

PERFORMANCE OF SOLAR PONDS

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ABSTRACT

Four ponds were constructed on the forecourt of the AIT research centre, Bangkok, Thailand and successfully operated as a first step towards the storage of solar energy. Sea-salt was used to produce the desired gradient at the pond. The bottom of the ponds were blackened with asphalt in one pond and cement and charcoal mixture in other ponds. The temperature was recorded at different depths of the ponds. The rate of energy accumulation in the ponds was calculated using a micro-computer.

Key words : Solar pond, Storage, sea-salt, Energy.

INTRODUCTION

The solar ponds is an artificial black bottom pond one or two meters deep in which convection is suppressed by having a strong density gradient from the bottom to top. The gradient is obtained by having a high concentration of salts at the bottom of the pond and a negligible concentration at the top. These ponds absorb solar energy (radiation) and achieve high temperatures (upto 95°C).

The heat accumulation in the solar pond can be utilized in many ways of which the following are important for agricultural purposes :

- i) the potential use of solar ponds for supplying energy to operate solar powered irrigation pump
- ii) to operate solar powered incubator in the rural areas
- iii) to supply energy to parboil paddy in rural areas
- iv) for house heating in the winter season.

Solar ponds offer a cheap method of collecting and storing solar energy (Hussain, 1978 and Hussain, 1977). The solar pond can be used day and night throughout the year (Rahman *et al.* 1989 ; Feist, 1982 ; Fitzgerald, 1895 ; Pinkus, 1962 and Tabor, 1963). Appliance that need solar energy for operation will work only when the sun is shining and other times they remain idle. For efficient use of solar energy, some sort of storage system is required. The objective of this study was to investigate the temperature profiles and energy accumulation in the pond and to recommend the feasibility of using solar pond for operating solar powered incubator in rural areas of Bangladesh.

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MATERIALS AND METHODS

Four ponds, each 2m x 2m square and depths 0.4m, 0.6m, 1m and 1m were constructed on the flat ground. The detail design is shown in Fig. 1. Breeze blocks were used to construct the ponds. The thickness of the blocks was 10 cm. Portland cement and sand were used as mortar for construction of the pond's wall. The bottom of the ponds were blackened with Asphalt in pond P₁ and with cement and charcoal mixture on the other ponds. Plastic film covers were provided on the top of each pond to protect it from dust particles and wind disturbances and also to prevent evaporation losses. Galvanized steel pipes of 2.54 cm x 15 cm were installed 10 cm apart with each other in the sides of the ponds with inside end closed and outside end opened to permit temperature measurement. Temperature was measured with the help of digital temperature recorder.

The density of salt solutions with different concentration of salt was determined by normal procedure (Fig. 2). The turbidity of the salt solution was determined by turbidity tester. Turbidity is expressed in JTU. 1 JTU is the turbidity obtained when one gm silicon dioxide is mixed with one litre of distilled water.

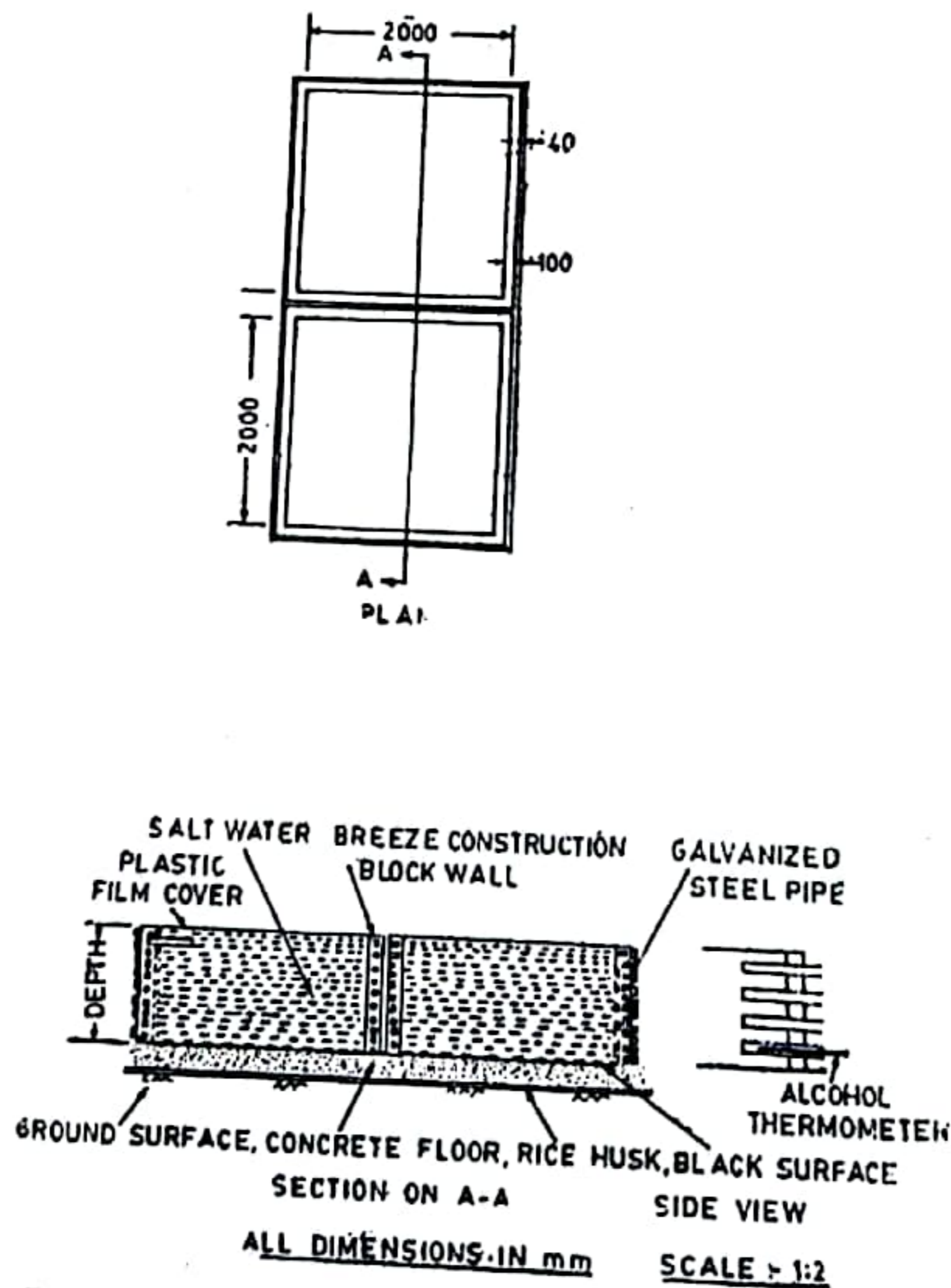


FIG. 1. DETAIL DESIGN OF SOLAR POND,

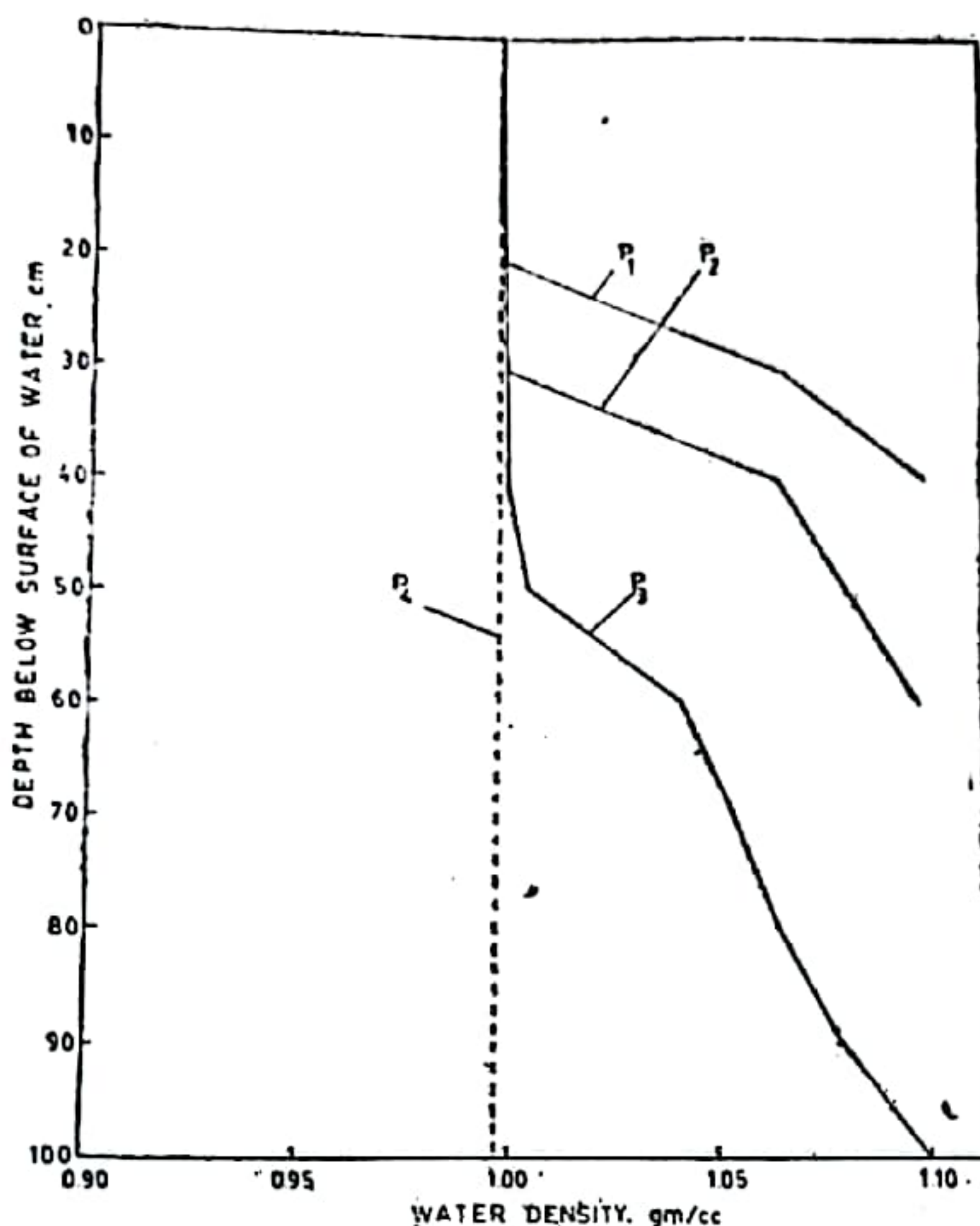


FIG 2 WATER DENSITIES AT DIFFERENT DEPTHS OF PONDS.

The desired salt solution obtained by dissolving the salt in a container. The salt solution was then fed in the tank. It was easy to fill the bottom layer with salt solution. After filling the bottom layer, the rest were fed very carefully without causing any disturbances of the previously fed layer. The salt solution into the pond was checked for density at an interval of 15 days. Sea salt (Sodium Chloride) was used to produce the desired density gradient at the ponds P1, P2 and P3 to suppress convection. Pond P4 contained water only with no salt added.

THEORETICAL CONSIDERATION

Energy Absorbed in the Pond

Energy absorbed in the pond during a particular time is obtained from the equation :

$$dQ_1 (X) = Mw (X) Cw (X) dT \tag{1}$$

The total energy accumulation can be found out by integrating the equation (1), we get

$$Q_1 = \sum_{x=1}^{x=h} Mw (X) Cw (X) \int_{T_o (X)}^{T_f (X)} dT \tag{2}$$

$$Q_t = \sum_{x=1}^{x=n} M_w (X) C_w (X) (T_f (X) - T_o (X))$$

Where Q_t Total energy accumulation at any time, kJ

M_w Mass of water in the pond, kg

C_w Specific heat capacity of pond's water (4.18 kJ/ kg -K) for fresh water

$T_o (X)$ and $T_f (X)$ are initial and final temperature at depth x from the surface of water

n number of layer of salt solution

Energy Losses From the Pond

Energy losses from the top of the pond will be in three ways, such as conduction, convection and radiation. From the concept of longwave radiation and by the knowledge of conduction and convection theory we can write the total energy loss from the top of the pond. Therefore, the total energy loss from the top of the pond is

$$Q_{lc} = h (T_p - T_a) + \sum_p \sigma (T_p^4 - T_a^4) \quad (2)$$

The first term represents convection and conduction and the second term represents the radiation losses.

Where Q_{lc} upward energy loss between the plastic film cover and the atmosphere. (Wm^{-2})

T_p the temperature of the plastic film cover. ($^{\circ}K$)

T_a the ambient temperature. ($^{\circ}K$)

σ the Stefan Boltzman constant, ($5.672 \times 10^{-8} Wm^{-2} (K)^{-4}$)

\sum_p the emissivity of plastic film, (dimensionless)

h convection coefficient, ($Wm^{-2} (^{\circ}C)^{-1}$). It varies with the air velocity.

The energy losses through the side walls and bottom were neglected because of good insulation. The insulation at the bottom was provided with 5cm thick layer of rice husk.

Efficiency of the Pond

Efficiency of the pond may be defined as the ratio of the total energy accumulated at any time in the pond divided by the total energy incident on the pond at the same time.

RESULTS AND DISCUSSION

Daily totals of global radiation over the period of experimentation was measured using the bimetallic actinograph. The highest recorded daily insolation was $700 Wm^{-2}$ and the lowest was $360 Wm^{-2}$. The net energy accumulated in the pond was calculated using the equation (2) and the energy loss through the cover was calculated from the equation (3).

The rise of temperature over the period for four ponds was recorded and the result is shown in Figure 3. The rise of temperature was very slow. Vertical temperature profiles of the four ponds are shown in Figure 4. The highest temperature was recorded in the bottom of the pond where the density of water was the highest. The temperature towards the top of the surface reduced. The reason was that at the bottom of the pond

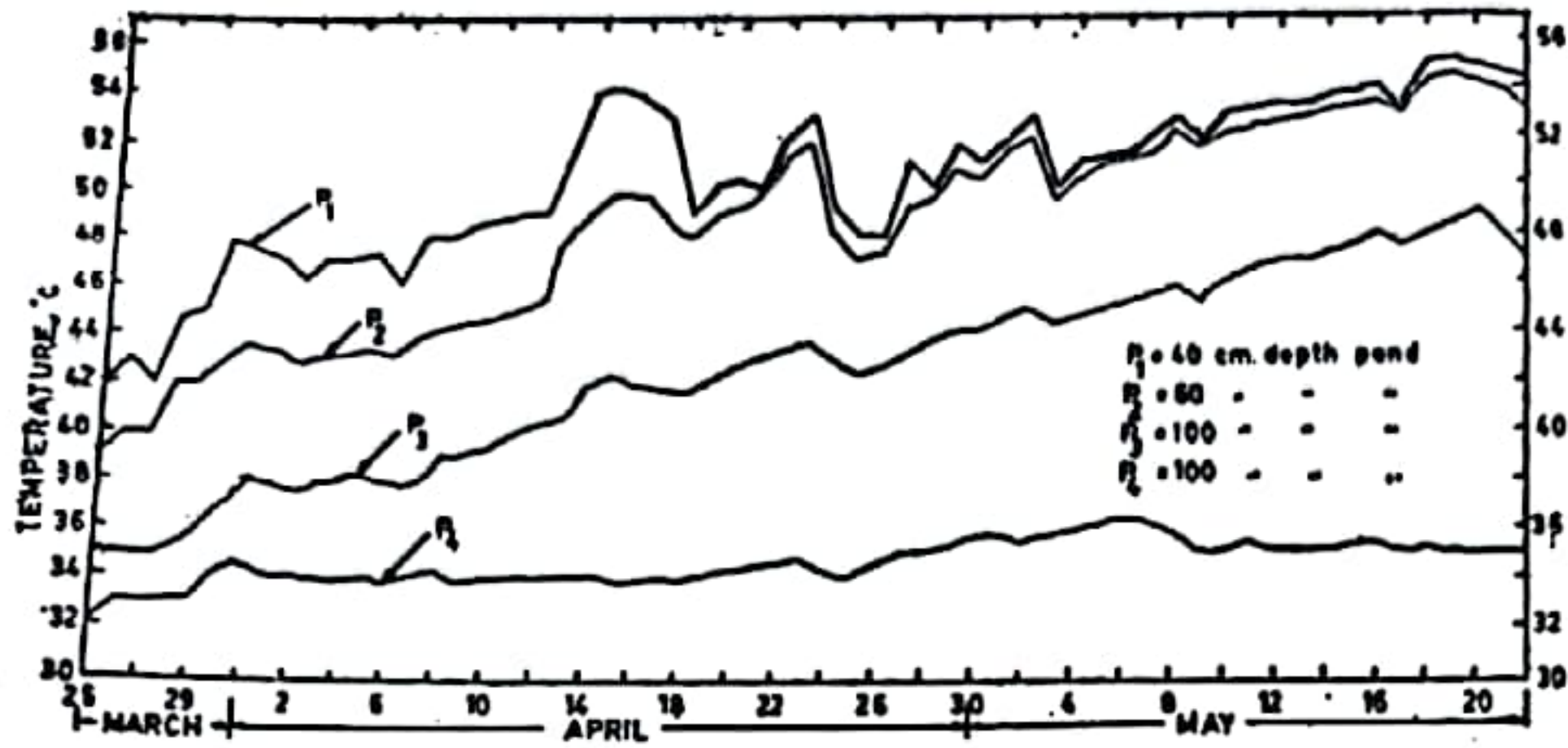


FIG. 3 COMPARISON OF TEMPERATURE RISE AT THE BOTTOM OF THE PONDS 25.3.1977-22.5.1977
ALL TEMPERATURE AT 2 PM AT THE BOTTOM OF PONDS

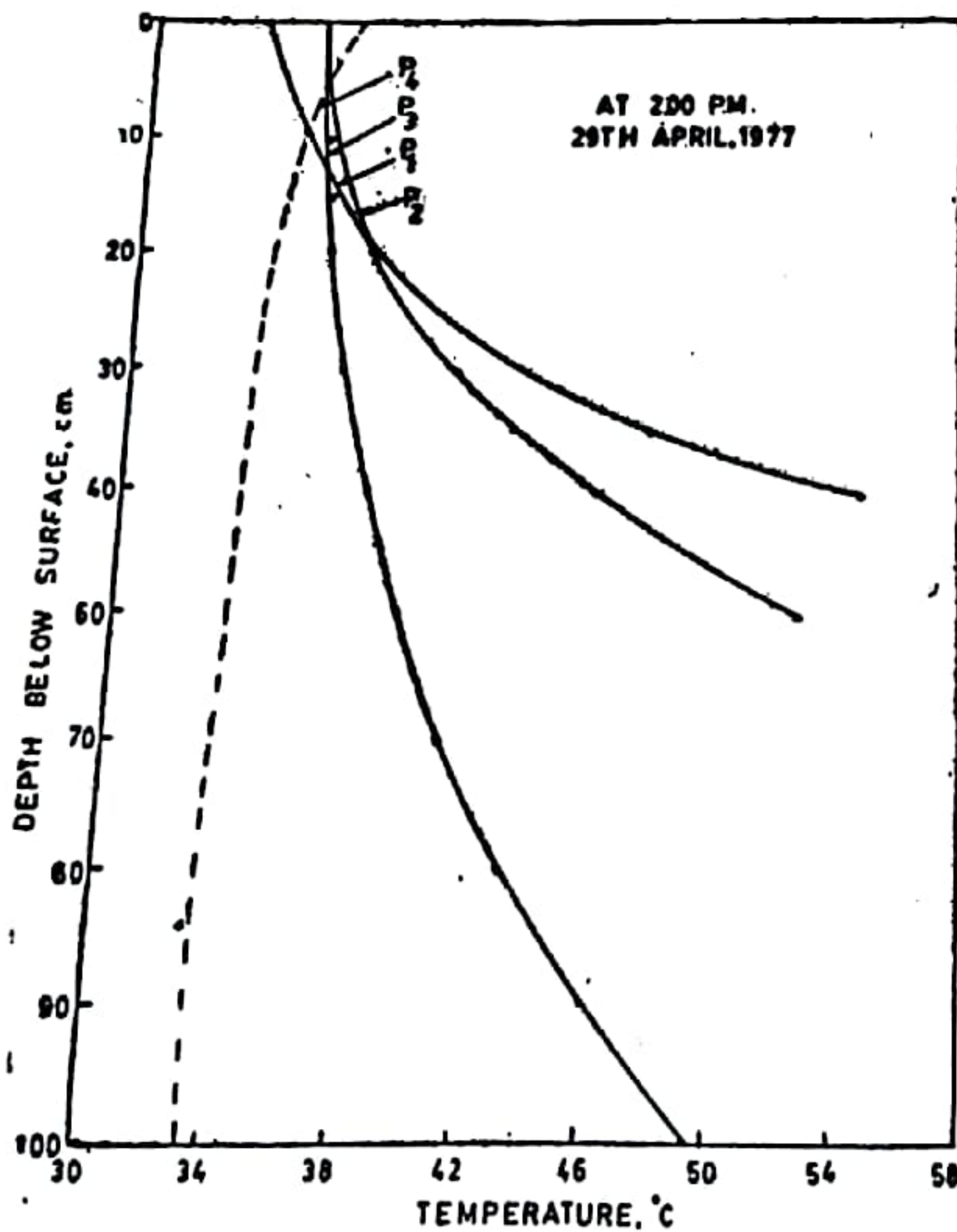


FIG 4 VERTICAL TEMPERATURE PROFILES

the convection current was totally suppressed and towards the surface of water, the convection current due to the rise of temperature could not be checked because of lower range of water density. Horizontal temperature profiles were also constructed and is shown in Fig. 5. The temperature was recorded from dawn to sunset, i. e., 6 AM to 6 PM. The highest temperature was recorded at 2 PM. Temperature at the bottom of the ponds in a particular day were 55°C, 64°C, 46°C and 34.5°C corresponding to the ponds P₁, P₂, P₃ and P₄ respectively. Although the system worked, the rate of energy accumulation was very slow. This may in part be due to the low absorptivity of solar radiation by the black bottom of the pond. During the experimentation the bottom was covered with a thin layer of suspended solids of salt solution. Also there may be some effect of degree of blackness of the absorbing surface. The asphalt gave very brilliant black surface in comparison to the surface of charcoal and cement mixture.

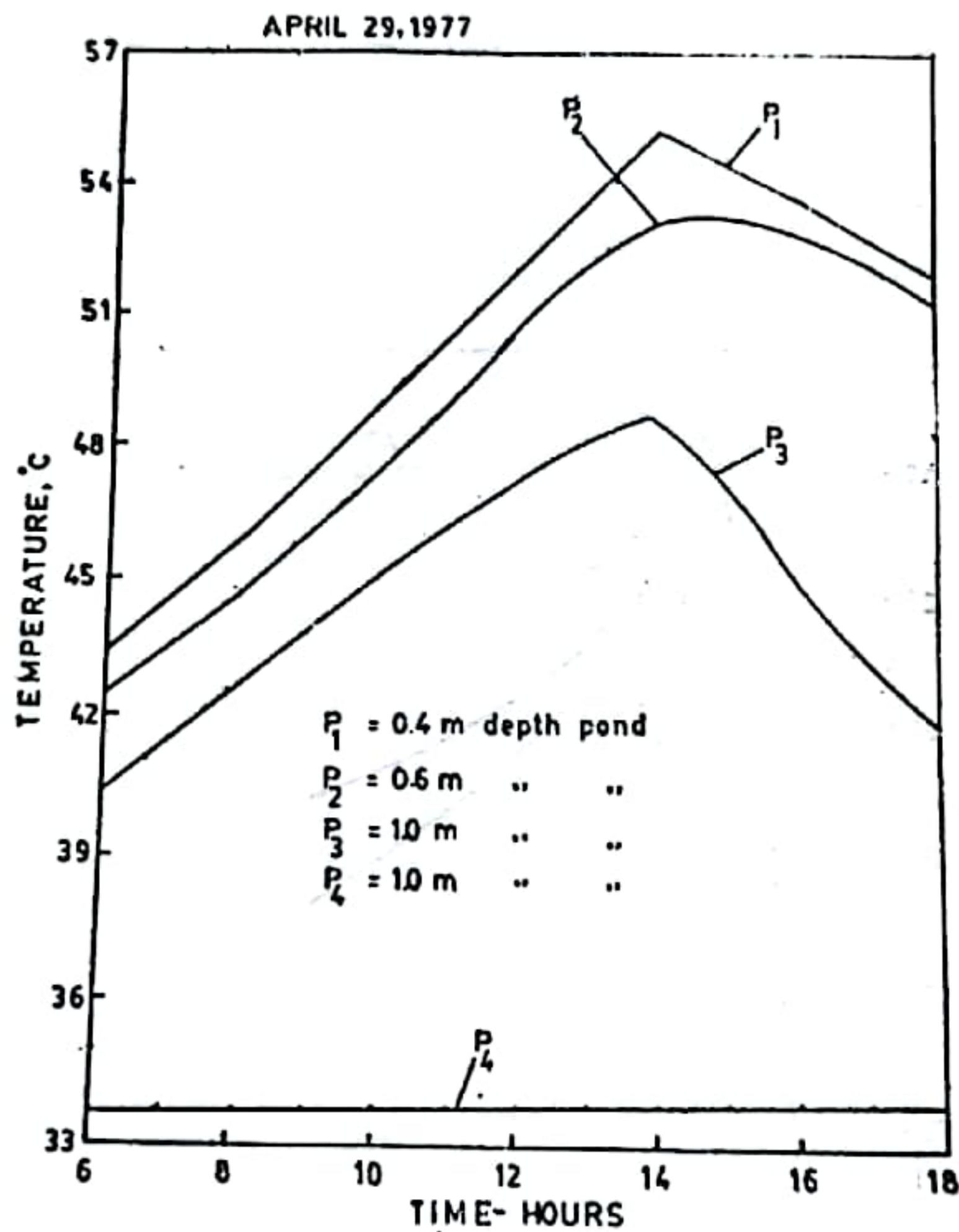


FIG.5 HORIZONTAL TEMPERATURE PROFILE AT THE BOTTOM OF THE POND DURING THE DAY.

At the time of charging the pond, the turbidity of salt solution was very high being about 200 JTU at the bottom of the pond. To obtain good results turbidity should be as low as possible. The turbidity of salt solutions at different concentrations is shown in Table 1. The specific heat capacities of salt solutions at different layers are shown in Table 2. The rate of energy accumulation between 6 AM to 10 AM was very low in the

Table 1. The turbidity and density at different concentrations

Concentration (%)	Density (gm/cc)	Turbidity (JTU)
22	1.0993	200
18	1.0807	154
15	1.0664	60
12	1.0554	35
8	1.0429	30
4	1.0063	13
2	0.9997	5
Tap water	0.9980	0.24
Distilled water	0.9967	0.02

Table 2. The density and specific heat capacities at different depth of the pond water.

Pond No.	Depth of water (cm)	Density (gm/cc)	Sp. heat capacity (KJ/kg-°C)
P1	30-40	1.0993	9.368
	20-30	1.0807	3.486
	10-20	0.9997	4.059
	0-10	0.9980	4.143
P2	50-60	1.0993	3.368
	40-50	1.0807	3.486
	30-40	1.0663	3.575
	20-30	0.9997	4.059
	10-20	0.9980	4.143
	0-10	0.9980	4.143
P3	90-100	1.0993	3.368
	80-90	1.0807	4.486
	70-80	1.0663	3.575
	60-70	1.0554	3.695
	50-60	1.0429	3.929
	40-50	1.0063	3.975
	30-40	0.9997	4.059
	20-30	0.9980	4.143
	10-20	0.9980	4.143
	0-10	0.9980	4.143

Pond P4 contained pure water only with no salt added. The density of the water was 0.998 gm/cc and specific heat capacity of water 4.143 KJ/kg-°C.

ponds P₂ and P₃ in comparison to pond P₁. Solar radiation could not reach the bottom of the ponds in the morning due to the constructional nature (vertical walls) of the ponds. The same effect was obtained in the evening. In the pond P₄, the energy accumulation

Table 3. Measured efficiencies of the ponds during a particular day.

Ponds	Depth of ponds (cm)	Efficiencies in different hours of day (%)					
		8	10	12	14	16	18
P1	40	15.0	11.6	9.4	16.4	12.6	12.4
P2	60	10.2	10.0	9.2	16.8	12.2	11.4
P3	100	6.0	8.0	7.2	18.0	12.8	12.0
P4	100	2.0	2.0	3.0	4.4	3.3	2.0

was very low because of the pond contained no salt and the temperature rise was not possible due to the convection current in the pond's water.

The observed efficiencies of the ponds between 12 noon and 2 PM were found to be approximately 16.4% in pond P₁, 19.8% in pond P₂, 18% in pond P₃ and 4.4% in pond P₄. Measured efficiencies of the ponds during a particular day is shown in Table 3. The capacity for absorbing solar radiation could be considerably improved by providing clean salt solution in the pond, a brilliant black surface at the bottom of the pond and a wind break. Pond P₄ contained water only with no salt added. In this pond, an appreciably higher temperature was found at the water surface of the pond rather than the bottom. The energy accumulation in the bottom layer of each pond on a particular day during the period 12 hour to 14 hour was 180 Wm⁻² in pond P₁, 112 Wm⁻² in pond P₂, 83 Wm⁻² in pond P₃ and 42 Wm⁻² in pond P₄ respectively. Statistical analysis was done to find out the effect of number of days of observation on the rise of temperature in the ponds and the relationship is follows ;

$$T_{p_1} = 41.8 + 0.555 D^* \quad (4)$$

$$R^2 = 0.955$$

$$T_{p_2} = 36.65 + 0.701 D^* \quad (5)$$

$$R^2 = 0.96$$

$$T_{p_3} = 34.38 + 0.638 D^* \quad (6)$$

$$R^2 = 0.91$$

T_{p_1} , T_{p_2} , T_{p_3} are the temperature in °C in the ponds P₁, P₂ and P₃ respectively.

D Number of days of observation.

R² Co-efficient of multiple determination.

* Significant at 1% level.

Number of day of observation had significant influence upon the accumulation of heat in the ponds. Turbidity, cloudness of the sky and wind conditions were not considered for the statistical analysis. Solar ponds would be most useful for use with solar incubator, solar pump or water heater. A heat exchanger would be necessary to install to transfer the heat energy from solar ponds to solar incubator or other appliances.

CONCLUSIONS AND SUGGESTIONS

The following conclusions were drawn based on the results obtained in the experiments :

- i) Insulation in the sides and in the bottom should be provided to increase the rate of temperature rise in the pond. Insulation is needed to preserve the heat in the pond for a long time.
- ii) To minimize the shades due to right angle walls, a trapezoidal pond should be constructed for further experimental works.
- iii) To investigate the affect of diffusion on concentration profiles in a solar pond would be a good contribution.
- iv) Pure sodium chloride should be used in the pond for further investigations.
- v) A mini-computer with interface and sensors in the pond could be installed for continuous data recording. After wards a model could be developed for prediction of the efficient use of solar pond in different aspects.
- vi) Solar pond would be a cheap source of power supply for the operation of solar pump, solar incubator and parboiling of paddy.

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REFERENCES

- Hussain, M. D. (1978). "Solar Pond and Storage of solar Energy" : *Agricultural Mechanization in Asia, Africa and Latin America*, 9 (2) : 55-58.
- Hussain, M. D. (1977). Design and Investigation of the performance of Solar Ponds of Thailand, Master of Engineering Thesis No. 1253, Asian Institute of Technology, Bangkok, Thailand.
- Rahrnan, M. A., M. Mollah, M. A. Reza and M. A. Quasem (1989). *Jahangirnagar Physics Studies : Heat transfer mechanism in a nonconvective salt gradient solar pond*, 4 : 28-35.
- Feist, E. M. (1962). The Research Council of Israel : Solar Pond Project Report S/130/62a : Utilization of a solar energy for power production.
- Fitzgera'd, D. (1895). *The Temperature of Lakes*, Transaction of the ASAE.
- Pinkus, A. (1961). *The Performance of and Experimental Solar Pond at the Dead Sea; The Nagev Institute for Arid Zone Research, Beer Sheba, Israel.*
- Tabor, H. (1963). Large Area Solar Collectors for Power Production, *Solar Energy*, 7(4) : 189-194.