Experimental Salt Gradient Solar Pond for Heat Storage and Solar Distillation

By

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Abstract

A Salt Gradient Solar Pond is a shallow body of water that collects and stores solar energy. Salt Gradient Solar Ponds consist of 3 layers The Upper Convective Zone (UCZ), The Non – Convective Zone (NCZ), and Lower Convective Zone (LCZ). Sunlight passes through the UCZ and moves through the NCZ where it is then stored as heat energy in the LCZ. Salt Gradient Solar Ponds can be used for many applications such as industrial process heating, space heating, desalination, and electricity production. Salt Gradient Solar Ponds offer an attractive option with growing concerns about Greenhouse gas emissions and freshwater availability. Today it is estimated that 10,000 tons of oil are used to produce 1,000 cubic meters. This research focuses on using an idealized Salt Gradient Solar Pond with a transparent plastic cover acting as the UCZ using produced brine water from the Maybee Ranch for the NCZ and LCZ layers.

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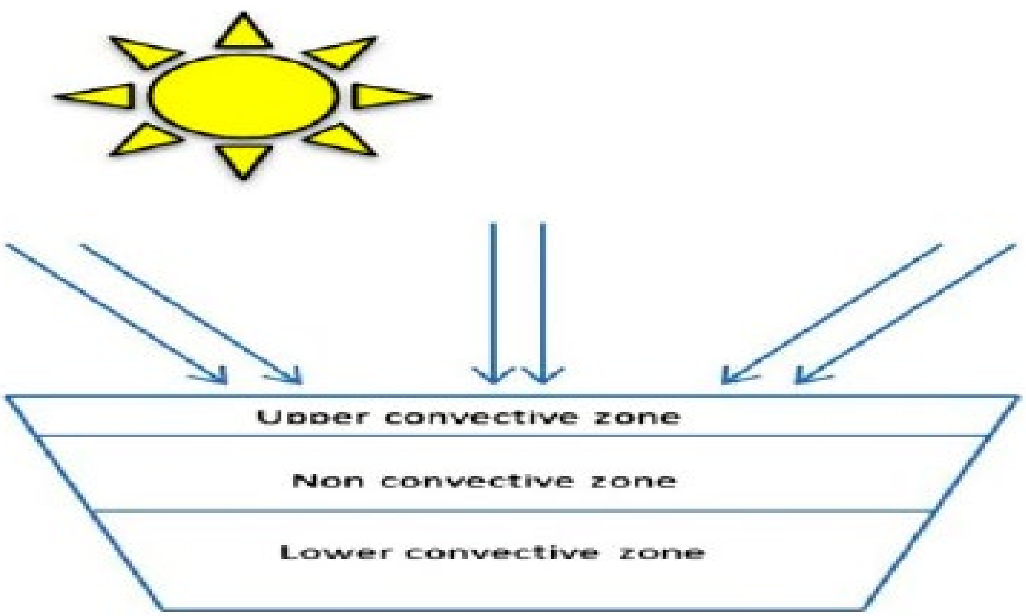
I. Introduction

A lack of potable water poses a major problem in many regions of the world today where freshwater is scarce and expensive (H.M. Qiblawey, F. Banat. 2008). Currently, desalination remains a popular form of water treatment with an array of desalination methods used. Desalination is performed by either direct or indirect methods. Direct desalination means all parts are integrated into one system. An example of direct desalination includes solar stills in which solar energy is collected within the basin and distillate is produced on the inside of the cover. Indirect desalination consists of 2 parts of the system, a solar collector and a desalination system, conventional desalination methods such as Reverse Osmosis (RO), Multi-stage Flash Distillation (MSF), and Multi-Effect Distillation (MED) as of current forms of indirect Thermal desalination. However, it has been estimated that 10,000 tons of oil per year is needed to produce 1,000 cubic meters of fresh water per day in conventional desalination plants and direct solar distillation is mainly suited where freshwater demand is less than 200 cubic meters per day ((H.M. Qiblawey et al. 2008). This poses a problem in many areas where fossils fuels are not abundant and the need for fresh water is in great demand. Therefore Salt Gradient Solar Ponds offer an attractive option for water desalination as Salt Gradient Solar Ponds provide both solar energy collection and long-term solar energy storage. A Salt Gradient Solar Pond (SGSP) is a relatively shallow body of water generally about 3-5 meters deep that collects and stores solar energy. Salt Gradient Solar Ponds consist of 3 layers.The Upper Convective Zone (UCZ), the Non-Convective Zone, and the Lower Convective Zone (LCZ) (Fig 1).



(Fig 1.0 Salt Gradient Solar Pond)

The Upper Convective Zone is a homogenous freshwater layer, the Non-Convective Zone is a density stratified layer meaning the salinity of this layer increases with depth and decreases towards the surface, and the Lower Convective Zone is a homogenous layer of high density saturated salt solution. As sunlight strikes the surface of the pond a part of the incident solar radiation is reflected into the atmosphere, while the solar radiation that is absorbed within the Upper Convective Zone, moves through the Non-Convective Zone and into the Lower Convective Zone where it is then trapped in the heavier denser brine and stored as heat energy. The Non-Convective zone acts as an insulator in which once sunlight moves through the Non-Convective Zone a temperature gradient is formed thus suppressing convection cells in the Upper and Lower Convection Zones and allows heat to be stored within the Lower Convective Zone. Salt Gradient Solar Ponds can be used in many applications such as desalination, industrial process heating, space heating, and electricity production. The purpose of this research is to see if an experimental Salt Gradient Solar Pond could act as both a form of heat storage and water desalination with a transparent plastic cover acting as the freshwater layer and then comparing the amount of heat stored within the Lower Convective Zone with that of an experimental conventional Salt Gradient Solar Pond to see if could be capable of energy production as well.

II. Literature Review

A Solar Pond was first discovered by Von Kalecsinsky in Medve Lake in Transylvania in the early 1900s. It was observed that the pond reached a maximum temperature of 70 degrees Celsius at a depth of 1.32 meters with a minimum temperature observed at 26 degrees Celsius at the beginning of spring, a concentration of 26% NaCl was observed at the bottom. Oher similar ponds in the form of natural lakes have been observed in other parts of the world such as Oroville in Washington, Vanda in Antarctica, and Eilat in Israel (A. Abdulsalam et al. 2015) Salt Gradient Solar Ponds have been used in a variety of applications as a way of solar energy collection and long-term heat storage. Salt Gradient Ponds have been used for desalination such as at the El Paso Solar Pond (H. Lu et al. 2001), the Atlantis Auto Flash Salt Gradient Solar Pond (T. Szacsvay et al.1999) Salt Gradient Solar Ponds have been used for space heating such as at the University of Illinois Salt Gradient Solar Pond (T.A. Newell et al.1990), industrial process heating such as at the Kutch Salt Gradient Solar Pond in India (A. Kumar et al 1990), and energy production such as at the El Paso Solar Pond. Though Salt Gradient Solar Ponds are an attractive source for renewable energy many factors play important roles in the performance of these ponds.

Brine clarity Maintenance

Maintaining the transparency of a Salt Gradient Solar Pond is one of the most important factors affecting the performance of the pond. Suspended particles in the pond increase the turbidity and prevent the penetration of sunlight into the pond. There have been several techniques used to control the transparency or turbidity of the pond.examples of injections that have been used to control the transparency of these ponds include the use of calcium hypochlorite and copper sulfate at the University of Illinois Salt Gradient Solar Pond ((T.A. Newell et al.1990), injection of dilute hydrochloric acid and copper sulfate at the Kutch Salt Gradient Solar Pond (A. Kumar et al.1999), and injection of hydrochloric acid at the El Paso Solar Pond (H. Lu et al. 2001) and the Granada Salt Gradient Solar Pond (A. Alcaraz et al. 2018.). Experimental studies at the RMIT Salt Gradient Solar Pond in Australia using both cupricide and chlorine in separate tests have been conducted to test different solutions for the maintenance of the pond (N. Gasulla et al. 2011). It was found that while cupricide was more expensive than chlorine, a much higher quantity of was not as effective as cupricide. (N. Malik et al. 2011) conducted experiments using hydrochloric acid and brine shrimp. The use of hydrochloric acid for increasing pond transparancy was found effective as the brine shrimp were used mainly for algae control. . While hydrochloric acid and brine shrimp were both effective in maintaining the clarity of the pond over time the brine shrimp became extinct in the pond due to lack of dissolved oxygen, and it was observed that hydrochloric acid needed to be kept at a pH of around 4.5 to prevent algal blooms from forming and to control the turbidity of the pond.

Maintenance of the Gradient Zone

The Gradient Zone or the Non-Convective Zone in the pond acts as an insulator that suppresses convection from the Lower Convective Zone to the surface of the pond thus allowing heat to be stored. Therefore conditions of the Gradient Zone must be monitored, such as pH, temperature, salinity, and turbidity to make sure the Gradient Zone is in good condition. The Gradient Zone of a Salt Gradient Solar Pond is mainly affected by convection cells. Convection cells generally form in one of two ways, either wave action formed at the surface due to wind, or when the temperature in the Lower Convective Zone (LCZ) reaches a critical point thus conduction occurs and heat is then lost from the top of the LCZ to the bottom of the NCZ resulting in convective motion forming in the LCZ eventually leading to erosion and destruction of the Gradient Zone. An experimental study was conducted by (X.Y. Li et al. 2001) to observe the effect of erosion of the Gradient Zone in a Salt Gradient Solar Pond once the LCZ reaches a critical temperature and a vertical temperature difference has formed and it was concluded that once this happens heat is lost to from the LCZ to the NCZ and erosion occurs. However, in a working Salt Gradient Solar Pond, a heat exchanger located on the bottom of the pond is used to send heat to the application that the pond is being used for as well as to remove heat and prevent the LCZ from reaching a critical temperature when the pond is not in use. Another experimental study performed by (C. Karim et al. 2010) observed the use of porous media in the bottom of the LCZ to help absorb heat and prevent erosion of the LCZ. This experiment used rocks and plastic spheres as the porous media and it was found that by doing this the stability of the NCZ increased due to a less rapid rise in temperature of the LCZ and the absorbance of heat by the porous media in the LCZ. To maintain the Gradient Zone salinity concentrations within it must be monitored to make sure convection and diffusion are not occurring. This may be done by regular flushing of the Upper convective zone to replenish losses due to evaporation and to keep the salinity concentration low. Heat extraction from the Lower Convective Zone is also useful in controlling the temperature of the LCZ thus preventing turbulent convection and conduction to the Gradient Zone from the LCZ.

Thermal efficiency

The thermal efficiency of a Salt Gradient Solar pond is defined as the ratio of heat removal from the pond to the amount of solar energy incident on the pond. The thermal efficiency is affected mainly by the clarity of the pond, pond configuration, depth of the Gradient Zone, and the temperature difference between the surface layer and the LCZ. Those ponds with a greater temperature difference between the surface and the bottom are less efficient due to more heat losses at higher temperatures. The thickness of the LCZ is also a factor in the performance of Salt Gradient Solar Ponds. Salt Gradient Solar Ponds with a thinner LCZ have higher daily temperature fluctuations, however Salt Gradient Solar Ponds that have a thicker LCZ take longer to reach a desired temperature (H. Lu et al. 2001.)

Heat extraction

Heat Extraction in a Salt Gradient Solar Pond is done in one of two ways, either using an in pond heat exchanger or by pumping brine directly from the LCZ where it is carried to an external heat exchanger. An in-pond heat exchanger circulates fresh water through a pipe or a series of pipes located within the LCZ, where it is heated and is then carried to an external heat exchanger. At the El Paso, Solar Pond heat extraction was done by pumping brine directly out of the LCZ through an extraction diffuser and carrying it to an external heat exchanger where it was in operation from 1985 until 2001 and has been used for many applications such as electricity production, a source for industrial process heat, and used for desalination. At the Pyramid Hill Salt Gradient Solar Pond an in-pond heat exchanger in which a 1,000 meter expansion tank circulates fresh water into the 1 bundle of 48 MDPE plastic tubes is located just below the NCZ-LCZ interface. Here the freshwater cirulates through the plastic tube and is carried away to an external heat exchanger for use in industrial process heat for the application of salt drying as part of a salinity mitigation plan (J. Leblanc et al. 2011).

Filling of the pond

Filling of a Salt Gradient Solar Pond is done in one of two methods: Stacking or redistribution. Stacking involves pumping a high salinity concentration brine into the pond and then adding successively lower concentration layers using a diffuser until only freshwater with a very low salinity concentration exists at the surface. Redistribution includes pumping high concentration brine the depth of the LCZ and half of the depth of the NCZ followed by the injection of fresh water above the NCZ-LCZ interface until only freshwater exists at the surface (F.A. Banat et al.1994). Filling of the Salt Gradient Solar Ponds needs to be done very carefully to avoid mixing of the layers within the pond, and regular monoriting and maintenance need to be undertaken once the pond has been established to achieve maximum performance.

Cost

When considering a Salt Gradient Solar Pond to be used for heat collection and long-term heat storage, the total project costs must be considered. A cost breakdown from the University of Illinois Salt Gradient Solar Pond is discussed by (T.A. Newell et al.1990.). The cost breakdown ranged from 35 to 50 dollars per square meter or 140,000 to 200,000 dollars per acre. This includes 5 dollars per square meter for excavation, 9 dollars per square meter for lining materials, 3 dollars per square meter for labor, 3 dollars per square meter for fencing around the pond, 15 dollars per square meter for salt, 15 dollars per square meter for evaporation surface, and 4.5 to 5 dollars per GJ of energy expended. Based on these estimations a Salt Gradient Solar Pond would begin to provide a payback on the investment in 7 to 11 years. These prices were all valued in 1990 so it can be assumed that the cost estimates listed abovewould be higher today.

III. Maybee Ranch

The Maybee Ranch is a 40,000-acre ranch that extends throughout Martin County, Texas Currently, the Maybee ranch operates 5 produced water Salt Water Disposal (SWD) recycle facilities as well as a conventional SWD. The purpose of these SWD recycle facilities is to remove hydrocarbons, solids, and any debris sent into the facility. Chlorine dioxide (ClO2) which is a mixture of Hydroflouric acid, Sodium Nitrite, and Bleach is created inside a trailer beside the system and mixed with fresh water using a pump inside the trailer where it is sent to meet the incoming produced water at the head of the facility ClO2 loading is generally at a concentration of 25 ppm. From here the produced water swirls up in the front tanks called desanders, and once a certain height is reached in the desanders the water then moves into the gun barrels, once the water has reached a certain level in the gun barrels it is carried into working tanks, as water flows through the working tanks it is passed through a filter at the back of the facility. The filters consist of a media of sand, rock, and glass, and are used to catch any debris that may have passed through the facility. Once the water has passed through the filters it is then carried into a holding pond where it will then be sent to a frack pond to be reused. Oil tanks sit just in front of the desanders to keep hydrocarbons from passing through the facilities. The filters are flushed regularly with fresh water to clean them out, this flushed water from the filters is then sent to a roll-off box where it will be pumped back to the head of the facility.

The main parameters that are monitored are pH, Iron, and Oxidation-reduction potential (ORP). The desired ORP leaving the facility is around 200-300 millivolts (mV) with the desired ORP of 150 mV to be kept in the holding pond. the desired pH leaving the facility is around 6 to 6.5, the desired iron leaving the facility is 0-5 ppm The #1 facility (Fig. 2.0)is the main facility at the Maybee ranch and it receives a daily rate of about 20-30,000 barrels per day (BPD) coming into the facility. Freshwater from the Million barrel pond is sent to the facility and pumped into the chemical trailer to be used to mix ClO2. Water is brought into the #1 facility from Concho and Diamondback SWD's. where it passes through 2 desanders, 4 gun barrels, and 6 workings tanks where it is then passed through the post filter and sent to a holding pit. Water Recycled from the facility is then sent to the 1640 pit where it will be held and monitored until it is sent to a frack pond for production.

(Fig 2.0 Maybee Ranch #1 Facility)

The # 2 facility is a smaller facility than the # 1 facility as about 10 – 15,000 BPD are sent into this facility. Water is sent in from Concho and Diamondback SWD's and runs through the system in the same way as the # 1 facility. However, the # 2 facility does not have any desanders it only has 2 gun barrels, 6 workings tanks, 4 oil tanks, and a post filter. Incoming water is met by ClO2 being pumped into the facility from the trailer and moves up through the gun barrels where it passes through the working tanks, and the filter and is then sent to the 1640 pit. An advantage of this facility is that because there is not as great of a rate of water coming in this allows for a greater average residence time of the produced water allowing longer contact with ClO2 and, therefore allowing more time for solids in the water to be removed. Water used to mix ClO2 is pumped from a water well near the chemical trailer. This facility can also bypass some of the incoming water that is greater than the rate designed for this system, then incoming water will be sent to water tanks adjacent to this facility and from there can be sent out to the # 5 facility.

(Fig 3.0 Maybee Ranch #2 Facility)

The # 5 and # 6 facilities (Figs 4.0 and 5.0) are designed and operated almost exactly as the # 1 facility with the only differences being that they only receive a rate of about 15 – 20,000 BPD and they have a water tank located behind the facility that is fed by the million barrel pond to be used to mix ClO_2. The # 5 and # 6 facilities are fed by the King and Winters SWD facilities. Again water is met by incoming ClO_2 and is passed up through the desanders where it passes through to the gun barrels and then into the working tanks. Once water at these facilities has been passed through the post filter it is then sent to the Section 6 pit.

(Fig 4.0 Maybee Ranch #5 Facility)

(Fig 5.0 Maybee Ranch #6 Facility)

The Encana facility (Fig. 6.0) is a unique Maybee Ranch facility in that it has two side-by-side systems. The Encana facility is two side-by-side # 1 facilities. This facility has two sets of systems that have 2 oil tanks, 2 desanders, 2 gun barrels, 6 working tanks, and a post filter. Most of the time however only one side of the facility is open with water passing through it. This facility receives water from Encana SWD facilities at a rate of about 10 – 15,000 BPD. Again water from the million barrel pond is sent to a water tank to mix ClO_2 in the chemical trailer and from there it is pumped to meet the incoming water, where it passed up through the desanders and moves through the gun barrels, into the working tanks and passes through the post filter where this water is sent to the peat pit which is not owned by the Maybee Ranch. Water can also be sent to the Section 6 pit at times as well.

(Fig 6.0 Maybee Ranch Encana Facility)

The 1640 pit (Fig 7.0) is a 280 x 290 or 81,200 square foot pond capable of holding 27,375 cubic meters or 172,071 barrels of water. This pond is fed by the # 1 and 2 facilities and receives 30 – 45,000 BPD of recycled water. The water level in this pond is kept at around 12 feet with a maximum depth of 17 feet. This pond has 6 aerators and a recirculation pump in it to keep the water from going sour. This pond is monitored several times a day to make sure that water quality is per the specifications that have been set. If at any time the water in the pond is not within specifications or if dirty water is being sent into the pond due to an error from a facility action is taken to correct the issue and get the water quality back up. Normally treatment of the pond includes injecting ClO_2 directly into the pond by using the chemical trailer located right near the pond. Bleach has also been used to shock the pond to get the pond back to where it needs to be. When monitoring the pond a sample is taken from the recirculation pipe and pH, ORP, iron, and DO measurements are recorded. Water from the 1640 pit is then sent to the Holdings pit where it will eventually be sent to a frack pond.

(Fig 7.0 Maybee Ranch 1640 Pit)

The Holdings pit (Fig 8.0) is a 300 x 300 or 90,000 square foot pond capable of holding 30,342 cubic meters or 190,721 barrels of water. This receives water from the 1640 pit, however, water can also be received from the # 5 and #6 facilities. This pond receives about 40-45,000 BPD. This pond has 4 aerators to keep the water in the pond from going stagnant and, but does not have a recirculation pump like that of the 1640 pit. This pit holds recycled water from the 1640 pit mostly and sends it out to a frack pit to be used for production. Monitoring of this pond occurs multiple times a day to ensure that the water quality is within the specifications that are set to be used for production. Parameters that are observed are pH, ORP, iron, and DO If at any time it is observed that the water quality is not within specifications actions like that that are undertaken at the 1640 pit which includes injection of ClO_2 or bleach to help get the pond back to where it needs to be. At times the Holdings pit can also be cut with freshwater from the million barrel pond in order to help control the water quality.

(Fig 8.0 Maybee Ranch Holdings Pit)

The Section 6 (Fig 9.0) pit is a 545 x 545 or 297,025 square foot pond that is capable of holding 100,282 cubic meters or 630,345 barrels of water. This pond is fed by the # 5 and # 6 facilities and occasionally receives water from the Encana facility. This pond does not have any aerators or recirculation pumps so it is important that the water quality in this pond be monitored. This pond's main function is to send water to frack pits and hold water coming into it from the #5 and # 6 facilities and receives about 30 – 40,000 BPD. This pond is monitored multiple times a day to ensure that the water quality is kept within the specifications that were set to be used for production. Parameters that are observed are pH, ORP, iron, and DO. If the water quality is found to not be within the specifications that were set the actions such as injecting ClO2 or bleach are performed to try and get the pond back to where it needs to be.

(Fig 9.0 Maybee Ranch Section 6 Pit)

The Million Barrell Pond (Fig 10.0) is capable of holding roughly 1,000,000 barrels of water. This pond is fed by the city of midland as well as water wells located on the ranch. The main purpose of this pond is to send water to the facilities for mixing of ClO2, as well as to send water to any of these ponds if water quality needs to be improved as well as if the demand for the recycled water is higher than what is coming into the facilities then the million barrel pit may send water to the pits to help supplement the demand.

(Fig 10.0 Maybee Ranch Million barrel Pond)

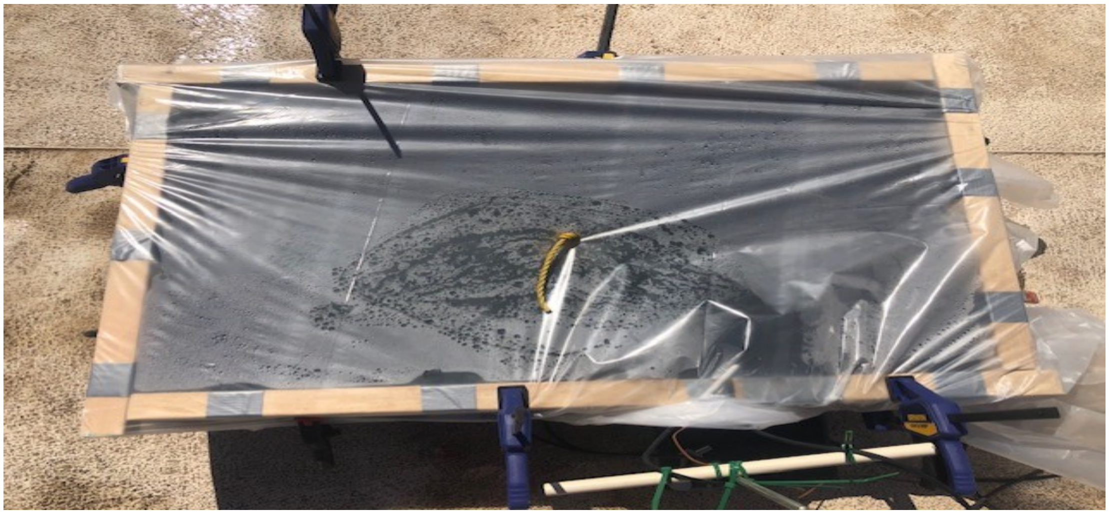
Based on what has been observed at the Maybee Ranch the goal of this research is to see if a Salt Gradient Solar Pond could be a viable option for both energy production and Solar distillation. Due to the concern of greenhouse gas emissions, it is possible that oil production could decline over the years with renewable energy systems growing more and more. Therefore the Maybee Ranch has several aspects that would make the use of a Salt Gradient Solar Pond an attractive option. First there would be no need to build a lot of infrastructure as the 1640 pit, the Holdings pit, and the section 6 pit already exists, but could be converted to a Salt Gradient Solar Pond, and these ponds already have adequate depth and liner to be used. Secondly, there would be no need to bring in a lot of salt the produced water that is sent to ranch ranges in 150,000 – 200,000 ppm in salinity which is suitable to establish a pond. The focus of this research is to determine if produced water taken from the Maybee Ranch would be suitable to store heat great enough for energy production. A secondary focus of this research is to determine the feasability of using a transparent cover placed over the top of the pond to act to enhance the LCZ such that not only would heat be stored in the LCZ of the pond but freshwater would be produced from high salinity water by performing solar distillation. If both could be accomplished electricity production could come from the heat stored in the bottom through a Rankine cycle system of the pond and freshwater could be produced and possibly used for functions such as irrigation, drinking water for cattle out on the ranch, and possibly be sent to the city of Midland and used as non-potable water for irrigation of peoples yards, showering, toilets or possibly depending on the quality of the distillate even drinking water, if so this could also serve as a form of water conservation.

IV. Materials and Methods

The exprimental portion of this research was conducted on the roof of the Agriculture and Natural Sciences building here at West Texas A&M University. For this experiment 2 36 x 24-inch mixing tubs with a depth of 8 inches were used to build 2 experimental Salt Gradient Solar Ponds. In both ponds, the depth of each layer the UCZ, NCZ, and LCZ were set at 2.5 inches with 0.5 inches taken off the top to avoid overflow. Each layer within the pond was labeled with color-coded tape with red being the top of the LCZ, yellow being the top of the NCZ and blue being the top of the UCZ. Omega Type K thermocouples were placed in the LCZ of both ponds with an accuracy of +/- 2.2 degrees Celsius. These Omega Type K thermocouples are capable of reading temperatures up to 450 degrees Celsius. Campbell Scientific T107 temperature probes were used to measure the temperatures in both the UCZ and NCZ of the covered pond and used to measure the temperature of the LCZ and the temperature directly under the plastic cover acting as the UCZ for the covered pond. These temperature probes have an accuracy of +/- 0.2 degrees Celsius and are capable of recording temperatures between -35 and 50 degrees Celsius with a survivability range of -50 – 100 degrees Celsius. The T107 temperature probes were fixed to a flask stand located adjacent to the ponds and were duck-taped to the sides of their respective layer to hold their position.

Both Omega K-type thermocouples and T107 temperature probes were connected to a CR1000X measurement and control data logger which was programmed to take measurements every 5 seconds and record the average of those measurements every 5 minutes. A CS301 Pyranometer was used to take solar radiation measurements with an accuracy of +/- 5 % and capable of recording solar radiation ranging from 0 – 2,000 watts per square meter. The CR1000X datalogger recorded solar radiation measurements every 5 seconds and recorded the average of these every 5 minutes. An Oakton PC 450 pH and Conductivity meter was used to record pH and TDS concentrations of the water in each layer before filling the pond. The uncovered pond (Fig 11.0) was designed to perform as a conventional Salt Gradient Solar Pond to compare the amount of heat being stored in the LCZ compared to that of the covered pond with a transparent plastic sheet acting as the UCZ. The covered pond was filled by adding Produced water from the Maybee Ranch to be used as the high salinity water in the LCZ. Produced water was added to its desired height of 2.5 inches consisting of 7 gallons of water. Next, a thin transparent plastic sheet was placed over the top of the LCZ to gently fill the NCZ. The NCZ water to be poured into the pond was a mix of 50% fresh water and 50% high salinity produced water and was gently poured over the thin transparent plastic sheet using a cup. Water in the NCZ was filed to its desired height using 7 gallons of water and then gently removing the plastic sheet. Lastly the UCZ was filled by placing a thin transparent plastic sheet over the top of the NCZ and carefully adding freshwater to its desired height of 2.5 inches using 7 gallons of water and then gently removing the plastic sheet. The covered pond (Fig 12.0) with a thin transparent plastic sheet acting as the UCZ was filled by adding produced water from the Maybee Ranch to its desired height of 2.5 inches using 7 gallons of water. Next, a thin plastic sheet was placed over the top of the LCZ where a mix of 50% produced water and 50% freshwater was used in the NCZ and carefully poured over the plastic sheet with a cup, and once the NCZ had reached its desired height of 2.5 inches using 7 gallons of water the plastic sheet was then carefully removed. A small 50 ml flask with a 2.5 weight sitting over the neck of the bottle to prevent flotation was placed into the pond where the top of the flask was stuck up over the top of the NCZ to collect distillate sloping down from the thin transparent plastic cover. Initially, a rope tied to the weight around the flask was run through the cover with a hole poked through it and tied into a knot to create a sloping of the cover, however, that would later be replaced with 2.5 oz fishing weights. Finally, the thin transparent cover was pulled over the top of the pond and secured with clamps. It should also be noted that 2 1 x 2 x 6 wooden boards were duck-taped prior to filling of the pond to the side to increase the slope of the cover and were secured with ducktape and clamps. Once both ponds were filled and secured, temperature measurements in the pond, as well as solar radiation measurements, began recording.

(Fig 11.0 Uncovered Salt Gradient Solar Pond)



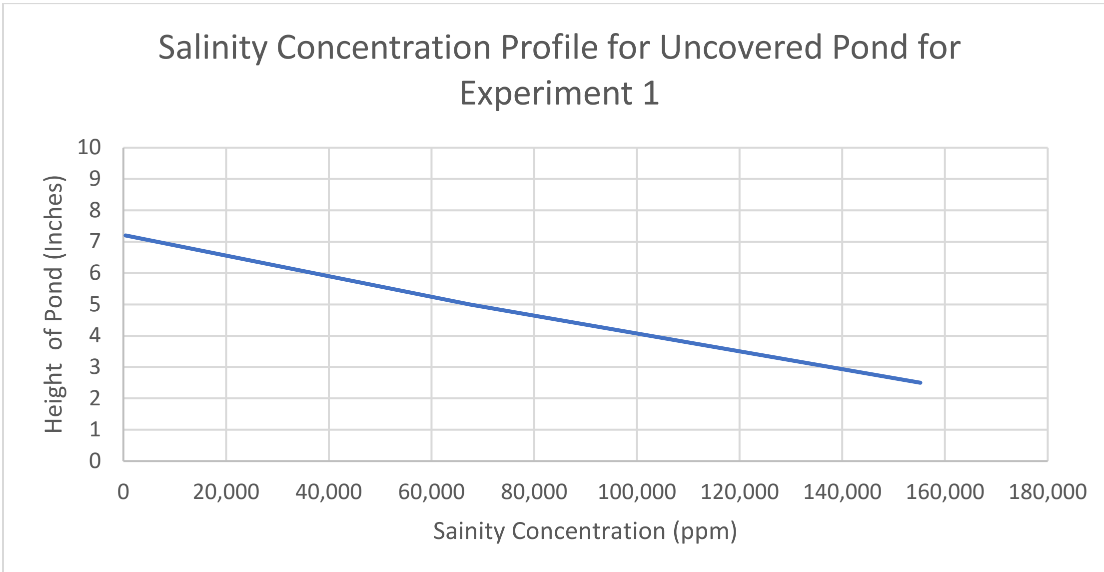
(Fig 12.0 Covered Salt Gradient Solar Pond)

V. Results

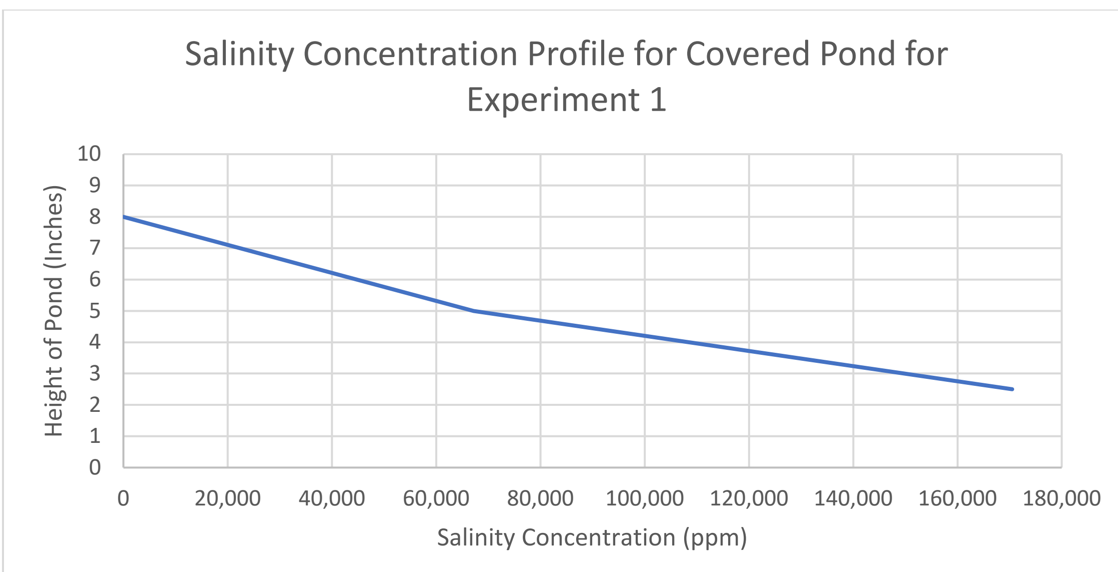
For this research, 2 separate experiments were conducted to see if a Salt Gradient Solar Pond with a thin transparent cover acting as the UCZ would be able to store heat within the LCZ suitable for electricity production compared to that of a conventional Salt Gradient Solar Pond as well as perform solar distillation. Experiment 1 ran from noon on April 30th until May 2nd at 9:45 am. Due to unforeseen errors resulting from a building power outage, Experiment 2 only ran from noon May 4th until 6:30 pm May 4th. Both experiments were conducted in the same manner with slight altercations being made for this research.

Experiment 1

Experiment 1 ran for 2 days until it was observed that there was no noticeable change in the performance of the pond. Experiment 1 day 1 ran from noon April 30th until 9:40 May 1st, and Experiment 1 day 2 rand from 9:45 am May 1st until 9:50 am May 2nd. Salinity concentrations for both the covered pond and the uncovered pond were collected prior to filling the pond. The uncovered pond had a salinity range of 155,200 ppm in the LCZ, 67,500 ppm in the NCZ, and 400 ppm in the UCZ (Fig 13.0). Salinity concentrations in the covered pond (Fig 14.0) ranged from 170,500 ppm in the LCZ, and 67,200 ppm in the NCZ while the thin transparent cover acted as the UCZ.



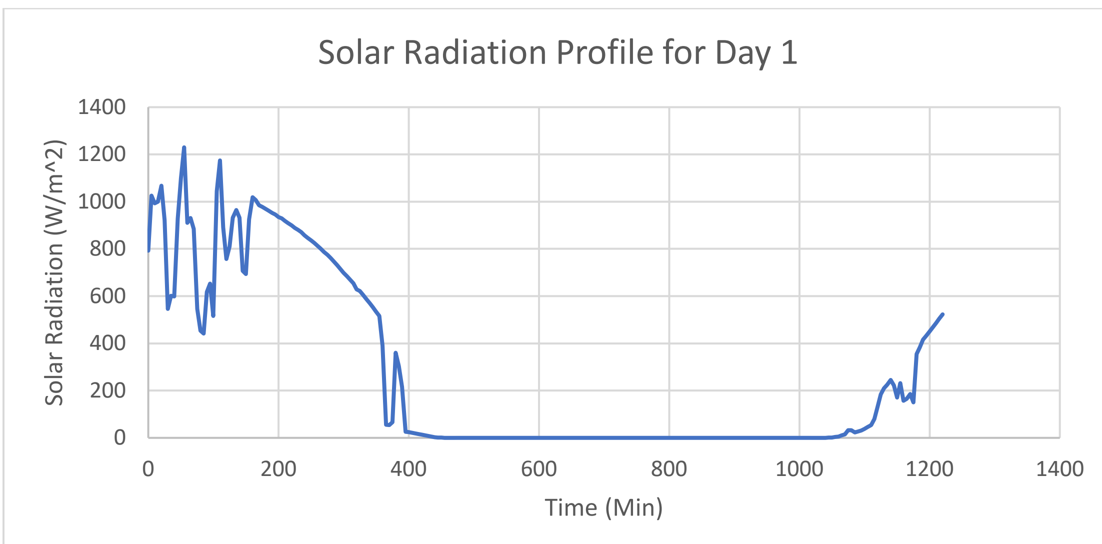
(Fig 13.0 Salinity Concentration Profile for Uncovered Pond for Experiment 1)



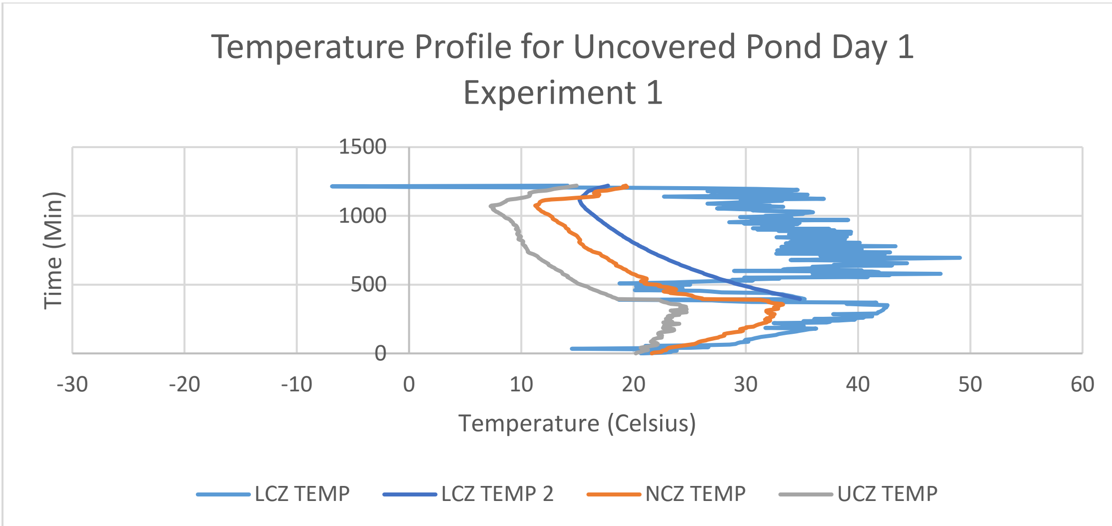
(Fig 14.0 Salinity Concentration Profile for Covered Pond for Experiment 1)

The amount of solar radiation incident on the pond is a major factor in the performance of the pond regarding the amount and temperature in which heat is stored within the LCZ. Therefore for adequate heat to be stored within the LCZ, there must be an adequate amount of incoming solar radiation onto the pond. For experiment 1 on day 1 incident solar radiation ranged from 400 – 1,200 watts per square meter with a peak measured at 12:55 pm at 1,230 watts per square meter (Fig 15.0). During day 1 of experiment 1, there were many fluctuations of incoming solar radiation due mainly to clouds moving over the sun at various points throughout the day, and then at around 6:00 pm, solar radiation began to drop quickly as the pond moved into the shade due to the movement of the suns position. As already stated the amount of incoming solar radiation plays a factor in the amount and temperature of heat stored within the LCZ (Figs 16.0 and 17.0). Therefore it was observed that as solar radiation increased throughout the day for day 1 of experiment 1 so did the temperature within the ponds (Figs 18.0 and 19.0). However at around 6:30 pm on April 30th for experiment 1 day 1 it was observed that the Omega K type thermocouples were giving noisy inaccurate readings of the LCZ temperature at times in both ponds (for reasons that are unknown) as measurements would jump from around 80 degrees celsius down to -15 to -30 degrees. Once this was observed T107 temperature sensors were placed within the LCZ of both ponds and observed for about 30 minutes to ensure that consistent measurements were being taken. Because of this, it cannot be said with confidence what the actual maximum temperature of the LCZ within both ponds was for day 1 of experiment 1. However, it can be noted that at 7:55 the temperature of LCZ for the uncovered pond was 34.82 degrees Celsius and a temperature of 36.22 in the covered pond suggesting that the covered pond had reached a higher temperature in the

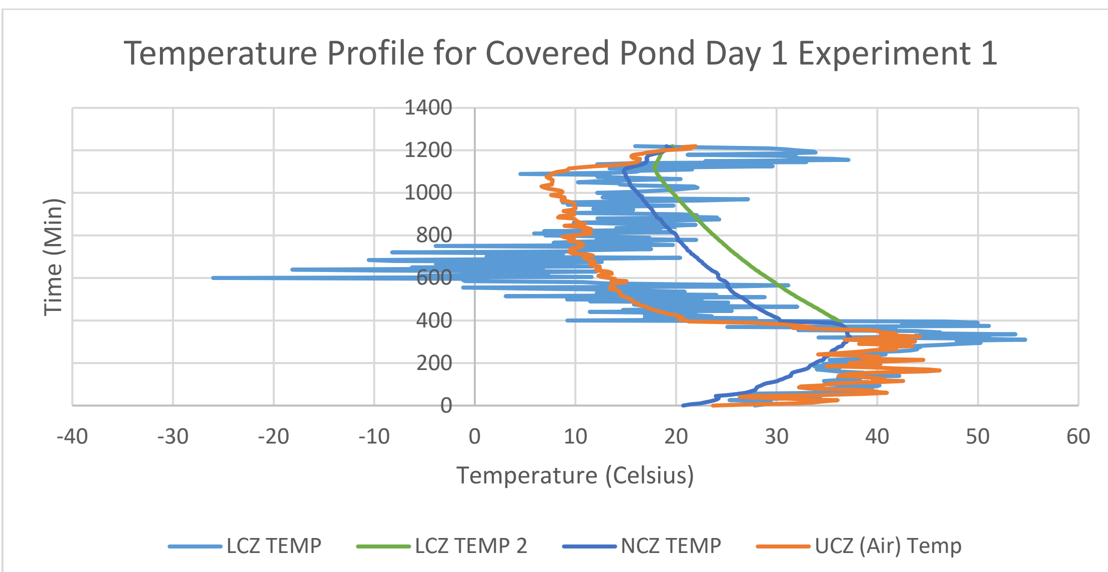
LCZ than that of the uncovered pond. It was also observed that once incoming solar radiation had ended heat loss within both the covered and uncovered pond occurred as the covered pond dropped from 36.22 degrees Celsius at 7:55 pm to 17.85 degrees Celsius at 7:55 am on May 1st when both solar radiation and temperature in the pond began to increase again. From looking at the observational data it is clear this heat loss was not due to the Gradient Zone not being established as there is a consistent temperature gradient in both ponds throughout the day. Therefore the likely hpothesized primary cause of heat loss was because these ponds were smaller in size and uninsulated, and it stands to reason that once incoming solar radiation was lost, conduction of heat occurred along the sides of the pond, and from the LCZ to the top of the roof surface.



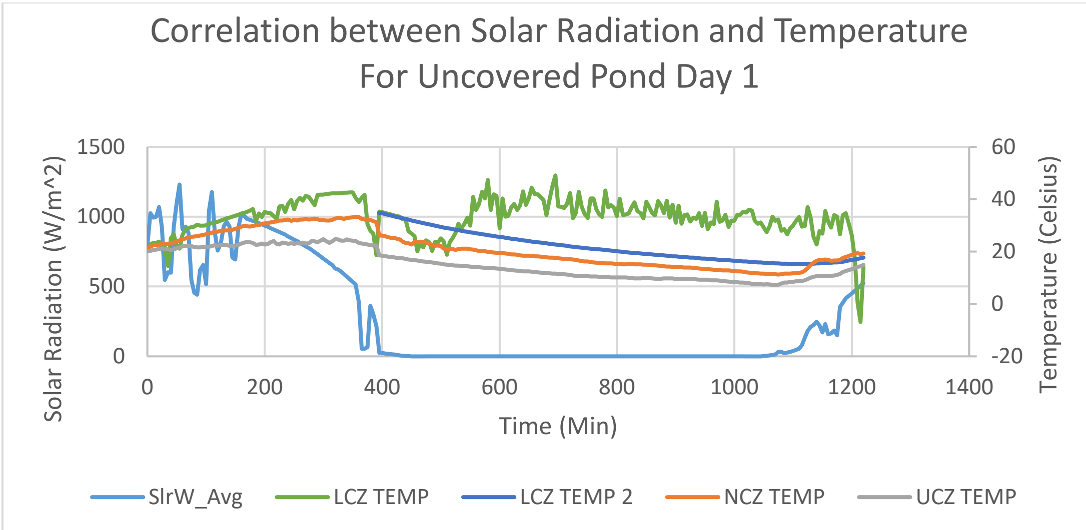
(Fig 15.0 Solar Radiation Profile for Experiment 1 Day 1)



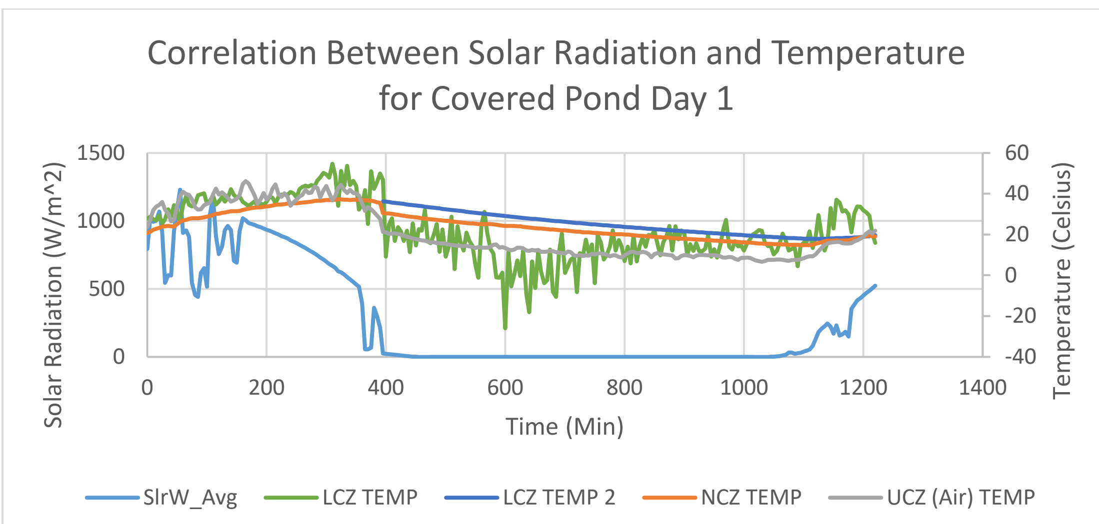
(Fig 16.0 Temperature Profile for Uncovered Pond Day 1 of Experiment 1)



(Fig 17.0 Temperature Profile for Covered Pond Day 1 of Experiment 1)



(Fig 18.0 Correlation between Solar Radiation and Temperature for Uncovered Pond Day 1 of Experiment 1)



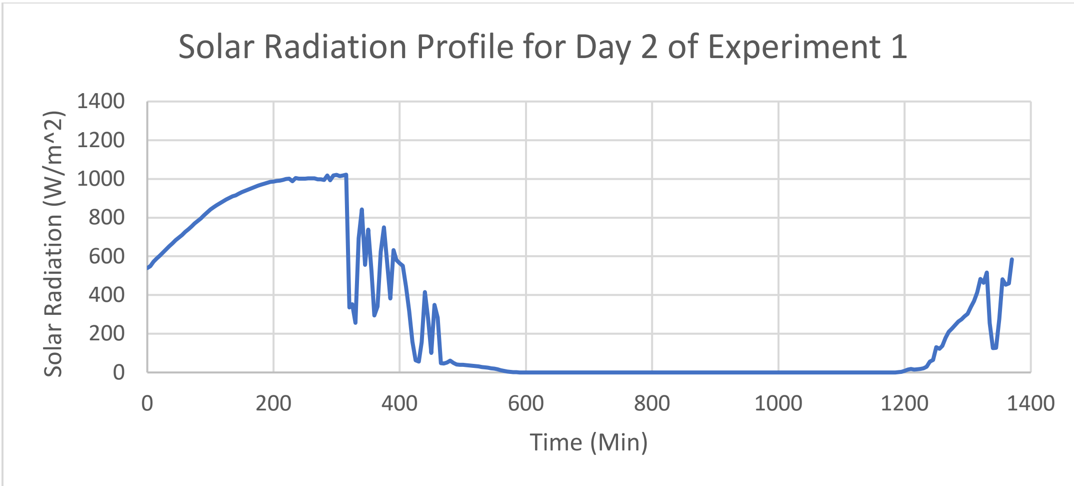
(Fig 19.0 Correlation between Solar Radiation and Temperature for Uncovered Pond Day 1 of Experiment 1)

Day 2 of experiment 1 was able to yield more consistent results for the temperature of the LCZ as the additional T107 temperature sensors were given a full day to collect temperature measurements of both ponds. Day 2 of experiment 1 ran from 9:45 am May 1st until 9:50 am May 2nd. On May 2nd at 9:40 am the datalogger was unplugged thus concluding Day 1 of experiment 1 in order to replace the cover for the covered pond. on day 2 of experiment 1 a new cover was placed onto the pond using 2.5 oz fishing weights to produce the slope on the cover for distillate to collect on (Fig 20.0). This was done to reduce heat loss escaping through the hole in the original cover and hopefully produce higher temperature stored in the LCZ of the covered pond. Once the cover was replaced temperature measurements in the pond as well as solar radiation measurements began again.

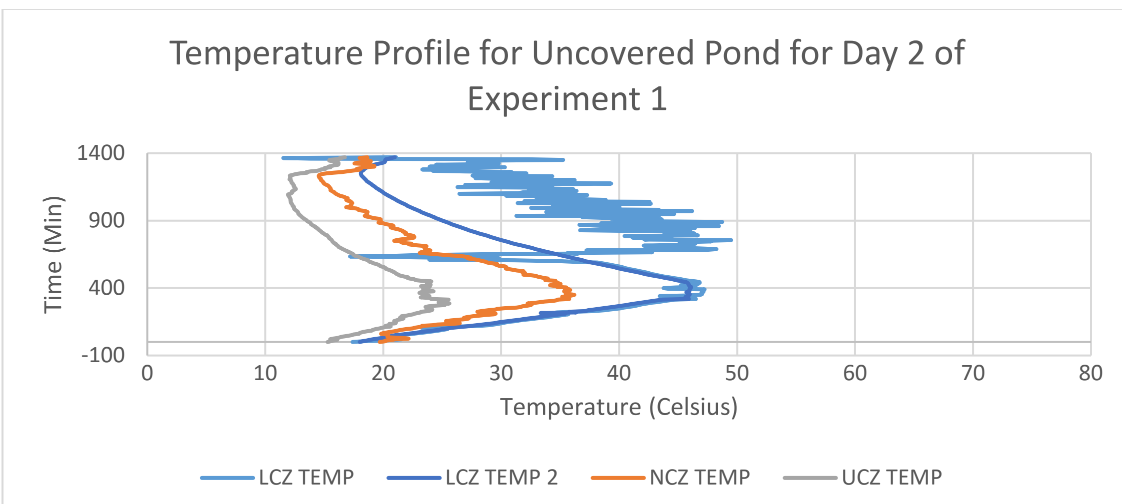
(Fig 20.0 Replacement of cover for Day 2 of Experiment 1.)

For the most part Day, 2 of experiment 1 yielded similar results as that of Day 1. Solar Radiation for Day 2 ranged from 500 – 1,000 watts per meter with a max solar radiation measurement observed at 3:00 pm on May 1st at 1,022 watts per square meter (Fig 21.0).

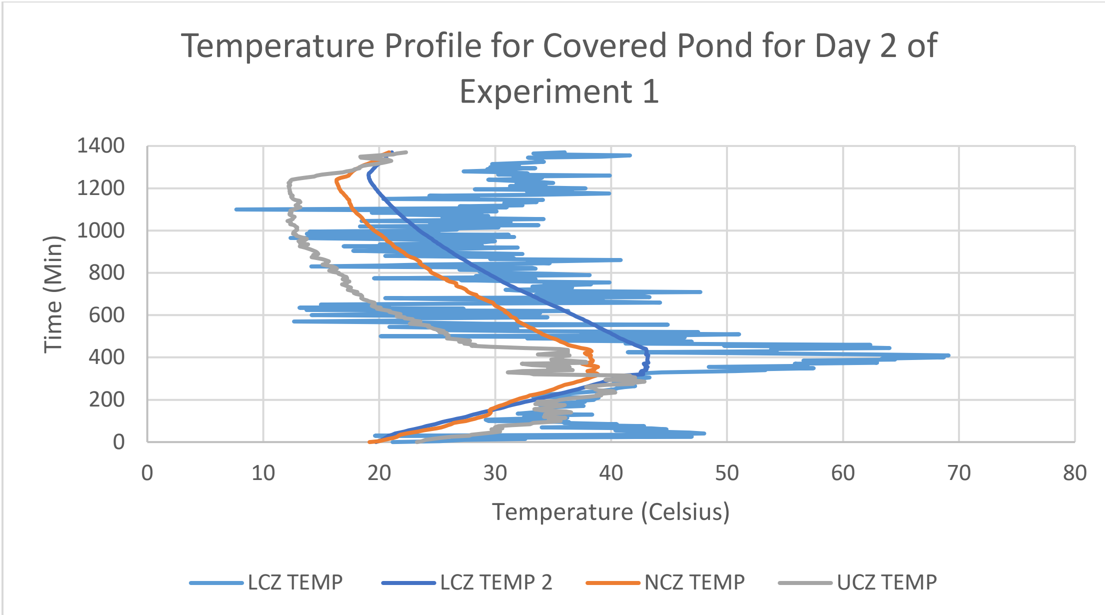
For experiment 1 day 2 a full day of data from the T107 temperature sensors that were placed in the LCZ of both ponds were collected. On day 2 of experiment 1, we again saw that the Omega K type thermocouples were likely giving noisy and inaccurate measurements thus the T107 temperature sensors were used to determine what the maximum and minimum temperatures were in the LCZ of both ponds (Figs 22.0 and 23.0). It was observed that the uncovered pond yielded higher temperatures. It was observed that the highest temperature observed for LCZ of the uncovered pond was 46.09 degrees Celsius at 5:45 pm May 1st, while the lowest observed temperature for the LCZ of the uncovered pond was 18.01 degrees Celsius at 9:50 am on May 2nd. The highest observed temperature of the LCZ for the covered pond was 43.21 degrees Celsius at 5:15 pm on May 1st, while the lowest observed temperature for the LCZ of the covered pond was 19.01 Degrees Celsius observed at 9:50 am on May 2nd. When looking at the data it was seen that it took longer for the covered pond to establish a temperature gradient in the pond and thus store heat within the LCZ once the temperature gradient was established. The main cause of this is likely due to the reflection of solar radiation by the condensation that formed on the inside of the cover (as well as possibly the cover itself, which is not completely transparent) thus preventing as much solar radiation from being absorbed by the covered pond than that of the uncovered pond. Also, because the cover on the covered pond is acting as the UCZ and a means to produce freshwater through solar distillation, conduction is occurring due to evaporation of water from the top of the NCZ meaning that some heat within the LCZ in the covered pond is lost, therefore explaining why the uncovered pond produced higher temperatures within the LCZ than that of the covered pond. However, we do see that the minimum temperature observed of the covered pond is greater than the minimum temperature observed on the uncovered pond suggesting that the covered pond stored more heat once solar radiation was lost. As was the case on day 1 of experiment 1 incident solar radiation played an important factor on both ponds in which we see that as Solar radiation increases throughout the day and so does the temperature of both ponds (Figs 24.0 and 25.0). Once incoming solar radiation was lost on both ponds, we again see that the temperatures decrease in the LCZ of both ponds simply because these ponds are relatively small in size and are uninsulated heal loss is mainly occurring from the sides of the pond, and by conduction from the LCZ to the top of the roof surface, a small amount of heat is lost from the surface of both ponds as well. Throughout the course of experiment 1, on both days 1 and 2, the salinity gradient of both ponds were observed to remain stable as temperature gradients formed in both ponds when solar radiation was incident on the pond with higher temperatures being in the LCZ suggesting that no erosion of the Gradient Zone had occurred. Experiment 1 concluded at 9:50 am on May 2nd at which point both ponds were emptied and all materials were put away and stored to be set up for experiment 2. It was observed that 4ml of distillate had been collected in the flask placed within the covered pond showing that with the use of the cover heat storage and solar distillation had been performed on the covered pond.



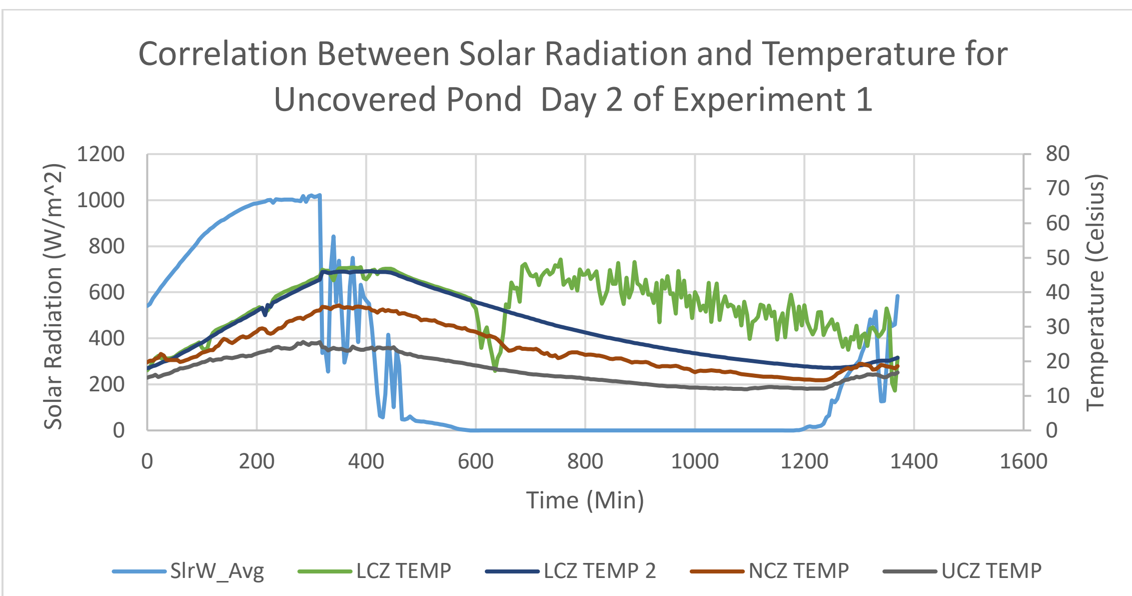
(Fig 21.0 Solar Radiation Profile for Day 2 of Experiment 1)



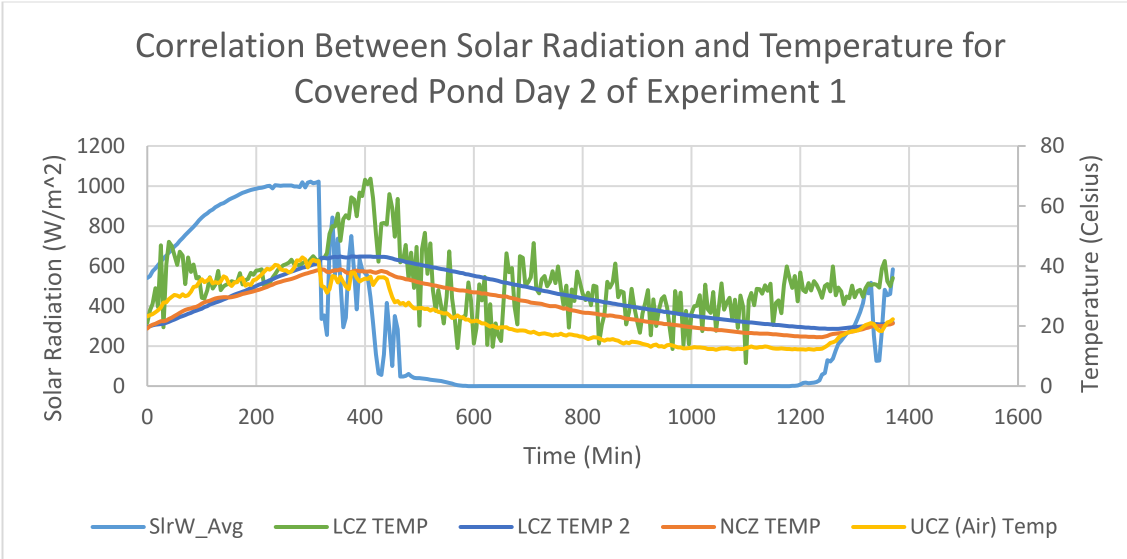
(Fig 22.0 Temperature Profile for Uncovered Pond for Day 2 of Experiment 1)



(Fig 23.0 Temperature Profile for Covered Pond for Day 2 of Experiment 1)



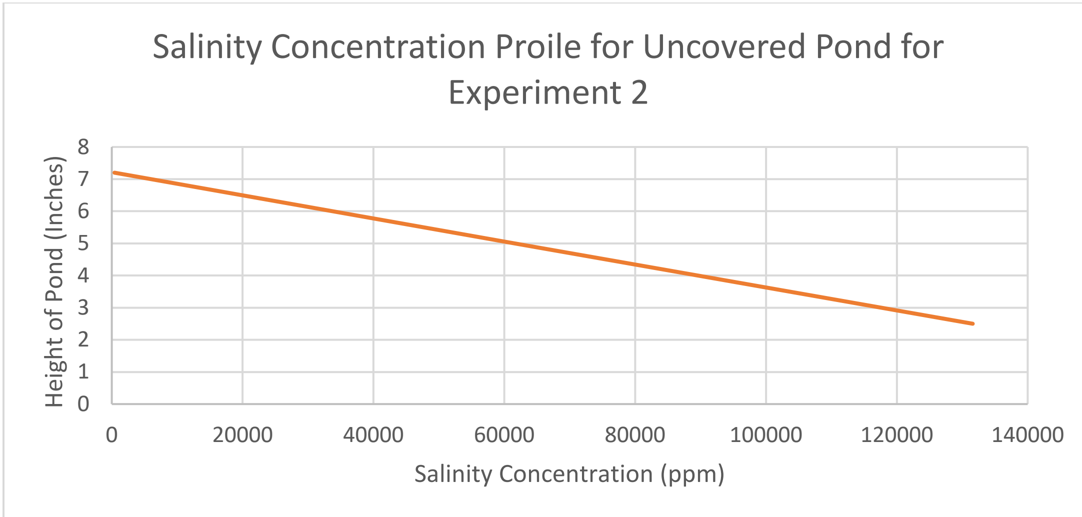
(Fig 24.0 Correlation Between Solar Radiation and Temperature for Uncovered Pond Day 2 of Experiment 1)



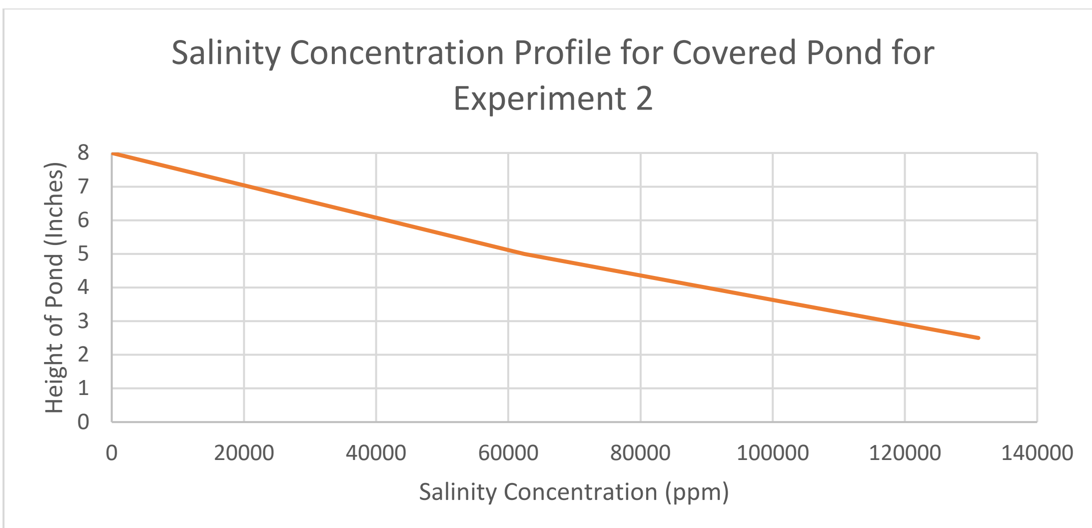
(Fig 25.0 Correlation Between Solar Radiation and Temperature for Covered Pond Day 2 of Experiment 1)

Experiment 2

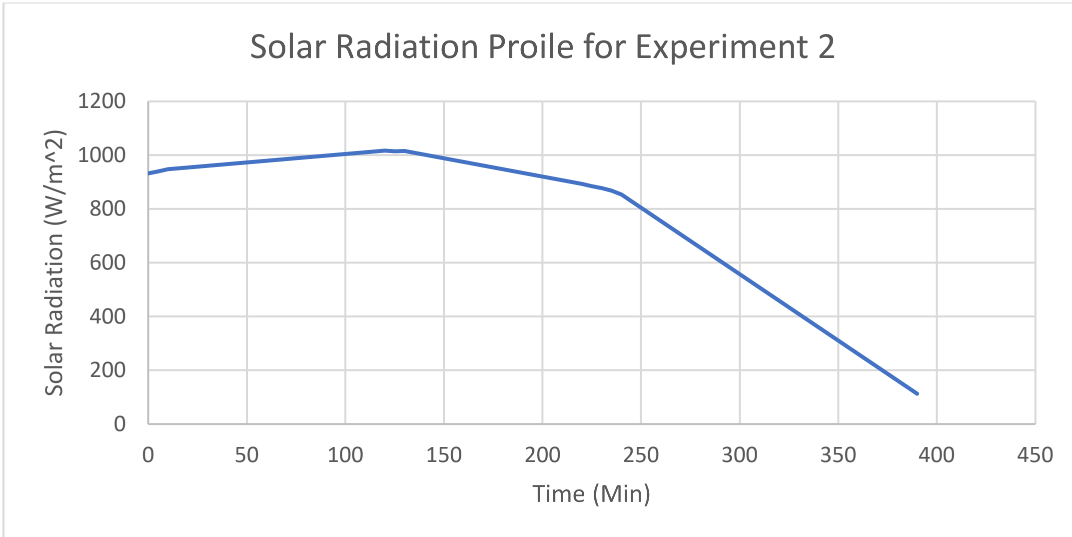
Experiment 2 was conducted from 12:05 pm on May 4th, 2021, until 6:30 pm on May 4th, 2021. Experiment 2 was conducted from 12:05 pm on May 4th until 11:15 am on May 6th and expected to collect data over two days like that of experiment 1. Unfortunately, due to external difficulties such as power outages within the building data was only recorded on the datalogger from 12:05 to 6:30 pm on May 4th. This was not noticed until it was time to end the experiment as the data logger showed measurements when it was checked every hour over the two-day period however measurements past 6:30 pm on May 4th were not being recorded due to the power outage. Both the uncovered and covered pond were filled and of the same design like those from experiment 1. Even with limited data for experiment 2, we can still see an obvious temperature and salinity gradient form in both ponds as higher temperatures were observed in the LCZ than in the NCZ and higher temperatures are observed in the NCZ than the UCZ in both ponds. Salinity concentrations for the uncovered pond (Fig 26.0) were 131,600 ppm in the LCZ, 61,600 ppm in the NCZ, and 412 ppm in the UCZ. Salinity concentrations for the covered pond (Fig 27.0) were 131,100 ppm in the LCZ and 62,400 ppm in the NCZ with a transparent plastic cover acting as the UCZ. Solar radiation for experiment 2 (Fig 28.0) ranged from about 850 – 1,000 watts per square meter throughout the day until solar radiation incident on the pond drastically decreased at around 6:30 pm due to the sun moving to the west of the tower on the building, resulting in the pond moving into the shade. The highest solar radiation measurement for experiment 2 was 1,017 watts per square meter observed at 2:05 pm, with the lowest observed solar radiation measurement being 113 watts per square meter observed at 6:30 pm. In experiment 2 the influence of incident solar radiation incident on the temperature with the ponds was again noticed. During experiment 2 as solar radiation incident on the ponds increased so did the temperatures within the LCZ of both ponds. For experiment 2 the T107 temperature sensors placed within the LCZ of both ponds were used to determine what the temperature of the LCZ in both ponds most likely were as the Omega K type thermocouples have continually given inaccurate measurements at times during both experiments 1 and 2. The Maximum temperature observed within the LCZ of the uncovered pond was 43.39 degrees Celsius at 6:30 pm on May 4th (Fig 29.0) while the highest temperature of the covered pond was also observed at 6:30 at 38.11 degrees Celsius (Fig 30.0). Experiment 2 shows that the uncovered pond reached a higher temperature within the LCZ than that of the covered pond. The reason for this has already been discussed in that the transparent plastic sheet acting as both the UCZ of the covered pond as well as acting as a source to perform solar distillation on the pond and producing freshwater. As water condenses along the inside of the cover solar radiation is reflected off both the cover and the condensate on the inside of the cover thus reducing the amount of solar radiation moving into the pond. Second, because solar distillation is being performed within the pond is reasonable to assume that heat is released as water evaporates. On May 5th a day that was initially supposed to record data for experiment 2 a second transparent plastic cover was placed over the existing cover to try and reduce the amount of reflection on the cover and increase the temperature in the LCZ. However, because only limited data was recorded on the datalogger it is unknown if this worked. However, it was observed at the end of experiment 2 20 ml of distillate was found to be collected in the 50 ml flask placed within the pond. This could be due to the second cover helping in maintaining higher heat within the pond thus increasing evaporation, or it could just simply be that the sloping of the covered pond was better aligned for condensate to collect into the flask than it was in experiment 1. Because we have limited data for experiment 2, we do not see how much heat is stored within the LCZ of both ponds once solar radiation is lost however, we do see the correlation between the temperature of the LCZ in both ponds and the amount of incoming solar radiation (Figs 31.0 and 32.0). It should be safe to assume however that once incident solar radiation was lost heat loss occurred from both ponds due to their relatively small size and due to the fact neither pond was insulated and heat loss most likely occurred along the sides as well as in the LCZ conducting heat to the top of the roof's surface. Once experiment 2 was concluded both ponds were emptied, and all materials were put away and stored.



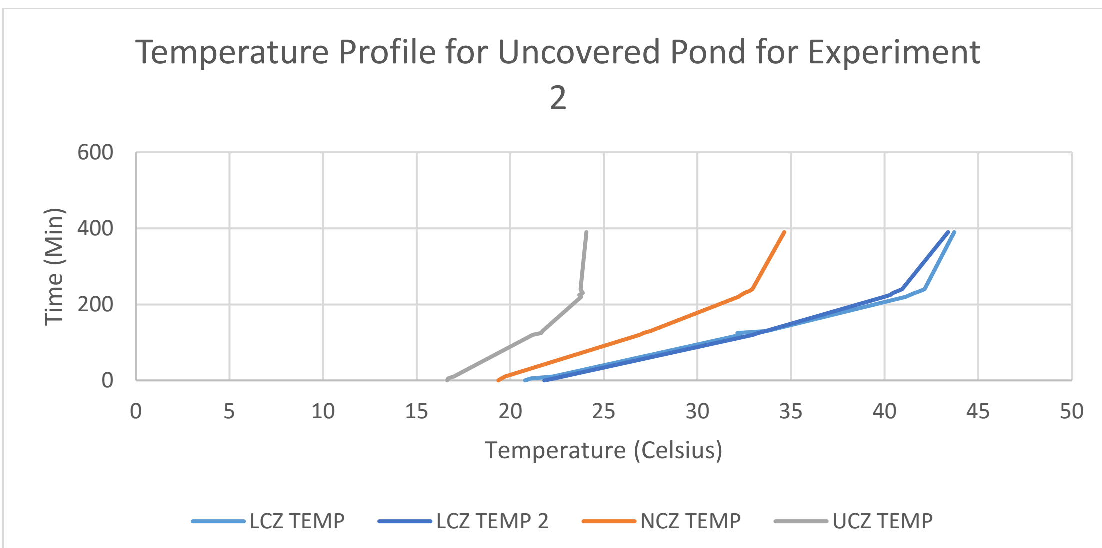
(Fig 26.0 Salinity Concentration for Uncovered Pond for Experiment 2)



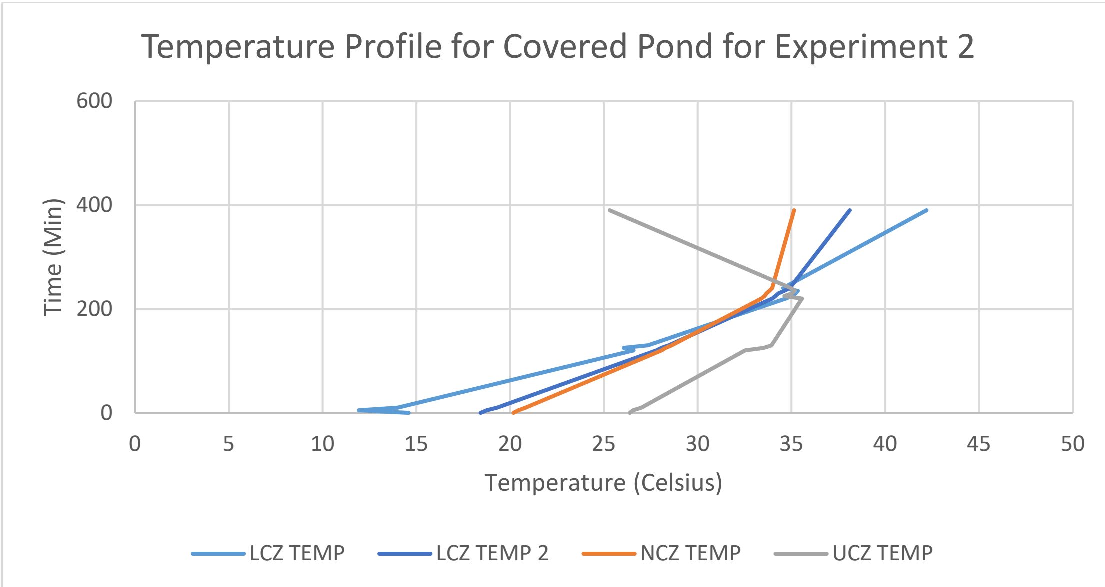
(Fig 27.0 Salinity Concentration Profile for Covered Pond for Experiment 2)



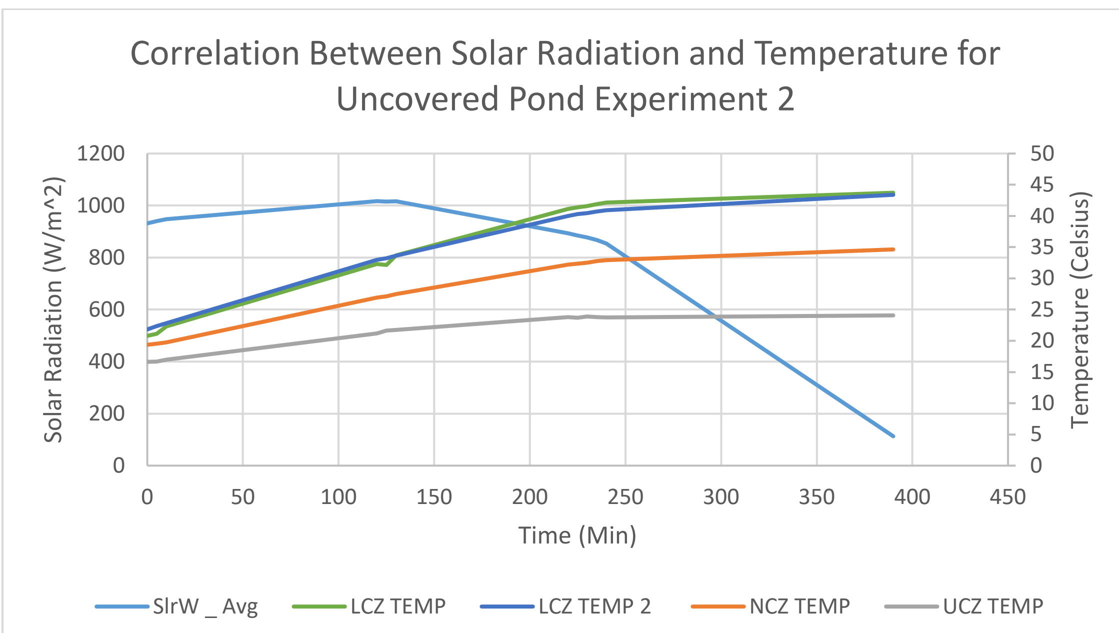
(Fig 28.0 Solar Radiation Profile for Experiment 2)



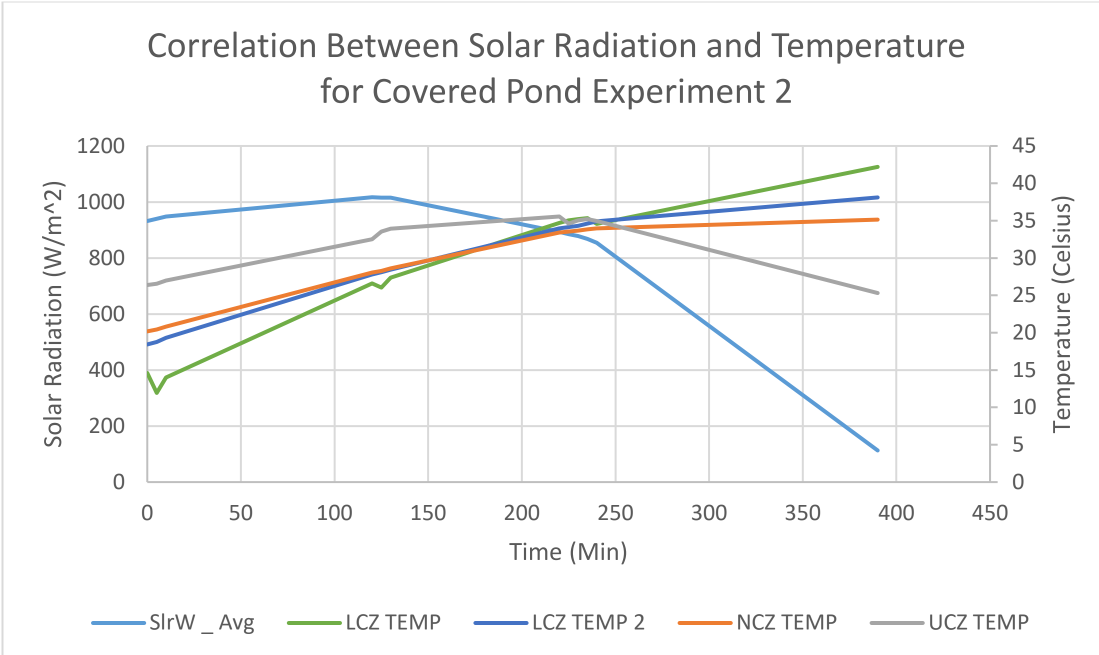
(Fig 29.0 Temperature Profile for Uncovered Pond for Experiment 2)



(Fig 30.0 Temperature Profile for Covered Pond for Experiment 2)



(Fig 31.0 Correlation Between Solar Radiation and Temperature for Uncovered Pond for Experiment 2)



(Fig 32.0 Correlation Between Solar Radiation and Temperature for Covered Pond for Experiment 2)

Calculations

For this experiment, we aimed to examine if a Salt Gradient Solar Pond using produced water from the Maybee Ranch with a transparent plastic cover placed over the top of it acting as the UCZ would be capable of storing sufficient heat within the LCZ as well as producing freshwater through solar distillation. In this experiment, it was observed that 4 ml of distillate was collected in the 50 ml flask in experiment 1, while 20 ml of distillate was collected in experiment 2. A typical solar still produces about 4-5 L per square meter per day so calculations were performed to see what the rate of freshwater production was for these two experiments and at that rate how much freshwater water would be produced from the holding ponds at the Maybee Ranch.

Experiment 1 Calculations

The dimensions of the covered pond were 36 inches (length) X 24 inches (Width) or 3ft X 2ft.so, 3 ft (.3048 m) = .9144 m.

2ft (.3048 m) = .6096 m.

Area of the pond = .9144 m x .6096 m = .557 square meters

4 ml was collected, so 4 ml / 1,000 ml = .004 L, .004/2 = .002 L per day,

So, the rate of freshwater production per day for experiment 1 = .002 L / .557 square meters = .0036 L / square meter / per day.

So, if we take the rate of .0036 L / square meter /day we can calculate how much freshwater would be produced on the ponds at the Maybee Ranch at the same rate as that from the covered pond in experiment 1.

1640 Pit Calculations

This pond is an 81,200 square foot pond 290 ft (length), x 280 ft (width), or

290 ft (.3048 m) = 88.4 m

280 ft (.3048 m) = 85.3 m

Area of the pond = 88.4 m x 85.3 m = 7,540 square meters

Freshwater production rate for experiment 1 = .0036 L/ square meter/ per day, so at this rate the 1640 pit would produce,

.0036 L / square meter / per day x 7,540 square meters = 27.14 L produced per day

Holdings Pit Calculations

This pond has an area of 90,000 square feet 300 ft x 300 ft, or

300 ft (.3048 m) = 91.44 m

91.44 m x 91.44 m = 8,361 square meters

The Freshwater production rate for experiment 1 =.0036 L / square meter / per day, so at this rate, the Holdings pit would produce,

.0036 L/ square meter/ per day x 8,361 square meters = 30.1 L produced per day

Section 6 Pit Calculations

This pond has an area of 297,025 square feet, 545 ft X 545 ft, or

545 ft (.3048 m) = 166.1 m

166.1 m x 166.1 m = 27,589 square meters

Freshwater production rate for experiment 1 = .0036 L / square meter / per day, so at this rate the Section 6 pit would produce,

.0036 L / square meter / per day x 27,589 square meters = 99 L produced per day

Experiment 2 calculations

The area of the covered pond for experiment 2 was also .557 square meters.

20 ml was collected in experiment 2, so 20 ml / 1,000 ml = .02 L = .02 / 2 days = .01 L / per day

So, the rate of freshwater production for experiment 2 was .01 L per day / .557 square meters = .018 L / square meter / per day.

If we take the rate of .018 L / per square meter / per day for experiment 2 we can calculate how much freshwater all 3 holding ponds at the Maybee Ranch would be produced.

1640 Pit Calculations

Area of the pond = 7,540 square meters

Freshwater production for experiment 2 had a rate of .018 L / square meter / per day, so at this rate, the 1640 pit would produce,

.018 L / square meter / per day x 7,540 square meters = 135 produced per day

Holding's Pit Calculations

Area of the pond = 8,361 square meters

Freshwater production for experiment 2 had a rate of .018 L / square meter / per day, so at this rate, the Holdings pit would produce,

.018 L / square meter / per day x 8,361 square meters = 150 L produced per day

Section 6 Pit Calculations

Area of the pond = 27,589 square meters

Freshwater production for experiment 2 had a rate of .018 L / square meter / per day, so at this rate, the Section 6 pit would produce,

.018 L / square meter / per day x 27, 589 square meters = 497 L produced per day

VI. Discussion

In this experiment idealized small scale Salt Gradient Solar Ponds were constructed. The uncovered pond was built to see if produced recycled water from the Maybee ranch would be sufficient to establish conventional heat storage capabilities within the LCZ of the pond, while the covered pond was constructed to determine if by having a transparent plastic sheet acting as the UCZ, if heat could be stored within the LCZ suitable for energy production as well as perform solar distillation on the pond thus producing freshwater as well. A typical salt gradient solar pond stores heat at around 50 – 90 degrees Celsius. It was observed in this research that during the day as solar radiation reached its peak temperatures within the pond rose and thus created a temperature gradient indicating that the salinity gradient within both ponds was sufficient to store heat within the LCZ. In both experiments, these ponds reached temperatures close to or above 40 degrees Celsius. Heat stored within these ponds was lower than that of a conventional large-scale Salt Gradient Solar Pond because these ponds were so much smaller in size and uninsulated. It can be seen that the uncovered pond reached higher temperatures than that of the covered pond in both experiments as there was reflection of incident solar radiation on the covered pond due to condensation forming on the inside of the transparent plastic sheet as well as heat losses due to a higher rate of evaporation. In experiment 1 it was observed that as solar radiation was lost the temperature within both ponds decreased significantly because these ponds are small in size as well as being uninsulated heat was lost on the sides and by conduction of heat from the LCZ to the top of the roof. However, the covered pond did store at higher temperatures in the LCZ once solar radiation was lost than did the uncovered pond. Experiment 2 collected a smaller amount of data than did experiment 1 due to uncontrolled external factors, however, enough was gathered to assess the performance of the ponds. Both experiments 1 and 2 yielded similar results regarding temperatures of the ponds, however, it is unclear what the temperatures within the LCZ were once solar radiation was lost. On the second day of experiment 2, a second transparent plastic cover was added to the cover in an attempt to reduce reflection of solar radiation as well as to increase the temperature of the heat stored within the LCZ. It is unclear if by adding a second transparent cover if solar radiation reflection on the pond was reduced, or if heat storage temperature increased because there was no data collected to suggest whether it did or not. Experiment 1 yielded 4 ml of distillate collected from the covered pond, while experiment 2 collected 20 ml of distillate into the flask. This could be due to the addition of the second transparent cover reducing the amount of solar radiation reflection thus increasing the temperature of the LCZ thereby increasing the rate of evaporation within the pond, or it could simply be that the transparent plastic cover in experiment 2 was better positioned over the flask placed in the covered pond than it was for experiment 1.

VII. Conclusion

The purpose of this research was to determine if a produced water taken from the Maybee Ranch would be suitable to establish a conventional experimental Salt Gradient Solar Pond, as well as determine if an experiment Salt Gradient Solar Pond with a transparent plastic sheet acting as the UCZ would be able to store heat suitable for energy production as well as to perform solar distillation to produce freshwater. In this research two experiments were carried out to observe the performance of these ponds, both experiments were conducted over two days while solar radiation and temperature measurements within the pond were observed regularly. In both experiments the temperatures within the LCZ of the uncovered pond and covered pond did not quite reach temperatures of 50 – 90 degrees Celsius like that of a conventional large-scale Salt Gradient Solar Pond because these ponds were small in size and uninsulated. As temperature decreased within the LCZ of both ponds once solar radiation was lost due to heat loss from the sides as well as conduction of heat from the LCZ to the top of the roof surface. Had these ponds been larger in size and insulated, looking at the data an assumption can be made that these ponds would have reached higher temperatures within the LCZ suitable for energy production. It was observed that in both experiments the uncovered pond reached higher temperatures within the LCZ than that of the covered pond due to reflection of solar radiation occurring on the transparent plastic cover from condensation forming on the inside of the cover. A second cover was added on day 2 of experiment 2, however, there is no data to see if the second cover helped to improve the amount of solar radiation reflection on the covered pond therefore it is unsure if higher temperatures were reached within the LCZ of the covered pond. In both experiments, solar distillation did occur with 4 ml of distillate being collected within the covered pond in experiment 1, while 20 ml of distillate was collected from the covered pond of experiment 2. It is possible that the increase of distillate collected in experiment 2 could be that higher temperatures were reached due to the addition of the second cover, or it could simply be that the cover was positioned in a better position to collect distillate in experiment 2 than it was in experiment 2. Calculations were on the 3 holding ponds at the Maybee Ranch based on the rate of freshwater production in both experiments 1 and 2. It can be seen in this research that the produced water taken from the Maybee Ranch was suitable to establish these experimental Salt Gradient Solar Ponds as both the uncovered and covered ponds in experiments 1 and 2 were able to store heat within the LCZ in both ponds as well as perform solar distillation and produce freshwater within the covered ponds. This research shows that a Salt Gradient Solar Pond with a transparent cover acting as the UCZ could both store heat within the LCZ as well as perform solar distillation and produce freshwater. However further research still needs to be conducted, but it stands to reason that this could be a viable option for the Maybee Ranch in the future.

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