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Modeling and experimental study of a corrugated wick type solar still: Comparative study with a simple basin type

K.K. Matrawy [a,b,*], A.S. Alosaimy [a], A.-F. Mahrous [a,c]

[a] Mechanical Engineering Department, Taif University, Al-huwayah, P.O. Box: 888, 21974, Saudi Arabia
[b] Mechanical Engineering Department, Faculty of Engineering, Assiut University, Egypt
[c] Mechanical Power Engineering Department, Menoufiya University, Shebin El-Kom 32511, Egypt

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ABSTRACT

In the present work, the productivity of a solar still is modified by forming the evaporative surface as a corrugated shape as well as by decreasing the heat capacity with the use of a porous material. This target has been achieved by using black clothes in a corrugated shape that are immersed in water where the clothes absorbs water and get saturated by capillary effect. Along with the proposed corrugated wick type solar still, a simple basin still type was fabricated and tested to compare the enhancement accomplished by the developed solar still. Inclined reflectors were used to augment the solar radiation incident on the plane of the developed solar stills. The energy balance in the developed mathematical models takes into consideration the glass covers, the porous material, along with the portion of water exposed to the transmitted solar radiation as well as the portion of water shaded by the corrugated surface. The developed mathematical model was validated by fabricating and testing two models for the proposed and simple basin solar stills under the same conditions. Good agreement between the simulated and experimental results has been detected. It has been found that an improvement of about 34% in the productivity for the proposed wick type solar still is gained as compared to the simple basin case. Also, the best tilt angle for the inclined reflector has been found to be about 30° with respect to the vertical direction of the setup under consideration.

1. Introduction

Supplying fresh and healthy water is still one of the major problems in different parts of the world, particularly in remote arid areas [1]. Solar still may provide a solution for those areas where it is cheap and having low maintenance cost, but it suffers from the lower productivity [2]. Accordingly, rigorous theoretical and experimental studies have been made to enhance the solar stills' productivity. Developed work by Tiwari and Tripathi [3] has been carried out on both passive and active solar distillation systems. They recommended that only passive solar stills can be economical to provide potable water. Rai et al. [4] studied experimentally a single basin solar still coupled with a flat plate collector under various modes of operation. The modes of operation incorporated the effect of water salinity as well as the thermosyphon and forced circulations. The experimental results showed that the daily variation of the stills' productivity ranged from 1.6 kg/m^2 to 2.4 kg/m^2 when adding a small amount of dye. Badran [5] found that the productivity was increased by about 52% in case of coupling the still with a flat plate collector. Akash et al. [6] showed that the productivity of basin solar still decreases with salinity and also decreases in a linear relationship while increasing the water depth. A maximum hourly yield with a value of 0.6 kg/m^2 was attained in the study. Omara and Kabeel [7] studied the performance of different sand beds solar stills. The influences of sandy bed height, type of sand, and water height above the sandy bed level on the solar still performance have been investigated. Maximum accumulated distillate yield of 4 kg/m^2 was achieved while the corresponding yield was 2 kg/m^2 in the conventional type. Nafey et al. [8] enhanced the productivity of the single slope solar still using black rubber and black gravel material as storage medium. They found that an enhancement of 19–20% in the stills' productivity can be achieved when using these materials. Other technique to enhance the stills' productivity was developed by feeding a water film over the glass cover of a multi- wick solar still to increase the productivity and also performs self-cleaning for the glass cover [9]. Incropera and Dewitt [10] have investigated the convective heat transfer between

* Corresponding author at: Mechanical Engineering Department, Taif University, Al-huwayah, P.O. Box: 888, 21974, Saudi Arabia. Tel.: +966 5495 31562; fax: +966 (2) 724 0614.
E-mail address: matrawy1958@yahoo.com (K.K. Matrawy).

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Nomenclature

A	area (m^2)
C_p	specific heat (J/kg K)
h	heat transfer coefficient (W/m^2 K), height (m)
h_{fg}	latent heat of condensation (J/kg C)
I	solar radiation (W/m^2)
m	mass (kg)
M_d	mass of distillated (kg)
L	length (m)
T	temperature (°C)
W	width (m)
Q	heat (W)
Q_s	absorbed solar radiation (W/m^2)
Greek letters	
α	absorptivity
β	slope angle (°)
θ	incidence angle (°)
δ	Boltzman constant (W/m^4 K)
τ	transmissivity
ρ	reflectivity
ε	emissivity
Subscripts	
1	corrugated solar still
2	simple basin solar still
a	air
b	bottom, beam
c	cover, convention
d	diffused
e	evaporative
G	global
p	porous
pt	porous top
pb	porous bottom
r	radiative, reflector
s	still
w	water, wind

the cooling film and glass cover while Sherwood et al. [11] have studied the heat transfer due to water evaporation associated with the cooling film. A solar desalination plant consists of solar parabolic collectors, steam generators, and MED unit was simulated and optimized using multi-objective genetic algorithm by Mokhtari et al. [12].

Recently, various technologies have been developed to meet the increasing demand of potable water such as double slope solar still [13], providing low pressure inside the still basin [14], using nanofluids and integrating the still basin with external condenser [15], enhancing the stepped solar still using internal and external reflectors [16], using a flat and ripped absorber in "V" wick type solar still [17], floating cum tilted wick solar still [18], using a corrugated galvanized iron steel as an absorber in between the wick strips [19] and multiple porous blackened jute absorbers floated on the water basin [20]. Moreover, Huang et al. [21] studied the multi effect diffusion type solar still (MEDS) coupled with a vacuum tube solar collector. They showed that the 10-effect MEDS produces pure water ranged from 13.7 to 19.7 kg/day/m^2 when the incident solar radiation ranges from 600 to 800 W/m^2, respectively. For the 20-effect solar still, the productivity increases by 32% compared to the10-effect one.

Thus, it may be concluded that the most recommended strategies to enhance the productivity are:

1. Decreasing the water depth in the basin.
2. Using a forced circulation to increase the rate of evaporation processes.
3. Feeding a water film over the cover to decrease the cover temperature.
4. Using a sand bed or black rubber as a storage medium.
5. Integrating an external condenser and using nanofluids.
6. Providing low pressure inside the still to decrease the evaporating temperature.
7. Floating blackened jute on the water basin.
8. Applying energy recovery for the condensate vapor (i.e. multi effect solar still).

Accordingly, the main objective of the present study was to enhance the evaporation processes in a simple basin solar still. This was satisfied by increasing the evaporative area using corrugated shape and decreasing the heat capacity of the evaporating water with the use of a porous material. Removing the salt and some impurities from the porous material was taken place through a periodic cleaning for the porous material. Description of the developed solar stills, mathematical modeling and experimental set up were presented in Sections 2–4, following by the results and discussions for the simulated and experimental results.

2. Description of the proposed corrugated wick type and simple basin type solar stills

A schematic diagram for the proposed corrugated wick type solar still with an inclined flat reflector is shown in Fig. 1.

From Fig. 1, it can be seen that the main components of the proposed solar still are:

1. Glass cover with a thickness of 6 mm to transmit the incident solar radiation and the reflected radiation from the reflector to both the porous material and the water in the basin. Also, the generated vapor is condensed along the lower surface of the cover and collected at the lower end.
2. Porous material that is black clothes with a thickness of 2 mm made in a corrugated shape. The porous material is partially immersed and wetted by the water in the basin by capillary effect to increase the rate of evaporation.

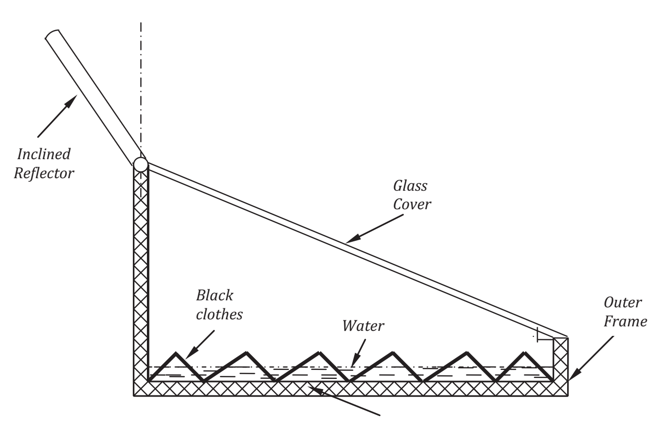

Fig. 1. Corrugated wick type solar still with an inclined reflector.