

D. Lower Convective Zone (LCZ)

Solar energy streams through the storage zone of the pond. After attenuation from the surface and gradient zone fraction of incident solar radiation is transmitted to the storage zone. Some fraction of the transmitted solar radiation from the gradient zone to the storage zone is reflected from the bottom, side walls and the major portion of the solar radiation is absorbed in the storage zone. So, the storage zone temperature is increased and a temperature gradient develops in the zone.

$$Q_{net}= Q_{in}-Q_{out} = (Q_{solar}- Q_{up}- Q_{side}- Q_{down}) \quad (3)$$

$$\eta_{lcz} = 1-(Q_{up} + Q_{side} + Q_{down}/ Q_{solar})$$

$$Q_{up} = U_{up}A_{lcz} (T_{lcz} - T_{amb})$$

$$Q_{side} = U_{side}A_{side} (T_{lcz} - T_{side})$$

$$Q_{down} = K\, A_{lcz} ((T_{down} - T_{lcz})/X_1)$$

$$Q_{solar} = ßA_{lcz}\, h_1$$

IV. Results And Discussions

The incident solar radiation energy flows in the inner zones of the pond are illustrated in Figures 3–18. The efficiency of the salt gradient 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). When solar radiation falls on the surface zone part of the incident solar radiation is reflected on the surface some is absorbed by the zone and part (often most) of the incident solar radiation is transmitted through the surface zone to the gradient zone. More amount of the incident solar radiation is transmitted to the gradient zone from the surface zone. Part of the incident solar radiation is absorbed by the gradient zone layers. From NCZ to the LCZ large incident solar radiation is passed and small amount of solar radiation is reflected back from NCZ to the UCZ. In LCZ more amount of radiation is stored from NCZ and while little is sent to the upper zones. During summer season the temperature is very high when compared to other months. The reason for the change is mainly due to the temperature losses from the pond to the atmosphere, absorption and reflection of the radiation on the top surface thermo physical property of the salty water. The saline density of the water in the surface zone and gradient zone will get varied considerably due to the evaporation of the water from the surface zone. By adding pure water often on the top of the pond the changes can be eliminated. In storage zone and surface zone remarkable changes takes place due to not using salt gradient protection systems. The heat losses by heat transfer from the pond during a day are determined by calculating the temperature differences for daily profiles of related months. To determine the heat losses interior side of the pond, the experimental temperature distribution profiles for the inner zones has been obtained in Figure 3. Temperature was measured at 6 points in the pond all through the day and finally it is averaged to determine the daily average temperature data. Depending on the absorbing solar radiation and the atmosphere condition the temperature is varied day by day. When the incident solar radiation per unit surface area increases the temperature in all the zones gets increased. The lower convective zone performance is significantly affected by heat losses in each zone. At an appreciable rate the heat losses to be minimized so that the efficiency and performance will increase. Regarding the experimental temperature distributions for the sodium chloride salt zones is shown in Figures 3-9.

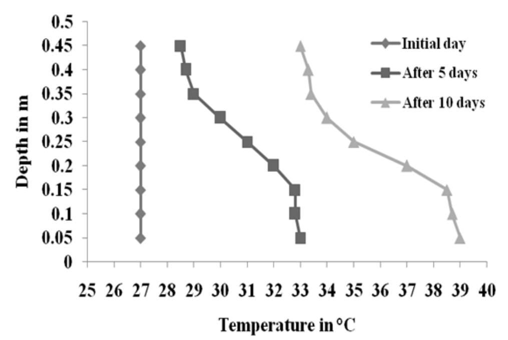

Figure3 Temperature distribution of Initial, 5 days & 10

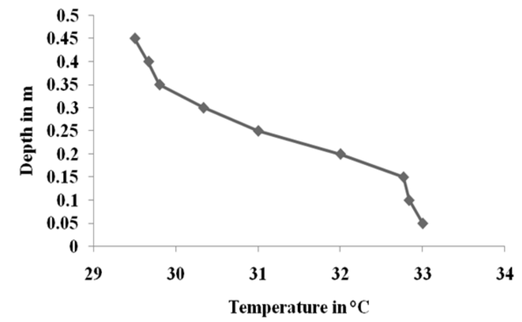

Figure4 Overall temperature distribution of pond with depth

The temperature of the UCZ is observed to be a maximum of 33°C after 10 days, and a minimum of 27°C initial day [11]. Similarly, the temperature of the NCZ is observed to be a maximum of 37°C after 10 days, and a minimum of 27°C initial day shown in Figure 14, while the temperature of the LCZ is observed to be a maximum of 39°C after 10 days, and a minimum of 27°C initial day. The UCZ efficiencies are seen in Fig. 16 to be 1.07%, 1.13% for mid of December. The NCZ efficiencies are seen to be 1.18%, 1.14% for mid of December. Shading area also has an important effect on the performance of the LCZ, for which the zone efficiencies are seen to be 1.22%, 1.1% for mid of December.

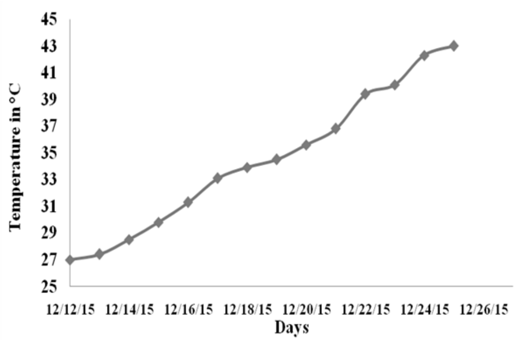

Figure5 Variation of temperature of LCZ with days

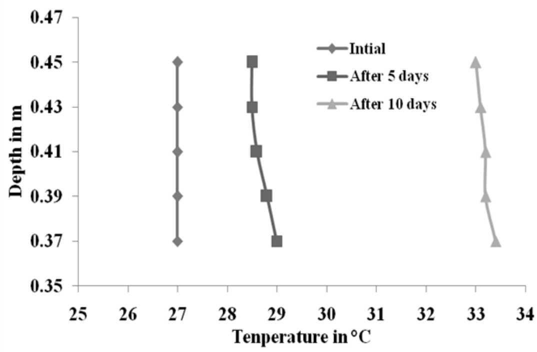

Figure6 Experimental temperature profile of UCZ

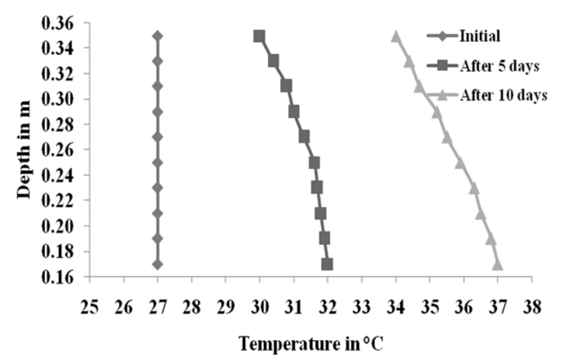

Figure7 Experimental temperature profile of NCZ

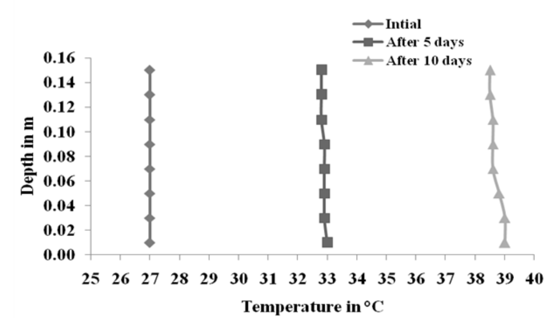

Figure8 Experimental temperature profile of LCZ

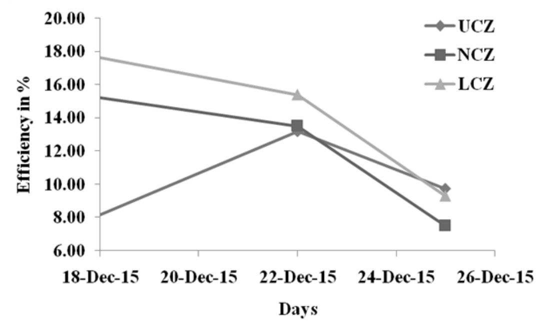

Figure9 Efficiencies of inner zones of the pond

Regarding the experimental temperature distributions for the sodium chloride salt zones is shown in Figures 10-16 for the table salt zones, the temperature of the UCZ is observed to be a maximum of 28.6°C after 10 days, and a minimum of 26°C initial day [12]. Similarly, the temperature of the NCZ is observed to be a maximum of 33.4°C after 10 days, and a minimum of 26°C initial day, while the temperature of the LCZ is observed to be a maximum of 34°C after 10 days, and a minimum of 26°C initial day. The UCZ efficiencies are seen in Fig. 16 to be 1.04%, 1.04% for mid of January. The NCZ efficiencies are seen to be 1.16%, 1.07% for mid of January. Shading area also has an important effect on the performance of the LCZ, for which the zone efficiencies are seen to be 1.19%, 1.05% for mid of January. The efficiency of the UCZ is rendered low because of the shading area rather than heat losses. Shading causes a shrink in the performance of the NCZ. A significant amount of incident solar radiation is absorbed by the LCZ and a little of the incident solar radiation is reflected from the bottom wall of the pond. Table salt the diffusivity will be high when compared to sodium chloride. The purity and other nutrients present in the table salt ill affect the perf ormance. Decreasing shading area from the top to the bottom of the pond allows less solar radiation to pass through and decreases the thermal potential of the pond and hence its performance [13]. The performance of the thermal energy storage depends upon the total radiation reaching the pond zones. The best performance of the heat storage zone can be usefully determined, by, using energy efficiencies. But in a solar pond, the stored energy is very low compared to incident solar radiation on surface of the zones, so, the efficiencies are also very low. The efficiencies are low due to the low thermal conductivity of the pond filled with salty water.

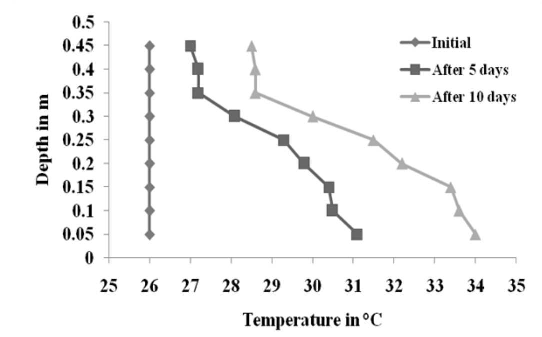

Figure10 Temperature distribution of Initial, 5 days & 10 days with depth

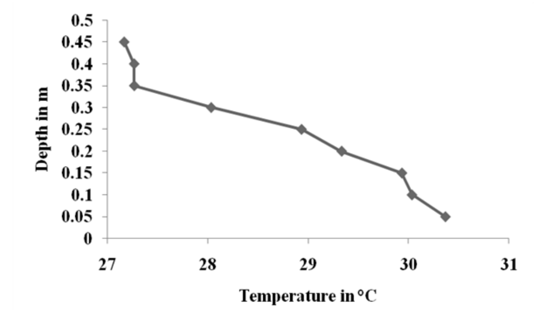

Figure11 Overall temperature distribution of pond with depth

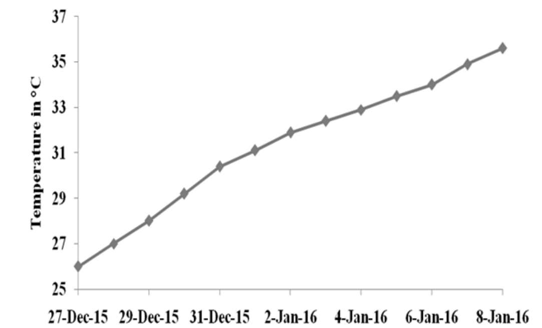

Figure12 Variation of temperature of LCZ with days

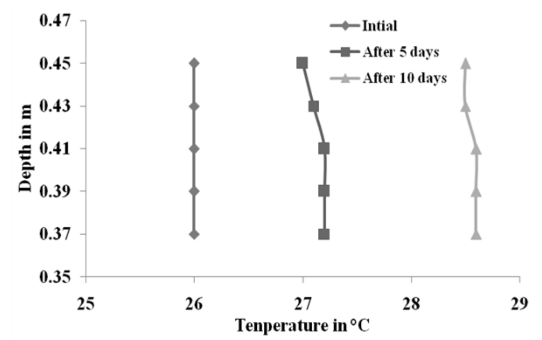

Figure13 Experimental temperature profile of UCZ

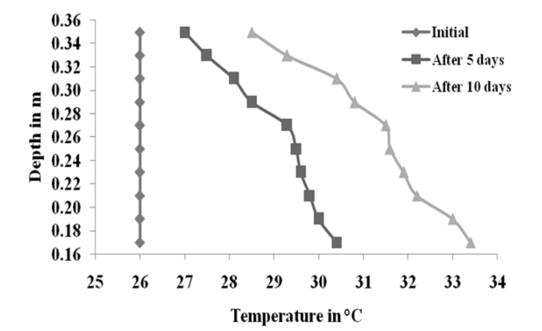

Figure14 Experimental temperature profile of NCZ

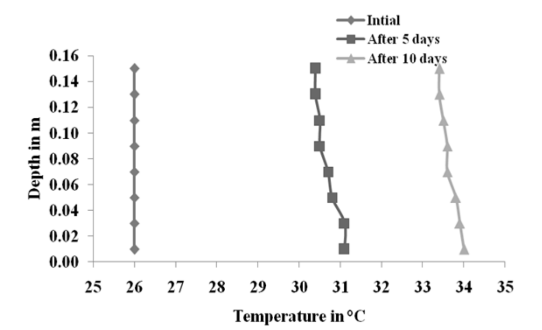

Figure15 Experimental temperature profile of LCZ

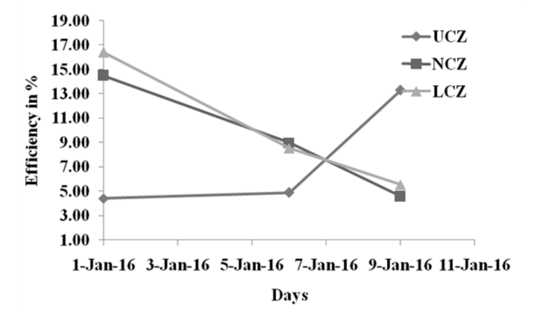

Figure16 Efficiencies of inner zones of the pond

Figures show the temperature differences of each zones of the temperature between mid of December to mid of January. The results for month of December and January have been found and compared. During day time the temperature increases in a small, and will decreases in a large during night time. Distribution of the temperature profiles for the inner zones is usually varied, affecting the zones efficiencies also. Despite the solar radiation intensity reaching the gradient zone decreases, these zones acquire lower heat losses and thus efficiency will be high compared to surface zone. Thus the temperature distributions have a significant effect on the performance of the pond [15].The experimental efficiency profiles for the UCZ, NCZ and LCZ of the pond, for different days of December and January are given in Figure 18. The top zone is upper convective zone so greatest amount of radiation will incident on it, but its efficiency will be low [14]. This is due to zone have a small thickness and its greater temperature losses to the atmosphere air from the surface area. The energy efficiency of the pond is decreased because of heat energy losses due to thermal transfer from the UCZ to air. A low fraction of the incident solar radiation is stored in the pond and the UCZ efficiency is negligible especially compared to that of the NCZ. The NCZ efficiency consequently has a greater effect on the performance of the pond. Most of the energy is stored in the LCZ of the pond. As a result, the interior regions of the pond stores more thermal energy in the month of May than other months due to the extensive temperature differences between the zones [16]. Heat losses significantly affect the thermal performance of the pond. Alter the interior zone temperatures, the diffusion of salt molecules from bottom to the top and temperature losses. From this suggest that heat storage, heat losses, shading areas and solar radiation absorption should be carefully considered when determining the thermal performance of solar ponds.

V. CONCLUSION

In this paper, a petite type Solar Pond has been designed and erected. By using this process, more amount of solar energy can be stored in storage zone and by using heat exchangers we can extract it. For this efficiencies like theoretical and experimental values are plotted in as shown in Figures 17 & 18.

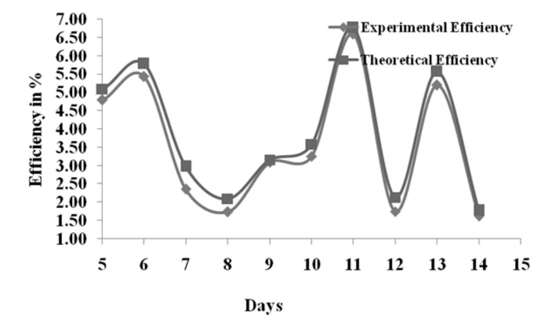

Figure17 Sodium Chloride Theoretical and Experimental Efficiency

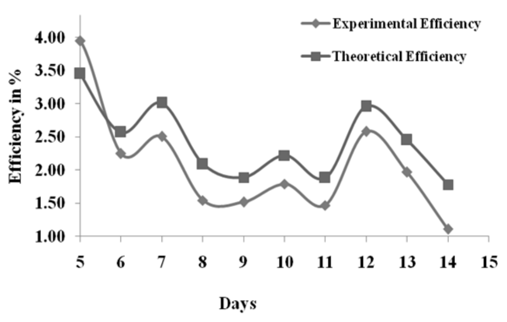

Figure18 Table salts Theoretical and Experimental Efficiency

The minimum efficiency for sodium chloride and table salt is 1.5% and 1 % and the maximum efficiency will be 6% and 4 %. To show the result of the insulated portable solar pond we carried out the efficiency calculations for each zones. Thus, from the above theoretical and experimental results the temperature rise of the solar pond for sodium chloride salt will meet more temperature when compared to table salt. This is due to the salt diffusivity property. For surface, gradient, storage zones the efficiencies have been stated using energy balance equations. The results show that pond performance is affected strongly by the temperature of the LCZ and the temperature profile with pond depth. Ponds temperature losses on the sides and the bottom of the walls will be considerably negligible due to the presence of insulation. In order to enhance the efficiency for the lower convective zone, temperature losses from surface zone, bottom and side walls, reflection, and shading areas in the gradient and storage zones should be decreased. The temperature of each layer of the inner zones depends on the incident radiation, zone thicknesses, and overall heat losses. To attain more efficiency and firmness of the pond, zones thickness should be altered according to the way. By varying the designs we can able to extract more amount incident solar radiation and the ponds' performance can be sustained. Experimental values are used to find out the efficiency of the portable solar pond. It is revealed that the introduction of the other two zones (surface and gradient zones) provides many conveniences in calculating the storage efficiency in the heat storage zone. Therefore, the energy efficiency of the inner zones of a solar pond is an important parameter in practical applications. The case study carried out in this research shows that the Salt gradient solar pond technology is ideally suited to arid and semi-arid areas where there is an abundance of solar radiation, the thermal energy from which can then be employed to generate power for desalination purposes. Thus, it can be concluded that it is a viable option, Solar Pond technology can be most cost effective, the costs involved in solar pond construction are quite reasonable given a lifespan of decades, and these ponds are on the whole ideal when specifically designed for use with desalination plants.

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