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EXPERIMENTAL ANALYSIS OF THERMAL STRATIFICATION IN SHALLOW SOLAR PONDS UNDER NATURAL SUNLIGHT

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ABSTRACT
The core research objectives is to investigate and analyze the phenomenon of thermal stratification in shallow solar ponds. The solar pond consists of the plastic bag and the encasement box; for the plastic bag, two transparent polythene materials of 75 cm x 55 cm were heat – seated with soldering bar at about 250OC. One side of the bag was pointed with bituminous black selection. A CDG-10B solar radiation sensor pyranometer and a thermograph were used to record the climatological data of solar irradiance and the ambient temperature respectively. A wooden box having three apartments was constructed. The lower convective zone, non-convective zone and the upper convective zone, each playing role in heat collection and storage.In the first mode of operation, the temperature indicated a maximum of 77OC at 1.30 pm.in the second mode of operation, the temperature indicated a maximum 85oC at 3.00pm. While in the third mode operation, the temperature indicated a maximum of 86OC at about 3.00pm. By providing a low – cost sustainable solution for heating and electricity generation, enabling efficient thermal energy storage for application like water heating, space heating or agricultural drying, and by offering a potential alternative to fossil fuels, reducing energy costs and environmental impact, this study and its findings can contribute to solar energy utilization and thermal energy storage in low resource settings.

Keywords: Thermal Behaviour, Shallow, Solar Pond, Investigating

INTRODUCTION
Shallow solar ponds represent a low-cost thermal energy storage solution particular relevant for off-grid and low – income regions. The aspect of shallow solar ponds (SSPs) that remains underexplored includes operational efficiency under specific climatic conditions – understanding how SPPS perform in regions with variable solar radiation , temperature fluctuations, or unique weather patterns, design optimization for varying applications, exploring optimal designs for different uses, such as water heating, space heating, or agricultural drying; and long – term stability and durability-investigating the long term performance maintenance requirements and potential degradation of SSPs
Those areas listed above require further research to enhance the efficiency reliability and scalability of SSPs for diverse applications.
While Ramadan et al., (2014) focused on continuous heat extraction, EL- Sebaii et al.,(2021) explored open cycle heating both highlighting the challenge of night –time losses which this study aims to mitigate.
This study investigates thermal retentions strategies in SSPs to address over -night heat loss, a known limitation in prior designs
Solar energy is a rapidly expanding field of human endeavours.
A thermal system capable of collecting and storing solar energy is a solar pond. It supplies low grade heat for long periods of time on a large scale. The use of solar pond is becoming more attractive in today's energy scene.
A shallow solar bond (SSP) is a water bag placed within an enclosure. It is generally constructed from a clear upper plastic film and a black lower plastic film. The depth of water in SSP is only a few centimeters (Shanmugasundaram and Janarthanan; 2014). A previous work (Osamah et al; 2020) has discussed the possible applications of SSPs in domestic, agricultural, commercial and industrial sectors.
Ramadan et al; (2014) have made an attempt to find the thermal performance of shallow solar pond. There existed a glass cover whose role is to reduce the total heat loss coefficient of the pond to about 54 and 44%.
The performance of a mobile covered shallow pond was studied by El-Reidy and Ibrahim (2015). The result obtained showed that the pond was suitable for water heating.
Kishore et al; (2019) have presented the construction and fabrication details of portable shallow solar pond. The results confirmed a shallow solar pond favourable for use by middle income class as a result of its low cost.
El-sebaii et al; (2021) studied the thermal performance of a SSP under an open cycle continuous heating mode. The result indicated that the heat exchanger was capable of extracting the heat.
This study investigates the performance of a shallow solar pond fabricated at Obafemi Awolowo University Energy Research Centre, Ile-Ife Osun State with three different modes of operation.

MATERIALS AND METHODS
The solar pond was designed to hold a maximum capacity of 10 litres, but for safety reasons, it was tested with 7.5 litres of water to prevent the thin bag material from stretching or bursting. The addition of glazing serves to enhance the retention of captured solar radiation, maximizing the pond's energy collection efficiency.
The booster area and inclination were such as to increase the concentration of the radiation reaching the pond by about 40%.
The design and structural components of the shallow solar pond are illustrated in Fig. 1(a) and 1(b) respectively. The pond consists of the following (Kishore et al; 2019). The pond linear has transmissivity and reflectivity of 0.85 and 0.10 respectively

Data Collection
The data were collected using a calibrated measurement system- thermograph (accuracy of ±0.1OC). The collected data were processed using data filtering (to reduce noise and

improve signal quality). Also, the uncertainties associated with the measurements were evaluated based on non-statistical methods and the processed data were verified by comparing with reference values.
A CDG-10B solar radiation sensor pyranometer with an accuracy of ±0.1OC of was used to measure solar radiation

The Plastic Bag
Ideally special transparent PVC plastic sheets that have good optical properties like glass and also have high strength should be used (Osama et al., 2020). The cover film has transmissivity and emissivity of 0.90 and 0.85 respectively. However, due to non-availability of such materials locally, thin polythene materials were used. The thickness of the material is 5 cm with thermal conductivity of 0.023 W/mk and density 30 kg/m2
Two transparent polythene materials of dimensions and shapes as shown in fig 1(a) were heat-seated with a soldering bar at a temperature of about 2500C leaving the provision of 36m gap as inlet. One side of the bag was painted with bituminous black solution 9586 85/2 of Dulux products. The inlet was fitted with a short rubber tube and clipped firmly with a hose clip. The bag was placed in an encasement box with the black coated surface downwards on an insulator of thickness 5 cm.

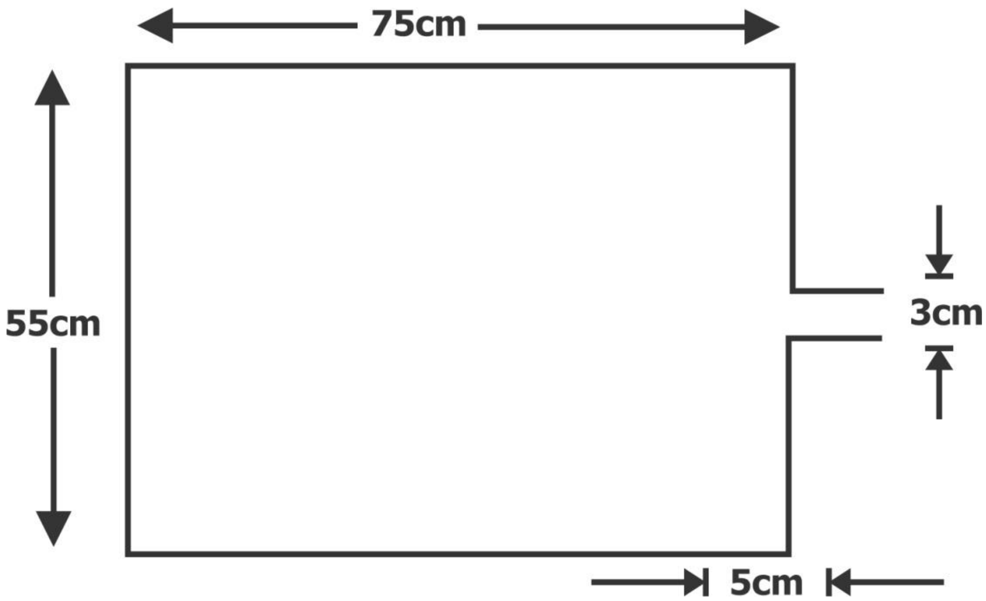


Figure 1(a): Plastic Bag of the Solar Pond

Encasement Box
A wooden box having three apartments was constructed with the designed dimensions as shown in fig. 1(b). The lower compartment encasing the plastic bag has the dimensions 77x57x14cm. Along the width but close to the top a hole of about 2cm in diameter was drilled for the inlet/outlet provisions of the plastic bag. At the opposite side, a hole of diameter 0.8cm was also drilled for a thermometer insertion to measure the internal air temperature of the box. Attached to the lower compartment is a glazing tray lid of 77x57x0.3cm fitted with glass. The compartment is a lid made of thicker wood. On the inside a mirror 77x40cm was securely fitted to act as a reflector when it is in operation. The hinges of the reflector mirror apartment were attached along the length opposite to that of the glazing lid. This made the reflector lid and glazing to open in opposite directions.
The design except for the durability of the bag, is free from operational problem such as draining off of the pond water to an insulated tank during off sunshine hours as required in case of plastic bag type SSP, which can be utilized later. Specifically, the insulation is placed at the bottom and sides of the pond, while the cover film is placed on top.
The pond liner is used to prevent leakage and ensure that the water does not come into contact with the insulation

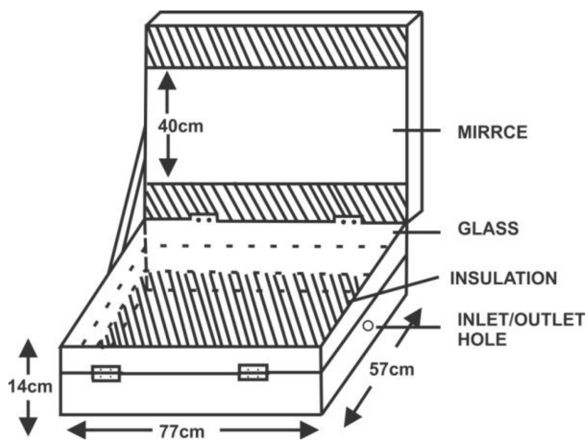


Figure 1(b): Encasement Box of the Solar Pond

RESULTS AND DISCUSSION

Performance of the SSP and Results

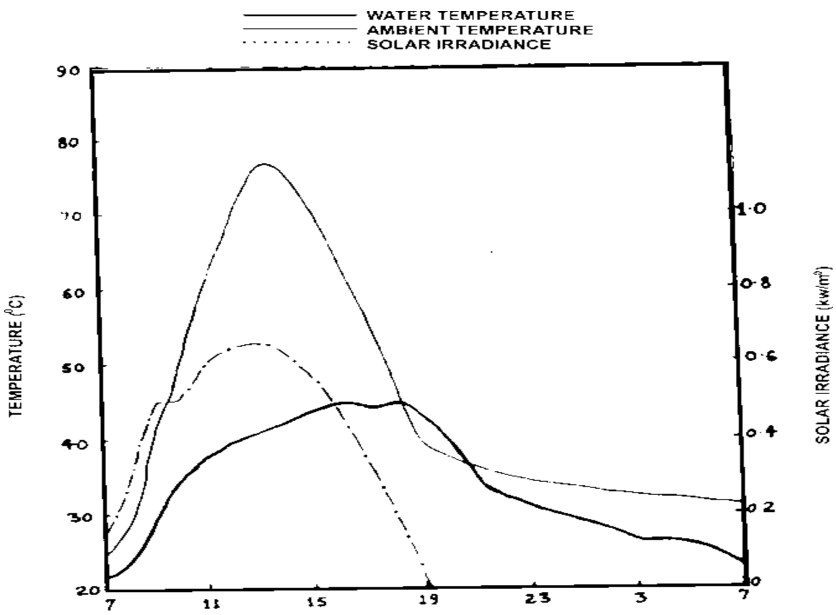
The performance of the SSP has been studied in Ile-Ife, Osun State, in the Month of March, 2024.

The maximum capacity of the plastic bag is about 10litres and it bulges out in the shape of a flat pillow when filled with water. The system was experimented to study its performance for three different modes of operation Viz, without glazing, with glazing and with glazing and booster. The results are given in figs. 2, 3 and 4 respectively.

A CDG-10B solar radiation sensor pyranometer was used to record the climatological data of solar irradiance while the ambient temperature was recorded using a thermograph. All of these were carried out at the Obafemi Awolowo University Energy Research Centre Ile-Ife, Osun State.

As mentioned earlier the bag was filled with 7.5 litres of fresh water in the morning at 7.00am. The air in the bag was expelled by slightly lifting the fitted pipe and compressing the air towards the pipe. This was done until there was no air space inside the SSP. The system was mounted in a horizontal position in the sun.

In the first mode of operation (without glazing), the temperature of the water was observed every 60 seconds by placing a thermometer at the outlet. The temperature indicated a maximum value of 770C at 1.30pm, and thereafter it increased. After sunset, the system was covered from the top with the other wooden compartments, which acts as insulator to prevent heat losses from the system during off-sunshine hours. As shown in fig. 2, the temperature of the water inside the bag was recorded till 12.00 midnight and in the next morning at about 7.00am, together with the variation of the solar irradiance and the ambient temperature. This test was carried out on a very clear day. In this mode of operation, the average solar energy collection efficiency (energy collected in the pond/solar system incident on the pond x100%) for increasing water temperature period (7.00am-1.30pm) of the system comes out to be 30.6% while that to maximum ambient temperature (7.00am-4.15pm) comes out to be 16.8%.



TIME (HOURS)

Figure 2: Observed Variation of Temperatures and Solar Irradiance (Without Glazing)

In the second mode of operation (with glazing), the solar pond was exposed to insulation with glazing. The amount of water taken in the bag was same as in the first case. The temperature of water, the internal air temperature and the glass temperature were recorded every half-hour. The results obtained on a clear day are shown in Figure. 3.

A maximum temperature of 83.50C was recorded at 3.00pm and thereafter it decreased.

The observations were continued till midnight and on the next day at about 7.00am. The average solar energy collection efficiency of the system again for increasing water temperature period (7.00am-3.30pm) comes out to be about 25.6%, while that to maximum ambient temperature (7.00am-4.00pm) is 25.1%.

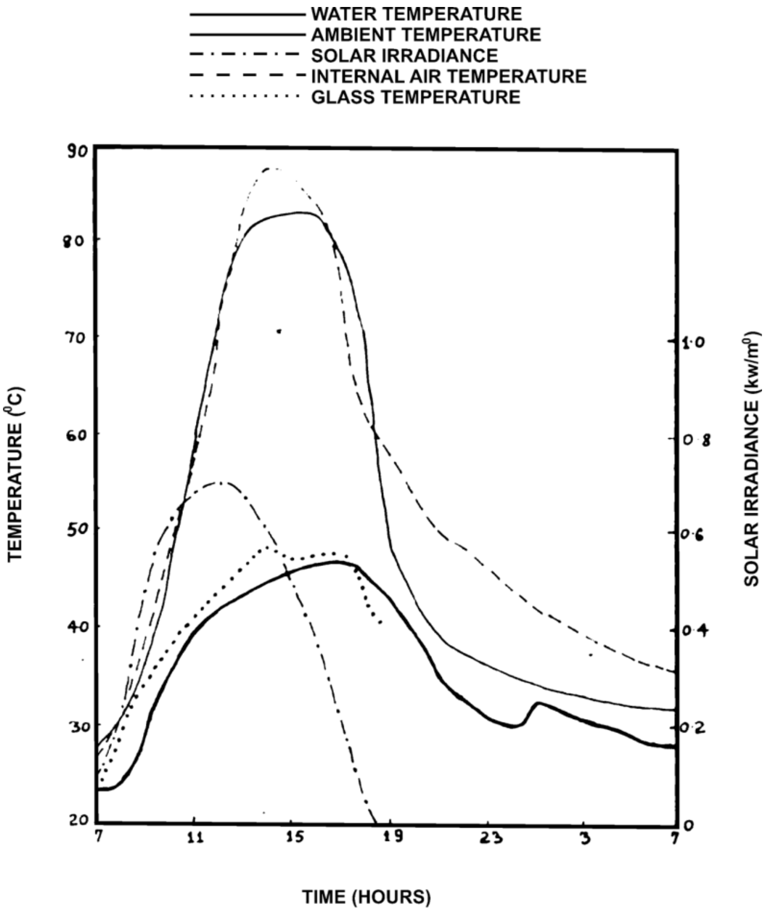


Figure 3: Observed Variation of Temperatures and Solar Irradiance (Without Glazing)

The third mode of operation (with glazing and booster) incorporated the application of the booster together with the glazing. The same amount of water was filled in the bag. The booster is cylindrical in shape, and of 59 mm (diameter) and 114 mm (length).The material is cast primer with high strength and density.

Half-hourly temperature of water enclosed air and glass were taken while the booster angle was adjusted.

The results for a day with occasional cloud patches are shown in Figure. 4.

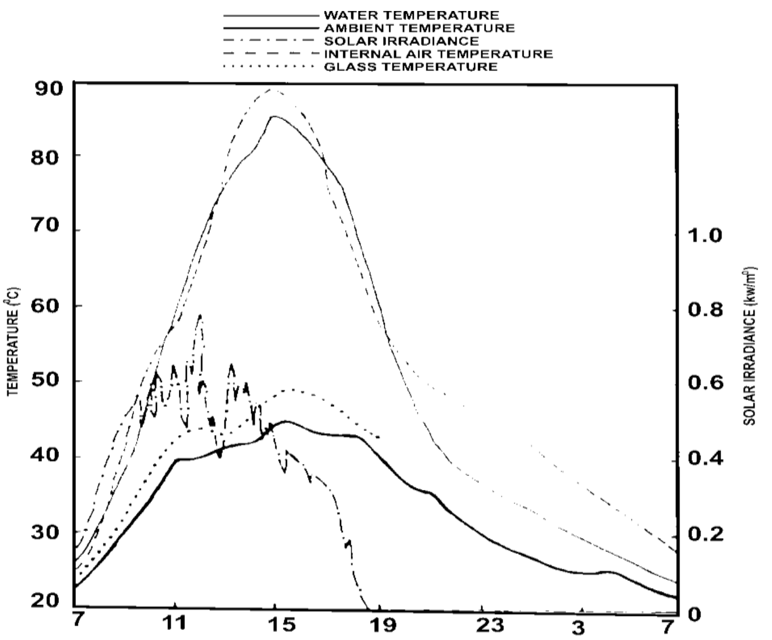


Figure 4: Observed Variation of Temperatures and Solar Irradiance (with Glazing and Booster)

The maximum temperature of 860C was recorded at about 3.00pm. With a 40% increase on the solar radiation falling on the glazing due to application of the booster. In this study, 40% with booster as compared with 25% without booster (Ramadan et al., 2014) shows a clear increase in performance
The average solar energy collection efficiency of the system in this mode of operation comes out to be about 21.1% for the increasing water temperature period (7.00am-3.00pm) and 18.4% to maximum ambient temperature (7.00am-3.30pm), in both cases taking the concentration effect of the booster into consideration.

Thermal Performance Results

In the first mode of operation (without glazing) the plastic bag is exposed to the surrounding and the thermal losses in such a case are expected to be the highest among the three modes of operation presented, which results into lower water temperatures obtained in this case.
It is observed that there exists a time long between the water/air temperature and the solar irradiance however, such a conclusion cannot be drawn with the ambient air temperature.
The various modes of thermal losses in a shallow solar pond with glazing are shown in fig 5.

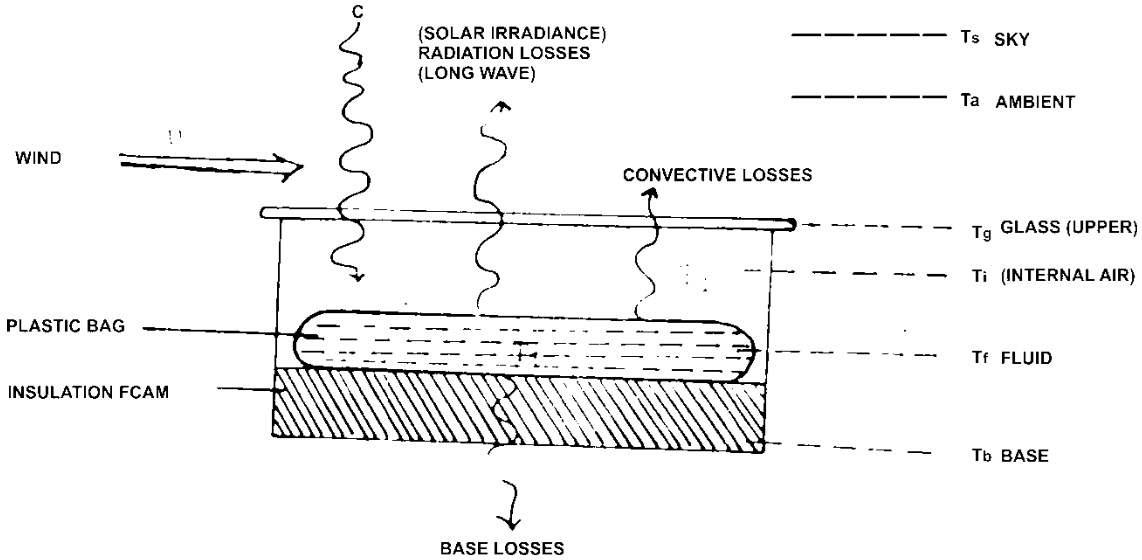


Figure 5: Modes of Thermal Losses in Shallow Solar Pond

The outward heat transfer occurs in the pond in three stages listed below:
Air circulating freely within the gap facilities heat transfer to the glass through convection. In parallel with this the bag radiates heat at wavelength equal to 10mm. At these wavelengths glass is not transparent but strongly absorbing (El-Sebaii, et al; 2021). As a result, this radiation is not emitted directly to the sky; instead, it is absorbed by the glass. The heat transferred to the glass through convection and radiation is subsequently conducted through the glass to its outer surface.
From the outer surface of the glass, the heat is then dissipated to the surroundings through a combination of free and/or forced convection, as well as radiation.
Operating the pond with glazing seems to give a flattened curve between 12.00noon and 4.00pm.
Application of booster requires regular inclination adjustments.
It does not seem to make an appreciable increase on maximum water temperature, although its effect on glass temperature is noticeable. It can further be seen from the curves that the water and the internal air temperature curves for the case with glazing only, and with both glazing and booster operating before 10.30am and after 4.30pm are similar.
The solar energy collection efficiency of the system for the increasing water temperature period is highest in the first mode of operation, although the maximum water temperature reached is the lowest. This is due to the fact that in the later two modes of operation, the highest temperature maintains for longer time, and hence increased solar irradiance for computation of efficiency and reduced efficiency.

CONCLUSION

From the curves given in Figs 2, 3 and 4, it can be seen that there is a drastic fall in the water and internal air temperature immediately after the sunset even though the system was closed to reduce the heat losses.
The temperature reached on the next morning show that the pond is not suitable for overnight heat storage. However, it is felt that the system can further be improved by incorporating insulation on the sides and making the system air tight. A special insulation sheet can be placed between the glazing and the lid after the sunset to further reduce the thermal losses. Some literatures have that better overnight heat storage can be obtained if this type of system is covered immediately after the temperature started showering a decreasing trend.
The maximum temperature achieved in the first mode of operation (without glazing) is 77oC at 1.30pm
In the second mode of operation (with glazing), the maximum temperature achieved is 83.5OC at 3.00pm. Whereas, in the third mode of operation (with glazing and booster) the maximum temperature achieved is 86oC at about 3.00pm
In the first mode of operation, the time to peak temperature is 5 hours while in the second and third modes of operations, the time to peak temperature is 7 hours
These results are promising for various applications including low-cost thermal energy storage (the systems simplicity and low cost make it an attractive option for thermal energy storage particularly in developing regions or rural areas
Sustainable heating systems (the use of solar energy for heating can significantly reduce greenhouse gas emissions and reliance on fossil fuels, contributing to a more sustainable future

Integration into hybrid renewable systems 9 the shallow solar pond can be integrated with other renewable energy sources, such as wind or photovoltaic systems, to create hybrid systems that optimize energy production and storage

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