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Comparison of three solar ponds with different salts through bi-dimensional modeling

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Abstract

We consider three experimental small solar ponds (1 m × 1 m × 1 m) each pond contains one of the following salts, namely NaCl, Na_2CO_3 and $CaCl_2$ respectively. The thermal behavior of these three ponds is being investigated numerically and experimentally over a period of 28 days. A bi-dimensional heat diffusion equation has been resolved numerically using the finite differences scheme of Crank–Nicholson. The experimental results show a good agreement with those obtained by simulation with an error of less than 1.5%. This study shows that $CaCl_2$ pond responds thermally more quickly than the two other ponds without reaching saturation. This extends further the applications scope with possible higher temperature despite relatively its higher cost which deserves further investigation.

Keywords: Salt gradient solar pond; Sodium carbonate; Calcium chloride; Bi-dimensional heat diffusion equation; Small solar pond

1. Introduction

Since the oil crisis of 1973, the price of oil, characterized by an almost permanent instability, has continued to rise. Besides, the global warming problem places emphasis on the necessity to improve and to intensify the use of the renewable energy. Such a move would conserve the environment and delay the exhaustion of hydrocarbons. These latter would no longer be required as source of energy.

The substitution of non-renewable fossil energy is a major challenge for humanity in the years to come, not least due to the undesirable emission of CO_2 leading to the 'greenhouse effect'. Therefore, it becomes crucial to replace this energy by renewable and appropriate sources. In this context solar energy, by virtue of its abundance (average of 800 W/m^2) and its omnipresence, is potentially interesting to investigators in the renewable energy field.

Numerous earlier studies have shown that it is possible to exploit the solar energy by transforming it into various forms: electrical (photovoltaic), thermal (generation of vapors and other effects), chemical, etc. But in spite of its abundance and availability solar energy has not been able to displace fossil fuel energy, mainly because of its intermittent character requiring storage equipment of high fixed and operating cost. The salinity gradient solar pond (SGSP), being simultaneously a collector and a storer of energy in the form of heat, is an interesting option in the

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Nomenclature

C	concentration of the brine (kg/m^3)
C_p	specific heat (kJ/kg °C)
h	heat transfer coefficient (W/m^2 °C)
k	heat conductivity coefficient (W/m °C)
q or Q	heat transfer (W/m^2)
s	salinity of the brine (%)
T	temperature; true measured temperature (°C)
t	time (s)
η	amplitude coefficient of transmission function
μ	extinction coefficient of transmission function (m^{-1})

ρ	density (kg/m^3)
$\overline{T}$	average or mean value of T
σ	standard deviation of T
σ_m	standard error (the error in the mean)
T	true measured temperature

Subscript

a/amb	ambient
s	surface

field of solar energy harnessing with a reasonable overall cost. For temperatures up to 100 °C the SGSP is the least expensive means of energy storage known nowadays (Agha, 2009).

The idea of the solar pond appeared in 1902 when Kalecsinsky (Tundee et al., 2010) observed in Transylvania (Hungary) that in the natural salt lake, the fluid temperature at a depth of 1.32 m reached 70 °C in summer and 26 °C in winter. This observation spawned the idea of creating artificial ponds with a salinity gradient for the collection and storage of solar energy.

The solar pond with salinity gradient consists of three superimposed zones (Fig. 1). An Upper Convective Zone (UCZ), located at the surface, can have a thickness of some centimeters. This zone is usually slightly or not salty at all. A Lower Convective Zone (LCZ) of greater thickness is generally saturated of salt and thus, with its highest density, lies at the bottom of the pond. These two zones are separated by a third zone called the Non-Convective Zone (NCZ) or the zone of salinity gradient. This zone is itself composed of several layers of increasing salinity toward the bottom. Thus the salinity gradient created prevents theoretically any natural global convection.

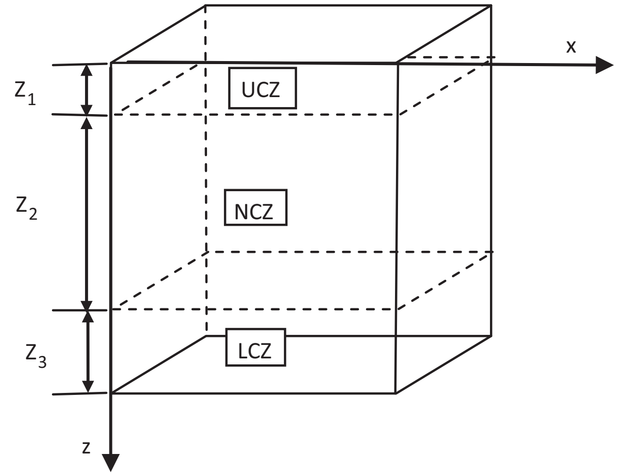

Fig. 1. Different zones of the solar pond.

The amount of sun rays reaching the LCZ is partially absorbed and converted to heat. This heating up increases the LCZ volume, and therefore, its density decreases. Nevertheless because of its highest salinity, its density remains higher enough to be able to rise. Consequently the LCZ mass of water remains at the bottom of the pond accumulating heat because any natural convection is blocked. This phenomenon occurs also between the NCZ layers where the convective currents are impeded by the salinity gradient. So the NCZ, due to its transparency, allows the solar radiation to pass through it to reach the LCZ. Once this radiation is absorbed and transformed to heat, this latter can no longer escape via the natural convection. Therefore, the NCZ is playing the role of something akin to a “thermal diode”.

Several researchers have studied various aspects of this type of solar energy storage together with means to extract and use this energy. The NCZ is the ‘milking system driving force’, i.e. it is the most important element of the pond and has been the subject of the majority of research in this domain.

The most frequently used salt in solar ponds is NaCl; but other salts have shown their readiness to form salinity gradients in a solar pond. Therefore, various salts were tested to study their effects on the performance and stability of a SGSP and the effect of this latter on the environment.

Jain and Mehta (1980) used KNO_3 instead of the conventional NaCl because it differs from the latter by the fact that its solubility depends strongly on the temperature. In Hull (1989) demonstrated the detrimental effect that NaCl could exert on farmlands; he preferred salts of ammonium (sulfates, nitrates, phosphates, and chlorides) which are not harmful to the ground and to the subterranean waters in the event of a disastrous leak.

In Hull (1989) showed that $(NH_4)_2SO_4$ exhibits similar thermal behavior and hydrodynamics to NaCl, but has greater stability at higher temperatures within the LCZ, reaching 83 °C. Vinter et al. (1988) have used $KAl(SO_4)_2$, $12H_2O$ in their saturated pond. They found that the stability is permanent only at a certain level of temperature. In Subhakar and Srinivasa (1991) carried out experiments