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Research Article

Experimental Study of an Integrated Single Basin Solar Still with Bees Wax as a Passive Storage Material

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Abstract

In this work comparison is made between the conventional solar still without storage and still integrated with passive storage material. Experiments were conducted at Chandrapur (19^0 56' N , 79^0 18' E) of a City in Maharashtra State , India . Basin area of the still was 0.5 m^2 and bees wax was used as a storage material beneath the basin liner. Effect of varying depth of storage and water in basin is experimentally investigated. With increase in depth of storage and depth of water increases the overnight productivity substantially but daylight productivity is found to be less than conventional stll. Overall , Solar still with least depth of storage and water is found to give highest daily productivity in summer. PCMS are not found suitable in winter.

Keywords: *Single Basin Solar Still, Bees Wax, Passive Storage, Productivity, optimum storage*

1. Introduction

Water is vital resource for human consumption, industrial and agricultural uses. solar distillation seems to be the best possible alternative for water purification in remote and arid regions. Water impurities is a major cause to health problems and has been a challenge faced by humanity since long and has assumed enormous magnitude over last few decades and thus has been a priority for all nations to provide their populace pure potable water.

Solar still has inherent advantages such as simple design, ease in fabrication and even unskilled workers can operate it. But this device has not been found attractive owing to its lower output. Researchers have been actively working on enhancing its productivity by employing various means such as increasing evaporation and condensation rates and utilizing available solar energy with minimum heat losses (G.N.Tiwari, *et al* ,2008).

Solar still being coupled with a thermal storage element is one such possible method of improving the Productivity (H.E.S.Fath, 1998). Appropriate selection of sensible and latent heat(i.e. phase change)storage materils (PCM) will result in storing the heat through the basin liner during day time and can be released during off -shine hours. PCMS score over sensible materials with regard to high energy storage density and heat release at constant temperature. Phase change energy material (PCEM) of Paraffin wax, Paraffin Oil and water was introduced beneath the basin (Naim M.M., *et al* ,2002). It resulted in higher daylight and overnight productivity. It has more pronounced effect on overnight Productivity. Fatty acids such as Lauric Acid and Myristic Acid have also been tried and tested which improves the daylight and overnight productivity (Ali A.F.Hamdani, *et al* ,2012)

(A.A.El-Sebii, *et al*, 2009) performed transient mathematical analysis of Solar Still with Stearic Acid beneath basin liner. The analysis indicated higher daily Productivity, almost being doubled with the use of PCM. Overnight productivity is found substantially higher than conventional solar still.

Transient mathematical analysis was carried out by (Omar Ansari *et al* , 2013) using set of PCMs, under the basin liner having different melting temperatures.

(AbdulhaiyM.Radhwan,2004) studied transient performance of a stepped solar still with built in latent heat thermal energy storage and found slight decrease in efficiency and daily productivity.

Active stills and Passive stills have been tried with various attempts to improve the Productivity. The Present work is related to passive solar still. Passive solar stills are self operating, simple in construction and relatively maintenance free, (John A Duffie *et al*.2006). Also it is observed from the literature that double slope doesn't score over single slope solar stills (G.N.Tiwari *et al* ,2008).

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Single basin solar still was provided with various absorbing materials and fins on basin by (V. Velmurugan, *et al*, 2008) and found to improve the operational efficiency. (F. F. Tabrizi , *et al* , 2010) carried out experiment on a weir type cascade solar still with built in Latent heat thermal energy storage system using paraffin wax as PCM. Productivity on Sunny day was lower than the conventional still whereas on a Partial cloudy day it was substantially high.

The Present work deal with experimental investigation of single slope single basin solar still with all new material, bees wax, as a passive storage material used beneath the basin liner. Passive solar stills are efficient, economic and offers ease in fabrication (G.N.Tiwari *et al* ,2008). The choice of Bees wax is apparent with ready availability in the local region and being cheap. They contain palmitates and easters and score over other materials such as hydrated salts, Paraffin wax, fatty acids etc. Being thermally stable, non reactive and with other advantages (Atul Sharma *et al*, 2009, S.D.Sharma *et al*,2004 S.M.Hasnain, 1998) . They fulfill the requirements of a suitable PCM for solar still applications as can be seen from the properties listed in Table 1.

Table 1 Thermo physical properties of bees wax

Property	Value
Melting temperature	61.8°C
Thermal conductivity	0.25W/mK
Specific heat	3.4kJ/kgK
Latent heat of fusion	177kJ/kg
Density	950kg/m^3
Flash point	204°C
Discoloration	85°C

The objective of the present work is to determine experimentally the optimum quantity of bees wax for a given quantity of basin water so that highest daily productivity is achieved. Experiments were conducted during summer months of May and winter month of December at Chandrapur (19° 56’ N , 79° 18’ E) Maharashtra State, India.

From the literature review it is seen that experiments have not been done exhaustively for PCM in general and bees wax in particular and thus there is a need to optimize the storage material for highest Productivity. Also simulation results looks impossible to achieve in Practice after preliminary experiments. Subsequently a need was felt to verify the claims made by researchers (A.A.El Sebaii, *et al* ,2009 , Omar Ansari *et al*, 2013)

The daylight, overnight and daily productivity of Single slope single basin Solar stills provided with different quantities of bees wax is compared with conventional solar still i.e. solar still without storage. Experiments were conducted for different water depths in basin.

2. Experimental Set-Up

A Schematic of the solar still fabricated in the current investigation is shown in fig. 1. The Photographs of the Upper unit containing basin (A), bottom tray meant for storing bees wax (B) and the assembled Solar still (C)are displayed in Fig. 2.

A still has square basin surface of 0.5m^2 (0.71 m x 0.71 m)and is fabricated from mild still sheet of 1.2mm thickness and the high side wall height is 0.245m and low side height is 0.065m. Bottom surface is coated with polyester paint satin black. The upper unit that houses the basin and the bottom tray that houses the bees wax are also made from the same sheet. Vertical faces of upper unit are coated off white for better reflections (John A Duffie, *et al*,2006). The bottom and lateral surfaces of the still are insulated with 50 mm thick mineral wool (k=0.036W/m-K) to reduce the heat loss. Insulation is covered with 12 mm thick waterproof ply (k=0.17W/m-K) and is painted white. Provision is made for water feeding and a valve is provided at the back wall to add the hourly distillate back to the basin to maintain constant water depth in the basin.

Plain window glass of 4 mm thickness is fitted on the still with the silicone sealent to ensure vapor tight seal. The glass cover makes an angle of 15° (G.N.Tiwari *et al* ,2008). Distillate rolls down the glazing cover and is collected at the bottom trough provided at the top of the low side wall.

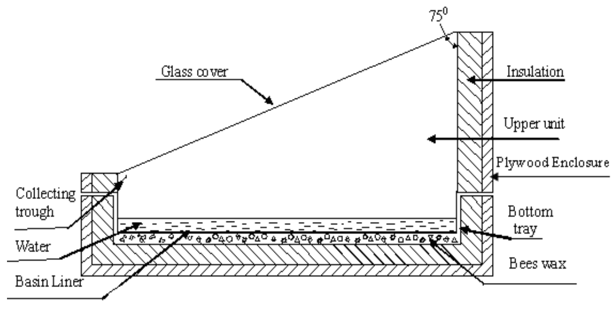
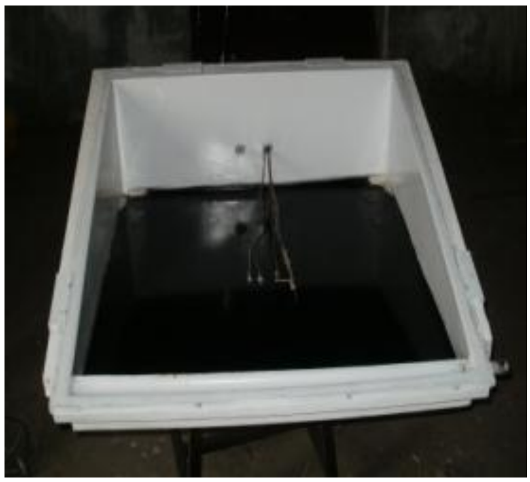


Fig. 1 Schematic of single slope single basin solar still with passive storage element



(a)

(b)

(c)

Fig. 2 Photographs of upper unit (A), bottom tray containing bees wax (B) and assembled solar still(C).

Four such units were fabricated for simultaneous operation. One conventional still is fabricated which is enclosed in Plywood body without a bottom tray referred as the base unit. This simple arrangement allows to vary the storage and water depths.

All the four units, three with varying quantity of PCM material (Bees wax) and a conventional one are mounted side by side on a test bench with glass cover facing south to receive the maximum radiation.

The experimental set up is suitably instrumented to measure Solar radiation, productivity, wind velocity and still temperatures. The solar radiation is measured with a pre-calibrated pyranometer (epply type)(±2.5%) and the temperatures were measured withPT-100sensors (±0.5%). A 500 ml jar with least count of 5ml and 100 ml jar with 1 ml least count was used to measure hourly distillate of each still. Hourly wind speed was measured with Benetech make digital anemometer

3. Experimental Procedure

The experiments were conducted in the month of May and December by charging the units with different quantities of bees wax, which corresponds to 0.5 cm (2.4Kg), 1.0 cm(4.8 Kg) and 1.5 cm (7.2 Kg) thickness of wax. In the beginning water depth of 0.6 cm (3Kg) was maintained in all the four units. Experiments were conducted from 7 A.M. to 6P.M. in summer and from 8 A.M. to 8 P.M. in winter. Every hour still temperatures such as basin, water, inner glass , outer glass and bees wax were recorded apart from insolation, ambient temperature, distillate (productivity) and wind velocity also being recorded. Hourly distillate was poured back into the respective stills to maintain constant water level in the basin of the still. Experimentation was conducted for three days for a given combination of system parameters. Similar experiments were repeated for water depths of 1 cm, 1.5 cm and 2 cm respectively. Higher water depths were not considered as the productivity of the stills diminishes (G.N.Tiwari *et al* , 2008)

4. Results and Discussions

Hourly Variation

Solar still performance with and without bees wax have been studied experimentally in summer months of May and winter month of December 2014 for the city of Chandrapur , Maharashtra state , India

Fig. 3 and Fig. 4 shows typical variation in the hourly solar insolation and temperatures measured at different locations in the solar still in summer and winter respectively. Hourly relative humidity and ambient temperatures are also plotted.

The recorded data corresponds to 0.6 cm water depth (corresponding to 6kg/m^{2}of the basin area) and bees wax depth of 0.5 cm/m^2 (4.8 Kg/m^2 of the storage tray area).

It can be seen from the figure that

- Variation in the solar insolation is parabolic in nature that peaks at 1P.M. and becomes zero at 7 P.M. It peaks at 12noon and becomes zero in winter.
- The basin liner temperature (T_b),basin water temperature (T_w) , glass temperature(T_g) and bees wax temperature(T_s) follow insolation curve but with a phase difference. This is obviously due to heat storage effect.
- Due to small quantity of water in the basin T_b and T_w are almost same. Charging of the bees wax takes place upto1 P.M. and discharging after 4 P.M. where in stored heat is given back to water. In winter charging takes place up to 2 P.M.and discharging after 4P.M.
- As bees wax mass is less, charging (phase change) is not evident as a constant temperature phase in the figure.
- The glass temperature is less than water temperature for most of the operational time by around 4^0-6^0 C. In the first two hours of operation

of still in summer, glass temperature is greater than the water in the basin the reason being heat capacity of glass is far less than water resulting in very less yield. In the first 2-3 hours i.e. 8 to 10A.M. and last 2 hours i.e. 6-8 PM inner glass temperature is less than outer glass temperature. Similar observations were seen during winter too.

- The peak value of T_b, T_w, T_g and T_s are recorded as 82^{0}C, 81 ^{0}C, 72 ^{0}C ,79^0 C at around 2 PM respectively in summer. The ambient temperature was found to peak at 46^{0}C, at 4 P.M in summer. In winter peak values were 72 ^{0}C , 71 ^{0}C , 65 ^{0}C, 66 ^{0}C respectively corresponding to 1 P.M. and peak ambient was 33^{0}C at 2 P.M.
- Relative humidity is found to bottom at 2P.M. and generally it is observed that it corresponds to highest hourly productivity.

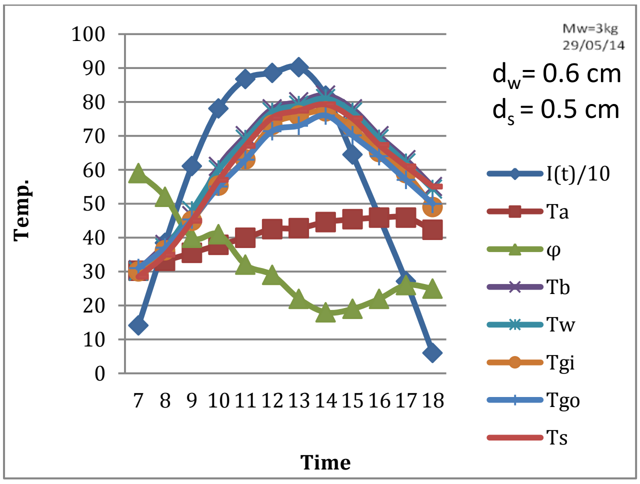


Fig. 3 Hourly variations of solar insolation, still temperatures and relative humidity on a typical summer day in Chandrapur

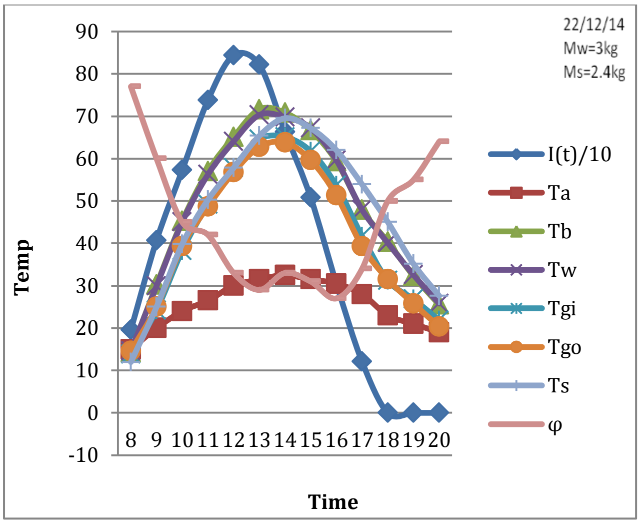


Fig. 4 Hourly variations of solar insolation and still temperatures , reative humidity on a typical winter day in Chandrapur

Hourly Productivity

Fig 5. And fig 6 Shows variation of hourly productivity for various units with varying depth of bees wax with constant water depth of 0.6cm for summer and winter days respectively. The area under the curve indicate daylight productivity of respective solar stills. Similar trends were observed for higher depths of 1 cm, 1.5 cm and 2 cm. As highest daily Productivity is reported for least depth of water the figures discusses its performance corresponding to this depth. It can be clearly observed from the figure that

- As expected, the hourly yield follows the solar radiation trend.
- For the unit without storage, peak hourly productivity occurs at around 1 PM whereas for with storage units, it peaks at 3 PM. In summer and 2 P.M. in winter. This can be attributed to heat storage effect.
- Units with bees wax found to yield higher than base unit after 2 PM however they lag in the morning hours. This can be attributed to heat being utilized in heating the bees wax to its melting point and further causing phase change.
- Stored heat in the bees wax is released (discharged) in the evening hours and thus overnight yield of units with storage is quite large as compared with the base unit.
- The maximum hourly productivity(353ml) was observed for base unit followed by (342 ml) for unit with bees wax depth of 0.5 cm, (296 ml) for 1.0 cm bees wax depth and the least being (230 ml) for highest depth of 1.5 cm of bees wax under observation in summer. For winter the peak hourly productivities are found to be (309 ml), (242 ml), (212ml),(188ml)respectively.

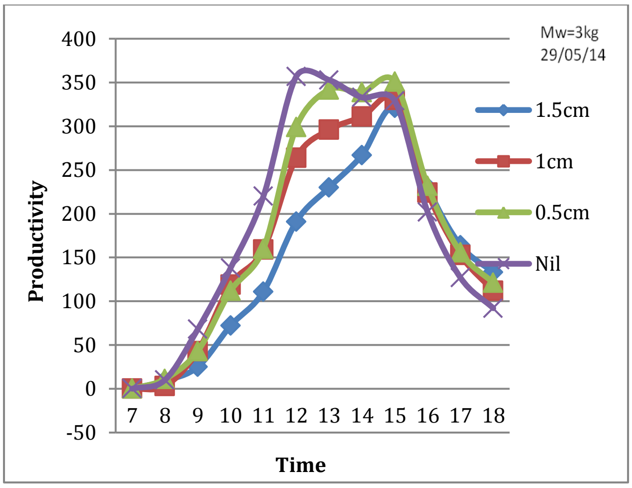


Fig. 5 Hourly productivity for different depths of bees wax on a typical summer day

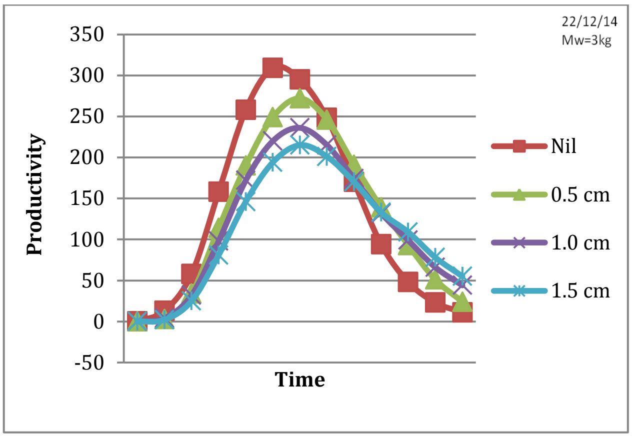


Fig. 6 Hourly productivity for different depths of bees wax on a typical Winter day

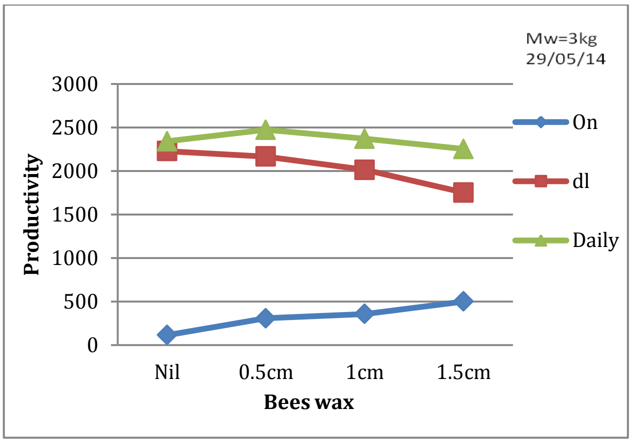


Fig. 7 Daily ,daylight and overnight productivity for different bees wax depths for a typical summer day

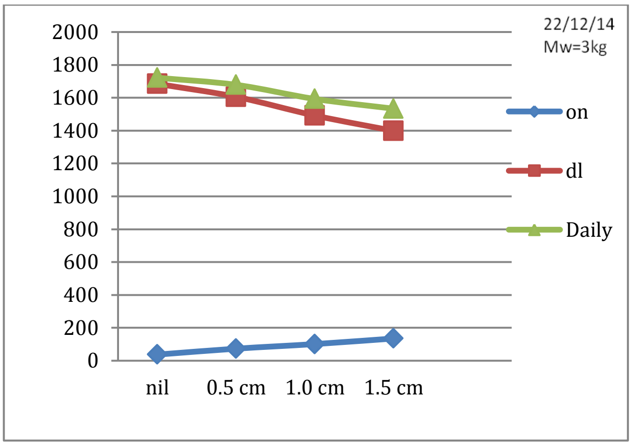


Fig. 8 Daily ,daylight and overnight productivity for different bees wax depth for a typical winter day

Fig.7and Fig.8 shows daily, daylight and overnight productivity of the solar stills with basin water depth of 0.6 cm and different Bees wax depth on a typical summer and winter days respectively. This trend was seen for higher depths of water too. It can be seen from this figure that

- The overnight productivity is much less compared to the daylight productivity. This is because, during night time, the heat stored in the bees wax is the only heat source to the basin water which is much less than the solar insolation available during the day time. The overnight yield is directly proportional to the mass and the latent heat of the storage material.

- With the increase in the storage size;

    - The overnight productivity increases.
    - The daylight productivity decreases.
    - The daily productivity also decreases.

- Only unit with 0.5 cm depth of Bees wax for water depth of 0.6 cm gives daily productivity higher than base unit. For higher depth of bees wax and water depths base unit gives higher daily productivity.

- Thus it can be concluded that only on sunny days in summer with least depth of bees wax around 6 % gain is observed., where as for winter day base unit performs better over the units with storage. This could be because of less excess heat stored in the bees wax which does not melt wax completely and obviously does not releasing heat during dicharging process. This is in contrast to the simulation findings of (A.A. El Sebaii *et al*, 2009) who has categorically stated that with the increase in PCM quantity daily productivity also increases . A experiment was conducted with a bees wax depth of 2.5cm(12Kg) where in it was clearly observed that melting of bees wax doesn't take place completely and thus although there is substantial gain in overnight productivity but a drastic reduction in daylight productivity is observed.

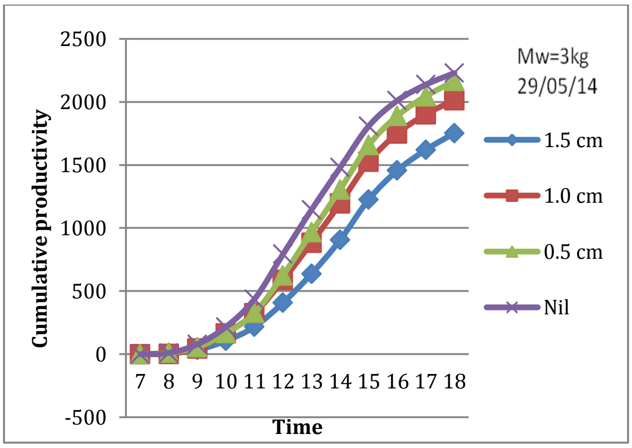


Fig. 9 Cumulative productivity for different bees wax depths on a typical summer day

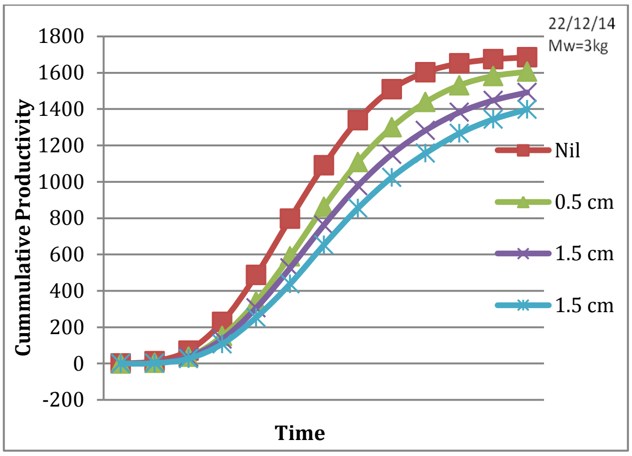


Fig. 10 Cumulative productivity for different bees wax depths on a winter day

- Fig. 9 and fig 10 shows cumulative yield for various depths of bees wax such as 0.5 cm , 1.0cm and 1.5 cm corresponding to water depth of 0.6 cm. for summer and winter respectively.

It is clearly seen from the figure that during the day time, unit without storage i.e. base unit gives higher hourly distillate and all the units with storage have lower hourly Productivity than the base unit. Also it is clearly observed that daylight productivity in summer is over 2000 ml as compared to under 1500 ml as they correspond to 6828 W/m^2 and 5175 W/m^2 solar radiation received during experiment in summer and winter day respectively.

Conclusions

Experiments were conducted in summer and winter on single slope single basin solar still with bees wax as storage material (PCM) and results were compared with base unit i.e. without bees wax. The following conclusions are drawn for the chosen still geometry, for summer and winter season.

- Units with least depths of storage and water gives higher daily productivity than the base unit in summer season. In winter however storage is not recommended owing to lower daily productivity reason being incomplete melting of wax owing to lower solar insolation.
- Overnight productivity is substantially higher in units with storage over the base unit and daylight productivity of base unit is always higher than units with storage in both the seasons.
- It is recommended to use bees wax with 0 .5 cm depth beneath basin liner to have better performance in summer with least water depth.
- As for higher depth of bees wax melting is not complete hence latent heat materials with lower melting temperatures may be investigated.
- The units under investigation are not integral type and thus might have little higher heat losses , so integral unit with minimum depth of storage be investigated experimentally.
- PCMs have lower conductivities, which can be augmented by adding metal powder or providing fins at the bottom of basin to improve heat characteristics of storage element. Wick type stills with passive storage could be investigated.

Nomenclature

A	Area (m^2)
d	Depth of Water/ Bees Wax(cm)
I(t)	Insolation (W/m^2)
P	Productivity (ml)
PCM	Phase Change Material
T	Temperature

Subscripts

b	basin
d	daily
dl	daylight
g	glas
on	overnight
w	water

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