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A Study on the Thermal Performance of a Cabinet Model Solar Still Coupled with PCM Thermal Storage Arrangement

[1]S.Gowthaman, [2]S.Ganesh, [3]S.Arumugam
[123]Solar Energy Division, Department of Physics, Gandhigram Rural Institute – Deemed University, Gandhigram, Dindigul, India.
[2]sganeshss14@gmail.com

Abstract*— The demand of portable water is increasing rapidly in the world with the growing of its population. Desalination using solar energy is one of the suitable methods to produce portable water in remote and arid areas. It could be used as eco friendly to produce portable water from saline and brackish water. In this study, an experimental investigation has been carried out on Cabinet Model Solar Still [CMSS] which was fabricated in the laboratory with the facility of PCM thermal storage arrangement to enhance the productivity of distillate water. The experiment has been performed in the climatic conditions of Gandhigram [Latitude 10.26^{0}N, Longitude 77.93^{0}E] in Tamilnadu during the month of March 2015. The still has been studied for its thermal performance of still water load of 8 liters and with energy absorbing materials such as hollow iron pipes and the same hollow iron pipes encapsulated with PCM. Here paraffin wax was used as the phase change material (PCM) for the latent heat thermal energy storage phenomena. Three modes of operation have been performed on the (i) CMSS with water alone, (ii) water plus hollow iron pipes (iii) water plus PCM encapsulated iron pipes. The water load volume was kept constant throughout the experiment. The still was operated for 24 hrs on three successive sunny days. The parameters like ambient temperature, wind velocity, still water temperature, temperature of the PCM and the iron pipes were recorded. The temperature of air inside above the water surface and the humidity are also have been measured. The still performance has been studied in terms of the distillate yield and efficiency of the system. Based on the experimental results, the total productivity of the Cabinet Model Solar Still with PCM encapsulated iron pipe was found to be slightly higher than the other two modes of operation mentioned above. The night time yield of the Cabinet Model Solar Still with PCM encapsulated iron pipe was found to be higher than the other two modes results. The productivity of the still was found to be increased due to the integration PCM encapsulated iron pipe along with the water load. Further research is in progress to improve the distilled yield.

Keywords: Cabinet Model Solar Still, PCM, Iron pipe, Latent heat thermal storage.

I. Introduction

Desalination process is considered to be one of the simplest and widely adopted techniques for converting seawater into fresh water. One of the main advantages of the distillation process is that it requires heat only up to 120 °C which can be supplied from solar energy or other cheap fuels. It could be used as eco friendly to produce portable water from saline and brackish water. Latent heat thermal energy storage is an proficient way to collect and to store thermal energy for heating water by the energy received from sun. Phase change material (PCM) are capable for melting and solidifying at a particular temperature and they are also competent for storing and releasing thermal energy. Tabrizi et al. [1] studied two cascade solar stills with latent heat thermal energy storage system (LHTESS) and without LHTESS. Both stills had the optimum inclination through the year atZahedan, Iran. They noticed that the total productivity of still without LHTESS is slightly higher than the still with LHTESS. Dashtban and Tabrizi [2] developed a theoretical model for a still with and without phase change material (PCM). They concluded that the daily productivity of the still with and without the PCM was 6.7 and 5.1 kg/m2 /day respectively. Murugavel et al. [3] studied the effect of minimum depth of water with different storage materials in the basin. The performance of the solar still was compared with different types of energy storing materials like quartzite rock, washed stone, cement block pieces, red brick pieces and iron scraps.Scrivani et al. [4] presented the concept of utilizing solar concentration of plants for water production; remediation, waste treatment and processing landfill percolate in arid regions where conventional depuration systems are expensive and impractical. Rehim and Lasheen [5] conducted an experimental and a theoretical study of a solar desalination system coupled with a solar conical concentrator to a focal pipe and simple heat exchanger. The results show that the temperature values of the modified system are higher than the conventional one. In case of the modified design, the fresh water productivity increased an average of 18%. Chaouchi et al. [6] designed and built a small solar desalination unit equipped with a conical concentrator. The results show that, the maximum efficiency corresponds to the maximum solar irradiation obtained towards 14:00. At that hour, the boiler was nearly in a horizontal position, which maximizes the offered collection area. The experimental and theoretical study concluded with an average relative error of 42% for the distillate flow rate.

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The present study is designed by using cabinet model solar still coupled with PCM thermal storage arrangement. The thermal performance of the still with different parametric variations was investigated on successive sunny days. The efficiency and the water yield are also estimated and are reported.

II. Materials and Methods

Fig 1. Pictorial view of the whole setup of cabinet solar still coupled with PCM

A pictorial diagram of the laboratory model solar still is shown in fig.1.The laboratory model solar still was fabricated with the dimension of 0.50*0.50*0.35m with an aperture area of 0.25m^2.The wall thickness of 0.003m. In order to reduce the loss of heat through all sides and bottom of the solar still, it was insulated with ash of thickness 0.08m. It was painted black over on all sides and bottom of the solar still to absorb the solar energy and to hold the water. A transparent glass cover of thickness 0.005m was used to cover the still and the top of the cover was placed over the grooves for a slope of 23˚ with uniform support. Transmittance of the glass cover was 91%. Commercial grade paraffin wax was used as a latent heat storage material because of wide availability and low cost. The thermo-physical properties of the paraffin wax is 56-60˚C, latent heat of fusion 209 kj/kg, specific heat capacity 2890 j/kg.

The solar radiation is transmitted through the glass cover and was absorbed by the still and PCM; hence these cause increase in temperature. Part of the energy absorbed by the still is transferred by convection to the still water and the other transferred by conduction to the cooler PCM resting on the still. As the pipes are heated, heat is first stored as a sensible heat until the PCM reaches its melting point. At this time, the PCM starts to melt and after complete melting of the PCM, the heat will be stored in the melted PCM as a sensible heat. After noon, when the solar radiation decreases, the still components stat to cool down and the liquid PCM transfers heat to the still until the PCM completely solidified. The PCM will act as a heat source for the still water during the night; consequently, the still continues to produce fresh water after sunshine hours.

Fig.2. Pictorial view of the PCM encapsulated iron pipes.

A hollow iron pipe of thickness 0.015m for a length of 0.30m and diameter of 0.022m was taken and both sides were closed with end cap to hold the PCM inside the pipe. The pipes are painted black to absorb the solar intensity. The pipes were filled with the commercially available paraffin wax. In this work 4 numbers of pipes were taken and each pipe was filled with0.125kg of paraffin wax as PCM and overall 0.500kg of paraffin wax was used. Calibrated copper constantan thermocouples were used to measure the temperature at different location of the still as well as water. All these thermocouples were connected to Rishimulti with 0.25% basic accuracy to measure the thermo emf. The ambient temperature was taken by using thermometer with an accuracy of 0.1˚C.Velocity of the wind was measured by using integrating Anemometer. The global solar radiation incident on the still cover was measured using a pyranometer. The relative humidity of the ambient air was measured with an analog hygrometer.The distillate output from the solar still depends on many parameters like climatic parameters such as solar insolation, ambient air temperature, wind velocity, atmospheric humidity etc. an important parameter affecting the output is solar insolation on the still. Then the efficiency of the solar still is given as [7]

$$\eta = ML / AIT \tag{1}$$

where "A" is the area of aperture and "I" is the solar radiation, t is the total time of collection of solar energy and L is the latent heat of evaporation.

III. RESULT AND DISCUSSION

The experiments have been performed to investigate the effect of the still performance. Initially the still was filled with 8 liters of water and operated from 9AM to 9AM of the next day. It is known that the productivity of the solar still is depend on the solar radiation incident on it, ambient temperature and wind velocity. So the efficiency of the still is calculated from 9AM to 5PM and the yield of distilled water is measured for 24 hrs. The performance of the solar still is studied for three different parametric variations as water alone, with iron pipe and PCM encapsulated iron pipes for three successive days. fig3. depicts the hourly variation of solar insolation , ambient temperature, water temperature, wind velocity, collected water and humidity with respect to time.

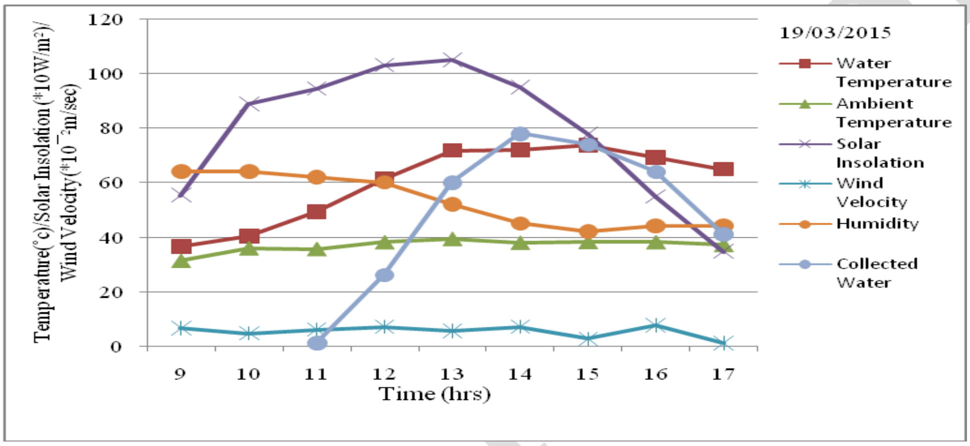

Fig 3.Hourly variation of solar insolation, ambient temperature, water temperature, wind velocity, collected water and humidity with respect to time.

The results from the fig 3. Shows that the water temperature of the still for 8 liters of loaded volume of water was 36.4, 40.3, 49.2, 61.2, 71.7, 71.8, 73.6, 69, 64.7˚c with the ambient temperature of 31.2, 35.8, 35.5, 38, 39.2, 37.8, 38.1, 38, 37˚c for the solar insolation 553.303, 888.119, 944.664, 1029.683, 1049.926, 950.062, 777.323, 547.905, 245.612W/m² respectively. The collected water is 1, 26, 60, 78, 74, 64, 41 ml/0.25m² and humidity is 64, 64, 62, 60, 52, 45, 42, 44, 44% respectively. The maximum water temperature of 73.6˚c is found in the still at 3PM and total solar insolation was 6850 W/m² on 19/03/2015.

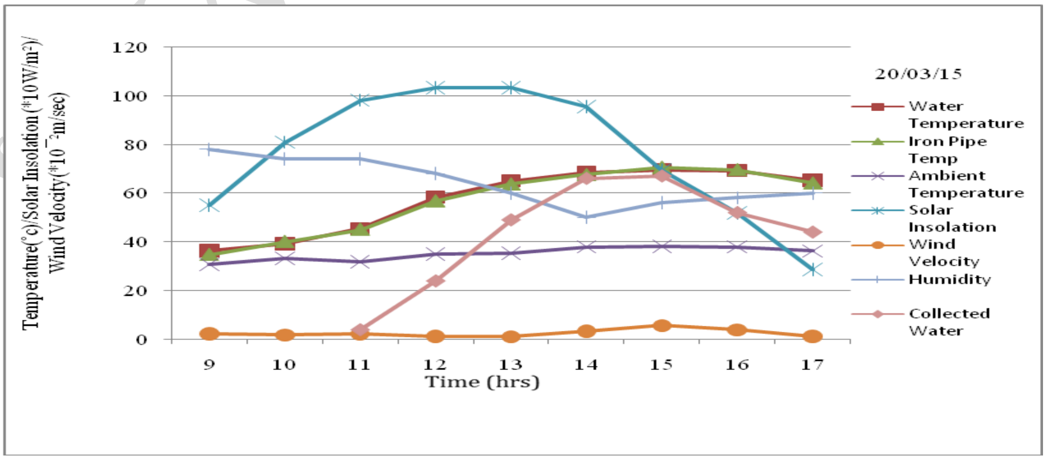

Fig 4.Hourly variation of solar insolation, ambient temperature, water temperature, hollow iron pipe temperature, wind velocity, collected water and humidity with respect to time.

The obtained results from the fig 4. Shows that the water temperature of the still for 8 liters of loaded volume of water was 36,2, 39, 45.3, 58.2, 64.9, 68.3, 69.5, 69.3, 65.1˚c and hollow iron pipe temperature was 34.7, 40,45, 56.7, 63.7, 67.5, 70.5, 69.5, 64.1˚c with the ambient temperature of 30.7, 33, 31.8, 35, 35.2, 37.8, 38, 37.8, 36.1˚c for the solar insolation 549.25, 808.36, 981.110, 1031.03, 1032.388, 954.46, 695.002, 518.21, 286.09 W/m² respectively. The collected water is 4, 24, 49, 66, 67, 52, 44 ml/0.25m² and humidity is 78, 74, 74, 68, 60, 50, 56, 58, 60% respectively. The maximum water temperature of 69.5˚c and maximum iron pipe temperature of 70.5 ˚c is found in the still at 3PM and total solar insolation was 6990 W/m² on 20/03/2015.

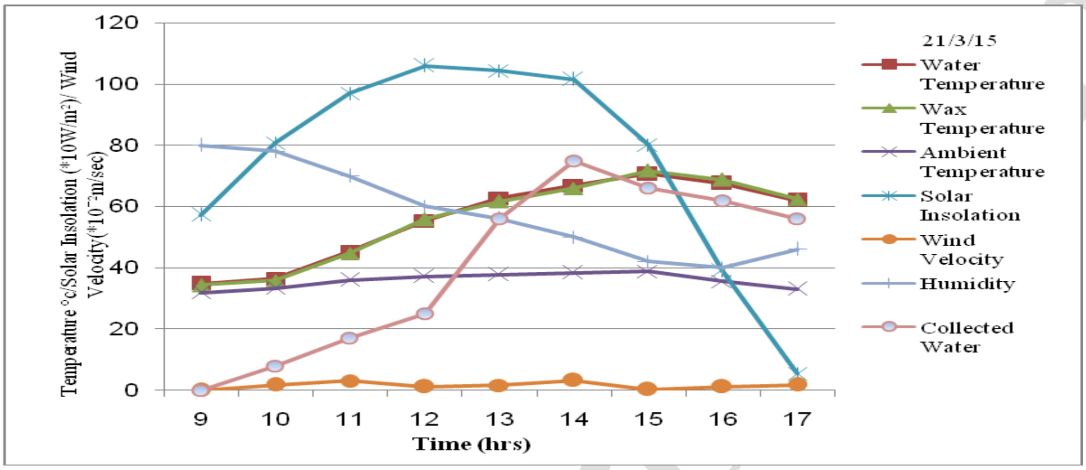

Fig 5. Hourly variation of solar insolation, ambient temperature, water temperature, iron pipe with PCM temperature, wind velocity, collected water and humidity with respect to time

The results from the fig 5. Shows that the water temperature of the still for 8 liters of loaded volume of water was 34.8, 36.5, 45.2, 55.3, 66.9, 70.6, 67.6, 62˚c and iron pipe with PCM temperature was 34.3, 35.8, 44.7, 55.8, 61.7, 65.7, 71.7, 68.7, 62.4˚c with the ambient temperature of 31.7, 33.3, 36, 37, 37.5, 38.5, 38, 35.5, 33˚c for the solar insolation 572.19, 807.01, 968.95, 1059.37, 1043.47, 1014.83, 801.61, 390.11, 53.98 W/m² respectively. The collected water is 0, 8, 17, 25, 56, 75, 66, 62, 56 ml/0.25m² and humidity is 80, 78, 70, 60, 56, 50, 42, 40, 46% respectively. The maximum water temperature of 70.6˚c and maximum iron pipe with PCM temperature of 71.5 is found in the still at 4PM and total solar insolation was 6715 W/m²on 21/03/2015.

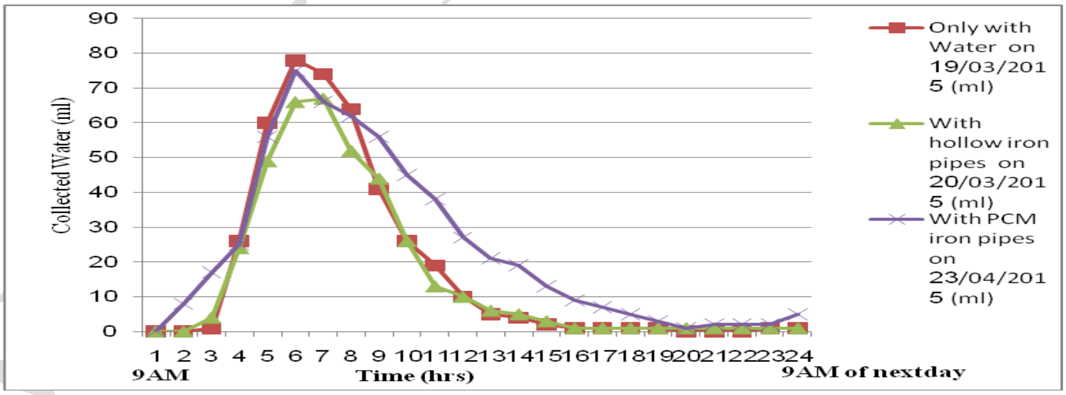

Fig . 6. Hourly variation of collected water for only water, hollow iron pipe, PCM iron pipes with respect to time.

The total output of the collected water from solar still with water alone was 426ml/0.25m², and 377ml/0.25m² for the solar still with iron pipes and 564ml/0.25m² for the solar still with PCM iron pipes. The maximum amount of collected distilled water of 78ml at 2PM for water alone and 67ml at 3PM for iron pipe and 75 ml at 2PM for PCM with iron pipes. From the Fig.6 the maximum amount of collected water is noticed in the still at 12PM to 3PM. The distilled yield of water for 24 hrs on the successive days was obtained that the yield of the distilled water after 5PM to 9AM of next day was 72ml, 72ml, and 199ml for water alone, with hollow iron pipe and PCM iron pipes respectively. From the collected yield it is concluded that the night time yield is 17.3%, 19%, 35.2% of the total yield of water alone, with hollow iron pipes and PCM iron pipes respectively. The efficiency obtained for the still is 13.5%, 12.4%, 23.5% for water alone, with hollow iron pipes and PCM iron pipes respectively.

IV. Discussion

The distilled water collected with PCM iron pipes is much higher than that of water alone and with hollow iron pipes throughout the whole day (24hrs). This behavior happens because the PCM iron pipes absorb the heat from the water and black painted surface of iron pipes. The PCM iron pipes increase the still water temperature as well as the yield during the second half of the day and night time hours. The paraffin wax starts to melt in the morning hours due to high intensity of solar radiation from the still. It starts to get melt from 12.00 hrs to 15.00 hrs, subsequently it get decrease in temperature and becomes solid state again by releasing sensible heat into water even after sunshine hours. The obtained results are similar with the results of Arunkumar.Tet., al [8] studied in the augmentation of distillate yield using phase change material. So when comparing the night time yield of distilled water the PCM iron pipes yields 18% more than that of water alone and hollow iron pipes and the efficiency of the still with PCM iron pipes is higher with 10% and 11% of with water alone and hollow iron pipes respectively.

V. Conclusion

The cabinet model solar still with PCM iron pipes, with hollow iron pipes and water alone has been investigated to enhance the performance of the still. The raise in temperature of the PCM is due to the absorbed energy through the black painted iron pipes. After sunshine hours, the PCM acts as a heat source for the still water to maintain temperature difference. The PCM becomes more effective at still water during night time hours. The PCM becomes more efficient at the squat volume of still water during off sunshine hours. Therefore it is suggested to incorporate the PCM thermal storage array in the solar still to turn out distilled water over night. This cabinet model solar still yield was found to be 426 ml/0.25m^2/day, 377 ml/0.25m^2/day and 564ml/0.25m^2/day for water alone, with hollow iron pipes and with PCM iron pipes respectively.

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