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Thermal Performance Study on Parametric Variation of Storage Volume of Water Loaded in a Small and a Domestic Size Experimental Shallow Solar Ponds (SSP)

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ABSTRACT: The thermal performance of a small size and a domestic size Shallow Solar Pond (SSP) have been investigated by varying the volume of water stored in the SSPs and their performance are compared. The thermal performance curve for SSPs has been obtained and from the curve the heat loss coefficient of the SSPs has been experimentally determined. A small size shallow solar pond have been fabricated using a ceramic sink of size 0.47m x 0.30m x 0.13m and was properly insulated along the inside bottom and side walls with black Polyurethane foam (PUF) in sheet form of thickness 12mm. A Low Density Polyethylene (LDPE) black sheet liner of 200 micrometer thickness has been laid all along the bed side and inner peripheral sides for better solar energy capture. Once the study volume of water is loaded in the SSP, a clear transparent PVC sheet of 150 micrometer thickness was laid over the top surface of water and used as evaporation suppressing membrane. A single transparent glass cover of 5mm thickness was fixed for air leak proof on top of SSP inorder to reduce the convective heat losses due to wind effect. Copper - constantan thermocouples have been used in different numbers to measure the temperature at different locations of the SSP system. Small size SSP was made for a maximum storage volume of 10 liters and the study was conducted initially loaded with 2 liters of water and further studies were made for the increased storage volumes of water in steps of 2 liters upto 10 liters. It is inferred from the obtained results that the temperature attained by the small size SSP was found to have maximum at 81.5^{0}C, 74.2^{0}C, 71^{0}C, 66.5^{0}C, 70^{0}C for the storage volumes of 2, 4, 6, 8, 10 liters respectively. The mean instantaneous heat collection efficiency was estimated as 37.2% and the estimated mean heat loss coefficient was 4.23 W/m^{2} ^{0}C. The mean τα product of the system is estimated as 0.48. A domestic size shallow solar pond has been fabricated inorder to hold larger volume of water, using a metal tray made of GI sheet of size 1.02m x 0.68m x 0.10m and was tested for its performance for the increased storage volumes from 15 liters to 50 liters in steps of 5 liters a day. The domestic size SSP has attained maximum temperatures of 87^{0}C, 83.3^{0}C, 88.3^{0}C, 86.3^{0}C, 75.4^{0}C, 70^{0}C, 62^{0}C, 75.5^{0}C, when the domestic SSP loaded with the storage volumes of 15, 20, 25, 30, 35, 40, 45, 50 liters respectively. The mean instantaneous heat collection efficiency was estimated as 51.5% and the estimated mean heat loss coefficient was 3.84 W/m^2 ^{0}C. The mean τα product of the system is estimated as 0.68. The maximum temperature of the SSP water was found to be decreasing with the increase in the storage volume of water. The shallow solar pond of the type discussed here could be utilized as a source of hot water which could be suitably used for the domestic and industrial heat applications process. A large size shallow solar pond of similar type could provide necessary hot water for the generation of even electrical power when properly designed and coupled through an ORC engine.

KEYWORDS: Shallow solar pond, Storage volume variation, Instantaneous efficiency, Thermal performance curves, Overall heat loss coefficient.

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I. INTRODUCTION

A shallow solar pond (SSP) is a solar energy collector using large volume of water of small depth for absorbing and storing solar radiation as heat energy. It is a low cost collector where water is directly exposed to solar radiation and enclosed in a thermal insulating material. The depth of the SSP is also typically only a few centimeters in which the water is holding in the blackened tray. The black bottom of the SSP absorbs the solar radiation and result the water gets heated. The shallow solar pond is a solar water heater which has a capacity of heating large volume of water to the typical temperature by the weather condition. The cooling effect by evaporation is prevented by a transparent clear film in contact with the top surface of the water. The collection efficiency of the SSP is directly proportional to the water depth and the water temperature is inversely proportional to water depth.

In the Shallow Solar Pond the layer of water act as the absorber plate, this is resting on the thermal insulating base and side material with one or two transparent glazing laid on the top. H.P.Garg *et al* [1] reviewed the work done by the various researchers on the shallow solar pond and concluded that there are losses due to conduction, convection, radiation. The performance of the system depends on the various parameters such us water depth, average ambient temperature, total heat loss coefficients, number of glazing. In order to reduce these losses the proper choice of material, optimizing the design and the mode of operation plays the role in SSP. J.Gonzalez *et al.* [2] studied mathematically that it is possible to obtain accurate predictions of the thermal behavior of the SSP water heaters with a dark colored bags of portable water. H.M.Ali and M.Akhlaghi [3] indicated that with the use of reflector water depth of 10cm is suitable to use as a source for low temperature applications during winter season and 5cm depth of water can be used for moderate temperature applications. H.M.Ali [4] concluded that the compact shallow solar pond can provide a suitable water temperature to be used for low and moderate temperature applications even in winter with 0.10m water depth. S.C.Sharma and Ashesh tiwari [5] investigated that the uses of glass cover glazing along with the PVC cover can enhance the pond performance in terms of storage water temperature. S.Aboul-Enein *et al* [6] concluded that the better performance of the SSP can be achieved by using the double glass cover with outer mirror under batch mode of heat extraction. The main parameter which affects the SSP performance is the water depth. H.M.Ali [7] has studied that the effect of gap and spacing between the glass covers on the SSP and shown that the change in the gap and spacing of the glass covers in the shallow solar pond has no effect on the performance of the pond. In this study, the thermal performance of the experimental shallow solar pond of small and domestic size with the parametric variation of storage volume of water has been investigated under batch mode of operation. These types of SSP have been performed and the measured temperatures of the pond are used to calculating the mean instantaneous heat collection efficiency and mean heat loss coefficient of the systems. The shallow solar pond of the types discussed here could be utilized as a source of hot water which could be suitably used for the domestic and industrial process heat applications for the climatic conditions of the tropical regions.

II. MATERIALS AND METHODS

The small size experimental shallow solar pond was fabricated with the locally available rectangular ceramic sink with the dimension of 0.47 x 0.30 x 0.13m with the wall thickness of 0.012m. A domestic size shallow solar pond was also fabricated with a metal tray made of GI sheet of thickness 0.002m for the size of 1.02m x 0.68m x 0.10m. For both SSPs, black polyurethane foam (PUF) of thickness 0.012m was used for insulation through all sides and bottom of the pond to reduce the heat loss. In order to capture the better solar energy a Low Density Polyethylene (LDPE) black sheet liner of 200 micrometer thickness was laid all along the bed side and inner peripheral sides of the shallow solar pond and to hold the water. A clear transparent polyvinyl chloride (PVC) sheet of 150 micrometer thickness has been used as evaporation suppressor and a transparent glass cover of thickness 0.005m was used to cover the pond. The maximum storage capacity of the small size SSP was 10 liters and the study was conducted initially loaded with 2 liters of water and further studies were made for five different storage volumes of water increased in steps of 2 liters upto 10 liters. Domestic size SSP was tested by increasing the storage volumes from 15 liters to 50 liters in steps of 5 liters a day. The pond was operated under batch mode. Calibrated copper constantan thermocouples were used to measure the temperature at different location of the pond as well as water. The ambient temperature was taken by using

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thermometer with an accuracy of 0.1^0 C. The global solar radiation incident on the pond cover was measured using a pyranometer. The measured values of different temperature are used for calculating the instantaneous heat collection efficiency and heat loss coefficient.

The Hottel – Whiller – Bliss (HWB) equation for the instantaneous rate of heat collected per unit area of the shallow solar pond [8] is given as,

$$\dot{q} = (\alpha\tau)I - U_L(T_f - T_i) \quad (1)$$

The instantaneous collection efficiency (η_i) of the SSP $_{is}$ defined as

$$\eta_i = \frac{\dot{q}}{I} = (\alpha\tau) - U_L(T_f - T_i)/I \quad (2)$$

It is also useful to define the daily collection efficiency η_d as

$$\eta_d = \frac{mCp\,\Delta T}{AIt} \quad (3)$$

III RESULTS AND DISCUSSION

A. Study on Small Size SSP

The experiments have been performed to investigate the pond performance and the SSP was operated form 9.00AM to 5.00PM, during the period from 9.00AM until noon most of the heat is utilized for heating the pond water and absorber sheet. A transparent glass cover of 0.005m has been placed on top of the SSP to prevent the pond from the wind velocity. The experiments have been performed simultaneously for 5 successive days. Fig.1 shows that the hourly variation of pond water temperature, average ambient temperatures and average solar insolation with respect to time.

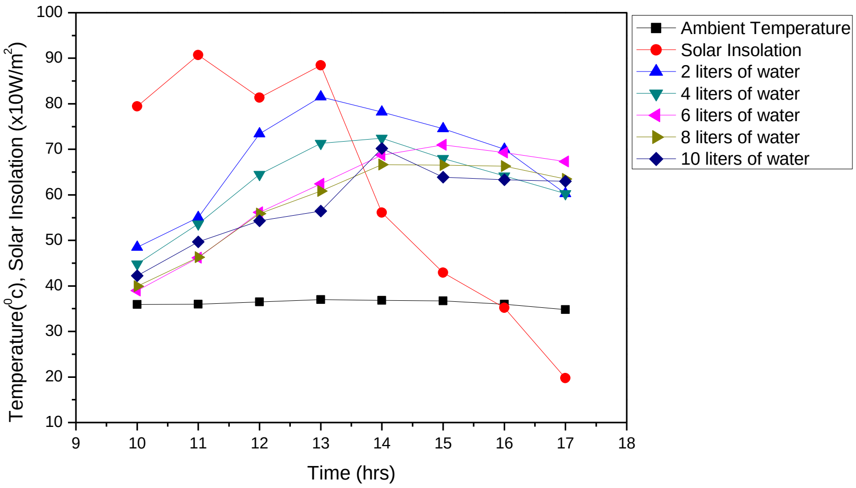

Fig. 1. Hourly variations of the water temperature, average ambient temperature, average solar insolation with respect to time.

It is inferred from fig.1 that the temperature attained by the small size SSP was found to be maximum of 81.5^0C, 74.2^0C, 71^0C, 66.5^0C, 70^0C for the storage volumes of 2, 4, 6, 8, 10 liters respectively. The hourly variations of the average ambient temperatures are 35.9^0C, 36^0C, 36.5^0C, 37^0C, 36.8^0C, 36.7^0C, 36^0C, 34.8 ^{0}C for the time period 10, 11, 12, 13, 14, 15, 16, 17 hours and the average solar insolation variations of 794.58, 906.82, 813.61, 884.50, 560.79, 428.84, 351.67, 197.74 W/m^2 for the time period 10, 11, 12, 13, 14, 15, 16, 17 hours respectively. From the obtained values the maximum heat collection efficiency was 57.3% for 10 liters of pond water. The mean instantaneous heat

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collection efficiency was estimated as 37.2% and the estimated mean heat loss coefficient was 4.23 W/m^{2} ^{0}C. The mean τα product of the system is estimated as 0.48.

B. Study on Domestic Size SSP

In an attempt to increase the storage volume of water, a domestic size SSP was taken for this experimental study and to investigate the pond performance. Inorder to hold large volume of water a metal tray made of GI sheet was taken with proper insulation and was operated form 9.00AM to 5.00PM for the successive days. Fig.2 shows that the hourly variation of pond water temperature, average ambient temperatures and average solar insolation with respect to time.

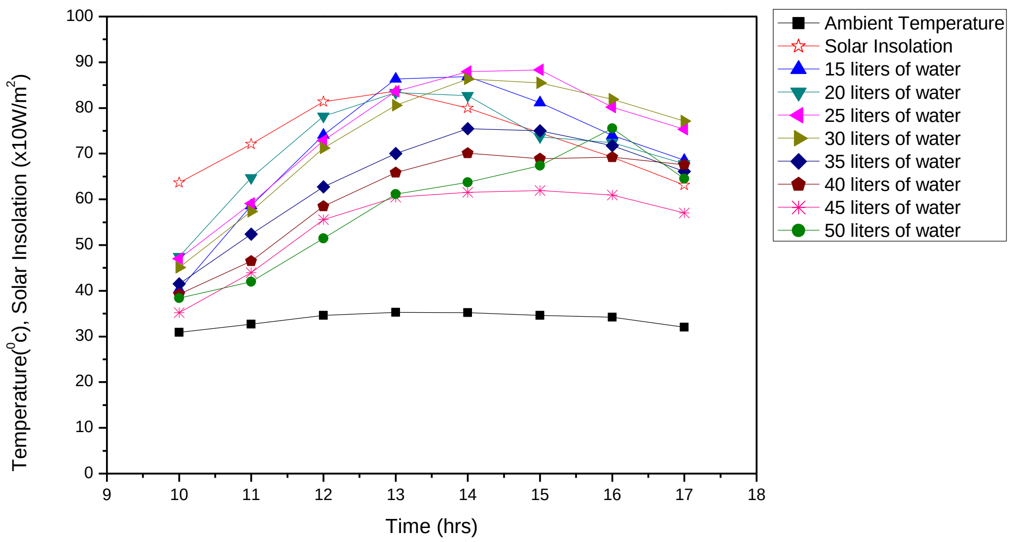

Fig. 2. Hourly variations of the water temperature, average ambient temperature, average solar insolation with respect to time.

It was concluded from fig.2 that the maximum temperature of the water on the domestic size SSP are obtained as 87^{0}C, 83.3^{0}C, 88.3^{0}C, 86.3^{0}C, 75.4^{0}C, 70^{0}C, 62^{0}C, 75.5^{0}C for the storage volumes of 15, 20, 25, 30, 35, 40, 45, 50 liters respectively. The hourly variations of the average ambient temperatures are 31^{0}C, 32.7^{0}C, 34.6^{0}C, 35.3^{0}C, 35.2^{0}C, 34.6^{0}C, 34^{0}C, 32^{0}C for the time period 10, 11, 12, 13, 14, 15, 16, 17 hours and the average solar insolation variations of 636.73, 720.97, 813.64, 837.04, 799.93, 745.26, 692.30, 631.47W/m^{2} for the time period 10, 11, 12, 13, 14, 15, 16, 17 hours respectively. From the measured values the mean instantaneous heat collection efficiency was estimated as 51.5% and the estimated mean heat loss coefficient was 3.84 W/m^{2} ^{0}C. The mean τα product of the system is estimated as 0.68.

C. Efficiency of the small size and domestic size SSPs

The hourly variations of the temperatures of water on both the SSPs are measured and the results indicate on the fig 1 and fig 2 the The maximum temperature obtained by the small size SSP was 81.5^{0}C for 2 liters of storage volume water and 48.5^{0}C temperature was minimum for the same. For the domestic size SSP a maximum temperature of 88.3^{0}C for the storage volume of 25 liters of water and the minimum of 47^{0}C. The instantaneous efficiency for both the SSP was calculated by using Hottel-Whillier-Bliss(HWB) model and the mean heat collection efficiency, mean heat loss coefficient, mean transmittance-absorbtance and peak temperature of both the SSPs are tabulated in tab 1. The

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performance curve of the SSP for the variations of the efficiency with respect to ($\Delta T/I$) for both condition of the pond. A least square fit of straight line with negative slopes are obtained and are used to determine the SSPs

Table 1: Thermal Performance of the Shallow Solar Pond for various loaded volume of water.

Loaded Volume of Water (Ltrs)	Peak Temperature Tw °C	$\tau\alpha$ $x10^{-2}$	U_L (W/m² °C)	η_i Mean
2	81.5	24.8	3.39	0.1315
4	72.4	35.3	2.05	0.2927
6	71.0	52.2	4.33	0.3948
8	66.5	57.8	4.34	0.4640
10	70.0	72.2	7.12	0.5737
15	87.00	61.5	3.85	0.3892
20	83.35	55.9	3.16	0.4140
25	88.35	64.4	3.99	0.4659
30	86.35	65.4	3.22	0.5170
35	75.45	83.4	5.46	0.6030
40	70.10	78.8	4.76	0.5973
45	62.00	67.6	3.01	0.5094
50	75.50	71.8	3.34	0.6239

characteristic. Based on the intercept of the obtained lines, the transmittance-absorbtance product ($\tau\alpha$) and heat loss coefficient U_L values were obtained. The mean instantaneous heat collection efficiency was estimated as 37.2%, 51.5% for small size and domestic size respectively. It is also found from the slope of the performance curves that

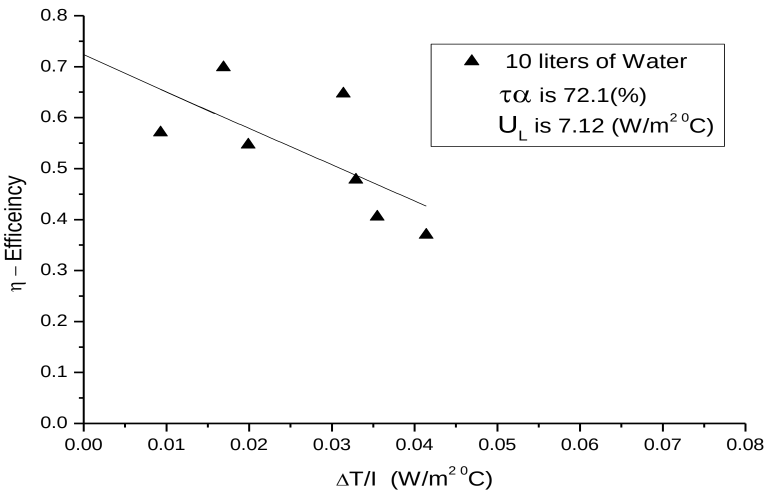

Fig.3. A Typical Thermal Performance Curve of small size SSP for a Storage water load of 10 Liters

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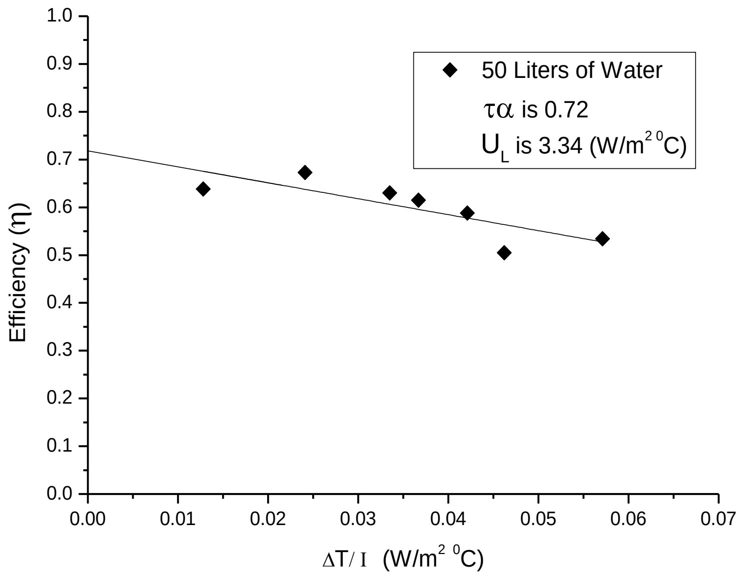

Fig.4. A Typical Thermal Performance Curve of domestic size SSP for a Storage volume of 50 liters of water

the mean heat loss coefficients ($U_{L)}$ has been estimated as 4.23 and 3.84 (W/m$^{2\,0}$C) for small and domestic size SSP. The mean transmittance-absorbtance product (τα) value obtained for small size was 0.48. The corresponding value of (τα) for the domestic size SSP was 0.68. It was found that the temperature obtained the maximum at noon and get decreases slowly afterwards and it agree with those obtained by A.I.Kudish and D.Wolf [9]. From the results indicated that the maximum temperature of the SSP water was found to be decreasing with the increase in the storage volume of water. The types of Shallow Solar Pond investigated here could be use as hot water source for the domestic and industrial heat applications.

IV CONCLUSION

From the experimental results it is concluded that the shallow solar pond operated in batch mode condition, for a storage volume of 10 liters the small size SSP attained a temperature 70^{0}C. The domestic size SSP has attained the maximum temperature of 75.5^{0}C for the maximum storage volume of 50 liters of water. Referring to the table 1 the maximum temperature attained by the SSP was found to be decreasing with the increase in the storage volume of water. It is suggested that once the SSP attains maximum temperature the stored water can be drained out for storage in a thermos flask type structure for after sunshine hour uses. From the performance analysis it is observed that the SSP is more efficient to provide hot water required for the domestic and industrial needs. It is concluded that a large size shallow solar pond could provide more volume of hot water for the required high temperature below 100^{0}C and could be utilized for the generation of electric power supply when suitably coupled with an orc engine.

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