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Solar Still Productivity Enhancement by PCM and Nano-PCM Composites as Energy Storage

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Abstract:
Availability of potable water is essential for human survival and domestic need. Incorporating nano-PCM in a solar unit as thermal enhancer and thermal storage has become a promising means to enhance the productivity and efficiency of the still. A solar unit performing with PCM and nano-PCM (NPCM) materials is used to examine the effect of productivity of the still. The mixture of PCM & NPCM is filled into 12 copper tubes and are immersed in 1cm level of water in the still. The present paper is attempted to compare the four different cases with fixed level of water(1cm) in the basin. The different cases are namely : Conventional still (Case 1),Still with 12 empty copper rods (Case 2),Still with only PCM of 142g in each tube (Case 3) , Still with NPCM of sample 1 with 0.75%of nano particle concentration+142g PCM in first 6 tubes, sample 2 with 2% of nano particle concentration+142g of PCM in next 6 tubes (Case 4). Paraffin wax with melting point of 62^0C is used as the latent heat storage material and aluminum oxide(Al2O3) with 20nm-30nm particle size is used as nano particles. The experiment is conducted in the climatical conditions of Vaddeswaram, Vijayawada, India (Latitude-80.6480^0E,longitutude-16.5062^0N) . Differential scanning calorimeter is used to examine the thermal properties such as melting point, latent heat fusion, of the NPCM compositions. The results of the experimentation were recorded in hourly basis and it shows that productivity &efficiency of case 1 are 2.66L/m2/day&46.23% . The productivity of case 2,3,4 are 3.17 ,3.58 ,4.27 L/m2/day respectively. Addition of nano particles enhances the latent heat of fusion & specific heat capacity of PCM. The results reveals that use of NPCM increases the productivity by 19.4%&efficiency by 9.5 % than PCM.
Keywords*: NPCM, Aluminum oxide, Thermal storage, Solidification, Productivity, efficiency.*

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INTRODUCTION

Potable water is a lacking commodity and is running as a short supply in many parts of the world. Of all the water present on earth, a small part of portion is used as drinking water. Most of it is captured in icecaps or stored underground. Only 0.3% of potable water can be easily accessible. A region experiencing the scarcity of fresh water depends on its location. The regions with warm climatical conditions are most likely to affect to the lacking of potable water. Desalination, a innovative technology having a capability of producing millions of liters of pure water per day. But the only disadvantage of the

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solar desalination is less productivity. To overcome this demerit , many absorbing materials namely sponge cubes, pebbles, sand, phase change material (PCM) came into existence to increase the yield of the solar still. Among these absorbing materials, PCM is the most accurate and can store more capacity of heat. PCM can act as both sensible heat storage medium and latent heat storage medium and after all the researches ,PCM has been declared as the most chemically inert and non-corrosive friendly medium to store the heat at high temperatures. PCM has many classifications but paraffin wax is mostly used and available PCM among all the types and used in the experimentation to increase the storing capacity[1]. Several factors should be taken into account while selecting the PCM which includes high latent heat of fusion, high density, high melting point and long durability. Paraffin wax with high melting point has attained high productivity in the still by exergic analysis and it is used in any electrical and heating applications due to its advantage of having high melting range from 40°C-90°C [2]. Hydrated salts are the another kind of PCM which has more latent heat of fusion per weight , high thermal conductivity for non-metals and shows less volume change when the material changes its phase. Paraffin wax is used as the best of all PCM's because of its advantages of being chemically compactable with most of the metals. Paraffin as a latent heat storage medium acts as a attractive way because of its high storage density with small volume change at constant temperature which increases the scope of the application [3]. Many experimentations and modeling's on solar desalination were taken place by researchers and noticed an increase in efficiency of solar still by 40% using PCM [4]. A experimental study with the modification of combining PCM & fins was made to the conventional still to increase its heat transfer characteristics and the productivity at night times. The observations made that the still with PCM embedded pin fins gives higher productivity of 7h storage capacity whereas still with individual PCM gives 5h storage capacity. Researches noticed that composite PCM has the best yield of output than using single PCM. A experimental, comparative & economic study were conducted on the solar still to increase the storage capacity. Organic PCM A48 & inorganic PCM capric palmitic acid were used as composite PCM and found increase of 92% productivity when compared to simple solar still [5]. The experiment was conducted by stuffing the mixture of three different PCM's namely lauric acid, paraffin wax and stearic acid in the copper cylinders and placing them in the still basin at equidistant positions with varying depths of water. After the investigation it was noticed that there is an increase in distillate production of 1120,1050,950ml/m^2/day by using lauric acid, paraffin wax and stearic acid respectively[6]. Bin Li has performed a numerical modeling of a still using composite PCM of expanded graphite (EG) and erythritol with a melting point of 119°C. The composite PCM of 3 wt% of expanded graphite was chosen as the best material for heat storage and is filled in the aluminum pipes by placing them in the evacuated tubes and then heat pipes are immersed in PCM to increase the heat transfer between them . After all the observation it was noticed that the storage efficiency had increased to 40.7% [7]. Although PCM is a good latent heat storage medium which acts isothermally ,it has some limitations which effects the properties which indirectly effects the thermal performance of the PCM. In order to overcome this issue , world has brought a technology as a prominent one which is called as nano technology[8]. Nano technology provides the particles sizing from 0.1-100nm with tunable thermo physical and physicochemical properties and helps in long run of PCM which is becoming the emerging field in every thermal and electrical applications. The nano technology has attracted the researchers in such way that they started experimenting the different nano particles on the solar still. S.W. Sharshir conducted an experiment to check the effect of flake graphite nano particles ,PCM and the film cooling. The author conducted the experiments in four different cases namely 1.Addition 0.5% flake graphite nano

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particles to water 2. Flake nano particle with PCM 3. Flake nano particles with film cooling 4.All the above three cases. The outcome of the results were greater in case 4 than case 2 than case 1 than case 3 [9]. An investigation on SiC nano fluid was made to examine the stability ,thermal conductivity and the optical properties when it is combine with the salt water. The investigation has proved that SiC nano fluid has the good stability properties when it is mixed only with the less concentration of salt water. The researchers made investigation and concluded that concentration of nano particles plays a major role in enhancing the productivity of the still [10]. Changjun Zou made an experimental investigation using multiwall carbon nano tubes (MWCNT) and the recoverable multiwall carbon nanotubes were prepared by dispersing the Fe_2O_3 in saline water for recyclability. Use of MWCNT has enriched the evaporative efficiency upto 76.65% [11]. From the literature, it was noticed that efficiency and productivity of the solar still increases by enhancing the thermal conductivity of PCM with the addition of nano particles. In this present work ,comparison of conventional still with modified still is experimented using different ratios of NPCM to find the best one.

II. EXPERIMENTAL SETUP

A solar still with single slope is fabricated and the experiment was conducted on it. The still basin is made of galvanized iron. Glass wool & thermocol is used as a insulation with 3mm thickness. A glass cover with 5mm thickness is placed on the top side of the still at an angle of 16.5° for condensation. The still is in the shape of rectangle with 1060mm length, 1774mm width, while its height at back side is 404mm reducing to 135mm at front side. The still basin is painted black to increase the absorpivity of solar radiation. Copper rods of 12 quantity with 1.5cm diameter is filled with PCM & NPCM are immersed in water by placing at equidistant positions. Experimentation was carried out in 4 different cases with 1cm level of basin water: conventional still (case1),still with 12 empty rods (case 2), still with 12 rods filled with 142g of PCM in each tube (case 3), still with 0.75%nano+PCM in 6 rods and 2%nano+PCM in other 6 rods (case 4). The schematic diagram & modified experimental setup of solar still connected to a arudino are shown in Fig.1& Fig.2 respectively and the specification of the materials used in the still are shown in Table no.I

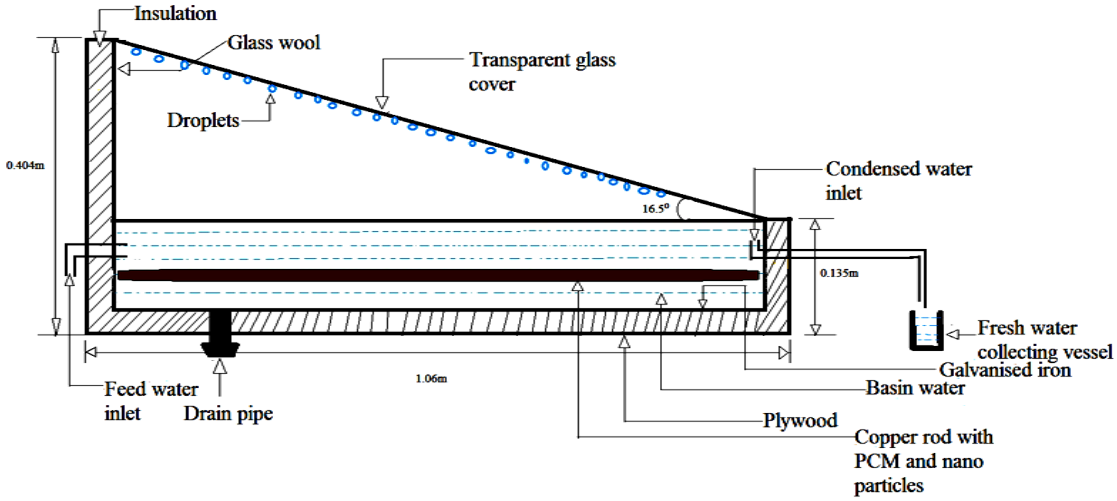

Fig. 1. Line diagram of Experimental setup

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Fig. 2. Experimental setup of solar still on left & arudino connected with 100k thermistor on right

2.1. Materials

Solid paraffin of melting point 62°C is used as the latent heat storage material and it was purchased at chittinagar, Vijayawada, India. Nano particles Al_2O_3 of 25grams quantity was purchased from GK life sciences ,Guntur, India. The amount of input water and the collected water has been taken by keeping in the mind for a family having 4 persons. Characteristics of PCM and nano particles are mentioned in Table no.II

Table-I: Specifications of the experimental setup

Parts	Material used	Dimensions/Quantity
Frame	Wood	-
Basin	Galvanized Iron	164 x 90cm
Insulation	Glass wool &Thermocol	7cm each side
Glass cover	Transparent glass	5mm thickness
PCM	Paraffin wax	1.993kg
Coating	Black paint(Thermal sprayer)	2
Nano particles	Alpha aluminum oxide	25g
Storage pipe	Copper (12)	Dia-1.5cm;L-87cm;t-0.2mm

Table-II: Physical properties of PCM &nano particles

S.no	Property	PCM(Paraffin)	Nanoparticles (Al_2O_3)
1	Melting point	58-60°C	-
2	Thermal conductivity	0.240W/mK	35 W/mk
3	Density	930kg/m^3	3.5-3.9 g/cm3
4	Specific heat capacity	2.14KJ/kg K	880J/kg K
5	Latent heat	351.7KJ/ kg K	-
6	Appearance	White	White

2.2. Synthesis and Sample Preparation

This mixing of nano-PCM can be made in two methods namely 1.One step method 2. Two step method, and by the observation it was proved that two step method is the effective method to examine the thermal properties of the mixture[12-15]. Solid paraffin wax is melted to a temperature above its melting point before it is blended with the nano particles. Only 142ml of paraffin is required in each tube. By keeping the liquid paraffin at above its melting point, aluminum oxide nano particles are added at 0.75% & 2% concentration to liquid paraffin. The mixture of PCM & nano particle is stirred using magnetic stirrer at 350rpm for 45mins

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to avoid agglomeration of nano particles as shown in Fig. 3& samples of NPCM in Fig.4

Fig. 3. Pure PCM with magnetic stirrer on left & Thick solution of NPCM on right

Fig. 4. Samples of NPCM with 0.75%&2% of Al_2O_3

2.3. Stabilization and Characterization of the Nano mixed PCM

The shape and size of the nano particle depends upon the method used for synthesis. In this experiment, nano-PCM mixture was prepared by two step method and measured by differential scanning calorimeter (DSC) which is serving as the effective tool to find out the thermal properties of the latent heat storage material and specific heat capacity of the material[16]. Researches were made to screen out the thermal properties and the characterization of the nano fluids using the differential scanning calorimeter, XRD analysis & TEM analysis[17-18].

2.4. Data Collection

In this experimentation, a device called arudino mega max was used to record the temperatures . NTC thermistors are used as the temperature sensing elements which can with stand upto 250°C. 8 thermistors are placed at different positions in the solar still and temperature was recorded for every 60mins.

III. ERROR AND UNCERTAINTY ANALYSIS

Experiments were conducted on the clear day in the time of January-march from 9:00AM-5:00PM. The temperatures of copper rod, ambient, glass, evaporation, basin water were measured using NTC Thermistor of range 250°C. The distillate output is measured using a measuring beaker. The solar radiation is measured using TES solar power meter. Uncertainty analysis of the measuring instruments were noted in Table no.III

Table-III. Uncertainty analysis of various measuring instruments used in experiments

S. no	Instrument used	Parameter	Symbol	Accuracy	Range	Least count	Uncertainty
1	Thermistor	Temperature	T	±0.1°C	150 °C	0.1 °C	±0.1°C
2	Solar power meter	Solar intensity	I(t)	±10 w/m^2	2000 w/m^2	1w/m^2	±1 w/m^2
3	Measuring Beaker	Distillate output	m	±0.01 L	1L	0.01L	±0.01L
4	Measuring tape	Solar still length, width, height	L,W,H	±12cm	10 M	0.1 cm	±0.1cm

IV. RESULTS AND DISCUSSION

During experimentation, various parameters namely water temperature, basin temperature, glass temperature, evaporation temperature, rod temperature were recorded for every 1hr in same climatical conditions at fixed depth of water in the basin (1cm).

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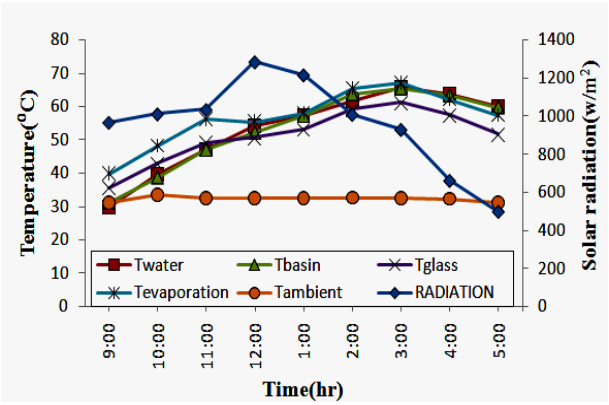
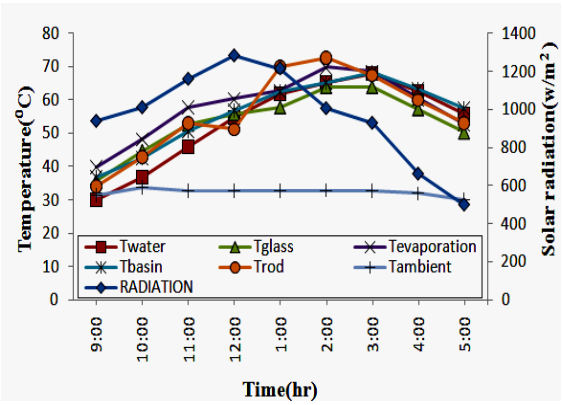
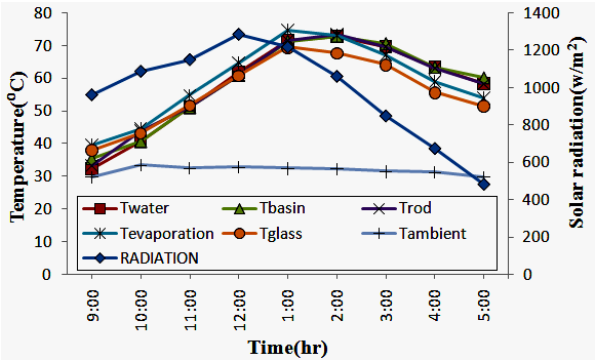
4.1 Performance of various temperatures for different Solar stills along with Radiation



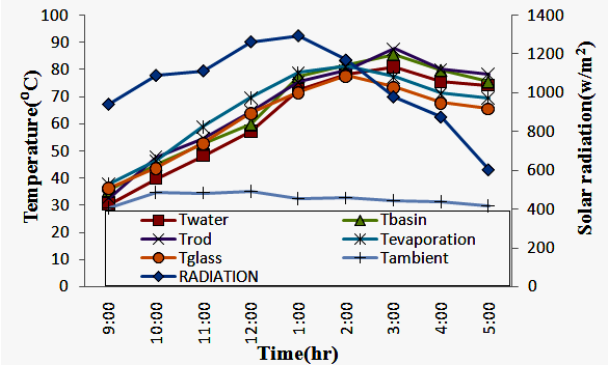
a) Hourly temperature profiles of conventional solar still



b) Hourly temperature profiles of still with empty rods



c) Hourly temperature profiles of still with PCM rods



d) Hourly temperature profiles of still with NPCM rods

Fig. 5. Hourly temperature profiles of 4 different stills along with solar radiation

The solar intensity varies from 575 to 1286 w/m^2 throughout the experimentation . The experimentation was conducted for all the 4 different stills at identical solar intensities. During the experimentation, the thermal performance of stills with NPCM & PCM rods were compared with the stills with empty rods & conventional stills at fixed depth of water (1cm) and at same climatical conditions.

Fig.5a-5d shows the variations in temperatures of water, basin , glass, rod, ambient, evaporation and solar radiations of four different stills. It was noticed that the solar intensity gradually increases and attain its apex value at 12:00 in the afternoon and slowly decreases to its lowest value at 5:00PM. Fig.5a depicts the maximum temperature of water about 65.8°C, at the same time maximum temperature of condensing cover, evaporation, basin were 61.2,67.1,65.3°C respectively for a conventional still. Fig.5b exhibits the maximum water temperature about 67.9°C,while the maximum temperature of glass, evaporation, basin were 63.9,68.6,68.3°C respectively for a still with empty rods. Fig.5c presents the highest temperature of water about 72.9°C, and during the same time it depicts peak temperature of glass, evaporation, basin were 67.8, 74.2, 72.8 respectively for a still with PCM rods. Fig.5d showcases the peak water temperature about 80.9°C, and at the same moment it shows the maximum temperature of glass, evaporation, basin were 77.8, 81.2,85.7°C respectively for a still with NPCM rods. The maximum temperature of empty rod, PCM rod, NPCM rod were 72.6,73.5,87.7°C respectively. The PCM used in the stills were identical and are used above its melting point to achieve good energy storage during charging time. The melting of PCM in the stills takes place at 12:00 noon during daytime and the variance between temperature of water & temperature of is very high at mid-day. The

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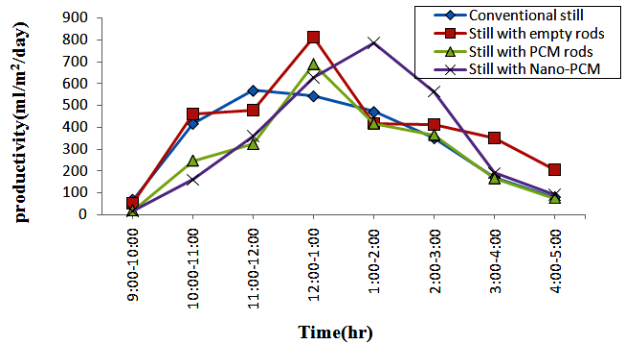
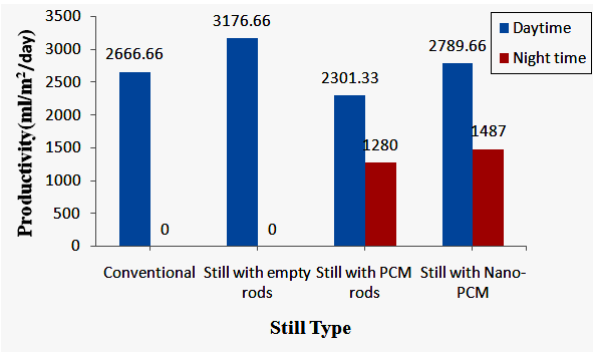
difference between T_w & T_g is more for the still with PCM rods than the still with NPCM rods.

Fig.6 shows the hourly productivity of 4 stills from 9:00AM-5:00PM along with the nocturnal productivity for stills with PCM & NPCM rods. The still productivity depends upon the amount of heat absorbed by the solar radiation, and its peak value reaches at 11:30AM and gradually starts decreasing after 3:00PM. This results in increase in productivity of still upto 1:00PM and decrease in productivity after 2:00PM and no yield is produced after 5:00PM in still 1 & still 2.





a) Hourly productivity of all various stills
b) Day & night time productivity of various solar stills

Fig 6. Overall productivity of different stills

The output yield of the conventional still is less than the still with empty copper rods, due to the incorporation of copper rods for more absorption of radiation from 9:00AM-5:00PM. The productivity of still with empty copper rods is higher than the still with PCM&NPCM rods at daytime. As PCM has more sensible & latent heat, it affects the daytime productivity whereas helps at nocturnal productivity. The day & night time productivity of NPCM still is higher than PCM still due to the addition of nano particles. This is because, nano has the property of enhancing the thermal characteristics of PCM which in turn increases the hourly productivity. Therefore, the heat energy stored in PCM helps in the time of discharge from 5:00PM-9:00AM. The conventional still & empty rod still gives the productivity only when the radiation exists, whereas PCM still & NPCM still gives productivity at both day and night times. With the presence of latent heat energy in PCM ,it helps to prolong the discharge time. During the melting of NPCM , the water temperature is maintained at a very high rate compared with PCM still water temperature. The temperature difference between water & glass is more at daytime and decreases at nocturnal time. Latent heat energy storage allows water to evaporate for only some extent &stores remaining energy in it to increase the evaporation at night time discharge. The day time productivity of conventional still & still with empty rod are 2.66 & 3.17 L/m^2/day respectively which is higher than PCM still and NPCM still of 2.30 &2.78 L/m^2/day respectively. Though overall productivity of NPCM still is higher than other stills but the daytime productivity is less than other 3 stills. The productivity per day of NPCM still is higher at nocturnal times than other stills.

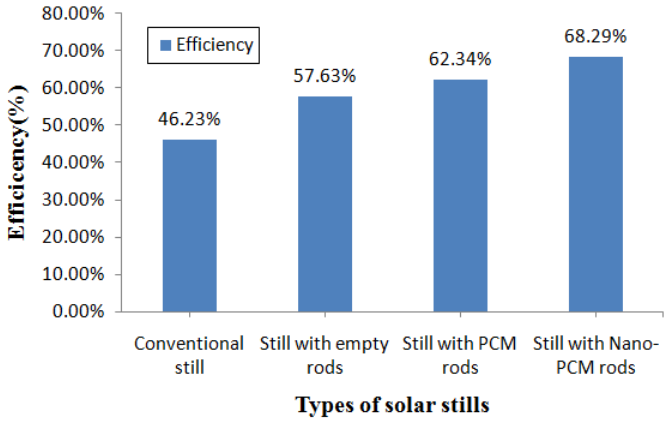


Fig 7. Overall efficiency of different stills

The overall productivity of case 2,3,4 are 3.17,3.58 &4.27 L/m^2/day respectively. The nocturnal productivity of NPCM still is 19.4% higher than the PCM still. The efficiency of case 1,2,3,4 are 46.23, 57.63, 62.34,68.29% respectively and are shown in

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Fig.7. Thus the overall productivity of case 2,3,4 are 19.12 , 34.31 , 60.37 % respectively more than case 1.

V. CONCLUSION

In this experimental investigation, the increase in productivity of the still with NPCM rods is compared with the still with empty rods, still with PCM rods & conventional still. This experimentation was conducted to examine the effect of PCM at nocturnal times and nano particles at daytime in enhancing the efficiency and the productivity of the solar still. Use of NPCM increases the yield to a very higher rate and the following conclusions were made by performing the experimentation:

- Readings with empty rods has been taken and the temperature of rod at mid day increased to 68^0C by giving 3176.66ml of yield from 9:00 AM to 5:00PM.
- By employing PCM into rods , the temperature of rod at mid day (1:00PM) has increased to 79^0C by giving 2301.33ml of yield from 9:00 AM to 5:00PM. While productivity from 5:00PM-9:00AM is 1280ml.
- By employing NPCM into rods , the temperature of rod at mid day (1:00PM) has increased to 86^0C by giving 2789.66ml of yield from 9:00 AM to 5:00PM. While productivity using PCM from 5:00PM-9:00AM is 1487ml.
- The efficiency of conventional still, still with empty rod, PCM still & NPCM still were found to be 46.23%, 57.63%, 62.34%,68.29% respectively.
- The increase in productivity & efficiency of NPCM still was 60.37% & 22.06% higher than conventional still respectively.
- Mass concentration of the nano particles plays a vital role in enhancing the thermal properties of PCM. The nano-PCM proportion should be kept at optimum values for improving the thermo physical properties of PCM for long term basis.
- Use of nano enhanced PCM increases the storage capacity of PCM and decreases the charging time in turn increases the productivity at night times and efficiency of the solar still. Temperature of water and evaporation has increased very quickly by using PCM .
- Energy storage medium increases the productivity and the efficiency of the solar still and hence can be concluded that the use of pure nano particles and nanocomposites will enhance the evaporative rate in turn increases the productivity.

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