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Productivity Enhancement of a Single Basin Double slope Solar Still Coupled with PCM Tubes

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ABSTRACT
In the last years the demand of fresh water is increasing tremendously all over the world. The future demand will be high and the fresh water resources are getting depleted at a faster rate. Solar still is a very simple device for converting the available brackish water into potable water. The main drawback of passive type solar still is its lower efficiency and distillate output. The usage of PCM enhances the still productivity especially after the sunset. In this work a passive type single basin double slope solar still was fabricated and studied experimentally in two modes 1).Solar still without PCM 2). Solar still with PCM tubes. The water temperature, basin temperature, glass top temperature and PCM tube temperatures were measured periodically. Experimental results indicate that the efficiency of the still is increased by 27.44% with latent heat thermal storage.
Keywords – Solar still, Still productivity, Paraffin wax, Phase Change Material, Thermal Energy Storage.

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I. INTRODUCTION

Desalination is the only remedy to meet the growing demand for fresh water. Solar desalination has been one of the best ways to produce fresh water. The solar still is the very simple device for purification of water. The low production rates of solar still constraints its usage in large scale. Though solar energy is abundant in nature its availability and demand sometimes not occur simultaneously. Some times more energy might be produced than demanded and vice versa. One of the main parameters in developing the energy utilization is storing it in suitable form. Thermal energy storage systems are categorized as sensible and latent energy storage. Sensible thermal energy storage systems store energy by changing the temperature whereas latent heat thermal energy storage systems store energy through phase change.

PCM is a substance with high heat of fusion which is melting and solidifying at a certain temperature. PCM materials are capable of storing and releasing large amount of energy. Heat is absorbed or released when the material changes from solid to liquid and liquid phase to solid respectively. Latent heat thermal energy storage is an effective way to store thermal energy for heating water by energy received from sun. The storage of heat energy enhances the performances of thermal systems and extends the output over a greater period.

Many researchers have done theoretical and experimental investigation on the use of phase changing material (PCM) as latent heat thermal energy in distillation technique. Kabeel et..al [1] had done the theoretical performance comparison of a conventional solar still with three different phase changing materials (PCM). The results showed that the system productivity is increased about 120 to 198% and the system working time increased to 2 to 3 hours. Ravishankar et..al [2] designed a triangular pyramid solar still with phase changing material (PCM) on its basin and achieved 20% of increase in the still productivity. Mauli K.Dube et..al [3] used stearic acid as phase changing material (PCM) in a stepped solar still with pyramidal glass cover and concluded that the productivity can be increased by the usage of phase changing material (PCM) having higher heat storage capacity. Kabeel et..al [4] performed a comparative study on the solar still performance with different organic and inorganic phase changing materials (PCM) and the results showed that the inorganic PCM Capric-Palmatic and organic PCM A48 increases the productivity with 92% compared with conventional solar still. Deshmukh and Thombre [5] used Bees wax as phase changing material (PCM) in beneath the basin liner in a single basin solar still and they concluded that only on sunny days in summer with least depth of Bees wax around 6% gain is observed. Avesahemad S.N.Husainy et..al [6] studied experimentally a double slope solar still with and without thermal heat storage by phase changing materials (PCM). They found that the distillation produced is increased to 10-25% with PCM. Dashtban and Tabrizi [7] developed a theoretical model for a still with and without phase changing material (PCM). They concluded that the distillate yield of the still with PCM is 6.7 kg/m^2/day whereas for still without PCM is 5.1 kg/m^2/day. Dnyaneshwar Sonawane et..al [8] achieved the increased distillate yield by 62% in a modified still when compared with conventional solar still and maximum output of water obtained at 34^o . Arunkumar et..al [9] used PCM balls in a concentrator coupled hemispherical solar still and achieved the increased still productivity by 26%.

In this study, a single basin double slope solar still is augmented with paraffin wax as PCM. Copper tubes of 1mm thickness are used to store PCM and are arranged inside the basin in cascade form. The productivity of the still with and without PCM are studied on clear sky days and are reported.

II. MATERIALS AND METHODS

The overall size of the water storage basin of the still is 100cm X 100 X 8cm and the effective area of the still is 1sq meter. The basin of the still is made up of an aluminium sheet of 1mm thickness and painted with flat black paint to absorb more solar radiation. The top of the still is covered with two glass plates of 4mm thickness inclined at an angle 12^o to the horizontal which is equivalent to the latitude of the place where the still was placed so that the solar radiation falls normally on the surface of the glass plates throughout the daytime. The basin is kept inside the metal box of dimension 113cm X 113cm X 20cm. Sawdust is used for the insulation purpose which is filled within the spacing between the basin and outer metal box. The thickness of the insulation belt is 10cm at the bottom and 5cm at the sides. The condensed water is collected in the channel provided below the glass lower edges on both sides of the still. The collected water is continuously drained through the pipe and stored in a measuring jar. A hole in the basin side wall allows inserting thermal wires for the measurements of temperatures of water, basin, pcm tube. The hole is closed with insulating material to avoid heat and vapor loss.

The experiment was carried out in the month of April and May 2019. The temperatures of water, basin, pcm tube and glass top cover were recorded with the help of calibrated K-type thermocouple wires in combination with a digital multimeter. The ambient temperature is measured with alcohol thermometer. The wind velocity is measured with an electronic anemometer. The solar radiation is measured with the help of a calibrated pyramometer. The hourly distillate yield is collected and measured by means of a measuring jar. All the operating and climatic parameters were measured and recorded for every one hour time period from 10am to 10pm during the experimental days.

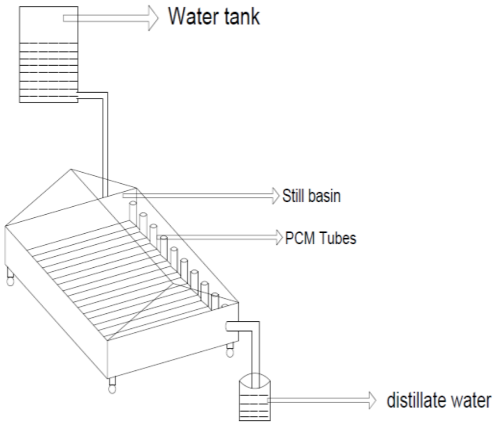

Figure.1 Schematic view of single basin double slope solar still with pcm tubes

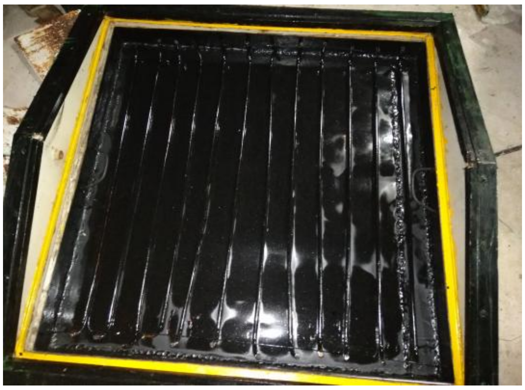

Figure.2 Pictorial view of pcm tubes arrangement in still basin

Figure.3 Schematic view of single basin double slope solar still

The thermophysical properties of the phase change material (paraffinwax) are mentioned inTable.1 whereas the technical details of the still are mentioned in Table.2

Table.1

Thermophysical properties of paraffin wax [9]

Properties	Value
Melting temperature	58-60^{o}C
Thermal conductivity	0.24W/m ^{o}C
Solid density	818kg/m^3
Specific heat capacity	2.95kJ/kg
Latent heat of fusion	226kJ/kg ^{o}C

Table.2

Still technical details

Parameter	Symbol	value
Area of still basin	A_b	1m^2
Absorbtivity of basin	α_b	0.96
Emissivity of basin	ε_b	0.96
Absorptance of glass cover	α_g	0.1
Transmittance of glass cover	τ_g	0.9
Depth of water in still basin	d	1.5cm
Specific heat capacity of water	C_w	4190 J/kgK
Latent heat of vaporization	L	2372 kJ/kg

III. MECHANISM

The sunlight is irradiated through the glass cover and heats the basin water and the pcm tubes. The heat energy is absorbed by the basin liner and a part of it is transferred through convection to the basin water and a part of energy is transferred through conduction to the pcm tubes. The pcm inside the tubes are getting heated and reaches the melting point. At this time the pcm starts to melt. When the pcm is melted completely then the heat will be stored as a sensible heat in the melted pcm.

The solar radiation starts to decrease after the noontime and the still components will start to cool down. At this time the liquid pcm will start to transfer the heat to the basin water. This process continuous till pcm becomes solidified completely. The pcm will act as a heat source for basin water during the low intensity solar radiation periods as well as during the night time. Since copper is a very good thermal conductor it transfers the heat at fast rate to the basin water and maintains the water temperature to an optimum level to enhance the evaporation rate and hence the distillation yield.

IV. RESULTS AND DISCUSSION

The productivity rate of solar still mainly influenced by the solar radiation. Fig.4 represents the variation of solar insolation and ambient temperature with respect to time. The solar radiation is measured in the range of 296 W/m^2 to 1327 W/m^2 whereas the ambient temperature was observed in the range of 31^{o}C to 37 ^{o}C.

Fig.5. shows the hourly variation of water temperature, basin temperature, outer glass cover temperature of conventional solar still without PCM. The maximum water temperature observed was 72 ^{o}C. Similarly the maximum basin temperature measured was 72 ^{o}C. The glass temperature ranges from 29 ^{o}C to 61 ^{o}C.

Fig.6 depicts the hourly variation of water temperature, basin temperature, PCM tube temperature and outer glass cover temperature of solar still with PCM tubes with respect to time. The maximum water temperature achieved was 77 ^{o}C and the maximum basin temperature observed was 76 ^{o}C. Similarly the glass temperature was observed in the range of 30 ^{o}C to 58 ^{o}C. The maximum PCM tube temperature achieved was 67 ^{o}C.

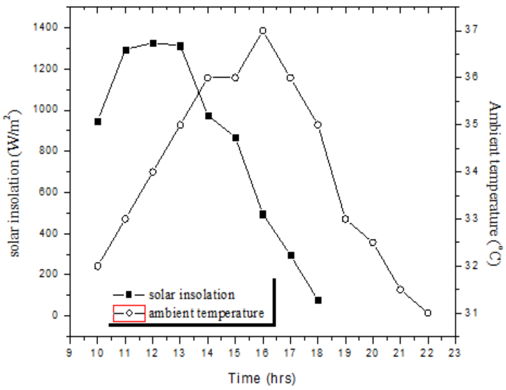

Figure. 4. Hourly variation of solar radiation and ambient temperature with respect to time

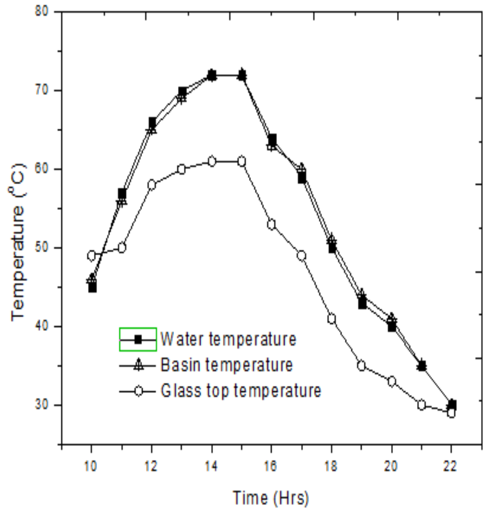

Figure. 5. Hourly variation of temperature of conventional solar still without PCM

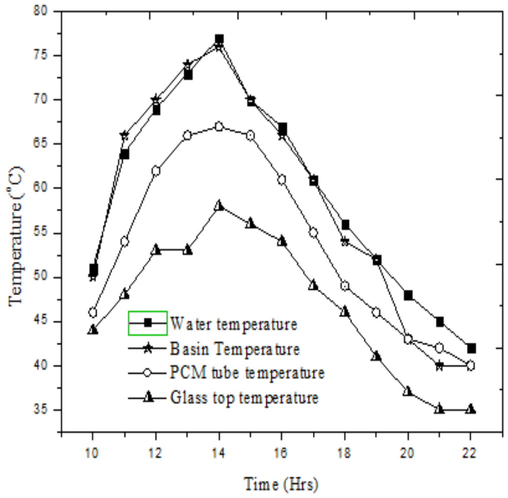

Figure. 6. Hourly variation of temperature of solar still with PCM

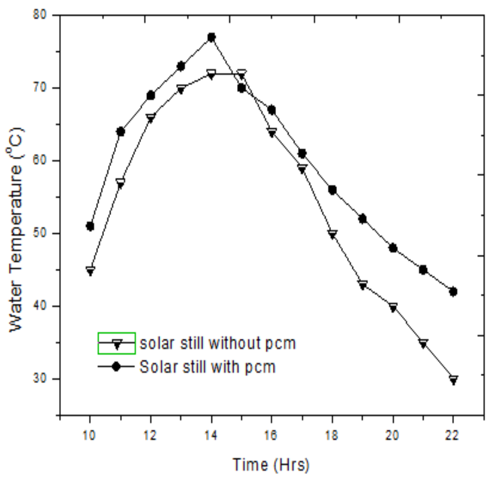

Figure. 7. Hourly variation of water temperature of solar still with and without PCM

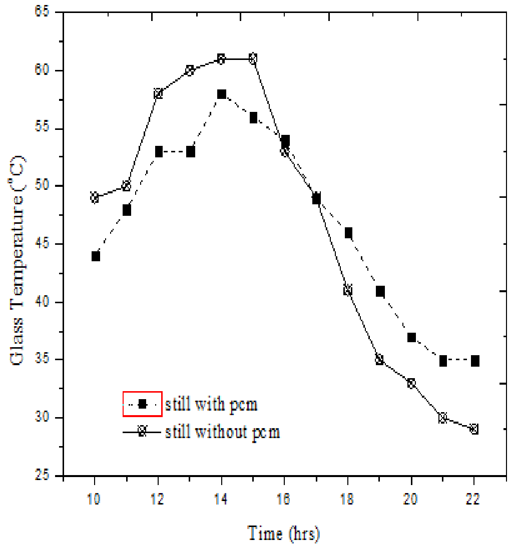

Figure. 8. Hourly variation of glass temperature of solar still with and without PCM

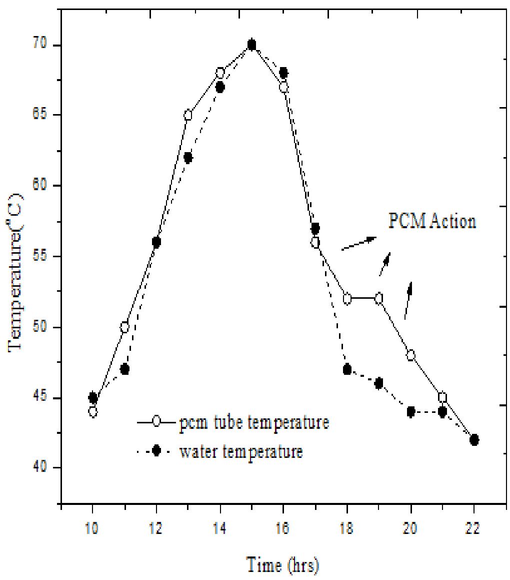

Figure. 9. Hourly variation of water temperature and PCM tube temperatureof solar still with PCM

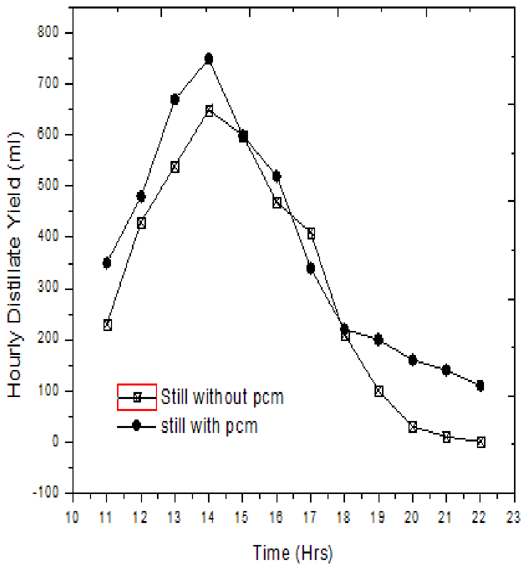

Figure. 10. Hourly variation of water temperature of solar still with and without PCM

Fig.7. depicts the comparative analysis of water in still for the two modes still operation, (with and without PCM). It was observed that the presence of PCM tubes in the still increases the temperature of basin water throughout the experimental period. The water temperature of still with PCM reaches the maximum value at 2pm and then starts to decrease. At this time the liquid PCM starts to transfer its energy to the still water. From the Fig.7. it was clearly observed that the rate of fall of water temperature becomes reduced appreciably and hence the water temperature is decreasing gradually. This mechanism extends the evaporation process even after the sunset. The conventional solar still produced the distillate output upto 8pm whereas the still with PCM produced distillate output beyond 12am. Hence it was concluded that the usage of PCM tubes prolongs the distillation period of the desalination system upto 6 to 7hours after the sunset. Fig.8. shows the hourly variation of glass temperature for the still with and without PCM. The glass temperature reaches the maximum value at 2pm for the two modes of the still when the solar insolation was maximum. In Fig.8. it can be noticed that the glass temperature of still with PCM are comparatively greater than still without PCM after 5pm. This may be due the PCM action inside the still.

Fig.9. indicates the hourly variation of PCM tube temperature and water temperature with respect to time. It was observed that the PCM tube temperature is comparatively greater till 3pm. After that when the solar radiation starts to fall the system components are getting cooler and the PCM action starts to take place at 5pm. In the Fig.9. it is clearly noticed that the water temperature becomes greater than PCM tubes temperature. This is due to that the liquid PCM starts to solidify and transfer its heat to the basin water and getting cooler. This process continues till the PCM and water reach thermal equilibrium with each other.

Fig.10. represents the comparative analysis of hourly still productivity for the two modes of the still, with and without PCM. The maximum distillate output was obtained at 2pm for the two modes of the still when the solar insolation was high. The still without PCM produced distillate productivity about 3680ml/m^2/day whereas the still with PCM tubes produced the distillate output about 4690ml/m^2/day.

V. CONCLUSION

A single basin double slope solar still has been investigated experimentally without and with PCM latent heat storage. The usage of PCM tubes enhances the still productivity both during the day time and after the sunset. The PCM acts as heat source when the solar radiation has low intensity to the basin water. The effect of PCM is observable after 5pm. The efficiency of the solar still was increased about 27.44% when it was coupled with PCM tubes. The daily distillate productivity for still without PCM was 3680ml/day/m^2 whereas for the still coupled with PCM tubes it was 4690ml/day/m^2.

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