Experimental Investigation of Single Basin Solar Still with Phase Change Material and Nanoparticles

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Abstract: An experimental investigation of a basin solar desalination with a single basin solar still having phase change material, phase change material with nanoparticles was carried out to improve the output.The experiment carried out for 9 different days with variation in salinity and mass at department of mechanical engineering at birla vishwakarma mahavidyalaya,vallabh vidhyanagar(22.5459° N, 72.9294° E). The productivity of conventional solar still, SSPCM and SSNPCM is optimum at 5 litre of water mass with 2000TDS and 3000TDS.The night time yield of the conventional solar still, SSPCM and SSNPCM is $0.200l/0.5m^2$, $0.360l/0.5m^2$ and $0.475ml/0.5m^2$ respectively and the overall productivity of conventional solar still, SSPCM and SSNPCM is $1.00l/0.5m^2/day$, $1.320l/0.5m^2/day$ and $1.395l/0.5m^2/day$. The efficiency of SSNPCM (63.10) is higher compare to SSPCM (56.5) and conventional solar still. The efficiency of SSPCM (56.5) is higher compared to the conventional (30.64) solar still.

***IndexTerms* - solar still efficiency, phase change material, paraffin wax, productivity**

1 INTRODUCTION

A need for quality drinking water has become one of the prime demands for all living beings for their survival. Although the available water sources are plenty in nature on earth only 1% of water is readily available for drinking purpose and the remaining 97% of saline water, 2% in the form of glaciers and polar ice caps are unsuitable for drinking purpose. Animals and the human being need safer drinking water to avoid dehydration, as dehydration kills humanity faster than starvation. Water that apparently looks drinkable can contain harmful microorganisms, which could lead to illness or even death if consumed.

Due to rapid population growth and industrial developments, the need for quantum of drinking water has increased. So far, the possible natural way of getting drinking water is from rivers, lakes, wells, etc., which must be purified as they may contain harmful microorganisms and mineral contents. And the purification process involves namely sand filtration, chlorination and boiling. India comprising of 18% of total world population has only 4% of water sources available to serve for Indian community. Annual per capita of water available in the world has decreased from 6042 m^3 during 1947 to 1816 m^3 in 2001 and subsequently to 1545 m^3 in 2011. The latest survey has predicted that, this water availability will be further reduced to 1340 m^3 by 2025 and 1140 m^3 by the end of 2050. A solar still is a green energy product that uses the natural energy of the sun to purify water. The solar-still process uses the sun instead of other sources such as fossil fuels to gain the energy needed for purification. Solar stills are then able to supply pure water for drinking and cooking, even in areas where there are no other sources of energy, while still being friendly to the environment The production capacity of a simple type still is very less. This makes the system highly uneconomical. Numbers of methods are available to improve the effectiveness of the still. Depend on the methods used to enhance, the stills are passive and active type solar still. In active type of stills, additional condensers or collectors are used. In passive type stills either simple modification will be done inside the still or some materials are used in basin along with saline water. Enormous works have been carried out by researchers to improve the production capacity of the still by adopting different techniques. This chapter briefs the important works carried out in this area. As water depth increases the volumetric heat capacity of the basin, reduces the water temperature for given solar radiation input. But the temperature and production rate are uniform and will not be affected by sudden solar intensity variation due to cloud passing for a short period of time. The heat stored in the water mass is released during the absence of sunshine and production continuous even during night (Tiwari and Tiwari 2006) [17]. For a shallow basin still the volumetric heat capacity of water is less and the temperature of water will be high. This will increase the evaporation rate and productivity of the still. But any change in solar radiation will have immediate effect on water temperature and production.

Some black materials can store more amount of heat energy and increase the volumetric heat capacity of the basin in addition to increasing the basin absorption. Glass, rubber and gravel are such materials having these properties (Nafey et al 2001, Abdel-Rehima and Ashraf Lasheen 2005). Experimental results show that black rubber with 10 mm size increases the

productivity of the deep basin still by 20% and black gravel with 20-30 mm size increases the productivity of a shallow basin still by 19%.

The productivity of solar stills may be improved by using storage systems. These storage systems could be sensible or latent heat systems. This adopted method utilizes the heat dissipated from the bottom of the still. The latent heat thermal energy storage systems have many advantages over sensible heat storage systems including a large energy storage capacity per unit volume and almost constant temperature for charging and discharging modes. Recently, many papers have appeared concerning the use of PCMs as storage media integrated with some solar thermal energy systems; such as that considered the use of phase change materials as storage media in solar stills [18].

Recently, many papers have appeared concerning the use of phase change material (PCM) as storage media integrated with some solar thermal energy systems for the purpose of fresh water production during the night and improve the productivity of the systems.

Al-Hamadani and Shukla [19] examined a single slope solar still with myristic acid as phase change material (PCM), the melting point and latent heat of myristic acid is 50-54 ℃ , 177 kJ/kg respectively. The daily productivity and efficiency was affected by mass of PCM and basin water under indoor simulated condition. Basic energy balance equations are modeled to expect the temperatures of water and glass, daily distillate output and efficiency of the single slope solar system with PCM. It was found that daily productivity and efficiency of the system increased with the higher mass of PCM and lower mass of basin water, but daily productivity was reduced when the amount of PCM exceeds 20 kg. The new solar still with PCM has increased the day distillate output by 35-40 % and the night distillate output by 127%.

Swetha and Venugopal [20] have added a heat reservoir under the linear of a single slope solar still using Lauric acid with (41-43) ℃ melting point as (PCM) and sand as sensible heat storage. It was observed from numerical calculations that 36% increase in collection of fresh water when the still used Lauric acid and 13% increasing when the still used sand as heat reservoir.

Kantesh [21] used bitumen (melting point:54 ℃) as PCM to enhance the productivity of single basin double slope solar still and to store the solar thermal energy in the form of latent heat. The efficiency of the solar still without PCM was about 25.19% while in presence of PCM (Bitumen) it was 27.%.

El-Sebaii [22] presented a mathematical model for single basin solar still with and without PCM under the basin liner of the still. Numerical calculations were carried out using stearic acid as PCM (melting point: 52℃), on a typical summer day. The effect of mass of the PCM on the daylight productivity, overnight productivity, daily productivity and efficiency of the still for different masses of basin water was studied. The results of the study showed that the productivity at daylight decreased as the mass of PCM increased; but overnight productivity and day productivity were increased significantly with the increase of PCM mass due to the increased amount of the stored heat within the PCM. During discharging of the PCM, the convective heat transfer coefficient from the basin liner to basin water is doubled; thus, the evaporative heat transfer coefficient is increased by 27% when using 3.3 cm thickness of stearic acid beneath the basin liner. Therefore, on a typical summer day, a value of day productivity of 9.005 L/m2 /day with a daily efficiency of 85.3% has been obtained compared to 4.998 L/m2 / day when the still is used without the PCM.

Ramasamy and Sivaraman [23] have designed a cascade solar still with and without PCM for water purification. The system mainly consisted of stepped absorber plate connected with PCM sub-system and single slope glass plate. Paraffin wax was used as Latent heat storage material due to its feasible general and economic properties. The hourly productivity is slightly higher in the case of solar still without PCM during sunny days. The maximum obtained total productivities were 1.85 and 1.680 l/day for 0.76 m2 area of still without and with use of PCM, respectively. The disadvantages of using PCM are corrosion when in direct contact with metal piping or housings. It was concluded that the inclined solar stills have higher efficiency than conventional solar stills due to smaller air gap, but the total productivity with PCM was less than that without PCM, so the latent heat storage enhanced the productivity just at night hour but it is not good for this system. The performance of still mainly depends on water flow rate and solar intensity.

Dashtban and Tabrizi [24] designed a weir cascade solar still with latent heat thermal energy storage system to improve the productivity. They used18 kg mass of paraffin wax (2 cm thickness) as heat storage system. This heat storage system was placed under the absorber basin plate to keep the operating temperature of the still high enough to produce distilled water during

the lack of sunshine, especially at night. Theoretical models were also developed for the still with and without PCM, and the calculated results were compared with the experimental data. Moreover, other important parameters affecting the performance of the still were investigated, such as water level on the absorber plate and distance between water and glass surfaces. The daily theoretical productivity was found to be 6.7 and 5.1 kg/m2. day, for the still with and without PCM, respectively. The results showed that the productivity of the still with PCM was, theoretically, 31% higher than that of the still without PCM.

2 DESIGN OF SOLAR STILL

- The single basin solar still is design is for 1.4litre at the average radiation of $500^W/_m 2$. The optimum output of single basin solar still is 1.190 liter at 18/3/2021 for the 5 liter water mass. The dimension is select because of we have need the 0.5mtr square basin for 1.4litre water output.The 220mm lower side height because of basin contain the high quantity of water like,30 or 40litre of water mass for the find out the optimum depth for the optimum result of solar still. The glass cover angle is 23° because of latitude of the Anand. For 5litres of water mass the 1.4litre water get evaporated.

- The brine water are 3.6litre.The distilled water is collected 1.190litre.190-200ml water are loss from the system.It's a maximum water get evaporated by solar still at the min depth with 5litre water mass at 18/3/2021.For the 10litre of water mass 9.9 liter get evaporated by solar radiation.The brine water quantity is 8.710 liter and 790 ml is output distilled water per day
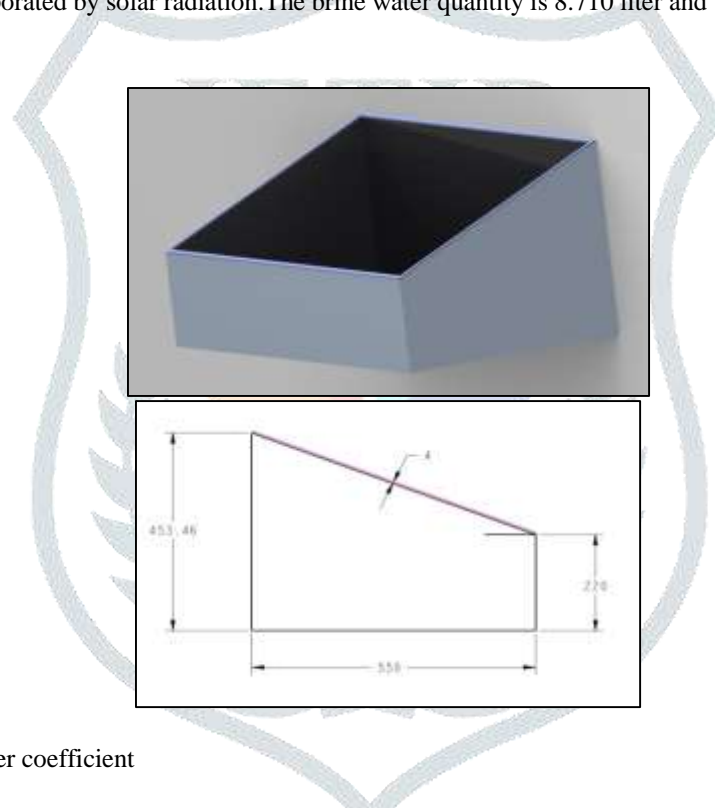
The evaporative heat transfer coefficient

$$ ❖ \quad h_{evap(w-g)}=16.227*10^{-3}h_{c(w-g)}*\frac{(Pw-Pg)}{(Tw-Tg)} $$

Where,
$h_{evap(w-g)}$=The evaporative heat transfer coefficient from basin water to inner glass cover
$h_{c(w-g)}$=The convective heat transfer coefficient from basin water to glass cover
Pw=pressure of water
Pg=pressure of glass cover

The convective heat transfer coefficient

$$ ❖ \quad h_{c(w-g)}=0.884\{Tw - Tg + [\frac{(Pw-Pg)(Tw+273)}{(268900-Pw)}]\}^{1/3} $$

Where,
$h_{c(w-g)}$=The convective heat transfer coefficient from basin water to glass cover
Tw=temperature of water
Tg=temperature of glass
Pw=pressure of water
Pg=pressure of glass cover

The hourly output is calculated by,

$$ P_h=\frac{h_{evap(w-g)}(Tw-Tg)*3600}{L} $$

Where,
$h_{evap(w-g)}$=The evaporative heat transfer coefficient from basin water to inner glass cover
L=Latent heat of vaporization of water

The daily output:

$$P_d = \sum_{24\ hours}(P_h)$$

2.1 Efficiency Calculation:

From the measured quantity mentioned in observation table we were calculate the efficiency of output to compare efficiency with conventional, PCM and PCM with nanoparticles.

$$\eta = \frac{m * h_{fg}}{A * I}$$

Where,
m = Distillate output from the solar still (kg/0.5 m²/day);
h_{fg} = Latent heat of vaporization of water (2260 J/kg);
A = Area of glass cover (0.5 m²);
I = Solar radiation (W/m²)

3 SELECTION CRITERIA FOR DESIGN

The desalinated yield of solar still is greatly influenced by environmental, operational and design parameters. As environmental conditions are beyond human control, one can use optimum operational and design conditions to boost the output of solar still. In the present work, the model that used for the experimentation is also designed based on optimum design criteria.

Design and Operational Parameters	Selected Dimension/Design	Optimal Range / Conclusion
Depth of water in basin	1-5 cm	Decrease in depth of basin water increases productivity
Inclination of glass cover	23° (Latitude angle)	Glass cover having inclination equal to latitude of the location gains solar radiation nearer to normal throughout the year
Orientation	East-West Orientation (Slopes facing due East and West direction)	Distilled Output for East West (E-W) Orientation is higher than North - South(N-S) Orientation
Insulation thickness	30 mm Polystyrene foam	20 to 40 mm
The selection of the material (1) Cover (2) Absorber Plate (3) Sealant	Cover - Glass (3.5 mm thick), Absorber plate - Aluminium, Sealant - Silicon sealant	Cover - Glass thickness 3 - 6 mm, Absorber plate - Aluminium, Aluminium has higher conductivity, Sealant - Silicon rubber is most effective than other sealants

4 EXPERIMENTAL SETUP

4.1 Specification of Setup

- Area of collector – 0.5 m2
- Lower side height – 220mm
- Higher side height – 453.46mm
- Width- 550mm
- Top cover tilt angle - 23°
- Material of basin - GI sheet

5 METHODOLOGY

The experiments were conducted on single basin single slope solar stills for conventional solar still, solar still with PCM and solar still having PCM with Nanoparticles. The solar still was placed in such a way that its slopes face the East directions, which means slope was facing east direction. The experiment was done for various water depths from 1 cm to 5 cm to obtain the maximum productivity. From these experiments, the optimum water depth and maximum distilled water output were identified. Then the experiment was done with solar still with PCM and solar still having PCM with Nanoparticles for the time duration of 24 hours (11 am to 11 pm).

6 EXPERIMENTAL PROCEDURE

Single basin single slope solar stills were fabricated. The experimental setup was placed on uniform ground surface to avoid the titling of solar still. Inclination angle of glass cover of slopes was kept 23° at the location of Anand (22.556° N, 72.951° E).Glass beakers was placed at output pipe to collect the distilled water output.Various thermocouples were used for measuring the temperature and were placed at different locations, in basin water, at inside surface of glass cover, and one in open air for measuring ambient temperature.Water quality was checked before start of experiment by measuring TDS of sample water. At the end of experiment, again the TDS of distilled output water were measured for ensuring that TDS value is under the limit of pure drinking water.After setting experimental setup with measuring instruments, water was filled in solar stills.Observations of collected distilled water were taken for regular interval of time of half hour. Simultaneously, the temperature of solar still at various location was measured by indicator and the solar radiation intensity was measured by calibrated Solar Power Meter.

7 RESULT AND DISCUSSION

7.1 Temperature And Solar Radiation

The experimental setup was installed at the Department of Mechanical Engineering, Birla Vishvakarma Mahavidyalaya Vallabh Vidyanagar. Most of the experiments were conducted between 9:00 A.M. to 11:00 P.M. The experiments were done from March 17, 2021 to May 09, 2021.

Due to pandemic situation, experiments were conducted between March 17, 2021 to March 25, 2021 for conventional solar still, April 21, 2021 to April 29, 2021 for solar still with Phase Change Material and from May 01, 2021 to May 09, 2021 for solar still having Phase Change Material with Nanoparticles.

The work involved two parts; parametric study to find the best conditions within a certain range for each parameter then the results from this part are used to study the system performance and productivity during 24 hours period.

Figure 1 and Figure 2 shows the temperature variation of basin water temperature (Tw), glass temperature (Tg) and ambient temperature (Ta) and Solar radiation respectively for a typical summer day, conventional solar still. It is clear from Figure 1 and Figure 2 that the increase in basin temperature is directly proportional to the input solar energy which is similar to typical solar radiation.
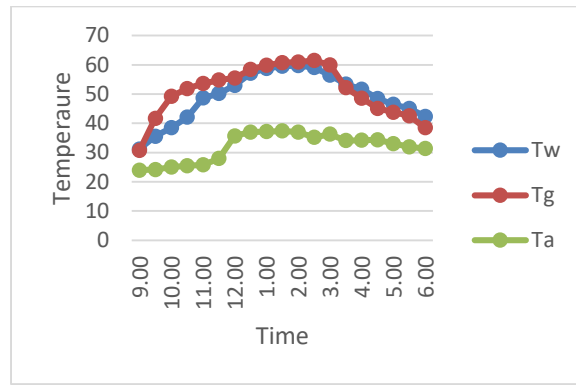
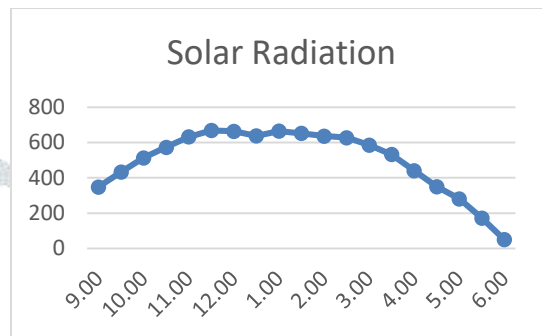Figure 1: Temperature variation on March 23, 2021

Figure 2: Solar Radiation variation on March 23, 2021

The energy is stored in paraffin wax which keeps the basin water temperature slightly high and keeps the system operating during night time. As shown on Figure 3, around 6:00 P.M. the basin water temperature for solar still with PCM is higher compare to conventional solar still, which means that the PCM starts giving energy to the basin water during night time. The decreasing trend of basin water temperature is very sharp after 10:30 P.M.; and because of this the distillate output is decreasing due to the small difference in temperature between the glass cover and basin water until the next day morning.
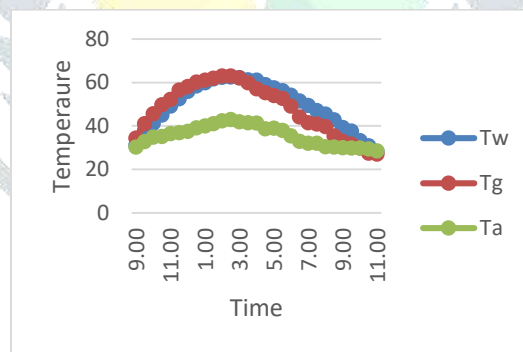
Figure 3: Temperature variation on April 23, 2021
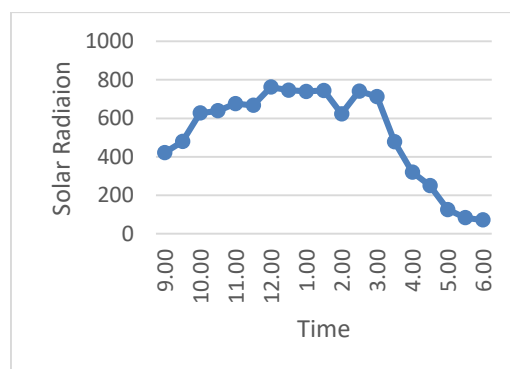
Figure 4: Solar Radiation variation on April 23, 2021

Figure 5 and Figure 6 shows the shows the temperature variation of basin water temperature (Tw), glass temperature (Tg) and ambient temperature (Ta) and Solar radiation respectively for a typical summer day, solar still having PCM with nanoparticles. On

comparison with other two, the basin water temperature of solar still having PCM with nanoparticles is higher than the other two conditions.
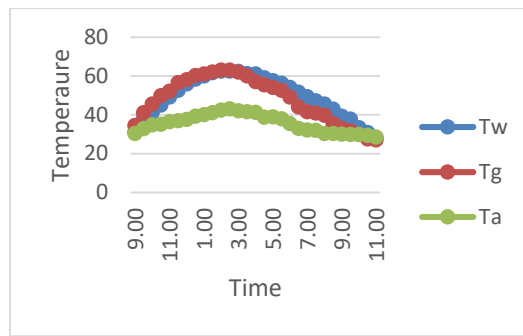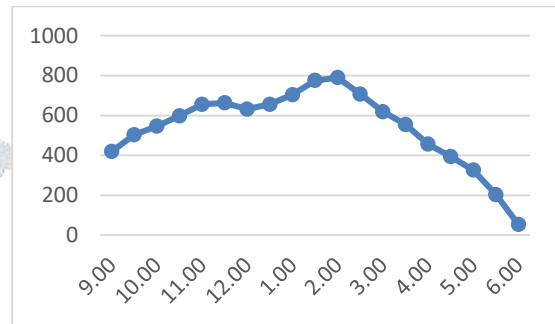
Figure 5: Temperature variation on May 05, 2021

Figure 6: Solar Radiation on May 05, 2021

8 PRODUCTIVITY COMPARISON

The productivity of fresh water for day and night hours is presented in Figure 20. The maximum productivity obtained for conventional solar still is 1000 ml/day. The maximum productivity obtained for solar still with PCM is 1210 ml/day and for solar still having PCM with Nanoparticles is 1400 ml/day. The system is producing fresh water at night. The amount of fresh water produced for the solar still having PCM with nanoparticles during the day is 900 ml and that during the night is 500 ml.
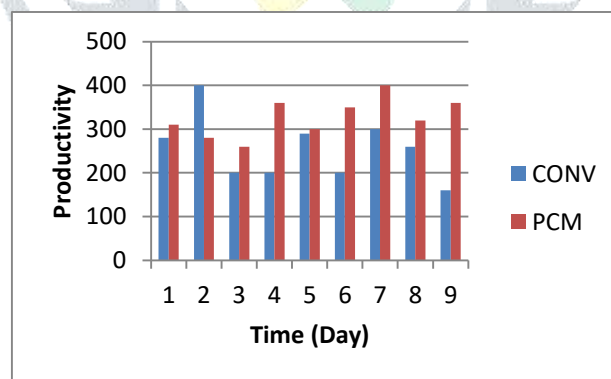
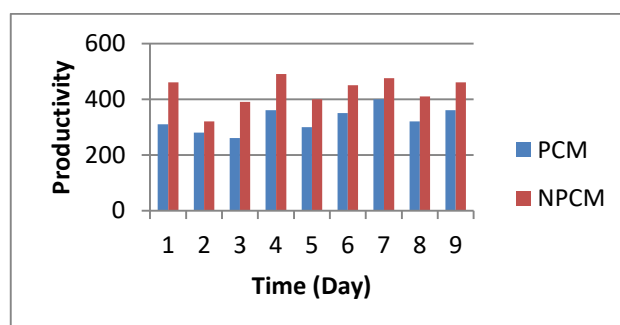Figure 7: Productivity Comparison for Conventional v/s PCM

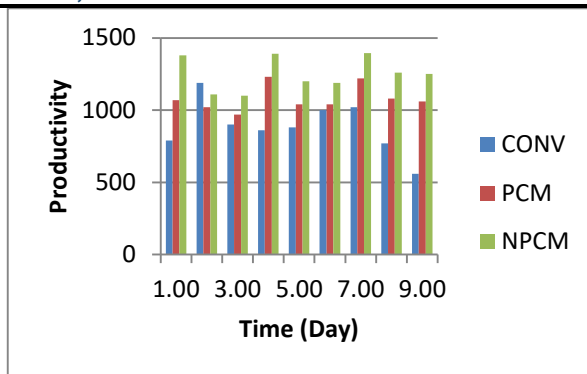Figure 8: Productivity Comparison for PCM vs PCM with Nanoparticles

Figure 9: Productivity comparison

8.1 Behavior of Output Due to Water Depth

The effect of basin water level was studied during the months of March 2021.Each 1 cm water level for a basin having an area of 0.5 m2 represent 5 litre of water in the basin. Figure 21 shows that as the basin water level decrease, the cumulative productivity increase.

The lowest mass of basin water (5 litre) when the basin level was 1 cm takes the solar energy to make water temperature higher than that for (40 litre) when the basin level was 4, and 5 cm respectively. Thus, the productivity increased as the basin water temperature increased.

Al –Hamadani et al [19] designed a simple solar still with luaric acid as PCM to examine the effect of basin water level on the daily distillate productivity. They found that the highest productivity rate corresponded to the least water depth, which is in agreement with this work results.
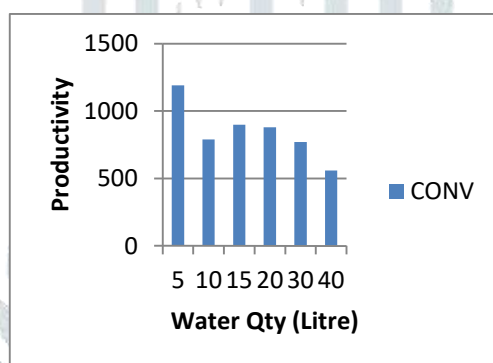

Figure 10: Productivity vs Depth of water in basin

8.2 Efficiency Comparison

The efficiency of solar still depends on solar radiation, water mass, productivity, area of the basin and climatic condition. The efficiency of conventional solar still, solar still with pcm and solar still with pcm and nanoparticles is discussed here.

Figure 22 shows the efficiency comparison for three different cases of day 01. In morning time efficiency of conventional as well as SSPCM and SSNPCM is lower. The evaporation rate of the solar still is lower at morning time. Efficiency depends on evaporation rate as well as condensation rate. The efficiency is calculated at the tape water (523 ppm) TDS. The water mass of that is 10 litres.

The efficiency at the (5.30 to 6.00) the bigger variation is because of the solar radiation are suddenly change (129 to 24) and at that time the productivity is higher because of high condensation rate.

After the 3.00 hour the solar radiation decrease (517-24) at that time the condensation rate of solar still is increase and productivity and efficiency are improved at that time.

In the SSPCM the efficiency of solar still is also the same behaviour at day time but after the sunset the evaporation rate is start because of release the energy that they stored at sunshine hours.
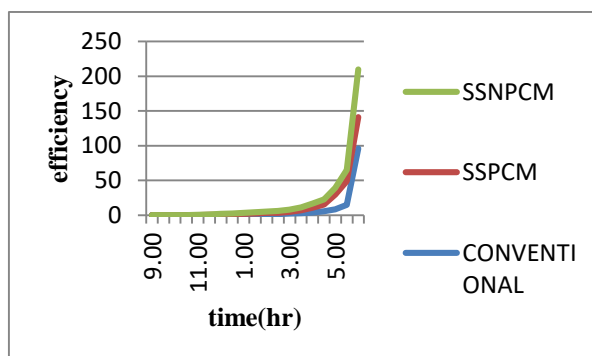

Figure 11: Efficiency Comparison Day 01

Figure 12 shows the efficiency comparison for three different cases of day 02. The comparison of efficiency for 5 litre water mass and tape water are used. The lower water mass is that optimum output for all the three solar still. The evaporation rate is also start at 10.00 am.In afternoon 12.00 to 3.00pm the water temperature is at the pick point(63°C) so that the water evaporation rate is higher at that point.

In the evening (4.00 to 6.00) the condensation rate quickly increases at those points the solar radiation are decrease (461 to 28w/m2) so that the efficiency at that point is higher. The efficiency of SSNPCM is higher than the SSPCM and conventional solar still.
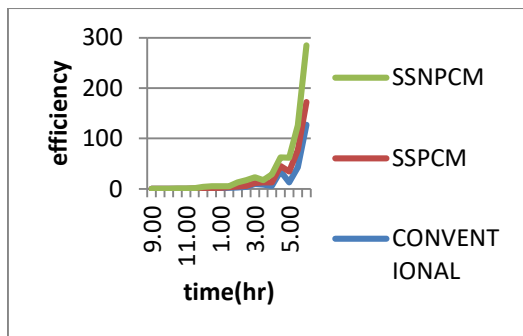

Figure 12: Efficiency Comparison Day 02

Figure 13 shows the efficiency comparison for three different cases of day 03. The efficiency comparison is for 15 litre masses with tape water are used. The efficiency at start at the afternoon because of the more time required to water get convert into vapour.

The efficiency of conventional solar still is lower from both solar still. In day time the efficiency of conventional solar still is (60.84) and SSPCM (88) and SSNPCM is (68). after the sunset time the efficiency of SSNPCM is higher than conventional and SSPCM.

Figure 14 shows the efficiency comparison for three different cases of day 04. The efficiency is compared of conventional, SSPCM and SSNPCM solar still for the 3000 TDS and 10 litre water mass. The conventional solar still efficiency at the day time at the end of the day is (53). after the sunset the efficiency of conventional solar still is not much that SSPCM and SSNPCM.

The efficiency of SSPCM at the end of the day is (81) is higher than both. But after that sunset the night-time efficiency is higher than the SSPCM. So overall efficiency of SSNPCM is higher than both.
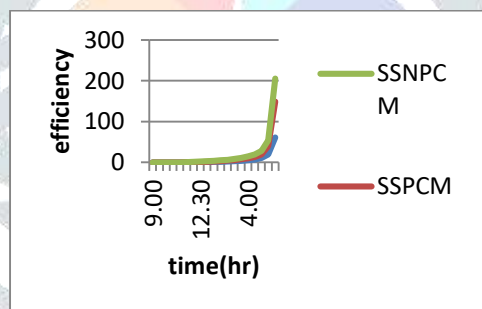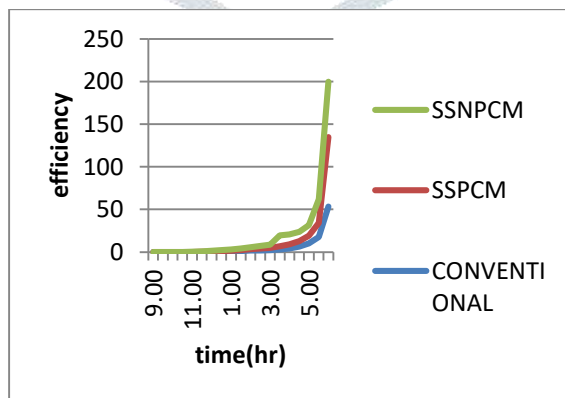

Figure 13: Efficiency Comparison Day 03

Figure 14: Efficiency Comparison Day 04

Figure 15 shows the efficiency comparison of conventional, SSPCM, SSNPCM for day 05. The efficiency comparison for 3000tds and 20 litre water mass. In the morning time the efficiency approximately very law because the 20 litre water mass is convert into vapour required more time.

The efficiency of conventional solar still at the end of the day is (51) and SSPCM is (50.53).and SSNPCM is (58.37). After the sunset hour the SSPCM and SSNPCM is obtain optimum efficiency compare to conventional solar still.
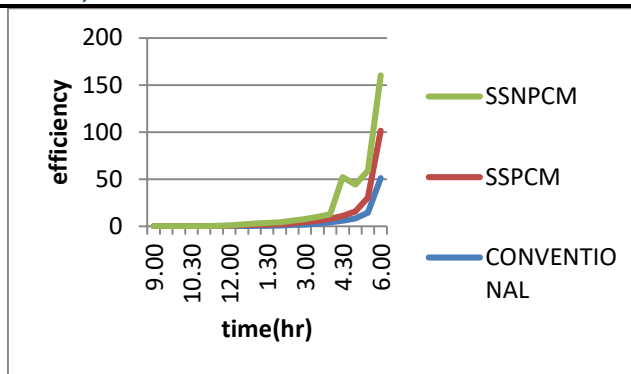
Figure 15: Efficiency Comparison Day 05

Figure 16 shows the efficiency comparison of conventional, SSPCM, SSNPCM for day 06. The efficiency is compared of conventional, SSPCM and SSNPCM solar still for the 3000 TDS and 5 litre water mass. The lower water mass is that optimum output for all the three solar still. The evaporation rate is also start at 10.00 am. The efficiency at the end of the day of conventional, SSPCM and SSNPCM is (72), (82) and (69) respectively. The SSNPCM efficiency is increase at night time hours compare to conventional and SSPCM.

Figure 17 shows the efficiency comparison of conventional, SSPCM, SSNPCM for day 07. The efficiency is compared of conventional, SSPCM and SSNPCM solar still for the 2000 TDS and 5 litre water mass. The efficiency at the end of the day of conventional, SSPCM, and SSNPCM is (63), (97) and (89) respectively. The efficiency of the 24 hour of SSNPCM is higher than the conventional and SSPCM. The efficiency of SSPCM is higher than the conventional solar still.
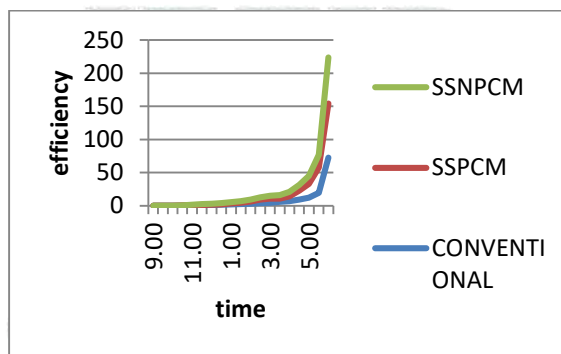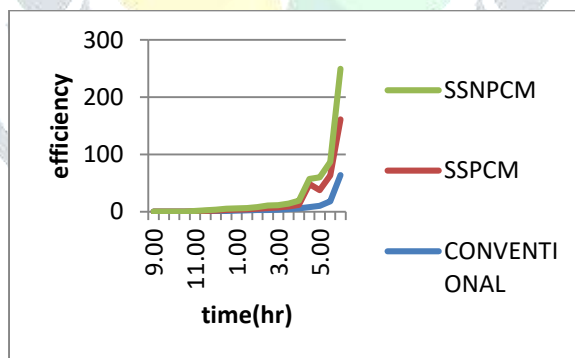

Figure 16: Efficiency Comparison Day 06

Figure 17: Efficiency Comparison Day 07

Figure 18 shows the efficiency comparison of conventional, SSPCM, SSNPCM for day 08. The efficiency is compared of conventional, SSPCM and SSNPCM solar still for the 2000 TDS. The 30-litre water mass of conventional solar still and 10 litre water mass of SSPCM and SSNPCM. The efficiency at the end of the day of conventional, SSPCM, and SSNPCM is (40.44), (64.81) and (68.22) respectively. The efficiency of SSNPCM is higher than the conventional and SSPCM.

Figure 19 shows the efficiency comparison of conventional, SSPCM, SSNPCM for day 09. The efficiency is compared of conventional, SSPCM and SSNPCM solar still for the 2000 TDS. The 40-litre water mass of conventional solar still and 20 litre water mass of SSPCM and SSNPCM.

The efficiency at the end of the day of conventional, SSPCM, and SSNPCM is (30.64), (56.5) and (63.10) respectively. The efficiency of SSNPCM is higher than the conventional and SSPCM.
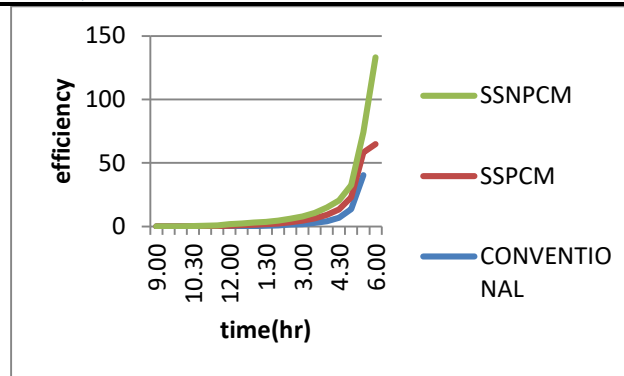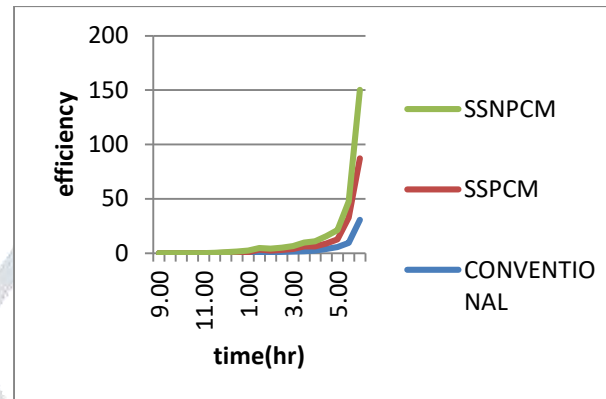
Figure 18: Efficiency Comparison Day 08

Figure 19: Efficiency Comparison Day 09

Several results shows that the efficiency of SSPCM and SSNPCM are nearly or SSPCM efficiency is slightly higher compare to the SSNPCM. The reason for that are solar radiation and climatic condition are responsible for that. In the end of day time the solar radiation of SSNPCM is slightly higher than the SSPCM Solar radiation that's why the condensation rate of SSNPCM is slightly lower than SSPCM. But after the sunset the productivity and efficiency are optimum for the SSNPCM compare to SSPCM and conventional solar still.

9 CONCLUSION

The unit designed in this work was capable of producing desalinated water with salinity 2000-3000 ppm under BVM weather conditions. Five tubes containing Paraffin Wax as PCM and Aluminium Oxide as nanoparticles were placed beneath the basin liner to extend productivity overnight. From the results, the following conclusions are drawn:

• The selected PCM worked well to supply energy during night time period.
• The productivity of the unit is found to depend on temperature of water basin, ambient temperature and the amount of water in the basin.
• The PCM becomes more effective at lower masses of water in the basin.
• Overall performance and productivity of solar still is affected by water mass and it decreases with increase in the water mass.
• 01 cm depth of water basin i.e., 5 litre of water supply found to be optimum for maximum output of water.
• Overall productivity of conventional solar still, SSPCM and SSNPCM is 1.00l/0.5m2/day, 1.320l/0.5m2/day and 1.395l/0.5m2/day respectively.
• The night time yield of the conventional solar still, SSPCM and SSNPCM is 0.200l/0.5m2, 0.360l/0.5m2 and 0.475ml/0.5m2 respectively.
• The productivity of single basin of solar still having phase change material and nanoparticle is higher than other two cases.
• The efficiency of SSNPCM (63.10) is higher compared to SSPCM (56.5) and conventional solar still. The efficiency of SSPCM (56.5) is higher compare to the conventional (30.64) solar still.

10 FUTURE SCOPE

• Used absorber plate as copper sheet for better evaporation rate and black paint replace with asphalt for enhancement of performance of solar still.
• Change the phase change material and nanoparticle or used different pcm and nanoparticle and check the results.
• Change the design of pcm reservoir, pipes replace with another material for improve the heat transfer rate.
• Used the stepped basin for enhancement of performance of solar still.
• Prepare the design of that type that sensible heat storage material and latent heat storage both are used for enhancement of productivity.

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