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Construction of sustainable heat extraction system and a new scheme of temperature measurement in an experimental solar pond for performance enhancement

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Abstract

This paper describes the authors' experience of constructing a 113 m^2 solar pond at Umm Al-Qura University, Saudi Arabia. The work demonstrates the technical viability of solar pond technology in the Middle East. A sustainable system for heat extraction from the experimental pond was designed and implemented. A new scheme for the measurement of temperature throughout the pond was also introduced for the purpose of further enhancing performance. The aim of this research is to develop an operational protocol which achieves high levels of thermal and mechanical efficiency and within which salt is conserved by first concentrating the surface discharge of saline in an evaporation pond followed by its re-circulation to the base of the pond via a salt charger.

Keywords: Aqueous sodium chloride; Heat extraction; Temperature monitoring system; Solar pond; Salt-gradient

1. Introduction

This investigation encompasses basic research in respect of the initiation and development of the salinity and temperature profiles of a salt-gradient solar pond, and also applied research in respect of issues such as power generation, industrial process heating and water desalination.

The primary objective of this paper is to explain the authors' experience of constructing and preliminary operation of a considerably medium-size experimental solar pond (113 m^2). Thus, the feasibility of solar pond technology in the Middle East is technically revealed. It is of great interest of this research to build up an operational procedure that can achieve high levels of thermal and mechanical efficiency within which salt is conserved by first concentrating the surface discharge of saline in an evaporation pond followed by its re-circulation to the base of the pond via a salt charger.

1.1. Background

The terminology *solar pond* refers to a salt lake that is managed to act as a large, low cost, collector of solar energy (Enersalt, 2016) via the very low cost production of hot saline. This cheap heat can be used

(i) Directly to warm farm buildings, aquaculture systems, glasshouses or for other rural, industrial or municipal purposes (*e.g.*, to heat public swimming pools);

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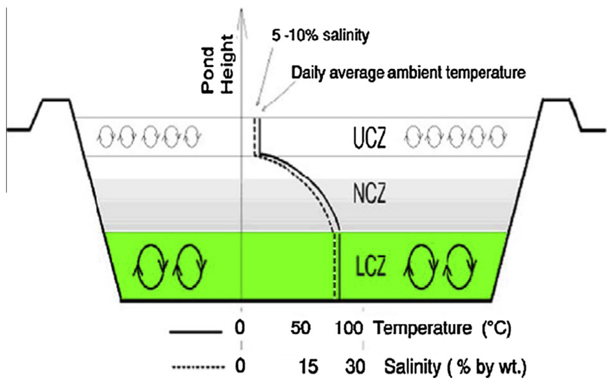

Fig. 1. Salinity and temperature profiles in a salt-gradient solar pond (Leblanc et al., 2011).

(ii) To desalinate water;
(iii) To produce electrical power for remote areas.

Any lake typically absorb solar energy in the form of heat. Normally, this heat is lost as warm water rises to the surface of the lake and cools by radiation, convection and evaporation. Water, however, is a poor conductor of heat, and so if this natural circulation is stopped by the presence of a salinity gradient that causes the fluid density to increase with depth, then heat can be trapped at the bottom of the lake (Enersalt, 2016). A solar pond constructed in this way typically comprises a non-convective zone (NCZ), or barrier zone, sandwiched above by a relatively shallow upper convective zone (UCZ) of low salinity and below by a lower convective zone (LCZ) of high salinity. Solar radiation reaching the bottom of the pond is trapped in the LCZ (or storage zone) for later extraction (Leblanc et al., 2011), first because the NCZ contains a sufficiently strong downwards salinity gradient to suppress convection (Hull et al., 1989), and second, because the thickness of the NCZ in combination with the poor thermal conductivity of saline constitutes a thermally insulating layer. Fig. 1 shows typical salinity and temperature profiles in a non-convective salt-gradient solar pond (Leblanc et al., 2011).

Water temperature within a solar pond largely increases with depth and can exceed 100 °C under favorable circumstances, but temperatures exceeding 80 °C are common place within the tropics. In Southern Australia, 65 °C is easily achievable even during winter (Enersalt, 2016). The primary difficulty in the efficient operation of a solar pond is to extract heat at the optimal rate throughout the year without causing the pond to boil or 'turn over'. Both of these events would destroy the integrity of the pond as a source of heat because each would cause all stored heat to be lost by convection. Solar ponds have several important advantages (Enersalt, 2016).

(i) The heat storage is massive and the energy is available for 24 h a day. Hence, a solar pond can operate as a source of 'base-load' power: no batteries or other storage mechanisms are needed.
(ii) Solar ponds can have a very large surface area for a low cost of construction. The amount of thermal energy storable in the pond is directly proportional to its surface area.
(iii) The major production of thermal energy coincides with the period during which there is usually peak demand for electrical-power, *i.e.* in mid-summer.

1.2. Types of solar ponds

Solar ponds are divided into two primary categories, namely non-convecting ponds which reduce heat losses by inhibiting convection within the pond, and convecting ponds, which reduce heat losses by placing a cover over the surface of the pond to hinder evaporation (USA Dept. of Energy, 2015).

1.2.1. Non-convecting ponds

1.2.1.1. Salt-gradient pond. Salt-gradient ponds have three distinct zones each containing brine (typically sodium or magnesium chloride) of different concentrations, see Fig. 1. Each zone absorbs incident solar radiation with the maximum storage of heat and highest temperatures being achieved in the bottom zone of the pond. Heat is extracted from the pond by either pumping the hot brine from the base of the pond through an external heat exchanger or evaporator, or by means of a heat transfer fluid which is pumped through a heat exchanger facility in the LCZ (USA Dept. of Energy, 2015).

1.2.1.2. Membrane pond. A membrane pond inhibits convection by physically separating the layers with thin transparent membranes.

1.2.2. Convecting ponds

1.2.2.1. Shallow pond. A shallow pond consists of pure water enclosed in a large bag that allows convection but prevents evaporation. The bag has a blackened base, rests on a thermally insulating material and is glazed on top with either glass or plastic sheeting. The sun heats the water in the bag during daylight hours, while during night hours the hot water is pumped into a large heat storage tank to minimize heat losses. In practice, however, the development of shallow solar ponds has been limited by excessive heat losses when pumping the hot water from the bag to the storage tank.

1.2.2.2. Deep salt-less pond. A deep salt-less convecting pond differs from a shallow solar pond only in the respect that the water is not pumped into and out of storage. Deep salt-less ponds are covered by double-glazing which is further covered with insulation to reduce heat losses during night hours, or when solar energy is unavailable (USA Dept. of Energy, 2015).