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Multi-Layer Heat Extraction from Non-Convective Zone of Solar Ponds for Efficiency Enhancement

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Abstract. Heat from solar pond has been successfully extracted from lower convective zone (LCZ). An attempt to extract the absorbed heat in non-convective zone (NCZ) using external heat exchanger is introduced with aim to enhance the overall efficiency of solar pond. A sets of external heat exchanger system are installed to extract heat at different level in NCZ by withdraw the hot brine and re-injecting it back at the same level. Cold brine from upper convective zone (UCZ) is used to collect the extracted heat from each of heat exchanger. The result shows by extracting heat from NCZ, the thermal efficiency of solar pond could be increased by up to 50% compared to the common heat extraction solely from LCZ and reducing the upward heat lost to surrounding.

1. Introduction

A salinity gradient solar pond (SGSP) is a simple concept of using salt water as solar collector and heat storage producing low grade temperature below 100 °C [1]. The SGSP consists of three differences layer or zone as shown in Figure 1. A thin layer on top is upper convective zone (UCZ) with uniform low salinity and temperature closed to ambient. Next layer below it is non-convective zone (NCZ) where the density and temperature gradually increased with depth. The NCZ is large enough to suppressed any form of convection and minimise the upward heat loss. Heat trapped in LCZ constitutes only 20% or less from the amount of solar radiation received at the UCZ as explained by Bryant and Colbeck [7]. As the radiation penetrates through the depth of solar pond, thicker layer of NCZ absorbs large portion of heat. The bottom layer is lower convective zone (LCZ) act as storage zone with homogenous high concentrated brine and high temperature as 90 °C. Solar radiation penetrated through the depth of the pond is trapped as heat energy in LCZ. Practical applications of SGSP are using direct heat for heating purposes at temperature between 50 °C to 90 °C. Among the applications are industrial process heat as demonstrated in El Paso, Bhuj in India and Pyramid Hill [2-4].



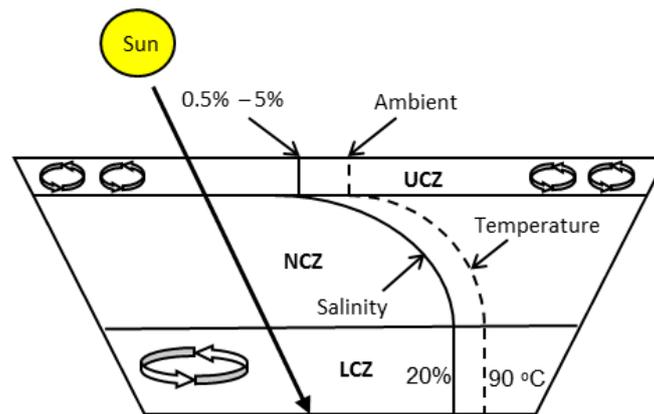


Figure 1. Schematic diagram of salinity gradient solar pond

Commonly heat in solar pond is removed solely from LCZ by heat extraction process using external or internal heat exchanger. An alternative method of extracting heat from NCZ using internal heat exchanger have been investigated theoretically by Andrews and Akbarzadeh [5]. Later, an experimental investigation to confirm the earlier theoretical result was performed by Leblanc et. al [6]. The results shown, heat extraction from NCZ has increased the overall thermal efficiency of SGSP by up to 50% compared to heat extraction only from LCZ and reducing the upward heat lost. However, the installation of internal heat exchanger for larger scale solar pond (e.g 10,000 m²) is impractical and costly. Leblanc et al. [6] had recommended further experimental of using external heat exchanger to extract the absorbed heat in NCZ. The current study is proposing multi-layer heat extraction system using external heat exchanger from NCZ with aim to enhance overall thermal efficiency of SGSP. Sets of external heat exchangers are installed in series at RMIT University solar pond to extract heat at different level in NCZ by withdraw the hot brine and re-injecting it back at the same level. Cold brine from upper convective zone (UCZ) is used to collect the extracted heat from each of heat exchanger.

2. The RMIT University Solar Pond

Figure 2(left) show the RMIT University solar pond with 8.3 m diameter, surface area of 53 m² at 2.05 deep with straight vertical concrete wall. It was constructed 1.35 m below the ground level, and the rest of 0.7 m wall above the ground level. The twelve months LCZ temperature tracking is shown in Figure 2 (right). In the peak summer, the average solar radiation received at 335 W/m² while maximum average ambient temperature was 27 °C, and a maximum LCZ temperature of 61 °C was recorded. It has created a temperature different of 34 °C between LCZ and UCZ.

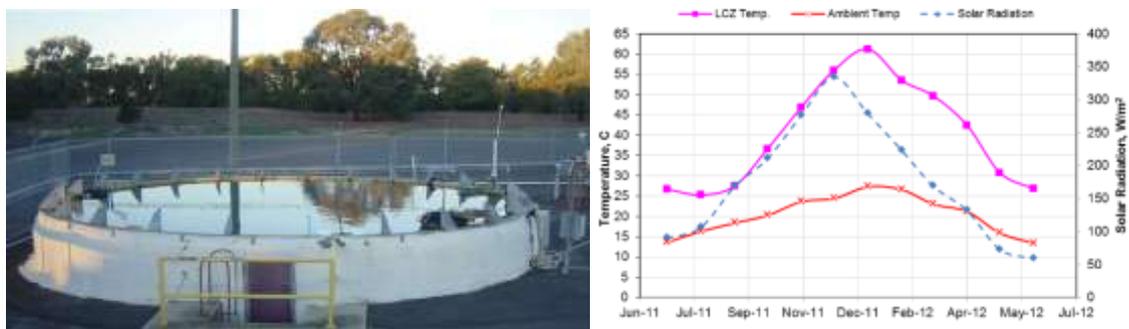


Figure 2. The RMIT University solar pond (left) and the LCZ temperature tracking in twelve months (right)

3. Experimental Set-up

There are seven units' shell and coil heat exchangers which connected each other in series to extract heat from different level in NCZ as shown in Figure 3. The 12V pump is used to withdraw hot brine marked by red arrow and circulates through the coil each heat exchanger and returns it to the same level as marked by yellow downward arrow. The cold brine from surface is pumped at controlled flow rate through the shell of 1st to 7th heat exchanger to collect heat in increasing order as marked by blue arrow. Semi-circle diffuser with diameter of 120 mm and opening gap of 3mm is attached at the inlet and outlet of the heat exchanger in order to minimize the disturbance in NCZ. The 1st diffuser level was set at 1.7 m from the bottom and the 7th diffusers are fixed at 0.8 m from the bottom with 0.15 m interval between the diffusers.

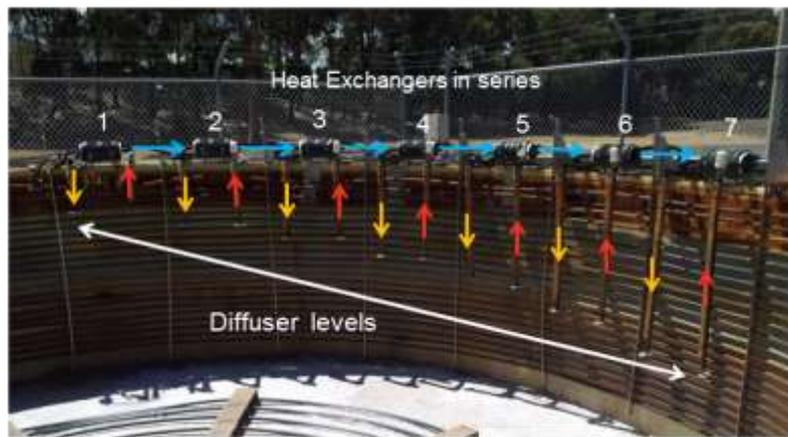


Figure 3. The arrangement of heat exchangers and diffusers level

The valves were attached to each of heat exchanger coil surface water pump to control the flow rate of hot and cold brine. The mass flow rates for both hot and cold brine were controlled at 0.03 L/s and 0.012 L/s respectively. The DataTaker (DT500) data acquisition system is tracking the data in every 15 minutes continuously in 24 hours for the period of two weeks in April 2012.

4. Result and Discussions

The output temperature of each heat exchanger and diffusers are shown in Figure 4. The hot brine from difference layer in NCZ is circulated in each coil to transfer the heat. The cold brine from surface is used as heat transfer fluid to extracting the heat from the coil in heat exchanger no. 1 to no. 7 in increasing orders to create large temperature differences. At constant mass flow rate of 0.01 Kg/s and 0.03 Kg/s for cold and hot brine, a 31 °C temperature difference was obtained.

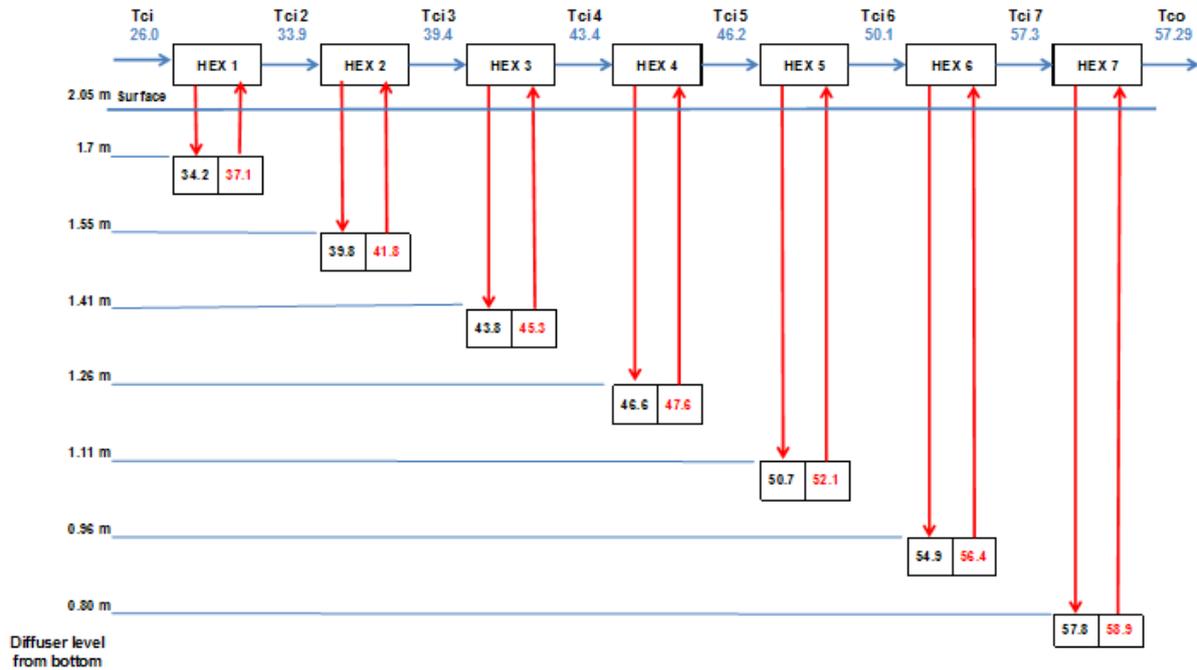


Figure 4. The temperature output for every heat exchangers and diffusers

Figure 5 (left) shows the amount of heat extracted for each of heat exchanger and the total amount of 1438 W or 28 W/m² of heat can be extracted from gradient layer. The amount of heat are calculated based on $\dot{Q} = \dot{m} \cdot C_p \cdot \Delta T$, where \dot{m} is the mass flow rate of the brine, C_p is the brine specific heat and ΔT is the temperature difference between inlet and outlet flow. The performance of the heat exchangers shows no. 1 produced the highest amount heat and the lowest is heat exchanger no. 7. Temperature profile on 18/1/2012 as shown in Figure 5 (right) is taken as a case study for current analysis. Based on that profile, the thickness of UCZ, NCZ and LCZ are 0.1 m, 1.3 m and 0.65 respectively. The UCZ temperature on top is 26.5 °C and the maximum temperature of 62 °C in LCZ.

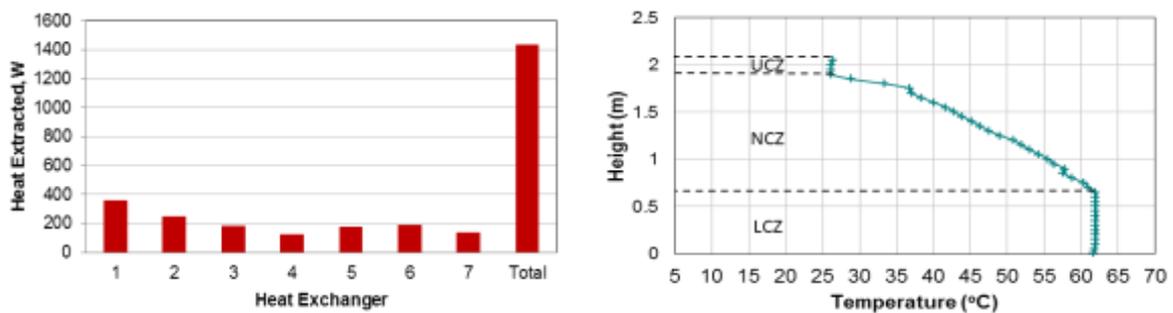


Figure 5. Heat extracted by each heat exchanger (left) and solar pond temperature profile (right)

The total amount of heat trapped in LCZ is calculated employing Bryant and Colbeck [7] formulation;

$$H_x = 0.9H_o[a - (blnx)]$$

where H_x is the solar radiation available in W/m² at a depth of x in the pond, H_o is the solar radiation available

at the surface, a and b are constants equal to 0.36 and 0.08 respectively, x is the distance of the LCZ from top of surface of the pond in m and 0.9 is assuming 10% of solar radiation reflected at the surface.

Some portions of solar radiation penetrated into solar pond are lost to UCZ and to the ground by conduction. The heat loss calculations are performed using heat flux equation;

$$\dot{Q} = kA \frac{dT}{dx}$$

where k is the thermal conductivity of the medium in $\text{W/m}\cdot^\circ\text{C}$, A is the pond surface area in m^2 and dT is the temperature difference within the thickness of dx in meter.

The solar pond thermal efficiency is calculated using below proportion;

$$\eta = \frac{\text{Solar Radiation Input in LCZ} - \text{Losses}}{\text{Solar Radiation at Surface}}$$

Figure 6 shows the local solar radiation received at the surface of solar pond in the month of January 2012 together with the breakdown of heat loss and heat trapped in LCZ in W/m^2 . The information also includes the amount of heat which was extracted from NCZ. The total heat is referring to the sum amount of heat in LCZ and heat that can be extracted from NCZ.

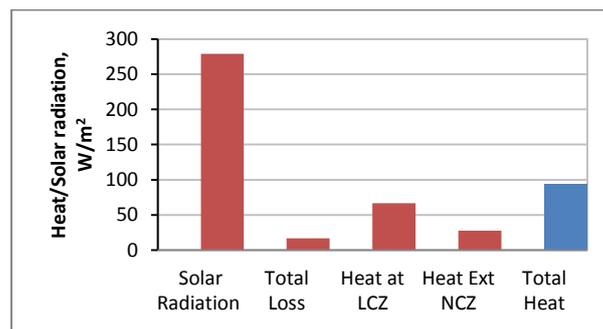


Figure 6. The potential total amount of heat to be extracted

The average solar radiation received at the surface of solar pond was 279 W/m^2 . The calculated amount of heat trapped in LCZ is approximately 67 W/m^2 , which is reflected to overall thermal efficiency of 24% comparing heat trapped in LCZ to the solar radiation at the surface. By considering heat in LCZ and heat that can be extracted from NCZ, the total heat available increased to 95 W/m^2 . The total overall efficiency is enhanced from 24% to 34%. Hence, by extracting heat from NCZ, the overall thermal efficiency of solar pond can be enhanced by up to 40%.

5. Conclusion

In the present study, the concept of multi-layer heat extraction from non-convective zone has been investigated experimentally to enhance the overall thermal efficiency of salinity gradient solar pond. The performance of each heat exchanger was measured. The implementation of heat extraction using external heat exchanger from NCZ has able to tap some amount of heat that available in that layer. In total, by adding the amount of heat trapped in LCZ and the amount of heat extracted from NCZ, the overall thermal efficiency of solar pond could be improved from 24% to 34%. This is by comparing between the total heat potentially can be extracted and the solar radiation received at the surface. The result indicates, the thermal efficiency of solar pond can be enhanced by up to 40% in W/m^2 by adding the amount of heat extracted from NCZ and the amount of heat available in LCZ. Hence, the multi-

layer heat extraction system is very practical to be implementing to the large scale of working solar ponds that could attract the interest of the industries globally.

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