Energy Conversion and Management 85 (2014) 112–119

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Simulation study of a capillary film solar still coupled with a conventional solar still in south Algeria

Moussa Zerrouki [a,*], Noureddine Settou [b], Yacine Marif [a], Mohmed Mustapha Belhadj [a]

[a] Unité de Recherche en Energies Renouvelables En Milieu Saharien, URERMS P.O. BOX 478, Center de Développement des Energies Renouvelables, CDER, 01000 Adrar, Algerie
[b] Laboratory of Valorization and Promotion of the Saharan Resources 'VPRS', Kasdi Merbah University, P.O. BOX 511, Ouargla, Algeria

ARTICLE INFO

Article history:
Received 6 February 2014
Accepted 8 May 2014
Available online 13 June 2014

Keywords:
Solar distillation
Solar stills
Capillary film
Surfaces ratio
Numerical simulation

ABSTRACT

This work presents a numerical simulation of capillary film solar still (distiller) coupled in series with another conventional solar still. Different transfer phenomena of heat and mass are considered to evaluate the daily distillate production. The study takes into account the quality of brackish water with moderate salinity in Adrar city (south of Algeria). The performance of the system is evaluated and compared with that of conventional solar still under the same meteorological conditions. A numerical simulation is carried out to appreciate the developed model and to optimize the relationship between both distillers collecting surfaces. The obtained results show that the system daily production is at 54–83% higher than that of the conventional one. In addition, some parameters influences are studied to define the optimal operating conditions for the present system. For the first solar still, the inclination angle and surfaces ratio have a significant effect on distillate production. Brine flow rate and wind speed have slight effect on still production.

1. Introduction

In Algeria, lack and scarcity of drinking water due to dryness and the overexploitation of the underground waters becomes progressively an important issue. However, in the south of the country, drinking water missing, exist a considerable amount of ground water, this non renewable resource is characterized by high temperature which can reach 60 °C, a salinity of 1–5 g/l and a depth varying between 100 and 1000 m [1]. The department of Adrar lies in the far South west of Algeria occupies 427.968 km^2 that represents 17.98% of Algeria territory. It is located in a hot dry area at 27° 53′N latitude and 0°17′W longitude, at 264 m above sea level. Typical values of the maximum and minimum temperatures and humidity in July are 45 °C, 27 °C and 20% respectively [2].

Adrar region has the following favorable advantages for solar distillation:

- High ambient temperature average which can reach 34 °C in July.
- High solar radiation intensity.
- Large number of clear and semi clear days throughout the year.
- A low salinity of ground water less 3 g/l.
- This region is characterized by very vast territory where the population is scattered in small agglomerations (294 ksour) and villages.

In Adrar region solar distillation can be considered not only as a solution which respect environment and economic, but also as a real alternative to the traditional energy resources of origin fossils.

In the literature, there are many works concerning the conventional solar distiller. Tiwari and Tiwari [3] determine as standard productivity 1.7 kg/m^2 Day in New-Delhi, India. Improves distiller production in several configurations. Velmurugan et al. [4] study the increase in absorber plate area and free surface area of water. Boubekri et al. [5] treat active solar distillation use, which takes the solar distiller basin as integrated part of collectors group coupled with photovoltaic-thermal solar water heater. Adhikari et al. [6] recover the released vapor latent heat to improve distiller production. Tanaka et al. [7] investigated a multiple-effect solar distiller with a triangle cross-section, which is consisted of a horizontal basin liner, their experimental results show that distiller with 5 mm diffusion gaps between 11 partitions produces distillate water at 14.8–18.7 kg m^{-2} day^{-1}. Bouchekima [8] proposes distillers with multi effects using capillary films composed by rugged design of high efficiency multi-stage solar distiller; under the climatic conditions of Touggourt city (south of Algeria) this conception produces more than 20 l/m^2 day. Among several researchers

* Corresponding author. Tel./fax: 213 49 96 04 92.
E-mail address: Moussa.Zerrouki@yahoo.fr (M. Zerrouki).

http://dx.doi.org/10.1016/j.enconman.2014.05.062
0196-8904/

Nomenclatures

A	area (m^2)
a	thermal diffusivity (m^2/s)
Cp	specific heat capacity (J/kg °C)
d	distance (m)
D_m	mass diffusivity (m^2/s)
G	solar radiation (W/m^2)
g	gravity acceleration (m/s^2)
Gr	Grashof number
h	heat transfer coefficient (W/m^2 °C)
h_m	convection mass transfer coefficient (m/s)
i	tilt angle (degrees)
L	length (m)
Le	Lewis number
Lv	water vaporization latent heat (J/kg)
m	mass (kg)
M	molecular weight (kg/mol)
M_d	daily distillate yield (kg/m^2)
$\dot{m}$	the mass flow rate of brine (kg/s)
$\dot{m}d$	distillate mass flow (kg/s)
Nu	Nusselt number
P	total pressure (N/m^2)
p	vapor pressure (N/m^2)
Pr	Prandtl number
Q	heat transfer rate (W)
R	surfaces ratio
Ra	Rayleigh number
R_{gaz}	universal gas constant (kJ/kg °C)
Sh	schmidt number
Sc	sherwood number
T	temperature (°C)
t	time (s)
V	wind speed (m/s)

Greek symbols

α	absoptivity
β	thermal dilatation factor(1/°C)
ρ	density (kg/m^3)
ε	thickness (m)
τ	transmission factor
ϵ	emissivity
η	efficiency
λ	Thermal conductivity (W/m °C)
μ	dynamic viscosity (Ns/m^2)
ϱ	conversion rate
σ	Stefan-Boltzmann constant (W/m °C)

Subscripts

a	ambient
ha	humid air
b	basin
c	convection
c	condenser
$CFSS$	capillary film solar still
CSS	conventional solar still
da	dry air
co	conduction
e	evaporation
eff	effective
f	feeding
g	glass
ins	insulation
p	plate
r	radiation
v	vapor
w	water
$(1-a)$	from first glass cover to atmosphere
$(2-1)$	from evaporator to first glass cover
$(2-3)$	from evaporator to condenser
$(3-a)$	from condenser to atmosphere
$(4-a)$	from second glass cover to atmosphere
$(5-4)$	from water to second glass cover
$(5-6)$	from water to Basin liner
$(6-7)$	from Basin liner to insulation
$(7-a)$	from insulation to atmosphere

studied simulation and experimentation of inclined solar water distillation system, Aybar [9] obtains the slope by the use of the wicks and Radhwan [10] obtains the slope of distillation basin. Minasian and AL-Karaghouli [11] present a solar distiller formed by connecting a small conventional basin-type (installed in shadow and having an opaque cover) with a wick-type solar distiller, the total yearly amounts of distilled water indicates that the wick-basin-type produces 85% more than the basin-type and 43% more than the wick-type solar distiller.

In the present work, distiller configuration is constituted by coupling in series a capillary film solar still (CFSS) and a conventional solar still (CSS), to exploit the quantity of outgoing brine of the first distiller. The effect of distiller surfaces ratio on this configuration production is examined. For the distiller, a numerical simulation is carried out using governing equations system with different transfer coefficients. The obtained results are graphically presented and discussed.

2. The system description

In this work, three types of solar stills were investigated in this work under the same meteorological conditions. The first is capillary film solar still, the second is the conventional solar still and the last configuration constituted by coupling in series a capillary film solar still with a conventional solar Still (see Fig. 1). The brackish water supply (1–3 g/l of salts) is carried out using wicks by capillarity effect, brackish water passes in first cell (CFSS) under the plate evaporating. Part of the water evaporates and condenses when it touches the condenser plate, the condensate flows into a condensate channel and is taken out of side of the first cell. The conversion rate in this cell does not exceed 45% under optimal operating parameters (feed flow, inclination angle, the cell form factor) [8,9]. In order to increase this rate, the rest of the non distilled water (1.84–5.5 g/l of salts) , which is hot water at a considerable high temperature 60 °C or more, flows into second cell (CSS). The process of evaporation and condensation to continue in the second cell. The condensate of this cell is separately collected from the first quantity.

3. Mathematical model and resolution of the system

3.1. Capillary film solar still

The energy balance diagram for a distiller with capillary film is shown in Fig. 2.