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Study the Performance of the Solar Ponds for Iraq Marshes

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ABSTRACT

Salt gradient solar ponds are large area, low cost devices for collection solar energy and storing it in the water as thermal energy. High salinity is maintained in the bottom layers of the pond and low salinity in the upper layers. The lower layers containing uniformly distributed brine is known as the lower convective zone (LCZ) or storage zone, and the upper layer which contains varying brine concentrations, which increases with the depth, is known as the gradient zone, or non-convective zone(NCZ), whereas the upper layer is thin and called the upper convective zone (UCZ). The incident solar radiation penetrating the pond warms the bottom layer of water. Because of its high relative density (due to its salt content), this hot water cannot rise to the low-salinity layers, thus heat is stored at the bottom. This stored energy can be removed by means of heat exchange system. This solar-heated water can be used to supply industrial process heat, or to operate heat engines using low boiling point fluids which flow into turbines to generate electrical power, also in space heating, water distillation.

This work deals with Iraqi Marshes (north of Iraq) as a solar pond. A computer model was made to simulate the dynamic behavior of the pond. Hourly data are used for solar radiation, ambient temperature, wind speed and relative humidity which have been taken from Iraqi Meteorological Organization for Iraqi Marshes. The governing heat balance equations of the pond are solved numerically, using the finite difference method, taking into account heat losses from the surface, side walls and bottom. The response of the pond to solar gain and heat losses is followed for one year. After running the computer program for different cases, the results were compared with those theoretical and experimental results available in the literature and a good agreement was achieved from this comparison.

الخلاصة

البحيرات الشمسية المتدرجة الملوجة تمتاز بمساحات كبيرة ، اجهزتها القليلة الكلفة تستعمل لتجميع الطاقة الشمسية وخزنها في الماء كطاقة حرارية، ان التركيز الملحي العالي يبقى في الطبقات السفلية من البحيرة بينما التركيز الملحي الواطئ فيكون في الطبفات العليا، تسمى الطبقات السفلية من البحيرة والحاوية على المحلول الملحي المتوزع بشكل متجانس بالطبقة الحملية السفلى او منطقة الخزن الحراري. بينما تحتوي الطبقة التي فوق الطبقة الحملية السفلى على محلول ملحي ذو تركيز متغبر يتزايد مع عمق البحيرة وتسمى هذه الطبقة بالمنطقة المتدرجة او الطبقة اللاحملية، في حين تكون الطبقة العليا من البحيرة ذات سمك قليل وتدعى بالطبقة الحملية العليا.

يقوم الاشعاع الشمسي الساقط الذي ينفذ في البحيرة بتسخين الطبقة السفلى من الماء ولان الطبقة الحملية السفلى ذات كثافة عالية نسبيا بسبب محتواها الملحي العالي فان الماء الساخن لا يمكن ان يرتفع فوق الطبقات ذات التركيز الملحي الاقل، وعلى هذا الاساس فان الحرارة تبقى مخزونة في قعر البحيرة. الطاقة الحرارة المخزونة يمكن ان تسحب بواسطة منظومة تبادل حراري ويمكن ان تستخدم هذه الطاقة في تجهيز حرارة العمليات الصناعية او لتشغيل المحركات الحرارية التي تستعمل سوائل (درجة غليانها منخفضة) تجري في التوربينات لتوليد الطاقة الكهربائية، وكذلك تستخدم في التدفئة المركزية وتحلية المياه.

هذا العمل يتعامل مع الاهوار العراقية كبحيرات شمسية وتم بناء برنامج حاسوبي لمحاكاة او لتحليل الاداء الحراري لهذه البحيرة، معادلات التوازان الحرارية حلت عدديا باستخدام طريقة الفروق المحددة، حيث اخذ بنظر الاعتبار الفقدان الحراري من سطح البحيرة والجدران الجانبية والقعر. اجريت هذه المحاكاة لمدة سنة واحدة، استخدمت في هذا العمل معلومات الارصاد الجوية لكل ساعة حيث احتوت هذه المعلومات على كمية الاشعاع الشمسي الساقط ودرجة حرارة الجو المحيط وسرعة الرياح والرطوبة النسبية.

تم تشغيل البرنامج لعدة حالات مختلفة وتمت مقارنة النتائج المستحصلة من العمل الحالي مع النتائج النظرية والعملية المتوفرة، فاظهرت توافق جيد.

1 INTRODACTION

The stratified densification in a salt gradient solar pond is achieved by dissolving a salt in water at different concentrations along the depth of the solar pond which is divided into three zones viz., upper convective zone, gradient or non-convective zone and lower convective or storage zone. The upper convective zone acts as a sacrificial layer while the non-convective zone behaves as an insulating layer for the lower convective zone through which the useful heat is extracted. The solar radiation penetrating the pond is absorbed in different layers and causes the temperature rise. The thermal convection is suppressed because of the unfavorable density gradient and hence the bottom layers remain hot the only possible loss is by conduction and water being bad conductor of heat, the loss from LCZ is minimum to the upper layers.

2 LITERATURE SERVAY

The concept of solar lake was first proposed by Kaleciusky who found that Madre lake in Transylrania was showing a maximum temperature of 70 C° at depth of (1.32 m) at the summer end. This followed the identification of similar solar natural lakes in other

parts like Orovilro in Whoshington state [*Anderson, C. G. 1959*], Vanda in Antarctic [*Wilson, A. T. and Wellmann, H.W. 1962*] and Eilat in Israel [*Cohen, Y., et al. 1977*].

The idea of creating artificial solar ponds was proposed by Dr. Rudolph Bloch in 1954 and a research director of the deal sea works suggested the study of solar lakes with a view to word practical utilization. It was expected that higher temperature and useful collection efficiencies could be achieved in artificial pond. Experiments with small (1200 m) ponds, temperatures greater than 103 C° were measured & collection efficiencies of grater then 15 percent for extraction at 70 C° to 90 C° was achieved [*Tabor, H. and Weinberger, Z. 1981*].

[*Usmanov, et al. 1971*], studied the optical characteristic of magnesium chloride solutions. [*Eliseev, et al. 1971*] investigated theoretical methods of calculating the heat regime of solar ponds.

The performance of ground storage beneath a solar pond was investigated and also a computer simulation predicting the performance was carried out by [*Akbarzadeh, A. and Ahmadi, G. 1980*]. The maximum temperature rise for no heat removal is 154 C°, then decreases to 116 C° for 40 percent heat removal from the pond.

[*Haider, H. A. 1994*] in 1994 studied the influence different parameters on the thermal characteristics of solar ponds from which valuable results have been obtained.

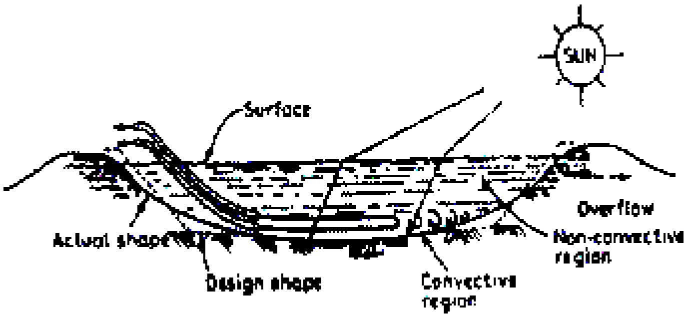
[*Abdul-Jabbar, A. 1996*] in 1996 studied the investigation of solar pond capability in providing space heating for residential buildings in Baghdad. A computer model program has been developed to analyze a solar pond thermal performance under realistic weather and energy extraction conditions. The results show that solar ponds could be used in this region for a space heating.

[*Banibal, N. J. 2000*] studied the performance of the solar ponds for the middle region in Iraq. Experimental model was built by scale (1:10) for circular pond and the sidewalls for the pond with slop 30° with horizontal at the bottom there is concrete. The model was operating at July, August and September at Baquba city. The following obtained results increase the heat storage capacity by putting concrete layer at bottom of the pond. The thermal energy stored in the bottom is homogenous.

[*Ramakrishna, G. R., et al. 2002*], solar ponds are studied for relevance in India Agriculture from the viewpoints of application process and operational parameters.

During the seventies when the oil crisis occurred and also later through the eighties, much research and development was done on the potential of using a solar pond as an alternative power-generating source, [Fig.(2) and (3)]. But due to the continuous low price of oil, there has not been much development in the solar pond technology since then Fisher, 1999[*Fisher, U. 1999*].

They shows that solar ponds can have a significant role in paddy processing, sugarcane treatment, vegetable processing and doing plants a part from meeting the domestic hot water requirements.



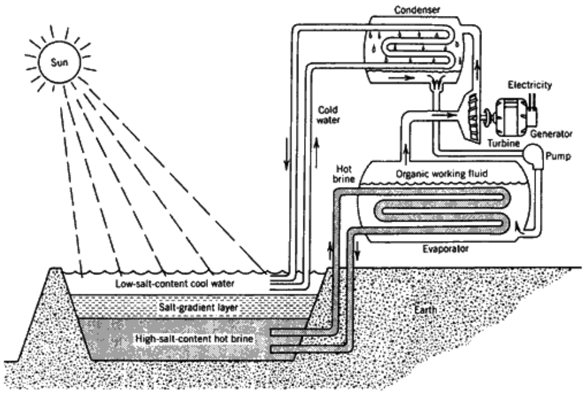


Fig 1. Non-convecting salt pond cross section "Prootototype economic"

Figure 1 Non-convecting salt pond cross section "Prototype economic"

Figure 2 Electrical power production concept using salt-gradient ponds [*Lin, E.I. (1982)*]

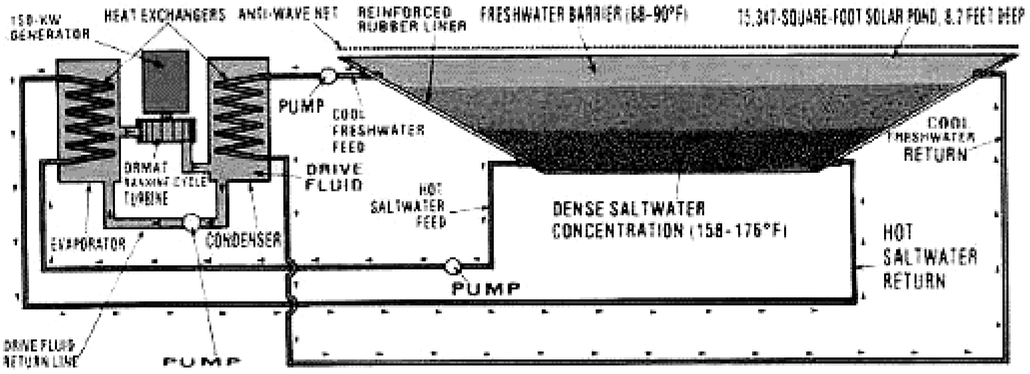


Figure 3 Israel's 150-KW solar pond

3 THEORATICAL ANYLYSIS

3.1 STABILITY OF GRADIENT ZONE

Salt constitutes the major and most expensive component of a solar pond; thus the knowledge of salte gradient requirement and the technology to establish and mountain is required for efficient pond operation.

In the solar pond the density (ρ) of the fluid is a function of salt concentration, so and temperature (T). In case of pond stability against vertical convection, the magnitude of the salt density gradient $(\partial\rho/\partial s)$ due to salt concentration gradient $(\partial s/\partial x)$ must be greater than the negative density gradient $(\partial\rho/\partial T)$ produced by temperature gradient $(\partial T/\partial x)$.

Considering x-axis along the vertical direction and measuring positive downwards the equilibrium state can be expressed as Fig. (5).

$$\frac{\partial\rho}{\partial s}\frac{\partial s}{\partial x}\geq-\frac{\partial\rho}{\partial T}\frac{\partial T}{\partial x} \qquad \text{……… (1)}$$

$$\frac{\partial s}{\partial x}\geq\frac{\alpha}{\beta}\frac{\partial T}{\partial x} \qquad \text{……… (2)}$$

When $\alpha=-(1/\rho)(\partial\rho/\partial T)$ is the thermal expansion coefficient and $\beta=(1/\rho)(\partial\rho/\partial s)$ is the salt expansion coefficient.

Equation (2) gives the "static stability" criterion

$$(\Delta s)_{\min}=\frac{\alpha\Delta T}{\beta} \qquad \text{……… (3)}$$

Denotation the minimum concentration difference required for the fluid to be stable against vertical convection occurring due to temperature difference between these points [*Tiwari, G.N. and Ghosal, M.K. 2005*].

To determine the stability coefficient the properties of solution must be known. Some properties of sodium chloride solution (NaCl) as a function of temperature.

Equation (3) may be written as :

$$\frac{(\Delta s)_{\min}}{\Delta T}=\frac{\alpha}{\beta} \qquad \text{……… (4)}$$

Where $(\Delta s)_{\min}$: is the concentration difference between layer (LCZ) & surface layer (UCZ).

ΔT : is the temperature difference between bottom layer and surface layer.

$\frac{\alpha}{\beta}$: the stability coefficient, following (for this work), the value of stability coefficient is 0.118 (% by weight/C°) [*Haider, H.A. 1994*], the salt concentration at top layer (LCZ) is taken to be 1% by weight at the bottom layer the concentration is 20% by weight [*Wang, Y. and Akbarzadeh , A. 1982*]

For the value above

$$\frac{\alpha}{\beta}=\frac{19}{70}=0.271$$

Therefore the pond operated under stable conditions

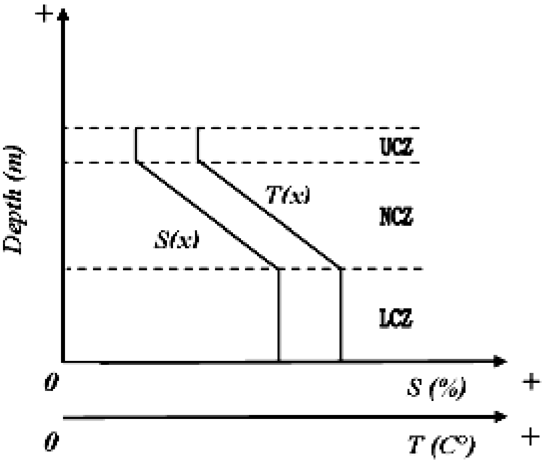


Figure 4 Schematic diagram of concentration and temperature profiles of the solar pond

3.2 MODEL DEVELOPMENT

3.2.1 Calculation of the Total Average Solar Radiation Incidence Arrived to SP Surface.

The calculation of the monthly average total radiation for horizontal surface (SP surface), from the equation below (5) [*Tiwari, G.N. and Ghosal, M.K. 2005*].

$$\frac{\overline{H}}{H_\circ} = a + b\left\{\frac{\overline{n}}{\overline{N}}\right\}$$ **……… (5)**

a and b, constant, there value depend upon the location, Al-Nasiyah located at 31°05 latitude and 47°17 longitude so that the value of a and b calculate from the equations. (6) And (7) receptivity.

$$a = -0.110 + 0.235\cos\phi + 0.325\left\{\frac{\overline{n}}{\overline{N}}\right\}$$ **……… (6)**

$$b = 1.449 - 0.553\cos\phi - 0.694\left\{\frac{\overline{n}}{\overline{N}}\right\}$$ **……… (7)**

From the metrological data for monthly average daily data for year's 2005, the actual sunrise hour for Al-Nasiryah location is calculated from the equation (8)

$$N = \frac{2}{15}\cos^{-1}(-\tan\phi\tan\delta)$$ **……… (8)**

δ**, represents the sun declination angle which values obtained from the table (1), based on the equation (9)**

$$\delta = 23.45\sin\left(\frac{360}{365}\right)$$ **……… (9)**

$H_\circ$ **Calculation from the equation (10) as below**

$$H_\circ = \frac{24\times3600}{\pi} I_{sc}\left[1 + 0.033\cos\frac{360n}{365}\right]\times\left[\cos\phi\cos\delta\cos\omega_s + \frac{2\pi\omega_s}{360}\sin\phi\sin\delta\right]$$

……… (10)

Where I_{sc} **constant and equal to 1367 W/m^2**

ω_s**, calculated from equation (11)**

$$\omega_s = \cos^{-1}(-\tan\phi\tan\delta)$$ **……… (11)**

***Table 1 Recommended average days for months and values of n by months,* [Diffie, J.A. and Beckman, W.A. 1991]**

Month	n for ith day of month	For the average day of the month		
		Date	Day of year (n)	Declination
January	I	17	17	- 20.9
February	+ I	16	47	- 13.0
March	31 + I	16	75	- 2.4
April	59 + I	15	105	9.4
May	120 + I	15	135	18.8
June	151 + I	11	162	23.1
July	181 + I	17	198	21.2
August	212 + I	16	228	13.5
September	243 + I	15	258	2.2
October	273 + I	15	288	- 9.6
November	304 + I	14	318	-18.9
December	343 + I	10	344	- 23.0

3.2.2 The Solar Radiation Transmutation Behaviors through SP Zones.

The surface of lake reflects apart of incidence radiation and that depends on the incidence angle which called zenith angle (θ_Z), and this ability is called albedo (*a*), the solar radiation quantity below the surface lake evaluated from the equation (12),

$$H_S = (1-a)\overline{H}_{\circ} \qquad \dots\dots\dots (12)$$

In this paper the value of (*a*) assumed to be constant [*Sukhatme, S. P. 1984*].

At any depth from the lake surface the solar radiation calculated from the equation below.

$$H(x) = H_S(1 - f)\exp(-\mu z)$$ **… … … (13)**

Where *z* , represent the length of path of solar radiation through the layer and

$$z = (x - \delta)\sec\theta_r$$ **… … … (14)**

δ , small distance from the surface, which is assumed to be equal to 0.06 m [*Jashi, V., et al. 1984*]

The zenith angle, which represent the incidence angle on the surface calculated from the equation, (15)

$$\cos\theta_i = \cos\theta\cos\delta\cos\left(\frac{2\pi t}{24}\right)\sin\delta\sin\phi$$ **… … … (15)**

$$n_{air}\sin\theta_i = n_{water}\sin\theta_r$$ **… … … (16)**

3.3 ENERGY BALANCE FOR SP ZONES

The energy balance equation for UCZ is represented as below, Fig. (5),

$$\rho c p \mathrm{X}_{UCZ}\frac{\partial T}{\partial t} = \phi_I + \phi_K - \phi_{TS} - \phi_{WD}$$ **… … … (17)**

The first term on the R.H.S. represents heat effect of the solar radiations absorbed in UCZ. The second term represent, heat transfer by conduction from the layer below it. Third term represents losses due to convection, radiation and evaporation from the surface. Finally the forth term represent losses due to conduction with surrounding soil [*Sonntag, R.E., et al. 2003, Moran, J.M. and Shapiro H.N. 2004*].

The energy balance equation for NCZ

$$\rho c p\frac{\partial T}{\partial t} = \phi_{KN} - \phi_{IN} - \phi_{GN}$$ **… … … (18)**

The first term on the R.H.S. represents thermal conduction from layer below, The second term represents, solar radiation effect and third term represents losses due to surrounding soil by conduction [*Sonntag, R.E., et al. 2003, Moran, J.M. and Shapiro H.N. 2004*].

The energy balance equation for LCZ as below

$$\rho c p \mathrm{X}_{LCZ}\frac{\partial T}{\partial t} = \phi_{IL} + \phi_{KN} - \phi_{GL} - \phi_{LG}$$ **… … … (19)**

Where the first term on the R.H.S. represent solar radiation effect, second term represents, the heat transfer by conduction to the upper zone. Last two terms represent losses due to ground and sidewall surface [*Sonntag, R.E., et al. 2003, Moran, J.M. and Shapiro H.N. 2004*].

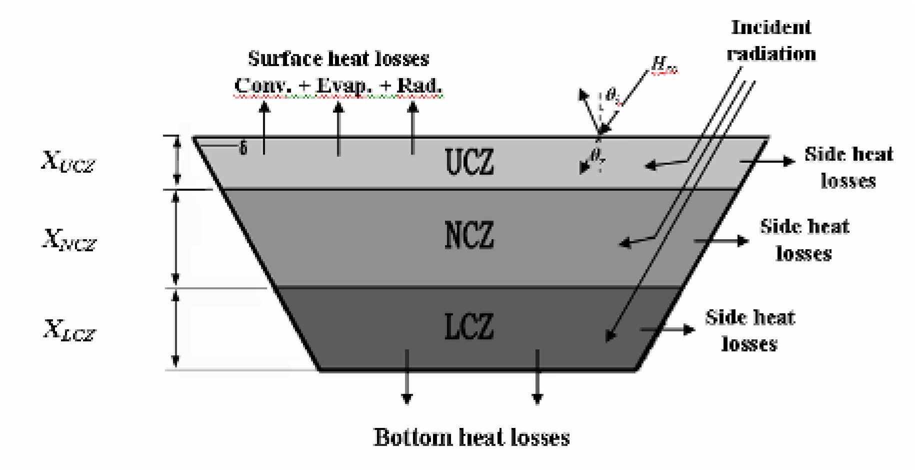


Figure 5 A schematic diagram of solar pond showing gains and heat losses

3.4 SIMULATION OF THE PERFORMANCE OF A SOLAR POND

The performance of a SP, which uses solar energy as the heat source, is affected by the weather conditions prevailing in the SP site. Among the meteorological parameters, which affect the performance of SP, are the solar radiation, ambient temperature, wind velocity and humidity. A weather data file was created using the measured data covering the period of the year of 2005, and used as in input in the computer model. Figs, (7), (8), (9) and (10) shows the profile development of meteorological data for Al-Nassriyah City. In order to simulate the operating performance of such SP to some degree of accuracy, a computer-based program is indispensable. One-year simulation of SGSP operation was done for Al-Nassriyah. Al-Nasiryah lies approximately on the 31°05 latitude and 47°17 longitude. Furthermore, the information about the depth of the pond, the physical properties of brine must be provided. In the simulation, the normal UCZ thickness was taken to (0.1m), the NCZ (1.2m) and the LCZ (1m). The NaCl is the assumed salt in the model and all physical properties of NaCl solution are treated as functions of salinity and / or temperature. The thermal conductivity of the ground was assumed to be 0.59 W.m^{-1}C^{-1}.

Using the numerical method of the finite difference [*James, B.B., et al. 1985; Rama, B.B. and Chakraverty S. 2004*] does the simulation of the transient behavior of the SGSP. The LCZ and the UCZ are assumed two distinct layers and the NCZ is divided into N

uniformly layers of equal thickness Fig. (6)The salinity and temperature at the node i in the NCZ is obtained from those at the adjacent nodes by a fully implicit discretisation_of equations (16), (17) and (18) using the technique described by Patankar.

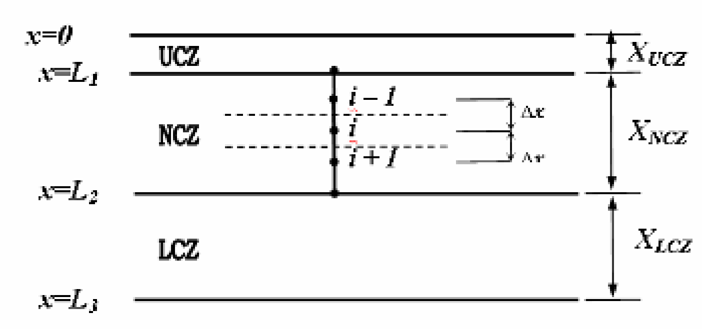


Figure 6 The physical structure of the coordinate system of the model solar pond

4 RESULTS AND DISCUSSIONS

Results were obtained from the simulation of the operation of during a period of one year. Calculation starts on the 1 January, assuming uniform initial temperature field throughout the SP. The initial salinity of the UCZ and the LCZ are equal respectively to 10% and 20% per weight. A space step $\Delta x = 0.1$m has been selected with a time step $\Delta t=1$ hr.

By using the Finite Difference Method, the equations of the mathematical model have been solved for each layer for limited period that begin from January 2005 and with 10 hours sunrise.

Through the informational available to temperature degree of the area and by using the equations (5) to (11), the solar radiation falls on the horizontal surface has been counted and this information is entered to a computer program.

Figs. (7), (8), (9) and (10) Show the distribution of the wind speed, solar radiation, average air temperature and average of relative humidity in the studying area and for one year 2005.

Figs. (11) and (12) show the temperature gradient at LCZ increasing with time, this profile agreement with physical of solar pond and also shown a good agreement with experimental solar pond, [*Hassab, et al. 1989; Kurt, et al. 2000 & 2005*].

Fig. (13), shows the concentration profile of the model, which are obtained from the numerical solution of mass diffusion governing equation, the concentration profile is quantitatively and qualitatively in good agreement with respect to physics of solar pond concentration gradient [*Kurt, et al. 2000 & 2005*].. According to the results it has been say that concentration differences between the UCZ and LCZ should be at least 216 kg/m^3 of NaCl concentration develop the desired pond.

In general, the variation of the storage zone temperature was studied over a period of the one year and the results are shown in Figs. (14) to (18). The storage zone temperatures reached peaks of 142 C°, 135 C°, 148 C°, . . . , and 145 C° around the end of September in the one year of the simulation. The increase in temperature in the next months of the simulation are due to a decrease in heat losses from the pond to the soil surrounding the pond, and accumulated heat during the next months.

Our possible shortcomings of the results presented in Figs. (14) to (18) are that the temperature at the bottom of the pond exceeds the boiling point of water at atmospheric pressure which is not possible in actual solar ponds. It is clear that in a real solar excessive heat must be removed as a useful heat for various applications in order to prevent the brine from boiling, since it will destroy the salt gradient and as a result the insulating non-convecting layer.

The results shown in these figures are similar to theoretical results found in the literature [*Hadidy, et al. 1981*].

The results are plotting in Fig. (14), it may be seen that a thicker bottom convective layer reduces the temperature fluctuation due to its greater heat capacity. The maximum temperature of the LCZ varied inversely with its depth because the absorbed radiation energy in the deeper storage zone heats a larger volume of brine per unit surface area than in case for the shallow LCZ. In addition, increasing the depth of the LCZ caused some delay in the time at which its maximum temperature was achieved.

The results are shown in Fig. (15) indicate effect of the thickness of the non-convective zone on pond performance, when the thickness of the NCZ decreases, the temperature of the storage zone increases through one year.

Fig. (17) shows the effect of 0.1 m styrene foam insulation on the performance of the solar pond. The addition of this 0.1 m styrene foam insulation at the bottom of the solar pond increases the bottom temperature by 13 C°. Another advantage of the bottom insulation to prevent the leakage of the salt solution into the salt surrounding the pond.

Fig. (18) shows the effect of the sloping side wall angle on the storage temperature. When the angle of the wall, with the horizontal line, decreases causes increasing the temperature of the storage zone due to the reducing

shading of the storage zone and due to reducing the volume of the pond at constant surface radius and total depth.

Fig. (19) shows that the circular shape gives higher temperature than rectangular shape. The circular shape has minimum lateral area leading to minimum side wall heat losses to the soil surrounding the pond.

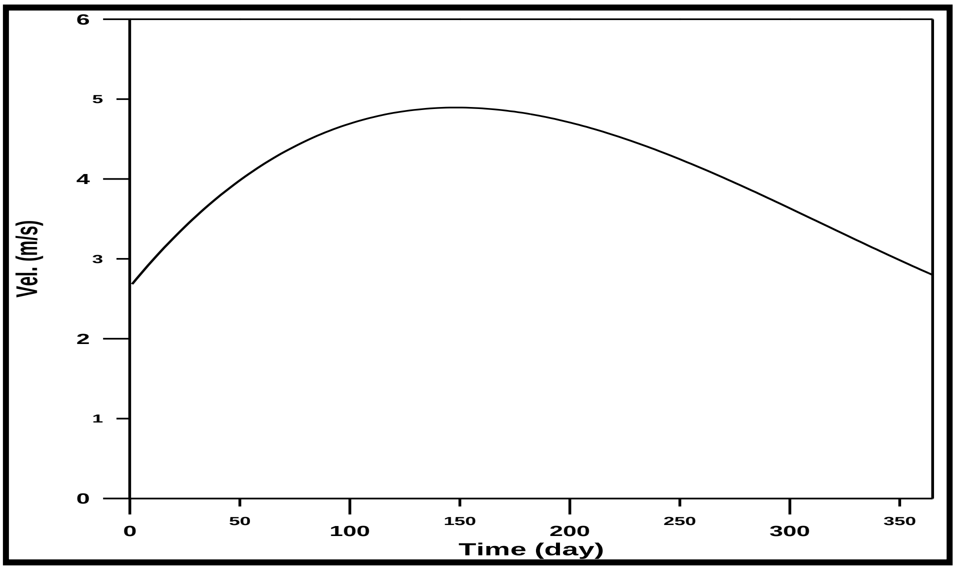


Figure 7 The daily average of wind speed based 2005.

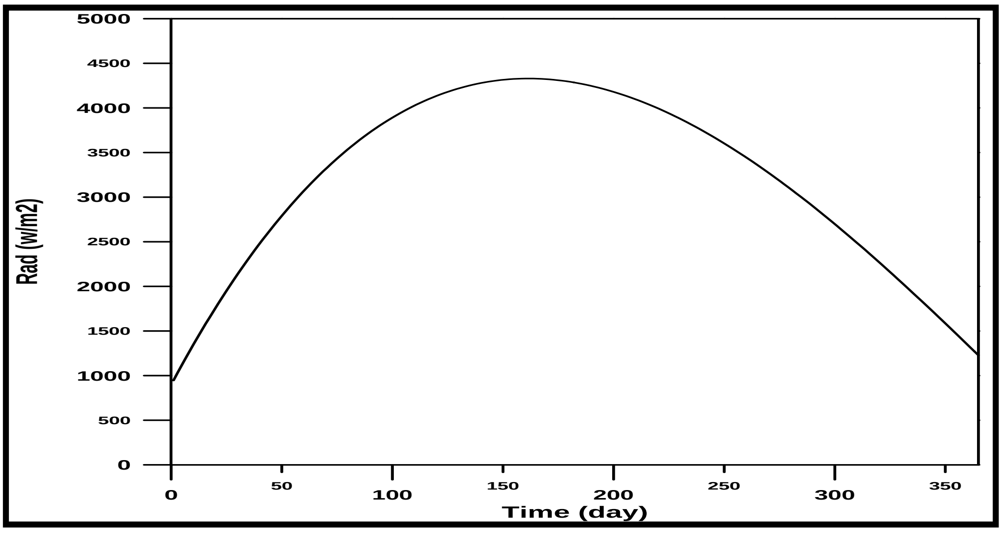


Figure 8 The daily average of solar radiation based 2005.

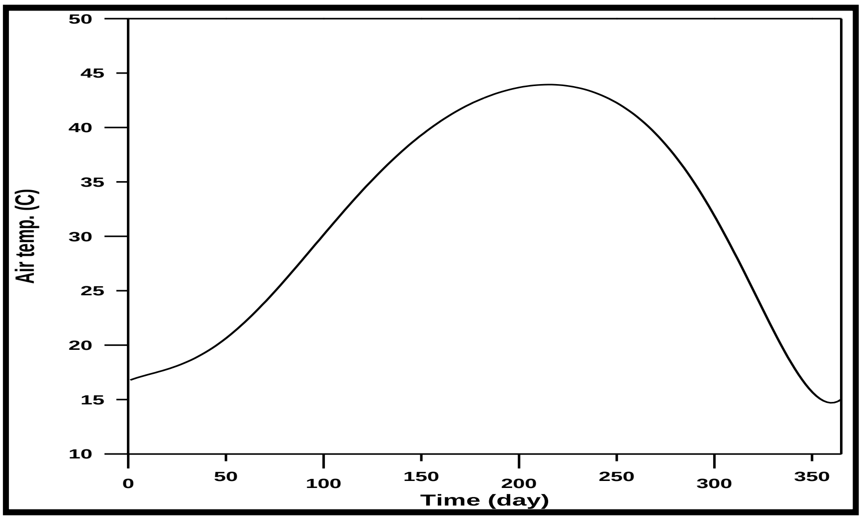


Figure 9 The daily average air temperature based on 2005.

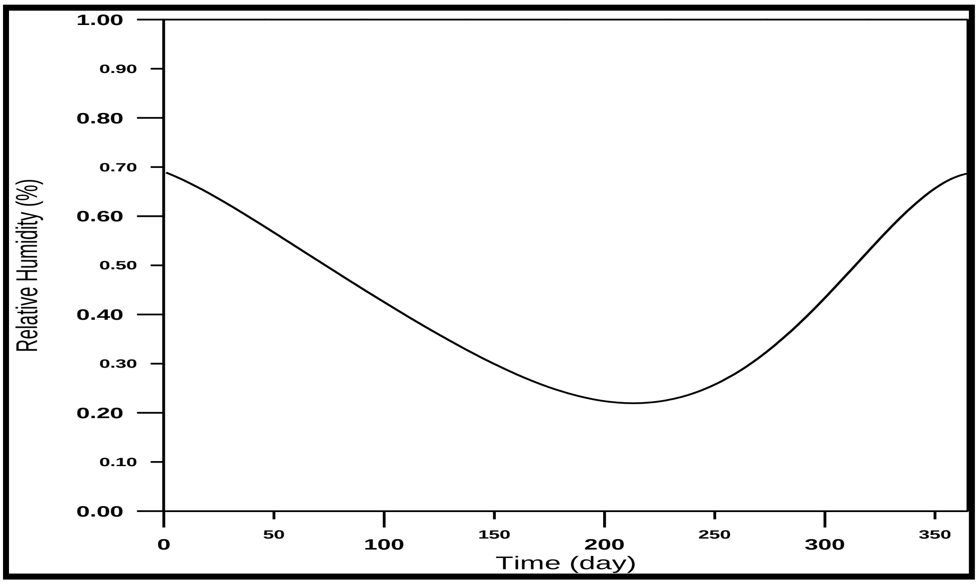


Figure 10 The daily average of relative humidity based on 2005.

Figure 11 The pond temperature distribution on 28 April 2005

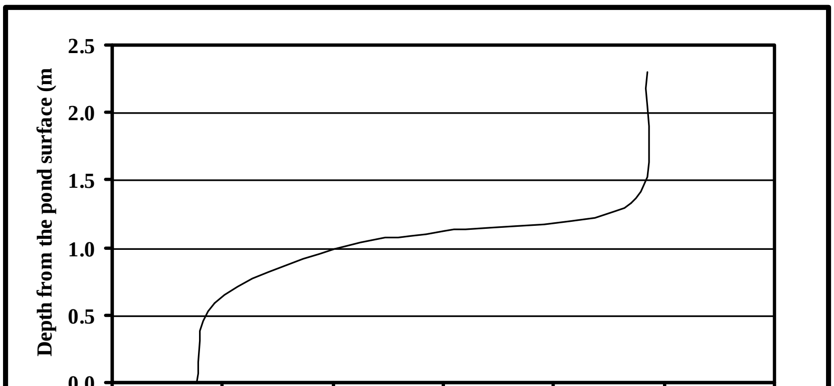


Figure 12 The pond temperature distribution for one year, 2005.

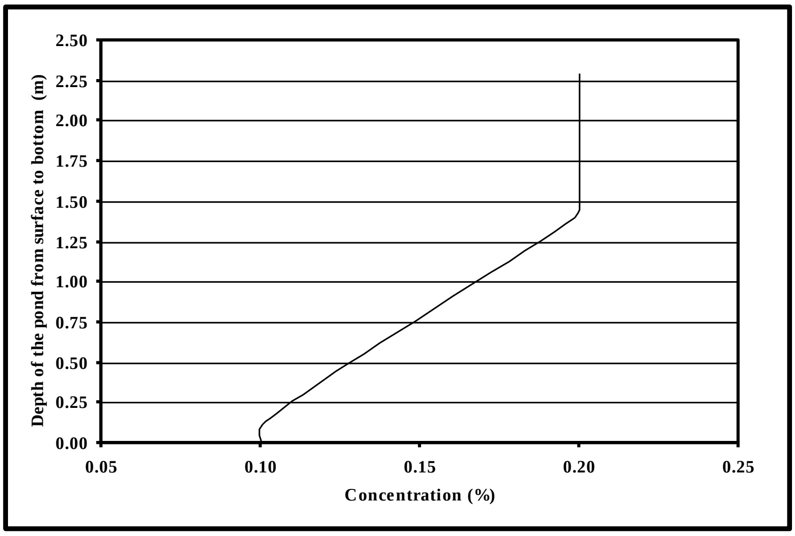


Figure 13 The pond concentration distribution on 28 April 2005

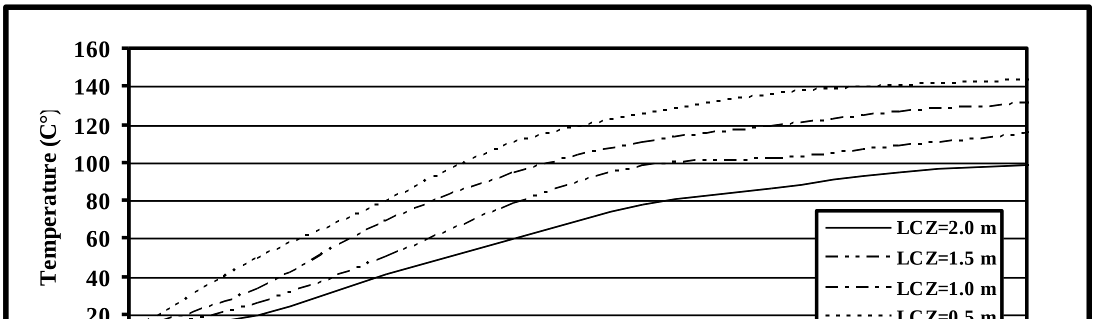


Figure 14 Variation of the storage temperature with variable depth of LCZ

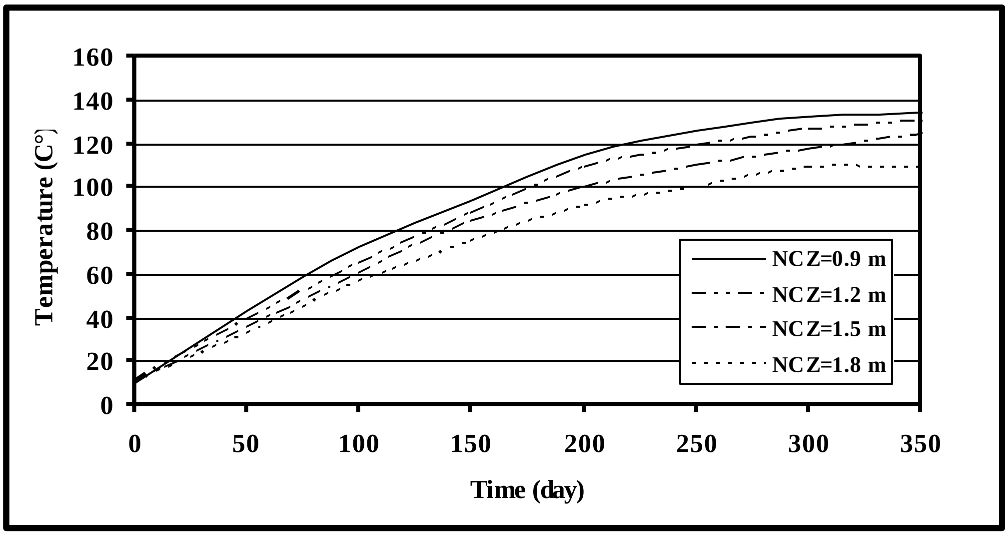


Figure 15 Variation of the storage temperature with variable depth of NCZ

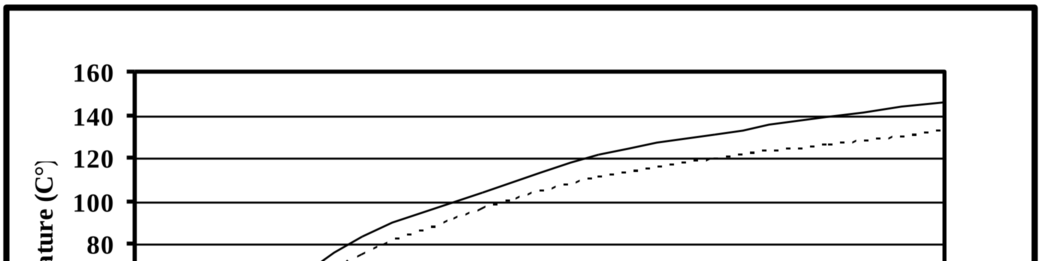


Figure 16 Variation of the storage temperature due to bottom insulation

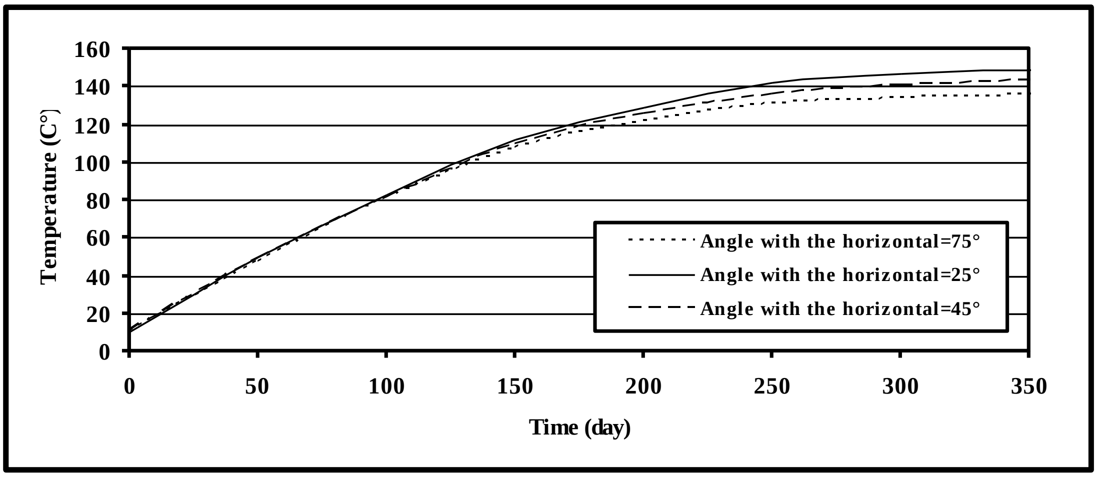


Figure 17 Effect of the sloping wall angle on the storage temperature.

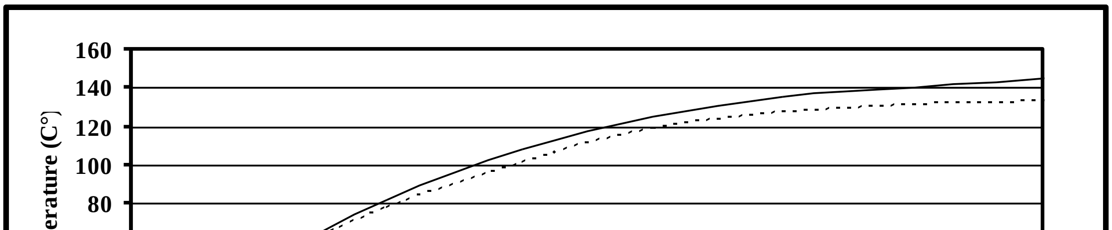


Figure 18 Variation of the storage temperature due to pond shape.

5 CONCLUSIONS

The solar ponds are reliable solar collectors for production of hot water year round. As can be seen, the temperature at the bottom rises rapidly and the warm up period is no more than tow months. Heat should be extracted from the pond to an extent that boiling does not occur which would disturb the salt concentration gradient.

The pond bottom temperatures are strongly dependent on the extinction coefficient of water used. Maintenance of high transparency in operational solar ponds should dramatically improve pond temperatures.

A solar pond with a relatively thick storage zone has a higher collection and storage efficiency (lower heat losses) and is able to store a larger quantity of heat for longer periods of time. However, the maximum temperature is lower. This makes deeper ponds more suitable for lower temperature applications such as space heating or as a heat source for heat pumps. The storage zone increases the maximum available temperature. Higher temperatures are required for electricity generation. However, heat losses are higher and storage periods are shorter.

The thickness of the gradient zone is also important. A thinner non-convective zone increase the amount of solar radiation which reaches the storage

zone, but reduces the amount of insulation which the NCZ provides leading to greater heat losses.

The sloping walls and a circular plan section may be a desirable design feature to minimize pond effects and side wall heat losses in smaller ponds. The circular shape maximizes volume per unit wall area.

6 REFRENCES

1. **Abdul-Jabbar, A. (1996), "An Investigation of Solar Pond Capability in Providing Space Heating for Residential Building in Baghdad", M. Sc. Thesis, University of Baghdad.**
2. **Akbarzadeh, A. and Ahmadi, G. (1980), "Computer Simulation of the Performance of a Solar Pond in the Southern Part of Iran", Solar Energy, Vol. 24, Pp.143-151.**
3. **Anderson, C. G. (1959), "Limnology of a Shallow Saline Meromitic Lake", Limnology and Oceanography No. 3, pp.259-269.**
4. **Banipal, N. J. (2000), "The Study on Using Salt-Gradient Solar Pond for Greenhouse Heating" M. Sc. Thesis, University of Technology.**
5. **Cohen, Y., Krumbein, W. and Shilo, M. (1977), "Solar Lake (Sinai). Limnology and Oceanography, No. 22, Pp.609-634.**
6. **Diffie, J. A. and Beckman, W. A. (1991), "Solar Energy of Thermal Processes", John Wiley and Sons, New York.**
7. **Eliseev,V.N., Usmanov,Y.U. and Teslenko,L.(1971),"The Theoretical Investiga- tion of Heat Regime of Salt Solar Pond", Geliotekhnika, Vol.7, No. 4, Pp.63-67.**
8. **Fisher, U. (1999) Solar Pond as an Energy Source for Desalination. Available online at** http://wire0.ises.org/wire/doclibs/SWC1999.nsf/id/2BC6811C3138CED5C1256920003D6194/$File/114.pdf
9. **Hadidy, M., Nimmo, B. and Zubair, S. (1981), "Salt Gradient Solar Ponds in the Eastern Province of Saudi Arabia", Solar World Forum, Edition by David, O. and June, M., Pp. 844-851.**
10. **Haider, H. A. (1994), "Salt flats (Solar Ponds) as Solar Collectors for Industrial Purposes", M.Sc. Thesis, University of Baghdad.**
11. **Hassab, M. A,, Tag, T. A. and Kamal, W. A. (1989), "Problems Encountered in Operating Salt Gradient Solar Ponds in the Arabian Gulf Region", Solar Energy , Vol. 43, No. 3, Pp. 169-180.**
12. **James, M. L., Smith, G. M. and Wolford, J. C. (1985), "Applied Numerical Methods for Digital Computation", 3rd Edition, University of Nebraska, Harper and Row, Publishers, New York.**
13. **Jashi, V., Kishore, V. and Rao, K.S. (1984), "A Digital simulation of Non-convecting Solar Pond for India Conditions", Proc. Int. Symp. Workshop on Renewable Energy Sources, Lahore, Pakistan.**
14. **Kurt, H., Halici, F. and Korhan, B. (2000), "Solar Pond Conception- and Experimental and Theoretical Studies", J. Energy & Management, Vol. 241, Pp. 939-951**
15. **Kurt, H., Mehmet, O. and Korhan, B. (2005), "The Theoretical and Experimental Investigation of Temperature and Salinity Gradients in Salt Gradient Solar Ponds", J. Fac. Eng. Arch. Gazi Univ., Vol. 20, No. 1, Pp. 125-135.**
16. **Lamoureux, J. (2003), "Heat Transfer in Outdoor Aquaculture Ponds", M.Sc. Thesis, Louisiana State University.**

17. **Lin, E.I. (1982), "Regional Applicability and Potential of Salt Gradient Solar ponds in the United States", DOE/JPL-1060-50, Vol. 2.**
18. **Moran, J. M. and Shapiro H. N. (2004), "Fundamentals of Engineering Thermodynamics", 5th Edition, John Wiley and Sons, New York.**
19. **Ramakrishna, G. R. and Pandey, K. P. (2002), "Solar Ponds - A Perspective from Indian Agriculture" Department of Agricultural and Food Engineering, Indian Institute of Technology, Kharagpur-721302, India.**
20. **Rama, B. and Chakraverty S. (2004), "Numerical Analysis in Engineering" Alpha Science International Ltd, UK.**
21. **Tiwari, G. N. and Ghosal, M. K. (2005), "Renewable Energy Resources", Alpha Science International Ltd, Harrow, UK.**
22. **Sonntag, R. E., Borgnakke, C., and Wylen G. J. (2003), "Fundamental of Thermodynamics", 6th Edition, John Wiley and Sons, New York.**
23. **Sukhatme, S. P. (1984), "Solar Energy-Principles of Thermal Collection and Storage", 2nd Edition, India Institute of Technology, Bomby.**
24. **Tabor, H. and Weinberger, Z. (1981),"Non-Convecting Solar Ponds", Solar Energy Handbook, Krielder & Kreith, McGraw-Hill Book Company, Chapter 10.**
25. **Usmanov, Y., Eliseev, V. and Umarov, G. (1971), "The Ponds as Accumulators of Solar Energy" Geliotekhnika, Vol.7, No. 1, Pp.19-22.**
26. **Wang, Y. and Akbarzadeh , A. (1982), "A Study on the Transient Behavior of Solar Ponds", Solar Energy , Vol. 7, No. 12, Pp. 1005-1017.**
27. **Wilson, A. T. and Wellmann, H.W. (1962). "Lake Anda, an Antarctic lake, Nature", No. 196, Pp. 1171-1173.**

NOMENCLATURE

$\bar{H}$	**The monthly average daily radiation on a horizontal surface, W/m^2**
H_S	**The radiation just beneath the surface, W/m^2**
$\bar{H}_\circ$	**The global radiation incident on the surface of the pond, W/m^2**
$H_\circ$	**The daily solar radiation on a horizontal surface, W/m^2**
$\bar{n}$	**The monthly average daily hours of bright sunshine**
$\bar{N}$	**Monthly average of the maximum possible daily hours of bright sunshine**
ϕ	**The latitude angle, (°)**
Γ	**Angle of side surface, (°)**
δ	**Declination, , (°)**

ω_s	The sunset hour angle
a	The albedo of water surface
β	Salt expansion coefficient
α	The thermal expansion coefficient
n_{water}	Index of refraction of water
n_{air}	Index of refraction of air
N	The number of daylight (sunshine) hours
θ_i	The angle of incidence, (°)
θ_r	Refraction angle, (°)
F	Fraction of the incident radiation absorbed within short distance
X_{UCZ}	Depth of the UCZ,(m).
X_{NCZ}	Depth of the NCZ, (m)
X_{LCZ}	Depth of the LCZ, (m)
A	Surface of solar pond, (m^2).
X	The depth measured from the surface of the pond, (m)
Z	The length of path of solar radiation through the layer, (m)
S	Salinity, (%).
T	Time, (hour).
J	Number of the sub layers in NCZ,