A Solar Still Desalination System with Enhanced Productivity

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Abstract

Purpose: Increasing the productivity of solar stills has been the focus of intensive research. Many introduced developments, however, require complex components and entail notable increases in cost and land requirements. Developing a compact, productive and easy-to-operate system is a main challenge. This paper describes a sustainable modification of the solar still that significantly enhances its productivity without forsaking its basic features.

Methods: A simple amendment in the form of a slowly rotating drum is introduced allowing the formation of thin water films that evaporate rapidly and are continually renewed. The performance of this system was compared against a control without the introduced drum.

Results: Throughout the experiment, the new system gave considerably higher yield than the control with an average increase in daily productivity of 200%. Moreover, during sunshine hours, the increase in yield could surpass 6-8 times that of the control.

Conclusion: Important parameters such as ease of handling, material availability, efficacy, low cost, safe water quality and space conservation are maintained. One side-benefit of this design is solving stagnation problems that usually develop in conventional stills. The new simple modification in this study presents a cost-effective and efficient design to solar stills especially in areas with abundant sunshine.

Keywords: Brine; Drum; Productivity; Solar Still

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1. Introduction

Renewable-energy-based desalination methods offer a promising solution to both water shortage and environmental pollution problems that continue to aggravate worldwide. The solar still is one such sustainable method that has been in operation for hundreds of years, especially in arid areas. In their simplest design, solar stills consist of transparently-roofed basins that are normally black-painted to maximize solar heat absorption. Brackish or seawater is placed in the basin and slowly evaporates due to heating by the sun rays. This vapor condenses as it hits the cooler cover of the still and trickles down where it is collected by separate channels as distillate. The stills can have various forms, shapes, and cover materials and their operation requires little maintenance besides regularly flushing the basin to remove accumulated salts.

The major limitations on the use of solar stills, however, include their low productivity per unit installation area compared to fuel-based desalination methods, their high initial costs per production unit, the need for large installation areas, variability of the energy source and limited experience with large-scale applications. Increasing the productivity of solar stills has therefore been the focus of intensive research. Some studies have used different heat absorbers such as gravel [1, 2], sponge cubes [3-5], rubber [6,7], glass balls [8], charcoal [9,10], dyes and inks [7, 11,12] among others [13] in order to maximize heat absorption in the still basin. Other researchers experimented with solar stills that are coupled to reflectors [14-18] that concentrate solar rays, flat-plate-collectors [19-22] to further increase the temperature of the water in the basin or to separate condensers [23-28] that are cooler than the still cover. Others used multiple-effect stills [29-36], wicks [37-39], vacuum technologies [40, 41], excess solar energy storage [42,43], humidification-dehumidification processes [44-46] and computerized sun tracking device for rotating the solar still with the movement of the sun [47]. In some cases, new designs of the solar still were employed such as utilizing a transportable hemi-spherical dome-shaped still [48], using tubular stills [49] and horizontal transparent tubes instead of basins [50]. A critical literature review of various developments in solar stills has been recently presented [51]. It was noted that many of these developments increase the productivity to a limited extent while often introducing complex or expensive components that may not match the low level of expertise and infrastructure that characterizes places with severe water stress and that lend themselves to solar stills application. The installation of solar panels as well as of collectors, ponds, condensers, sun-tracking devices and other productivity-enhancing devices also require considerable space and can entail notable increases in cost. The yield increase obtained by these additions in many cases does not justify the added drawbacks and therefore developing more compact and easy-to-operate systems with low cost increase is a main challenge.

The objective of this paper is to present a detailed description of a novel modification into the simple conventional solar still. The introduced modification was found to significantly increase the productivity of the still while maintaining its basic features and advantages such as compactness, sustainability and ease of handling. The performance of the new system is compared against that of a conventional basin solar still used as a control and experimental results for the modified solar still and the control are discussed.

2. Project Description

The basic principle in the new design is to expose a considerably larger amount of water to sunlight than that exposed in conventional stills. Increasing the evaporating surface increases the output of the solar distillation unit. Although some studies have addressed this fact by modifying solar stills to increase the evaporation area by using sponges, wicks or fins, the design introduced herein is totally different and none of the previous work used a similar concept. A partly submerged slowly-rotating hollow cylinder or drum is introduced into the still. As it rotates, a thin film of water is formed around its circumference (both the internal and external) and this film easily evaporates due to the high temperature of the drum, which is constructed of a cheap yet sustainable heat-absorbing material. Only a low rotational speed of the drum is needed and hence the required energy for this rotation can be provided by solar or wind energy. Figure 1 shows a schematic of the proposed solar still design. The performance of this system is compared against a similar one without the introduced drum. Both systems have a double-sloped or triangular cover geometry. The proposed design presents a sustainable and environmental-friendly development to the conventional solar still that notably enhances the productivity without forsaking other important parameters such as ease of handling, material availability, efficacy, low cost, safe water quality and space conservation.

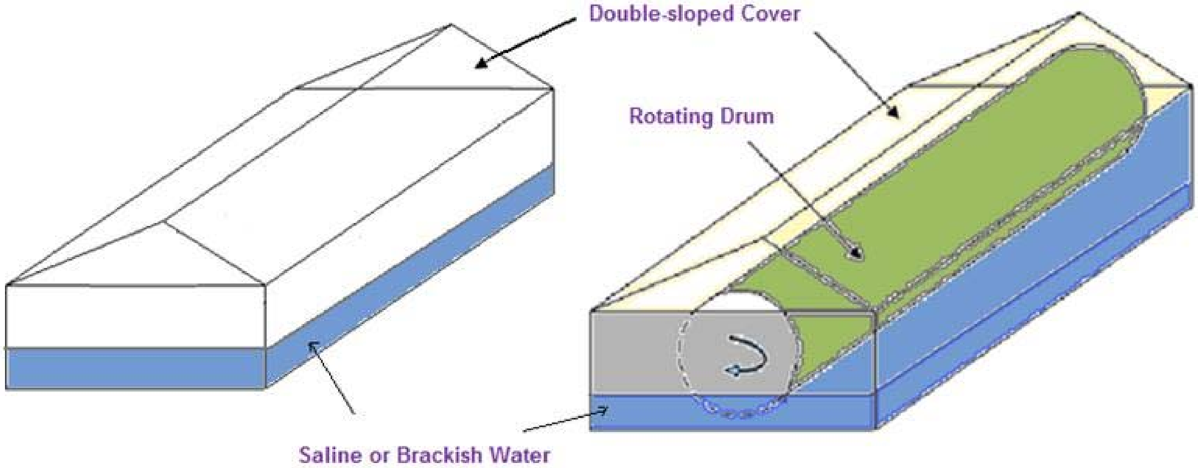

Figure 1- Conventional solar still (left) and new system (right)

3. Materials and Methods

Water basins for the stills were constructed of plywood 18 mm thickness and coated with black fiberglass material. This material has a relatively long life expectancy, is easy to handle and does not require any kind of insulation on the sides and bottom while rendering the basin leak-proof. Grooved edges were made in the wood at the sides, covered also with fiberglass, to allow for ease of placement and removal of the covers as well as provide a tight seal at the joints. The dimensions of the still basin were 0.67m x 1.5m, giving a unit squared meter of surface area for each still. Aluminum channels for distilled water collection were fixed in place to collect the condensed distillate. Photovoltaic (PV) panels were used to operate the motors on solar energy during sunshine hours. These panels were connected to storage batteries in order to operate the systems during the night. The current intensity required to run one motor was 0.1A. Aluminum sheets mill finish 3000 x 1500 x 1.0 mm for the drum (0.6 m diameter, 1.4 m length) were purchased and wrapped into cylinders that were then painted in black mat. Low-carbon steel shafts 20 mm diameter x 1.7 m length and mounted on 20 mm ball-bearings were used to install the drum within the solar still.

The still covers were made of plexi-glass that was cut into the required dimensions and assembled as shown in Figure 2. Inlets to allow for basin filling, outlets connected to the aluminum channels for distillate collection as well as outlets at the bottom of the basin for brine discharge were installed and controlled with ball-type valves. Thermocouples (Type K) were installed to measure temperature at four locations for each of the experimental stills: inside and outside cover, inside still and in the basin water. The thermocouples were attached to a board connected to a PC for continual reading of temperature. Digital scales (CPWplus) to measure the distillate water output were supplied by AdamEquipment (adamdu@adamequipment.com) and were equipped with a software that allows continual reading of the collected weights. Distillate was collected in 6-liter pyrex Erlenmeyer flasks (Figure 3). Once all equipment became available and fixed in place, experimental data collection proceeded for the relevant parameters, which included continual recording of the weather conditions, weight of collected distillate, rotational speed of the drum, water level in the still, temperatures for the inside and outside cover as well as temperatures of the ambient air inside the still cavity and for the water in the basins.

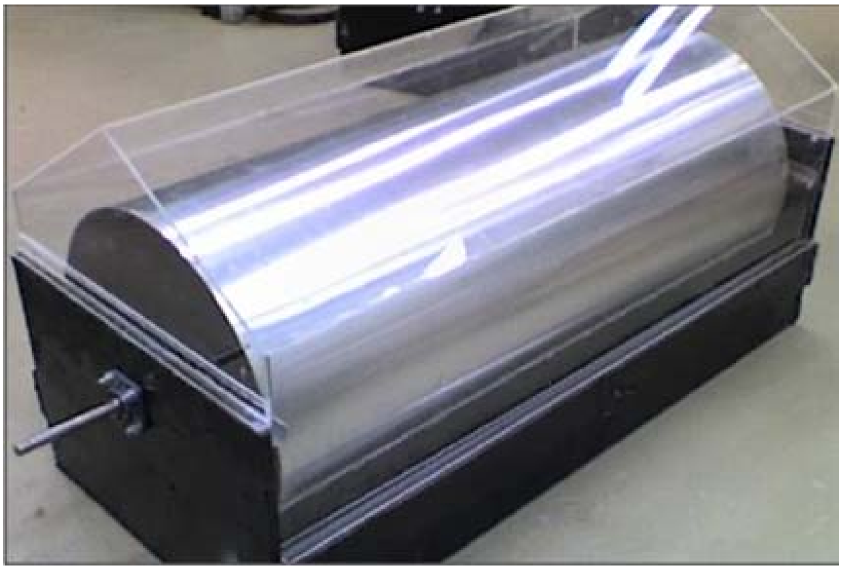

Figure 2- Modified double-sloped (triangular) solar still during construction

Figure 3- Thermocouple measuring temperature within the still (top left); Storage battery and speed control panel (bottom left); Distillate collection flask mounted on digital scale (right)

4. Performance Comparison against the Control Still

Experimental data were collected over a period of 6 months starting in May and ending in October, 2010. Throughout the experiment, the new system with the drum gave considerably higher yield than the control. Figure 4 shows sample results for the productivity of the new double-sloped (triangular) system with the drum and the conventional double-sloped system, which is used as a control. It can be observed from the graph in Figure 4 that the enhancement in productivity for a given day exceeded 200% in many cases and the percent improvement varied from month to month depending on operational and environmental parameters.

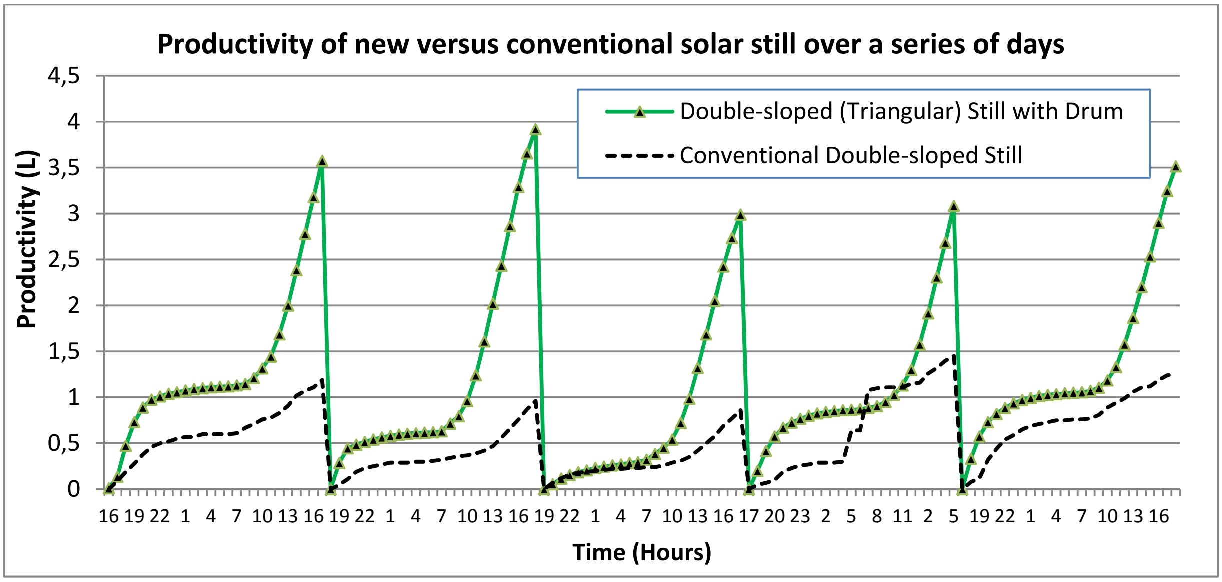

Figure 4- Productivity of new system versus the control

5. Discussion of Experimental Results

5.1 Induced productivity levels

The results shown in Figure 4 indicate that the introduction of the drum has contributed significantly to increasing the productivity of the simple solar still due to several reasons. The most important factor is having an increased surface area available for evaporation and the layer of water available for evaporation is thin relative to the much larger water depth in the basins of conventional stills. The effect of the rotating drum is double-sided as both the inner and outer surfaces of the drum (increasing the evaporation surface area from 1 m^2 for the conventional unit to 5.4 m^2 for the modified still) are available for the thin water film to form. This water is also subjected to a higher evaporation temperature than that in the basin due to the higher temperature of the drum itself, which is made of a high-heat-absorbing material and covered by a relatively thin water film and which also receives more direct sunlight due to the particular system configuration. As shown in Figure 5, even higher improvement rates than the ones shown in Figure 4 are obtained if only sunshine hours are considered.

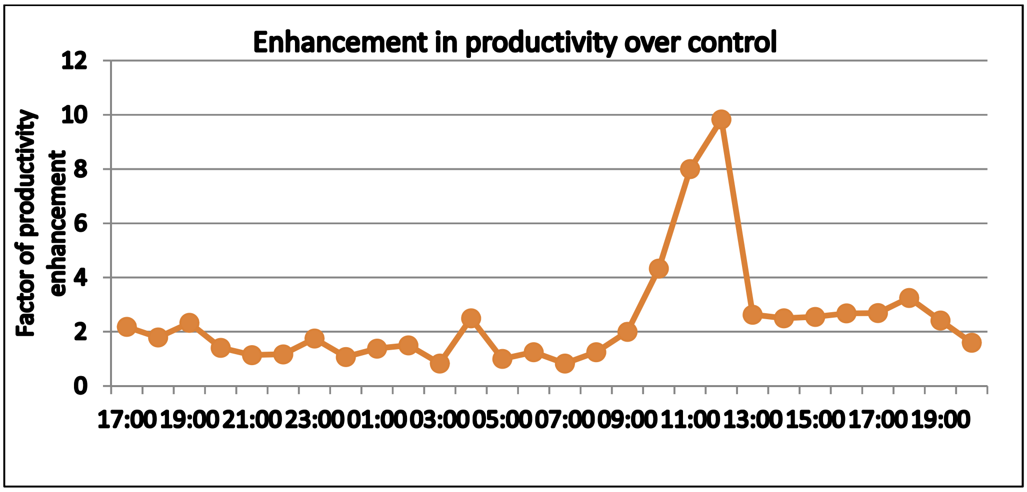

Figure 5- Variation in productivity enhancement relative to the control system in a typical day

In fact, during sunshine hours, the increase in yield could surpass 6-8 times that of the control. This leads to further energy saving by stopping night operation which contributes little to the productivity, eliminating the need for storage batteries and inducing savings in initial costs. Moreover, the significant problem of stagnation that is present in simple solar stills is now solved: No shielding layer forms at the evaporating water surface as is the case for the control shown in Figure 6. The growth of algae and other micro-flora particles on the brine surface and in the basin of simple solar stills generally reduces heat transfer to the brine [52]. The introduced drum, on the other hand, serves to continually break any clogging layers at the surface of the still water in the basin and the thin evaporating film at the drum surface is persistently renewed as it gets immersed in the basin water.

Figure 6- The shielding surface layer in the control still

5.2 Comparative productivity results

In studying the effects of important parameters influencing the performance of solar stills, Khalifa and Hamood (2009) developed four correlations for the effects of brine depth, dyes, solar radiation and cover tilt angle on productivity based on data from several studies. These correlations apply for passive stills with a galvanized iron body, an insulation thickness of 5-10 cm of polystyrene or other insulation with similar conductivity, glass cover with 5°- 45° tilt angle, 1 - 10 cm brine depth, 20°- 35° latitude angle, 50 - 100 mg/L dye concentration and under solar radiation of 8 - 30 MJ/m^2/day. In order to compare with the performance of other conventional stills reported in the literature, the correlation suggested by Khalifa and Hamood (2009), solar radiation *I* in (MJ/m^2/day) is used to calculate the productivity as follows [53]:

$$y = 0.0036I^2 + 0.0701I + 0.2475$$

where *y* is the productivity of the conventional solar still. The results obtained using this equation and applying the values of solar radiation for different months gave close results to the experimental values obtained for the productivity of the control system. These results are shown in Figure 7, which is adopted from Khalifa and Hamood (2009) and modified to include the modified solar still and the control presented in this study. It is observed from Figure 7 that the results for the conventional solar still used as a control in this study fall on the lower range of the graph, mainly due to the particular climatic and geographic conditions and also to the materials used, for example glass compared to plexi-glass covers, of the experiment conducted herein. For different weather conditions and in areas where the other studies [54-60] have been conducted, the control is expected to yield a higher productivity and accordingly the productivity of the new system would also shift upward for higher ambient temperatures and more sunshine.

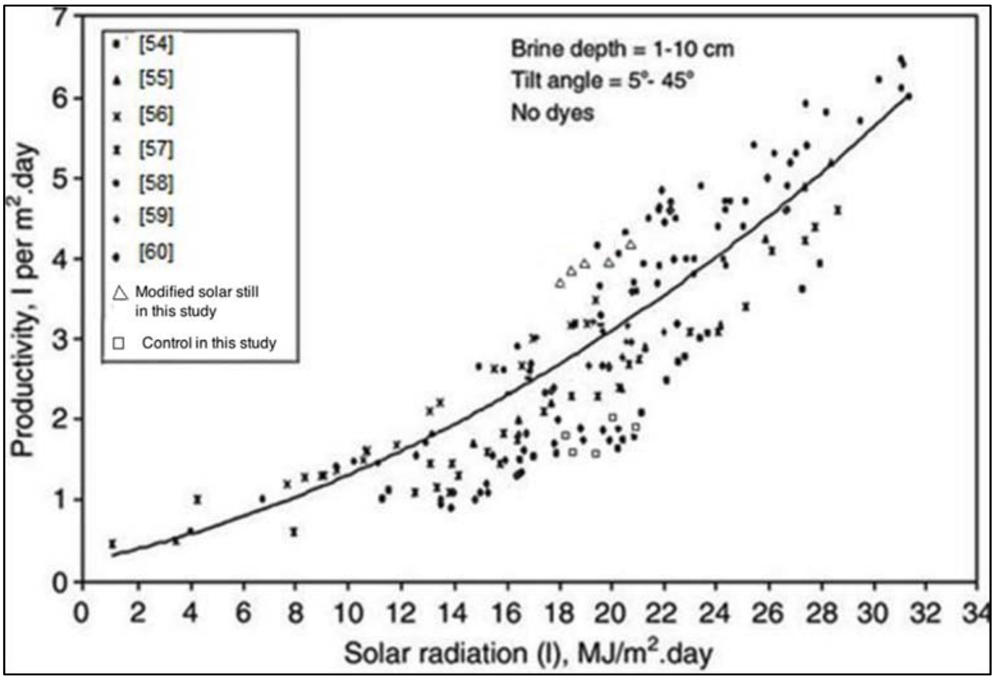

Figure 7- Benchmarking results with values in the literature (Adopted from [53])

6. Conclusion

Although enhancing the productivity of solar stills to minimize their cost has been the subject of extensive research, the success rate of many such endeavors is limited. It is crucial in enhancing the system performance to maintain its basic advantages of ease of construction, maintenance and operation, simplicity and adaptability to low-tech regions. Many proposed developments in the literature enhance the still performance and productivity but only to a limited extent whereas a greater enhancement often comes at the expense of simplicity in design, compactness, low-cost, low-tech and low-labor requirements. Moreover, the increase in system productivity that is obtained in almost all cases is limited to less than 100%, often varying between 10-40%. Promoting solar stills thus requires focusing research efforts on improving existing technologies with minimal additional as well as with more compact installations that would reduce land use, since large space requirement is the major contributor to the high initial costs of solar stills.

The introduced modification in this study significantly increases the productivity (more than 200% on average) while preserving the key advantages of the solar still in being simple, compact and low-tech, requiring little maintenance and entailing low additional costs. The proposed idea builds on exposing a larger amount of saline water to sunlight than that normally exposed in conventional basin stills. The slowly rotating drum introduced into the still cavity for this purpose allows a thin water film to continually form and evaporate. The drum is hollow on both of its vertical edges and hence the water film forms on both its inner and outer sides. The thin water film evaporates at a fast rate as opposed to the much deeper water brine found in the basin of conventional stills. The fast evaporation of the water film is also attributed to the high heat of the rotating drum, which receives more direct sunlight than the basin water. One side-benefit of this design is solving the stagnation problem that usually develops in conventional basin solar stills. The modified solar still with the rotating drum allows a constant renewal of the evaporating water film layer. This new system, therefore, presents a cost-effective and efficient design to solar stills especially in areas with abundant sunshine and where the cost of obtaining fresh water is high.

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