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Effect of blade installation on heat transfer and fluid flow within a single slope solar still☆

Mojtaba Edalatpour [a], Ali Kianifar [a,*], Shamsoddin Ghiami [b]

[a] Mechanical Engineering Department, Ferdowsi University of Mashhad, Mashhad, Iran
[b] Chemical and Process Engineering Department, University of Leeds, Leeds, UK

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ABSTRACT

In this paper, natural convection heat transfer and fluid flow within a single slope solar still (SSSS) are investigated numerically. To enhance the productivity and performance of this system, the differences of bladed and non-bladed solar stills in terms of vortices resulted from natural convection heat transfer are presented. It is assumed that the flow within the still is two-dimensional, steady and laminar. The numerical method is based on SIMPLEC algorithm and is used for discretization and solving continuity, momentum, energy and concentration conservation equations. The blades are installed on the non-insulated walls of solar stills in two different ways; downward and upward. Results are posed for different blade locations, Rayleigh and Nusselt numbers. Moreover, results depict that exploiting a blade can augment system's performance substantially in comparison with more than one. Comparison of the present numerical approach and well-known published empirical correlations proves the acceptable accuracy of this study.

1. Introduction

Water is a pivotal factor to sustainable development and is a necessity for health, food security and economic development, as well. Even though water covers 71% of the earth surface, less than 0.1% of the existing water is accessible freshwater which is distributed disproportionately [1]. Some observers assessed that by 2025, more than half of the world population will have encountered water-based vulnerability [2]. Thus, it is indispensable to use efficient methods for obtaining potable water.

As supply and transmission of fresh water to inaccessible locations of countries, facing water shortage, is expensive and costly, it is a great idea to exploit solar energy to produce potable water out of saline water. Solar still usage is cheaper, more compatible to environmental circumstances and has simpler technology in contrast to other conventional processes namely reverse osmosis, nanofiltration and multi-stage distillation. Thus, several experimental and numerical investigations were performed in this regard.

Tiwari et al. [3] experimentally evaluated three different types of solar stills in terms of geometry, and concluded that a single slope solar still has better performance compared to double slope one in winter, while the opposite happens in summer. Water depth on heat and mass transfer was shown to be influential in the productivity of solar stills by Tiwari et al. [4]. Samee et al. [5] made a simple basin solar still and reported that the amount of insulation and ambient temperature influences its efficiency directly. Rahim [6] illustrated that utilization of black aluminum plate in the basin and water pumping on the black walls enhanced the water productivity. Al-Hinai et al. [7] showed that solar radiation, wind velocity and ambient temperature can directly influence productivity theoretically. Rheinländer [8] used a finite difference algorithm for solving the governing equations in a solar still. He reported that there is a good adaptation between numerical and experimental results. Papanicolaou and Belessiotis [9] used CFD to study the unsteady behavior of laminar and turbulent flow regime in an asymmetric trapezoidal enclosure. They indicated that the number of multicellular flow field depends on the Rayleigh number and geometry. Omri et al. [10] reported that buoyancy force effects on flow and vortexes behavior inside the stills.

So far, no comprehensive investigations for installation of blades on inner walls of solar stills were studied to the best knowledge of the authors. This article illustrates that positioning blades at various locations has different impacts on heat and mass transfer. Additionally, installation of blades in specific locations with appropriate heights can improve performance and efficiency of single slope solar still since it enhances heat and mass transfer coefficients due to increasing in the number of vortices.

2. Physical description

Geometry detail and thermal boundary conditions of discussed bladed single slope solar still is shown by a schematic diagram in Fig. 1 and Table 1. The solar radiation after reflection and absorption by the glass cover is transmitted inside the solar still. The transmitted radiation is further partially reflected and absorbed by the water surface. These

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* Corresponding author.
E-mail address: a-kiani@um.ac.ir (A. Kianifar).

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Nomenclature

A_s	Area of solar still (m^2)
Br	buoyancy ratio
c	concentration of species ($kg\ m^{-3}$)
c_w	water surface species concentration ($kg\ m^{-3}$)
c_g	glass species concentration ($kg\ m^{-3}$)
C	dimensionless species concentration
C_p	specific heat ($J\ kg^{-1}\ k^{-1}$)
g	gravitational acceleration ($m\ s^{-2}$)
Gr	Grashof number
H_l	height of the left side of solar still (m)
H_r	height of the right side of solar still (m)
H	specific length of solar still (m)
h_c	convective heat transfer coefficient ($W\ m^{-2}\ K^{-1}$)
h_{ev}	evaporative heat transfer coefficient ($W\ m^{-2}\ K^{-1}$)
h_{fg}	Latent heat of vaporization of water ($J\ kg^{-1}$)
k	thermal conductivity ($W\ m^{-1}\ K$)
L	length of solar still (m)
Le	Lewis number
L_v	latent heat of vaporization ($J\ kg^{-1}$)
$\dot{m}$	hourly distillate yields ($kg\ s^{-1}$)
M_{mix}	molecular weight of water vapor–air mixture ($kg\ mol^{-1}$)
$\overline{Nu}$	average Nusselt number
Nu^*	normalized Nusselt number
p	dimensional pressure (Pa)
P	non-dimensional pressure
Pr	Prandtl number
P_g	partial pressure of vapor at glass temperature ($N\ m^{-2}$)
$\dot{q}_c$	rate of convective heat transfer ($W\ m^{-2}$)
P_w	partial pressure of vapor at water temperature ($N\ m^{-2}$)
Ra	Rayleigh number
Sc	Schmidt number
T	temperature
T_g	glass temperature
T_i	mean operating temperature
T_w	water temperature
ΔT	temperature difference
u	horizontal velocity component ($m\ s^{-1}$)
U	dimensionless horizontal velocity component
v	vertical velocity component ($m\ s^{-1}$)
V	dimensionless vertical velocity component
x	horizontal coordinate (m
X	dimensionless horizontal coordinate
X'	The ratio of $\frac{L_b}{L}$
y	vertical coordinate (m)
Y	dimensionless vertical coordinate
Y'	The ratio of $\frac{H_b}{H_{avg}}$

radiations eventually reach the bottom wall and are mostly absorbed. After absorption of the radiation at the basin, most of the thermal energy is transmitted to the glass cover via convection. Hence, the water gets heated.

3. Theoretical background

Conduction, convection and radiation are different modes of heat transfer inside solar stills. Evaporative and natural convective heat transfers are assumed to be independent of radiation heat transfer. The convective heat transfer takes place in form of double-diffusive natural convection within solar still. In the following sections several thermal models and numerical methods are described for evaluating internal heat transfer coefficient.

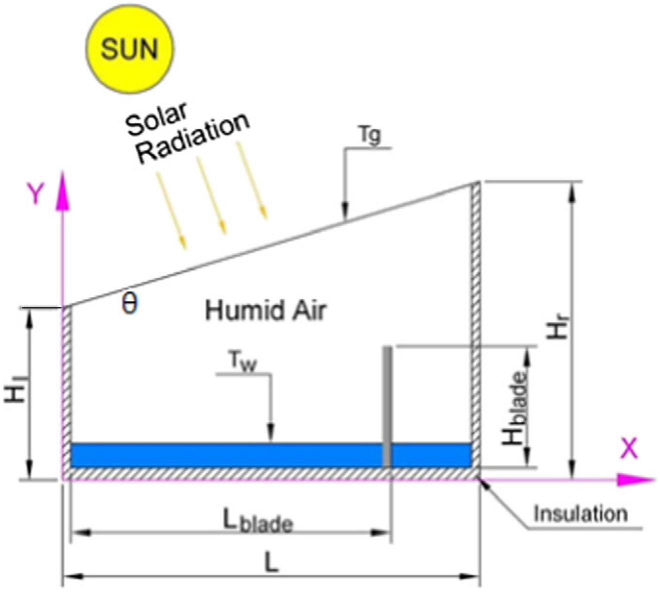

Fig. 1. Schematic and geometry of a single slope solar still.

3.1. Thermal model

Natural convection heat transfer within the solar still is generated by buoyancy due to simultaneous temperature and concentration gradients in fluid. The heat transfer inside the still is responsible for the transportation of the water in vapor form, depositing all impurities in the basin, whereas the heat transfer outside the still is responsible for the condensation of fresh vapor as distillates. Convective heat transfer rate, q_c, from water surface to glass cover is given by:

$$q_c = h_c A_s (T_w - T_g) \tag{1}$$

Where A_s, T_g and T_w are area of solar still, glass temperature and water temperature, respectively. The convective heat transfer coefficient, h_c, is the function of following parameters [11]:

(a) Operating temperature range.
(b) Geometry of still.
(c) Physical properties of the vapor at operating temperature.
(d) Flow characteristics of the fluid.

Afterwards, evaporative heat transfer coefficient, q_{ev}, can be described as below:

$$q_{ev} = h_{ev} A_s (T_w - T_g) = \dot{m}\, L_v \tag{2}$$

Where h_{ev} is convective heat transfer, L_v is latent heat of vaporization and $\dot{m}$ is hourly distillate yields.

3.1.1. Dunkle model

A widely-used experimental equation for assessing heat transfer coefficient within still was developed by Dunkle [12]. This model was

Table 1
Geometry and thermal boundary conditions.

L (cm)	H_l (cm)	H_r (cm)	θ (deg)
43.8	7.5	18.7	14.35