**Water solar distiller productivity enhancement using solar collector and phase change material (PCM)**

Prof. Dr. Abbas Sahi Shareef¹, Dr. Farhan Lafta Rashid², Hasan Fathi Alwan³

University of Kerbala, College of Engineering

¹E-Mail: abbasmarem@yahoo.com
²E-Mail: engfarhan71@gmail.com
³E-Mail: hassan.fathy130@gmail.com

**Abstract.** This paper examines the use of a solar still associated with a solar collector, and phase change materials, in improving productivity in solar distillation. We contrasted productivity from a solar still associated with a solar collector both with and without PCMs, and explored relevant issues around design and installation. Experiments were conducted at an east–west orientation in Karbala at the end of October and beginning of November. Polyvinyl pyrrolidone (PVP K-30), polyethylene glycol (PEG 6000) and carboxymethyl cellulose sodium salt (CMC ), were used for their chemical properties as latent heat energy storage. The hourly output rose little where the solar distillation was coupled with solar collector but without LHTESS, through sunny days. There was an increase of about 30%–50% in freshwater output for LHTESS than was the case without. As daylight progressed the pure water created by the solar still increased. A solar still with solar collector for LHTESS is found to be increased according to the type of additive used. Water temperature was measured in a specified period. We studied the use of a solar still associated with solar collector both with and without PCM as thermal storage. The system run time was increased with the addition of PCM. System productivity and system efficiency also increased, by about 120 % and 40% respectively.

**Keywords:** Phase change materials, solar still, flat plate collector, thermal energy storage, water distillation.

**Introduction**

An increasing human need for pure drinking water, and associated lack of supply, has led to the development of technologies for better production and supply of clean water. The water crisis is particularly acute in developing countries, due largely to population growth and industrial expansion and demand. Industrial activity has also
increased water pollution in such places. Rivers and lakes have become an outlet and dumping places for household and industrial wastes. According to reports [WHO 2014], there are now approximately 748 million people around the world suffering from a lack of clean drinking water.

Current technologies produce safe pure water, but are costly in terms of energy. Pure water is essential in most household applications, and many within industry. In some remote areas, current technologies fail due to a lack of electricity. Therefore, if energy can be efficiently provided at a large scale, it will help to meet the rising demand for drinkable water.

The solar still is a solar distillation unit. It is manufactured with a double basin, all upper sides covered and with glass forming a pyramid [1]. With a solar still, drinking water can be made from polluted water by utilizing the sun as a source of thermal energy. The solar still can be easily manufactured and designed using low-cost materials such as aluminum and glass. Presently, a solar still is one of the most important devices used in distillation and desalination applications. However, its use is limited by the leakage of water vapors where the glazed lid joins the solar still basin and lack of efficiency is a key reason for the limited use of solar stills.

Clearly, research in this field can be highly beneficial. Some have studied solar still production by adding phase change materials (PCM) and using a solar collector along with the solar still, to obtain an increase in distilled water production and thereby to increase the efficiency of the solar still. In the solar distillation process, the progress of solar thermal energy through from the glass cover to the solar still basin is the driving force for the distillation process and its relationship to the production of distilled water is not monolithic; the solar thermal energy used in water evaporation does not come directly from the produced water, but is recovered by the intensification of water within the solar still, where a traditional solar still’s efficiency is improved by adding phase change material [2].

By use of a thin layer of PCM down the basin underlay, a large amount from heat can be stored in that PCM throughout the hours of sunshine, rather than being lost to the surroundings. The stored thermal heat energy can keep the basin water at a temperature sufficient to manufacture pure water during the night. This has been found to improve the productivity of water, especially during the night [3]. It was found that the chosen phase change materials depend greatly on the extreme temperature of brackish water. The performance enhancement has been observed in a concentrator-coupled hemispherical basin solar still, utilizing a PCM [4]. The performance of a solar still, associated with a solar collector, utilizing three different types of PCM, has also been studied experimentally [5].

This work aims to study and evaluate the productivity of a solar still associated with a solar collector, both with and without PCMs, in the weather conditions of Karbala, Iraq.
Solar still coupled with flat plate collector

In a solar still that is couple with a solar collector, the solar collector is used to increase water temperature within the solar distillation basin. The process of recycling water using the flat plate collector and the solar still can be either natural or forced, i.e. in the process of recycling natural, flowing water because of the difference in water density, or in the process of forced recycling where a pump is used to push water through the system [6]. Scholars have found that the daily production of pure water after connecting the flat plate collector may increase by about 24% compared to the use of a solar still alone [7].

PCMs as Storage Material

The PCM storage materials, Polyvinyl pyrrolidone (PVP K-30), polyethylene glycol (PEG 6000) and carboxymethyl cellulose sodium salt (CMC) were used for the performance study of a solar still associated with a solar collector. The PCMs were diffused at a constant thickness of 10 mm at the aluminum base. The PCM storage material can store a large amount of thermal energy and also boost the thermal capacity in the basin and PVP K-30, PEG 6000 and CMC generate useful matter for thermal storage applications. PCM materials utilizing chemical binds to store and release heat. The phase of the material changes, from solid-state to liquid, or vice versa, due to absorption of solar thermal energy. Unlike traditional thermal storage materials, when PCMs arrive at the temperature at which they change phase, they absorb greater amounts of thermal energy without becoming hotter.

When an ambient temperature is achieved by the PCM, it releases its stored latent thermal energy. PCMs absorb and issue heat while maintaining an almost stationary temperature. With a tolerance extending from 20 °C to 45 °C, the latent thermal storage materials are highly efficient and helpful for sustaining the daytime temperature at night.

Experimental Work

The photographic and schematic diagram illustrating the setup for this study is shown in Figures 1 and 2, respectively. The solar distillation basin is made from 1.1 mm thick stainless steel sheets with a length of 1.23 m, an active area of 1.23 m², and width 0.98 m. The solar distillation basin goes inside the PCM basin made of stainless steel, which has the same specifications of the distillation basin, but with greater dimensions in terms of width (1 m), and length (1.25 m). The solar distillation basin is isolated from the PCM basin to avoid mixing water in the basin solar distillation and PCMs, and to avoid the effect of PCMs on the water productivity. The gap between the two basins is filled with 18 liters of PCM.

The second stage was the manufacture of the upper part of the solar still, which consists of transparent glass with a thickness of 6 mm with a slope on the four sides at the angle of 32°. Glass wool is used with a thickness of 5 cm, to isolate the solar
distillation basin from the bottom and the four sides and then it has been placed in a wooden box to increase thermal insulation and reduce the loss of energy. A channel is placed along the perimeter of the upper edge of the solar still basin to direct the resulting water, and send it to an external graded vessel there the water product is measured. A floater is fixed inside the basin, to maintain the water level at a constant 6 cm. Thermocouples of type-K are used in measuring temperatures and are installed at different places in the solar still and solar collector.

Figure(1). Schematic of solar still coupled with a flat plate collector
Figure. (2): Photographic views of the solar still associated with solar collector

**Principle of Solar Desalination**

The solar still basin has a thin water stratum, with a translucent glass cover on top of the water and the basin conduit. The sun’s rays traverse the glass cover surface to saline water within the solar still or water basin, the temperature of which is through the solar radiation that passes into a glass cover surface and is absorbed via the undermost basin solar still.

In a solar still, the temperature variation between the surface (glass) cover and water is the driving force for the production of fresh water. Vapor flows upwards from the hot surface water in the basin, and forms condensate on the inside of the surface glass lid. This condensate, distillate water is then gathered through the channel. When a solar still is associated with solar collector, the temperature of the water entering the solar distillation will be higher, thus increasing the evaporation rate and increasing the distillation of the solar distillate, compared to a solar still operating without a solar collector.

**Measurement Devices**

For measurement purposes we used a solar power meter (TES-1333) to measure the direct solar radiation, an SD card data logger of 12 channels, and a graduated vessel. The graduated vessel was used to measure the volume of fresh water distilled from the basin solar still. Thermocouples of type-K were used to measure temperature inside and outside the surface glass cover, ambient and vapor temperatures.

**Results and Discussion**

Our experiments were conducted outdoors, using a single basin associated with a solar collector, both with and without PCM at various ratios from 8.00 am to 22.00 mm. During the day the maximum intensity of solar irradiation and the temperature of water, glass, the basin and ambient temperature per one-hour time interval were measured.

The production of solar distillation is dependent on the prevailing solar radiation. The Figure 3 shows the differences in solar irradiation influx with time. It is observed to increase with time until 1:00 pm, with the influx reaching 720 W/m2. Solar radiation increased during the morning until the afternoon, when at 1:00 pm it began to taper off.
Figures 4 indicates the differences in water temperature with time when using different mass flow rates (1, 2, 3 L/m respectively). It is obvious that the highest water temperature is achieved using the mass flow rate 1 L/m.
Figures 5 and 6 indicate the difference in water temperature and basin temperature with time, respectively. Both temperatures are observed to increase and peak at 53°C.

Figure (5): variance water basin temperature with time

Figure (6): variance of basin temperature with time

Figure 7 shows water vapor temperature during the operating period of the solar still associated with a solar collector, with and without PCM. Clearly, water vapor
temperature increases with increasing solar intensity and using a flat plate collector, with and without phase change material variation, the maximum value is achieved between 12:00 to 3:00 pm. This indicates that the amount of water evaporated at this time period is the greatest value.

Figures 8 and 9 present the quotidian variation the internal and external temperatures of the of glass, respectively. It is important to have a difference of temperature between the inside and outside of a solar distiller, to achieve the greenhouse phenomenon required as a driving force for fresh water production. It is observed that the variation between the external and internal glass cover temperatures was 5 to 11 °C at the peak (12:00 to 2:00 pm), and this was due to wind on the external surface of the glass cover, which reduces the temperature at this point.
Figure (9): variance of glass cover outside temperature with time
Figure 10 shows the PCM temperature during the operating period of the solar still associated with a solar collector. We see that PCM temperature increases with increasing solar intensity, reaching the maximum at 2:00 to 3:00 pm. The PCM temperature was increased with increasing PEG concentration, and the largest value occurred with 18 gm of PVP and 12 gm of PEG.

Figure 11 shows the differences in daily distillate output of the solar still associated with solar collector, both with and without various PCMs. Over the full range of time, the distillate output from the solar still associated with solar collector with PCMs is greater than that achieved without PCMs. The addition of PCMs is associated with an increase in distillate output between 40% and 120%. This is because when using PCM, the system’s working time increased from 3 to 5 hrs. Moreover, PCM increases the thermal resistance to heat loss.

Figure 12 presents the relation between the hourly overall thermal efficiency and the tested time. The system’s efficiency is associate with the PCM type used in testing and with solar intensity. It achieved its top value at 5:00 pm. At this hour, PCM
distillers showed the topmost efficiencies particularly with (PVP+CMC). With regard to this distiller, an average extreme efficiency realized was 35.5% for the tested period.

![Graph](image.png)

**Fig. (12): The overall thermal efficiency variation with time**

**Conclusions**

In the current study we focused on the design and build of an effective solar still, associated with a solar collector. Production of pure water from a solar still is, given its accessibility, one of the better ways to secure safe water, especially in the absence of technical equipment. In our experimental study, the mixing of Polyvinylpyrrolidone (PVP K-30), and carboxymethyl cellulose sodium salt (CMC) in water gave the best yield when compared with that from Polyvinyl pyrrolidone (PVP K-30) only or Polyvinyl pyrrolidone (PVP K-30) and polyethylene glycol (PEG 6000) utilized as phase change materials. This may be due to higher heat storage and because the melting point temperature is higher than that of polyethylene glycol (PEG 6000).

1. It has been proved that the output from the solar still associated with a solar collector system can be greatly enhanced via the use of phase change materials. The distillate output from the solar still with PCM is increased by about 40 to 120%.
2. Using PCM increases the system working time by 3 to 5 hrs.
3. The properties of PCM can enhance still productivity.
4. The use of a flat plate collector can enhance still productivity.
5. PCM decreased the total heat lost from the still.
6. In the present study, mixing carboxymethyl cellulose sodium salt (CMC) with Polyvinyl pyrrolidone (PVP K-30) is considered the best PCM, with which maximum solar still productivity was obtained and maximum heat storage period achieved in this test.

References
[1] B.I. Ismail, (2009) Design and performance of a transportable hemispherical solar still Renew. Energy 34, 145–150.

[2] Sagar Suresh Agrawal, (2015) Distillation of water using solar energy with phase change materials International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622

[3] Demirbas, F. (2006), Thermal Energy Storage and Phase Change Material: An Overview Part B, 1: pp.85-95. London: Taylor & Francis.

[4] Arunkumar T. D. Denkenberger, A. Ahsan, R. Jayaprakash (2013), The augmentation of distillate yield by using concentrator coupled solar still with phase change material, Desalination, 314, pp.189-192.

[5] Gugulothu R., N.S. Somanchi, D. Vilasagarapu, H.B. Banoth (2015), Solar water distillation using three different phase change materials, Materials Today: Proceedings, 2, pp.1868-1875.

[6] Rai SN, Tiwari GN. (1983), Single basin solar still coupled with flat plate collector, Energy Conversion and Management ; 23(3):145–9.

[7] Rai SN, Dutt DK, Tiwari GN.(1990), Some experimental studies of single basin solar still, Energy Conversion and Management; 30(2):149–53.