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Partitioning of solar still for performance recovery: Experimental and numerical investigations with cost analysis

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ABSTRACT

In this paper, the effects of partitioning in solar still on performance recovery are investigated experimentally and numerically. Two single slope solar stills containing conventional and modified by installing a partition are fabricated and tested, simultaneously. Two stills have a same basin area. All experiments were performed in Semnan with geographical coordinates of 35° 33′ N, 53° 23′ E, Iran. Hourly temperature, productivity, and efficiency for the modified and conventional stills are obtained and compared. Moreover, a numerical simulation based on SIMPLE algorithm is utilized and different contours are drawn to more discuss about the physics of this problem. Finally, a cost analysis is performed to investigate the modified still, economically. It is found that the partitioned still works at much higher temperature difference between water and the condensing area especially for afternoon hours. Moreover, the productivity increases by installing the partition in the still. These enhancements are about 4.81%, 4.82%, 5.62%, and 8.16% for first, second, third, and fourth days of the experiment, respectively. Finally, the cost analysis studies reveal that the costs per liter of the fresh water production for the conventional and modified stills are 0.0096 and 0.0104 $/L/m^2, respectively.

1. Introduction

Within the last couple of decades, freshwater rarity has become a critical issue for human beings all around the world. Population growth, global climate changes, and urbanisation are among the main reasons for this issue. Moreover, only 0.014% of available water in the earth can be utilized for the human's consumption purposes. This storage issue discloses the importance of desalination techniques as well as the similar technologies. Solar stills are recognized as valuable solar devices to purify the impure water (Sharshir et al., 2017). The low productivity of this device is a critical problem and should be considered as a major drawback for designers. Accordingly, researchers have focused on different active and passive techniques for improving the efficiency of this device. Kabeel et al. (2014) used aluminium oxide nanoparticles and vacuum in a solar still to enhance the productivity. They increased the distillate about 125% and 88.97% for the two cases of with and without employing the fan, respectively. They obtained those promising results by utilizing aluminium oxide nanoparticles. Throughout a different study, El-Sebaii et al. (2015) used fins with different shapes in a solar still. They found that the productivity of the still recovers with an increase in the fin length, while it drops with an increase in the fin width or the number of the utilized fins. It is worth mentioning that increasing the number of the fins will lead to the increase in the shadow area created by fins and this has a negative impact on the still productivity. Some researchers used thermoelectric cooling in solar stills (Rahbar et al., 2016). Esfahani et al. (2011) used thermoelectric cooling in a portable active solar still to increase the fresh water production. They observed the maximum efficiency about 13% for their still in winter days. Throughout a different research, Rahbar and Esfahani (2012) used the heat-pipe and thermoelectric module, simultaneously. They added a heat-pipe cooling device to drop the temperature of the hot side of the thermoelectric. They achieved to a higher fresh water production rate by combination of heat-pipe and thermoelectric cooler in their still. Recently, Heydari and Rahbar (2016) used a periodic injection on enclosure walls of a basin type solar still. They observed about 7% and 75% increments in the efficiency and the fresh water production rate, respectively due to using the wet walls. Prakash and Velmurugan (2015) reviewed some effective parameters on the productivity of the solar stills. They reported that maintaining vacuum conditions and the utilization of reflectors and condensers will improve the productivity of the

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Nomenclature

a	accuracy of the instrument
A	area (m^2)
AC	annual cost ($)
AMC	annual maintenance operational cost ($)
ASV	annual salvage value ($)
Cp	specific heat ($J\ kg^{-1}\ K^{-1}$)
CPL	cost per liter ($\$\ L^{-1}$)
CRF	capital recovery factor
D	mass diffusivity ($m^2\ s^{-1}$)
FAC	fixed annual cost ($)
g	acceleration due to gravity ($m\ s^{-2}$)
H	height of the still (m)
I(t)	solar radiation fall on the still ($W\ m^{-2}$)
i	interest rate (%)
L	length of the still (m)
L	latent heat of the water ($J\ kg^{-1}$)
$\dot{m}_{ev}$	fresh water production rate ($kg\ s^{-1}$)
M	average annual productivity (L)
n	life of the still (years)
p	pressure (Pa)
P	capital cost ($)
S	salvage value ($)
SSF	sinking fund factor
T	temperature (K)
u,v	velocity components ($m\ s^{-1}$)
x,y	rectangular coordinate components (m)
u	standard uncertainty

Subscripts/superscripts

b	basin
g	glass cover
w	wall

Greek symbols

η	efficiency
θ	tilt of the glass cover (degree)
φ	relative humidity
ω	mass fraction
ρ	density ($kg\ m^{-3}$)

stills. Srivastava and Agrawal (2013) mounted porous fins in the basin water of a solar still. These fins were covered by blackened old cotton rags and were partially dipped in the basin water. They introduced their modification for the solar stills as a simple and economical method to improve the efficiency of stills. Al-Nimr and Eslam Dahdolan (2015) proposed a novel concentrated solar still filled with a porous evaporator and an internal condenser. They introduced the dark painted sponge or hay as the porous evaporator due to low total thermal capacity. It is worth mentioning that most of the absorbed thermal radiation can be used to increase the temperature of water for evaporating due to the low thermal capacity of the porous evaporator.

Omara et al. (2014) used internal and external reflectors in weir-type cascade solar still to improve the performance. In their study, the productivity of this type of still has been increased about 88% in comparison to the conventional one. Matrawya et al. (2015) compared the efficiency of corrugated wick type solar still with conventional one. They observed 34% increment in water fresh output for corrugated solar still in comparison to the conventional one. Farshchi Tabrizi et al. (2016) coupled a stepped solar still with a humidification–dehumidification system in an experimental work. They observed 131% increment in daily productivity by using humidification–dehumidification system in their still.

Aside from the experimental researches, there are some numerical studies on solar stills. Rahbar and Esfahani (2012) estimated the convection heat transfer coefficient in a single slope solar still. Their results showed that the Nusselt number drops with an increase in the aspect ratio at a constant value of Rayleigh number. Rahbar et al. (2015) repeated this problem for a tubular solar still. They observed inverse and direct effects for glass and water temperatures, respectively on the performance of this type of solar still.

Some researchers performed a cost analysis for different passive and active solar stills. El-Bialy et al. (2016) performed a review on the cost analysis for different types of solar stills. They recommended passive solar stills as they have lower values of present capital cost with relatively high output pure water.

Some researchers have studied the natural convection heat transfer in partitioned enclosures. Nag et al. (1994) investigated the effects of a partial horizontal partition on the heat transfer in a square cavity. The partition was attached to the heated vertical wall of the cavity. Their results revealed that except for material with poor thermal properties, thermal conductivity of the partition has a negligible effect on the heat transfer. Bilgen (2002) conducted a numerical approach to study the natural convection heat transfer in the enclosures with partial partitions. They concluded that the heat transfer decreases by using two partitions in the enclosure instead of one. By implementing a numerical study, Ben-Nakhi and Chamkha (2006) investigated the natural convective airflow in an inclined enclosure with partitions. They found that the flow speed within the partitioned enclosure reduces as the partition height enhances. This leads to decrease in the heat transfer.

Yousefi et al. (2013) first proposed the idea of the partitioned solar still. Accordingly, they placed a straight partition in the basin of a 2-D solar still in a numerical work. Edalatpour et al. (2015) evaluated the effect of blade installation on heat transfer and fluid flow within a single slope solar still. They concluded that there is no direct relationship between the height and location of the blade on the average Nusselt number. After that, Rashidi et al. (2016) numerically optimized the location and size of the partition in the single slope solar still to achieve the maximum heat transfer rate. Moreover, they performed a sensitivity analysis to obtain the sensitivity of the Nusselt number to the location and size of the partition.

The existing studies within the literature illustrated that the enhancement of productivity of a solar still is an interesting topic for researchers. The technique of partitioning in solar still is introduced as a simple and good method to improve the productivity of solar stills. There is no experimental data in the literature that the researchers can use to validate the accuracy of numerical results for this problem. Accordingly, it would be hard to justify about their claims. This paper tries to fill the existing gap regarding this problem. Moreover, the cost analysis has a key role in the field of solar desalination techniques. Finally, this analysis is arranged for the proposed solar still.

2. Experiment part

2.1. Experimental setup

Two single slope solar stills containing conventional and modified by installing a partition have been fabricated using