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Transient heat and mass transfer and long-term stability of a salt-gradient solar pond

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Abstract

In this work, the problem of transient heat and mass transfer and long-term stability of a SGSP has been numerically investigated using a 2D-transient-variable properties model and a finite-control-volume numerical method. The pond, which was assumed initially stabilized with linear temperature and salinity profiles, has been subject to real weather conditions. The numerical model has been satisfactorily validated against measured temperature data. Numerical results have clearly shown that the solar heating effect appears considerably more pronounced during the hot seasons (spring and summer) than during the cold ones (winter and autumn). The existence of two critical zones, one beneath the water surface and the other one located near the pond bottom, has clearly been established at a very early time of operation. It has been found that such critical zones have progressively become more vulnerable in time. Also, the solar heating effect, the heat losses through the free surface as well as the water transparency have an important influence on the pond stability characteristics and its temporal evolution. The presence of a heat extraction with its cooling effect tends to stabilize the pond. Such a beneficial effect, which is mainly observed in the bottom region of the pond, has been found to be more pronounced during the summer than during the winter time. Results have also shown that the pond with good transparency water would likely be more susceptible to develop instabilities than the one with poorer transparency water. Such an effect appears to be more important inside the lower critical zone.

Keywords: Heat and mass transfer; Transient behaviour; Salt-gradient solar pond; Stability; Solar energy; Numerical simulation

1. Introduction

Because of its potential applications in thermal and solar energy systems such as in heating and desalination, the salt-gradient solar pond (SGSP), Fig. 1a, has received much attention from the researchers.

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Nomenclature

C_p	specific heat of the fluid, kJ/kg K
C_s	humid heat capacity of air, kJ/kg K
D	coefficient of salt diffusion, m^2/s
k	thermal conductivity of the fluid, W/m K
P_a	partial pressure of water vapor in ambient air, mm Hg
P_s	vapor pressure of water at the surface temperature, mm Hg
P_t	atmospheric pressure, mm Hg
q_0	incident solar radiation upon the free surface of the pond, W/m^2
Q_c	the convective heat loss, W/m^2
Q_{ev}	the evaporation heat loss, W/m^2
Q_r	the radiation heat loss, W/m^2
S	salinity (kg of salt/kg of solution), –
S_h	heat source generating from the solar absorption (Eq. (5)), W/m^3
t	time, s
T	saline temperature, K
T_a	ambient temperature, K
T_g	ground temperature, K
T_{sky}	sky temperature, K
X, Y, Z	spatial coordinates along axes, m
U_g	heat transfer coefficient of the ground, W/m^2 K
V	wind average velocity, m/s

Greek symbols

Φ	relative humidity, –
α	coefficient of thermal expansion, K^{-1}
β	coefficient of salt expansion, –
ε_w	emissivity of the water free surface, fixed to 0.97, –
λ	latent heat of evaporation of water, kJ/kg
μ	extinction coefficient (Eqs. (4) and (5)), m^{-1}
ρ	fluid density, kg/m^3
σ	Stefan–Boltzman constant, W/m^2 K^4

Subscripts

a	ambient condition
g	ground
r	reference condition (293.15 K)
s	surface

In the past, many experimental solar ponds have been constructed, operated and instrumented around the world; see in particular (Folchitto, 1997; Alagao, 1994; Al-Marafie, 1991; Reid, 1989; Joyce, 2001). The temporal behaviors of the thermal field within the pond and the effects due to a strong wind on the mixing of the surface zone as well as on the gradient zone have been studied for solar ponds located in an arid region (Al-Marafie, 1991). Many analytical and numerical works have been published in the domain as well, shedding interesting insight into the thermal behaviours and performance of a SGSP under various