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Exergy analysis of a passive solar still

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Abstract

This paper presents a steady-state and transient theoretical exergy analysis of a solar still, focused on the exergy destruction in the components of the still: collector plate, brine and glass cover. The analytical approach states an energy balance for each component resulting in three coupled equations where three parameters—solar irradiance, ambient temperature and insulation thickness—are studied. The energy balances are solved to find temperatures of each component; these temperatures are used to compute energy and exergy flows. Results in the steady-state regime show that the irreversibilities produced in the collector account for the largest exergy destruction, up to 615 W/m^2 for a 935 W/m^2 solar exergy input, whereas irreversibility rates in the brine and in the glass cover can be neglected. For the same exergy input a collector, brine and solar still exergy efficiency of 12.9%, 6% and 5% are obtained, respectively. The most influential parameter is solar irradiance. During the transient regime, irreversibility rates and still temperatures find a maximum 6 h after dawn when solar irradiance has a maximum value. However, maximum exergy brine efficiency, close to 93%, is found once $T_{\mathrm{col}} < T_{\mathrm{w}}$ (dusk) and the heat capacity of the brine plays an important role in the modeling of collector–brine interaction. Nocturnal distillation is characterized by very low irreversibility rates due to reduced temperature difference between collector and an increase in exergy efficiency towards dawn due to ambient temperature decrease.

Keywords: Thermodynamics; Solar stills; Exergy; Efficiency; Renewable energy

1. Introduction

Shallow solar stills are commonly used in arid coastal zones to provide low-cost fresh water from the sea. The simplest design of a solar still consists of a rectangular box with a transparent upper cover, Fig. 1. The solar distillation process is as follows: (a) the still is partially filled with brine in the bottom deposit which is a black surface (collector) used to absorb incoming radiation after it passes through the glass cover and the brine, (b) the collector increases its temperature and transfers heat to the brine, (c) water evaporates at the free surface, (d) a natural convection flow of humid air circulating inside the enclosure takes place due to the temperature difference between the free surface of the heated brine and the upper cool cover, and (e) this inclined transparent sheet serves as a condensing plate where the distillate water runs by gravity along its internal face to a small collector channel in the shortest sidewall of the arrangement. Distillate rates close to 5 l/m^{2}day in La Paz, México (24°N latitude) on a sunny summer day can be currently achieved, making the process economically attractive for those water-scarce areas. Looking into the basic phenomena within the still, a highly unstable process, consisting of evaporation, moisture convective transport and condensation is produced. A detailed description of the apparatus and its operation can be found in [1].

Although the basis of solar still modeling are well understood, there are recent studies in this area [2–6] trying to improve heat transfer equations by taking into account all the parameters, conditions and geometric configurations. Most of the models used to study solar distillation are based on a lumped parameter analysis that considers three main subsystems [7–9]:

(1) The collector plate, which acts both as the water recipient and the absorbing surface of radiation.

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Nomenclature

T	absolute temperature (K)
C	heat capacity per unit of area (J m^2 K)
q	heat flux (W m^2)
B	exergy flux (W m^2)
t	time (h)
c	specific heat (J kg K^{-1})
z	brine depth (m)
I	irreversibility rate (W m^2)
G	global solar irradiance (W m^2)
S	entropy (J k^{-1})
A	area (m^2)
x	thickness (m)
H	enthalpy (J)
K	thermal conductivity coefficient (W m^{-1} K^{-1})
h	convective heat transfer coefficient (W m^{21} K^{-1})

Greek latters

ρ	density (kg m^{-3})
ε	emissivity
η	efficiency
Δ	change with time

Subscripts

rw	radiation transfer between the brine and the glass cover
cw	free convection
ev	evaporation
wg	Global heat interaction between the brine surface and the glass cover.
w	brine/interaction between collector and brine
g	glass cover
col	collector
max	maximum value
a	ambient/interaction between the glass cover of the solar still and the surroundings
ins	insulation
S	sun
ref	reference state
ex	exergy
i	initial condition

(2) The brine to be evaporated.
(3) The glass cover where water vapor condensates.

The result is a system of three coupled equations describing the thermal behavior of the three components:

$$\varepsilon_{col} G = h_3(T_{col} - T_w) + \frac{K_{ins}}{x_{ins}}(T_{col} - T_a) + C_{col}\frac{dT_{col}}{dt}, \quad \text{collector,} \tag{1}$$

$$h_3(T_{col} - T_w) = h_1(T_w - T_g) + C_w\frac{dT_w}{dt}, \quad \text{brine,} \tag{2}$$

$$h_1(T_w - T_g) = C_g\frac{dT_g}{dt} + h_2(T_g - T_a), \quad \text{glass cover.} \tag{3}$$

In Eqs. (1)–(3), h_1, h_2 and h_3 are the heat transfer coefficients due to convection, evaporation and radiation between the brine surface and the glass cover, radiation and forced convection between the glass cover and the surrounding air, and free convection between the collector and the brine, respectively. These heat transfer coefficients are constants, independent of temperature. T_{col}, T_w, T_g and T_a are the temperatures of collector, brine, glass cover and ambient, respectively. G is the solar irradiance arriving at the collector surface, ε_{col} is the emissivity of the collector, K_{ins} and x_{ins} are, respectively, the thermal conductivity and

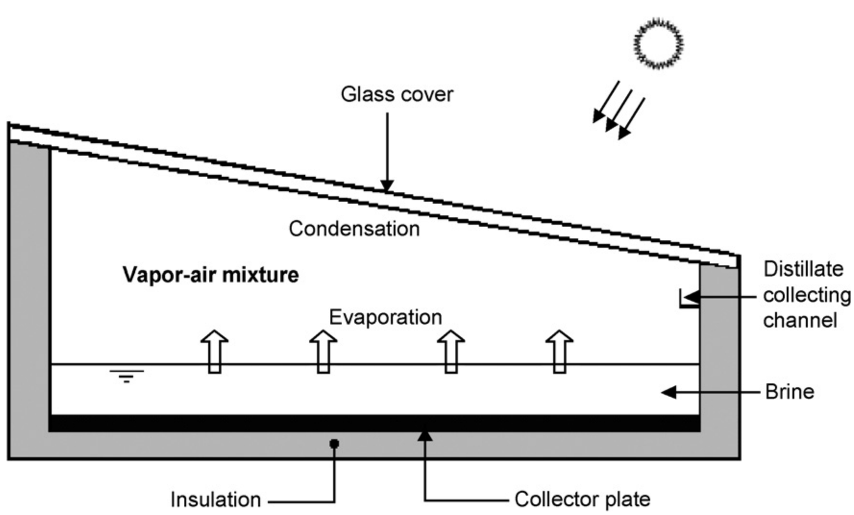

Fig. 1. Schematic view of a solar still.