PERFORMANCE TEST OF A SALT-GRADIENT SOLAR POND

BY
MD. AFTABUL ISLAM
M. ENGINEERING (MECHANICAL)

A REPORT

SUBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING, BANGLADESH UNIVERSITY OF ENGINEERING & TECHNOLOGY, DHAKA, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING IN MECHANICAL ENGINEERING.

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA
AUGUST, 1990.

THIS IS TO CERTIFY THAT THIS WORK HAS BEEN DONE BY ME AND HAS NOT BEEN SUBMITTED ELSEWHERE FOR THE AWARD OF ANY DEGREE OF DIPLOMA.

SIGNATURE OF THE SUPERVISOR.

Md. Aftabul Islam

SIGNATURE OF THE CANDIDATE

PERFORMANCE TEST OF A SALT-GRADIENT SOLAR POND

ACCEPTED AS SATISFACTORY FOR PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING (MECHANICAL).

EXAMINERS

Dr. Abdur Razzaq Akhanda
Professor
Dept. of Mechanical Engg.
BUET, Dhaka.

Chairman.

Dr. A.M. Aziz - Ul Huq
Professor
Dept. of Mechanical Engg.
BUET, Dhaka.

Member.

Dr. S.M.Nazrul Islam
Professor & Head
Dept. of Mechanical Engg.
BUET, Dhaka.

Member.

PERFORMANCE TEST OF A SOLAR POND

ABSTRACT:

Unlike other solar energy utilization devices a solar pond can collect as well as store the solar energy for future use. A salt gradient zone is maintained in the pond which suppresses the convective current of the heated brine and thereby a thermal insulation is provided. Brine solution was poured, in a previously constructed solar ponds, in layered sections. Temperatures at different layers of the pond have been recorded from time to time to describe the time dependent behaviour of the layers. Also salinity and temperature profiles as a function of time have been determined in this investigation. After observing a diffusion of salt from lower denser region to the upper lighter region. The experiment suggests a method of maintaining the salt gradient in the non-convecting region.

CONTENTS

LIST OF FIGURES:

CHAPTER 1

INTRODUCTION:

Salt gradient solar ponds have been studied for several decades as a means of generating low temperature thermal energy at a relatively low cost, depending on the availability of land and salt. While several important problems remain to be solved, solar ponds are slowly becoming recognized as one of the more ppromising solar technologies. The basic vertical stratification in a solar pond is composed of the typical three-layer structure consisting of upper and lower convecting zones seperated by a gradient zone. The ability of a pond to collect and store heat in the lower layer depends on the establishment of a stabilizing salinity gradient to supress natural thermal convection. The gradient zone acts to insulate the lower layer from the upper mixed layer which is in direct thermal contact with the atmosphere. The effectiveness of the gradient zone may be lessened as either of the convecting zones encroaches into the gradient region and also by the development of internal convecting zones. Both of these processes have been observed in operating ponds and tend to increase the upward flux of heat and salt, thus decreasing the pond's thermal efficiency. Internal convecting zones result from instabilities associated with the strong temperature gradients established, while encroachment at the gradient zone boundaries is caused by entrainment driven by the convective motions in the upper and lower layers.

Solar ponds are simply constructed using relatively inexpensive materials. A salt gradient is maintained to suppress the convective currents of heated water and thus providing a thermal insulation, solar energy is collected and stored.

The Non-convecting solar pond is a horizontal surfaced solar collector using the absorption of solar energy as heat at the bottom it. Typically a solar pond is a shallow body of water about 1 meter deep containing dissolved salts to generate a stable density gradient. Where solar energy enters a pond, the infrared components is absorbed within a few centimeters near the surface since water is opaque to longwave radiation. The visible and uttraviolet ray can penetrate clear water to a depth of several meters. These radiation component can be absorbed at the bottom of the pond by dark coloured surface. The lowest layer of water is then the hottest and would tend to rise because of its lower density if measures are not taken to prevent it.

In Non-convecting solar pond the water at the bottom is madeheavier than that at the top by dissolving salt in the water. The concentration of salt is decreased from bottom to top so that the natural tendencg of the pond water. To mix by creation of convective currents is effectively eliminated if density gradient is adequate. Normally a concept of 3 zones (i) a relatively thin homogeneous ans convective surface layer (ii) a Nonconvective gradient zone in which there are gradients in salinity and temperature (iii) a homogeneous convective bottom zone for heat storage is adopted in solar pond fabrication. The Non-convective gradient zone transfers heat by conduction only, water being opaque to thermal radiation at the temperature of operation. It acts as a partially transparent window of low thermal conductivity that allows some of the solar radiation to penetrate into the bottom zone and heat it. The gradient zone remains gravitationally stable and Non-convective despite the heating of the bottom because the salinity gradient is sufficient to maintain a stabilizing density gradient and thus it is possible for the lowest layer of a well-designed solar pond to boil. It must be avoided as it destroys the stable density gradient.Therefore, the design of solar pond for heat generation must involve a mechanism for useful heat removal in sufficient quantity to avoid boiling.

CHAPTER 2

LITERATURE REVIEW:

There are a number of research work on solar pond. Researchers all over the world have studied the solar ponds elaborately and in some instances on a particular side.

Bloch (year of Publication 1971) suggested the study of solar lakes with a view towered practical utilization. Under controlled conditions, it was to be expected that higher temperatures and useful collection efficiencies could be achieved in artificial ponds. Subsequently in experiments with small ponds temperatures greater than 103°C were measured and collection efficiencies greater than 15% for heat extraction at 70 to 90°C achieved.

Tabor (year of publication 1971) studied the solar pond experimentally and analytically and outlined the general concept and major problems of the pond. He carried out theoretical investigations of the underlying physics of the solar pond and made laboratory and field tests. The salt concentration gradient required for stability, the filling procedure of the pond, The maintenance of the salt concentration gradient, the repair of a disturbed halocline, the absorption of radiation, the temperature of heat extraction, the efficiency, the diurnal temperature variation and maximal temperature gradient in the pond, heat storage in the pond and many others pros and cons of the solar pond have been analysed and noted in his paper.

Weinberger (year of publication 1971) carried out studies of the heat extraction based upon his theoretical model of the solar pond. After the initial warm up period, he finds that for a given-extraction temperature there is a particular value of the pond depth at which the rate of heat extraction is a maximum. It transpires that this optimum rate of energy withdrawal is equal to the radiation reaching the pond bottom, and thus in this case the pond is heated only by the radiation absorbed through its depth. Weinberger has calculated the optimum extraction temperature and collection efficiency as functions of the pond depth.

M. Rothmeyer (year of publication 1971) have investigated soret effect (The diffusion of salt can be driven by a temperature dradient) in salt gradient solar ponds. He argued that the diffusion of salt from a denser layer to a lighter layer depends not only on the concentration gradient, but also on the temperature gradient in the pond.

Shah. Ted. and Peter (year of publication 1971) made a computer model of a salt gradient. Solar pond used as an annual cycle solar energy collection and storage system and tested it with the conclusions that (a) by increasing the collection efficiency of the pond from 20 to 30% during collection mode, 44% more energy can be stored at a 25.5°C higher temperature (b) changes in shape and size of the pond could improve the overall performance of the pond. A trapezoidal pond collects and stores more energy as compared to rectangular pond deeper storage zone at lower temperature results in lower heat losses and consequently higher amount of stored energy.

K.A. Meyer (year of publication in 1971) has developed a numerical model of a salt gradient solar pond to describe the time dependent behavior of the interfaces between the convecting and non-convecting regions. The model includes the determination of salirity and temperature profiles as a function of time.Emperical correlations from the oceanographic literature that describes the heat and salt fluxes across the interfaces have been utilized by the model. The model also represents a treatment of entrainment caused by wind generated turbulence. He also has determined the pond performance under various operating conditions.

Kamal, Neilson and Hull, Lin. Shah (year of publication in 1971) tried to determine the dependence of ground heat loss upon solar pond size and perimeter insulation. Ground heat losses from solar ponds have been calculated numerically for various perimeter insulation strategies and several solar pond sizes. The numerical simulations are steady state calculations of heat loss from a circular or square pond to a heat sink at the outer boundaries of an earth volume that surrounds the pond perimeter on the bottom and sides. Simulation results indicate that insulation on top of the ground around the pond perimeter is rather ineffective in reducing heat loss, and then uninsulated sloping side walls are slightly more effective than insulated vertical side walls, except for very small ponds.

Akbarzadeh, Macdonald and Wang (year of publication in 1971) have investigated the phenomenon of mixing in the top region of solar ponds. The factors causing this problem and the effects of wind in creating the top layer convective zone are discussed in their papers. They derived necessary formulas for determination of amplitude and frequency of the wave generated by the winds in terms of wind velocity and fetch length. Also the problem of wind driven currents in solar ponds has been discussed. They have currently introduced the idea of small circular floating rings as wave suppressors and described their effectiveness in decreasing the thickness of the top convective zone. They have also proved that the floating ring wave suppresses can successfully decrease the depth of the top mixing layer in the pond.

Bathy, (year of publication in 1971) carried on experiments to determine by computer simulation, the optimum thickness of the non-convecting zone in the salt gradient solar pond. They found that the non-convecting gradient zone (NCZ) of a salt gradient solar pond tends to more effectively transmit incident solar energy to the storage brine below as its thickness is reduced and that same gradient zone tends to more effectively reduce heat loss from the warm brines as its thickness is increased.

Therefore, there exists an optimum gradient zone thickness for which the net rate of energy collected and retained is a maximum. They argued that significant improvement in pond efficiency may be obtained it the thickness of the gradient zone is adjusted monthly, seasonally or even it is maintained at the annual average optimum thickness as compared with operating the pond with other than an optimum gradient zone thickness.

Their experiment resulted that maximum energy can be extracted from the pond by maintaining optimum NCZ thickness; which would very seasonally or monthly. In the summer when the ambient temperature and solar insolation rates are both relatively high the optimum Non-convective gradient zone thickness would likely be less than during the winter when ambient temperature and solar insolation are relatively low.

again raised to .3048m. Thus the pond is now, 1.3048m deep. To prevent possible leakage of the brine with the pond walls and the bottom are made with 10" brick walls having a cement liner. It is done so that the water cannot be muddy with the dirt washed in from the walls either by motion of the water in the pond or by rain. The ponds long sides are made with east west direction. The south wall is made some what inclined with vertical so that the pond interfaces cannot be shaded at the optimum period of solar radiation. On the north side of the pond threr is a platform to maintain the thermocouple with the lead sorew.

The walls of the pond are painted with write commercial paint in order to reflect the sun rays into the pond bottom. The bottom is painted with blaok paint in order to have the absorption co-efficient of a blackbody. Both paints are used with conformity that these are not washed off with hot salt water. The insulation is provided to the height of 1m from the bottom. So, 0.3048m at the top is not insulated. This is done to study the pond only with 1m depth. Since the insulation is 1.5" thick, it reduces considerable volume of the pond.

CHAPTER - 3
THE SOLAR POND

3.1 Description:

The solar pond under study is rectangular in shpae with its south wall inclined at 20^{o} with vertical. It is 1 m deep having an area of 3m X 1.87m at the top and 3m X 1.5m at the bottom. To prevent the rain water and other contaminants, the pond wall is again raised to .3048m. Thus the pond is now, 1.3048m deep. To prevent possible leakage of the brine with the pond walls and the bottom are made with 10" brick walls having a cement liner. It is done so that the water cannot be muddy with the dirt washed in from the walls either by motion of the water in the pond or by rain. The ponds long sides are made with east-west direction. The south wall is made some what inclined with vertical so that the pond interfaces cannot be shaded at the optimum period of solar radiation. On the north side of the pond threr is a platform to maintain the thermocouple with the lead sorew.

The walls of the pond are painted with write commercial paint in order to reflect the sun rays into the pond bottom. The bottom is painted with blaok paint in order to have the absorption co-efficient of a blackbody. Both paints are used with conformity that these are not washed off with hot salt water. The insulation is provided to the height of 1m from the bottom. So, 0.3048m at the top is not insulated. This is done to study the pond only with 1m depth. Since the insulation is 1.5" thick, it reduces considerable volume of the pond.

Cork is used here because of its numerious advantages. Firstly, it is comparatively cheap and available. Its thermal conductivity is very low. Again it is unaffected by salt and it cannot be wetted & decomposed with water. It is easier to fix with the brick walls of the pond. Pertex can not be used in water, other insulating materials are either costly or unavailable. However, for insulation in water, cork serves better.

Walls and bottom are provided with 1.5" thick cork insulation. For this end in view the 2" grooves are made on the walls and in each groove a 5" bolt is pressed with concrete. The insulation is made attached to the walls with 3" X 3/4" wooden lears.

The Bangladesh Council for Scientific and Industrial Research (BCSIR) conducted an experiment on the principle of solar pond. In that experiment a cylindrical Jar of dia. 4 inch and height 10 ft. was taken and filled with bresh water and Nacl salt was sprinkled which settled at the bottom. After a salt gradient has been established, the temperature at the surface and bottom were measured. It was found that when the surface temperature was 25°C, then the bottom temperature was raised to 50°C. In conclusion it was mentioned thats for low temperature heating purpose, solar pond would work in Bangladesh.

3.2 INSULATION OF THE POND:

The heat loss from the perimeter of this pond to the side walls and the ground is not at all negligible. In case of a large pond, this heat loss may be very small compared to the overall heat absorbed by the pond.

So effective insulation have been provided in order to reduce heat loss along the walls.

and salt. While several important problems remain to be solved, solar ponds are slowly becoming recognized as one of the more ppromising solar technologies. The basic vertical stratification in a solar pond is composed of the typical three-layer structure consisting of upper and lower convecting zones seperated by a gradient zone. The ability of a pond to collect and store heat in the lower layer depends on the establishment of a stabilizing salinity gradient to supress natural thermal convection. The gradient zone acts to insulate the lower layer from the upper mixed layer which is in direct thermal contact with the atmosphere. The effectiveness of the gradient zone may be lessened as either of the convecting zones encroaches into the gradient region and also by the development of internal convecting zones. Both of these processes have been observed in operating ponds and tend to increase the upward flux of heat and salt, thus decreasing the pond's thermal efficiency. Internal convecting zones result from instabilities associated with the strong temperature gradients established, while encroachment at the gradient zone boundaries is caused by entrainment driven by the convective motions in the upper and lower layers.

Since the insulation is white in colour, the walls serve the purpose of reflecting the sun rays into the bottom. The bottom insulation is painted with black paint to absorb the solar radiation. The nuts and wooden lears used on the bottom are also provided with black paint and those on the side walls are provided with white paint.

3.3 FILLING PROCEDURE OF THE POND:

The pond has been filled in layered sections with small saline differences between adjacent layers. For convenience, the depth of the pond is fractioned into 10 layers and there has been maintained a uniform saline difference between the layers. The bottom most layer contains a brine of specific gravity 1.14 having a salt salubility of 21gm/100cc of water and that the 3rd layer from the top has a specific gravity of 1.032 with a solubility of 4gm/100cc of water. First two layers are filled with fresh water. The bottom most layer is filled first and successively lighter layers are floated upon the lower denser layers.

For large pond the filling procedure is different from that for a small pond. Generally for large pond, fresh water is filled to the appropriate depth and salt dissolved to make concentrated brine in the bottom portion of the pond. The next layer of slightly lower salinity is produced by pumping a stream of brine out from the bottom through a mixing valve. Where it is diluted with the desired proportion of fresh water and then deposited on the pond surface. The process is repeated with successively increased proportions of fresh water to give layers of decreasing salinity until the desired total pond depth is reached.

Here for this pond the brine mixtures have been prepared prior to pouring with required salinity and placed upon the previous layer. To prevent excessive stirring during pouring, the leading pipe is directed towards a small box placed on a 3' X 3' wooden platform which floats on the pond. So that the water flows over the rim of the box to the periphery of the platform and thence to the pond.

For preparation of brine, a drum of size 56cm diameter and 86cm height has been used. Since the volume of each layer is greater than that of the drum. So for pouring a layer brine mixture of the same salirity had to be prepared for two or more times.For rapid and well mixing, a typical stirrer was used. The brine has been led to the pond by a hose pipe of dia 1 1/2inch through a gate valve.

Soon after the step wise filling process, the pond gradient smooths itself effected by diffusion. The smoothing of the density profile is necessary because otherwise the individual layers themselves are unstable and convective cells can establish themselves in the individual layers. There is partial mixing of the adjacent layers caused by the kinetic energy of the liquid flow injected into the pond during filling process.Part of this kinetic energy is converted into gravitational potential energy by partially mixing the adjacent layers. The rest of the kinetic energy is dissipated in viscous flow at the walls of the pond.From energy consideration, the flow into the pond has been kept limited to approximately .12m/s.

3.4 INSTRUMENTATION OF THE SOLAR POND:

In order to monitor the stability, collection efficiency and clarity of the solar pond, measurements of temperature, salinity and insulation within the pond, and measurements of temperature, humidity, insulation and wind velocity outside the pond are required.

Temperatures at various layers of the pond are easily recorded by installing thermocouples. A thermocouple probe has been designed with the mechanism to shift the thermocouple at different layers to record the temperatures of the convective zones as well as the temperature gradient in the gradient zone.

Chromel - Alumel

Iron-constantant thermocouples have been used and those have been led to the millivoltmete by insulated copper wir. The thermocouple wires are passed through 1/8" dia stainless steel tubes. Each tube is 1.2 meter in length and they are set on a frame 0.75meter apart. The frame is welded to a nut which can be screwed upward and downward by rotating a lead screw.Four rods guide the nut in it's way.

There is a diffusion of salt in the upward direction from the bottom to the top. This diffusion causes instability of the salt gradient. So maintenance of the salt gradient is very important.

For this reason it is required to check salinity at different level and take necessary measures. Salinity measurements are made by extracting brine from chosen levels in the pond. This extraction may be with the help of a small pump and piece of tubing. For this reason small-diameter sampling tubes are installed permanently at different levels of the pond. On temporary basis, large syringe with plastic tubing has been used to extract liquid. The extracted liquid is poured into a cylinder and a hydrometer is used to measure salinity.

Insulation within the pond is measured by using encapsulated silicon detectors.To control dirt which is mixed with commercial salts, a filter should be used. Here a cloth wraped around the wooden platform has been used to serve this purpose. It would be better to use filterbox packed with charcoals, sands and rocks.

CHAPTER V

RESULTS AND DISCUSSION

Ten Sets of Temperature readings have been taken starting from 8 A.M. to 5 P.M. each day. In each set there are eleven readings of different layers starting from top surface of the pond to the bottom. Obviously these readings have been taken at dayhighttime with a certain interval.

Fig. 5.1 & 5.2 are plots of temperature vs. day time for various depths for 1st day & 2nd day of running respectively. It is evident from these graphs that as time goes on from moring temperature increase at all depths. Temperature is found to be maximum at around 2.30 P.M. to 3.00 P.M. everyday. Temperature also increase with increase of depth. On the second day of running temperature at a particular time is found to be higher than that of 1st day of running. This indicate storage of solar energy in the pond.

Fig. 5.3 & 5.4 are plots of temperature vs. depth at day times for 1st & 2nd day of running respectively. From these figures, it is found that temperature is found to be maximum when depth is .7m to .8m.As time goes on from monring temperature also increases.

The water has been poured in layers in the pond.There are ten layers and each layer has a thickness of 10 centimeters. So there are ten uniform density regions. As the solar radiation is absorbed by the brine, the layers get heated. While being heated the density of the brine decreases, it becomes lighter and comes up. So, in each layer, there is a convective current, taking the hot brine to the upper boundary of each layer. This heat is conducted to the lower boundary of the next upper layer. In this transmission of heat convection cannot work as the brine of upper layer is lighter than that of the lower layer. That is in each layer, the upper boundary region is hotter than the lower boundary region. It is seen that highter temperature is obtained, as one goes deeper, but at the extreme depth the temperature again goes down. This is probably due to perimeter heat loss. At the bottom of the ponds there is ground water flow, that takes away heat from the pond bottom.

As the time goes it is seen that the temperatures of the different layers increase gradually. From this phenomenon it can be concluded that the smoothing effect of the density gradient goes on gradually and so there is no convective mixing and thus heat is not transmitted to the pond surface from where it is taken away by atmosphere. That is the heat storing capacity, in this away, developes and if proper insulation is given a high temperature, near about the boiling point can be obtained. Heat collection capacity of a pond depends on the clarity of the pond. There are many dirts in commercial salts and if before pouring the brine into the pond, no filtering action is adopted, the existing dirt particles will absorb and reflect the sun radiation on its way to the pond bottom. Lower temperature at the bottom layers may also be due to this. In this investigation, a cloth covered around the wooden platform was used as a filtering media. This reduced the amount of pouring of brine into the pond so a proper filter must be used.

Density gradient are plotted in Fig. 4.5. It is evident from the figure that as the thickness of the layers are smaller, the smoothing effect of density gradient is better and takes less time to gain temperature.The temperatures of the intermediate layers are seen to be higher than those of bottom layers. Which is an abnormal phenomenon for a solar pond. This is not at all expected. Because the higher temperature in this zone may upset the stability of the density profile which acts as a thermal insulation to the lower convective zone. Most probably. This is due to much dirt accumulation in this zone. Which causes most of the heat to be absorbed here not let go to the deeper.

CHAPTER -5

CONCLUSIONS

The following conclusions can be made from this study:

1. As time goes on temperature is found to increase & it is the maximum at 2.30 P.M. to 3.00 P.M. After 3.00 P.M. temperature begines to decrease.

2. Temperature is found to be maximum at a depth of .7m to .8m.

3. During the second day of running temperature at a particular day time & at a particular layer is found to be higher than that of 1st day of running.

Suggestions for Future Work:

The following suggestions are made future work.

1. Heat removal : A heat Exchanger should be designed for this aspect.

2. Perimeter heat loss: For a small pond, most of the absorbed and stored heat are lost through the perimeter. For large pond, this loss is negligible. So by providing good insulation, the pond should be studied.

3. Maintenance of salinity gradient: It requires surface washing and salt replerishment.

4. Gradient zone thickness: An optimum gradient zone thickness should be found out for maximum heat removal.

5. Zone boundary control: There is a tendency to increase the thickness of the upper convective layer and simultaneously the upper boundary layer of the lower convective zone tends to move upward and as a result the gradient zone thickness decreases. So, the zone boundary should be controlled.

6. Control of Wind effects: Wind generates waves and surface drift. The kinetic energy of the waves and surface drifts is partly converted into potential energy by mixing lighter upper layer brine with denser lower layer brine and partly dissipated by viscosity.

The thickness of the surface convective zone is greatly increased by a wind storm. New interval convective layers deep in the pond near the lower boundary of the gradient zone have been observed following service wind. It is suggested that wave ampitudes can be controlled by floating wave barries on the pond surface.

7. Fasibility of the pond in Bangladesh. Where there are frequent cyclone, heavy rainfall and other natural calamities may cause an adverse effect on a solar pond.

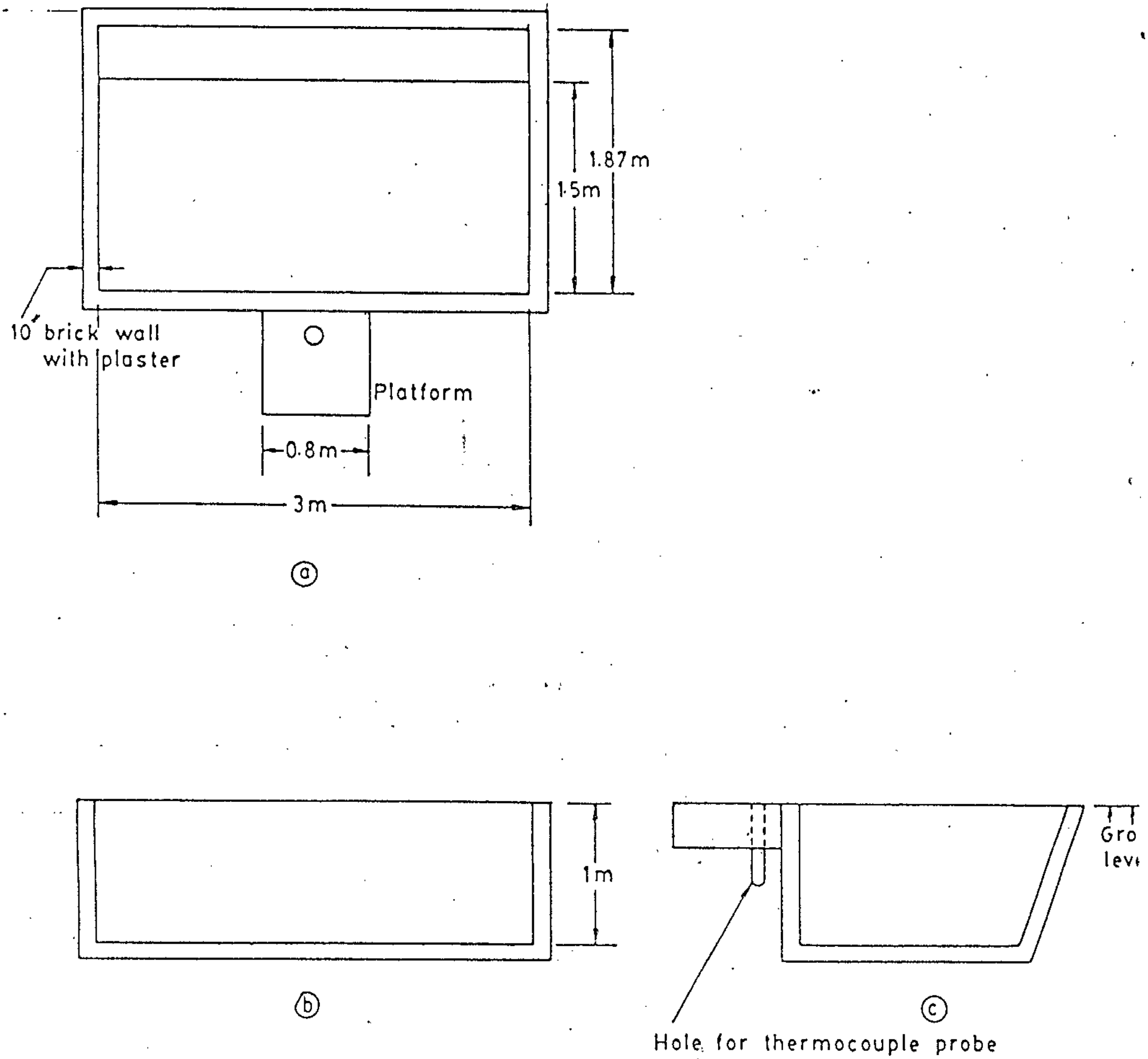

FIG. 3.1 A TYPICAL VIEW OF A SOLAR POND

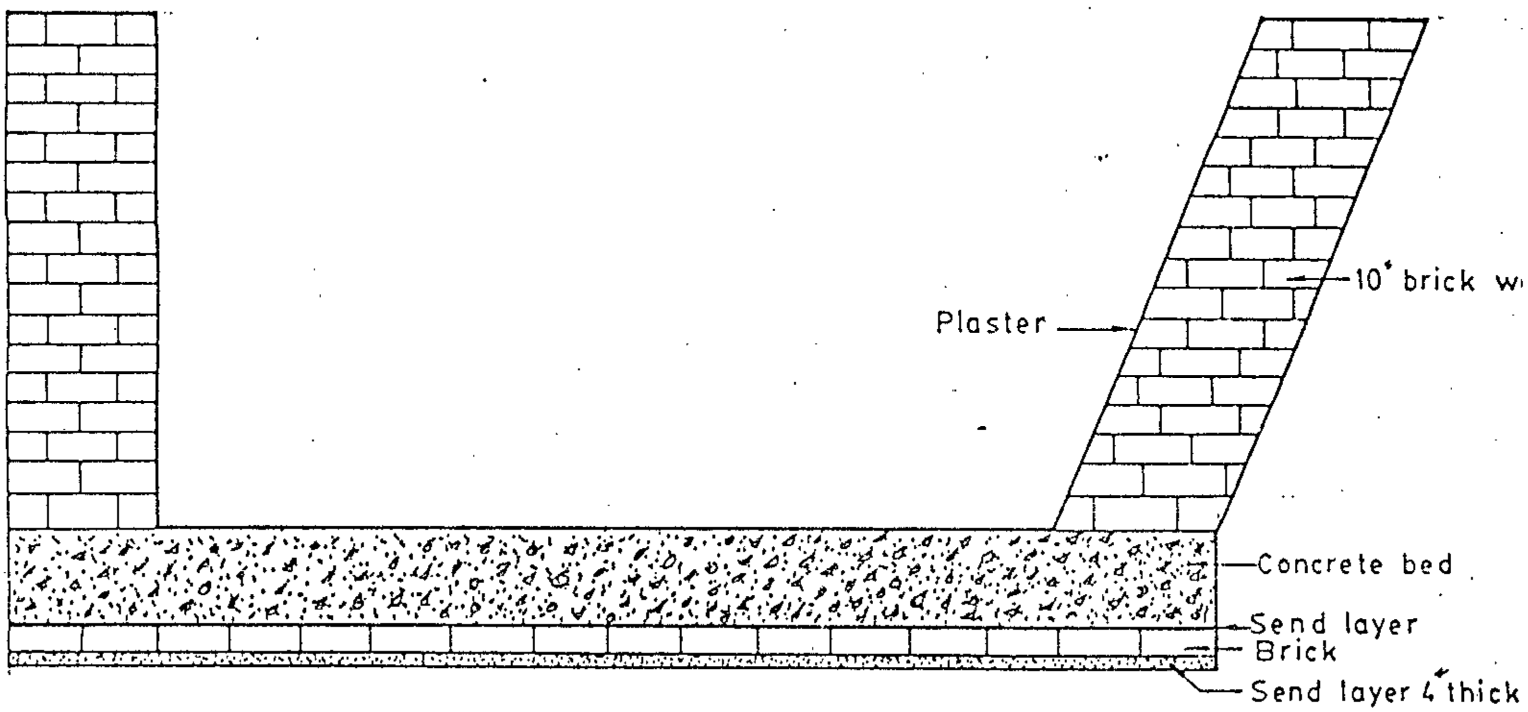

FIG. 3.2 DETAILS OF SOLAR POND

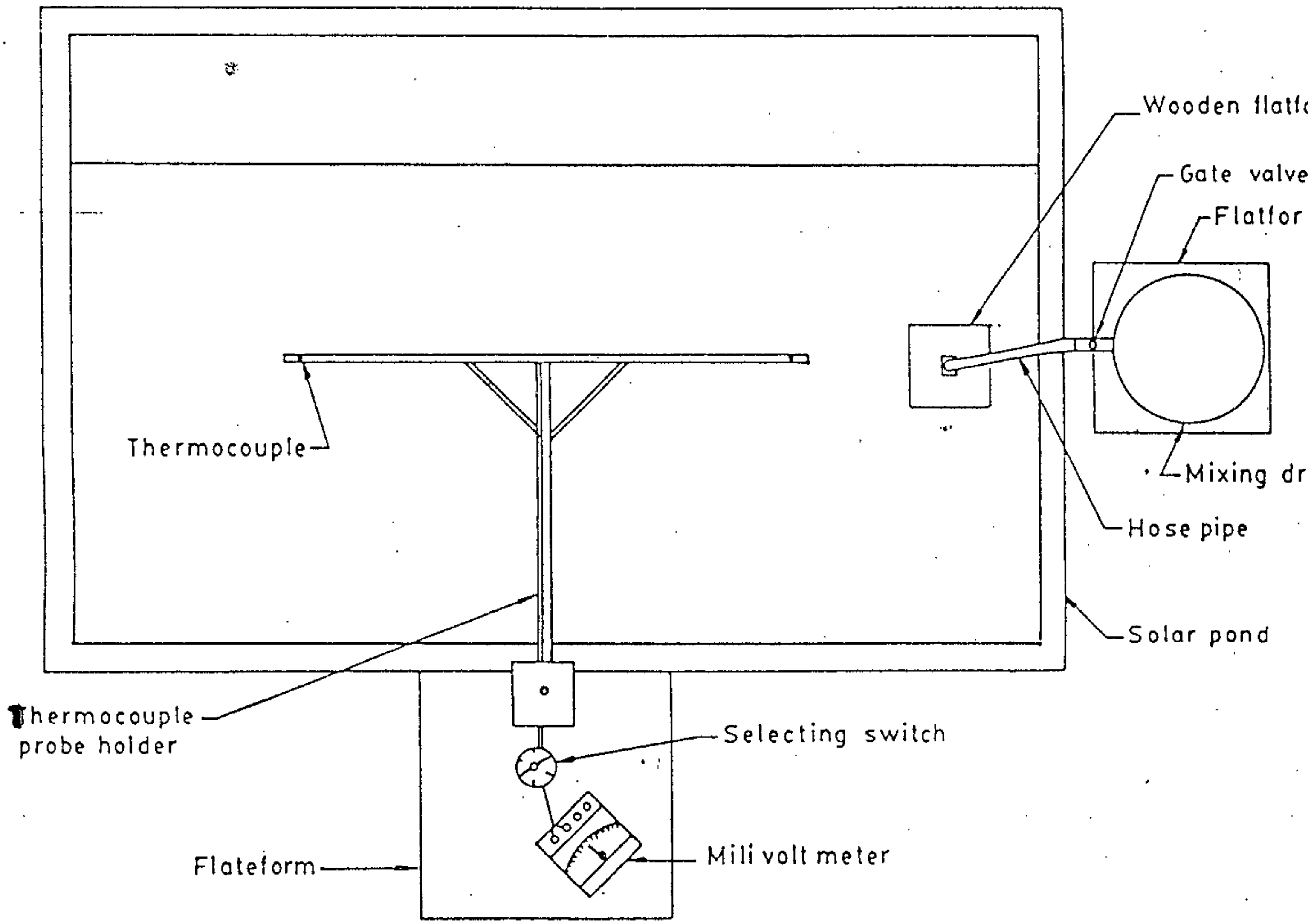

FIG. 3.3 SCHEMATIC DIAGRAM OF SOLAR POND

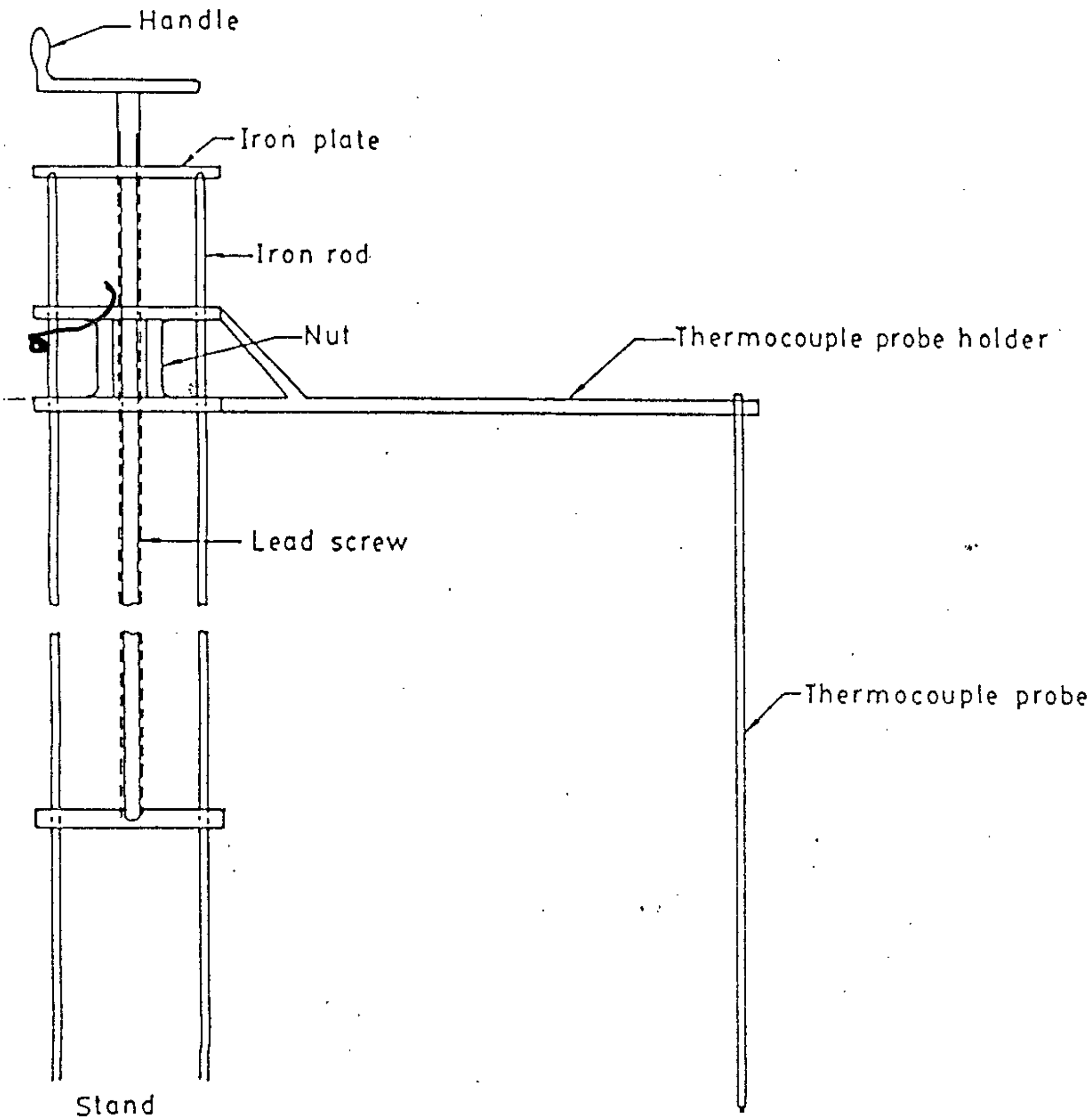

FIG. 3.4 THERMOCOUPLE PROBE WITH ITS STAND

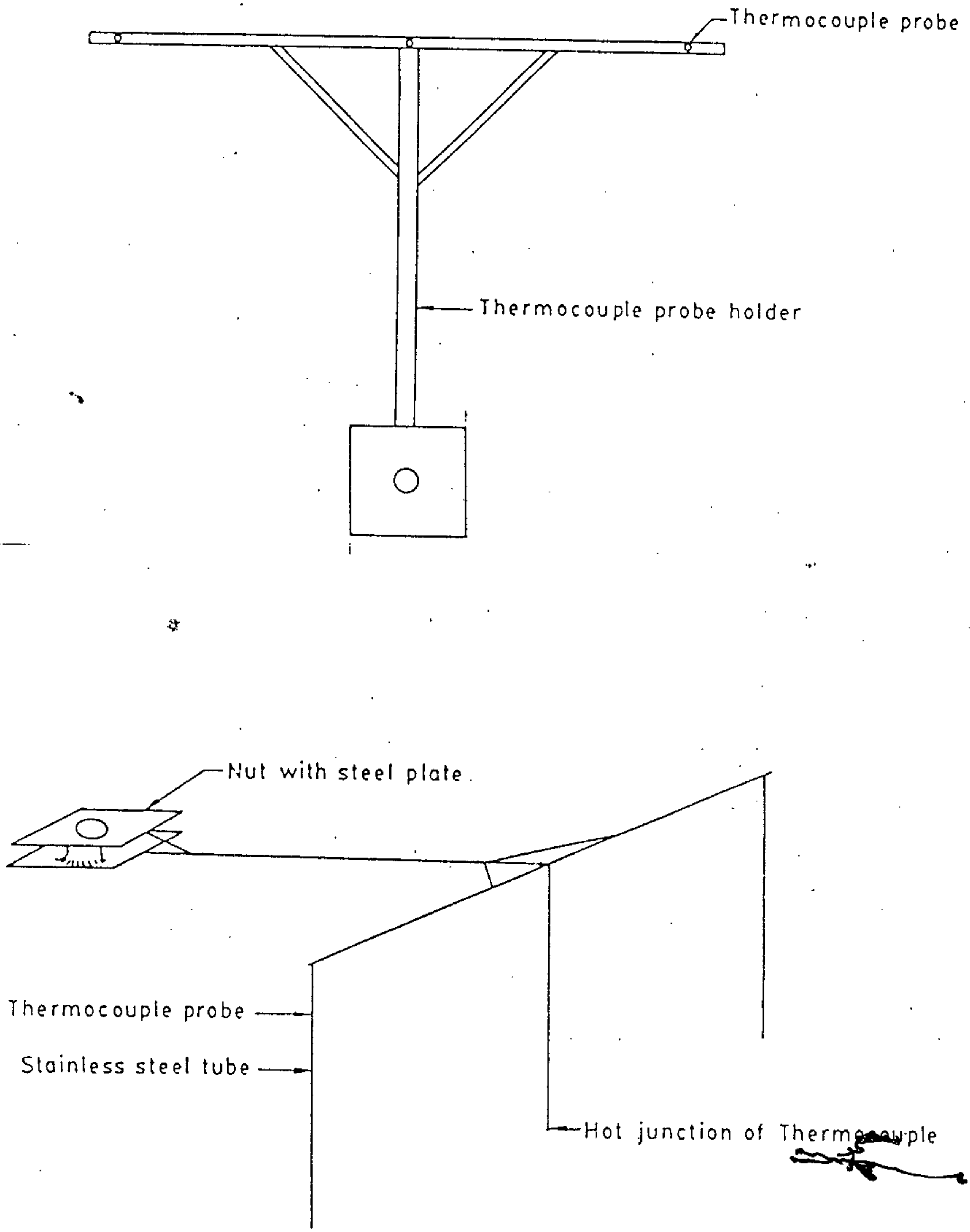

FIG. 3.5 DETAILS OF THERMOCOPLE PROBE

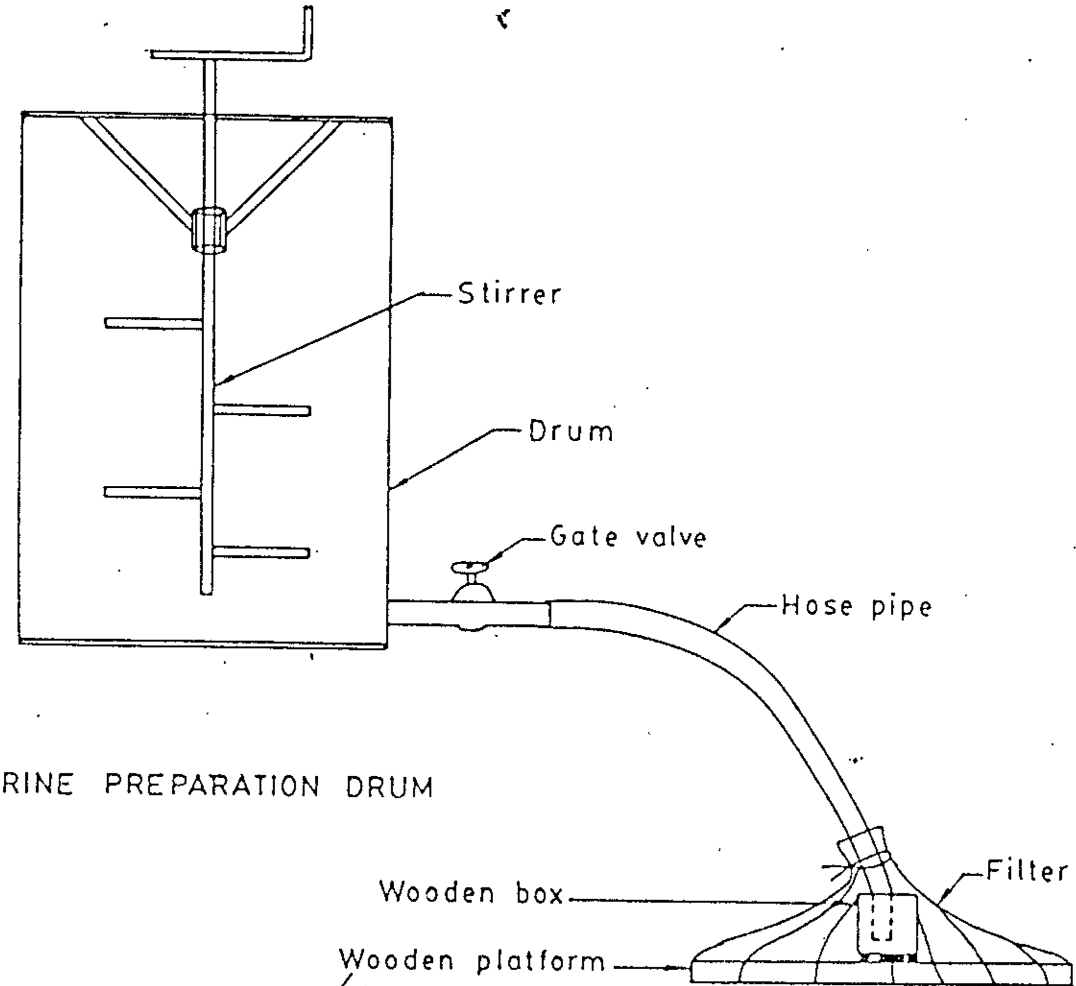

FIG. 3.6 BRINE PREPARATION DRUM

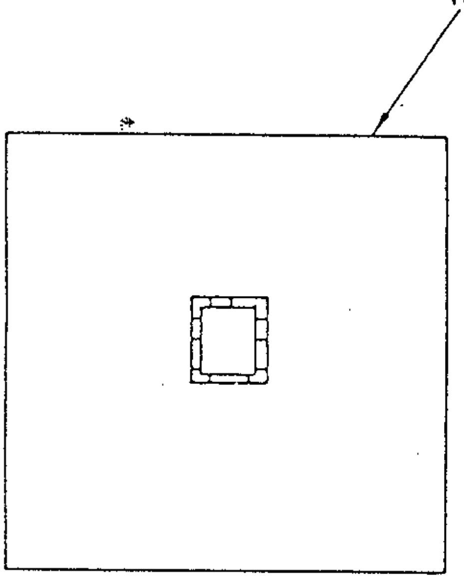

FIG. FIG. WOODEN PLATFORM FOR BRINE POURING

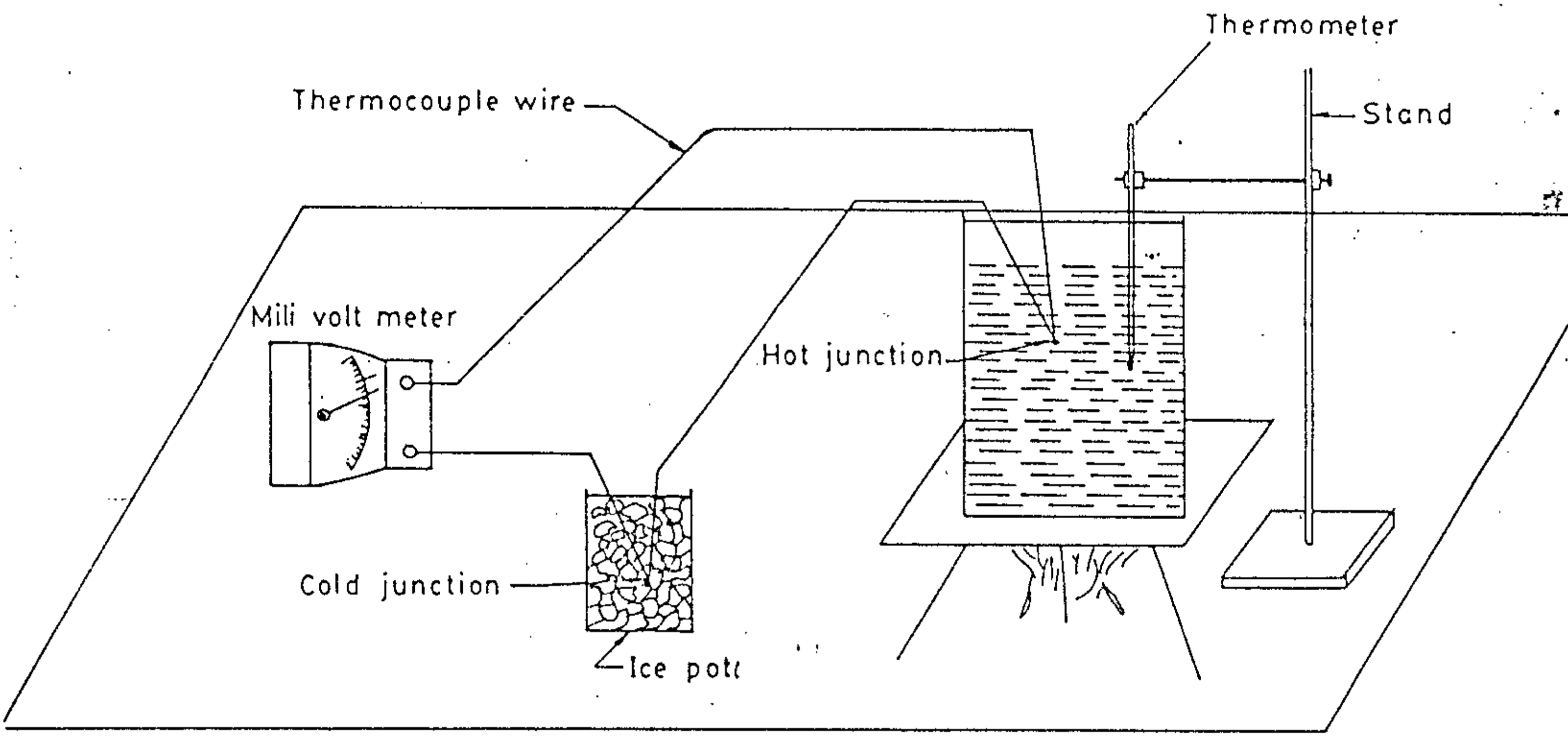

FIG. 3.8 CALIBRATION OF THE THERMOCOUPLE

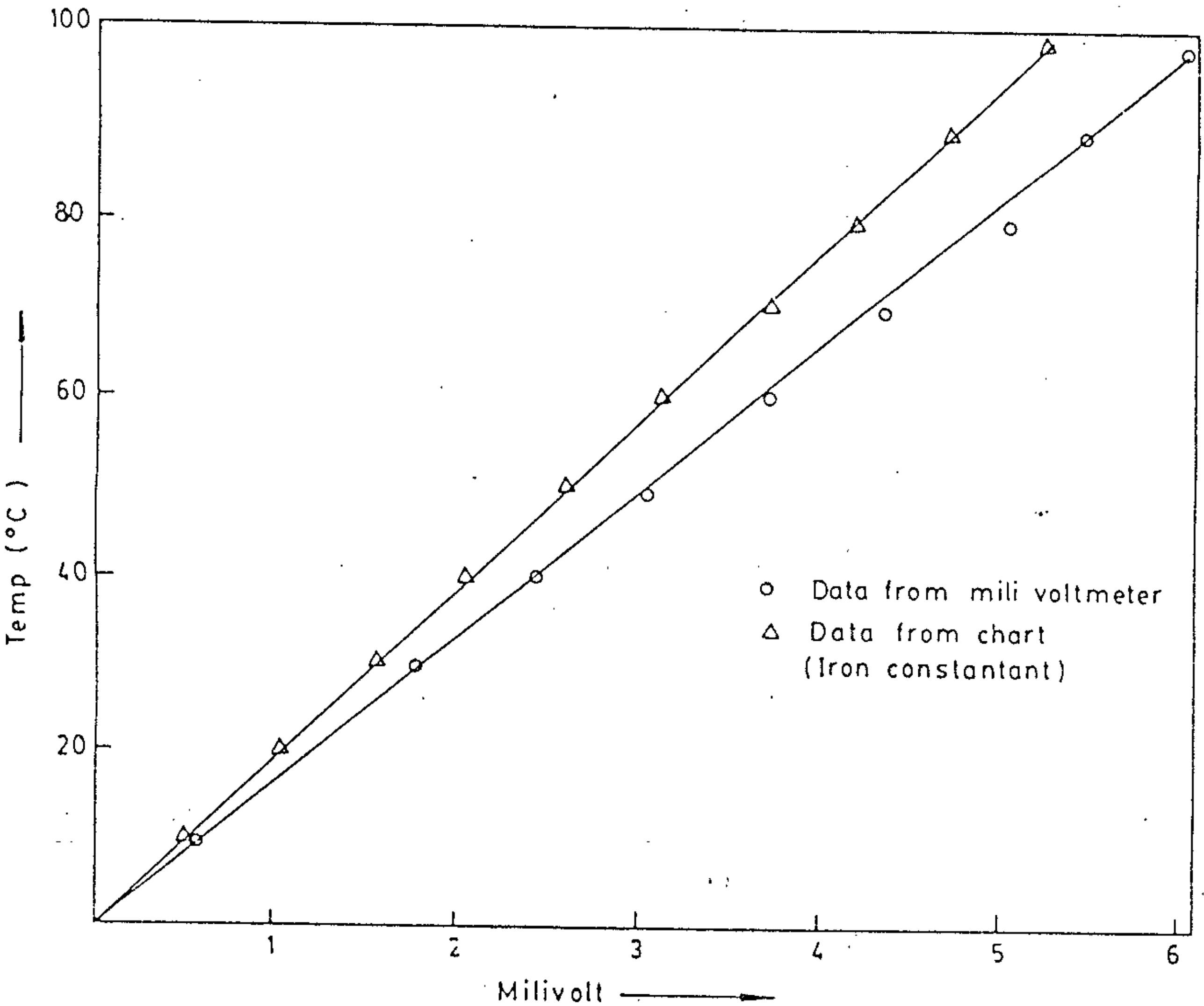

FIG. 3.9 CALIBRATION OF THERMOCOUPLE

APPENDIX - A

Calibration of ~~Iron-Constantant~~ Chromel-Alumel Thermocouple.

No. of obs.	Temp. reading (°C)	Millivolt meter reading	Millivolt meter reading (mv) from chart
1	0	0	0
2	10	0.56	0.518
3	20	1.04	1.0416
4	30	1.76	1.554
5	40	2.46	2.06
6	50	3.04	2.61
7	60	3.76	3.14
8	70	4.38	3.66
9	80	5.08	4.21
10	90	5.50	4.74
11	100	6.10	5.282

APPENDIX - B

Measurement of Temperature by Thermocouple

1st set of reading (after 1 day of running the Pond)

Ambient temp. = 31°C, at 9.00 AM

Depth (cm)	Thermocouple no. 1 (mv)	2 (mv)	3 (mv)	Average (mv)
0	0.0	0.0	0.0	0.0
10	0.2	0.22	0.18	0.2
20	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0
40	0.04	0.06	0.05	0.05
50	0.0	0.0	0.0	0.0
60	0.06	0.05	0.04	0.05
70	0.24	0.25	0.26	0.25
80	0.28	0.31	0.30	0.3
90	0.18	0.20	0.22	0.2
100	0.05	0.06	0.04	0.05

2nd set at 11.00 AM, Ambient temp. 34°C

Depth (cm)	Thermocouple no. 1 (mv)	2 (mv)	3 (mv)	Average (mv)
0	0.45	0.47	0.44	0.45
10	0.49	0.47	0.48	0.48
20	0.48	0.47	0.49	0.48
30	0.36	0.34	0.35	0.35
40	0.37	0.35	0.34	0.353
50	0.45	0.46	0.44	0.45
60	0.49	0.50	0.51	0.50
70	0.56	0.55	0.54	0.55
80	0.5	0.5	0.49	0.50
90	0.46	0.44	0.45	0.45
100	0.4	0.39	0.41	0.40

3rd set of reading (after 1 day of running the Pond)
Ambient Temp. = 38°C, at 12.30 PM

Depth (cm)	Thermocouple no. 1 (mv)	2 (mv)	3 (mv)	Average (mv)
0	0.7	0.81	0.8	0.8
10	0.7	0.68	0.72	0.7
20	0.68	0.67	0.65	0.67
30	0.61	0.6	0.59	0.6
40	0.5	0.5	0.5	0.5
50	0.4	0.39	0.41	0.4
60	0.45	0.44	0.46	0.45
70	0.6	0.58	0.62	0.6
80	0.59	0.6	0.61	0.6
90	0.5	0.5	0.5	0.5
100	0.8	0.78	0.82	0.8

4th set at 2.00 PM, Ambient Temp. 39°C

Depth (cm)	1 (mv)	2 (mv)	3 (mv)	Average (mv)
0	.05	.05	.05	.05
10	.13	.15	.17	.15
20	.05	.06	.04	.05
30	.0	.0	.0	.0
40	.05	.05	.05	.05
50	.04	.06	.05	.05
60	.45	.44	.46	.45
70	.5	.51	.49	.5
80	.45	.47	.43	.45
90	.65	.64	.65	.65
100	.65	.65	.65	.65

5th set of reading (after 1 day of running the Pond)
Ambient Temp. = 37°C at 3.30 PM

Depth (cm)	Thermocouple no. 1 (mv)	2 (mv)	3 (mv)	Average (mv)
0	0.15	0.14	0.16	0.15
10	0.29	0.30	0.31	0.3
20	0.16	0.15	0.14	0.15
30	0.1	0.09	0.11	0.1
40	0.0	0.0	0.0	0.0
50	0.3	0.29	0.31	0.3
60	0.48	0.47	0.46	0.47
70	0.4	0.41	0.39	0.4
80	0.47	0.46	0.48	0.47
90	0.5	0.48	0.51	[illegible]
100	[illegible]	[illegible]	0.7	[illegible]

6th set at 5.00 PM Ambient temp. 34°C

Depth (cm)	Thermocouple no. 1 (mv)	2 (mv)	3 (mv)	Average (mv)
0	0.0	0.0	0.0	0.0
10	0.1	0.09	0.11	0.1
20	0.15	0.16	0.14	0.15
30	0.1	0.1	0.1	0.1
40	0.0	0.0	0.0	0.0
50	0.1	0.1	0.1	0.1
60	0.16	0.14	0.15	0.15
70	0.25	0.26	0.24	0.25
80	0.4	0.39	0.41	0.4
90	0.5	0.5	0.5	0.5
100	0.5	0.52	0.48	0.5

1st set of reading (2nd day of running the Pond)
Ambient Temp. = 32°C at 11.00 AM

Depth (cm)	Thermocouple no. 1 (mv)	2 (mv)	3 (mv)	Average (mv)
0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0
30	0.08	0.09	0.07	0.08
40	0.15	0.2	0.19	0.18
50	0.18	0.18	0.19	0.185
60	0.42	0.45	0.47	0.45
70	0.33	0.34	0.32	0.34
80	0.29	0.28	0.27	0.28
90	0.22	0.25	0.22	0.23
100	0.23	0.24	0.22	0.23

2nd set at 11.00 AM, Ambient Temp. 34°C

Depth (cm)	1 (mv)	2 (mv)	3 (mv)	Average (mv)
0	0.0	0.0	0.0	0.0
10	0.05	0.04	0.06	0.05
20	0.25	0.26	0.24	0.25
30	0.2	0.2	0.2	0.2
40	0.3	0.29	0.31	0.3
50	0.25	0.26	0.25	0.25
60	0.2	0.2	0.2	0.2
70	0.3	0.3	0.3	0.3
80	0.31	0.29	0.3	0.3
90	0.23	0.25	0.26	0.25
100	0.35	0.36	0.34	0.35

3rd set of reading (2nd day of running the Pond)

Ambient Temp. = 35°C at 1.00 PM

Depth (cm)	Thermocouple no.			Average (mv)
	1 (mv)	2 (mv)	3 (mv)	
0	0.0	0.0	0.0	0.0
10	0.05	0.05	0.05	0.05
20	0.0	0.0	0.0	0.0
30	0.15	0.16	0.14	0.15
40	0.25	0.26	0.24	0.25
50	0.2	0.2	0.2	0.2
60	0.25	0.26	0.24	0.25
70	0.23	0.24	0.22	0.23
80	0.2	0.2	0.2	0.2
90	0.19	0.21	0.2	0.2
100 *	0.3	0.32	0.29	0.3

4th set at 2.00 PM, Ambient Temp. 38°C

0	0.2	0.2	0.2	0.2
10	0.35	0.37	0.36	0.36
20	0.4	0.41	0.39	0.4
30	0.5	0.5	0.5	0.5
40	0.3	0.3	0.3	0.3
50 *	0.29	0.31	0.3	0.3
60	0.29	0.32	0.29	0.3
70	0.1	0.1	0.1	0.1
80	0.2	0.21	0.19	0.2
90	0.29	0.32	0.29	0.3
100	0.5	0.5	0.5	0.5

5th set of reading (2nd day of running the Pond)
Ambient Temp. = 38°C at 3.00 PM

Depth (cm)	Thermocouple no. 1 (mv)	2 (mv)	3 (mv)	Average (mv)
0	0.34	0.36	0.35	0.35
10	0.45	0.45	0.45	0.45
20	0.15	0.16	0.14	0.15
30	0.4	0.42	0.39	0.4
40	0.15	0.15	0.15	0.15
50	0.15	0.16	0.14	0.15
60	0.14	0.16	0.15	0.15
70	0.15	0.15	0.15	0.15
80	0.19	0.22	0.2	0.2
90	0.34	0.36	0.35	0.35
100	0.4	0.4	0.4	0.4

5th set at 5.00 PM, Ambient Temp. 35°C

Depth (cm)	1 (mv)	2 (mv)	3 (mv)	Average (mv)
0	0.2	0.2	0.2	[illegible]2
10	0.24	0.26	0.25	0.25
20	0.1	0.1	0.1	0.1
30	0.15	0.15	0.15	0.15
40	0.14	0.16	0.15	0.15
50	0.05	0.05	0.05	0.05
60	0.08	0.12	0.1	0.1
70	0.17	0.2	0.18	0.18
80	0.19	0.21	0.2	0.2
90	0.34	0.36	0.35	0.35
100	0.37	0.39	0.38	0.38

32 W

Conversion of thermocouple reading (mv) to temperature

1st set of reading (1st day of running the Pond)
Ambient Temp. 31°C at [illegible].00 AM

Depth (cm)	0	10	20	30	40	50	60	70	80	90	
Ave. (mv)	0	0.2	0	0	.05	0	.05	.25	.3	.2	
Correc.(mv)	1.8	2	1.8	1.8	1.85	1.8	1.85	2.05	2.1	2	1[illegible]
Temp. °C	31	32.5	31	31	31.5	31	31.5	33	34.5	32.5	[illegible]

2nd set at 11.00 AM, Ambient Temp. 34°C

Depth (cm)	0	10	20	30	40	50	60	70	80	90	
Ave. (mv)	.45	.48	.48	.35	.35	.45	.5	.55	.5	.45	
Correc.(mv)	2.25	2.28	2.28	2.15	2.15	2.25	2.3	2.35	2.3	2.25	
Temp. °C	37	37.5	37.5	35	35	37	38	39	38	37	3[illegible]

3rd set at 12.30 PM, Ambient Temp. 38°C

Depth (cm)	0	10	20	30	40	50	60	70	80	90
Ave. (mv)	0.8	0.7	0.67	0.6	0.5	0.4	0.45	0.6	0.6	0.5
Correc.(mv)	2.6	2.5	2.47	2.4	2.3	2.2	2.25	2.4	2.4	2.3
Temp. °C	43.5	42	41.5	40	38	36.5	37	40	39.5	38

4th set of reading (1st day of running the Pond)
Ambient Temp. 39°C at 2.00 PM

Depth (cm)	0	10	20	30	40	50	60	70	80	90	100
Ave. (mv)	0.05	0.15	0.05	0	0.05	0.05	0.45	.5	.45	.65	.65
Correc.(mv)	2.4	2.5	2.4	2.35	2.4	2.4	2.8	2.85	2.8	3	3
Temp. °C	40	42	40	39	39.5	40	46	47	46.5	49	49

5th set at 3.30 PM, Ambient Temp. 37°C

Depth (cm)	0	10	20	30	40	50	60	70	80	90	100
Ave. (mv)	.15	.5	.15	.1	0	0.3	.47	.4	.47	.5	.6
Correc.(mv)	2.35	2.5	2.35	2.3	2.2	2.5	2.67	2.6	2.67	2.7	[illegible]
Temp. °C	39	41	39	38	37	41	44	43	44	44.5	46

6th set at 5.00 PM, Ambient Temp. 34°C

Depth (cm)	0	10	20	30	40	50	60	70	80	90	100
Ave. (mv)	0	0.1	0.15	0.1	0	0.1	0.15	.25	.4	.5	.5
Correc.(mv)	2	2.1	2.15	2.1	2	2.1	2.15	2.25	2.4	2.5	2.5
Temp. °C	34	35	35.5	35	34	35	35.5	37	40	41	41

Conversion of thermocouple reading (mv) to temperature

1st set of reading (2nd day of running the Pond)

Ambient Temp. 32°C at 9.00 AM

Depth (cm)	0	10	20	30	40	50	60	70	80	90	100
Ave. (mv)	0	0	0	.08	0.18	.185	.45	.33	.28	.23	.23
Correc.(mv)	1.82	1.82	1.82	1.9	2.0	2.05	2.3	2.15	2.1	2.05	2.05
Temp. °C	32	32	32	32.5	33	34	38	35	34	33	33

2nd set at 11.00 AM, Ambient Temp. 34°C

Depth (cm)	0	10	20	30	40	50	60	70	80	90	100
Ave. (mv)	0	.05	.25	.2	.3	.25	.2	.3	.3	.25	.35
Correc.(mv)	2.0	2.05	2.25	2.2	2.3	2.25	2.28	2.3	2.3	2.25	2.35
Temp. °C	34	34.5	37	36	37.5	36.5	36	38	38	37	39

3rd set at 1.00 PM, Ambient Temp. 35°C

Depth (cm)	0	10	20	30	40	50	60	70	80	90	100
Ave. (mv)	0	.05	0	.15	.25	.2	.25	.23	.2	.2	.3
Correc.(mv)	2.1	2.15	2.1	2.25	2.35	2.3	2.35	2.33	2.3	2.3	2.4
Temp. °C	35	35.5	35	37	39	38	39	38.5	38	38	40

4th set of reading (2nd day of running the Pond)
Ambient Temp. 38°C at 2.00 PM

pth (cm)	0	10	20	30	40	50	60	70	80	90	100
e. (mv)	.2	.36	.4	.5	.3	.3	.3	.1	.2	.3	.5
rrec.(mv)	2.5	2.65	2.7	2.8	2.6	2.6	2.6	2.4	2.5	2.6	2.8
mp. °C	42.5	43.5	44	45	43	43	43	40	41	43	45

5th set at 3.00 PM, Ambient Temp. 38°C

pth (cm)	0	10	20	30	40	50	60	70	80	90	100
e. (mv)	.35	.45	.15	.4	0.15	.15	.15	.15	.2	.35	.4
rrec.(mv)	2.65	2.75	2.45	2.7	2.45	2.45	2.43	2.45	2.5	2.56	2.7
mp. °C	43.5	44.5	42	44	42	41	42	41	41.5	43.5	44

6th set at 5.00 PM, Ambient Temp. 35°C

pth (cm)	0	10	20	30	40	50	60	70	80	90	100
e. (mv)	.2	.25	0.1	0.15	0.15	0.05	0.1	.18	.2	.35	.35
rrec.(mv)	2.3	2.35	2.2	2.25	2.25	2.15	2.2	2.28	2.3	2.45	2.48
mp. °C	38.5	39	36.5	37	37	36	36.5	37.5	38	41	42

REFERENCES

1. A. Rabl and C.E., Nelson-"Solar pond for space heating". Solar Energy 17 (1) (1975).

2. Carle Nielson, The Ohio State University,"Non-convective salt, gradient solar ponds".

3. Chair Batty, Paul Riley, Nitin K. Bhise of Ultah State University, Solar Energy-Journal volume-36,Nov.1, 1986.

4. Daffie and Beckman, " Solar Energy Thermal Process ".

5. G.D. Rai, " Solar Energy Utilization ".

6. H. Tabor, " Non-convective Solar Ponds ".

7. H. Tabor, " Solar Pond " Solar Energy Journal 7, 189-194 (1963).

8. H. Tabor " Solar Pond ", Solar Energy Vol. 27,1981.

9. J.F. Atkinson, J. Munich and D.R. Harlman- "A Note on Gradient maintenance in a salt gradient solar pond ", Solar Energy Volume 34, No.2 (163-169, 1985.

10. J.R. Hull, K.V. Liu, W.T. Sha, Jyoti Kamal and Nielson, "Solar Energy", Vol. 33, No. 1, PP. 25-33, 1984.

11. Jhon R. Hul, " Solar Energy ", Vol. 35, No.3, PP. 211-217, 1985.

12. M. Rothmeyer " New Mexico University ".

13. Shah, Ted and Peter, " Ohio Agricultural Research and Development.

14. S.B. Savage, " Solar Pond ".

15. Weinberger, " The Physics of Solar Pond "-Solar Energy Journals 8, (45-46) (1964).

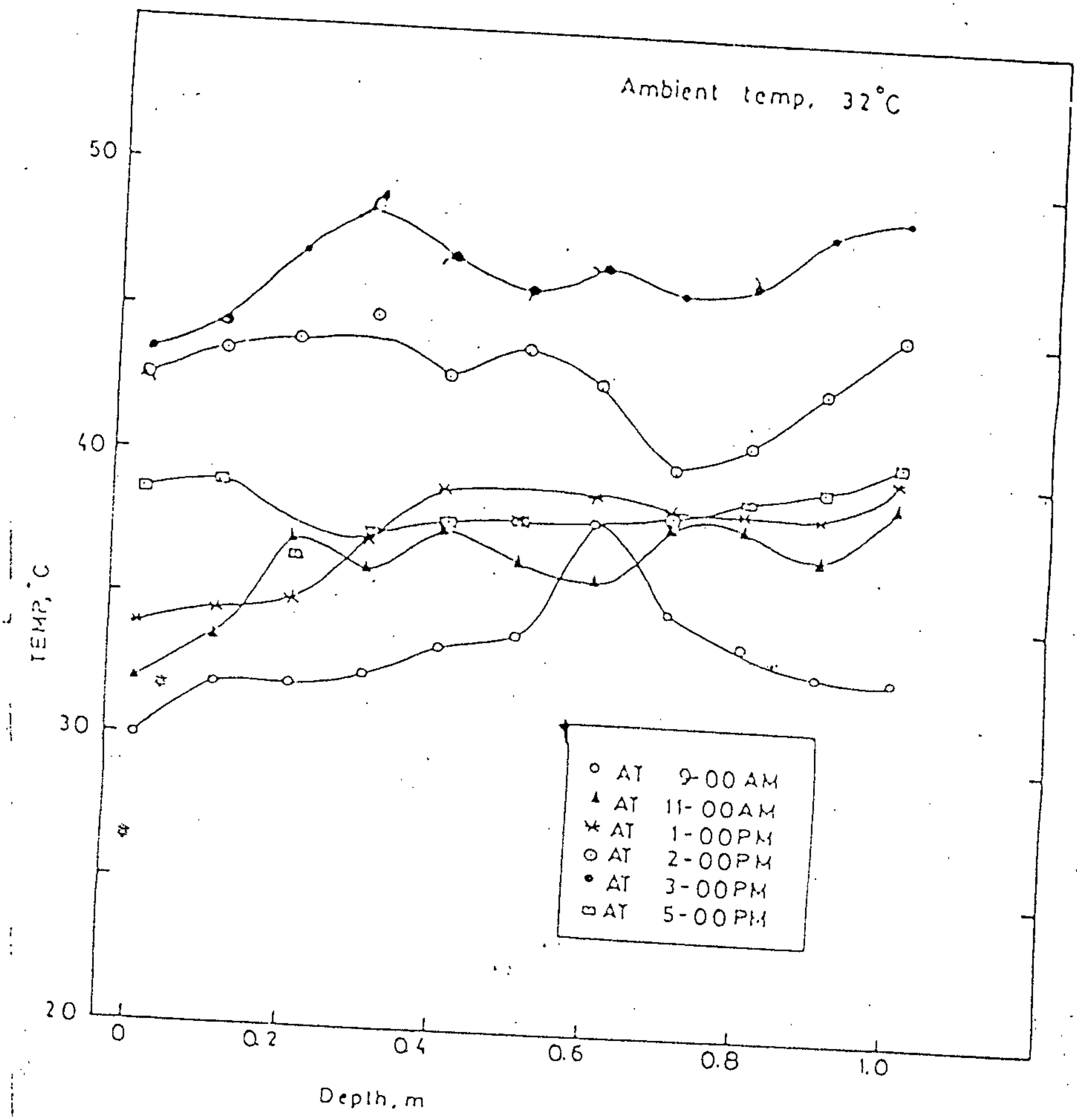

FIG: 5.4 TEMPERATURE DISTRIBUTION (2nd day of running)

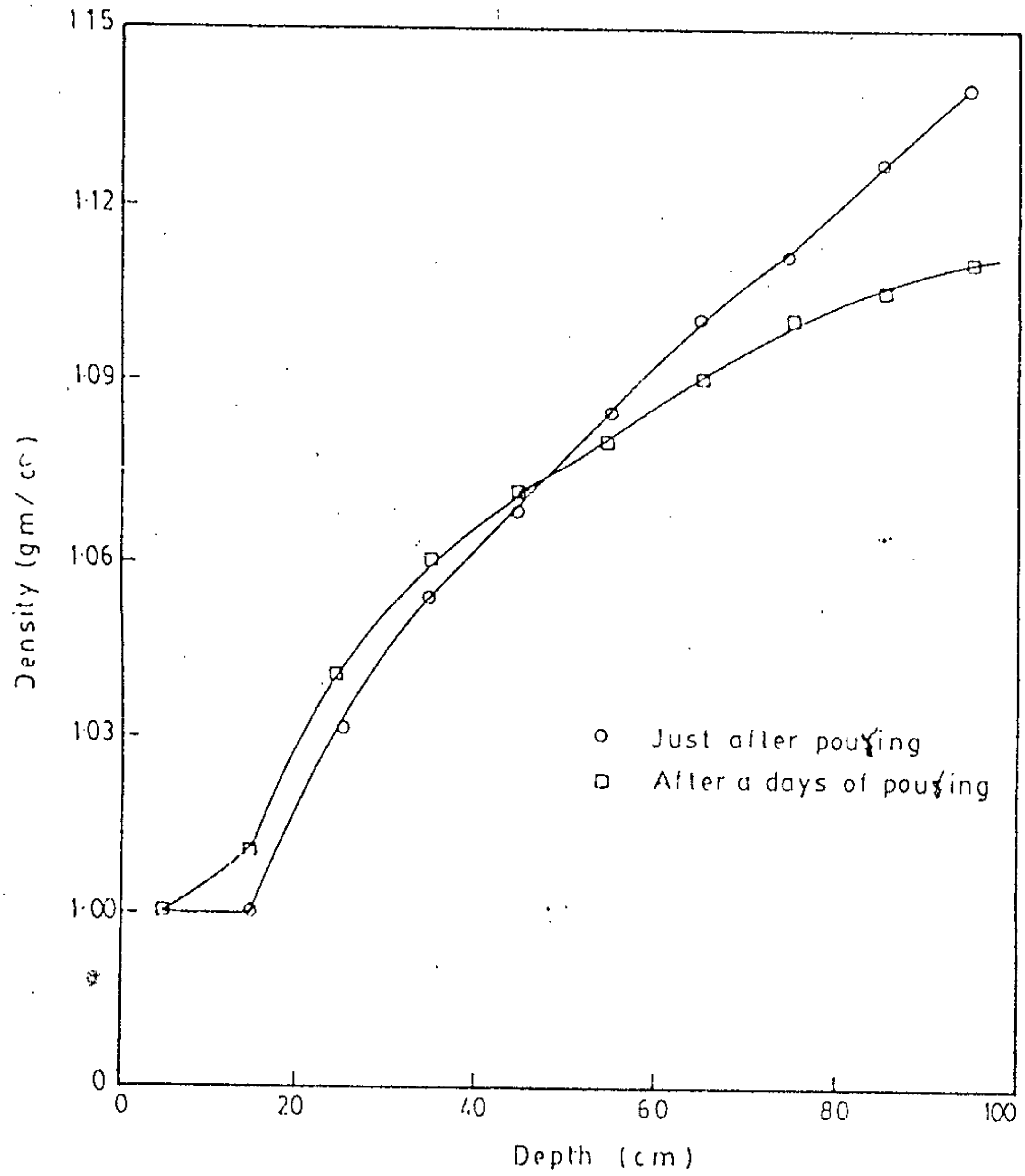

FIG.5.5 DIFFUSION OF SALT THROUGH THE LAYER

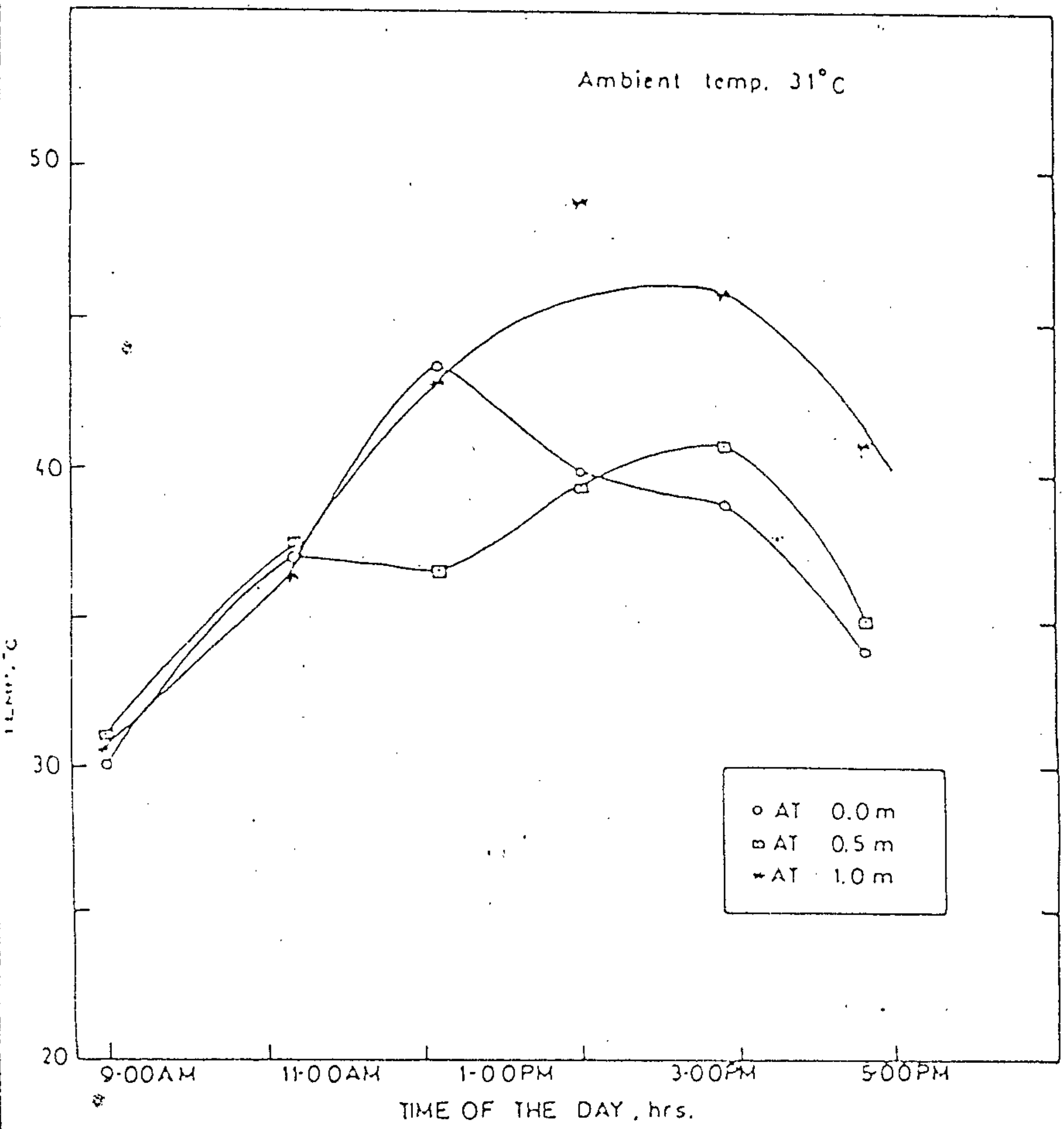

FIG: 5·1 TEMPERATURE DISTRIBUTION (1st day of running)

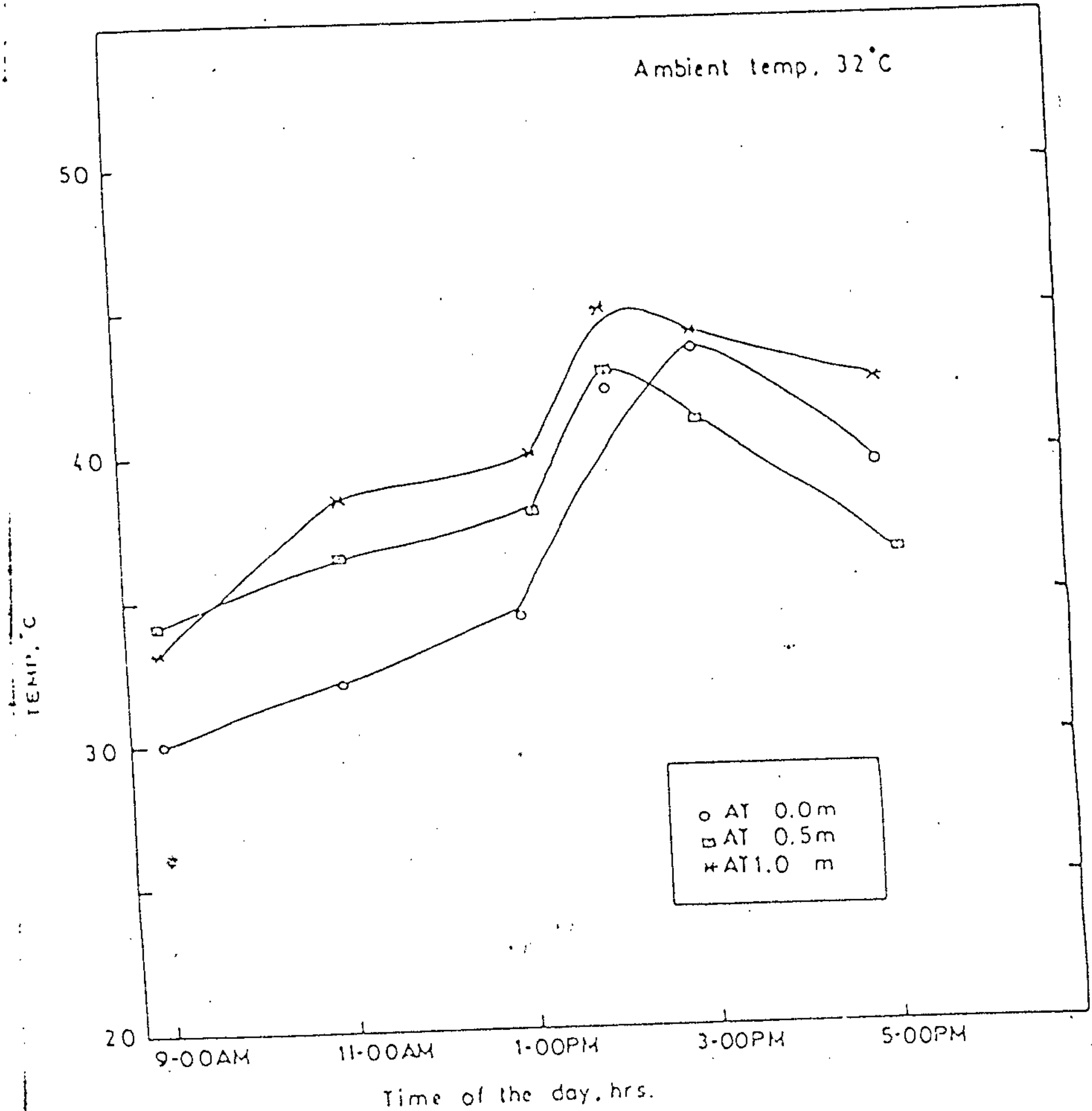

FIG: 5.2 TEMPERATURE DISTRIBUTION (2nd day of running)

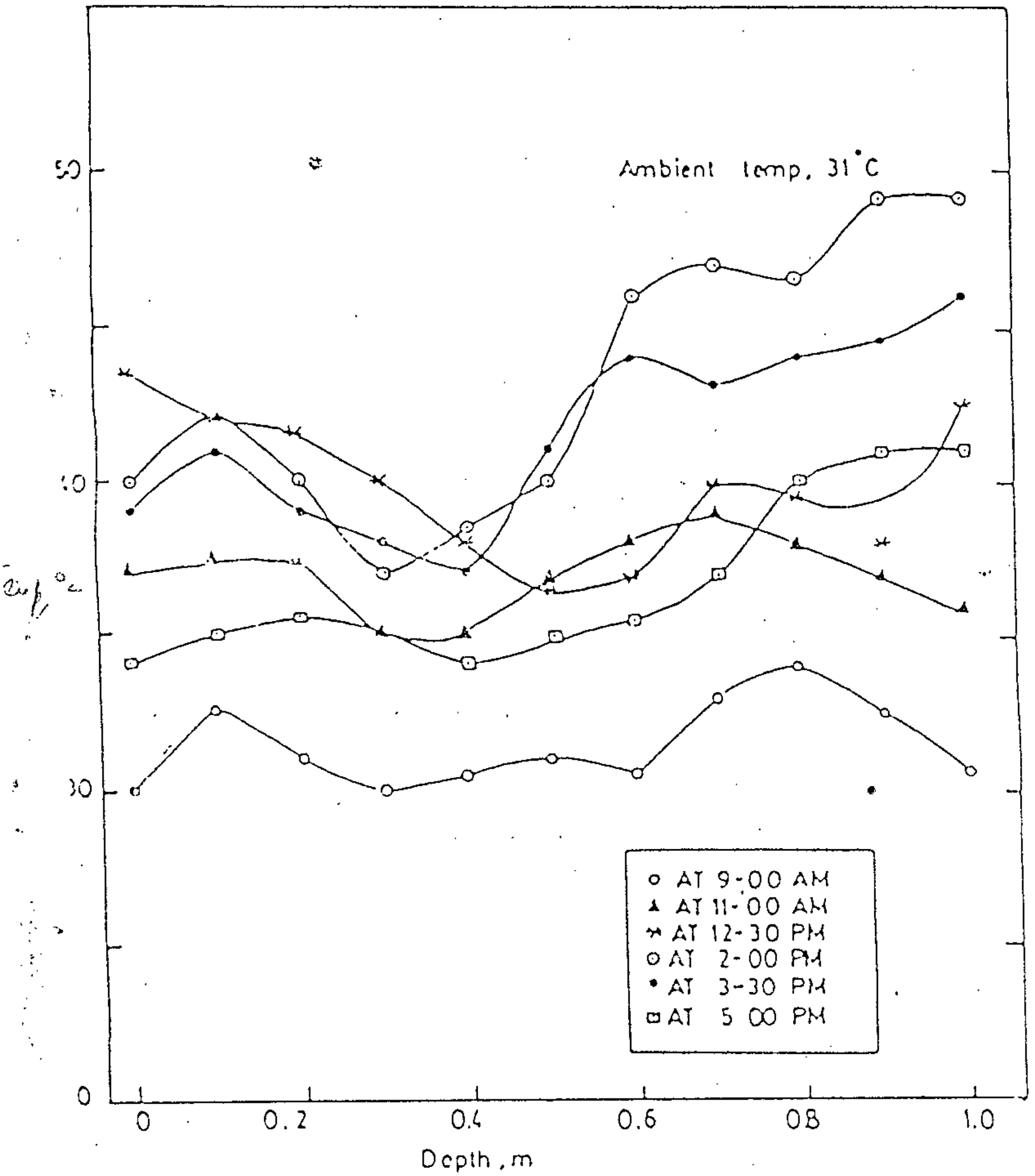

FIG: 5.3 TEMPERATURE DISTRIBUTION (1st day of runnig)