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ENHANCEMENT OF FRESH WATER PRODUCTION ON TRIANGULAR PYRAMID SOLAR STILL USING PHASE CHANGE MATERIAL AS STORAGE MATERIAL

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ABSTRACT

This paper presents the method of improvement of enhancing the performance of triangular pyramid solar still with and without latent heat energy storage. For comparing the productivity of solar still with and without LHTESS a solar still is designed, fabricated. Experiments are conducted in hot and humid climate of Chennai, India. Paraffin wax is used as LHTESS due to its feasible general and economic properties. The hourly productivity is slightly higher in case of solar still without LHTESS during sunny days. There is an increase of about 35% in production of fresh water with LHTESS than that of solar still without LHTESS. Also it was found that during the off shine period the fresh water produced from the still is higher. The solar still with and without LHTESS were found to be 4.5 L/m^{2}day and 3.5 L/m^{2}day during summer and in the winter the productivity was found to be 3.4 L/m^{2}day and 2.3 L/m^{2}day for the still with and without LHTESS respectively.

Keywords: *Enhancement, Phase change material, hourly variation, Efficiency.*

1. INTRODUCTION

Solar energy is the earliest source of energy, inexhaustible and non-pollutant in nature, solar distillation can provide an alternative source to generate clean water. Solar distillation exhibits a considerable economic advantage over other salt water distillation processes because of its use of free energy and its insignificant operating costs. This process removes salt impurities. Solar stills suffer from low efficiencies due to loss of heat of condensation to the surroundings from the glass cover. In order to improve the productivity, it is planned to incorporate partial thermal energy storage (Farell et al., 2006; Tabrizi et al., 2010).

The thermal energy storage system has become an important issue in the global energetic scene and has been widely used to increase energetic efficiency of different applications (El-Sebaii et al., 2009). These systems may be either sensible or latent heat systems. This method utilizes the heat dissipated from the bottom of the still. The latent heat storage system has many advantages over sensible heat storage systems including a large energy storage capacity per unit volume and almost constant temperature for charging and discharging. Here, phase change materials will act as a thermal energy storage medium. It is a substance with a high heat of fusion which, melting and solidifying at a certain temperature, is capable of storing and releasing large amount of energy. It changes its phase by absorbing latent heat during sun shine hours and it discharges the stored energy which is suitable for distillation purpose during off sunshine hours (Jinjia Wei at al, 2005) (Naim, 2002). With a thin layer of PCM under the basin liner of a solar still, a considerable amount of heat will be stored within PCM during sunshine hours instead of wasting it to surroundings. During freezing of PCM, the stored heat discharges to keep the basin water at a temperature enough to produce fresh water during night even thin layers of basin water. This causes enhancement of still productivity especially during night period (Demirbas, 2006).

Tabrizi et al. (2010) investigated the effect of built-in latent heat thermal energy storage on a weir-type cascade solar still. The hourly production of fresh water of solar still with PCM is relatively low when compared to solar still without PCM on summer. It has been reported that the solar still without PCM is well suited for sunny days and still with PCM was suited for cloudy conditions. (Tabrizi et al., 2010) experimentally investigated the effect of water flow on internal heat and mass transfer on a weir cascade solar still. It has been reported that the increase in mass flow on the basin of weir there will be a decrease in fresh water production. Results show that an accumulated yield of 7.4 and 4.3 kg/m^2 were achieved for minimum and maximum flow rates respectively. A triangular pyramid solar still with built-in latent heat thermal energy storage system was fabricated to improve the still productivity by (RaviShankar et al., 2013).

It was been found that the solar still with PCM and without PCM were found to be 4.2 kg/m^2.Another still with the same characteristics without PCM was also constructed for investigation of the internal convective heat transfer coefficient. In this paper an attempt has been made to find the use of paraffin wax as a heat storage material. Paraffin wax acts as a reliable, less expensive and non-corrosive heat storage medium (Naim, 2002).

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2. EXPERIMENTATION

Fig. 1 shows the experimental setup of triangular pyramid solar distiller. Experiments were carried out from 7 am- 6 pm. The plastic storage tank of capacity 50 l was used in order to avoid corrosion. Water from the storage tank enters the still through flexible hoses and a valve V, to maintain constant water level in the still. The valve 'V' can control the mass flow rate. Poly vinyl chloride (PVC) hoses were used for greater flexibility. The black painted still basin was placed inside the wooden box at a predetermined height. The area below the basin was filled with saw dust for insulation purpose. A small glass piece obstruction was fixed on the inside surface of the glass cover, to facilitate the deflection of the condensate return in to the collection channel, which in turn affixed with the still. The gliding water from the channel was transferred in to the measuring jar through the flexible piping. A heat reservoir is integrated with the still and filled by a phase change materials (PCM) that acts as a latent heat storage subsystem (LHTESS). Paraffin wax was selected as a LHTESS due to its thermal storage, safety, reliability and low cost. During the sunshine, when the absorber temperature is higher than the temperature of PCM, the heat is transferred to PCM and charging process is started to store solar energy as a sensible heat till PCM reaches its melting temperature. Additional charging heat is stored as the latent heat during the melting process. When the absorber temperature is lower than PCM (after sunset), reverse process is occurred (discharging process) till the PCM layer is fully solidified. Table 1 physical property of paraffin wax which is used as heat recovery. Calibrated NiCr-Ni thermocouples connected to a FLUKE 73 digital multimeter with accuracy 0.5^{o}C were used to measure the temperatures of the still elements, e.g. basin liner T_b, basin water T_w and the inner T_{gi} and outer T_{go} surfaces of the still cover every half an hour starting at 8:00 am until sunset. The experiments were continued until 8:00 am of the next day. The yield from the still was collected and measured every 1 h. The productivity of the still during the night period was also collected and measured using a measuring jar. The ambient temperature had been also measured. The horizontal global solar radiation was measured using an Epply EPSP pyranometer coupled to an Epply instantaneous solar radiation meter with sensitivity of 8.79x10^{-6} (V/Wm^2) and accuracy better than 5% in the range from 0 to 2000 W/m^2. The wind speed V was also measured using the Environmental Products Anemometer.

The thermocouples are used to measure the temperature of the glass plate, absorber plate, and water and phase change materials temperatures. Also the quantity of distilled water was measured**.** This experimental setup was designed, installed and tested at Hindustan Institute of Technology and Science, Chennai, Tamil Nadu, India.

Table 1. Thermo physical properties of paraffin wax (Haji-Sheikh, 1982)

Property	Value
Melting temperature (°C)	40-60
Specific heat of solid/liquid (kJ/kg °C)	2.95/2.51
Density of solid/liquid (kg/m^3)	818/760
Thermal conductivity of solid/liquid (W/m °C)	0.24/0.24
Heat of fusion (kJ/kg)	226

Table 2. Relevant parameters for calculation (Wong, 1977) and (Duffie, 1991)

Parameter	Value	Parameter	Value
A_b (m^2)	1.0	α_g	0.05
τ_g	0.90	k_s(W/m^{2}K)	0.059
τ_w	0.95	x_s (m)	0.05
α_b	0.90	C_w (J/kgK)	4190
α_w	0.05	k_g (W/m^{2}K)	1.05
σ (W/m^{2}K^4)	5.66x10^{-8}	x_g (m)	0.003
V m/s	0-20	k_w(W/m^{2}K)	0.628

Fig. 1 Pyramid type distiller

3. ENERGY BALANCE

The energy received by the saline water in the still I (t) solar radiation and Q_{cb-w} convective heat transfer between basin and water are equal to the summation of energy lost by Q_{cw-g} convective heat transfer between water and glass, Q_{rw-g} radiative heat transfer between water and glass, Q_{ew-g} evaporative heat transfer between water and glass and energy gained by the saline water: The remaining is by evaporation, due to partial vapour pressure difference between the water surface and lower surface of the glass cover. Water evaporated condenses at the distillate collector through the glass cover. A small part of heat is lost to atmosphere through basin bottom and side wall by conduction and convection. For shallow basin still, the basin bottom surface and water are assumed as single element (Prakash, 1986) and the temperature is taken as constant for basin and water. Raw water is continuously supplied to the basin to keep the water mass in the basin always constant. This compensating water mass takes sensible heat to attain equilibrium with basin water.

4. RESULTS AND DISCUSSIONS

Fig. 2 and 3 show the variation of solar intensity from which it is observed to be maximum at the mid-noon. The observation shows that the solar radiation profile seems to be the same on the experimental days. Fig. 4 shows the hourly variation of experimental and theoretical temperatures of basin of a pyramid type solar still. The theoretical and experimental values are found to be very close during the morning and reach the maximum of 82^{o}C. The RMS error for basin temperature is found to be 12% between theoretical and experimental values and these errors are minimized by proper insulation and higher wind velocity over the still which reduces the heat loss from water to ambient conditions.

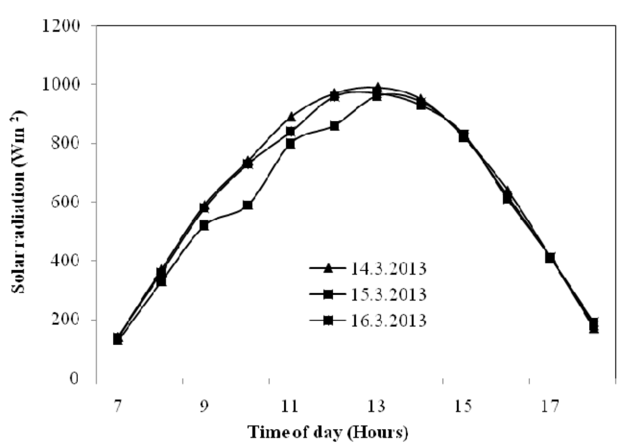

Fig. 2 Variation of solar radiation on summer day on Chennai climatic condition

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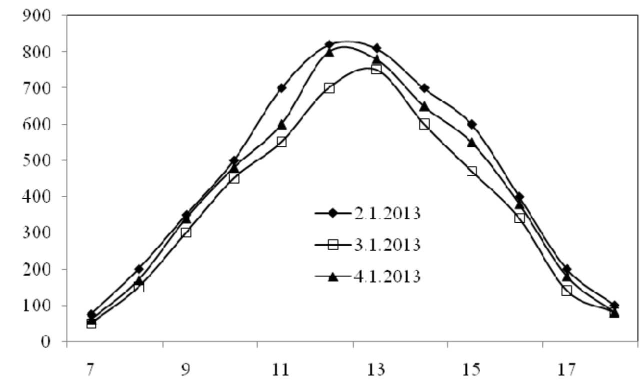

Fig. 3 Variation of solar radiation on winter day on Chennai climatic condition

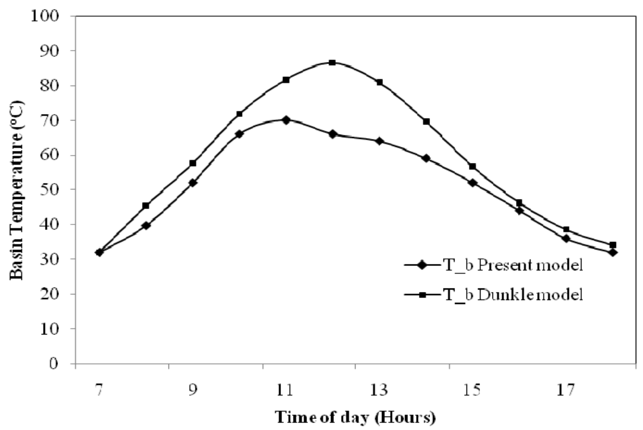

Fig. 4 Theoritical and experimental absorber plate temperature with time

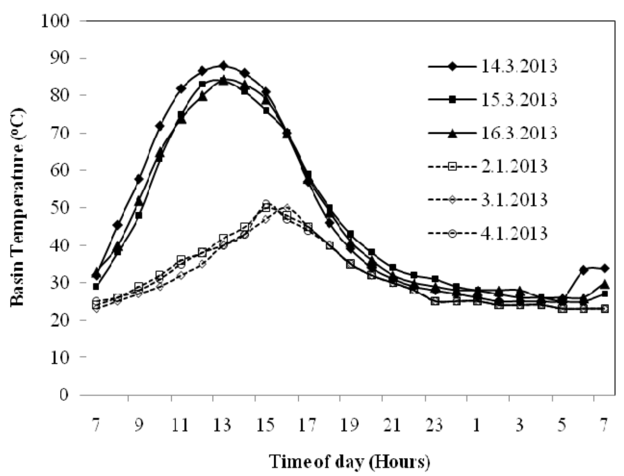

Fig. 5 Variations of absorber plate temperature without PCM

Fig. 5 and Fig. 6 show the variation of absorber plate with respect to time of solar still with and without use of LHTESS. The absorber plate temperature increases gradually with increase in solar intensity and have peak around 1 pm. The maximum obtained values for plate are 90 °C for still without LHTESS. Similarly for solar still with LHTESS, maximum obtained values for T_b is found to be 65°C. Temperature of plate is higher for still with LHTESS, due to the fact that some of energy was observed as phase change energy. It is cleared that in the early hours of the day the plate temperature is slightly higher than water temperature because in that period's glass is directly faces the solar radiation and its temperature rises faster in comparison with water temperature. Then, the increase in water temperature is faster in comparison with glass plate temp due to higher heat losses from the glass plate to the ambient.

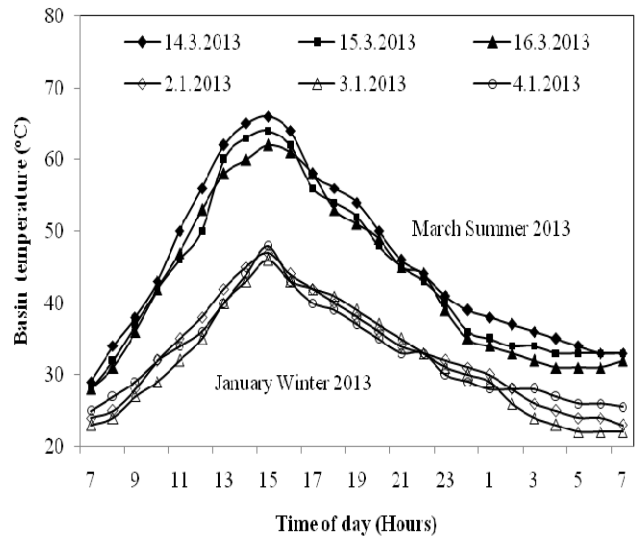

Fig. 6 Variations of absorber plate temperature with PCM

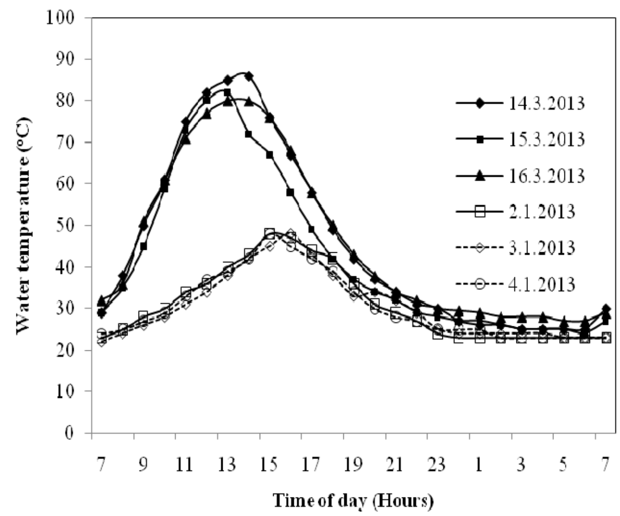

Fig. 7 Variations of water temperature without PCM

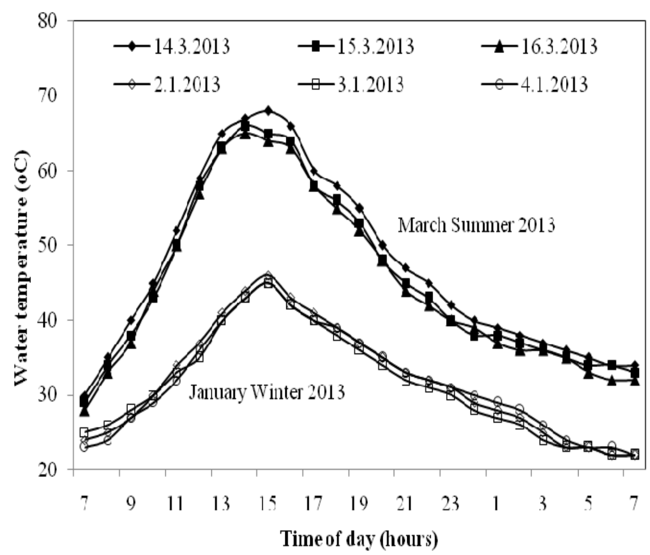

Fig. 8 Variations of water temperature with PCM

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Fig. 7 and Fig. 8 show the hourly variation of water temperature with and without PCM. From the theoritical analysis the maximum acheivable temperature of water is about 75°C. In the present model the temperatuer of water in the still with and without PCM achieved is about 70 and 85°C respectively. During the winter days, for the same solar still temperatue of water inside the still with and without PCM found to be 45°C and 48°C respectively.

Fig. 9 andFig. 10 show the diurnal variation of glass temperatures. It is observed that the driving force between water and glass acts as the prime source for fresh water production. Due to the forcing of wind over the surface reduces the temperature of glass for better enhancement.

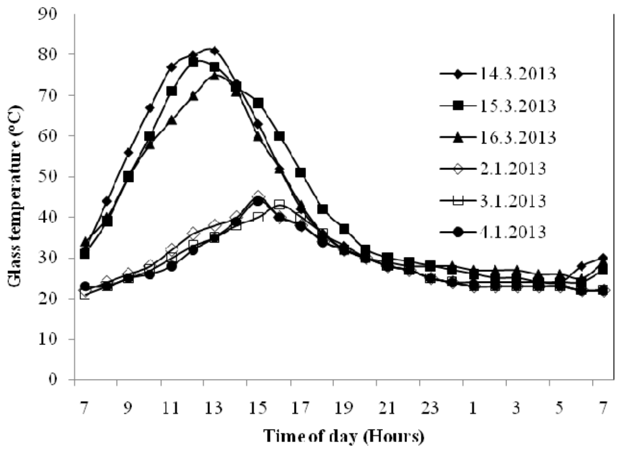

Fig. 9 Variations of glass temperature without PCM

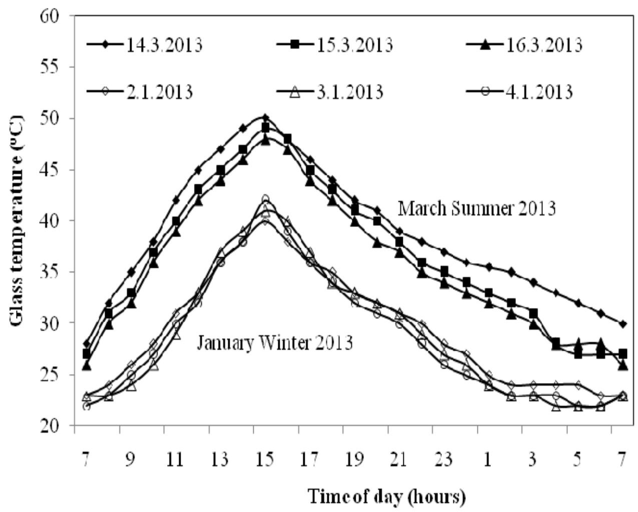

Fig. 10 Variations of glass temperature with PCM

Fig. 11 and Fig. 12 show the diurnal variation of fresh water producureion from the solar still with and without phase change material. It is clear obvious that the fresh water production from the solar still depends on solar intensity during the sunshine hours. And the results shows that the solar intensity is directly proportional to yield from the solar still. The yield obtained from the still without PCM shows a higher output compared to still with PCM. It is due to the amount of partial recovery of heat from the water to PCM in the basin. During the off shine period the heat which is recovered during the charging mode, discharges its heat to water.

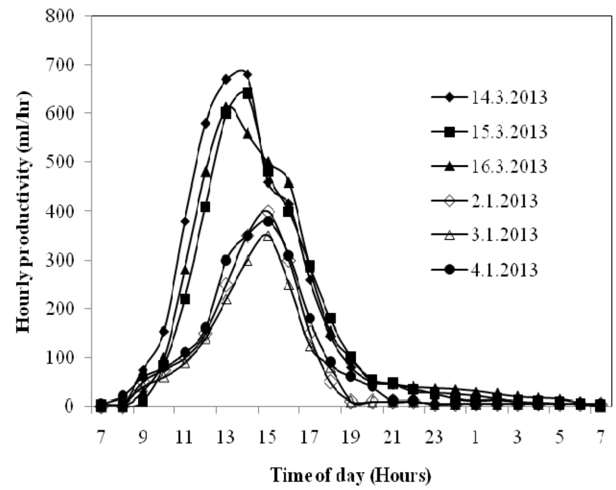

Fig. 11 Variations of distillate output without PCM

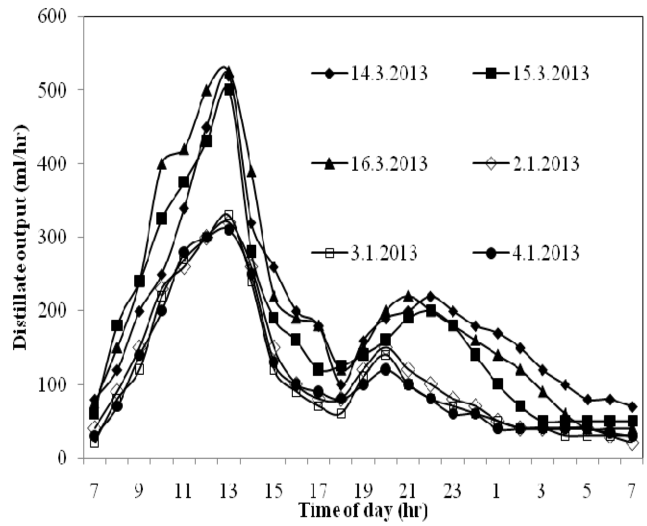

Fig. 12 Variations of absorber plate temperature with PCM

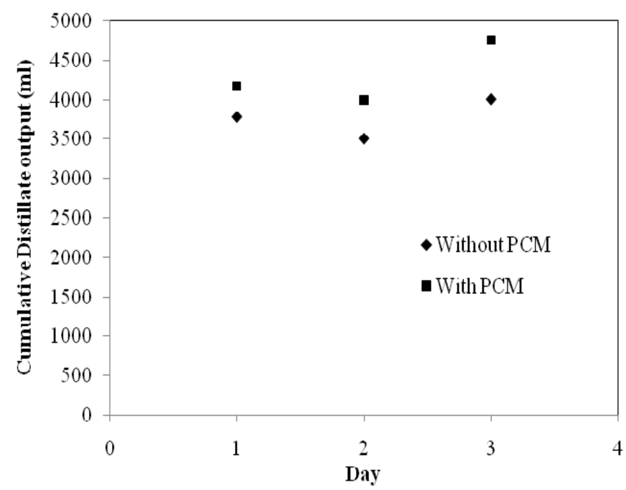

Fig. 13 Variations of cumulative yield on different experimental days in summer

Fig. 13 compares the accumulated yield of solar still with and without latent heat energy storage material. A triangular pyramid solar still with built-in latent heat thermal energy storage system was fabricated to improve the still productivity. Another still with the same characteristics without LHTESS was also constructed for investigation on hourly production of fresh water. Using a 1m^2 area of solar still the average production of fresh water about 3.4 liters/m^2 without LHTESS effect is possible. The effect of introducing PCM in the above setup shows an increase of 20% in the production of fresh water.

5. CONCLUSIONS

The daily efficiency was found to be 53% with LHTESS and 45% without LHTESS. Solar radiation on the test days reveals that the maximum intensity occurred during the mid-day, and the productivity shows that the solar radiation and production rate are directly proportional. The temperature difference between water and glass varies from 10-15.5^{o}C during the off-shine period. Experimental results concludes that with PCM the production of fresh water improved to about 4.3 liters/day for a 24 hour operation, its due to the higher specific heat capacity, better latent heat of fusion, and thermal conductivity of wax.

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