Construction and Operations of First Salinity Gradient Solar Pond in Malaysia

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ABSTRACT

Solar pond is an integrated solar collector and storage. An experimental salinity gradient solar pond was constructed to analyse the thermal storage capability. The solar pond consist of 2.4 m^2, 1.4 m deep with sodium chloride (NaCl) as the salt solution. For the development of salinity gradient, a diffuser was used to develop the salinity gradient. The salinity gradient solar pond consists lower convective zone (LCZ) with a height of 0.5 m with 1200 kg/m^3 density, non-convective zone (NCZ) with a height 0.8 m and upper convective zone (UCZ) with a height 10 cm. The temperature of (LCZ) as heat storage was recorded and analysed weekly. Maximum temperature of (LCZ) storage zone was recorded to be at 36.5 °C after four weeks and it showed and upward trend. The heat energy stored in (LCZ) can be used for power generation.

Keywords: *solar pond; salinity gradient solar pond.*

Introduction

As the world continuously running out of natural sources, it is no longer suitable to rely only on natural resources in producing energy for daily usage.

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Exploration on renewable energy is a must and it is already being taken as serious measure for certain countries and some of the countries already moved towards producing energy from renewable energy rather than using natural source energy which mainly consist of fossil fuel. On the other hand, to replace natural resources as main energy supply. There is a need to study and explore renewable energy.

There are many types of renewable energy in existence and one of it is solar energy. With solar energy, heat can be captured and stored for later use either for electricity generation, water heating or space cooling. With solar pond, heat is absorbed and stored in the pond which will make the solar power operation less complicated with no additional storage needed. In this project, the solar pond is constructed by using salinity gradient to collect and store energy in term of heat, in which acts as renewable energy source to reduce dependencies on natural energy sources.

Solar pond was first found at the beginning of 20th century in several naturally occurring lakes in a salt region of Hungary. Since then, scientific literature first started on solar pond where temperature was observed. These lakes were situated in foothills of the Carpathian Mountains (46°35’N, 25°6’E) which is in the north-central section of what is now known as Romania. The area coverage is 42000 m^2 and depth is 15 m deep. It is found that the lake exhibit as typical solar pond in late September where the temperature recorded about 65°C a meter below and near ambient temperature at the surface [1].

Numbers of commercial solar pond has been built to serve for different purposes. El Paso, Texas, solar pond was a research project led by University of Texas. The pond is running since 1986, operating with Organic Rankine Cycle engine and was able to generate 70 kW of electric power and it is further fed to grid [2]. In Israel, Bet Ha Arava, solar pond was built with the purpose of generating electrical power. It was the largest solar pond built which covered 210 000 m^2 area and generating 5 MW of electrical power. The pond operated until 1988 [3]. While in India, Bhuj solar pond was constructed in July 1987. The solar pond temperature remain stagnation until May 1991 however the pond failed. It was redesigned in June 1993 and began to supply the heated water to nearest dairy in September 1993. The pond faced problem once again in April. The heated water supply was resumed in August 1996 [4].

Salinity gradient solar pond is very sustainable to be operated in Malaysia. Malaysian weather is beneficial to operate the salinity gradient solar pond since the solar pond only require sunlight radiation and in Malaysia, sunlight is radiating all year long. The hot and humid climate will help to retain heat stored in the storage zone. It is relatively inexpensive to use salinity gradient solar pond as renewable energy since the cost is only mainly for setup which consist of pond construction, salt purchasing and salinity gradient maintenance to operate the solar pond. Another advantage to use salinity gradient solar pond is that it does not cause any harm that can lead to pollution. Thus, using salinity gradient solar pond as the renewable energy is the best way in promoting solar thermal energy in Malaysia.

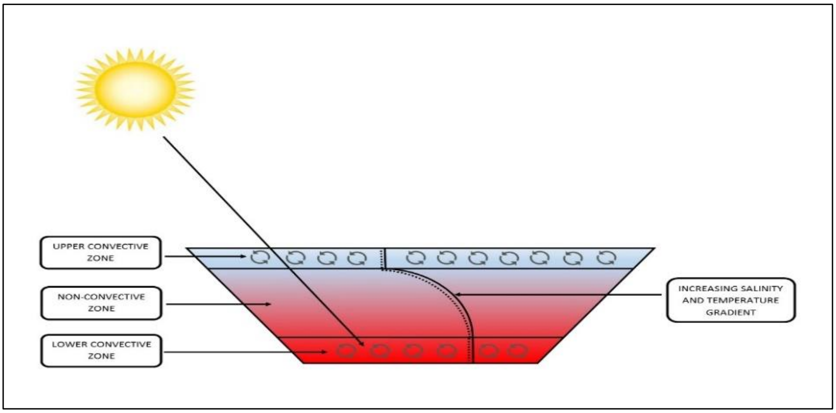

Figure 1: Salinity gradient solar pond diagram.

System design and analysed result

Salinity gradient solar pond construction

An experimental SGSP was constructed at lecturer car park level 3 Faculty of Mechanical Engineering, UiTM Shah Alam. Polyethylene tank with a surface area of 2.4 m^2 and 1.4 m deep was used as a solar pond. The pond foundation was made from layered of bricks, plywood and polystyrene as heat insulator. Heat insulator was also used to wrap the wall to prevent the heat loss trough the wall. At the wall, salt charger holder was attached to hold the salt charger. Salt charger was used to channel salt into LCZ in order to maintain the density of LCZ without disturbing UCZ and NCZ layer. On the other side of the wall, dual purpose holder was attached to the wall used for water injection process and data collection process. Automatic integrated system was introduced by installing ball valve and overflow passage on top of the sidewall to maintained water level.

To establish the salinity gradient, the pond was first having an aqueous solution made of NaCl. The process is done by mixing salt and water up to 920 mm height. The density of the solution must be 1200 kg/m^3 in order to develop LCZ and salinity gradient. To establish the salinity gradient, water injection process was introduced. Water was injected using diffuser into the salt solution. The technique used for water injection was fixed level method. Process was done by locking the diffuser with the holder that attach to the wall of the tank. The water injection began at 500 mm height from bottom of the tank which the bottom part left undisturbed for LCZ. The injection process was performed by raising the diffuser twice as water level increase for each water injected. For this salinity-gradient establishment diffuser was raised by 40 mm when water level increased by 20 mm. the injection process consist of 20 points of injection in order to establish the salinity-gradient for NCZ. The injection process can be seen in table 1. By the end of the injection, LCZ, NCZ and UCZ was having thickness of 500 mm, 800 mm and 100 mm respectively.

Table 1: Water injection table.

Diffuser injection level (mm)	Salt water level (mm)
500	920
540	940
580	960
620	980
660	1000
700	1020
740	1040
780	1060
820	1080
860	1100
900	1120
940	1140
980	1160
1020	1180
1060	1200
1100	1220
1140	1240
1180	1260
1220	1280
1260	1300
1300	1320
1340	1340
1380	1360
1420	1380

Table 1 explains the water injection process. First water injection was done at level 500 mm from bottom of the pond. At this level, aqueous solution that was prepared before was at level 920 mm from bottom. The injection process start at 500 mm to kept the LCZ zone at 500 mm with density of 1200 kg/m^3. After the aqueous solution rose by 20 mm to 940 mm, the second water injection process was done at 540 mm. The water injection process was repetitive until the last water injection level at 1300. The rest was filled with fresh water without mixing the aqueous solution to develop UCZ. The water injection process was done step-by-step to develop the gradient layer of salinity. The density of each layer will decrease when water is injected and mix with aqueous solutions in each layer. Thus, the salinity gradient of solar pond was formed.

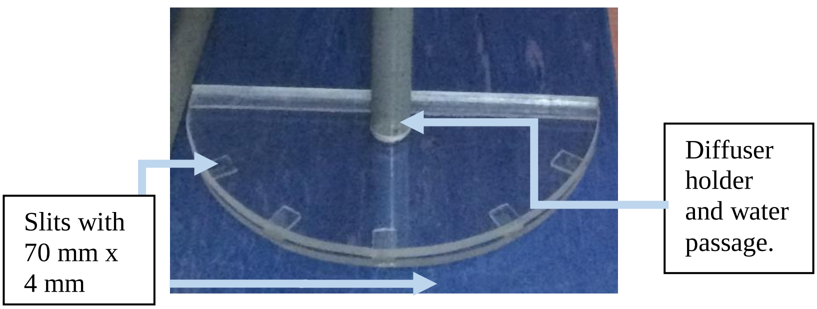

Figure 2: Diffuser

The diffuser was made up of perspex with semi-circular shape consist of 6 slits. The gap of each slit is 70 mm wide and 4 mm height. During water injection process, it was required to maintain the Froude' number less than 18 in order to prevent the water mix with the fluid from below the diffuser level. Before injection process was done, the flow rate of the diffuser was calculated and the results showing the Froude' number was less than 18.

$$Fr = \left[\frac{\rho v^2}{(g \Delta \rho B)}\right]^{1/2} \tag{1}$$

Where ρ (kg/m) is the density of the surrounding saline fluid, v (m/s) is the injection velocity at the diffuser outlet, g (m/s^2) is the acceleration due to gravity, $\Delta\rho$ is the density difference between the injected fluids and B (m) is the gap width of the diffuser.

Thermal performance

The thermal performance of a solar pond can be represented in a form similar to that used for conventional flat plate collectors.
Assuming a steady state condition,

$$Q_u = Q_a - Q_e \tag{2}$$

where ;
Q_u = useful heat extracted,
Q_a = solar energy absorbed,
Q_e = heat losses.

The thermal efficiency of a solar pond can be defined as

$$\eta = \frac{Q_u}{I} \tag{3}$$

where;
I is the solar energy incident on the pond.

Thermal effeciency can be written as

$$\eta = \eta_o - \frac{Q_e}{I} \tag{4}$$

where η_o is called the optical efficiency of the pond (Qa/I).
We express

$$Q_e = U_o(T_s - T_a) \tag{5}$$

where;
T_s is the pond storage-zone temperature
T_a is the ambient temperature
U_o is the overall heat-loss coefficient.

If we neglect heat losses from the bottom and sides of the pond and assume that the temperature of the upper mixed layer is same as the ambient, then

$$U_o = \frac{K_w}{b} \tag{6}$$

where K is the thermal conductivity of water and b is the thickness of the gradient zone.

Based on [7], if the thickness of the gradient zone is too high the transmission of solar radiation is reduced while if it is too small it causes high heat losses from the bottom to the top of the pond. The optimum value of the thickness depends on the temperature of the storage zone of the pond. Nielsen (1980) has provided a steady state analysis of a solar pond and has included the effect of solar radiation absorption in the gradient zone on the temperature profile. In the steady state, the energy equation becomes

$$K\left(\frac{d^2T}{dZ^2}\right) = I\left(\frac{d\tau}{dZ}\right) \tag{7}$$

where;
K is the thermal conductivity of water
τ is the fraction of solar radiation I reaching a depth Z.

This equation can be integrated to get

$$\left(\frac{dT}{dZ}\right) = \left\{\frac{I}{K}\right\}\{\tau(Z) - \tau(Z_1) + \left(\frac{dT}{dZ}\right) z_2\} \tag{8}$$

where;
Z_2 is the interface between the gradient zone and storage zone.

If η is the fraction of the incident solar energy which is extracted from the system as heat (including ground losses), then an energy balance of the storage zone gives

$$\left(\frac{dT}{dZ}\right) z_2 = \left\{\frac{I}{K}\right\}\{\tau(Z_2) - \eta\} \tag{9}$$

We can combine (8) and (9) to obtain the temperature profile in the gradient zone as

$$\left(\frac{dT}{dZ}\right) = \left\{\frac{I}{K}\right\}\{(\tau(Z) - \eta)\} \tag{10}$$

The effect of ground-heat losses on the performance of a solar pond has been analysed by Hull et al (1984). They have shown that the ground heat-loss coefficient can be expressed as

$$U_g = K\left(\frac{1}{D} + \frac{bP}{A}\right) \tag{11}$$

where;
K is the ground conductivity
D is the depth of the water table
P and A are the pond perimeter and surface area
b is a constant whose value(depending upon the side slope).

The thermal efficiency of a steady state solar pond can now be written as

$$\eta = \frac{1}{Z_2 - Z_1}\left[\int_{Z_1}^{Z_2} \tau(Z)dZ - \frac{k_w \Delta T}{I}\right] - \frac{U_g \Delta T}{I} \tag{12}$$

where;
ΔT is the temperature difference between the storage zone and the upper mixed layer.

Solar pond maintenance

The main concern in maintaining solar pond is the salinity gradient and the clarity of the pond. To maintain the salinity-gradient, salt was added in the LCZ via the salt charger. Salt will enter and stored in the LCZ further will dissolve slowly and maintain at 20% density level of the LCZ. The salinity gradient was monitored weekly to ensure the gradient is at the right level. In order to maintain the clarity of the pond, surface cleaning was done weekly to encompass the solar radiation and heat absorb by the solar pond. Surface cleaning is also needed to maintain the availability of the UCZ. The salinity gradient was measured using hydrometer and the acidity of the pond was measured using pH meter. The process was done simultaneously during obtaining temperature profile.

Heavy rain Effect

Rainfall can also provide positive effects on the operation of a solar pond. If the rainfall is not heavy, it helps to maintain the density of the surface layer at a low value. During raining, there was no need for flushing the surface layer to maintain its density at a low value. Heavy monsoon rainfall can, however, penetrate to the gradient zone and dilute it. The analysis of heavy rainfall (greater than 40 mm per hour) episodes in the Bangalore [7] solar pond indicates that raindrops can penetrate to about 50cm from the surface. Hence, it may be desirable to maintain higher surface zone thickness during the rainy season.

Data Extraction

The result was taken by extracting the solutions of each desired level from LCZ, NCZ and UCZ using syphoning method. Syphon tube and thermocouple is attach to the holder and the holder can be adjust to each level for data extraction. In this experiment, the solution was extracted from 150 mm from bottom of the pond until surface of the pond by incremental of 50 mm. For each level, temperature and density of the solution extracted was recorded and later tabulate and convert into chart. The data was taken for 4 weeks which the reading was on 4th November 2016, 10th November 2016, 15th November 2016, 17th November 2016 and 24th November 2016. At the fourth week of the SGSP operations, the acidity level of the pond was taken using pH meter. All the data was taken simultaneously using the solutions that was extracted from the pond.

Result and Discussion

Solar pond operations and maintenance

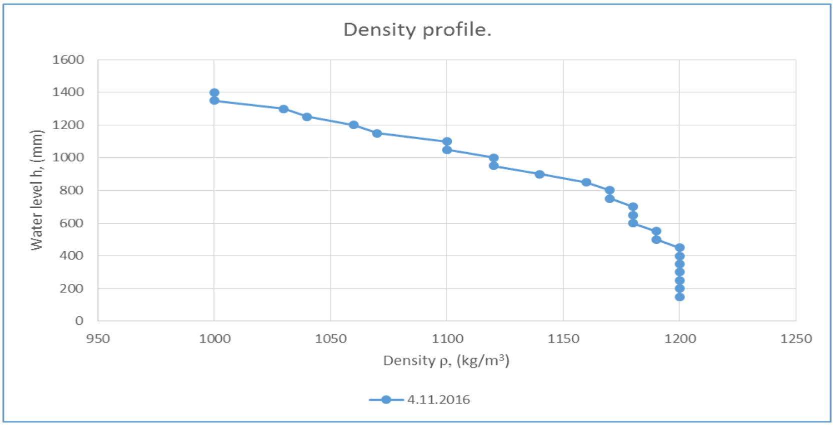

Figure 3: Density profile after establishment of salinity gradient.

The salinity gradient solar pond was successfully established by referring to the first reading on 4th November 2016. The density gradient for NCZ was achieved by having increasing in density from 1000 kg/m^3 to 1200 kg/m^3 at water level from 1300 mm to 500 mm from bottom of the pond. By referring to the chart, LCZ was successfully kept at 500 mm thick and NCZ was constructed as planned to have a thickness of 800 mm. While UCZ was having thickness of 100 mm.

The main concern in maintaining solar pond is the salinity-gradient and the clarity of the pond. To maintain the salinity-gradient, salt was added in the LCZ via the salt charger. Salt will enter and stored in the LCZ further will dissolve slowly and maintain at 20% density level of the LCZ. The salinity gradient is monitored weekly to ensure the gradient is at the right level.

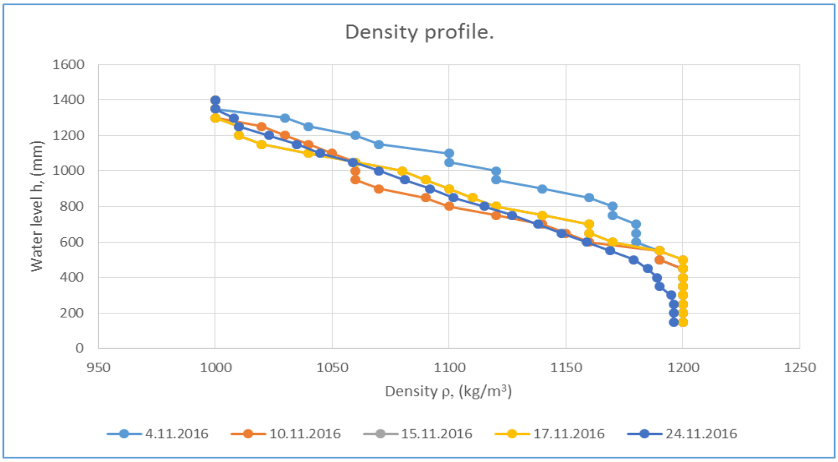

Figure 4: Density profile of SGSP

Chart above indicates the density measurement at each water level. Density of the salinity gradient solar pond is taken simultaneously during recording temperature. LCZ is made up from bottom of the pond up to 500 mm height. NCZ is made up from 500 mm to 1300 mm height. And UCZ is made up from 1300 mm to 1400 mm height. The first reading was taken on 4th November 2016 and the legend showing that the salinity gradient that was newly developed increase from top to bottom level of NCZ. The data showing positive result as the gradient is there which NCZ must made up of layer of salinity gradient. On 10th November 2016. The legend indicates that the UCZ was maintained at 1000 kg/m^3 density and LCZ is maintain at 1200 kg/m^3 density. On 24th November 16, the salinity gradient is getting smoother compared to previous data taken. The smoothness indicates that the gradient is properly mix around with the surrounding fluid. From the chart, salinity gradient for NCZ is at optimum level since there is gradient exist from the top of the NCZ level to the bottom of NCZ level. The data indicates that the salinity gradient solar pond is working at optimum level since it first established.

Clarity and turbidity.

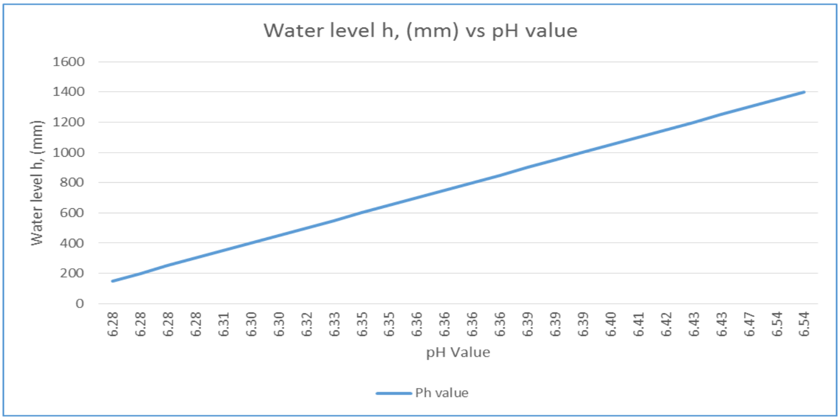

Figure 5: Acidity level of SGSP

At early stage after the establishment of salinity gradient, the pond clarity is very cloudy, the turbidity of the pond is high as the mark at the bottom cannot be seen. The turbidity is mainly caused by the dust that carried by the salt that used to developed the solutions. Other than that, the debris from the leaves and from the insect also caused the turbidity. After a month of establishment, these particles settle down to the bottom of the pond and some of the debris is suspend at certain level in the gradient layer. After a month of SGSP operations, the clarity has increase as the mark and the salt at the bottom of the pond can be seen. The acidity of the SGSP can be seen in figure 5, it shows that the acidity of the pond decrease from the bottom until surface of the pond. The acidity level is important to maintain the clarity of the pond. If the acidity is too high, crystallization of sodium chloride would occur. The clarity and turbidity of the pond is very important as its maximise the light transmission through the gradient to encompass the solar radiation and heat absorb by the solar pond.

Figure 6 and 5: The clarity of solar pond before and after the particles settle down to the bottom of the pond.

Data Observations.

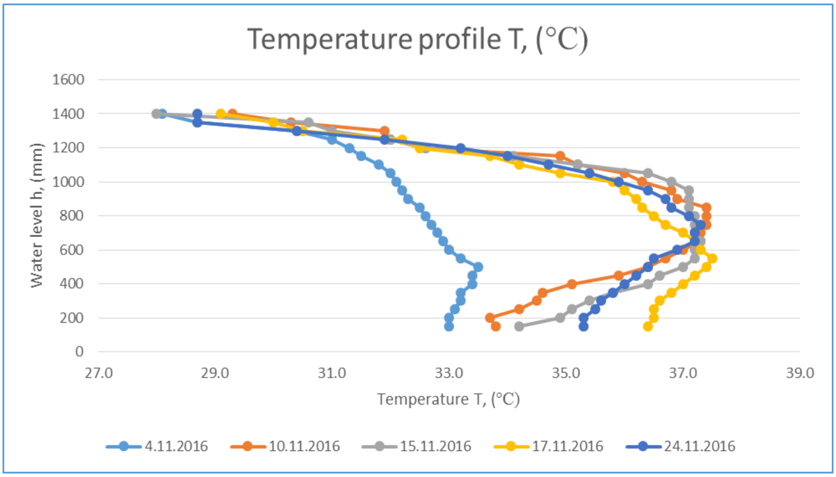

Figure 7: Chart of Temperature profile.

The chart above indicates water level (mm) vs temperature °C of the solar pond. LCZ is from 0 mm to 500 mm, NCZ is from 500 mm to 1300 mm and the remaining is UCZ. From the chart, it indicates that the temperature of all data is increasing from the top of the pond to the bottom of the pond. At 4th November 2016, the first reading is taken and it is showing that the heat stored for the LCZ is 33 °C. The LCZ is charged at 33.5 °C as the chart indicated at NCZ level. UCZ temperature was equivalent to the surrounding temperature, which is the temperature recorded for this day is 28 °C. The second data is taken on 10th November 2016 and the chart shows that the heat stored by the LCZ has increase to 33.5 °C. The sunny day increase the ability to charge the solar pond and it can be seen that the solar pond was charged at 38 °C. On this day, the surrounding temperature is recorded to be 29.3 °C. At 15th November 2016, the third reading was taken and the temperature of LCZ has increase from 33.5 °C to 34 °C. The LCZ is charged at 37 °C. On 17th November 2016, the highest temperature was recoded for LCZ among all the data taken. The LCZ was recorded to be 36 °C and was charged at 37.5 °C. The final reading was recoded on 24th November 2016. Temperature for LCZ found to be decreasing from previous reading, it is found that LCZ temperature was 35.3°C and LCZ was charged at 37.3 °C. Even though it was charge at almost constant temperature compared to previous reading, LCZ temperature turn to be much lower due to the heat is losing since it cannot be charged because of continuous raining for previous day. Thus, it took much effort to charged LCZ on 24th November 2016.

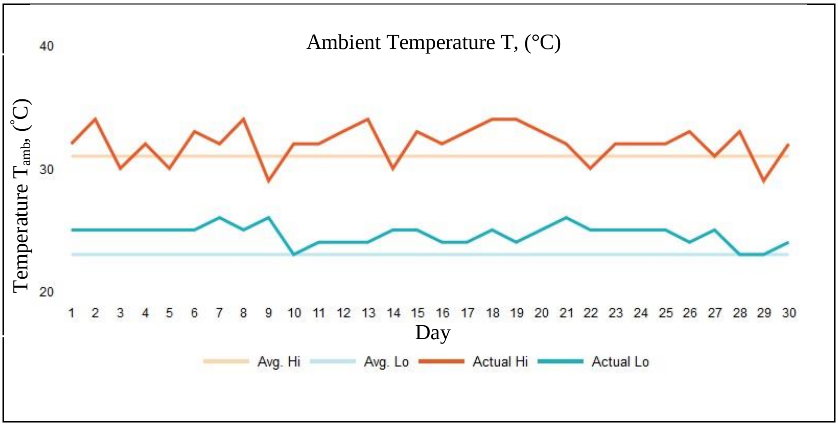

Figure 8: Chart of Ambient Temperature °C November 2016 [5].

The chart in figure 8 showing daily ambient temperature °C in November 2016 for UiTM Shah Alam. The spike indicates ambient temperature at noon while the increasing and decreasing indicates rising in temperature during sunrise and decreasing temperature as sun is setting. By comparing data taken with this chart, it clearly show that the highest ambient temperature was recorded on 18th to 19th November and this phenomenon lead to highest temperature can be stored by the LCZ. The chart also proved that from 18th to 22th November, the ambient temperature is decreasing and caused LCZ to drop in temperature. The temperature was increase a day later, however the temperature rose was not as high as before.

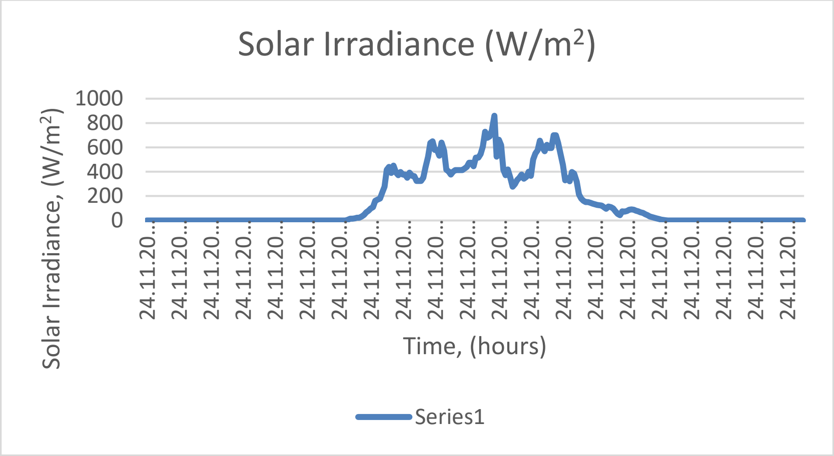

Figure 9: Chart of Solar Irradiance (W/m^2) in a day.

Figure 9 showing global solar irradiance for a single day in November 2016 for Uitm Shah Alam. The data were obtained from Green Energy Reseacrh Centre (GERC) Faculty of Electrical Engineering Shah Alam. From the data, the legend ilustrate the solar irradiance reading for every hours from 00:00 am until 23.55 pm. The data showing that solar irradiance increase from morning and spikes at noon and decreasing until night indicates that sun is rising and is setting for everyday.

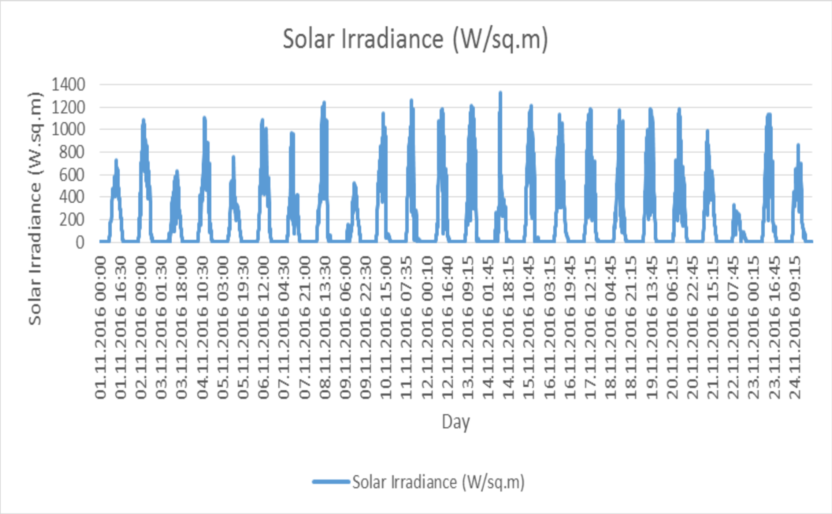

Figure 10: Chart of Solar Irradiance (W/m2) in November 2016

Figure 10 indicates solar irradiance reading for the whole month in November 2016. The given data is later converted into Peak Sun Hour (PSH) daily average reading to indicate the daily average solar insolation in (h) received by Uitm Shah Alam. The term "Peak Sun Hours" refers to the solar insolation which a particular location would receive if the sun were shining at its maximum value for a certain number of hours. For November 2016, until 24th day, the daily average PSH reading is 4.316 h. The larger the PSH reading showing more sun is shining for the month. By referring solar irradiance data in fig, it is found the solar irradiance is decreasing from 17th November 16 until 24th November 16 and the lowest is on 22nd November 16. Thus mentioning that amount of solar radiation received by the solar pond decreased until 24th November 16.

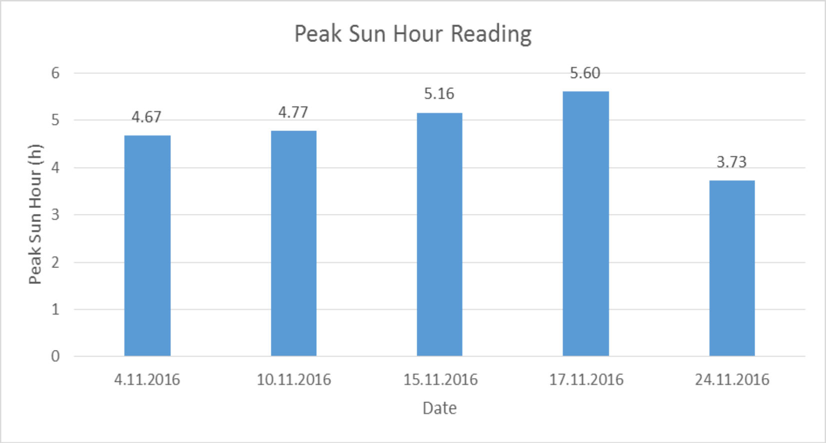

Figure 11: Chart of peak sun hour of day data taken.

From the chart above, the PSH does affects the temperature store by LCZ. From Fig 26, LCZ temperature is increasing from 4th November until 17th November. It was due to the solar pond received increasing number of PSH reading. The pond was exposed to sunny day much longer from 4th November 16 to 17th November 16. Thus explained the increasing heat stored in LCZ. In contrast, the PSH for 24th is the lowest shown by the chart. By referring figure 10, the amount of solar irradiance received by the solar pond is decreasing from 17th November 16 until 24th November 16. With this phenomenon, the low reading of PSH received by solar pond on 24th November 16 took huge effort for solar pond to recover from the losing heat due to heavy downfall from previous days.

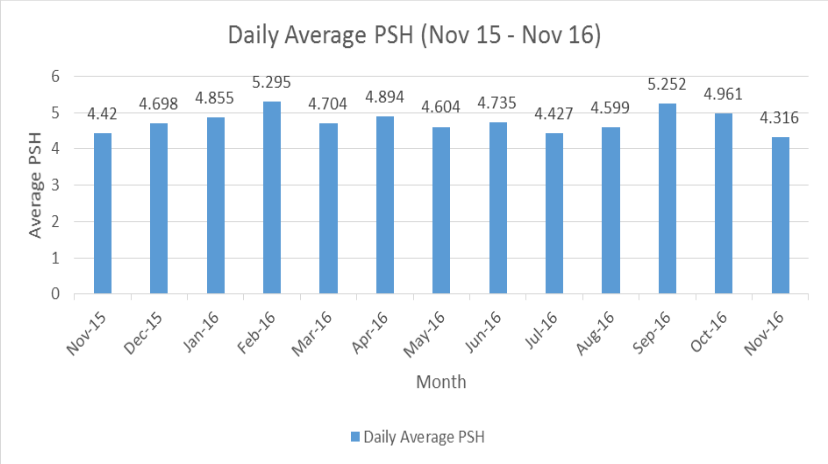

Figure 12: Chart of Daily Average PSH (Nov 15 – Nov 16)

From the chart above, it can be seen that UiTM Shah Alam received large number of PSH on February 2016 and September 2016. In contrast, November 2016 received the lowest PSH reading compared to the reading from last 12 months. The cloudy and raining season is one of the factor that reduce the PSH for November 2016. From the chart above, the salinity gradient solar pond is operate at low PSH in November 2016 and reduce the capabilities of the solar pond to capture and store larger heat.

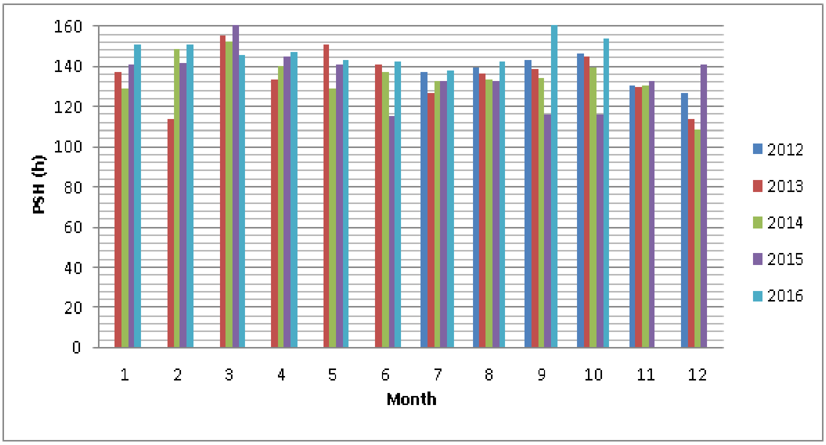

Figure 13: Chart of Monthly Average PSH (2012-2016)

From figure 10, the PSH data is provided from 2012 until 2016. For each year, the trend was showing that the peak season of PSH was in March and October. However, in 2016, peak PSH had shifted a month earlier which leads to peal PSH value is in February and September. Despite the difference reading for yearly indicator, the trend is showing that the PSH is increasing in January until March and decreading from March until July. Later PSH increase again from July until October and decreasing from October until December each year. With the trend display in the chart, the capabilities of solar pond to capture and store heat is influenced by the solar insolation received by the solar pond. Technically, with the increasing number of PSH will help the salinity gradient solar pond to capture and store more heat.

Conclusion

In this experiment, salinity gradient solar pond was constructed and operated to monitor the capability of the pond to store heat. The salinity gradient solar pond was successfully constructed by having thickness of UCZ, NCZ and LCZ at 100 mm, 800 mm, and 500 mm respectively. The salinity gradient was able to maintain the density profile as it was first operated without having any major maintenance required. The solar pond was capable in storing heat as the maximum temperature was recorded to be at 36.5 °C after four weeks and it showed an upward trend. Since the salinity gradient solar pond was first constructed and operated in Malaysia, this solar pond experiments contribute a great deal towards the research and development of upcoming renewable energy technology.

Acknowledgement - Several people contributed to this project and space is too short to name all of them individually. However, the support and contribution of some individuals merits special mention. I would like to acknowledge Prof Maliki Omar for the support of Green Energy Research Centre (GERC) at Universiti Teknologi Mara (UiTM), Shah Alam in conducting this study.

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