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Numerical study of a double-slope solar still coupled with capillary film condenser in south Algeria

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ABSTRACT

The effect of joining a condensation cell to a single-basin double slope solar still was investigated numerically. Direct solar radiation heated the saline water then evaporated. A fraction of the resulting vapor is condensed on the inner glass cover plate and the rest on the outer metal plate. Solar radiation, ambient temperature and the temperatures at different system components were monitored. The performance of the system was evaluated and compared to that of a conventional solar still under the same meteorological conditions. The proposed prototype functioned perfectly and its daily yield reached 7.15 kg m^{-2} d^{-1}. Results show that the productivity of the present system was about 60% higher than that of the conventional and capillary film types. The contributions of the glass cover, metal plate and condenser plate are 43%, 18% and 39% of the total distillate yield respectively. It was noticed that the productivity of the capillary film solar still was sensitive to the mass flow of the feeding water. It was also found that the absorptivity coefficient and the diffusion gap have significant effect on distillate production of the system.

1. Introduction

In some parts of the world, particularly in the Middle East and North Africa, the production of fresh water is often a serious problem. Algeria is considered a dry country due to the severe scarcity of its water resources. The demand for fresh water is increasing at 4–5% per annum. Water scarcity is aggravated by high population growth. The population is expected to reach 46 million by the year 2020 [1]. The demand for fresh water has largely exceeded the amount that fresh sources can meet. This led to an increasing interest in new desalination technologies in order to fulfill the fast growing socioeconomic needs.

Conventional techniques for desalination can broadly be classified into thermal and membrane based categories. The former class of techniques includes Multi-Stage Flash (MSF) [2], Multi-Effect Desalination (MFD) [3] and Mechanical Vapor Compression (MVC) [4,5]; while the latter type comprises Reverse Osmosis (RO) [6] and Electro-Dialysis Reversal (EDR). These technologies used electrical power [7,8] which is an environmental concern because a large portion of this power is generated by coal or gas based power plants. They are not used in regions with low infrastructure either for the supply in decentralized regions due to their permanent need of qualified maintenance and electricity supply. The small scale example solar desalination is chosen as an alternative solution ever since this technique has proved useful for producing distilled water in large amounts.

Most of the remote, arid regions in the south of the country are devoid of natural fresh water and depend entirely on underground water for drinking and other domestic uses. Numerous low-density population localities lack not only fresh water availability, but in most cases, electrical power grid connections as well. Favorably, these zones profit from an important renewable energy potential; the use of which in water desalination exhibits an interesting chance to offer a secure source of potable water.

The integration of solar energy in desalination and purification of available brackish water seems to be a logical and attractive answer for supplying these small remote agglomerations with fresh water.

For small-scale applications (from 5 to 100 m^3/day water production), the cost of water production systems is much higher than for large-scale systems. The cost of water production for large-scale can go up to US$ 30/m^3 [7] for stations of smaller capacity.

The desalination of brackish or seawater by solar distillation using basin-type solar stills is an operation largely used in the arid and semi-arid areas. These types have the advantage of being simple devices in terms of construction, operation and maintenance. They are cost free energy, environment friendly, usually more targeted

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Nomenclature

a	thermal diffusivity ($m^2\ s^{-1}$)
Cp	specific heat ($J\ kg^{-1}\ K^{-1}$)
D_{cs}	steam diffusivity ($m^2\ s^{-1}$)
d_c	thickness of cell (m)
E	thickness (m)
F	fraction (dimensionless)
Gg	global irradiation ($W\ m^{-2}$)
Gr	Grashof number (dimensionless)
h	length (m)
h	coefficient of heat transfer ($W\ m^{-2}\ K^{-1}$)
h_m	coefficient of mass transfer (ms^{-1})
h_f	latent heat ($J\ kg^{-1}$)
L	length (m)
l_r	width (m)
M	mass (kg)
$\dot{m}$	rate of mass flow ($kg\ m^{-2}\ s^{-1}$)
Nu	Nusselt number (dimensionless)
P	pressure (Pa)
Pr	Prandtl number (dimensionless)
R	constant of perfect gases ($J\ K^{-1}\ mol^{-1}$)
Ra	Rayleigh number (dimensionless)
R_c	ratio (dimensionless)
S	surface (m^2)
T	temperature (K)
t	time (s)
U	heat transfer coefficient ($W\ m^{-2}\ K^{-1}$)
W_s	wind speed (ms^{-1})

Greek symbols

α	absorptance (dimensionless)
β	coefficient of thermal dilatation (K^{-1})
ε	emissivity (dimensionless)
λ	thermal conductivity ($W\ m^{-1}\ K^{-1}$)
μ	dynamic viscosity (Pa s)
ν	kinematic viscosity ($m^2\ s^{-1}$)
$\Re$	reflectance (dimensionless)
θ	angle inclination of glass cover (°)
ϕ	angle inclination of metal plate (°)
ρ	density ($kg\ m^{-3}$)
σ	Stefan–Boltzmann constant ($W\ m^{-2}\ K^{-4}$)
γ	surface azimuth angle (°)
γ_s	solar azimuth angle (°)
η	efficiency (dimensionless)

Subscripts

a	ambient
b	basin liner
ba	from basin liner to ambient
bw	from basin liner to water saline
c	convective
cs	condenser plate
csa	from condenser to ambient
dba	from conductive basin to ambient
e	evaporative
eff	effective
eq	equivalent
g	glass cover
ga	from glass cover to ambient
m	mixture
p	condenser–evaporator metal plate
pc	from condenser–evaporator to condenser plate
Ref	reflect
r	radiative
w	brackish water
wg	from water to glass cover
wp	from water to condenser–evaporator plate
sky	sky

towards poor communities and more importantly, they can run unattended for long periods of time in remote isolated sites.

Recently, numerous researchers are interested in solar desalination. For example, the work on passive solar stills has been reviewed by Malik et al. [9]. Bechki et al. [10] carried out experiments in which they investigated the effect of partial intermittent shading on the performance of a simple basin solar still in south Algeria. Their series of tests consisted in lowering the glass temperature by an intermittent shading of the north glass cover. This procedure resulted in a further 12% enhancement in the daily distillate output. Tanaka et al. [11] constructed and tested a simple solar distiller coupled to a distiller with vertical multi-effect. The distance between the vertical cells was approximately 5 mm. The theoretical estimated daily increase in the total productivity of the distiller was about 15.4 $kg\ m^{-2}\ d^{-1}$ for a number of cells equal to 10 and a space of 5 mm between the walls. Bouchekima et al. [12] presented the results of experiments carried out with a capillary film distiller using solar energy. Boukar and Harmim [13] reported performance evaluation of one-sided vertical solar still tested under desert climatic conditions of Algeria. Their study showed that still output varies between 0.5 and 2.5 $kg\ m^{-2}$ for the fabric surface sponges. The effect of the use of an internal condenser on the performance of a solar distiller was investigated experimentally by A.S. Ahmed [14]. Their results showed that the combination of an internal condenser with the solar distiller improved the performance of a distiller. Abu-Arabi et al. [15] displayed a wide literature survey and modeled a solar still with cooling water flowing between a double glass cover. Fath and Hosny [16] proposed a theoretical study of a single-sloped basin with enhanced evaporation and built-in additional condenser.

The greenhouse solar still types are simple to construct and do not present great technical difficulties. However they present the disadvantage of having a somewhat poor yield and their production remains insufficient. In order to enhance this production, large-sized installations had to be carried out. The present work provides a study of a double slope still joined to a capillary film condenser cell. The meteorological conditions influencing the performance of this distiller were investigated. The performance of the present system was evaluated and compared with that of a conventional type.

2. System description and modeling

Fig. 1 shows a sketch of the solar still used in this study. The system is constituted of coupling between conventional solar still (CSS) and a capillary film solar still (CFSS). The main components of the present system are: The absorber of the (CSS) was blackened on the surface to ensure maximum absorption of solar radiation for effective heating of the water. The base of this assembly was lagged with a thick polystyrene insulation. This base was covered with glass orientated in the south and a metal plate orientated in the north. A wick was homogenously placed on the surface of the metallic plate. The latter was tightly held with a wooden frame and covered with a glass cover which was sealed tightly by silicone sealant to prevent any vapor leakage.