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# Observational study of modified solar still coupled with oil serpentine loop from cylindrical parabolic concentrator and phase changing material under basin

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ABSTRACT

The performance of a cylindrical parabolic concentrator with focal pipe - coupled with a developed solar still with (oil heat exchanger, Phase Change Material (PCM)) have been experimentally investigated to improve the freshwater productivity. The cylindrical parabolic concentrator with focal pipe and oil heat exchanger (serpentine loop) represent the external heat source to increase the temperatures of the basin water and PCM. The PCM used as a heat storage medium. The influences of high heat exchanger oil temperature on the performance of the developed solar still are experimental investigated. A comparison between a developed solar still and the convenstional solar still is carried out to evaluate the enhancement in the freshwater productivity under the same ambient conditions. The experimental results indicated that, the freshwater productivity approximately reached 10.77 L/m$^2$ day for the developed solar still, while its value is recorded 4.48 L/m$^2$ day for conventional solar still. The freshwater productivity of the developed solar still is 140.4% higher than that of the conventional solar still in average. Also, the daily efficiency approximately reached 25.73% for the developed solar still, while its value is recorded 46% for conventional solar still. The percentage decrease in the daily efficiency for the developed solar still about 44% compared to the convenstional solar still in average. In the present experimental work the estimated cost of one liter of freshwater productivity reaches approximately 0.1359 LE (0.0174 $) and 0.1378 LE (0.0177 $) for developed solar still and conventional solar still, respectively. This results is obtained during the period from June to August 2015 under the Egyptian conditions.



## 1. Introduction

The availability of freshwater on the earth's surface is decreasing day by day, due to the continued increase in population density and rapid development in the industry. Therefore, it was necessary to use solar energy in the desalination of sea water to overcome this problem. Solar stills represent a good option and a simple technique compared to the other distillation methods.

The main problem encountered with the solar stills are the low productivity of freshwater, and that is within the limits 2.5–5 L/m$^2$ day. The basin water depth is important factor affecting on the productivity of the solar stills. Phadatare and Verma (2007) studied the behavior of a single basin solar still at different water depth. This study showed that, the freshwater productivity of the solar still decrease with the increase in the basin water depth. Tripathi and Tiwari (2005) experimentally studied the impacts of water depths on the productivity for passive and active solar stills. This study showed that, the convective heat transfer coefficient between the inner glass cover and basin water depends on the water depth. After the sunset the productivity increases for increase the water depths. Rajamanickam and Ragupathy (2012) studied the effect of water depths on the productivity for a double slope and a single slope solar stills. This study showed that, the productivity of the still decreases with increase the basin water depth. Khalifa and Ahmad Hamood (2009) experimentally studied the impacts of water depths on the freshwater productivity of still. This study showed that, the still productivity decreased by 48% for increase the water depth from 1 to 10 cm. Tiwari and Tiwari (2006) experimentally studied the effects of water depths on the evaporative mass transfer coefficient for a passive single-slope solar still. Tiwari and Tiwari (2007) studied the effects of water depths on the productivity for a single slope passive solar still. They found

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that, increasing the water depth decreases the still productivity up to depths of about 10 cm but at greater depths than this the productivity becomes almost constant.

The water evaporation rate depends on the free area of saline water in basin still. Abu-Hijileh Bassam and Rababa'h Himzeh (2003) use the sponge cubes in the basin water to increase the free area of the saline water, their results showed an improvement in the distillate water productivity. Velmurugan et al. (2008a,b, 2009) found that, the use of the sponges in a single basin still and stepped still improved the productivity by 15.3%.

The freshwater productivity of solar still depends on the temperature difference between basin water and glass cover. Abdel-Rehim and Lasheen (2007) studied the performance of modified solar stills includes a solar energy concentrator. This study showed that, the productivity of modified system is 18% higher than that of conventional solar still. Sanjay and Sinha (1996) experimentally studied the behavior of a double slope solar still integrated with cylindrical parabolic concentrator. This study showed that, a double slope solar still integrated with cylindrical parabolic concentrator gives the maximum productivity at all basin water depth, the rate of increase was about 94% higher than that of conventional solar still in average. The performance of the solar still integrated with flate plate solar collector have been conducted by Tiwari et al. (2009), Lawrence and Tiwari (1990), Yadav (1991), Tiris et al. (1998). These studies showed that, the distillate water productivity of the solar still integrated with flate plate solar collector is higher than that of a conventional solar still. Singh et al. (2016) experimentally studied the performance of active solar still integrated with two hybrid PVT collectors. Jahangiri Mamouri et al. (2014) experimentally evaluated the performance of a single basin solar still with evacuated tube collectors and achieved the efficiency of 22.9%. They also found the optimum depth of water as the length of the heat pipe condenser. Kargar Sharif Abad et al. (2013) used flat plate collectors and pulsating heat pipes in conjunction with the solar still and achieved the maximum yield of 0.875 L/m$^2$ h. Feilizadeh et al. (2015) studied the effect of the number of flat collectors on multi-stage solar stills. This study showed that, in the summer, 48% and 23% more productivity were obtained by adding the second and third collector, respectively.

Singh et al. (2001) experimentally studied the productivity of a double slope active solar still and photovoltaic integrated flat plate collector. This study showed that, the production rate has been accelerated to 1.4 times than the single slope active solar still and photovoltaic. Dev and Tiwari (2012) experimentally studied the productivity of an evacuated tubular collector integrated solar still. This study showed that, the daily productivity of an evacuated tubular collector integrated solar still higher than that of a single slope solar still. Singh et al. (2012) numerically and experimentally studied the performance of a double slope active solar still with two flat plate collectors connected to the basin of solar still. Singh et al. (2013) numerically studied the performance of a solar still integrated with evacuated tube collector in natural mode. The results show that, the overall energy and exergy efficiencies has been found to be in the range of 5.1–54.4% and 0.15–8.25% respectively at 0.03 m water depth. Kumar et al. (2014) numerically studied the productivity of a single slope solar still integrated with an evacuated tube collector. This study showed that, the optimum daily productivity has been obtained as 3.9 kg with energy and exergy efficiencies as 33.8% and 2.6% respectively. Tiwari et al. (2015) presented an exergoeconomic and enviroeconomic analyses of partially covered photovoltaic thermal flat plate collector integrated solar stills.

Abdel-Rehim and Lasheen (2005) studied the effect of packed layer and rotating shaft installed close to the basin water surface on the productivity of modified solar stills. This study showed that, the productivity of modified solar still using packed layer as simple thermal storage system was increased from 5% to 7.5%, while it was increased from 2.5% to 5.5% for the modified one using rotating shaft compared to conventional still. Nafey et al. (2001) experimentally studied the effect of black rubber and black gravel materials on the productivity of a single basin sloped solar still, their results showed that the black gravel (20–30 mm size) improves the productivity by 19% and the black rubber (10 mm thick) improves the productivity by 20%. Naim and El Kawi (2003) studied the effect of charcoal particles on the productivity of the solar still. Different factors such as size range of charcoal particles, brine flow rate, and still inclination to the horizontal have been investigated.

Also, the phase change materials used to enhance the freshwater productivity of solar still. Many researchers (El-Sebaii et al., 2009; Radhawan, 2004) studied the impact of the PCM on the productivity of a basin still and stepped still, respectively. Dashtban and Tabrizi (2011) studied the effect of the PCM on the performance of cascade solar still. Arunkumar et al.(2013)studied the effect of PCM on the productivity of the concentrator-coupled hemispherical basin still. The results show that, the freshwater productivity with PCM is 26% higher than that without PCM. Kabeel and Abdelgaied (2016) experimentally studied the effect of PCM on the performance of a solar still, their results showed that the daily freshwater productivity for solar still with PCM is 67.18% higher than that of the conventional solar still. Kabeel et al. (2016) experimentally studied the performance of a double passes solar air collector–coupled modified solar still with PCM, their results showed that the daily productivity for a double passes solar air collector–coupled modified solar still with PCMis 108% higher than that of the conventional still.

Due to the low freshwater productivity of the solar stills, these studies aims to improve the productivity of the solar still, by using a cylindrical parabolic concentrator with focal pipe - coupled with a developed solar still with (oil heat exchanger, Phase Change Material (PCM)). Oil is flowing in a closed cycle through the heat exchanger and focal pipe by using small pump. The PCM that acts as latent and sensible heat storage system. The PCM used in the present work is the Paraffin wax because of wide availability and low cost. The basin water in the developed solar still is heated directly by solar radiation absorbed by absorber plate and also, by the high oil temperature flow through the heat exchanger. The effect of high oil temperature on the performance of developed solar still are experimentally investigated. A comparison between a developed solar still and the convenstional solar still is carried out to evaluate the enhancement in the freshwater productivity under the same ambient conditions.

## 2. Experimental work

In the present experimental work, two solar stills were designed, fabricated and constructed to compare the freshwater productivity of the solar desalination. The present experimental work was carried out in Faculty of Engineering-Tanta University, Egypt (Latitude 30.47°N and longitude 31°E) in the period from June to August 2015. The experimental measurements were carried out from 6:00 am to 10:00 pm. One of them is a developed solar still with (oil heat exchanger, Phase Change Material (PCM)) - integrated with a cylindrical parabolic concentrator with focal pipe and the other is the conventional solar still as shown in Figs. 1 and 2. Fig. 1 shows the schematic diagram of the present exprimental work. In addition, Fig. 2 shows a photo of the present exprimental work.

As shown in Fig. 1, a conventional solar still has a basin area of 0.72 m$^2$ (0.6 m × 1.2 m). The basin still made from a galvanized iron sheet of 1.5 mm thick. The elevations of low-side wall and the high-side wall have been kept at 0.12 m and 0.47 m,