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Heat Transfer Enhancement of Solar Still Using Phase Change Materials (PCMs)

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Abstract*—In the recent scenario, distillation process with solar still plays vital role for getting pottable water from brackish and sea water. In this paper, attempt has been made to enhance the productivity of the solar still with the help of LHTESS(Latent heat thermal energy storage sub-system). Latent heat storage in a phase change material PCMs is very attractive because of its high storage density with small temperature difference. For experimentation and comparison purpose, a Cascade Solar Still with and without LHTESS were designed and constructed for water purification with a view of enhancing productivity. Solar still of the present study mainly consists of stepped absorber plate integrated with phase-change energy storage sub-system or LHTESS and single slope glass plate. This setup will be placed at an angle of 25° to the horizontal. Paraffin wax is used as LHTESS due to its feasible general and economic properties [1]. The hourly productivity is slightly higher in case of solar still without LHTESS during sunny days. The disadvandages of phase change material is corrosion when in direct contact with metal pipings or housings [5].

***Index Terms*— Distillation, Solar Still, LHTESS, Paraffin wax, salt hydrated phase change materials, PCMs.**

I. INTRODUCTION

The amount of solar energy reaching the earth surface is nearly thousand times greater than the availability of fossil fuels. Solar energy, which 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 is ultra-pure and always economical to use”. 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. “As a device, solar still eliminates all harmful minerals, chemical contaminates, salt, minerals and any other impurities from most varieties of water”. The still performance was found to increase with thinner films of water films. However, decreasing thickness of basin water results in a decrease of overnight productivity of the still. 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 Highlight a section that you want to designate with a certain style, and then select system in the project [1,2]. 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 [10]. It is very useful to correct the mismatch between the supply and demand of energy. The partial storage system minimizes capital investment and cost of energy. 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 [7, 8]. 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

In this work, Paraffin wax has been used as thermal storage medium to retain heat collected by a solar still. Paraffin wax is safe, reliable, less expensive, chemical stability, non-corrosive, significant latent heat of fusion and also 100% recyclable [9)]. Paraffin wax is a plastic like substance which is solid at ambient temperature. However, the inherent low thermal conductivity of paraffin could results in low heat transfer rates during melting/ freezing process. These PCMs are belongs to organic PCMs and they are melts at temperature higher than 0°C (32°F). Salt hydrates may be regarded as alloys of inorganic salts and water forming a typical crystalline solid [2]. It has better thermal conductivity but it yields severe corrosion .

II. LITERATURE SURVEY

“Ref. [1]” F.F Tabrizi, et al., have conducted an experimental investigation on a weir-type cascade solar still with built-in latent thermal energy storage system. The total productivity of still without LHTESS was slightly higher than the still with LHTESS in sunny days. There was a significant difference in productivity of still with and without LHTESS. They have reported that the still without LHTESS was preferred for sunny days due to its simplicity and low construction cost and the still with LHTESS was proposed for partially cloudy areas due to its higher productivity.

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"Ref. [3]" Farshad Farshahi Tabrizi, et al., has investigated the effect of water flow rate on internal heat and mass transfer and daily productivity of a weir type cascade solar still. The results showed a decrease in the internal heat and mass transfer rates as well as daily productivity with an increase in water flow rate. The daily productivity obtained was about 7.4 and 4.3 kg/m^2 day for minimum and maximum flow rates.

"Ref. [2]" Antony J Farell, et al., conducted experiments to study corrosive effects of salt hydrate phase change materials used with aluminum and copper. The copper samples experienced greater mass loss, varying as average between 0.8 and 0.145 g/m^{3}h. But Aluminium had lesser pitting corrosion at an averages mass loss of 7 x 10^{-5} g/m^{2}h which was observed from metallographic examination.

"Ref. [5]" Anant shukla, et al., conducted a thermal cycling test on few selected inorganic and organic phase change materials. Inorganic PCMs were not found suitable after some cycles while thermal cycling for organic PCMs can be done upto 1000 thermal cycles and gradual change was found in melting temperature and latent heat of fusion.

"Ref. [7]" Jinjia wei, et al., have conducted studies on a PCM heat storage system for rapid heat supply. In numerical studies, the PCM was encapsulated in four different capsules (Sphere, cylinder plate and tube). They have found that, the sphere capsules showed the best heat release performance among the four types of investigated capsules where as the tubular capsule with low void fraction was not ideal for rapid heat release of the thermal energy.

III. EXPERIMENTAL SET UP

It consists of stepped absorber plate or solar collector, glass plate integrated with energy storage subsystem such as phase change materials. The absorber plate is painted with matte black paint to increase the absorbtivity. The setup is made up of Galvanized Iron (GI). The total setup (includes absorber plate, glass plate) is placed at an angle of 25° to the horizontal. Solar collector collects the energy in the form of radiations from the sun, convert it into heat, and then transfer that heat to colder fluid. Feed water passes through the stepped absorber plate and it's heated by solar energy. The water evaporates and condenses on the inner sided of the glass plate after releasing the latent heat. It is important for greater efficiency that the water condenses on the plate as a film rather than as droplet which tends drop back into saline water.

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. 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.

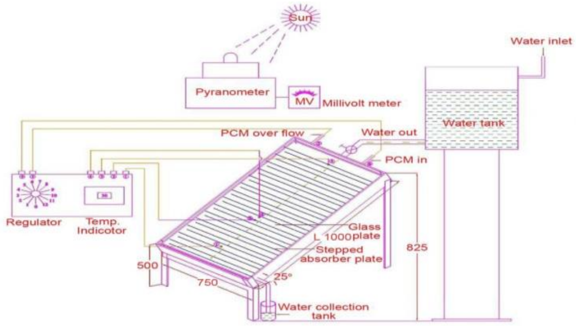

Fig. 1 Schematic diagram of Experimental Setup

IV. TABLE I

DESIGN SPECIFICATIONS (FOR SINGLE- SETUP)

Material (collector)	G.I
Length of collector	0.98 m
Width of collector	0.78 m
Area of collector	0.98 x 0.78 = 0.76 m^2
Air gap between glass plate and Collector	8 cm
Size of step	Horizontal surface - 5 cm Vertical surface - 3 cm
Weir on each steps	1 cm
Number of steps	16

TABLE II

THERMO PHYSICAL PROPERTIES OF PARAFFIN WAX

Solid/liquid Density	818/760 kJ/kg
Melting temp	40 - 60 °C
Latent heat of fusion	226kJ/kg
Thermal conductivity	0.25 W/m°C
Solid/liquid sp. Heat	2.95/2.51 kJ/kg°C

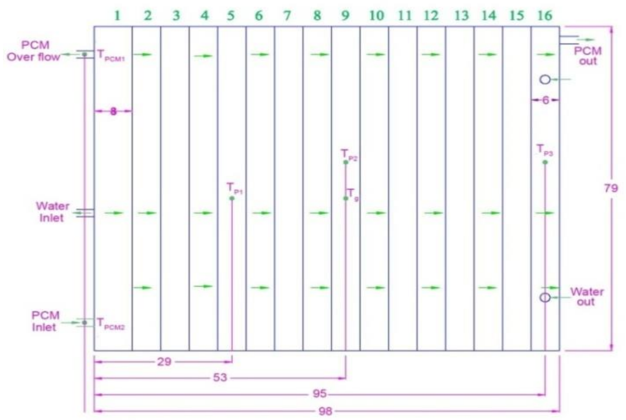

Fig. 2 Schematic diagram of thermocouple locations in the Experimental Setup

V. RESULTS AND DISCUSSION

Figure 3 shows the variation of absorber plate and glass plate temperature with respect to time of solar still with and without use of LHTESS. The absorber plate and glass plate temperature increases gradually with increase in solar intensity and have peak around 1 pm. The maximum obtained values for T_p & T_g are 76 °C & 70 °C for still without LHTESS. Similarly for solar still with LHTESS, maximum obtained values for T_p & T_g are 61°C & 58 °C obviously, T_p & T_g values are higher in the still without LHTESS than with LHTESS due to the fact that some of energy was observed as phase change energy.

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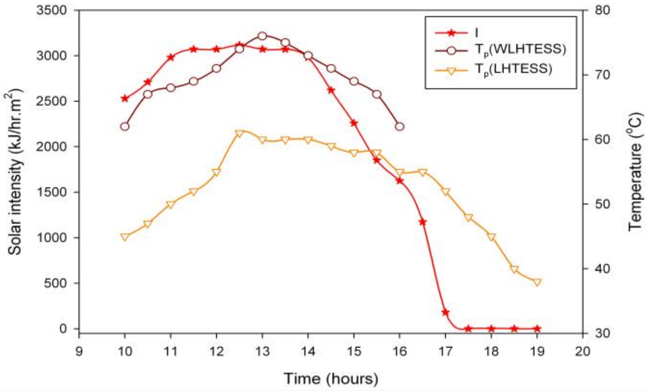

Fig. 3 Temperature distribution of the still elements with & without LHTESS in typical sunny days

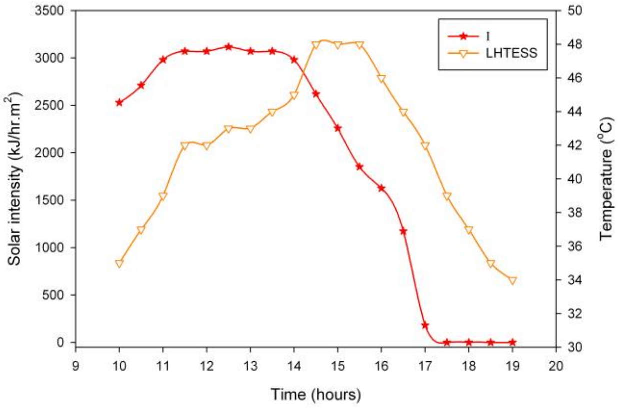

Fig. 4 Variations of PCM temperature with time for stills with & without LHTESS

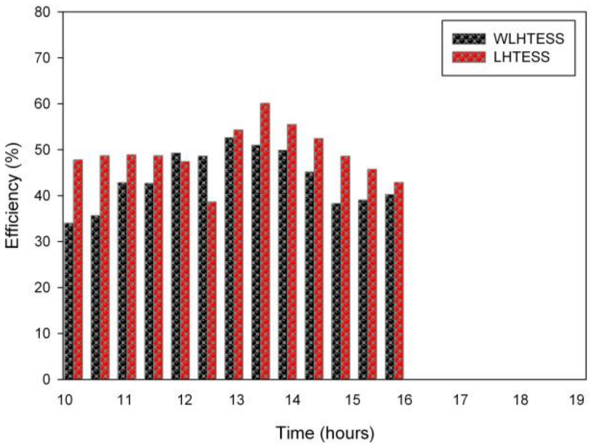

Fig. 5 Variation of efficiency of stills with & without LHTESS

Figure 4 indicates that the variation of PCM temperature with respect to time of solar still without and with use of LHTESS. The temperatures are increases with respect to time. The maximum PCM temperatures are °50C around 12.30 pm. On the other hand, the PCM temperature increases with time thereby the increase rate of heat transfer from absorber plate to the PCM as the solar radiation increases. Thermal energy stored as sensible heat in solid wax till T_{pcm} reached to its melting point which is about 50°C around 12.30 pm to 1 pm.This is the melting temperature of selected phase change material. During this period phase change process takes place at constant temperature. After that the discharge process is started around 2 pm with constant temperature until the PCM completely solidified and then its temp decreases slowly with time.

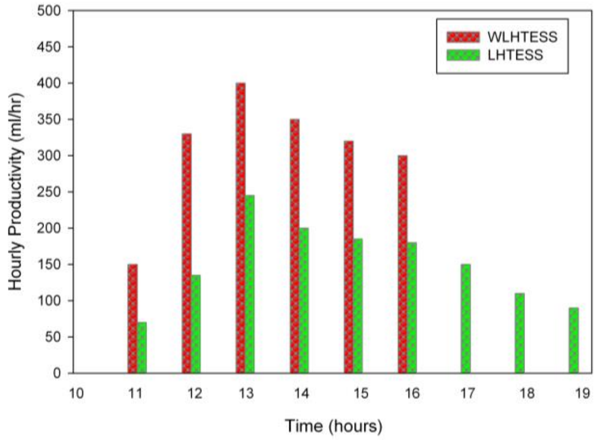

Fig. 6 Variation of hourly productivity with time for stills with & without LHTESS

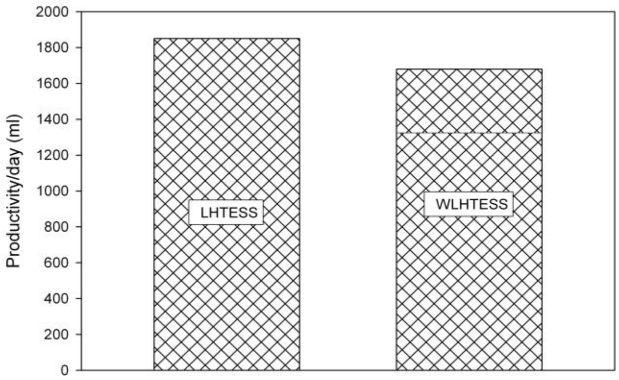

Fig. 7 Variation of total condensate collected on particular day in the still elements with & without LHTESS

It is cleared that in the early hours of the day the glass 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 temp is faster in comparison with glass plate temp due to higher heat losses from the glass plate to the ambient.

Figure 5 indicates that the variation of efficiency with respect to time of solar still with and without use of LHTESS and has peak value around 12.30 pm and 1 pm respectively. The maximum obtained efficiencies in the still with and without use of LHTESS are 60.11 % and 52.62 % respectively. The efficiency of still is mainly depends upon water flow rate and solar intensity. The efficiency of still is high in case of solar still without LHTESS may be due to the fact of higher intensity on that day and also partial amount of heat is transferred to phase change material which yields lower efficiency in case of the Still with LHTESS. And also the efficiency of still is slightly affected by wind speed, ambient temp, water temp, etc., From above obtained results; the overall efficiency of still without LHTESS is higher than the efficiency of still with LHTESS. Figure 6 shows that the variation of hourly productivity with respect to the time of solar still with and without use of LHTESS. Based on obtained results, the hourly productivity is slightly higher in case of solar still without phase change material in typical sunny days; the maximum obtained total productivities are 1.85 l/ day and 1.680 l/day for 0.76 m^2 area of still without and with use of LHTESS respectively.

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But the productivity enhancement is possible in the still with LHTESS during evening hours or off sunshine hours such that the obtained total productivities are 0.36 liters in the still with LHTESS system.

VI. CONCLUSION

The proposed design of stepped solar still with and without phase change material shows great potential in terms of higher distillation yield per unit area as compared to other available designs of solar still. The concluded results are presented as follows:

- Using stepped solar still will increase the residence time which enhances the condensation process leads to higher productivity.
- And also using weir on each step of the stills, leads to a forced flow and increases the residence time. Moreover, the weirs are to keep the water film as shallow as possible (with low heat capacity) while avoiding dry spots.
- The inclined solar stills have received many attentions due to their higher productivity than the conventional basin type solar stills and offering better orientation and minimum air gap.
- The efficiency of still is also dependent on flow rate of water. The still performance was found to increase with thinner films of water. However, decreasing thickness of basin water results in a decrease of overnight productivity of the still.
- The total productivity of still without LHTESS is slightly higher than the still with LHTESS (phase change material) in typical sunny days. The still with LHTESS causes enhancement of still productivity especially during night periods.
- The results showed that days of increased distilled output are approximately nearer to the corresponding day of average maximum solar intensity.
- The performance of still is also depends upon the wind speed, ambient temperature, water temperature, etc.
- The difficulties with salt hydrates as a phase change material is their corrosiveness and the cycling stability, which can often only be guaranted if certain conditions are met.
- Salt hydrated phase change material creates severe corrosion effect with collector base material such that aluminium, copper, galvanized iron.
- The inorganic phase change material gives better results of productivity in solar stills due to its better thermal conductivity and specific heat than paraffin wax.

Preliminary tests on the distilled water proved that the distilled water is suitable for domestic usages

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