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Comparative Study of Shallow Solar Ponds with Different Depths

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Abstract

In this paper, an attempt has been made to design and construct the shallow solar ponds with different depths such as 0.06 m and 0.15 m at Coimbatore (11^{o} - latitude and 77^{o} - longitudes), Tamilnadu, and India. The experiments have been carried out during the period from January-March 2012. The energy balance equations have been written for different elements of the two shallow solar ponds such as upper glass cover, lower glass cover and pond water and solved analytically. The performance of the two shallow solar ponds has been compared and found that the maximum temperature of the pond water in different depths (0.06 m and 0.15 m) of shallow solar pond is found to be 57 °C and 42 °C.

Keywords: Shallow Solar Pond, Energy Storage, Heat Exchanger, Renewable Energy

1. Introduction

A shallow solar pond is a simple and low cost device which can be used to collect and store heat. The name implies that the depth of water in the solar pond is relatively small so it is called shallow solar pond. The effect of a baffle plate on the transient performance of a shallow solar pond water heater has been studied by Madhuri and Tiwari [1]. It is inferred that the shallow solar

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pond also be used as a built in storage water heater, baffle plate performance being achieved, when using baffle plate. The transient analysis of a shallow solar pond water heater integrated with baffle plate has been presented by Dutt *et al.,* [2] and observed that the results obtained by the proposed model are nearly same as the rigorous analysis. El-Reidy [3] has analyzed the performance of a mobile covered shallow solar pond and concluded that the performance of the pond to be trouble – free and suitable for practical water heating use. The calculated values are in good agreement with the experimental value. El-Sebaii *et al.,* [4] have investigated the thermal performance of a shallow solar pond under an open cycle continuous flow heating mode for heat extraction and the heat exchanger has been used to extract the heat. The effect of different parameters has been studied on the performance of the pond. El-Sebaii [5] has investigated the thermal performance of a shallow solar pond integrated with a baffle plate theoretically and experimentally. For validating the theoretical model, experiments have performed under the batch mode of heat extraction with and without vents in the plate. Comparison between experimental and theoretical results shows that the theoretical model can be used for estimating the pond performance with good accuracy. Kishore *et al.* [6] have presented the construction and fabrication details of portable shallow solar pond. The results have shown that the Portable shallow solar pond water heater was suitable of middle income groups due to low cost. Ali [7] has proposed a theoretical model to predict the performance of a shallow solar pond in Tehran. The theoretical results obtained are in close agreement with experimental results. Aboul-Enein *et al.* [8] have proposed transient mathematical model of shallow solar pond to predict the thermal performance under the batch mode of extraction. The theoretical results are in close agreement with the experimental observations and also the pond has given about 88 l of hot water at maximum temperature of 60°C at sunset. Ramadan *et al.*[9] have made an attempt to find the thermal performance of shallow solar pond. The additional glass cover has reduced the top and total heat loss coefficient of the pond by 54 and 44%.

The aim of the work is to design, fabricate and study the performances of the two shallow solar ponds with the depth of 0.15

m and 0.06 m experimentally and theoretically and also to compare the performances between ponds.

2. Material and Methods

2.1 Construction of the system

Schematic diagrams of the shallow solar pond are shown in the Figures 1 and 2. The shallow solar ponds are fabricated by using galvanized ion sheet with depth of 0.06 m and 0.15 m.

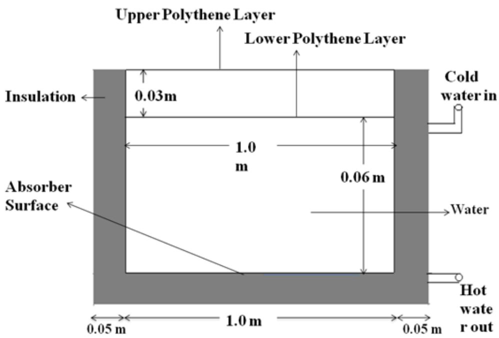

Fig. 1. A schematic diagram of the shallow solar pond

The shallow solar ponds have two enclosures made of ply wood.

The gap between enclosures filled with the 0.05 m thick insulating material of glass wool. Bottom of the pond surface painted black in order to maximize the absorption of incident solar radiation. The surface area of the pond absorber plate is 1 m^2. The glass cover thickness of 0.004 m has been used to cover the pond. The glass cover is always in contact with the top surface of the pond, in order to prevent cooling effect due to evaporation. Two PVC pipes are connected with the sides of the pond, one of them used to fill water in the pond and other one is used to extract heat from the bottom of the pond as shown in Figures1 and 2.

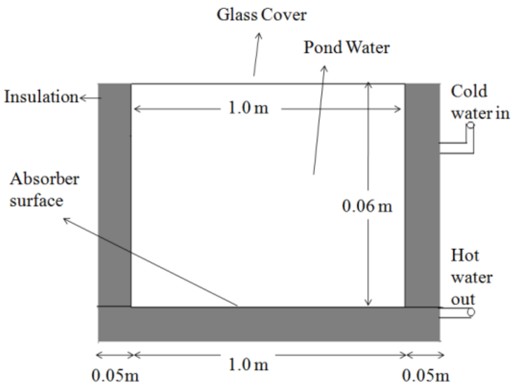

Fig. 2. Schematic diagram of the shallow solar pond with single glass cover

2.2 Experimental study

The performance of the shallow solar pond with different depths has been tested under Coimbatore climatic conditions. The photograph of the shallow solar pond with different depths is shown in Figures 3 and 4.

Fig. 3. Photograph of the shallow solar pond with 6cm depth

Fig. 4. Photograph of the shallow solar pond with 15cm depth

The various temperature components of the shallow solar ponds have measured with respect to time. The ambient temperature and solar radiation intensity for the corresponding working hours of the day measured using digital thermometer and solar radiation monitor respectively. The various measurements made for every 30 minutes interval from 9 am to 5 pm are mentioned given below.

1. Temperature of the upper and lower glass cover.
2. Temperature of the pond water.
3. Temperature of the pond absorber plate.
4. Temperature of the ambient air.
5. Total solar insulation.

3. Energy balance equation

The energy balance equations have been written following assumptions.

i. The system is thermally insulated such that the heat energy entering the system does not loss through insulation.

ii. The glass cover of the pond is in touch with water surface to eleminate convection losses from the water surface.

iii. There is no temperature gradient in the water in the pond.

3.1 Shallow solar pond with 6cm depth

Energy balance equation for upper glass cover:

$$H\alpha_{gu}A_{gu} + h_{clu}A_{gl}(T_{gl} - T_{gu}) + h_{rlu}(T_{gl} - T_{gu})A_{gl} = h_{cua}A_{gu}(T_{gu} - T_{au}) + h_{rua}(T_{gu} - T_a)A_{gu} \quad (1)$$

Energy balance equation for lower glass

$$H\tau_{gu}\alpha_{gl}A_{gl} + h_{cwl}A_w(T_w - T_{gl}) = h_{clu}A_{gl}\left(T_{gl} - T_{gu}\right) + h_{rlu}(T_{gl} - T_{gu})A_{gl} \quad (2)$$

Energy balance equation for water

$$H\tau_{gl}\tau_{gu}\alpha_w A_w = h_{cwl}A_w\left(T_w - T_{gl}\right) + U_s A_s(T_w - T_a) + m_w C_w(dt_w/dt \quad (3)$$

Temperature of the upper glass

$$T_{gu} = \frac{H\alpha_{gu} + T_{gl}(h_{clu} + h_{rlu}) + T_a(h_{cua} + h_{rua})}{h_{clu} + h_{rlu} + h_{cua} + h_{rua}} \quad (4)$$

Temperature of the lower glass cover

$$T_{gl} = \frac{H\tau_{gu}\alpha_{gl}A_{gl} + h_{cwl}A_w T_w + A_{gl}T_{gu}(h_{clu} + h_{rlu})}{h_{cwl}A_w + A_{gl}(h_{clu} + h_{rlu})} \quad (5)$$

Temperature of the water

$$T_w = \frac{f(t)}{a} + \left(T_w - \frac{f(t)}{a}\right)e^{-at/m_w C_w} \quad (6)$$

Where

$$f(t) = H\tau^2{}_g\alpha_w A_w + \frac{H\tau_{gu}\alpha_{gl}A_{gl}h_{cwl}A_w + h_{cwl}A_w A_{gl}(h_{clu} + h_{rlu})T_{gu}}{h_{cwl}A_w + A_{gl}(h_{clu} + h_{rlu})} + U_s A_s T_a$$

$$a = h_{cwl}A_w + U_s A_s - \frac{(h_{cwl}A_w)^2}{h_{cwl}A_w + (h_{clu} + h_{rlu})A_{gl}}$$

3.2 Shallow solar pond with 15 cm depth

Energy balance equation for upper glass cover:

$$H\alpha_{gu}A_{gu} + h_{clu}A_{gl}(T_{gl} - T_{gu}) + h_{rlu}(T_{gl} - T_{gu})A_{gl} = h_{cua}A_{gu}(T_{gu} - T_{au}) + h_{rua}(T_{gu} - T_a)A_{gu} \quad (7)$$

Energy balance equation for lower glass

$$H\tau_{gu}\alpha_{gl}A_{gl} + h_{cwl}A_w\,(T_w - T_{gl}) = h_{clu}A_{gl}\left(T_{gl} - T_{gu}\right) + h_{rlu}(T_{gl} - T_{gu})A_{gl} \quad (8)$$

Energy balance equation for water

$$H\tau_{gl}\tau_{gu}\alpha_w A_w = h_{cwl}A_w\left(T_w - T_{gl}\right) + U_s A_s(T_w - T_a) + m_w C_w(dt_w/dt \quad (9)$$

Temperature of the upper glass

$$T_{gu} = \frac{H\alpha_{gu} + T_{gl}(h_{clu} + h_{rlu}) + T_a(h_{cua} + h_{rua})}{h_{clu} + h_{rlu} + h_{cua} + h_{rua}} \quad (10)$$

Temperature of the lower glass cover

$$T_{gl} = \frac{H\tau_{gu}\alpha_{gl}A_{gl} + h_{cwl}A_w T_w + A_{gl}T_{gu}(h_{clu} + h_{rlu})}{h_{cwl}A_w + A_{gl}(h_{clu} + h_{rlu})} \quad (11)$$

Temperature of the water

$$T_w = \frac{f(t)}{a} + \left(T_w - \frac{f(t)}{a}\right)e^{-at/m_w C_w} \quad (12)$$

Where

$$f(t) = H\tau^2{}_g\alpha_w A_w + \frac{H\tau_{gu}\alpha_{gl}A_{gl}h_{cwl}A_w + h_{cwl}A_w A_{gl}(h_{clu} + h_{rlu})T_{gu}}{h_{cwl}A_w + A_{gl}(h_{clu} + h_{rlu})} + U_s A_s T_a$$

$$a = h_{cwl}A_w + U_s A_s - \frac{(h_{cwl}A_w)^2}{h_{cwl}A_w + (h_{clu} + h_{rlu})A_{gl}}$$

4. Result and discussions

4.1 Shallow solar pond with 6 cm depth

The performance of the shallow solar pond with 6 cm depth has been investigated theoretically and experimentally. The variation of the solar radiation and ambient temperature is depicted in Figure 5. It is observed that the intensity of the solar radiation is increased during morning hours and reached maximum at noon time. The maximum value of the solar radiation is 1262 W/m^2. The ambient temperature is closely following the solar radiation. The maximum temperature of the ambient was found to be 40 °C. The comparison between measured and theoretical temperature of the upper and lower glass cover of the pond is shown in Figure 6. It is found that the maximum temperature of the lower glass cover is higher than the upper glass cover due to the lower glass cover is always in contact with the water. The maximum temperature of the upper and lower glass cover of the pond is 51°C and 61°C obtained.

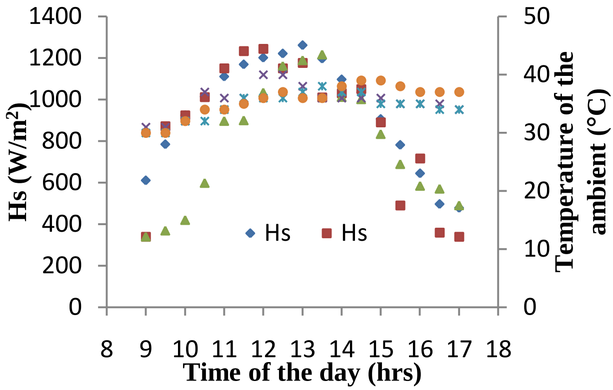

Fig. 5. Shows the variation of the solar radiation and ambient temperature for the experimental days

The comparison between measured and theoretical temperature of the pond water is depicted in Figure 7. The results shown that the temperature of the pond water is reaches maximum at 5pm due to the time required to warm up the pond water and thermal capacity of the pond water is high. The theoretical and experimental temperature of the pond water is found to be 57 °C and 56.9 °C. Theoretical results are in good agreement with the experimental results.

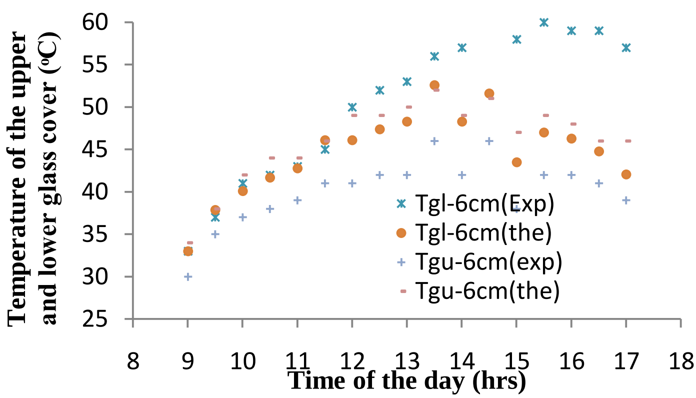

Fig. 6. Variations of experimental and theoretical temperature of the upper and lower glass cover of the pond.

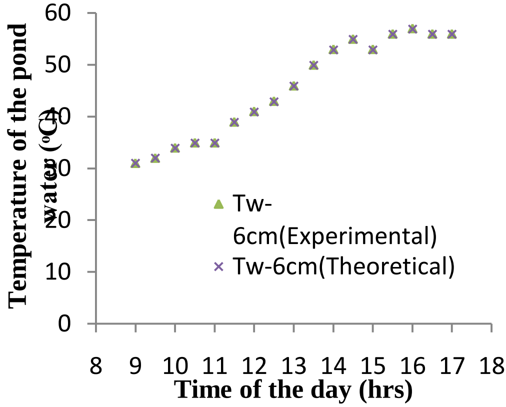

Fig. 7. Variations of the experimental theoretical temperature of the pond water.

4.2 Shallow solar pond with 15cm depth

The shallow solar pond has been tested with 15cm depth in the month of January to March 2012. Figure 8 shows the variation of solar radiation and ambient temperature for four typical days in the month of March. It has been observed that the intensity of solar radiation gradually increases and reaches a maximum at 13 hrs with fluctuations due to clouds. In the evening hours, the intensity gradually decreases. The ambient temperature for all the days have same trend, i.e., at 12 hrs for all the days, the ambient temperature is maximum.

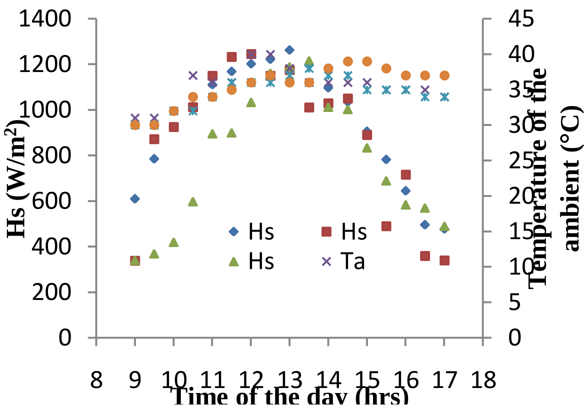

Fig. 8. Shows the variation of solar radiation and ambient temperature for experimental days

Figure 9 shows the variation of experimental and theoretical values of T_g. It is observed that the there is a close agreement between the theoretical and experimental results throughout the day. The variations of experimental and theoretical values of water temperature in the pond are shown Figure 10. It has been observed that the theoretical results are in close agreement with the experimental results. The maximum temperature of the pond water is found to be 42 °C and 42.4 °C

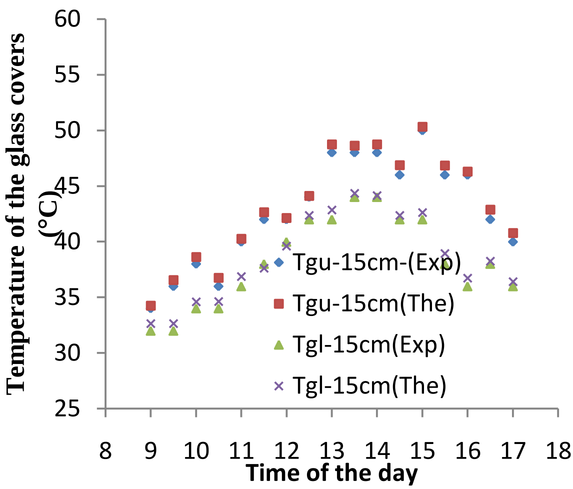

Fig. 9. shows the variations of experimental and theoretical value of glass cover of the pond.

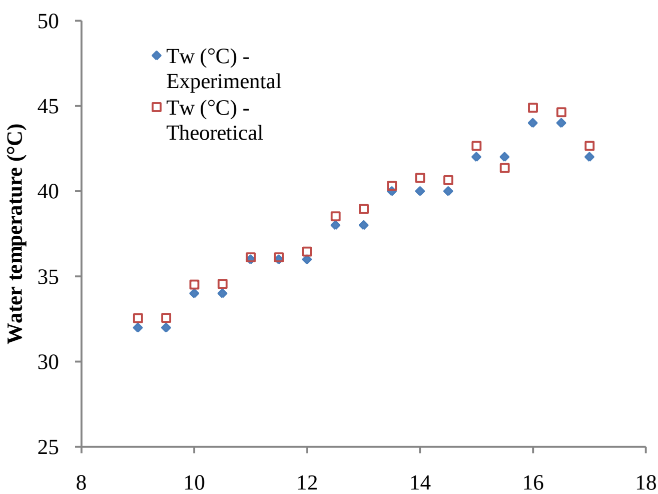

Fig. 10. Shows the variations of experimental and theoretical value of pond water.

4.3 Comparisons of performance of the shallow solar pond with different depths.

Figure 11 shows the comparison between theoretical and experimental temperature of the upper and lower glass cover for the SSP with different depths. It is observed that the there is a close agreement between the theoretical and experimental results throughout the day. The maximum temperature of the upper and lower glass of the SSP with depth of 0.15 m is found to be 50 °C and 44 °C, for 0.06 m, it was 51 °C and 61 °C. The upper glass cover has been used over the lower glass cover to suppress the convection from the lower glass cover to the ambient. The solar radiation is transmitted and partly reflected by the lower glass cover. The reflected radiation is trapped by the upper glass cover and hence convection from the glass cover is suppressed. Thereby the convection from the water in the pond to the glass cover is reduced. This leads to the storage of large of amount of thermal energy in the pond water.

Comparison between theoretical and experimental value of the pond water for the SSP with 0.15 and 0.06 m depths is shown in Figure 12. It is seen that the temperature of the pond water is increased gradually and reaches maximum at 4 pm. The time required to warm up the pond water due to thermal capacity of the pond water is high. The large amount of thermal energy is stored in the depth of shallow solar pond is 0.06 m than the shallow solar pond with 0.15 m depth. The maximum temperature of the different depths of pond water is found to be 42 °C and 57 °C. It is concluded that the pond water temperature is increased with the decrease of pond water depth.

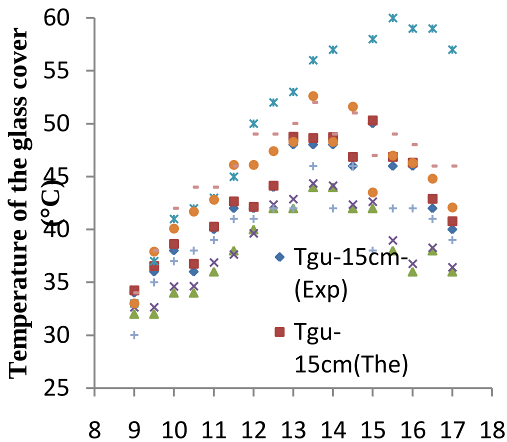

Fig. 11. Shows the comparison between theoretical and experimental temperature of the upper and lower glass cover for the SSP with different depths.

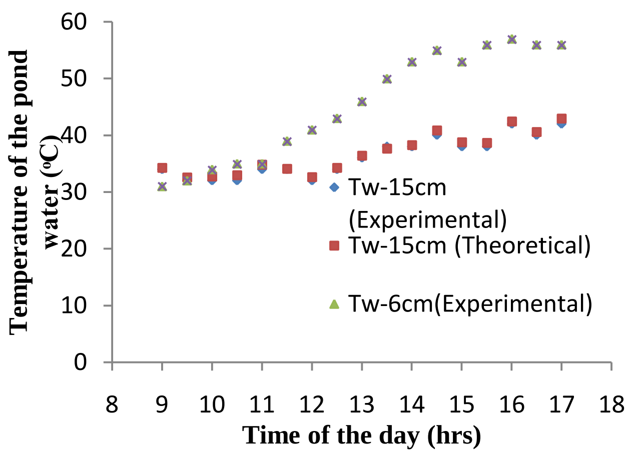

Fig. 12. Comparison between theoretical and experimental value of the pond water for the SSP with different depths

The performance of the shallow solar pond with different depths (0.06 m and 0.15 m) has been compared. It is suggested that the depth of shallow solar pond with 0.06 m seems to be better than the shallow solar pond with 0.15 m depth due to low thermal capacity.

It was found that the maximum temperature of the pond water with depths 0.15 and 0.06 m are 42 °C and 57 °C. The maximum thermal energy is extracted from the pond with depth (0.06 m) and large amount of thermal energy can be stored.

5. Conclusion

The shallow solar ponds have been fabricated with different depths (0.06 m and 0.15 m) and their performances were compared. On the basis of the present studies, the following conclusions were made.

1. The shallow solar pond with 0.06 m depth grants better performance than the depth of 0.15 m shallow solar pond.
2. The pond water temperature increased with the decrease of pond water depth due to the low thermal capacity of the pond water.
3. The maximum temperature of the pond water with 0.06 m depth was found to be 57 °C.
4. The maximum temperature of the pond water with 0.15 m was found to be 42 °C.
5. The systems works better at higher temperature and more the solar radiation is, the more thermal energy can be stored and extracted.
6. The theoretical and experimental results have been compared. It was found that the theoretical results are in good agreement with the experimental results.
7. The shallow solar pond with 0.06 m water depth, may used as a thermal sources in winter and summer.
8. The shallow solar pond with 0.15 m water depth, may used as a thermal sources in summer.

Nomenclature and units

H- Solar Insolation (W/m^2)

A_w- Area of the water (m^2)

T_w - Temperature of water in the pond (°C)

α_w - Absorption of the water

A_{gu} - Area of the upper glass cover (m^2)

A_{gl} - Area of the lower glass cover (m^2)

T_{gl} - Temperature of the lower glass cover (°C)

T_{gu} - Temperature of the upper glass cover (°C)

T_a - Temperature of the ambient (°C)

h_{clu} - Convective heat transfer coefficient form upper to lower glass cover (W/m^2)

h_{rlu} - Radiative heat transfer coefficient from lower to upper glass cover (W/m^2)

h_{cua} - Convective heat transfer coefficient from upper glass cover to ambient (W/m^2)

h_{rua} - Radiative heat transfer coefficient from upper glass cover to ambient (W/m^2)

h_{cwl} - Convective heat transfer coefficient from water to lower glass cover (W/m^2)

τ_{gu} - Transmittance of the upper glass cover

τ_{gl} - Transmittance of the lower glass cover

α_{gu} - Absorption of the upper glass cover

U_s - Side loss coefficient (W/m^2)

m_w - Mass of the water in the pond (K_g)

C_w - Specific heat capacity of water in the pond (J/K_g)

${\tau^2}_g$ - Transmissivity of glass covers

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