



Effects of water and basin depths in single basin solar stills: An experimental and theoretical study



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ABSTRACT

The effects of water depth in solar stills were studied in many earlier works. It was revealed that in the previous experimental works, the water surface-cover distance (WCD) was altered with the change of the water depth. However, in this research, the effects of water depth and WCD were investigated separately, and effects of water depth on the performance of solar stills with the same WCD were examined for the first time. In this way at first, some experiments were conducted in the summer and winter seasons using the stills with the same water depths, but different basin depths (i.e. different WCDs). It was found that WCD can affect the amount of distillate yield up to 26%. Thus, it was concluded that to study the effect of water depth accurately, different stills should be employed at the same time (to keep WCD constant). In the second step, some experiments were conducted using four stills in the summer, fall and winter seasons to examine the effects of water depth, while the WCD was constant. In addition, the stills with different water depths were modeled analytically and their performance was investigated. Moreover, an empirical relationship was obtained between the distillate yield and the water depth. By comparing the results of this empirical relation with previous studies, it was revealed that the past researches reported a lower dependency (in the average 15%) of the distillate yield on the water depth, since in their experimental works, WCD was changed along with the water depth.

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1. Introduction

Numerous solar desalination devices have been developed over the years. The most conventional solar desalination units are basin solar stills [1]. However, the main practical problem of this type of solar stills is their low productivity [2]. In the recent years, various experimental and numerical research have been performed to increase the productivity of solar stills. In this regard, significant attention devoted to build modified configurations of solar stills. Rahbar et al. [3] introduced an asymmetrical solar still utilizing a thermoelectric cooler and found that the productivity can be increased 9 times by using the cooler instead of the usual glass. Ahsan et al. [4] compared the performance of two innovative tubular solar stills and compared their design, fabrication and performance. Farshchi Tabrizi et al. [5] reported coupling a cascade solar still with a humidification–dehumidification system can

enhance the efficiency 9–20%. Arunkumar et al. [6] designed a novel hemispherical solar still and reported that by reducing the cover temperature the efficiency was increased 34–42%.

In addition, a significant number of researchers endeavored to elucidate the influence of increasing input energy. It has been shown that although by increasing input energy, the amount of productivity can increase significantly [7], increasing input energy may be limited due to heat losses from flat plate solar collectors which may increase considerably at high ratio of collector over basin area [8]. Kumar and Tiwari [9] increased input energy to a single slope solar still using a photovoltaic integrated flat plate solar collector. They showed that overall thermal efficiency of hybrid active solar still increased 20%. Taghvaei et al. [10] investigated the effect of number of solar collectors coupled to a solar still and illustrated that by increasing the number of augmented solar collectors, the distillate production increases, but the efficiency can decrease.

As solar reflectors are inexpensive in comparison to solar collectors, they may be preferable alternatives to increase input energy

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Nomenclature

A	area (m^2)	WCD	water surface-cover distance
c	specific heat capacity ($\text{J/kg/}^\circ\text{C}$)	α	absorptivity
h	heat transfer coefficient ($\text{W/m}^2/^\circ\text{C}$)	E	emissivity
h_{fg}	water latent heat of vaporization (J/kg)	Θ	angle between direction of air flow and normal to the glass surface
I	Incident solar radiation (W)	Σ	Stefan–Boltzmann constant ($\text{W/m}^2/\text{K}^4$)
k	thermal conductivity ($\text{W/m/}^\circ\text{C}$)		
L	length (m)		
m	mass (kg)	<i>Subscripts</i>	
$\dot{m}$	production rate of distilled water (kg/s)	A	ambient
Nu	Nusselt number	B	base liner
P	partial vapor pressure (Pa)	C	convection
Pr	Prandtl number	E	evaporation
R	reflectivity	g	glass cover
Re	Reynolds number	r	radiation
t	time (s)	W	brackish water
T	temperature (K)		
U	overall heat transfer coefficient ($\text{W/m}^2/^\circ\text{C}$)		

to solar stills [11]. It is reported that solar reflectors can increase the productivity of basin and stepped solar stills 34% [12] and 125% [13], respectively.

Instead of feeding additional energy to a still, the energy of condensed vapor can be recovered [14]. It is shown that increasing the number of stages up to 6–10 can significantly increase the amount of distillate production of a multi-stage solar still [15], and consequently, the overall desalination efficiency and performance ratio can respectively reach 0.91 [16] and 1.81 [14], by using this technique.

On the other hand, some other researchers focused on enhancing the solar collecting surface by changing its shape to inclined [17] or stepped [18] forms. In addition to these strategies that increase the amount of accessible energy, other approaches like energy management using storing materials [19] and installing additional condenser [20] can be followed to improve the efficiency. Furthermore, enhancement of mass transfer inside solar stills was perused by movement of air or water [21] or increasing evaporation area using wick [22].

All of these solutions require additional devices or consume extra energy; therefore, more capital or operating costs should be expended. However, optimization of the water depth can increase stills' productivity without extra payment, and therefore, water depth modification is a cost-effective way for the improvement [23]. Many researches were conducted to examine the effect of water depth in passive single basin solar stills up to now. Totally, it is accepted that by increasing the water depth, the amount of distillate production of passive solar stills decreases. However, all of the earlier research utilized only one still for conducting experiments with different water depths.

By alteration of the water depth in a specific solar still, the water surface-cover distance (WCD) will be varied. Ahmed et al. [24] showed that this distance has a strong influence on the amount of distillate production and increasing the height of the still from 26 to 36 cm will decrease the distillate productivity by 45%. To our knowledge, all of the previous experimental works did not utilize several basins to investigate the effect of the water depth, and consequently, the WCD was not constant during their experiments. The main novelty of the present research is the utilization of four stills simultaneously in the investigation of water depths, to keep the WCD constant during all of the experiments.

In this study, the effects of basin and water depths in single basin solar stills were examined separately. At first, to investigate

the effect of basin depth on the distillate yield as a novel work, some experiments were performed (in the summer and winter seasons) using four stills with different WCDs when all of them had the same water depth. Secondly, the effect of water depth on the distillate yield was tested (while WCD was constant as a practical approach) for the first time. The experiments were conducted in various seasons (summer, fall and winter) using four stills simultaneously to investigate the seasonal effects of basin and water depths on the distillate, as well. In addition, the solar stills with various water depths were mathematically modeled and their distillate predictions were validated by the current experimental data.

2. Experimental set-up and procedure

To investigate effects of basin and water depths on the distillate production, 4 similar double slope basins were constructed and tested. These basins had walls with heights of 25, 17, 13 and 11 cm. In order to receive the maximum amount of solar radiation, the glass covers were installed at 30° inclinations which is equal to the latitude of Shiraz [25]. The area of basins was 0.56 m^2 and their bottom surfaces were covered with a black rubber. K-type thermocouples were used to measure temperatures of various parts of the basin and measuring cylinders were utilized to quantify the distillate production. Fig. 1 depicts a schematic diagram of the stills as well as photograph of the experimental set-up.

The solar stills were kept due south and the experiments were carried out during the various seasons at the solar energy research center of Shiraz University. Shiraz is located at latitude of $29^\circ 37' \text{N}$, longitude $52^\circ 32' \text{E}$ and 1500 m above sea level. The brackish water of Shiraz was fed to the stills. This water had TDS of 825 mg/L and contained 109 mg/L Cl^- , 380 mg/L HCO_3^- , 98 mg/L SO_4^{2-} , 97 mg/L Ca^{2+} , 92 mg/L Na^+ and 32 mg/L Mg^{2+} [26]. During each experiment, the data of produced distillates and also the temperature of various parts of the basins were recorded continuously at intervals of one-hour, for 24 h during the periods of testing.

Moreover, the effect of WCD was examined, as well. In doing so, all stills with different basin depths were filled with 2 cm of water; and experiments were conducted both in summer (8 Aug.) and winter (21 Feb.).

However, to study the effect of water depth, the stills were filled with 16, 8, 4 and 2 cm of water. As a result, the WCD was the same in all of the basins. These experiments were performed in the summer (30 Aug.), fall (2 Nov.) and winter (21 Dec.).

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