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Zabuye Salt Lake Solar Pond in Tibet, China: Construction and Operational Experience

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ABSTRACT

We describe the construction of the Zabuye Salt Lake solar pond and our experience during its operation. The salinity gradient was experimentally determined in the pond, which has a surface area of about 3588 m^2, at different operation conditions and modes of operation. The method for establishing a salinity and temperature gradient can save large amounts of fresh water during the establishment of a temperature and salinity gradient in a solar pond. A technology to control solar pond operation was developed on the basis of our experimental results and is now being used to operate the pond.

INTRODUCTION

The structure and basic properties of solar ponds have been studied in China since about 1977 (Xu & Li 1983). Experiments have been performed in a wide geographical area (Figure 1) including Zhengzhou, GanSu, BeiJing, GuangZhou, GuangXi, and other sites (Song et al. 1984; Meng & Zheng 1991; Zheng & Meng 1991; Wang et al. 1992; Li 1994, 1995). The mechanism of operation, the heating regime, and the possible fields of application were reported by Li (1989, 1995). These studies have shown that solar ponds can be applied to supply heat to a marsh gas pool used to produce methane gas from organic waste and to aquaculture ponds. In practice, solar ponds have been successfully applied in the production of Glauber's salt in XinJiang (Yang et al. 1990; Ma et al. 1998; Ding et al. 1997; Ding 2002, 2003) and in aquaculture during winter in ShanDong (Chao & Song 2003). Solar ponds have also been successfully used for the production of lithium carbonate in Tibet since 2002 (Luo 2003a, 2003b).

Zabuye Salt Lake is located in central Tibet (Figure 1), about 1050 km from Zabuye in the direction of Lhasa, at an altitude of 4421 m. The air in this area is very dry. The lake brine is hydrochemically unique, forming a comparatively complex and special mineral assemblage characterized by alkaline minerals rich in lithium, boron, potassium, and sodium carbonate. The lake brine stores a huge amount of lithium carbonate in the form of the recently named mineral zabuyelite (Li_2CO_3) (Zheng et al. 1989). The average annual temperature is about 2.2^oC with about 229 days per year below freezing. As a result of the high insolation in the Zabuye Salt Lake area, there are about 248 days of sunshine per year, the highest radiation is about 10^7 kJ m^{-2} yr^{-1}.

Figure 1–The location of experimental solar ponds in China operated since about 1977.

Solar energy is the first economic alternative energy resource for exploiting the salt lake due to its remote location and the local climate. Mian-ping Zheng first suggested in 1996 that solar ponds could be used to exploit the lithium resource from Zabuye Salt Lake. Later, a solar pond was constructed and tests were initiated, and a pond with surface area of 40 m^2 and a depth of 1.4 m was constructed in 1999. This pond was used to study the possibility of supplying the heat necessary for producing lithium carbonate (Zhao 2003; Zhao et al. 2004). In 2000, the construction of a solar pond with a surface area of 1250 m^2 and a depth of 2.5 m was started near Zabuye Salt Lake as a collaborative effort between the Chinese Academy of Geological Sciences (CAGS) and the Tibet Zabuye High-Tech Lithium Industry Company Ltd. (ZBY). In this phase of the study it was shown that the solar pond could be directly used for the production of lithium carbonate (Luo 2003a, 2003b; Luo & Zheng 2004a, 2004b). A large solar pond for producing lithium carbonate was built in October 2002 with a surface area of 3588 m^2 and a depth of 4 m resulting from collaboration between Tianjin University of Science & Technology, ZBY and CAGS.

To operate the solar pond, the bottom 2-2.5 m was filled with saturated lithium carbonate brine to form the lower convective zone (LCZ). The upper part of the pond was filled with fresh water for establishing the non-convective zone (NCZ). After the NCZ layer is formed, the fresh water was filled to a depth of about 25 cm. This newly formed fresh water layer is called the upper convective zone (UCZ). The distribution of temperature and salinity in the pond, the mode of establishing the salinity gradient and the way the stability of the pond is maintained are very important for the recovery rate of the lithium carbonate and the production capacity of the pond. The method of the LCZ, NCZ and UCZ development will be discussed in following sections.

In this work we analyzed the temperature and salinity distribution in the pond in an attempt to develop a suitable method for establishing the salinity gradient and maintaining its stability.

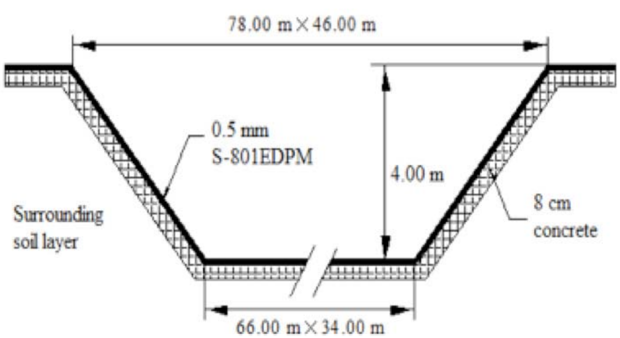

Figure 2–Dimensions of the Zabuye Salt Lake solar pond.

Construction of the Solar Pond

A barren tract of hilly land was available for construction of the solar pond on the southwest of Zabuye Salt Lake. The configuration of the "Zabuye Salt Lake solar pond" is trapezoid as shown in Figure 2. The dimensions of the pond are: bottom 66 x 34 m; surface 78 x 46 m, area 3588 m^2, and depth is 4 m. The slope of the side wall is 1.5:1. The soil was properly compacted after excavation according to the designed size. The pond bottom and the side surface were covered with an 8 cm thick layer of concrete. To reinforce the concrete surface of the pond, a steel grid was added in the corners and in the middle part of the pond bottom. The concrete surface had to be very smooth to affix a 0.5 mm thick sheet of S-801EPDM (Ethylene-Propylene-Diene-Monomer), applied to prevent brine leakage.

Experimental Design and Methods

To monitor the operation characteristics of Zabuye Salt Lake solar pond, an automatic temperature measurement system was installed prior to the start of operation of the pond. It included two digital thermometers, 32 thermistors, and a computer with a suite of control software. Every minute the system recorded 32 channels of the temperature profile as well as the soil temperature below the pond (Figure 3). The temperature at the surface of the pond was measured by a floating thermistor, and the surface level was recorded manually. The salinity of samples collected near the location of the temperature sensors was calculated from the specific gravity at 25^{o}C. Specific gravity was measured with an accuracy of ± 0.001, corresponding to an accuracy of approximately ± 0.5% by weight for the salinity values. A weather observation station was established near Zabuye Salt Lake in November 1991. The station provides meteorological data including incident light, hours of sunshine, air temperature, ground temperature, relative humidity, wind speed, rainfall, fresh water evaporation rate, etc.

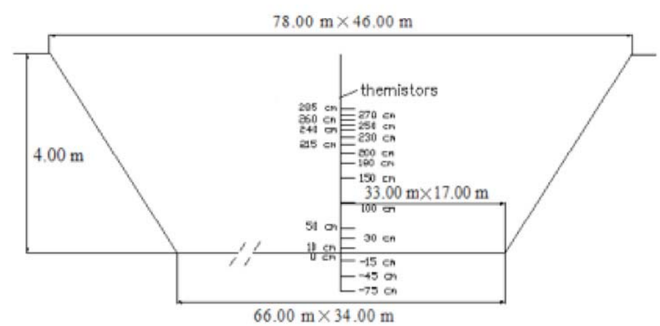

Figure 3–Location of the thermistors for measuring temperature profiles in solar pond.

The Salinity Gradient

Thirty ponds of similar size would be used to produce lithium carbonate at the same time in Zabuye. If the UCZ and NCZ were developed by using fresh water, a large amount of fresh water would be needed. As fresh water is rare in this area, a special method was developed to establish the salinity gradient in the Zabuye Salt Lake solar pond. The gradient has to be composed of three zones. The LCZ brine layer near the bottom is used as the brine for crystallization at increased temperature. To prevent heat loss from the pond, an NCZ has to be established in the pond. To maintain the salinity gradient in the NCZ, there has to be a UCZ layer. To achieve this, the bottom of the pond was filled with saturated lithium carbonate brine (the typical density of the brine is 1.267~1.288 g cm^{-3}) to form an LCZ of about 1.5-2.5 m depth. Then, fresh water was added directly on top of the LCZ layer to form a layer of about 5-20 cm. When the salinity of the surface of the fresh water layer started to increase, an additional similar amount of fresh water was added. Thus, a salinity gradient was gradually established in the NCZ layer. No salinity should be present at the surface of the pond. The final thickness of the UCZ depends on wind mixing, on the heating effect of the pond walls, and on the temperature distribution along the depth of the pond. The thickness of the NCZ layer was about 40-60 cm. It took about a month to establish the gradient. A typical salinity distribution for a perfectly established salinity gradient is shown in Figure 4, with a salt gradient zone (NCZ) of about 40 cm depth, an UCZ of about 25 cm, and an LCZ of about 2.1 m depth

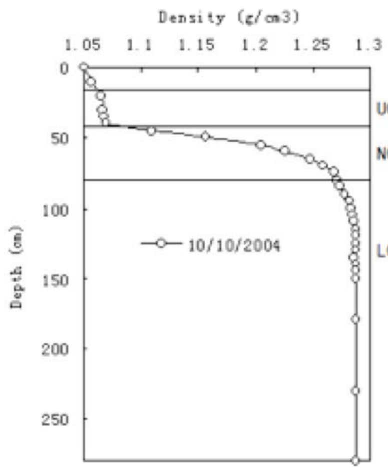

Figure 4–The density profile measured on October 10, 2004 in the pond after establishment of the salinity gradient.

Temperature Distribution

Information on the temperature distribution is important for the production of lithium carbonate. To control the production process, we measured the temperature changes with time and with depth. As climatic conditions changed dramatically over the seasons, the temperature distribution in the pond was also measured in an annual cycle. A typical temperature profile distribution during the operation period is given in Figure 5. The temperatures in the LCZ layer at different times of the year are shown in Figure 6. Figure 5 shows that the temperature increased with time. The lowest temperature is found on the pond surface, and the highest temperature occurs in the LCZ layer. This temperature distribution is very favorable for the production of lithium carbonate. The highest temperatures in the LCZ were observed in August and the lowest values were found in February. Thus, the summer season is more suitable for lithium carbonate production because the winter temperatures are too low for the process.

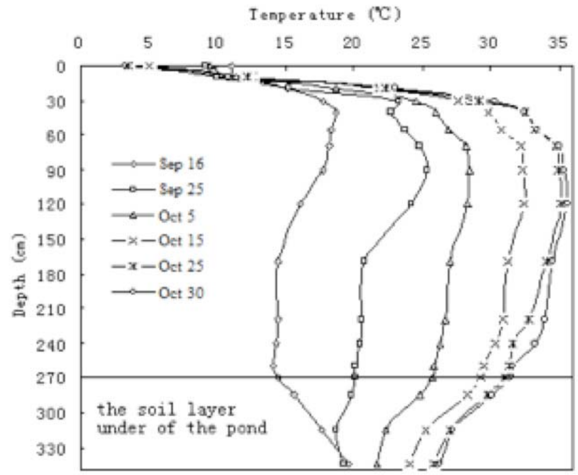

Figure 5–The temperature profile distribution in the Zabuye Salt Lake solar pond during 2004.

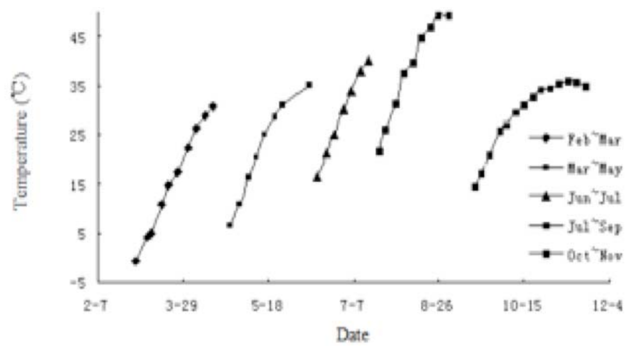

Figure 6–The temperature of LCZ distribution in Zabuye Salt Lake solar pond from February to November 2004.

Operation of the Solar Pond

Zabuye Salt Lake is exposed to strong winds from winter to spring, with wind speed up to 28 m s^{-1} and an average annual wind speed of 6 m s^{-1}. The wind can affect the establishment of the NCZ layer. When wind speed is lower than 10 m s^{-1}, the wind increases mixing of the UCZ and NCZ layers. This shortens the time needed to establish the NCZ layer, saving operation time. On the other hand, at wind speeds exceeding 10 m s^{-1}, the salinity gradient is destroyed and the NCZ layer cannot be established. To prevent destruction of the NCZ layer by wind, the size of the pond should not be too large. On the other hand, the "freeboard", which is the distance between the solution surface in the pond and the top of the pond, reduces the wind speed reaching the solution surface (Atkinson & Harleman 1987). The "freeboard" was controlled at 1.5 m in winter and spring and 1 m in summer and autumn. When the level of the brine in the pond was low, fresh water was added. This mode of operation provided good conditions for establishing the NCZ and maintaining a stable NCZ layer.

Zabuye Salt Lake contains high concentrations of sodium and potassium ions. When the temperature in the solar pond is close to 35-40^{o}C, the β-carotene-rich *Dunaliella salina* (Zheng et al. 1989) will develop in large numbers. This alga produces a red pigment that colors the brine, reducing penetration of solar radiation, decreasing the production rate and lowering the quality of the product. After the solar pond had been in operation fortwo months, the LCZ brine became red, and the temperature did not increase further. To avoid the effect of the carotene-rich *Dunaliella salina* growth on the production of lithium carbonate, the operation period was restricted to one and half months to two months.

The amount of heat stored in the solar pond is influenced by the depth of the LCZ. The deeper this layer is, the lower the temperature that can be reached in the pond, and the smaller the heat loss. The depth of the LCZ also affects the rate of temperature increase. To examine the effect of LCZ depth on the temperature changes in the pond, we experimentally varied the depth of the LCZ. It was found that the same temperature can be obtained for different depths of the LCZ, but the pond has to be operated for a sufficiently long time when the LCZ is deeper (Figure 7). Under optimal conditions, the brine depth (LCZ) is controlled at 2 m from February to May, and at 2.5 m in all other seasons. The depth of UCZ and NCZ are kept the same for different season.

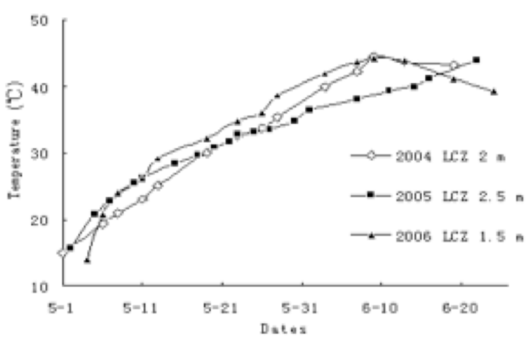

Figure 7–The temperature changes with time of the lower convective zone for different depths in the Zabuye Salt Lake solar pond form 2004 to 2006.

Theoretically, Zabuye Salt Lake solar pond can be operated throughout the year. However, during the winter the pond temperature does not increase sufficiently. Therefore lithium carbonate can only be produced from February until October. The operational period of the solar pond can be divided into four sections: (1) from February to March, for an operational time of 50 days, and temperature rising to 30-32^{o}C; (2) from April to May, for a period of about 45 days, with temperatures increasing to 34-38^{o}C; (3) from May to June, for an operational time of 40 days, temperatures reaching up to 40-45^{o}C; (4) from July to September, for a period of 55 days, with temperature maxima of 45-50^{o}C. The solar pond can be used for sodium carbonate production between October and February because the temperature is very low for producing lithium carbonate.

CONCLUSIONS

In this paper we described the basic construction of the Zabuye Salt Lake solar pond. The salinity gradient in the pond was determined for different operating conditions and methods. We have developed a suitable method for establishing the salinity and temperature gradients. The results prove that the method developed in this work can save large amounts of fresh water when building-up the temperature and salinity gradient in the solar pond. The technology to control the solar pond operation, based our experimental results, is now being used in routine operation of the pond.

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