Mansoura Engineering Journal, (MEJ), Vol. 22, No. 2, June 1997.

PERFORMANCE OF A SMALL SALTLESS SOLAR POND AUGMENTED BY PLANAR MIRROR

دراسة اداء بركة شمسية مزودة بسطح مستو عاكس ،

AHMED M. HAMED, H.E. GAD and S. S. EL SAYED
Mechanical Power Engineering Dept., Faculty of Engineering
Mansoura university, EL-Mansoura, Egypt.

خلاصة : يستعرض البحث نتائج التجارب العملية لبركة شمسية صغيرة مزودة بسطح مستو عاكس . وقد أجريت التجارب بكلية الهندسة جامعة المنصورة (خط عرض 31°N). وكانت البركة عبارة عن حوض بسطح مربع (1.23m x 1.23m) وعمق مياه 0.83m ومثبت معه عاكس رأسي ارتفاعه 1.6m وعرضه 2.5m مشترك مع سطح البركة في الحافة ومتجه الى الجنوب. وقد استخدمت شرائح بلاستيكية رقيقة شفافة كعازل للسطح العلوي. وقد تم قياس الأشعاع الشمسي المقوى بالعاكس ومقارنته بالقيم المحسوبة وكانت النتائج مرضية. كما بينت النتائج أن درجة حرارة سطح البركة تصل في شهر اكتوبر الى حوالي 60°C بكفاءة تتراوح ما بين 50% الى 66% .

ABSTRACT

In the present study, the performance of a small saltless solar pond augmented by planar reflector is presented. Experiments are carried out in the Faculty of Engineering, Mansoura University, Egypt (31° N). The experimental pond has a surface of 1.23 m x 1.23 m and 0.83 m water depth. A glass mirror with 1.6 m height and 2.5 m width is supported in a common edge with the pond surface. The glass reflector is south facing and vertical in position. Plastic films are used as a top covers for the pond surface. Measurements of solar radiation, ambient temperature and water temperatures at different heights in the pond are carried out. Measured augmented solar radiation is compared with that predicted by the radiation enhancement model. The comparison has shown a good agreement between the measured and the predicted data. The temperature gradient through the storage zone of the pond ranges around 5 °C, and the upper layer of water is highly dependent on the ambient conditions. Temperatures of the plastic layers are presented during the day time, and also during the build-up period. Water temperature on the pond surface of more than 60 °C could be attained in October, with a pond efficiency ranges from about 50 % up to 66 %.

INTRODUCTION

Solar ponds are simply constructed using relatively inexpensive materials. For some applications, They will provide as much or more heat per unit collector area as conventional systems and thus they are economically attractive. Also, solar ponds provide inexpensive means for collecting and storing solar energy at temperatures below 100 °C [1]. The salt-gradient solar pond usually suffers from some major drawbacks: (i) energy harvesting must be done in a well-controlled, sometimes complicated manner, in order to preserve the salt gradient; (ii) a large salt - base solar pond may endanger the quality of the ground water basin; and (iii) large amount of salt are required [2]. However, several concepts of saltless solar ponds have been proposed in order to alleviate these drawbacks [3-6]. Membrane-stratified pond [4] and honeycomb-stratified pond [5] are examples of these concepts. Also, a saltless solar pond with a semi-transparent multilayer surface insulation system has been proposed [7-10].

A few advantages of saltless solar ponds are given by [11] as : (i) since no salt is used in these ponds, they can be made maintenance free and low cost; (ii) there is no environmental or geological hazard with saltless ponds and (iii) a large depth of lower convective zone can be maintained in a saltless pond resulting in seasonal storage, less diurnal temperature variation, and higher collection efficiency. Although solar pond has the potential to become the most economical method for the collection of solar energy in large scale applications, specially designed ponds, however, can be installed on the roofs of factories, commercial buildings or houses. In winter months the solar pond could provide large supplies of water, substantially above ambient temperatures to heat pumps. Also, another promising applications of solar pond might be to supply hot water for absorption chillers, which are used in summer air conditioning systems, or to generate process steam with the use of the absorption heat transformer by temperature boosting of heat from solar pond [11].

As the free surface of water in the pond must be horizontal, the beam radiation collected by the pond is usually limited. However, absorbed solar radiation by the pond can be enhanced with the help of a planar reflector, which must be oriented in a certain position to maximize the collected radiation either in all year-round operation or for a certain period (seasonal operation). Analysis of radiation enhancement model was presented in [12].

In the present work, the validity of the previous radiation enhancement model given by [12] for small saltless solar pond with a planar reflector and multilayer upper insulating system is investigated. Also, the operation of this pond under the Egyptian climate conditions is experimentally tested.

EXPERIMENTAL SETUP

Figure 1 shows a sectional elevation of the experimental pond. The apparatus is fabricated from a steel sheet of 2 mm thickness to form, by welding, a tank of square cross section (1.23 m x 1.23 m) and 0.83 m height. The pond sides and back, which are painted with blackboard paint from their internal sides, are insulated with 10 cm glass wool layer from the outside. The upper surface of the pond is covered with a transparent cover which consists of six polyethylene layers. The transparent layers, which have the same dimensions as the pond surface, are supported in a wooden frame such that, the space between two adjacent layers is kept at 0.01 m as shown in Fig. 2. The south faced reflector, which is mounted by two side supports allowing a change of the degree of inclination of the reflector with respect to the pond surface is 1.6 m height and 2.5 m width. The reflector is vertically supported in common edge with the pond surface and its reflectivity is 0.75.

In order to measure the temperature gradient through the pond, nine Copper - Constantan thermocouples are vertically installed along the pond center. Also, the temperatures of the cover layers are recorded by six thermocouples. Solar radiation intensity, with and without enhancement, on the pond surface and the ambient temperature are also recorded during the experimental work. The experimental setup is prepared and located on the roof of the Combustion Laboratory, Faculty of Engineering, El-Mansoura University at 31° N latitude. Temperatures and radiation data are recorded each hour during the day time, and the **mean** pond temperature is calculated by using the following equation [13] :

$$T_p = \left[\sum_{i=1}^{9} (T_i + T_{i+1}) \Delta L_i \right] / 2 L_p \qquad (1)$$

Where, L_p is the pond depth and

ΔL_i is the distance between two adjacent thermocouples located in the **central part of the pond.**

RESULTS AND DISCUSSION

The short term experiments with the small saltless solar pond in no load condition and enhanced solar radiation collection took place during October 1996. The performance results are described here. Figure 3.a , 3.b show typical solar radiation data. obtained over two different days with moderate solar radiation intensity. Results of diffused. horizontal, and enhanced solar radiation (calculated and measured) are presented in the two figures. A reasonable agreement between the calculated values of the enhanced radiation [12] and that measured can be observed. It is clear that radiation of about 600 W/m^2 can be enhanced to a value of about 1100 W/m^2 (Fig. 3). As expected. the reflector position and the tilt angle allows the maximum values of enhanced radiation to occur during the period of higher solar radiation (10 - 13 hours) as shown in figures. The good agreement between theory and experiment proves that the previous radiation enhancement model can be applied at different locations and different seasonal operation of the system.

Experimental time trace of nine temperatures, that recorded by thermocouples vertically installed in the pond, are given in Fig. 4, for one day of system operation. As the pond functions as a collection and storage system, the temperature of different layers increases continuously during the day time. However, the rate of temperature rise of the upper water layer is seen to be highly affected by the solar radiation intensity. Therefore, its has the highest temperature of the pond. In the same figure, the calculated values of mean pond temperature is given. Figures 5.a , 5.b show the temperature-time curves of the six layers of the upper insulation system of the pond for two different days of operation. Also, the ambient temperature and the water surface temperature are presented in these figures. It can be observed that, cover layers experience a peak occurs in temperature at noon . The. temperature drop that follows each peak occurs with a rate following the solar radiation as expected. The upper layer of the water in the pond has a temperature curve which may have a peak value at noon time, as shown in Fig. , beyond this peak the temperature is reduced. Apparently, the storage capacity of this layer is lower than that of the other layers inside the pond.

Daily temperature variation of the pond layers and the mean pond temperature during the build-up period (1/10-24/10/96) are given in Fig. 6. The temperatures shown in the figure are those corresponding to the values measured at 12 noun every day. It can be observed that, the temperature difference between the bottom layer and that adjacent to the upper layer is nearly the same for all days of the build-up period. However, the difference in temperature between the upper layer and the adjacent one is seen to be higher than that between any other two layers. This may emphasize that, the upper layer is highly affected by the ambient conditions (solar radiation and ambient temperature). On the other hand, the inside layers are more stable and can be applied as the storage zone of the pond. The vertical temperature gradient along this zone is about 4-6°C. Figure 7 shows the recorded temperatures at 12 noon each day of the build-up period for the six cover layers with the ambient temperature and pond surface temperature. It can be noticed that, the temperature of the pond surface and the cover system follow that of the ambient which changes during this period. From Figure 6, it can be observed that, the pond temperature reaches a maximum value. at the end of the build-up period. The mean value of this maximum temperature is higher than the mean ambient temperature by more than 30°C.

The hourly efficiency of the solar pond is given by [11] as :

$$\eta = c_p \rho \ L \ \Delta T / H \qquad (2)$$

Where c_p is the heat capacity, p is the density of water, L is a water depth, ΔT is the water temperature rise during one hour of operation and H is the incident total solar radiation in this hour.

The pond hourly efficiency is calculated over two days of operation and presented here in Fig. 8 . As expected, the pond efficiency at lower temperatures is high and gradually decreases as the pond temperature increases. This indicates the increase in losses to the surrounding with the increase in pond water temperature. However, if heat is extracted during the day time, as in flat plate solar collector, the average pond temperature, and therefore thermal losses. will be reduced. Thus, a higher values of average pond efficiency is expected when the pond is working in load condition, and a large fraction of the total available solar energy can be utilized.

CONCLUSION

A small, freshwater solar pond augmented by a planar reflector is constructed and experimentally tested outdoor. Results are presented for the pond warm-up with no load condition. Measurements have shown that the mean pond temperature. in October, is 30 °C higher than that of ambient temperature. Also, the hourly efficiency of the pond is calculated and found to be highly dependent on the pond temperature. The agreement between the calculated and measured values of enhanced solar radiation is reasonable, and thus, the theoretical model of the previous work [12] can be applied for other locations and seasons. The fabrication of small pond is simple and cheap when it operates as a collection and storage unit in the same time. Finally, it should be recognized that further experimental work is required for long term performance of the pond to evaluate the seasonal variation of its performance.

NOMENCLATURE

C	heat capacaity
H	pond height, incident solar radiation

L	pond depth
T	temperature
Δ	difference
η	efficiency
ρ	density

Subscripts

i	thermocouple number
p	pond

REFERENCES

1- Gommed k. and Grossman, G. Process steam generation by temperature boosting of heat from solar ponds. Solar Energy, 41 , 81. (1988).

2- Sokolov M. and A. Arbel, Freshwater floating - collector - type solar pond. Solar Energy, 44, 13. (1990).

3- Hull, J.R Membrane stratified solar ponds. Solar Energy 317, (1980).

4- Ortabasi, U. F. H. Dyksterhuis, and N. D. Kaushika, Honeycomp stratified saltless solar pond. Solar Energy 31, 229, (1983).

5- Shaffer, L.H.r, Viscosity stabilized solar pond, Proc. Int. Solar Energy Soc. Congr. New Delhi, p. 1171, (1978).

6- Wilkins E. S.s and T. K. Lee, Development of the gel pond technology, Solar Energy 39, 33 (1987).

7- Kmiuto, K. Further design considerations for unevacnated horizontal multilayer insulation systems, Applied Energy 23, 297, (1986).

8- Churchill, S. W.II. Heat - exchanger design hand book. Hemisphere publishing Corp., p 2,5,8-3 (1982).

9- K. Kamiuto, Transient thermal characteristics of the convecting solar pond with the semi-transparent multilayer surface insulation system, Int. J. Solar Energy 5, 323 (1988).

10- Kamiuto K. Thermal performance of a convecting solar pond, Proc. ASME -JSES Solar Energy Conf. ASME, 1, 271,(1987).

11- Dickinson W.C.n and P. N. Cheremisinoff, Solar energy technology hand book, Part A (Engineering fundamentals), Marcel Dekker, Inc., New York, (1980).

12- Gad, H.E. Ahmed M. Hamed and El - Sayed, S.S. Radiation enhancement using planar reflector with solar pond, To be published, Proc. Seeond Engineering Conference, Mansoura, (1997).

13- Kamiuto, K. et. al.,, Thermal behavior of a small, saltless solar pond with the semitransparent multilayer surface insulation system, Solar Energy 41, 141 (1988).

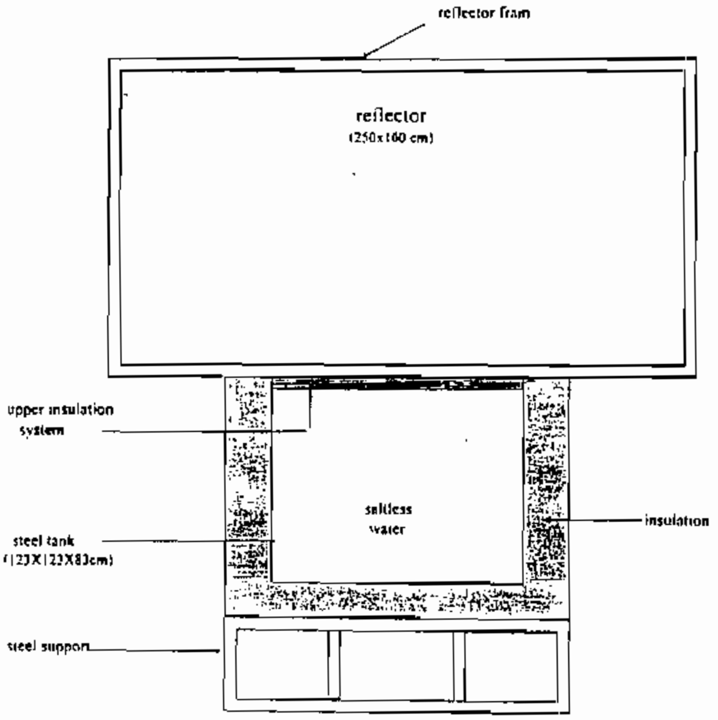


Fig.1 Sectional view of the experimental pond

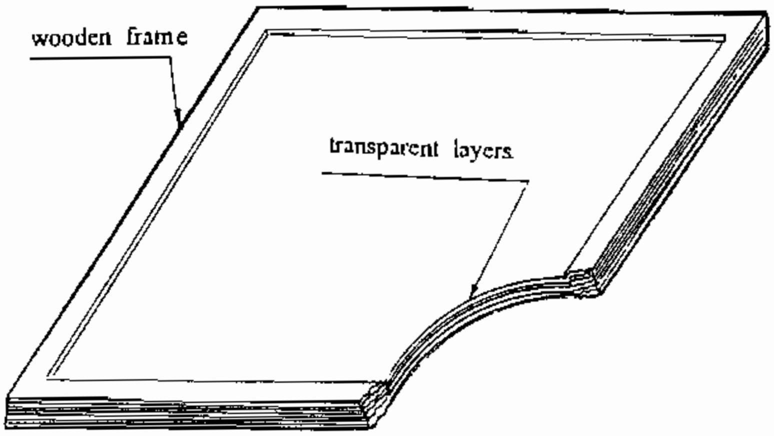
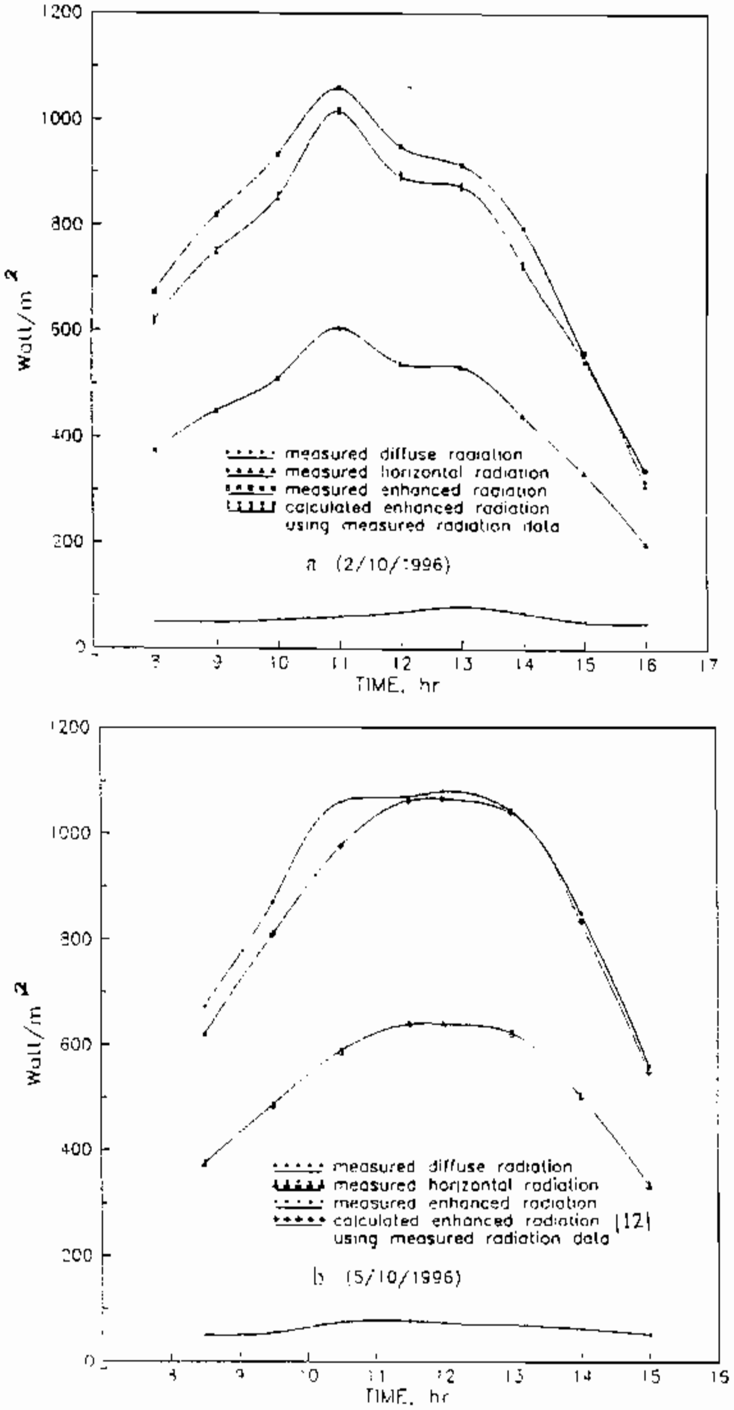


Fig. 2 The upper insulation system of the pond



. 3 Comparison between measured and calculated values of different radiation types

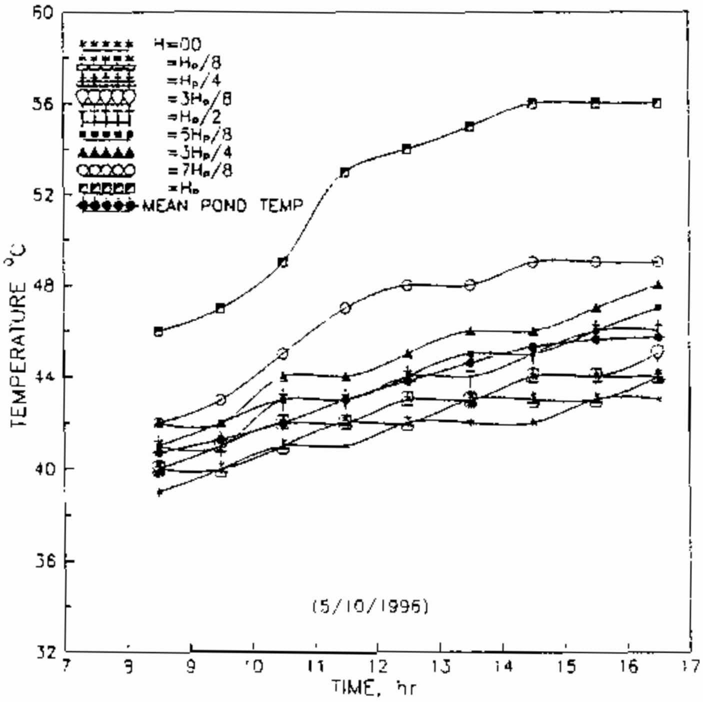


Fig.4 Pond temperature at different heights

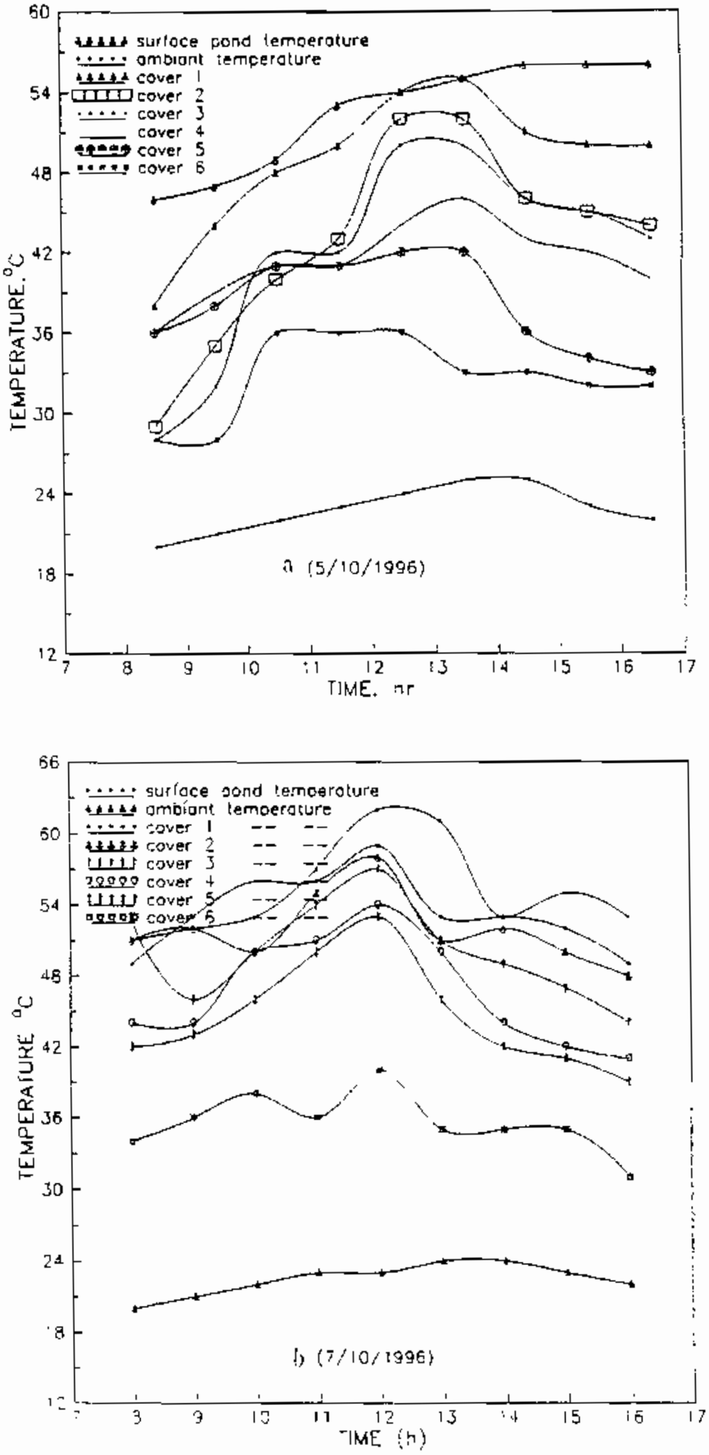


Fig. 5 The temperature - time curves of the six cover layers

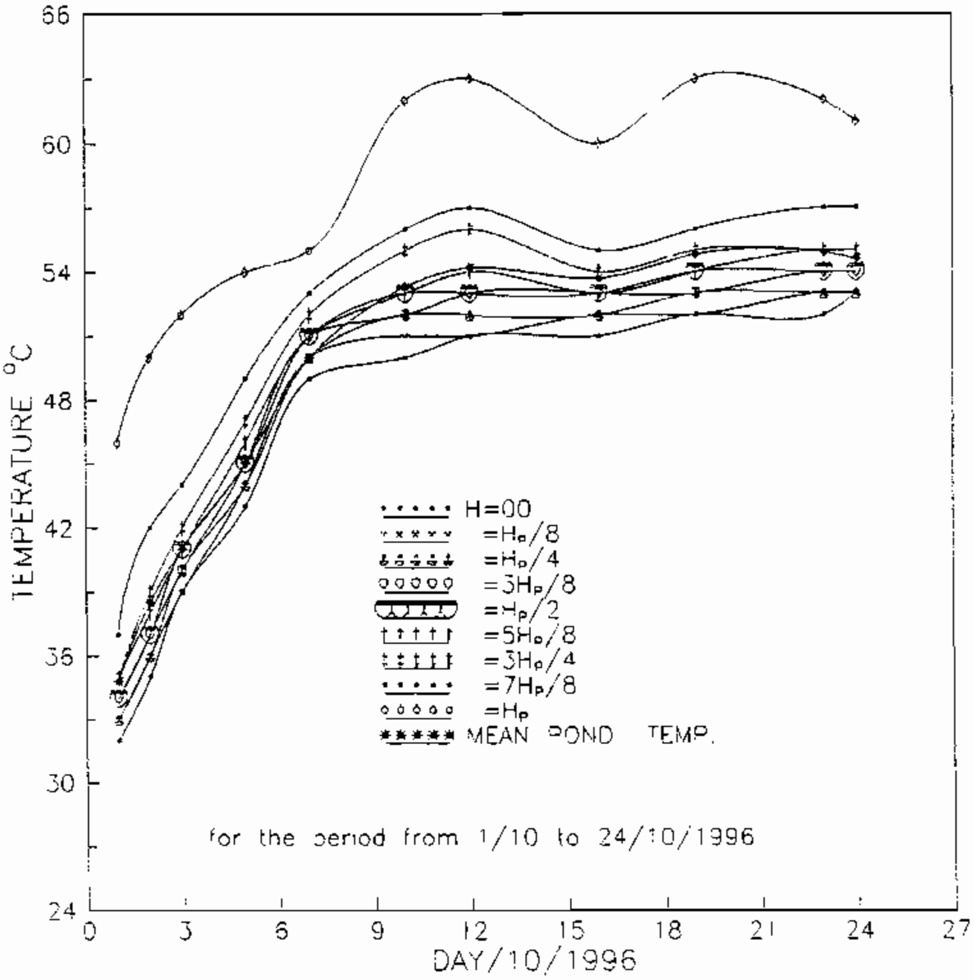


Fig.6 Pond temperature during the build-up period at different heights

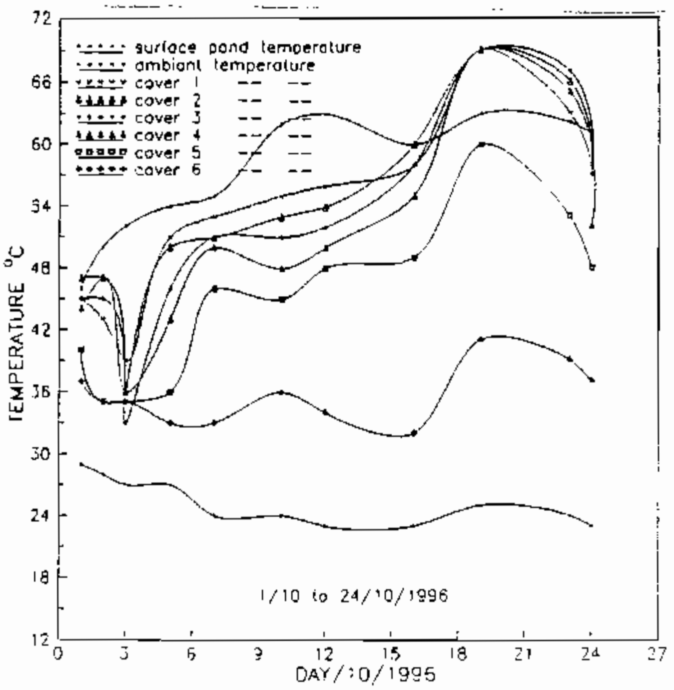


Fig 7 Temperatures of upper covers during the build-up period

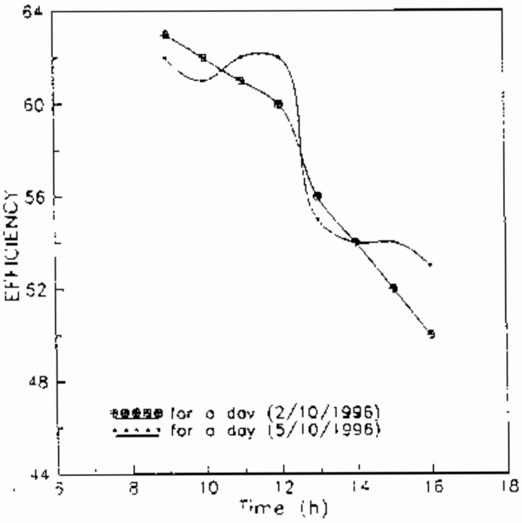


Fig 8 Overall thermal efficiency of the system