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Comparison of Thermal Storage Efficiency of Solar Pond with and without a Polyethene Membrane.

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Abstract- This paper presents the concept of using a polyethene film to address the shortcomings of the conventional solar pond which are low efficiency, short operation time among others. The thermal behavior of a solar pond with a polyethene has been analyzed and compared with that without a polyethene film. The experiments show that: the heat storage layer (LCZ) temperature rising rate was significantly higher than that of single layer porous media solar pond. The polyethene film of thickness 100µm was used. The polyethene film brings about the greenhouse effect where the solar energy that penetrates the film is trapped and improves the efficiency of the storage zone. Results show that the efficiency of a polyethene stabilized pond rises to about 69 % compared to the conventional solar pond with about 52 %.

Index Terms- Efficiency, Membrane, Polyethene, Solar pond, Thermal.

I. INTRODUCTION

Solar radiation constitutes a vast energy source which is abundantly available on all parts of the earth. Solar energy is in many regards one of the best alternatives to non-renewable sources of energy. One way to collect and store solar energy is through the use of solar ponds which can be employed to supply thermal energy for various applications, such as process and space heating, water desalination, refrigeration, drying and power generation. Thermal energy storage has always been the most significant method of energy storage. Solar ponds are a classical application of the thermal energy storage and their performance depends essentially on the storage capacity of the fluid, thermo physical properties of the pond, surroundings conditions, its thermal energy storage capacity, and on its construction and maintenance costs[1] [2]. Numerous experimental and theoretical studies have been undertaken. Most of the experimental work [3] [4] [7] concentrates on design, application, thermal measurements, efficiency and investigations of the thermal performance of various types of solar ponds of different dimensions. Many experimental studies focus on determining the efficiency of inner zones in solar ponds, and determining the zone performance that yields the best solar pond system[5][6].

The solar ponds which are conventionally referred to as salt gradient solar ponds (SGSP) consists of three distinct zones, the Upper Convective Zone (UCZ) the thinnest and which has a low and nearly uniform salt concentration. Beneath the (UCZ) is the Non-Convective Zone (NCZ) of medium thickness and has a salt concentration increasing with depth, and it is therefore a zone of variable properties. The bottom layer is the Lower Convective Zone (LCZ), also called the storage zone, which has the maximum thickness and has a nearly uniform high salt concentration. The Non convective zone (NCZ) also referred to as salt gradient zone (GZ) is the key to the working of a SGSP. It allows solar radiation to penetrate into the storage zone while prohibiting the propagation of long wave radiation because water is opaque to infrared radiation. The zone suppresses global convection due to the imposed density stratification. It offers an effective conduction barrier because of the low thermal conductivity and the zone thickness. This makes the GZ essentially a double-diffusive layer of salt and temperature. Maintaining the stability of the GZ is, therefore, crucial in its functionality.

Despite numerous studies on solar ponds, there are a number of difficulties and limitations that affect the performance of solar ponds and in some locations limit their use, many of them were recognized and several schemes for solution have been proposed to eliminate or minimize their effect. These problems include, among others, salt diffusion from LCZ to UCZ, wind mixing, evaporation, dust and dirt falling on pond surface. Some of these problems were first investigated by Tabor[8]. Weinberger[10] and Tabor[9]addressed the physics of pond's stability. Later, Hassab[11] presented a field report on a solar pond constructed in the State of Qatar. They reported the problems encountered in operating SGSPs in the Arabian Gulf region, characterized as a windy and dusty environment. Other problems are excessive erosion of the gradient zone, the formation of sizable localized convective zones, the deterioration of pond water clarity and high rates of surface evaporation. This weather related problems severely impair the pond operation and performance. The salinity in the UCZ increases due to convective mixing (wind, evaporation) with NCZ and salt diffusion from the bottom. In a typical case this diffusion amounts to about 60 tons/km^2/Day. Weinberger [10] estimated the annual rate of this natural diffusion of salts, to be in the range of 20 – 30 Kg/m^2, depending on the thickness of NCZ, the temperature profile and the concentration difference between the UCZ and the LCZ. Newell *et al.*,[4] estimated the salt transported per year from the LCZ to the UCZ for 2000 m^2 solar pond at the University of Illinois, in the range of 25 to 50 tons. Therefore, turbidity of water[12], the wall design[13], keeping of salt gradient, wall insulation as well as environment and climate will have an important impact on the solar pond performance. With these problems, LCZ temperature of the conventional solar pond is difficult to achieve a higher temperature. Since efficiency of the solar pond is measured by how much energy is stored in LCZ, increasing LCZ temperature of the solar pond has important significance.

Many innovations have been devised to improve solar pond efficiency among them is the use of multi layered porous media. The porous media solar pond is a four-layer model and added a layer of porous media at the bottom of the traditional solar pond. Porous media has a smaller thermal diffusivity with low thermal diffusion coefficient which has good thermal insulation performance. Sun Wence[14] proved that adding porous materials at the bottom of solar pond is favorable to raise LCZ temperature. Porous media is suitable to be selected as the colour black and low thermal diffusion coefficient materials, so cheap factory wastes, boiler slag [15] is a good alternative material, however adding too much boiler slag in solar pond leads to the pond not receiving enough solar radiation, resulting in a waste of porous media to a certain extent, and LCZ may not still reach the highest value. The bottom of SGSP is added two or more porous media layers, using different porous media properties to achieve the best thermal storage effect. Its advantages are that the darker porous media has strong ability to receive thermal radiation and weak ability to reflect heat radiation, which is conducive to the increase of LCZ temperature while glass balls have up to 90 % transmittance, and reflect about 8 % while absorb about 2 % [18]. Another means of improving the thermal performance of conventional SGSP is to increase the bottom surface area by making the surface corrugated wavy shaped, which increases the heat transfer capability to the fluid (water) and consequently increases the performance of the solar pond. Rubin *et al.*, [17] performed several numerical and experimental simulation of the solar pond mechanism; they eventually demonstrated that one of the most significant design modifications for increasing the solar pond thermal efficiency was the increased stability of the surface layer. The effect of the various parameters on the thermal behavior with a consideration of the stability criteria in a SGSP are studied results of the steady state indicates that the thickness of the NCZ has a significant effect on the performance of the SGSP.

Ebtism and Tac [19] discussed about the inherent problems encountered with the conventional salt gradient pond leading to the concept of the Solar Gel Pond in which the salt gradient (NCZ) is replaced by the transparent gel layer. They discussed about the relevant properties of the gel. Ebtism [20] discussed the design, construction and operation of trapezoidal 400 m^2 and 5 m deep gel pond. The pond obtained maximum temperature of 60^{0}C with optimal gel thickness of 60 cm. The concept of Solar Gel Pond is based on the presence of a Non Convective Zone to trap the solar energy. In a salt gradient pond, the variation in density as a function of salinity and temperature gives rise to the NCZ. By contrast, in the Solar Gel Pond the optical and thermal insulating properties of polymer gels are utilized in forming the NCZ. In a solar gel pond, the gel floats on the storage zone, which acts as the NCZ. At present, 3 to 8 % of salt solution is used in the storage zone to keep the gel layer to float on the top. The gel used in the upper layer comprises of 98 % water and 2 % of the appropriate polymer gel. The advantages of the solar gel pond are the elimination of evaporation and heat loss from the surface. The dirt and debris falling into the pond are retained by the surface and can be cleaned off periodically. There are only two zones, lower zone being the saline water and the gel layer floats above the salt water hence no salt gradient layers need be maintained as in the case of solar pond, leading to low maintenance requirements. If an appropriate gel is developed to float on water, then the environment hazard of salt handling can be eliminated. The salt requirements are less in solar gel pond when compared to salt gradient ponds thereby reducing cost and environmental hazard. The disadvantage is the cost of the chemicals required for making the gel is high. Experimental Collection efficiency for 0.25 m^2 model for the maximum storage temperature of 60 ^{0}C is 19.73 %. From the above investigations, the Solar Gel Pond is technically feasible and comparable to the performance of the Salt Gradient Solar Pond[21].

This study aims at improving efficiency of a salt gradient solar pond but with the use of a transparent polyethylene to separate the LCZ and the NCZ. The use of polyethylene proves to be effective because it brings in the greenhouse effect where the trapped solar energy is concentrated in the LCZ and minimizes salt and thermodiffusion. However, it must satisfy the following conditions;

- Transparent to visible radiation with very little absorption in all ranges of the solar spectrum.
- Chemically and physical stable with respect to a hot saline solution up to 100 ^{0}C or more
- Inexpensive
- High specific heat and low coefficient of volumetric expansion over the operating temperature range of the pond.
- Inert and nontoxic
- Non-degradable over repeated freezing melting cycles, and by ultraviolet radiation. Apart from that they are
- Mechanically strong and have stable structure.

The thermal performance and efficiency of a SGSP has been shown by Srinivasan [22] assuming steady state condition as;

$Q_u = Q_a - Q_e$

Where; Q_u = Useful heat extracted, Q_a = Solar energy absorbed and Q_e = Heat losses.

The thermal efficiency is defined by:

$$\eta = Q_u / I$$

Where *I* is the solar incident on the pond.

Therefore; $\eta = \eta_0 = Q_e / I$

Where $\eta_0 = Q_a / I$ = Optical efficiency of the pond.

Again, $Q_e = U_0 (T_s - T_a)$

Where T_a = Ambient temperature and U_0 = Overall heat loss coefficient

Neglecting heat losses from bottom and sides of the pond and assuming the temperature of the upper mixed layer to be the same as the ambient,

$$U_0 = K_w / b$$

Where K_w = Thermal conductivity of water and *b* =Thickness of the gradient zone.

II. MATERIALS AND METHODS

Model solar ponds rectangular in shape of dimension (0.6 x 0.4 x 0.2) m^3 were made. The walls and base were made of transparent float glass of 6 mm thick pasted with silicon. Inner surface of the glass plate were painted with matt black to absorb solar radiation. The models were insulated with saw dust of thickness 10 cm."K" type thermocouples made of Chromel alumel were used to measure the temperatures. Thermocouples were fixed at the middle of the three layers and one was used to measure the ambient temperature. A 12 channel temperature indicator was used to measure the temperature of the thermocouples with an accuracy of $\pm 0.1^0$c however a thermometer was used to confirm the values indicated by the digital thermometer. Known concentration of sodium chloride salt was used for the three zones. Mixing was carried out in order to ensure that the salt had completely dissolved in the water to obtain a homogeneous mixture. Polyethylene was used in one of the ponds to separate the NCZ and the LCZ. The polyethylene had to be suitable as it satisfied the requirement of the following properties like uniformity, specific gravity, transmissivity, cost, and resistance to corrosion and anti bacterial nature. In order to study the effect of climate and operational parameters on the performance of solar pond, experiment had to be carried on a daily basis varying the concentrations of the zones.

III. RESULTS AND DISCUSSIONS

In this section emphasis was put on thermal efficiency of the storage zone in both ponds; with a polyethene film and without a polythene film.

Temperature profile for LCZ (25 % salt) in solar ponds with polyethene and without polyethene

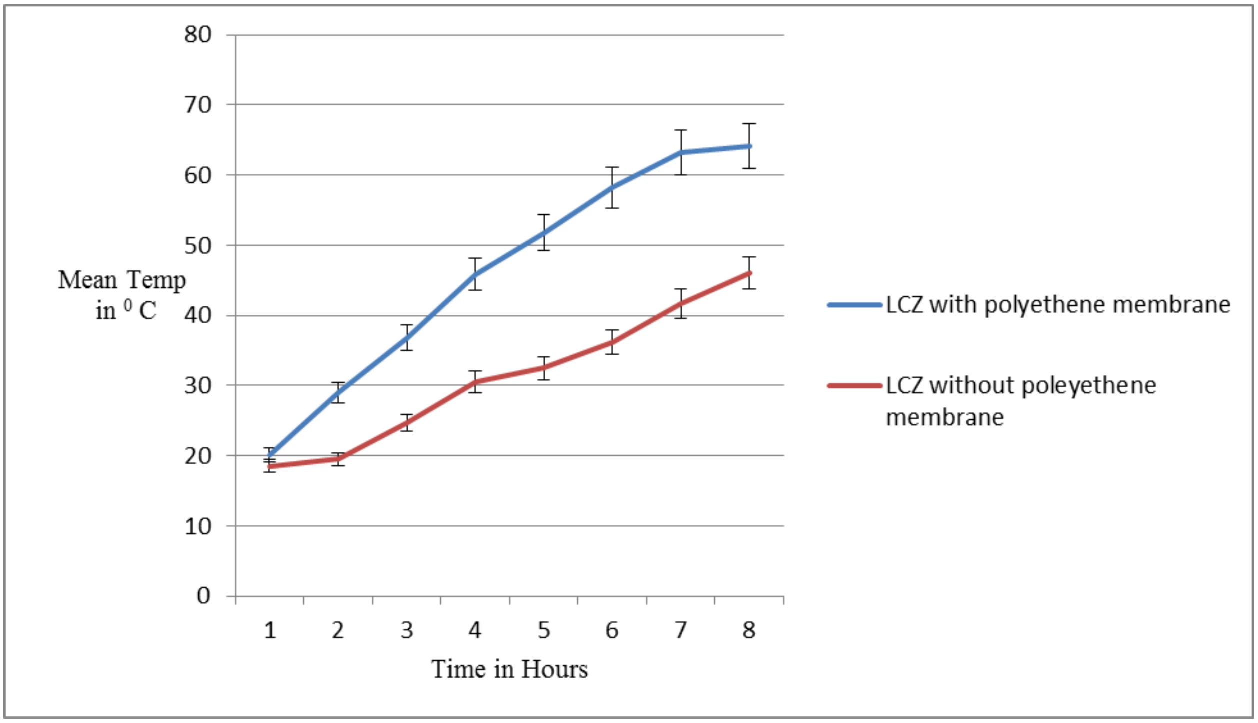

Figure 3.1 Graph of temperature profile for LCZ at 25 % salt concentration.

From figure 3.1, it is evident that a solar pond with a polyethene film as a membrane separating the LCZ and NCZ has a capacity to hold or accumulate more thermal energy as compared to a solar pond without a polyethene film. At 25 % salt concentration of the LCZ, after just 7 hours, the solar pond with a polyethene film had rose to 64.1^0C which represents 69 % efficiency as compared to that without with only 44.1^0C which is about 52 % efficiency.

Temperature profile for LCZ (20 % salt) in solar ponds with polyethene and without polyethene

Figure 3.2 gives a summary of the variation of temperature against time at 20 % salt concentration. Though the thermal storage efficiency for the two is low, it is clear that a solar pond with a polyethene film has a higher efficiency as compared to that without a polyethene film.

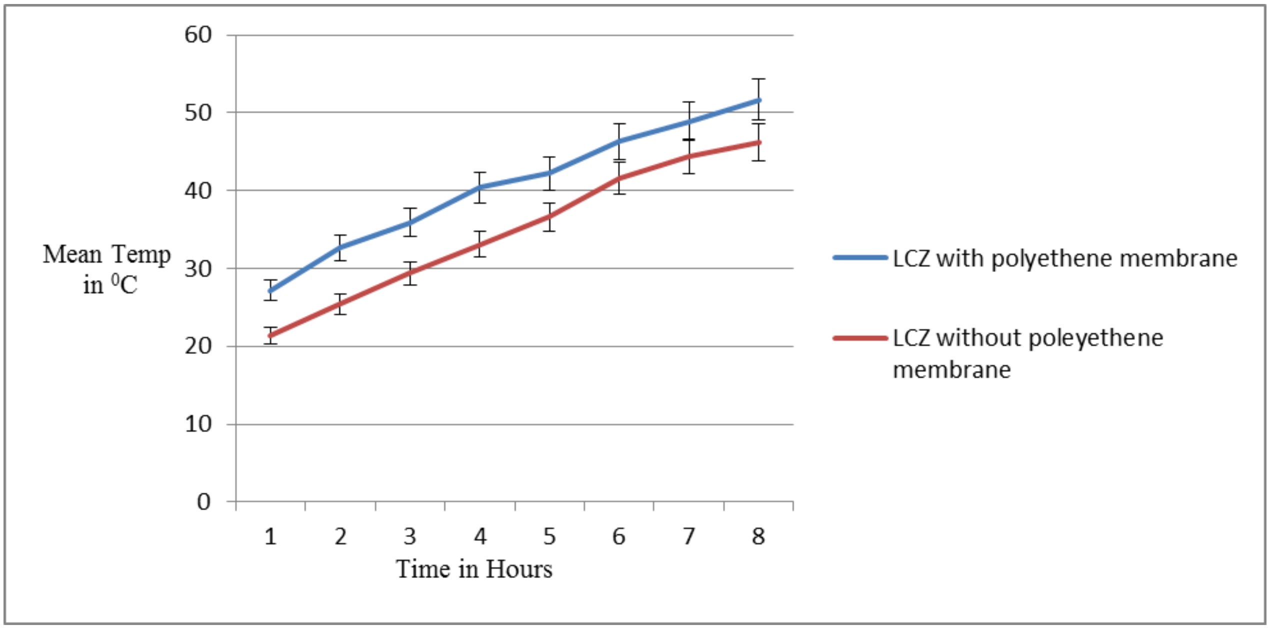

Figure 3.2: Graph of temperature profile of LCZ at 20 % salt concentration.

Temperature profile for LCZ (22 % salt) in solar ponds with polyethene and without polyethene

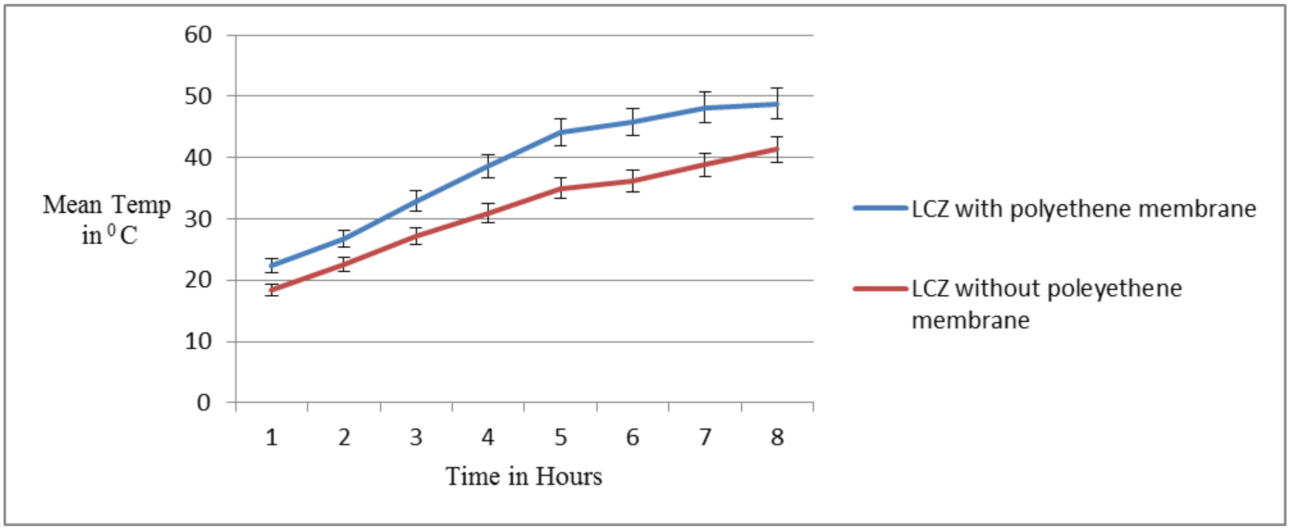

Figure 3.3: Temperature profile for LCZ at 22 % salt concentration

The graph shows the variation of temperature with time. In both cases, the variation is linear. Comparatively the solar pond with a polyethene film gains more thermal energy and thus the temperature rise is higher than that without a polyethene film.

IV. CONCLUSION

From the experimental study on the solar pond with and without a polyethene, the following conclusions can be made. Polyethene transmits solar energy and the energy is trapped in the storage zone thus heats up the zone. With respect to the concentration of the LCZ these results were obtained. It was found that, as the salinity of the LCZ increases, the temperature of the LCZ and efficiency of the pond increases. The maximum storage temperature was observed after 7 hours which was found to increase from 21^{0}C to 64^{0}C in a layer with saturated salt concentration of 25 % in a pond with a polyethene film as compared to that without polyethene at 46 ^{0}C. . The average temperature difference between storage zone and the ambient temperature was about 30^{0}C. Experimental Collection efficiency for the maximum storage temperature of 64 ^{0}C is 69 % in solar pond with the polyethene membrane and 52 % in that without a membrane. From the above investigations, the Solar Pond with a polyethene is technically feasible compared to the conventional solar pond.

NOMENCLATURE

GZ	Gradient Zone
LCZ	Lower Convective Zone
NCZ	Non Convective Zone
SGSP	Salt Gradient Solar Pond
UCZ	Upper Convective Zone

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