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Influence of condensation surface on solar distillation

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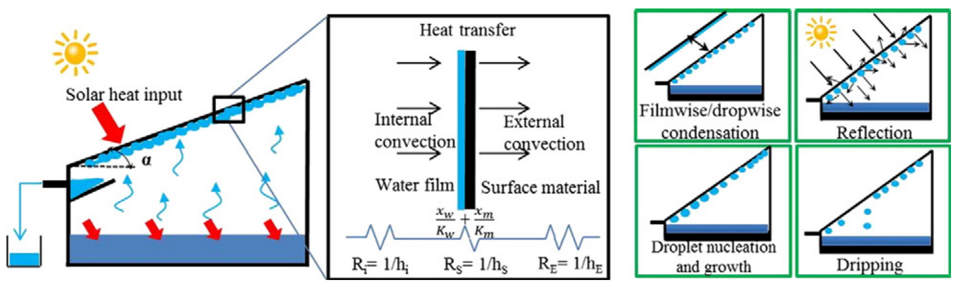
HIGHLIGHTS

- Reflection is demonstrated as the critical phenomenon effecting water production.
- Surface tension is demonstrated as the critical property for choosing a material.
- Thermal resistance offered by condensation layer does not affect the water production.
- Wiping of condensation surface does not increase the water production.

GRAPHICAL ABSTRACT



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ABSTRACT

Glass has been the preferable choice of material for its use as a condensation surface in solar distillation as it gives higher water production than other materials. However, it is not certain which property and subsequently which phenomena are responsible for higher production of water. In this paper, we study the influence of different condensation surfaces on the total water production in solar water distillation. From our results, we conclude that the contact angle is the most important parameter for choosing the material of condensation surface inside a solar water distiller. Subsequently, we also conclude that the reflection of solar irradiation from the surface is the most important phenomenon affecting the differences in water production from solar distillation.

1. Introduction

Solar water distillation uses solar radiation to drive evaporation of water and its subsequent condensation for production of clean drinking water [1,2]. More than 780 million people suffer from the absence of a reliable source of drinking water [3]. A solar distillation device or solar still can alleviate the need of clean drinking water for a majority of this population, which has an abundance of solar energy available [4,5]. However, solar still as a technology for water purification has faced challenges in its implementation for the past several decades [4,5].

One of the major challenges for putting solar still in practice is to work with the undesirable properties of glass as a material for mass production for solar stills [5–7]. Glass is heavy, brittle and has high replacement costs. On the other hand, plastic is light weight, relatively unbreakable, easy to transport and easy to process. Historically, plastic solar stills have been commercially more successful than glass solar stills and have sold over 400,000 units [8]. Still, due to higher amount of water production among other materials, glass has been the superior choice of material for its use as condensation surface inside a solar still [6].

Factors like the type of material, roughness, inclination, shape, transmittance, wiping and vibration of the condensing surface were found to

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have a significant impact on the production of water from the solar still [2,4,6,8–20]. The effect of condensing surface was covered in more detail by Tleimat and Howe [6], Ghoneyem and Ileri [12], Tiwari and Tiwari [14] and Dimri et al. [15]. The use of mechanically modified plastic against glass lowered the production of water by 18% [6]. The production of water from a solar still was found to be directly proportional to the thickness and thermal conductivity of condensing surface. The production of water decreased by 7% with an increase in glass thickness from 2 mm to 6 mm. The use of copper metal against plastic increased the production of water by 18% [15]. Further, the production of water was found to be highest for an inclination angle of 15° in summers and 45° in winters [14]. Other studies for the optimization of glass cover inclination were also performed [16,17,13,18]. Furthermore, renewal of surface through vibration or wiping also increased the production of water [9,10,20]. Menguy et al. [9] reported a 25% increase in production of water by wiping the condensation surface of a spherical solar still. Eldalil [20] reported an increase in water production by 72% with the combined effect of modified absorbing surface and vibratory condensation surface.

Still, there are two underlying issues which need to be resolved completely. First, which phenomenon relating to the condensation surface critically effects the production of water? And second, which material property significantly affects this phenomenon. An answer to these questions will explain why the use of glass in a solar still results in a higher production of water than other materials. Consequently, it will also suggest if the properties of plastic material can be tailored to match the properties of glass, and further use it as a condensing surface in a solar still.

This study examines the effect of condensing surface on the water production from a solar still. To study this effect, all the major phenomena (shown in Fig. 1 were tested and analyzed. Subsequently, the most important phenomenon and relating material property were identified and presented.

2. Theory

Fig. 1 shows the phenomena associated with the condensation surface of a solar still. These phenomena were first explained in detail by Dunkle [1]. On a broader level, heat transfer and vapor condensation have been extensively studied by Rose [21] and Beysens [22]. Furthermore, the effect of reflection of sunlight has been studied within greenhouses by Pollet and Pieters [19], Briscoe and Galvin [23], Pieters et al. [24] and Cemek and Demir [25]. Finally, the role inclined surface has been studied in the solar stills by Tiwari and Tiwari [14,16,17], Ghoneyem and Ileri [12], Aybar [13] and Artley et al. [18] and for greenhouses by Pollet and Pieters [26,19], Gbiorczyk et al. [27] and Montero et al. [28]. The following sections summarize these effects and their relationship with the solar still.

2.1. Reflection from the condensing surface

The phenomenon of reflection of light off a surface with condensing droplets has been studied previously [19,23,24,26,25]. Of the total solar radiation incident on the top of the solar still, a considerable part might get reflected. The reflection happens at two surfaces. First, at the condensation surface and then at the condensing droplet attached to the bottom of the condensation surface. The amount of reflection depends on the refractive indices of materials and the shape or mode of condensing droplet [23]. The mode of condensation depends on the contact angle of the condensation surface [22]. Filmwise condensation mode occurs at surfaces with low contact angles resulting in flat droplet formation. Dropwise mode occurs on surfaces with high contact angles resulting in hemispherical droplets. For materials having contact angles greater than 48°, the transmittance from the condensation surface was given by Briscoe and Galvin [23]. Pollet and Pieters [26,29] applied this study for greenhouse materials and reported a decrease of transmittance upto 25% when using plastic instead of glass.

2.2. Heat transfer from the condensing surface

The heat and mass transfer within the solar still have been previously investigated by Dunkle [1], Tiwari [2] and Lof et al. [30]. After reflection from the surface, the majority of the transmitted radiation is absorbed at the bottom of the solar still. The bottom of the still is usually a black material with a layer of water above its surface. The heat from the black bottom is then transferred to the water above it. Furthermore, the heat from the water is brought to the condensation surface in the form of vapor via internal convection. The vapor condenses and transfers its heat to the condensation surface. Finally, the condensation surface conducts it to outside environment via external convection. The overall heat transfer q, from vapors inside the solar still to the environment outside is given as $q = U\Delta T = \Delta T/R$. Where ΔT is the overall temperature difference from the vapor side to the environment. It is the driving force for the heat transfer. U is the overall heat transfer coefficient and represents the ability to allow transfer heat. $R = 1/U$ — is the overall thermal resistance and represents the ability to resist heat transfer. Furthermore, the value of the overall thermal resistance for the solar still is represented as [1]:

$$R = \left(\frac{1}{h_I} + \frac{1}{h_S} + \frac{1}{h_E}\right) \text{ where } h_S = \left(\frac{x_m}{K_m} + \frac{x_f}{K_f}\right)^{-1} \quad (1)$$

where h, K and x represent the heat transfer coefficient and thermal conductivity and thickness of the condensation surface respectively. Subscripts I, S, E represent internal, surface and external phenomena. Subscripts m and f represent the thickness of the materials and the

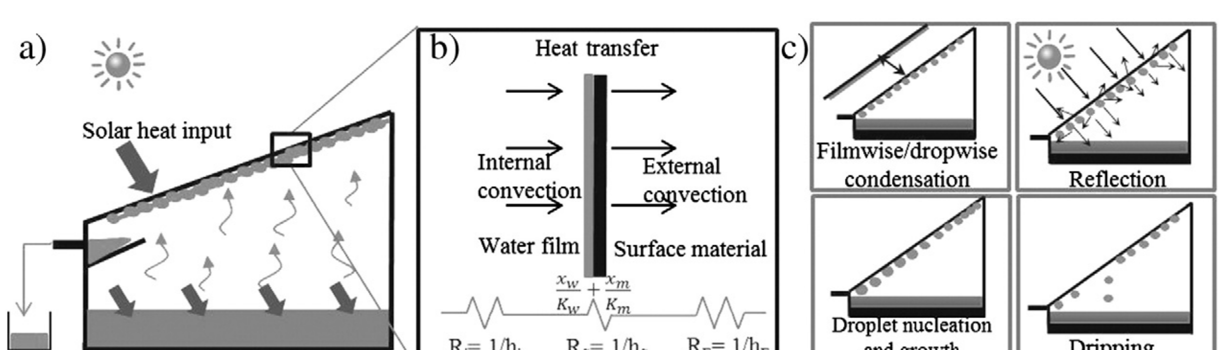

Fig. 1. (a) A schematic of a typical solar still. The incoming solar radiation heats up water, resulting in subsequent evaporation and condensation of vapors. (b) Thermal resistance diagram for heat transfer at the surface. R and h represent the thermal resistance and heat transfer coefficient respectively. Subscripts I, S and E represent internal, surface and external properties. (c) Phenomena associated with the condensation surface in a solar still.