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Thermal performance of 500 m^2 salinity gradient solar pond in Granada, Spain under strong weather conditions

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ABSTRACT

In this study, an experimental investigation of temperature performance and efficiency of an industrial solar pond during strong winter conditions is presented. Several temperature sensors connected to a data logger were used to measure the temperature gradient in a 500 m^2 solar pond. During the winter 2015 there was a snowfall in the solar pond of Granada (Spain), reaching a minimum air ambient temperature of −2.4 °C. The temperature of the storage zone in Granada solar pond remained constant (around 40 °C) indicating the system responds positively to weather variations and confirming the fundamental role of the salinity gradient as a thermal insulation layer. The stored energy during January 2015 was 13.3 GJ, the weekly efficiency reached 10% and finally, the solar pond was able to provide 247.1 MJ to the flotation unit during the week of the snowfall.

1. Introduction

World is now facing challenges in meeting its energy demand through burning fuels. Elevated level of CO_2 in the atmosphere is contributing to climate change. Therefore, there is an urgent need to conserve energy and move towards clean and renewable energy sources. Thermal energy storage is a key function enabling energy conservation across all major thermal energy sources, although each thermal energy source has its own unique context. Absorbing and storing the solar energy is the most important challenge in this field. Different collectors can be used for absorbing the solar energy for different purposes such as power generation, desalination, water heating, space heating, etc. A solar pond is a low cost solar collector for collecting and storing the thermal energy for a long period of time (Khalilian, 2017; Swift et al., 1987).

The solar pond is a technology that meets all requirements to be considered an energy storage device. It can store solar energy, charging during the months of high solar incidence (Spring-Summer), storing the energy through the time and making possible its use when it is requested. In broad terms, a solar pond is a large body of water that collects and stores solar energy in the form of heat.

A typical salinity gradient solar pond (SGSP) consists in three distinct zones (Zangrando 1980; Tabor & Weinberger 1981). The surface area formed by fresh water or low salinity water is called upper convective zone (UCZ) and it is a zone of constant temperature, close to the air ambient temperature, and salinity, between 2 and 3%. The thickness of this area varies from 0.1 to 0.4 m.

Below this UCZ, there is an intermediate zone consisting of several layers with different density. The brine density gradually increases towards the bottom of the pond causing a concentration gradient. This gradient prevents the occurrence of convection currents and, as a result of solar energy absorption, a gradient of temperature is also established. The gradient zone is known as a non-convective zone (NCZ) and it is the key of this technology. The thickness of this intermediate area ranges from 1 to 1.5 m. The lower zone has the highest density (highest salinity content), near saturation, and it is known as low convective zone (LCZ). This zone acts as a thermal storage with temperature ranging between 50 and 90 °C depending on the size of the pond.

In the last years, several studies have been carried out to analyse and evaluate the performance of salinity gradient solar ponds and to increase their overall performance. Experimental studies have focused on (i) alternative applications (Zhang et al., 2016; Rahaoui et al., 2017; Ziapour et al., 2017; Karakilcik et al., 2018); (ii) the addition of heat from external sources (Ganguly et al., 2017); (iii) the performance analysis to enhance the overall efficiency (Sayer et al., 2108; Simic and George, 2017; Abdullah et al., 2017; Torkmahalleh et al., 2107; Bozkurt and Karakilcik, 2015a); and (iv) the analysis of exergy efficiencies (Njoku et al., 2017; Khalilian, 2017a,b; Bozkurt and Karakilcik, 2015b).

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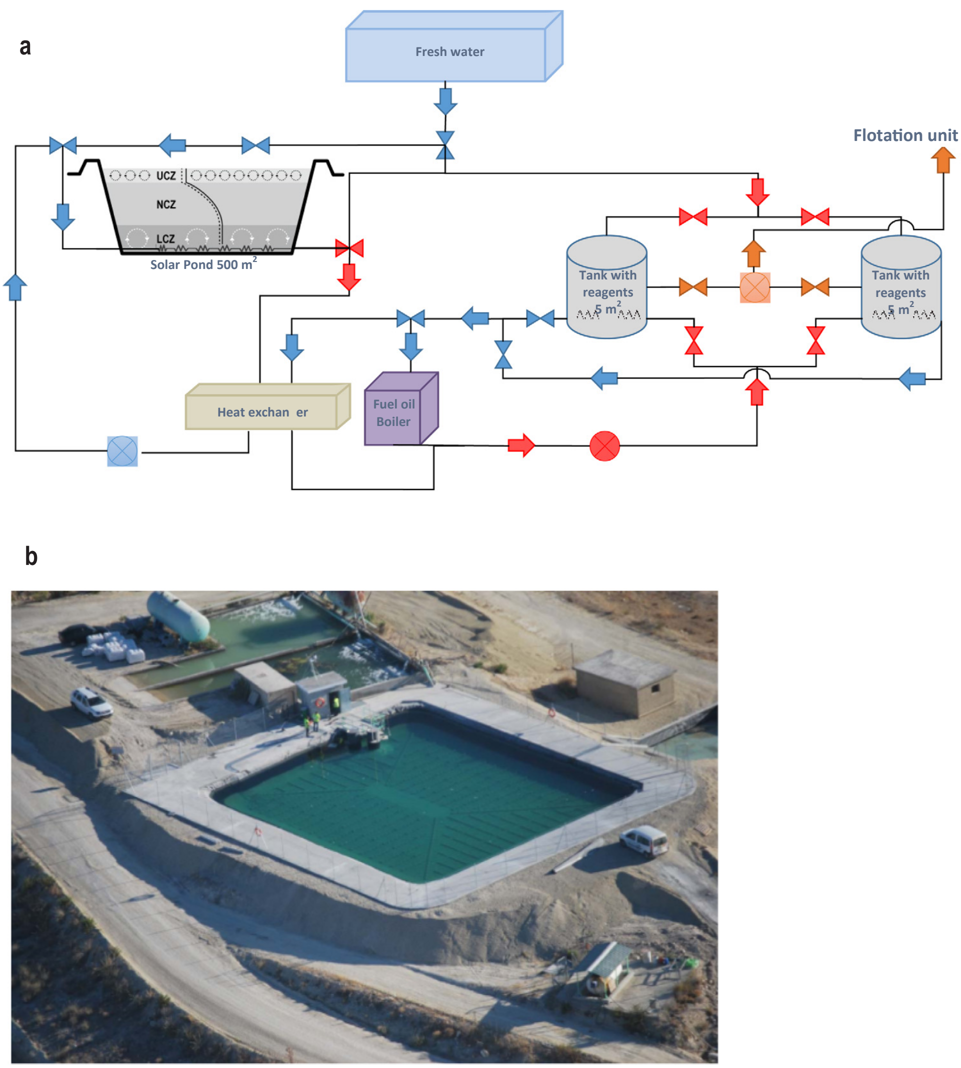

Fig. 1. Schematic view showing: (a) the integration of the solar pond in Solvay facilities and (b) view of the 500 m^2 solar pond at Solvay Minerales facilities (Granada, Spain).

The weather conditions determine the performance of any solar pond facility and can affect its long-term storage capability. Solar radiation, wind, heavy rain can cause instability in the system and make its efficiency decrease. The aim of this study is to evaluate a 500-m^2 industrial solar pond in Granada (Spain) during an event of extreme weather conditions of snowfall during the winter of 2015. The present note studies the influence of the weather conditions on the storage capacity and on the thermal efficiency of the solar pond. The rationality of the analysis is to evaluate if the technology of solar ponds is able to store energy even in extreme weather conditions and continue to provide the energy required in the flotation unit of the mining facility. This is of great interest in terms of the operation, as well as the ability to supply energy to an external application under unfavourable environmental conditions.

2. Materials and methods

In 2014, a salinity gradient solar pond was constructed in the Solvay Minerales facilities in Granada (South Spain). The solar pond design, construction and operation was described by (Alcaraz et al., 2018): The solar pond was constructed to deliver the heat needed to preheat the water (> 60 °C) used in the mineral flotation unit. Some features of this solar pond are: the total area of the pond is 500 m^2 (20 × 25 m) with a depth of 2.2 m. The thickness of the LCZ, NCZ and UCZ was 0.6 m, 1.4 m and 0.2 m, respectively. The heat extraction was carried out through a heat exchanger (PE pipe with an internal diameter of 28 m) located at the LCZ with a total length of 1200 m, which was divided into six independent spirals of 200 m. The solar pond is installed in a mine facility devoted to produce celestine ($SrSO_4$). The processed rock, with a celestine content of 30–50%, is milled and then concentrated up to a content of 90% by using a flotation stage. The aqueous solution containing the reagents should be heated to 60–65 °C. Before the installation of the solar pond, this was carried out using a boiler fed with gasoil. The solar pond was integrated with the flotation unit by connecting a pipe from the freshwater tank that travels through the LCZ of the solar pond and joins the existing pipe line. A view of the experimental solar pond in Granada is shown in Fig. 1.

3. Thermal efficiency of a salinity gradient solar pond

The solar energy can be collected and stored by the salinity gradient solar pond as follows, when solar radiation is incident on the solar pond, part of the radiation is reflected away from the top surface while most of the incident sunlight is transmitted down through the top surface of the UCZ. A fraction of the transmitted radiation is rapidly absorbed in the surface layer. However, this absorbed heat is lost to the atmosphere by convection and radiation heat transfer. Some of the remaining radiation is absorbed in the middle NCZ before the rest of the