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Performance of solar still with a concave wick evaporation surface

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ABSTRACT

Surfaces used for evaporation and condensation phenomenon play important roles in the performance of basin type solar still. In the present study, a concave wick surface was used for evaporation, whereas four sides of a pyramid shaped still were used for condensation. Use of jute wick increased the amount of absorbed solar radiation and enhanced the evaporation surface area.. A concave shaped wick surface increases the evaporation area due to the capillary effect. Results show that average distillate productivity in day time was 4.1 l/m^2 and a maximum instantaneous system efficiency of 45% and average daily efficiency of 30% were recorded. The maximum hourly yield was 0.5 l/h. m^2 after solar noon. An estimated cost of 1 l of distillate was 0.065 $ for the presented solar still.

1. Introduction

The shortage of drinking water is expected to be the biggest problem of the world in the next years due to higher consumption rates and population growth. Pollution of fresh water resources (rivers, lakes and underground water) by industrial wastes has increased the problem.

The total amount of global water reserves is about 1.4 billion km^3. Seawater constitutes about 97.5% of this amount, and the remaining 2.5% fresh water is present in the atmosphere, surface water, polar ice and ground water. This means that only about 0.014% is directly available to human beings and other organisms [1]. Therefore, the provision of fresh water is becomes an increasingly important issue in many areas of the world. In arid areas, potable water is very scarce and the establishment of a human habitat in these areas strongly depends on how such water can be made available. The importance of supplying potable water can hardly be overstressed.

Solar desalination is suitable for remote, arid and semi-arid areas. Where drinking water shortage is a major problem and solar radiation is high. These places mostly suffer also from energy shortage. The limitations of solar energy utilization for desalination are the high initial cost for renewable energy devices and intermittent nature of the solar radiation. Due to these limitations the present capacity of solar desalination systems worldwide is only about 0.01% of the existing large-scale conventional desalination plants [2,3]. Therefore, efforts must be made to develop new technologies that can collect and use renewable energy more efficiently and cost effectively in the production of clean drinking water. Besides, developing better technologies to store this energy for use whenever it is not available is also required.

Solar stills are commonly used in arid coastal zones to provide low-cost fresh water from the sea. In the Northern Hemisphere, the still is placed due south with long axis facing East–West direction. The primary aim in solar still is to achieve as high productivity as possible. Total daily output of the solar still decreases with increasing water depth, but overnight output increases with an increase in water depth, which contributes considerably towards the total daily output [4]. Solar stills are usually classified into two categories [5]: a single-effect type and a multi-effect type. Solar stills made from waste materials were studied [6]. The still made from a polypropylene tray and polyethylene-wrapping sheets were subjected to laboratory tests at steady and unsteady states for heat and mass transfer analysis. The integration between flat plate solar collector and a solar still is classified into passive [7] and active [8] stills. Single-effect passive stills are composed of convectional basin, diffusion, wick and membrane types [9]. Using a still with cover cooling [10,11] and a still with a multi-effect type basin have been studied by Tanaka et al. [12]. Complicated systems with a variety of solar stills are not applicable to desert technology. A tube-type solar still is proposed to integrate a conventional still and a water distribution network suitable to our concept of desert plantation. This still is directly set up on ground-like pipelines connecting brackish water or seawater pond [13]. Solar distillation practice for water desalination systems was studied [14].

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Nomenclature

Q_{ev}	The rate of heat (energy) transfer by evaporation (W)
m_{ev}	Distilled water production rate (kg/m^2 h)
A_b	Still base area (m^2)
A	Still area (m^2)
H	Total solar radiation fall upon the still surface (W/m^2)
L	Latent heat of water (J/kg)
V	Variable cost (O&M), LE
C	Total cost, LE
n	Expected still life time, years
P_n	Total productivity during the economical still life (kg)
P	Accumulated productivity during the day (kg)
t	day time (h)
η_d	The solar still daily efficiency
η_i	The solar still instantaneous efficiency

However, various scientists have made attempts to maximize the daily yield per still area in a single basin solar still in a passive mode [15,16]. In the conventional still the transparent surface has the disadvantage of increase in its temperature due to solar radiation. Also, a part of radiation is absorbed in glass surface and increases its temperature, which results in decreasing the condensation rate.

It has been reported that tilted-wick type solar stills have some advantages over the basin type, especially their attractive performance in distillation. Conducting an experimental study on a tilted-wick type solar still, Tanaka et al. [17] found an increase in distillate output of 20–50% against basin types.

From the previous work, it has been observed that the daily yield per still area in the basin solar still mainly depends on the evaporative area and condensing surfaces [18,20]. Increasing the surface area or decreasing the cover temperature will enhance the distillate output. New approaches to enhance the performance of solar still are highly welcome.

This work presents an experimental investigation on a new design of solar still with wicked concave surface. The aim of using wick is to increase the solar radiation absorption area as well as the evaporation area. This is to increase the productivity of the still. Also, this concave still design reduces the shading effect than the conventional type because all sides are glass. The performance of the presented still was evaluated.

2. Experimental setup

Wick concave type solar still is designed and constructed for the purpose of experimental work. Fig. 1 shows a schematic diagram of the solar still and a photograph of this solar still is shown in Fig. 2. The basin of the solar still is concave with a square aperture of 1.2 m × 1.2 m. Its frame is fabricated from steel of 2 mm thickness. The still basin is made of galvanized steel. The bottom and sides of the basin are insulated by glass wool of 5 cm thick layer surrounded by a steel sheet 2 mm thickness. The wick surface takes the same shape of the concave surface and has a thickness of 5 cm covering the basin. The wick surface is black painted to absorb maximum solar radiation. The basin depth is 30 cm at the centre. The depth of saline water in the still is 10 cm at the centre. Glass cover is used at four sides of the solar still with ordinary window glass of 3 mm thickness and tilted at an angle of 45 degree to the horizontal surface [19]. The distillate is collected by a galvanized iron channel fixed on the sides at the lower end of the glass cover and is taken out through two PVC pipes to two graduated flash as shown in Fig. 1. The channels were inclined such that no accumulation of water was observed. The whole system is made vapor tight using silicone rubber as a sealant to prevent any vapor leakage. One of the four glass cover faces south direction.

The experimental setup is suitably instrumented to measure the temperatures at different points of the still (brine temperatures, wick temperatures and glass covers temperatures), total solar radiation and the amount of distillate. The temperatures have been measured using copper constantan thermocouples which were connected to a digital temperature indicator. Wick surface temperatures are measured at different points. The thermocouples for glass temperatures measurement at one third of the perpendicular distance from the triangle vertices. While for brine water the temperatures are measured at the water surface, 5 cm from surface and near the bottom at the centre. The solar radiation intensity is measured instantaneously by solarimultimeter. A part of wick surface is dipped into the water and another part absorbs water by capillary action. Use of glass covers at four sides of the still reduces the shading effect compared with that of conventional solar still.

3. Experimental procedure

Experiments were conducted at Tanta University, Egypt. Experiments were started at 8:00 a.m. and after one hour warm up

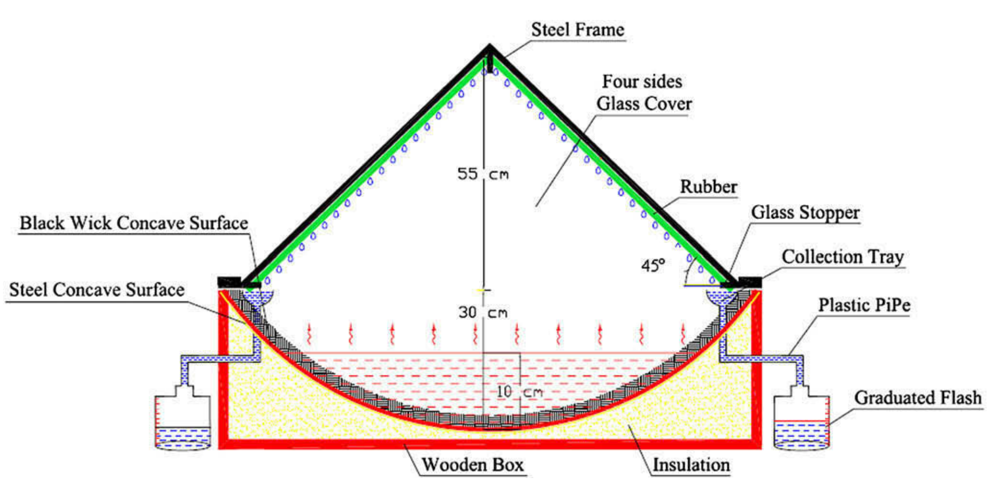

Fig. 1. Schematic diagram of concave wick solar still (drawn not to scale).