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Theoretical estimation of the optimum glass cover water film cooling parameters combinations of a stepped solar still

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In the present work, theoretical performance evaluation of a stepped solar still using water film cooling over the glass cover is investigated. The effect of film cooling thickness, flow rate, inlet temperature, and air wind speed on the stepped solar still daily productivity is studied. To increase the performance of the stepped solar still outlet water film cooling is recycled as a makeup water. It was found that film cooling thickness, volumetric flow rate, and water film inlet temperature have a significant effect on the daily distillate productivity. The presence of the glass cover water film cooling may increase the stepped still daily productivity by about 8.2% but the value of this percentage mainly depends on the combinations of film cooling parameters. On the other hand, the presence of the film cooling neutralized the effect of air wind speed on the still distillate productivity. Moreover, it was found that the proper combinations of film cooling parameters have a great influence on stepped still productivity and the best combination was: film thickness from 2.5×10^{-4} to 5.5×10^{-4} m, cooling water volumetric flow rate from 4×10^{-5} to 8.5×10^{-5} m^3/s, and glass cover length from 2 to 2.8 m. Finally a good agreement between the present theoretical work and previous experimental result has been obtained.

1. Introduction

Although water covers approximately 70% of the earth's surface, supplies of potable water are one of the major problems in many countries. This is because most of the water reservoirs are saline or has harmful bacteria. The use of solar stills as a cheap and simple method for providing potable water and it's safe outcome on the environment are the major attraction points to research interests. The weak points for using solar stills for distillation of sea or salty water are its low efficiency and production rate as compared to the conventional systems. The production capacity of a simple type solar still is in the range of 2–5 $l/m^2/day$ [1]. Therefore all research is focused on methods of increasing the still's efficiency and productivity.

An extensive review paper of various factors affecting the productivity of solar stills has been published by Velmurugan and Srithar [1]. The affecting parameters were solar intensity, ambient temperature, wind velocity, water–glass temperature difference, water free surface area, absorber plate area, glass angle and depth of saline water. They concluded that all previous parameters can be varied to enhance the productivity of the solar stills except metrological parameters i.e. solar intensity, wind velocity, ambient temperature. Also, previous studies showed that, the daily production rate of still was greatly enhanced by using sponge cubes, fins, stepped, thin cover thickness, highly cover thermal conductivity and using rubber as a basin material [2].

To find a better design for solar stills, some researchers used an experimental approach [3–6] and the others used the mathematical or numerical one [7–11]. In the last decades, many researchers use the theoretical or numerical techniques in their research studies. This is because numerical work has many advantages over the experimental work for example; cheap, no time consuming results, no scaling, can simulate tests that cannot be done in laboratories, and avoid any experimental work hazards (safer).

Stepped solar still was found to have better effectiveness than the traditional or conventional solar still [3–6]. Stepped and conventional solar still layouts are shown in Fig. 1. Omara et al. [6] found experimentally that the productivity of the stepped solar still was higher than that for conventional still by approximately 57%. Abu-Hijlew and Mousa [10] found numerically that using a class cover water film cooling increases the conventional solar still efficiency by approximately 20%. Moreover, Abu-Hijleh [11] found numerically that poor combinations of film cooling parameters can lead to significant reductions in still efficiency.

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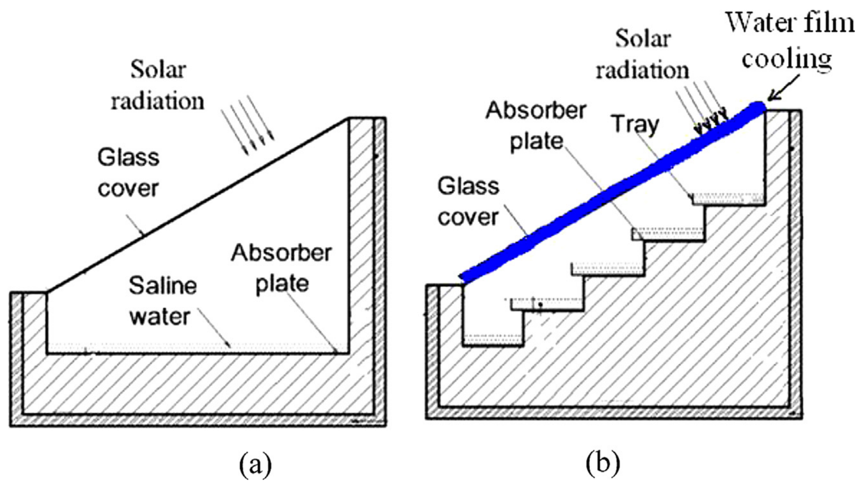

Fig. 1. Solar still, (a) conventional still; (b) Stepped still.

To the authors' knowledge, theoretical study of the performance of single basin stepped solar still using glass cover water film cooling is not studied. In the present study, performance evaluation of a single basin stepped solar still using water film cooling over the glass cover is obtained theoretically. To avoid poor combinations of film cooling parameters, a FORTRAN computer program called "solarstillopti.for" is designed to get the optimum combinations of film cooling parameters at which the distillate productivity is a maximum. The studied film cooling parameters are film thickness, cooling water volumetric flow rate, inlet film cooling temperature and glass cover length.

2. Mathematical model

The energy balance for the stepped solar still may be applied for four regions: basin (absorber plate), saline water, glass cover, and water in the film cooling. The basin plate temperature, saline water temperature, and glass cover temperature can be evaluated at every instant. The following assumptions are considered for the solar still energy equations:

- Steady state conditions throughout the stepped solar still
- The film cooling is assumed to be thin, therefore no incident radiation will be absorbed by the film.
- The glass cover is assumed to be thin, therefore no incident radiation will be absorbed by the glass and also the glass conduction resistance could be neglected.
- The solar still is vapour leakage proof.
- Evaporation from the film cooling is negligible as proved by Ref. [10]

Energy balance for the basin plate [12],

$$m_b Cp_b \frac{dt_b}{d\tau} = (\alpha_b) A_b I - Q_{bw} - Q_{loss} \quad (1)$$

Energy balance for the saline water [12,13],

$$m_w Cp_w \frac{dt_w}{d\tau} = (\alpha_w) A_w I + Q_{bw} - Q_{rw} - Q_{cw} - Q_e - Q_{mw} \quad (2)$$

Energy balance for the glass cover [11],

$$m_g Cp_g \frac{dt_g}{d\tau} = (\alpha_g) A_g I + Q_{rw} + Q_{cw} + Q_e - Q_{cf} \quad (3)$$

Energy balance for water in the film cooling [11],

$$m_f Cp_f \frac{dt_f}{d\tau} = m_{rf}\left(Cp_1 t_{f1} - Cp_2 t_{f2}\right) + Q_{cf} - Q_{ca} - Q_{rf} \quad (4)$$

where

$$t_f = \frac{t_{f1} + t_{f2}}{2} \quad (5)$$

It should be noted that the energy balance of the film cooling requires the use of cooling water inlet and exit temperatures. Hence, exit cooling water temperature is assumed and re-corrected when the temperature differences between cooling water at the inlet and exit, dt_f, is obtained.

For the conventional or stepped solar still without film cooling water, energy balance for the basin plate and the saline water, equations (1) and (2), can be used however; the energy balance for the glass cover, equation (3), will be replaced by the following equations [11,12]:

$$m_g Cp_g \frac{dt_g}{d\tau} = (\alpha_g) A_g I + Q_{rw} + Q_{cw} + Q_e - Q_{cg} - Q_{rg} \quad (6)$$

The right hand side terms of the equations (1)–(6) will be calculated as follows:

The convective heat transfer between basin and water [9,14]

$$Q_{bw} = h_{bw} A_b (t_b - t_w) \quad (7)$$

The convective heat transfer coefficient between basin and water, h_{bw} is taken as 135 W/m^2 K [9,14].

The heat losses by convection through the basin base and sides to the ground and surrounding, given as [15]

$$Q_{loss} = U_b A_b (t_b - t_a) \quad (8)$$

where U_b is taken [13] as, 14 W/m^2 K.

Due to solar still geometry, the thickness of insulation in the conventional solar still is smaller than that for the stepped solar still. Therefore, stepped solar still has smaller overall heat transfer coefficient than that conventional solar still.

The convective heat transfer between saline water and the glass cover is given by Refs. [9,14],

$$Q_{cw} = h_{cw} A_w (t_w - t_g) \quad (9)$$