

# Examining the Combination of a Parabolic Solar Collector with Phase Change Material (PCM) in Solar Distillation

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**Abstract.** An Experimental investigation had been executed in a solar distill unified with parabolic collector using PCM. This experiment had been compared with PCM less experimental setup. PCM and Parabolic solar collector are things embedded with the base system to increase the overall outcome. Used paraffin wax as PCM (Phase Change Material) was one of the most cost-effective approaches to store heat energy. The solar ray's incidence had been harvested by using the solar distill in which the water passed by the water tubes. This base solar still consist of double slope and the water tube filled with PCM. These experiments were done at the water depth of 15 mm. In these experiments produce the results indicated that a solar distillation system with a Parabolic Solar Collector coupled with PCM yielded higher productivity and temperature levels compared to not utilizing PCM, and these experiments demonstrated that the introduction of PCM in DSSD with Parabolic solar collector with or without it PCM resulted the improvements of the productivity of 33.25% and 57.31% respectively.

**Keywords:** Double Slope Solar Distill, Parabolic Solar Collector, Phase Change Material, Efficiency, Experimentation.

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## 1. Introduction

The per capita demand for portable water has been significantly reduced due to global population growth. The unthinkable increasing the shortage of drinkable water is modern problem, which is taken as most necessary issue which is needs to be taken care in developing countries like INDIA and so. We all know that the necessity of the pure drinkable water is largely avoidable in our daily life. At present, the water sources such as bore wells, rainwater, rivers and lake water are not in favorable conditions. The population growth and environmental pollution and common sense less citizens are the main reason for the impure drinking water. So, the water from the surface level gets purified by natural stagnation method or constructed lab purifying of water has been producing the pure portable water for the people consumption. This purification processes involve the following steps, like removing un-dissolved matters, dissolved matters and dangerous microbes. The old age classical water purifying method is by the solar energy. The main and biggest reason for fresh or pure drinkable shortages had been created because of the human's carelessness about the environment and their un-controllable population growth. Still the unused natural resources like sea waters are the only abundant in nature. Due to its high salinity level human can't consumed as it is. Even though lab treated sea water can be consumed with certain level. This sea water can be treated in the desalinated plants to convert it as potable water. The sea water mixed with the brakish water to increase the drinkable water and lessen the salt content in it [1]. This may look like an attractive way to tackle the shortages of pure water. But the cost of producing way higher than expected. And the quantity of water produced has been in the question mark. And the natural solar distilling also faces the same issues like productivity, atmospheric climate conditions. These climatic conditions can't control by human's as they are mostly coming under the meteorological terms. The systems assemble and design parameters can be controlled and flexible enough to convert it to the systems size and materials used and these changes also affect the efficiency of the system [2]. In this paper the author discussed about the thermal storage system and its effects on the desalination system for the different variable parameters likes of water depth, different material as solar collector, and added auxiliary setups (heat storage units, concentrators) and different environmental conditions. To evaluate the importance of the Phase Change Materials (PCM), the experiments had been conducted with and without PCM with the base experiment setup. Temperature point measurements of the experimental set up were measured at water level, atmosphere condition; DSSD systems inner surface and top glass cover by measuring devices like thermocouple, digital thermometer. This observation gives the exact comparison of using thermal storage unit with the single slope solar still integrated with the PSC. The productivity of this experiment gives almost 61% [3]. The DSSD coupled with relatively sun warmed solar pond (Shallow) showed the improved productivity than the others. This shallow solar pond is the auxiliary set up which is the main reason for this improved productivity. By make a comparison study with the shallow solar pond less DSSS we came to the exact difference. The experimental values of these above two different experiments are 5.10 liter / m<sup>2</sup> and 3.18 liter / m<sup>2</sup> per day respectively. The results were produced theoretically closely matched the experimental values shows the experiments setup had been constructed well [4]. The fluctuating atmospheric conditions exert a substantial influence on the productivity of the DSSD as evidenced by the fuzzy sets. Water depth, wind speed, integrate, sprinkler, solar intensity, ambient temperature these things are makes significant changes in the productivity of the solar concentration [5]. In comparison between glass covered solar stills to the plastic covered solar stills, the earlier gives more effective transmittance radiation. The water's surface receives both direct solar radiations and the reflected radiation by interior surface of the walls and then these interior walls absorb a fair amount of the reflected radiation. The effectiveness of the insolation has been impacted by the reflectivity of the inner walls upon

the saline water [6]. The maximum improvement in the final outcome were closed to 33.1% in solar distill of single slope integrated with copper used as flat plate solar collector under the specified experiment procedure [7]. Depth of the water is taken as variable to investigate a performance of the solar stills. The experimental setup was designed to create an angle of  $20^{\circ}$  (The inclination angle of solar rays to the earth is  $20^{\circ}$ ). In this experiment found that the total overall outcome of the system is very much higher when the water depth level low [8]. Here the parameters of the design have been taken as the determinants of the investigation. In which the water surface to top cover, depth of the water on the productivity of the system studied experimentally. This experiment produces the result that shows the less depth of water and the dimension from water surface to the glass cover measured 2.5 and 8.9 cm respectively has the higher total outcome [9]. Various collecting areas were created in an experimental approach to investigate how different water depths affect the productivity of active solar stills. It shows the productivity got reduced with the decreasing the depth of water, whereas the overall outcome steadily increases with improving the collecting area of solar energy [10, 11].

## 2. Experimental Works

The double slope solar distill (DSSD) system was designed and constructed for the analysis for the various depth of water and this system integrated with the heat storing unit filled with phase change material (PCM). The comparison study has been done with DSSD with PCM and without PCM. This experimental setup installed in the Government College of Engineering, Salem, Tamilnadu (Latitude  $11.6643^{\circ}\text{N}$  and longitude  $78.146^{\circ}\text{E}$ ) and this analysis carried out in the month of October 2022.

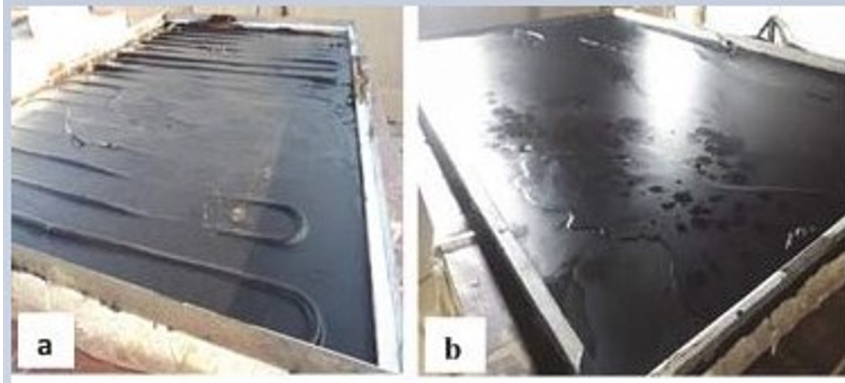
### 2.1 Experimental System Components

In this analysis the system was carried simultaneously in the two DSSD systems with closer identifications, one of the systems is without PCM and later one is with PCM as shown in Fig. 1. The DSSD was consist of double basins which are built from GI sheet a black painted but not shinny with the dimensional parameter of  $1 \times 1.5$  m width and length respectively with thickness of 1.50 mm and with various height differences. The het storing unit basin had been pervaded with the paraffin wax as PCM to acting as storing place to stag the heat and utilized when it is needed. This paraffin wax had been used because of its properties are good enough to use as storing medium compared to others [12]. The structure of the wax basin in the dimensions of DSSD and with the height of 0.005 m and it has staging capacity of 40 kg of PCM. It designs to covers heat exchanger pipe setup immersed in the system as shown in Fig. 2 (a & b) and the heat exchanger pipe, made of copper with a diameter of 11.30 millimeter and length 15 meter, was positioned with a 1-centimeter gap between it and the bottom surface. In the base basin, water intended for distillation was filled up to a height of 10 millimeter, which was situated on the PCM filled basin and insulated with insulator (silicone) to restrict any heat from escaping to the surroundings. The saline water filled experimental setup's inner surfaces were coated with black paint materials to enhance the basin's ability to absorb solar radiation. One of the main reasons for using thermal insulation is to restrict the losses in the basin bottom to the walls of the sides [13]. Here in this analysis the insulation made of glass wool 0.25 cm thickness and the thermal conductivity of  $4 \times 10^{-5}$  W/mK. The insulation of the system has been chosen mainly based on the properties of the insulators we used. Those parameters are like low thermal conductivity, lightweight, availability, cheap in cost and easily manufacturable. Then the bottom surface and walls of the systems were covered inside a frame made of wood has a dimension of 30 mm thick and 170 cm of length and 115 cm of width. The layer of polyurethane insulating foam was filled

the clearance between the basins and the wooden frame. This foam layer possessed quality of being cold and heat-resistant, with a temperature range of  $-50$  to  $+90$  degrees, which helped to minimize the heat loss to surroundings. Two glass cover of thickness  $0.04$  cm had been used as the top cover to the basins. This glass cover placed inclined to match the solar rays penetrates at the angle of  $21^{\circ}$ . Wooden frames were placed to support the both sides of the system and sealed with silicone to lessen the loss due to heat leakage between the top cover to the base box. This solar distill had been placed in the direction of the North-South of Salem, Tamilnadu, because the maximum solar incidence oriented towards this direction. A channel made of reinforced plastic was installed at the basin's base to gather the distilled water after condensation. This distilled water is consistently flowed out through a flexible hose in nature and collected and measured in a measuring jar. A vertical beam in the reinforced plastic is attached inside of solar Distell's top cover made of glass's bottom to accumulate the fresh potable water; this drinkable condensate water is constantly drained and collected by the hose which is flexible in nature and staged in the jar which has measuring limits in it. A source of the salinated water is constructed  $50$  cm above the base basin to maintain the equilibrium between the fresh potable water productions to the salinated water drain from the source tank. The parabolic concentrator used here as solar reflector to accumulate and guided on the solar collector in to the receiver tube, which means the solar harvesting improves comparatively more. This concentrator reflector manufactured by SS sheet, which has length has dimensions of length of  $200$  cm,  $106$  cm in aperture, and thickness of  $0.05$  cm and  $26.6$  cm of focal length. this parabolic concentrator had an SUS304 (absorber type) carbon / SS pipe with the dimension of  $200$  cm long and  $4$  cm diameter and  $0.03$  cm thickness and this parabolic concentrator is coated for anti-reflecting and to improve the incidence of solar radiation to its highest level.



**Fig. 1.** DSSD with Parabolic Collector Integrated with PCM



**Fig. 2.** (a) Heat Exchanger with Paraffin Wax Covered Basin (b) Without Paraffin Wax

**Table 1.** Paraffin Wax Properties

Solidifying point(°C)	Density in the liquid form (kg/m <sup>3</sup> )	Solid density (kg/m <sup>3</sup> )	Melting temperature (°C)	Thermal conductivity (W/mK)
55-60	825-850	900	46-68	0.19-0.35

In this system covered by glass of borosilicate evacuated tube 190 cm long and dia of 10 cm. This space of evacuated between the glass and steel tube and these tubes are consist by two main purpose, first one to remove the turbulence heat losses and the other one to enlarge solar radiation by the receiver tube [14]. If it is a fixed parabolic concentrator, this orientation mainly based on the latitude of the city Salem, Tamilnadu and it is orientated towards south. This observed radiation by the solar collector is transmitted the converted thermal energy to the heat storing PCM and tube which carries the water is going to distill. Water, which heat absorbed is shifted to the PCM and the parabolic concentrators increased the incidence intensity. The double slope solar collector is connected with parabolic concentrators. PVC pipes are employed to convey the heat accumulated water from the entry to the basin containing paraffin wax in the system. This PVC pipes are had the properties of low thermal conductivity and it is fully insulated outside to rectify the heat loss due to heat convection. The heated water at the inlet to distill had been transferred by the heat exchangers and it is passes through the PCM contained basin as well. A pump of pumping capacity 0.75 l/min is placed to pass the heated water through the tubes of the used DSSD. Parabolic solar collector setup is shown in Fig. 3.



**Fig. 3.** Parabolic Solar Collector

## 2.2 Experimental Procedure

The measurements of the analysis had been taken out from 09.00 am to 05.00 pm in the month of October 2022 for couple of days. The temperature value had been noted different places from the DSSD gives the exact information needed to get to the exact performance. During the experimental analysis the various temperature points like atmosphere temperature ( $T_{atm}$ ), the top glass cover temperature which is placed in the direction of south to north facing ( $T_{gsouth}$ ), ( $T_{gnorth}$ ), Salinated water ( $T_{water}$ ), the water filled base Basin ( $T_{basin}$ ), Steam temperature in the exchanger tube ( $T_{steam}$ ), inlet water temperature in the PCM filled wax basin ( $T_{waxi}$ ), temperature in the heat exchanger tube ( $T_{exchanger}$ ), temperature of water outlet from the PCM filled wax basin ( $T_{waxo}$ ), temperature of the surface of the PCM filled Basin ( $T_{PCM}$ ) and the Wax temperature in the PCM filled Basin ( $T_{wax}$ ) were taken the measurement simultaneously. The temperature of the top cover made of glass wall which is facing south and north was measured and it gives higher output and great impact on the performance of the DSSD compared to others. The temperature of the salinated water was noted at the clearance of 10 mm from the bottom of the base. These above temperature points were taken noted by the thermocouples of k type, the measurements taken by the AT4532 Multi channel thermometer modular programmable logic control. The sun tracker to track the sun rays fall angle and its position by the solar tracker. The solar radiation of intensity was taken noted by the Digital measuring device. The speed of the wind was measured by the anemometer. The rate of the water flow in the basin was maintained constantly at the rate of 0.045 l / s during all the analysis. The potable water produced after condensation was gathered in a measuring flask. The experiments were done at a salinated water depth of 15 mm. The readings were taken at the same 30 minute of time interval and recorded. The various measurement devices are illustrated in Fig. 4.



Fig. 4. Measurement Devices

## 4. Results and Discussions

The analyses were conducted simultaneously for both DSSD with PCM and without PCM in experiments in October 2022. All the experiments were conducted in a similar manner with respect to the thermal boundary conditions, so few experiments were selected to plot in the graph. The result of this experiments was carried out for the couple of days simultaneously both DSSD with Parabolic Concentrator attached with PCM and another one without PCM. The depth of the water for start of the experiment is 15 mm. these analyses were noted in the interval of 30 minutes from 10 am to 5 pm for couple days in October 2022. The overall production of the DSSD improves its productivity and rate of the salinated water evaporation in the DSSD and the rate of water condensation in the basin. Here this project aimed to improve the productivity of the DSSD by integrating PCM unit which has paraffin wax and the heat exchanger dipped in the heat storing unit coupled with the DSSD.

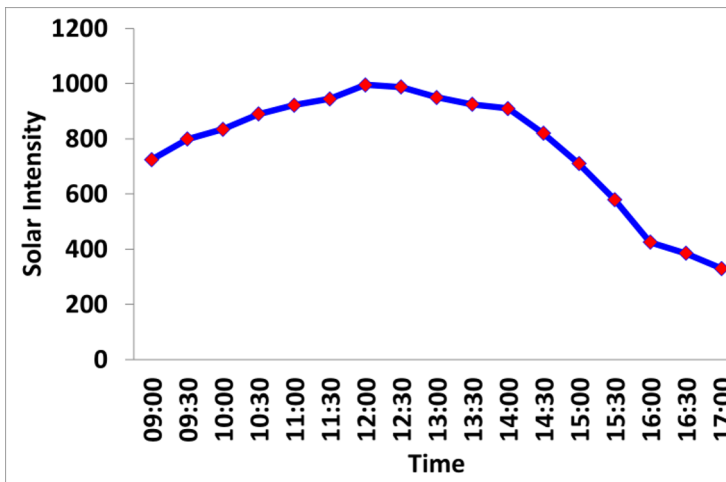
### 4.1 Solar Still Temperature

The temperature measurement of the different points of DSSD coupled with parabolic concentrator with PCM and without PCM has been taken simultaneously. This information gives the clear explanation and image to the production of the condensed potable water. This graph shows that the intensity of radiation of the solar intensity and the atmosphere temperature improves from the morning until around 12 pm, at which the intensity starts to drops. But at the same time temperature of the atmosphere increases up to 1 afternoon and it became semi stable and then drops gradually with the time. And then the next graph shows the hourly variations of the various temperature points like temperature of basin ( $T_{\text{water}}$ ), basin surface temperature ( $T_{\text{basin s}}$ ), and temperature of the wax ( $T_{\text{pcm}}$ ) and the temperature of heat storing unit ( $T_{\text{wax s}}$ ) for the DSSD with and without PCM. From these graphs, it observed that the temperature points of ( $T_{\text{water}}$ ), ( $T_{\text{basin s}}$ ) follows gradual upward trend until it reaches the maximum at 2 in the afternoon, the peak value for ( $T_{\text{wax}}$ ), ( $T_{\text{wax s}}$ ) at 4 pm and then drops gradually. To increase time of stableness of the temperature observed of water increased by

the heat storing unit by the use of PCM. This Paraffin wax improves either maintain the water temperature in the heat exchanger due to drop happens due to sun's position and cloud coverage of climatic conditions [15]. All the temperature readings were tabulated. At initial stages of the analysis the paraffin wax (PCM) absorbs and stores the energy in the form of heat and the double pass solar collecting plate which is absorbs the energy from the solar radiation. To rectify the irregular intensity of the radiation the heat storing unit works as the neutralizer. In the following charts the temperature points of the different system have been plotted as curves in the hourly basis, it shows the temperature variation along the time. Top glasses cover temperature accords when the evaporation process occurs. They also demonstrate the temperature of the water at different states had been plotted and it shows the differences in the water state at various places has been completely different or attains the state sooner than the system without PCM. Thermal properties drop gradually when the solar intensity reduces. So, it shows the system with PCM had been produces better results due to its heat storing capacity. Hence the rate of basin's water evaporation with PCM is higher and produces better outcome compared to the without PCM [16]. The paraffin wax as PCM to accumulate thermal energy from the radiation of solar power fallen on the solar collector integrated PSC which improves the solar intensity. Whereas the heat exchanger dipped in the heat storing unit which carries the hated water from initial water basin absorbs heat from the PCM even at the lesser intensity periods, that's why the performance of the DSSD with PCM had produced more. This unit absorbs the heat and kept it as latent heat. Substantially, with a constant dropping in the intensity of radiation along to the sunset, while the PCM releases its latent heat energy to the heat exchanger. This helps the heated water to the longer period of heating and it leads to the condensation for the longer time even in the night time. The variations on solar intensity radiation and temperatures with respect time for DSSD at depth of 15 mm is depicted in Fig. 5 and Fig. 6 respectively.

**Table 2.** Peak Temperatures of DSSD

Date	$T_{wax\ s^{\circ}C}$	$T_{wax^{\circ}C}$	$T_{basin\ s^{\circ}C}$	$T_w^{\circ}C$
18/10/2022	50.7	47.3	58.1	59.6
19/10/2022	50.9	48.3	57.3	59.9



**Fig. 5.** Variations on Solar Intensity Radiation with respect time for DSSD at Depth of 15 mm



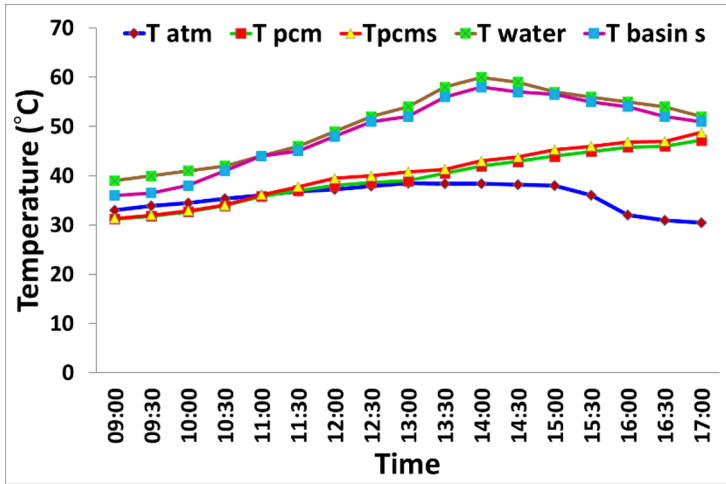


Fig. 6. Variations on Temperatures with respect time for DSSD at Depth of 15 mm

## 4.2 Total Daily Production

The potable condensed water from the DSSD with PCM is the higher compared DSSD without PCM, where this shows the importance of the PCM as indicated in the graph. The higher operating point of the temperature of the system because of the solar radiation falls on the DSSD and as well as directed towards the DSSD by the parabolic concentrator and heat stored at the PCM unit. This thermal energy contained within the paraffin wax is conducted through the basin to facilitate the evaporation of the salinated water and condensing the water at elevated temperature. The observed rise in temperature beyond the set time limit can be attributed to the influence of PCM. The Fig. 7 shows that total potable water productivity in DSSD with PCM is higher compared to the DSSD without PCM. This is because of the higher solar intensity due to parabolic concentrator and longer time PCM facilitates the transfer of heat. This leads to the high salinated water temperature and thus increases the condensation rate in DSSD with PCM than the DSSD without PCM as discussed early [17]. And the productivity also improves in the evening compared to the DSSD without PCM. In these researches the influence of the PCM with the parabolic concentrator of DSSD and the thermal storage materials influence the higher role enhance the internal energy within the DSSD [18]. And this paraffin wax has a property of the inducing faster manner inside the solar distill. One of the properties of the PCM is store the heat and releases it when the surrounding temperature reduces below the PCM. So, the PCM helps the system even after the sunset. Whereas, overall productivity of the system is also higher compared to the DSSD without PCM as discussed early. The potable water production in DSSD without PCM is 3015 and 3220 ml/day, and the DSSD with PCM is 4751 and 4425 ml/day respectively. This suggests that DSSD's productivity is greater when employing PCM compared to the DSSD without PCM.

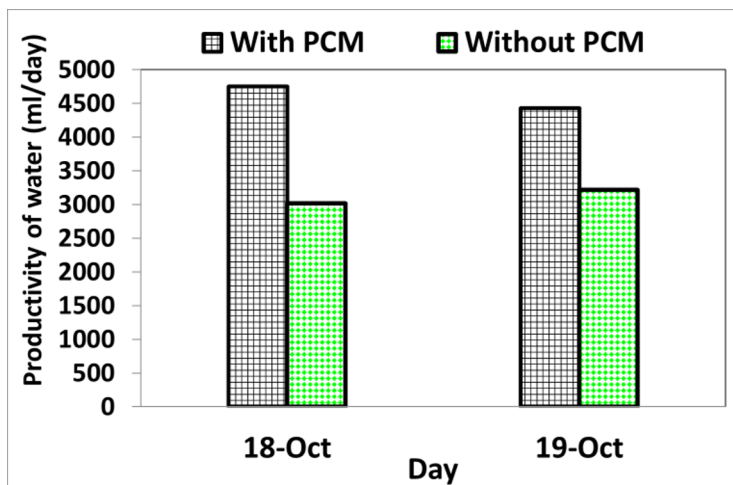


Fig. 7. Variation of hourly potable water productivity for DSSD with PCM and without PCM

## 5. Conclusions

The working of the double slope solar distill (DSSD) with the heat exchanger dipped in the paraffin wax filled Heat storing Unit and integrated with parabolic concentrator and the DSSD without PCM experimentally analyzed. From this analysis showed the DSSD with PCM coupled with parabolic concentrator produces higher maximum temperature point compared to DSSD without PCM. The overall productivity of the DSSD with PCM produces more potable water production in DSSD without PCM is 3015 and 3220 ml / day, and the DSSD with PCM is 4751 and 4425 ml / day respectively. In DSSD, the parabolic concentrator with heat exchanger improves the temperature of the PCM unit and the DSSD unit. The paraffin wax helps to neutralize the temperature drop during the climatic change occurs. And extend the condensation for longer time compared without DSSD. These experiments demonstrated that the introduction of PCM in DSSD with Parabolic solar collector with or without it PCM resulted the improvements of the productivity of 33.25% and 57.31% respectively.

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