Experimental Study on Modified Solar Still Using Convex Lenses on The Glass Cover and Radiating Surfaces Inside

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Abstract:

There is a problem of potable water shortage in many parts of the world nowadays. For many developing countries, desalination using solar energy is the solution to overcome this issue. This paper investigates the performance of a solar still using the convex lenses on the glass cover, and radiating surfaces below the lens to increase the solar radiation inside the solar still. The results of this study indicated that using a convex lens and radiating surfaces can significantly increase the daily productivity and the efficiency of the single basin solar still. Experiments were carried out *during March 29 to June 6, 2016, at Sabratha Engineering College, Libya. The amount of distilled water was measured starting from 10 A.M to 4 P.M each day. The results showed that the maximum daily productivity of the new still with a convex lens and radiating surfaces was 2.248 liter/day which is higher by 15% compared with the conventional still at the same operating conditions. While the daily efficiency of the modified still was found to be 63.64% at 4:00 PM on May 26, 2016.*

Keywords: *Solar still; productivity; solar radiation; convex lens*

1.0 Introduction:

The drinking water shortage is one of the biggest problems in developing countries. It is known that the fresh water represents only 3% of water on the earth. Only 1% is available for human use, and the rest is polar ice[1]. Nowadays the industrial effluents and sewage disposal resulted in pollution in rivers and lakes which led to a scarcity of fresh water in many big cities around the world. Sea water is the only available source for a large amount of water, but it contains high salinity, so it needs to desalination. Desalination methods use a large amount of energy to remove a portion of pure water from a salt-water source.

Solar stills are widely used in solar desalination. The single-slope solar still is the most popular due to its simple design, lower cost, better performance, and easy in operational and constructional procedures when compared to other types of solar stills but has low productivity per unit area. Different experimental and theoretical investigations were conducted by many researchers on the single basin solar still to increase the productivity[2], [3]. During last decades, many researchers around the world presented a lot of mathematical modeling, theoretical analysis, and computer simulation of different designs of solar stills in some articles[4][6]. They also tested a number of designs and modifications to the conventional solar still. Many researchers studied the design and operational factors affecting the solar still productivity such as glass cover cooling[7], glass cover inclination[8], basin insulation, basin water depth[9], [10], and absorbing materials[11], [12]. Other researchers studied the effect of local factors such as solar radiation[13], ambient temperature[14], wind velocity[15], on the productivity of the solar still.

To increase the heat transfer rate inside the solar still, many researchers used fins inside the still basin[16],[17]. Adding fins in the basin of a conventional single basin still decreased the preheating time required for evaporating the still basin water. Using fins in the solar still also increase the area of the absorber plate. Hence, absorber plate temperature and saline water temperature increased. As the temperature difference between water and glass increases, productivity increases. Velmurugan et al. designed and tested an experimental setup of solar stills with fin and concluded that the temperature difference between water and glass increases if fins were used and in turn average daily productivity increases. They found that the productivity is increased by 45.5% [16]. Velmurugan et al. [18] found that when using fin type solar still with black rubber, sand, or sponge immersed in the basin water, the productivity was increased by 58% to 70%. Adding sponge cubes in the basin greatly enhance the productivity of the single basin solar still. This method will increase the brine free surface and the evaporation rate. Bassam Abu-Hijileh et al. [19] reported that the increase in distillate production reaches 273% compared with the still without sponge cubes under the same condition.

Another promising method for increasing the productivity of the single basin solar is to increase the radiation intensity and, hence the temperature inside the still. This is done by using Fresnel lens concentrated solar power technology or convex lens integrated on the glass cover of the solar still. Fresnel lens is invented firstly in 1822 by a French mathematician and physicist, Augustin Jean Fresnel[20]. The working Principle of the lens is based on the law of refraction according to which a light ray travels in a straight path in a homogeneous transparent medium, but when it passes through the interface of a transparent medium having different density; it gets deviated from its original path at the interface. When a light beam enters from a rarer medium to denser medium, it refracts towards the normal. However, when the light beam enters from denser medium to rarer medium, it refracts away from the normal due to change in velocity of light in a different medium as resistance offered by the medium also changes. Fresnel lens is modified from the conventional lens, in which the contour profile of the conventional lens is maintained and undesired material removed, thus absorption losses and material requirement reduced substantially[21].

A Convex Lens is characterized by that all incoming rays that are parallel to the principal axis of the lens converging to a single point on the other side of the lens called the focal point of the lens. Its distance from the lens is called the focal length of the lens. There are limited previous works [22] done on the point focused solar collector system by using the convex lens for thermal applications. Chirag Rabadia[23] presented various factors influencing the productivity of the solar stills such as area of absorption, material of absorber, cooling of cover, minimum depth of brine, water–glass cover temperature difference, inlet water temperature, vacuum technology. S. A. El-Agouz[24] presented a comparison between modified solar still with a convex lens on the glass cover and conventional solar still to evaluate the enhanced performance system under the same climate conditions. The results indicated that the productivity of the modified still with the convex lens is higher by 26.64% than that for conventional still at water mass of 30 kg. On the other hand, a convex lens and black stone is higher than that for conventional solar still by 35.55 % at the same water mass [24]. This paper investigates a modification to the conventional solar still by using 12 convex lenses on glass cover and radiating surfaces at the foci of lenses, to collect the solar radiation and increase the temperature difference between the glass cover and surface of basin water. The effect of modified solar still using convex lenses and radiating surfaces on the daily distillate productivity and still efficiency is investigated.

2.0 Experimental Procedure:

The experimental work is done under local climate conditions of Sabratha City in Libya (latitude 32.8° N, longitude 12.5°E) at the roof of Environmental Engineering department an open area from 29th March 2016 to 6th June 2016. The readings are taken from 10:00 AM to 4:00 PM. The solar still have an effective horizontal surface area of 1 m^2. The basin liners are covered with black rubber and black stone to improve the solar energy absorption. The glass cover is mounted at an inclination angle of 30° to ensure that condensate on its inner surface will flow down the glass cover into the condensate-collecting channel. Silicon rubber is used to prevent leakage from any gap between the glass cover and the still box. The solar still box is made of fiberglass to prevent corrosion and reduce heat losses from the wall sides and the bottom of the basin. A photograph of the experimental setup for the glass cover with convex lenses and radiating surfaces are shown in figure 1 and figure 2 respectively.

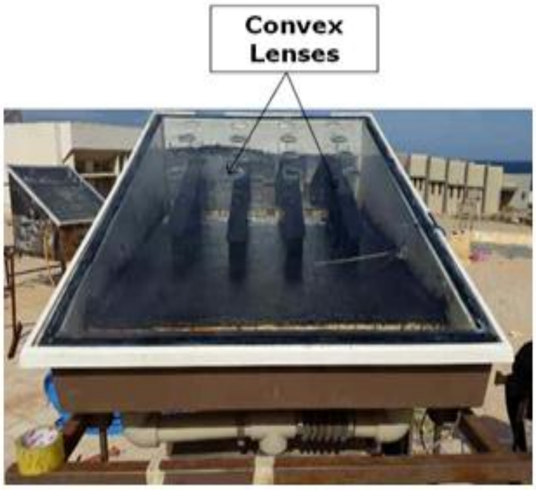

Figure 1: Modified solar still with Radiating Surfaces inside the basin

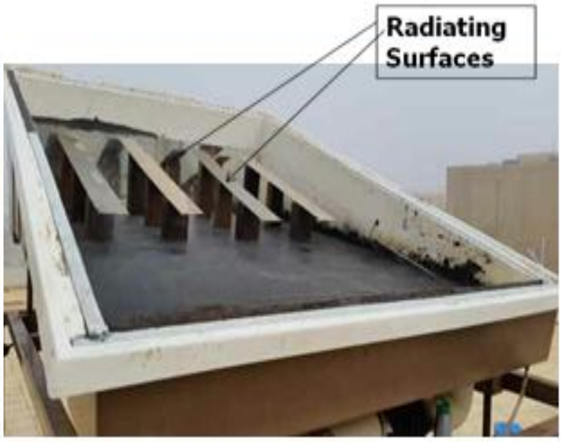

Figure 2: Modified solar still with radiating surface and convex lenses on the cover glass

The temperatures of inlet and outlet seawater, inner and outer glass cover, radiating surfaces, inner spaces of the still and ambient are measured continuously every 15 minutes by copper–constantan thermocouples with an accuracy of ±0.1 °C using a data logger. A Kipp-Zonen pyranometer with an accuracy of 3% is used for measurement of solar irradiance manually every 15 minutes. The distilled water is collected and measured on an hourly basis using a calibrated flask provided below the basin. The wind velocity is measured by using anemometer TM-401 with an accuracy of ± 0.1 m/s.

3.0 Results and Discussion:

The variation of the solar radiation (I), the ambient temperature (T_{amb}), the basin temperature at upper side (T_{bu}), the basin temperature at lower side (T_{bl}), the upper glass temperature (T_{gu}), the Lower glass temperature (T_{gl}), the brine inlet temperature (T_{win}), the brine outlet temperature (T_{wou}), the temperature of the radiating surface (T_{rsur}) and the Temperature of the vapor inside the still (T_{vap}) on 4^{th} of June 2016 are shown in figure 3. It is noticed that all temperatures increase as the time increase till they reach their maximum values at noon, then they start to decrease after that. The reason is that solar radiation intensity increases in the morning and its reaches its maximum value at the noon, then it starts to decrease by the afternoon, and it is dependent on the wind velocity. The variation of ambient temperature is between 26–29 °C and solar radiation received during the study is between 708–998 W/m^2. The convex lenses concentrate the solar radiation at their focii on the surface of the radiating plate, and this increases the water temperature and decreases the glass cover temperature. Thus the temperature difference between the water and glass increases.

The productivity of the modified solar stills on an accumulative hourly basis for different days is presented in figure 4. The results showed that the productivity of the modified still with lenses and radiating surface starts from zero in the morning when the experiment is started, then it increases gradually as the solar radiation starts to increase

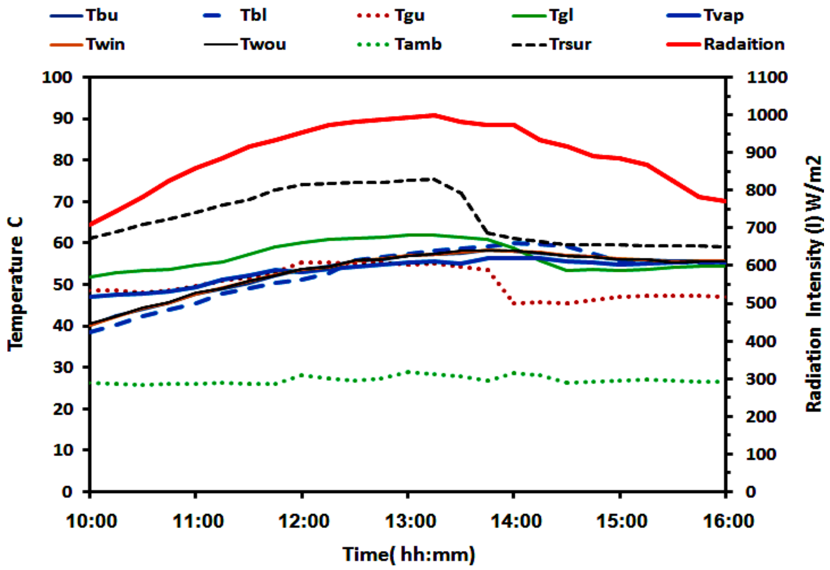

Figure 3: Hourly variation of the solar radiation and temperature of the modified solar still on June 4, 2016

This increase in the solar radiation results will increase the water evaporation and condensation due to the temperature difference between the water and the glass cover. The results indicated that the highest daily productivity for modified and conventional solar stills is 2.228 liter/day and 2.216 liter/day on 24th and 26th of June 2016 respectively.

The efficiency of the modified solar stills on an hourly basis for different days is shown in Figure5. The hourly and daily efficiencies are calculated from the following relation:

$$\eta_h = \frac{M_{w,h} * L_{w,av} / 3600}{\left(A_b * I + P_{pump}\right)} \qquad (1)$$

$$\eta_d = \frac{M_{w,d} * L_{w,av} / 3600}{\sum_{1}^{n}\left(A_b * I + P_{pump}\right)} \qquad (2)$$

Where (η_h) and (η_d) are the hourly and the daily efficiency respectively. $(M_{w,h})$ and $(M_{w,d})$ are the hourly and the daily productivity respectively in (kg/hr). (A_b) is the basin area $(1.0\,m^2)$. (P_{pump}) is the power of pump in (W). (I) is the incident solar radiation on the horizontal surface in (W/m^2). n is the number of effective running hours. $(L_{w,av})$ is the average of the latent heat of vaporization of water in (J/kg). $L_{w,av}$ depends on the basin water temperature (T_w) by the following correlation:

$$L_{w,av} = 10^3 * \left(2501.9 - 2.40706T_w + 1.192217T_w^2 - 1.5863*10^{-5}\,T_w^3\right) \qquad (3)$$

It is noticed that the efficiency of the modified solar still depends mainly on the productivity which depends on the solar radiation and the convex lens and the radiation surfaces. The highest value obtained for the efficiency is 63.64% on 26th May 2016. The productivity of 24th of May is higher than that of 26th because the solar radiation in 24th is higher, while the efficiency of 24th of May is lower than that of 26th because the efficiency is inversely proportional to the solar intensity according to equation 2

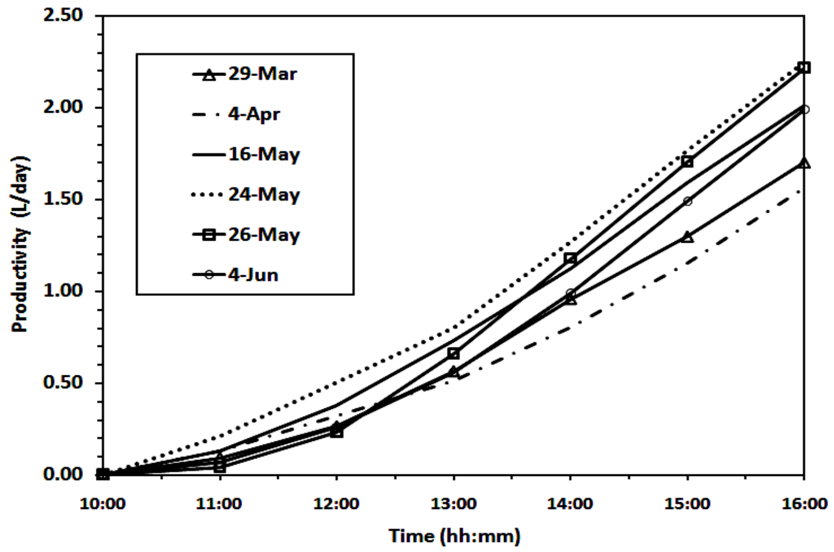

Figure 4: The productivity of the modified solar stills on hourly basis for different days

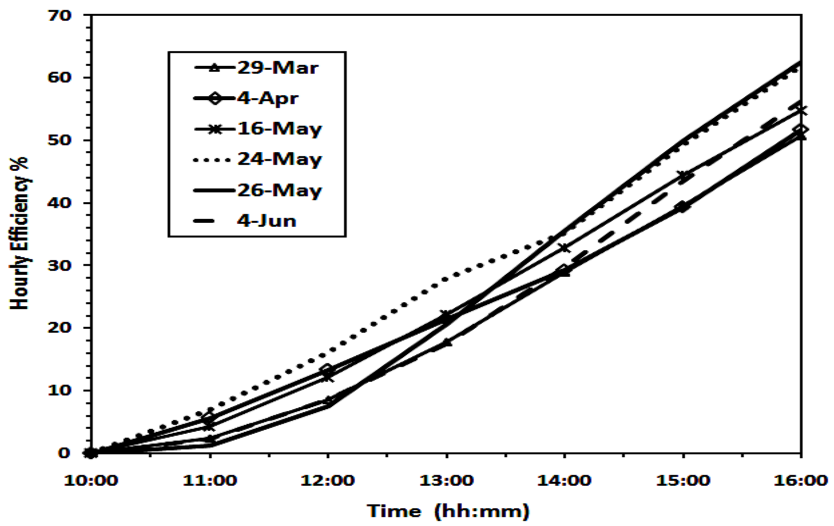

Figure 5: The efficiency of the modified solar stills on hourly basis for different days

4.0 Conclusion

In the this study, the performance of the modified solar still using lenses and the radiating surface is investigated experimentally. The performance is expressed in terms of the maximum productivity and efficiency gained during the experiment time. Based on the results obtained from the experimental work, the productivity of the modified still with a convex lens and radiating surface at water mass of 20 kg is 2.248 liter/day which is higher by 15% compared with the conventional still at the same operating conditions.. The maximum efficiency of the modified still with a convex lens and radiating surface is 63.64%.

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