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Experimental investigation on a semi-circular trough-absorber solar still with baffles for fresh water production

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ABSTRACT

The main objective of this research is to increase the contact time of water in the basin to enhance yield of fresh water by using a semicircular absorber solar still with baffles. An experimental as well as theoretical investigation is carried out. The productivity and efficiency of present still are analyzed with the influence of the number baffles and the water flow rate. A good agreement between the experimental and theoretical results is observed. The results indicate that, the daily yield of present solar still is higher than that for conventional still approximately by 16.66%. The outlet water temperature present solar still is high subsequently, it can be coupled with multi-state of solar stills to increase productivity. Therefore, the present solar still can be sufficiently extended for other continuous solar desalination systems. Economic analysis concluded that, the payback period of the present model solar still is quicker while comparing it with other solar still.

1. Introduction

Depletion of natural fuel resources from the earth increases the need and applicability of renewable energy sources. With the increase in population growth and water scarcity become important problems that need to be resolved. Nearly 70% of the earth is covered with salt water which cannot be consumed for drinking purpose. Solar desalination is one of the traditional, easiest and possible methods of getting fresh water. Somehow, these solar desalination techniques lack in the economic and lower fresh water yield aspects.

Over these years, there are several researches are carried out in a solar still for enhancing the fresh water yield. Some major studies with respect to the current text are discussed. Kabeel et al. [1] improved the solar still productivity by using nanofluids and providing vacuum. The performance of a solar still was studied with different types of nano materials. The results showed that the solar still productivity was enhanced by nanofluids and providing vacuum. Zerrouki et al. [2] presented a numerical simulation of capillary film solar still (distiller) coupled in series with the other conventional solar still. In addition, some parameters influences were studied to define the optimal operating conditions for the present system. The results showed that the system daily production was about 54–83% higher than that for the conventional still. Flow rate and wind speed were slightly effected on the fresh water yield. The enhancement of solar still by using nanofluids and integrating with external condenser was presented by Kabeel et al. [3]. Aluminum-oxide in water was used as solid particles. The results showed that the productivity was improved by 116% with nanofluids and external condenser.

Omara et al. [4] coupled a stepped solar still with internal and external reflectors to enhance energy input and productivity. The result showed that the output of the modified stepped solar still was significantly increased if it was coupled with internal and external (top and bottom) reflectors. Xiong et al. [5] designed a novel multi-effect solar desalination system with enhanced condensation surface. Experimental and numerical model characterizing of the heat and mass transfer process in the solar still was developed. It was observed that the solar still could generate freshwater about 40% of the total freshwater yield in the night. The overall desalination efficiency and performance ratio of the equipment can reach 0.91 and 1.86, respectively at temperature was relatively high. The effect of the tilt angle of glass cover on productivity was studied by Khalifa [6]. In addition, the value of the optimum tilt angle in different seasons and latitude angles was presented. It

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Nomenclature

A	area (m^2)
C_p	specific heat capacity (J/kg K)
h	heat transfer coefficient (W/m^2 K)
h_{fg}	latent heat of vaporization (J/kg)
I	total radiation (W/m^2)
n	number of baffles
p	partial pressure (N/m^2)
T	temperature, (°C)
u	wind velocity (m/s)
U	overall heat transfer coefficient (W/m^2 K)

Greek symbols

α	absorptivity
σ	Stefen Boltzman Constant (5.67×10^{-8} W/m^2 K^4)
ε	emissivity

Subscripts

a	ambient
b	basin
c	convection
e	evaporation
f	flow rate
w	water
g	glass
r	radiation
in	inlet
out	outlet

was observed that the tilt angle should be large in winter and small in summer. Ravishankar et al. [7] and Sathyamurthy et al. [8,9] experimentally investigated the effect of PCM on a triangular pyramid solar still. The effect of introducing PCM on the bottom of the basin improved the efficiency by 45% than that for other conventional solar still. At the same, Nagarajan et al. [10] conducted a detailed review on nano particle for solar applications and automobile radiators for extracting the waste heat. Nagarajan et al. [11] and Ravishankar et al. [12] carried out performance of a triangular pyramid solar still experimentally. The results showed that the improvement in fresh water yield from the solar still was 45% more than that for conventional solar still on the climatic condition of Chennai. Augmentations of tubular solar still productivity were discussed by Ahsan et al. [13–18]. Arunkumar et al. [19] investigated a concentric tubular solar still using air and water as cooling medium over the glass cover. The results showed that the productivity of solar still with the cooling water flow was increased by 64% compared with air flow. The concentric tubular solar still with the cold water flow had the highest productivity more than that for the normal still without air or water flow.

Previous researchers carried out experiments to augment the yield. Due to the higher construction cost, frequent replacement of wick solar still and non distribution of water in the basin as preventing it from practical and domestic use. Therefore, trough and absorber are made of plastic to avoid the corrosion effect than conventional solar still. In addition, a semicircular absorber with baffles is used to increase the contact time of water in the basin to enhance the yield of fresh water.

This paper presents an experimental and theoretical analysis of a semicircular absorber solar still with baffles. The influence of the number baffles and the water flow rate on the desalination system performance are studied. The productivity and efficiency of the present still are analyzed. The overall accumulated yield from solar still is expected higher with influence of baffle plates. In further, economic analysis was carried out to analyze the low cost distillation unit with high purity of fresh water.

2. Theoretical analysis

For theoretical analysis the following assumptions are assumed:

- Temperature of water and the basin are equal.
- Area of the water surface is equal to the glass area.
- Flow throughout the basin is uniform.
- The heat loss from the basin to the surrounding is neglected.

2.1. Energy balance of water

2.1.1. With baffles

From the energy balance equation, heat energy equal heat absorbed by water and it is given as:

$$I\tau_g(1-\alpha_w) = \left(\frac{1}{n}\right) m_f C_{pw}(T_{out} - T_{in}) + U_b(T_b - T_a) \quad (1)$$

$$T_{out} = \left[\frac{nI\tau_g(1-\alpha_w) - U_b(T_b - T_a)}{m_f C_{pw}}\right] + T_{in} \quad (2)$$

where I is the incident solar radiation on the horizontal surface, τ_g is the Transmissivity of glass, α_w is the absorptivity, n is the number of baffles, m_f is the water flow rate, C_{pw} is the water specific heat capacity, T_{in} and T_{out} are the inlet and outlet of water temperatures, T_a is the atmosphere temperature, T_b is the basin temperature. U_b is the overall heat transfer coefficient and is taken as, 14 W/m^2 K.

And the average water temperature, T_w, in the solar still can be expressed as:

$$T_W = \left[\frac{T_{in} + T_{out}}{2}\right] \quad (3)$$

2.1.2. Without baffles

From the energy balance equation, heat energy equal heat absorbed by water and it is given as:

$$I\tau_g(1-\alpha_w) = m_f C_{pw}(T_{out} - T_{in}) + U_b(T_b - T_a) \quad (4)$$

$$T_{out} = \left[\frac{I\tau_g(1-\alpha_w) - U_b(T_b - T_a)}{m_f C_{pw}}\right] + T_{in} \quad (5)$$

2.2. Energy balance of glass surface

Heat energy absorbed by glass + Heat liberated by vapor inside the still = Heat lost due to convection and radiation by the outside glass surface

$$I\alpha_g A_g + h_2(T_w - T_g) = h_3(T_g - T_a) \quad (6)$$

The above equation can be rewritten as:

$$T_g = \left[\frac{I\alpha_g A_g + h_3 T_a + h_2 T_w}{h_2 + h_3}\right] \quad (7)$$

where A_g is the area of glass, α_g is the absorptivity of water; T_g is the glass cover temperature.