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Optimization of partitioning inside a single slope solar still for performance improvement

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HIGHLIGHTS

- Installation of partition leads to increase in vortices number with smaller sizes.
- Smaller vortices provide sufficient pathways to heat exchange in the still.
- There is a rapid change in the temperature near the glass cover or water surface.
- Bottom Nusselt decreases with partition position parameter at high partition height.

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ABSTRACT

In this paper, an optimization procedure is performed by response surface methodology to optimize the position and size of the partition inside a single slope solar still. The partition is installed separately at bottom surface and glass cover of the still to improve the performance. The optimization procedure is performed to determine the maximum Nusselt number as a response. Two-dimensional steady equations with laminar assumption have been solved using a finite volume approach. Analysis is performed for a fixed value of Rayleigh number. Beside this, a sensitivity analysis is performed to calculate the sensitivity of the response (Nusselt number) to the position and size of the partition. Results show that the real optimized parameters for the maximum normalized Nusselt number of bottom installed partition are $X' = 0.23$ and $Y' = 0.18$. These parameters for the the maximum normalized Nusselt number of top installed partition are $X' = 0.53$ and $Y' = 0.56162$. Also, the installation of partition leads to an increase in vortices number with smaller sizes. Smaller vortices provide sufficient pathways to heat exchange and increase the still efficiency.

1. Introduction

Drinking water scarcity is a challenge traditionally. This problem is intensified in recent years due to the population growth, climate change, drought, urbanisation, etc. Beside this, only about 0.014% of global water can be applied directly for drinking water and other organisms.

Therefore, the accessibility to drinking water has become a critical challenge for researchers. There are various techniques and devices for water purification. A type of this device is solar still with high benefits. This device is free of charge for operating cost and there is no pollution during it's operation. Also, it can be used in arid remote areas. Cost savings and reduced consumption of fossil fuels are other advantages of such device. Recently, some researchers used some techniques to improve the performance of this device. Such technological development increases the application of such devices and leads to economic savings for such systems [27–29]. A review on these technologies is necessary to classify them.

Nafey et al. [17]) applied different rubbers and gravels to increase the solar still productivity. They found that the daily productivity of the solar still increases (~20%) with increase in the rubber thickness and gravel size. Rahbar and Esfahani [20]) used the heatpipe and thermoelectric module in a portable solar still (PTSS) to improve the temperature difference between condensing and evaporating zones. They observed a higher temperature difference by using the thermoelectric module in the still. Moreover, they reported that the productivity of PTSS may increase by combination of heatpipe and thermoelectric cooler. Kabeel et al. [14]) improved the performance of a solar still by using nanofluids and providing vacuum. They used different types of nanomaterials with different weight fraction concentrations. Their results revealed that the distilled productivity enhancements were in the vicinity of 133.64% and 93.87% by using cuprous oxide nanoparticles

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Nomenclature

a	number of factors (−)
ANOVA	analysis of variance (−)
b	number of center points (−)
Br	buoyancy ratio (−)
c	concentration of species (kg m^{-3})
C	dimensionless species concentration (−)
Cp	specific heat (J kg^{-1} K^{-1})
CCD	central composite design (−)
CCF	central composite face centered (−)
CFD	computational fluid dynamics (−)
DOE	design of experiments (−)
g	gravitational acceleration (m s^{-2})
Gr	Grashof number (−)
H	height of solar still (m)
L	length of solar still (m)
Le	Lewis number (−)
n	normal direction (−)
Nu	Nusselt number (−)
P	non-dimensional pressure (−)
p	dimensional pressure (*Pa*)
Pr	Prandtl number (−)
Ra	Rayleigh number (−)
Res	response (−)
RSM	response surface methodology (−)
Sc	Schmidt number (−)
T	temperature (K)
u, v	velocity components in x and y directions (m s^{-1})
U, V	dimensionless velocity components in x and y directions (−)
x,y	rectangular coordinates components (m)
X, Y	dimensionless coordinates (−)
X'	dimensionless partition position (−)
Y'	dimensionless partition height (−)

Subscripts/superscripts

ave	average (−)
b	bottom (−)
g	glass cover (−)
l	left (−)
R	right (−)
r	top (−)
w	wall (−)
*	normalized (−)

Greek symbols

α	thermal diffusivity of fluid (m^2 s^{-1})
α_0	average of the results of the replicated center point (−)
$\alpha_1, \alpha_2, \alpha_3$	main half-effects of the coded variables A, B and C (−)
$\alpha_{11}, \alpha_{22}, \alpha_{33}$	squared effects (−)
$\alpha_{12}, \alpha_{13}, \alpha_{23}$	two factor interaction half-effects (−)
θ	dimensionless temperature (−)
θ	sleep of the glass cover (degree)
v	kinematic viscosity of the fluid (m^2 s^{-1})

for the cases of with and without operating the vacuum fan, respectively. In another study, Elango et al. [9]) used different water nanofluids in a single basin single slope solar still. These nanofluids were water nanofluids of Aluminum, Zinc Oxide, Iron Oxide and Tin Oxide. Their research established that the nanofluids created a higher production in the still. Moreover, they showed that using the Aluminum Oxide has 29.95% higher production. Elango and Kalidasa Murugave [8]) investigated the effect of the water depth on the productivity for single and double basin double slope glass solar stills. They considered the water depths of 1, 2, 3, 4 and 5 cm and found that the lowered water depth has a significant effect on increase of the still productivity. Prakash and Velmurugan [19]) performed a review for the influence parameters of the productivity of solar stills. Their review showed that the productivity of the solar stills could be improved by using different modifications in the solar stills such as multi effect distillation with increased condensation surface and corrugated shape structure, weir type stills, thermoelectric cooling, inclined type stills, etc.

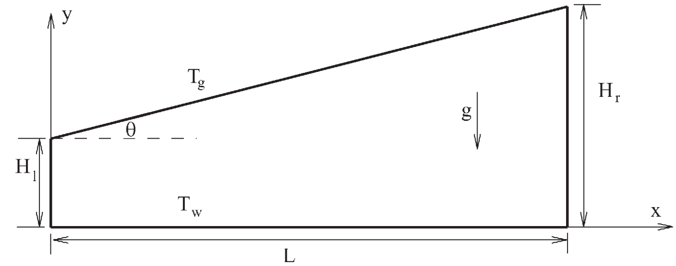

Fig. 1. The schematic view of the solar still.

Some researchers evaluated the performance of different solar stills. Rahbar and Esfahani [21]) determined the productivity of a single-slope solar still by theoretical and numerical techniques. They observed the similar trends for numerical water productivity and convective heat transfer coefficient with experimental ones. El-Agouz et al. [7]) analyzed the performance of an inclined solar still. Their results revealed that the productivity of solar still increases with decrease in water mass and increase in air wind speed. Recently, Rahbar et al. [22]) estimated the water productivity and convective heat transfer coefficient in a tubular solar still. They reported that the productivity decreases in the vicinity of 200% when a glass temperature increases 5 °C.

Some researchers used different fins inside the solar stills to enhance the productivity. El-Sebaii et al. [11]) investigated the effect of fin configuration on the single basin solar still productivity. Findings revealed that the productivity of the finned plate solar still increases with increase in the fin height and vice versa, it decreases with increase in the number and thickness of the fin. Recently, Rajaseenivasan and Srithar [23]) used the circular and square fins in the basin of a solar still. Their study showed a higher productivity for fins covered with wick materials. Also, they observed the same performance for circular and square fins.

Some researchers used optimization techniques in different solar stills. Mashaly et al. [15]) optimized the solar still performance by using an artificial neural network (ANN). The computed results showed that the model (ANN) is accurate for predicting the performance of the solar still with negligible errors. El-Maghlany [10]) optimized a double slope solar still geometry to collect the maximum solar energy.

Response surface methodology is a multivariate optimization technique with a set of mathematical and statistical materials based on the fit of a polynomial expression to the experimental data. Usually, this technique can be used when a response or a collection of responses

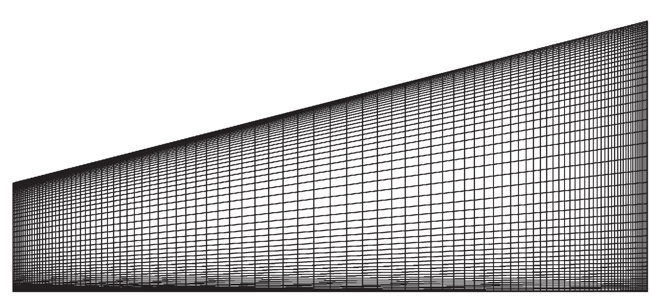

Fig. 2. The mesh distribution inside the solar still.