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# Investigating the Potential of Salinity Gradient Solar Pond as a Thermal Energy Storage System for Lahore Pakistan

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**Abstract**

This work is an attempt to experimentally study the ability of solar pond to store the thermal energy in the form of heat, and to explore the potential of solar energy and the prospects of solar ponds in Pakistan. A brief overview of the energy mix of Pakistan. Solar pond was built using a water tank of 300-galons. Halogen lamps were used to provide the heat and to resemble the sun's radiations. The temperature of upper convective zone (UCZ) and lower convective zone (LCZ) was recorded for 100 hours. A maximum temperature of 66°C was recorded for LCZ, while that for UCZ was almost 40°C. Cyclic variations occurred in the temperature measurements of both zones which occurred with a time period of 24 hours which showed that the variation was due to the variants in the ambient weather conditions. This study provided short overview on the prospect of solar pond to store solar thermal energy which can then be utilized for various domestic/commercial activities.

***Keywords:*** *Solar thermal energy; Salinity gradient; Solar pond; Energy mix; Thermal storage*

## 1. Introduction

A solar pond is a waterbody of saltwater which accumulates and stores solar thermal energy [1]. The saltwater naturally forms a salinity gradient in the vertical direction, which is also known as a "halocline". The water with low salinity floats on top of the water with high salinity [2]. The layers of different concentration of salt are stacked in a way that the concentration of salt, and therefore the density of the brine, increases with depth. After a certain depth has reached, the solution becomes almost uniform in salt concentration. They radiations of the sun reaching this water body, heat is absorbed by the high concentration region. This region is at the bottom of the pool, and when it gets heated up, its density decreases and convection currents kick-in. Solar ponds heat water by impeding this convection. Due to convection, salt concentration builds up until the lower layers of water cannot absorb more salt and become saturated. The water at the bottom of the pond, i.e., the one with high salinity, does not mix immediately with the low-salinity water above it. Therefore, when the bottom layer of water is heated, convection occurs separately in the bottom and top layers. This mechanism allows the lower layer to absorb more heat as heat loss is restricted. Therefore, the water in the lower zone could reach up to 90°C [3]. The hot water can then be utilized to produce electricity, or directly as a source of thermal energy [4].

Salt gradient solar ponds (SGSP) present an attractive method of collecting and storing solar energy [1]. A SGSP is typically discretized into three distinct zone, namely, the upper convective zone (UCZ) which is the topmost layer of the pond and is at the lowest temperature. The next in line is the non-convective zone (NCZ) where salinity gradient exists. And lastly the lower convective zone (LCZ) which is at the bottom of the pond and is at the highest salinity and temperature. These zones are of a typical thickness of 15 – 30 cm, 100 – 150 cm, and 100 – 200 cm for UCZ, NCZ, and LCZ, respectively. NCZ has a variable salinity therefore its properties vary with depth. LCZ is also called the storage zone as this is the layer where solar heat energy is absorbed and stored [5]. Fig. 1 shows the three distinct zones of a solar pond. The NCZ however it may seem useless but plays an important role for the essential functioning of the solar pond. It allows the solar radiations to pass through it allowing the LCZ to heat up. And acts as an insulator for LCZ due to its variable density, therefore not allowing the heat to escape through it [6]. Whether it happens naturally or is constructed artificially, the solar pond acts as a medium to collect and store solar energy. Brief summary on the research

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progress on the solar pond is available from the review conducted by Khalilian [7]. Solar ponds are most effective during summers and could turn out to be a reliable heat collector-storage system. However, the solar pond cannot work without a stable concentration profile. This means, the concentration should be increased downwards to prevent any gravitational overturn. A low salt gradient, otherwise, causes instability in solar pond and this affects solar pond's insulation, and energy (heat) might escape through the surface of the pond.

Sayer et al. [8] developed design and simulation tool to analyze the performance of a solar pond. Their model incorporated the effects of evaporation, convection, and heat loss from the pond to the walls and to the ground. Heat transfer between the zones of the solar pond was also considered. The output of the model was to evaluate the energy storage capacity of each zone and to find out the temperatures inside the zone. Model validation was done using the experimental results. High variability was only fund in the data of UCZ which was explained due to the open surface of UCZ to the atmosphere. Asim et al. [9] carried out TRNSYS simulation, using TMY2 data of Lahore, of solar powered absorption cooling system. They study revealed that Pakistan has the potential for utilizing solar powered thermal cooling systems during summers.

Salinity-gradient solar pond is a type of solar collector with the ability to store thermal energy for long period of time. The comparative advantage of solar pond over its rival solar collectors is that it has a low construction cost. It can achieve a temperature of 80-90°C.

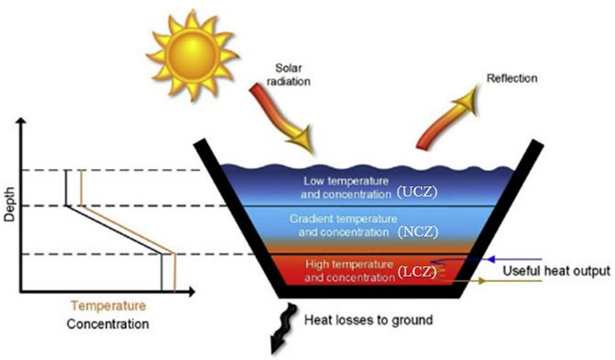


**Fig. 1. Demonstration Model for Salinity Gradient Solar Pond [10]**

## 2. Energy mix of Pakistan

Pakistan has suffered from electricity shortfall for decades. The disbalance between demand and supply has made the situation worse particularly in the last decade. The energy demand keeps on rising with time, due to the increase in population and the urbanization. However, the energy supply has not increased to match with the demand, thereby creating an energy deficit. The electricity generation capacity of Pakistan is about 37,261 MW [11], and the shortage is about 3000 MW – 6000 MW depending on the winter and summer season. The major chunk of Pakistan's energy mix consists of energy production from fossil fuels (61%), particularly the imported fuel oil and LNG, leading to the high per unit price of electricity [12]. The energy produced by renewable sources is just a minor share (see Fig. 2). According to the Alternative Energy Development Board (AEDB) Pakistan, 28 solar power projects are planned to increase the power share of the renewable sources. Several wind energy projects are also being considered [13].

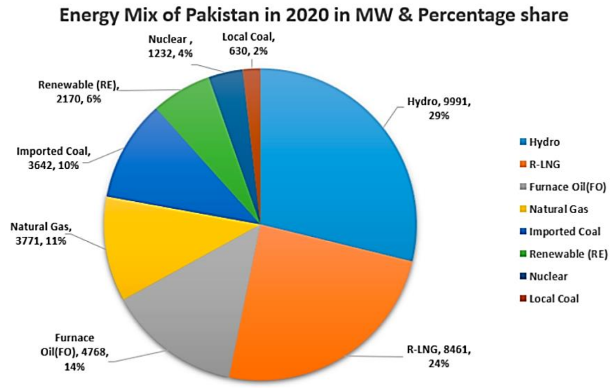


**Fig. 2. Energy mix of Pakistan for the year 2020 [12]**

## 3. Materials and Methods

### 3.1. Climate of Lahore

In order to study the mechanism and performance of a salinity gradient solar pond, and its commercialization in Lahore Pakistan, the first step needed was to collect the technical data for the operation of solar pond. The solar radiation data for Lahore was taken from World Bank via Energy Data [14] as shown in Table 1.

**Table 1. Climatic conditions of Lahore, Pakistan**

| Property | Location Climate Data for Lahore |
|---|---|
| Latitude | 31.5°N |
| Longitude | 74.4°E |
| Average Air Temperature | 24.4°C |
| Daily Solar Radiations Horizontal | 4.68 kWh/m$^2$/d |
| Heating degrees-days | 551 |
| Cooling degrees-days | 2840 |

A heating degree day (HDD) is a metric to quantify the amount of energy needed to heat a building in a particular area. Similarly cooling degree day is for the amount of energy needed to cool a building. Table 1 gives data for Lahore for HDD and CDD considering the base temperature of 18°C, which means that if the temperature drops below this value, the building needs heating and if it rises above this value the building needs cooling [15].

### 3.2. Solar Pond Design and Construction

The pond was designed to reach the temperatures of 70-90°C, and to attain this temperature and store the heat energy for a longer period of time, a large waterbody was needed. The aim was to develop efficient, compact, portable, and insulated pond.

A water tank of 300-gallon capacity was used for this purpose. The walls and bottom surface of the tank was insulated with polyethylene to prevent the water & tank from releasing thermal heat. Therefore, 12 layers of insulation, each of 0.5-inch thickness, and 8 layers of insulation were applied to the walls and the bottom of the tank, respectively.

Table 2 shows the thermal conductivity of various materials considered for insulation of the water tank. Polyethylene sheet was finally chosen as it has the lowest thermal conductivity apart from air.

**Table 2. Thermal Conductivity comparison for different materials**

| Material | Thermal Conductivity (W/m°C) |
|---|---|
| Glass | 0.780 |
| Polyethylene Foam | 0.04 |
| Wood (Dry) | 0.395 |
| Air | 0.026 |
| Cardboard (corrugated) | 0.064 |

The following material was used for the construction of solar pond:

- Water Storage Tank (300 gal)
- Polyethylene Foam
- Thermocouples
- Salts (CaCl & NaCl)
- Two halogen lamps 500W each

Fig. 3 shows the model built for testing and experimentation. The 300-galon water tank was covered with thick insulation of polyethylene foam. Two halogen lamps were used as a source of heat. Thermocouples were used to record the temperature of the zones of the solar pond. The dimensions of the model are given below:

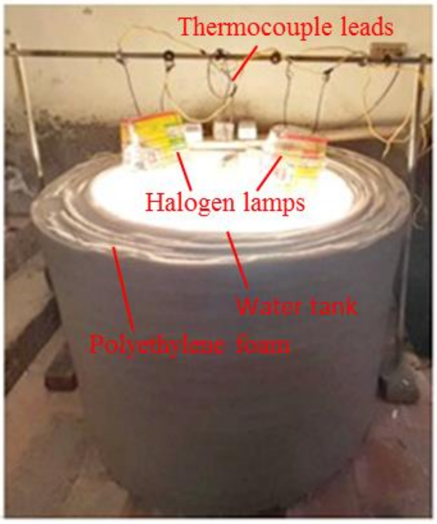


**Fig. 3. Salinity Gradient Solar Pond Demonstration Model**

### *3.2.1. Dimensions of the model*

Diameter of the tank = 31-inch
Height of the tank = 30-inch
Thickness of tank wall = 0.16-inch
LCZ sensor position = 3-inch from bottom
NCZ sensor position = 12-inch from bottom
UCZ sensor position = 23-inch from bottom
Thickness of foam = 0.5-inch
12 insulating layers of foam around tank = 6-inch
8 insulating layers of foam under the tank = 4-inch
Height of the Frame = 48-inch
Width of Frame = 48-inch

## 3.3. Weather Data Collection

Data regarding the soil and climatic conditions of Lahore is collected from Met Station - Weather Radar. Table 3 gives the three main factors to be considered for the selection of site for construction of a solar pond. Fig. 4 and Fig. 5 shows the variation in average monthly temperature and average monthly relative humidity for Lahore in a calendar year. From this data it is observed that in summer or areas where the temperature throughout the year remains high are best for solar pond construction.

**Table 3. Lahore average weather data throughout the year**

| Month | Ambient Temperature (°C) | Relative Humidity (%) | Wind Speed (kt) |
|---|---|---|---|
| January | 19 | 76 | 2 |
| February | 22 | 69 | 3 |
| March | 27 | 64 | 4 |
| April | 34 | 49 | 5 |
| May | 39 | 42 | 6 |
| June | 39 | 50 | 6 |
| July | 36 | 72 | 5 |
| August | 35 | 77 | 4 |
| September | 35 | 72 | 3 |
| October | 32 | 67 | 2 |
| November | 27 | 71 | 1 |
| December | 22 | 76 | 1 |
| Mean | 30.58 | 65.42 | 3.5 |

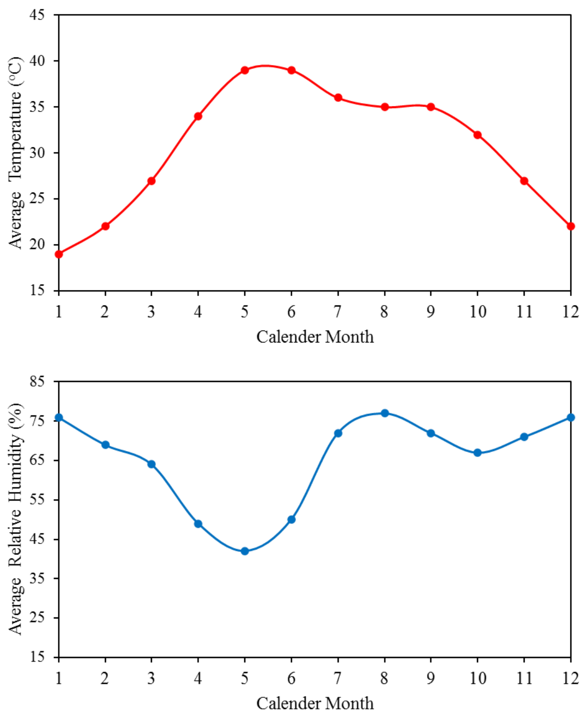


**Fig. 3. Annual distribution of temperature (top) and relative humidity (bottom) for Lahore**

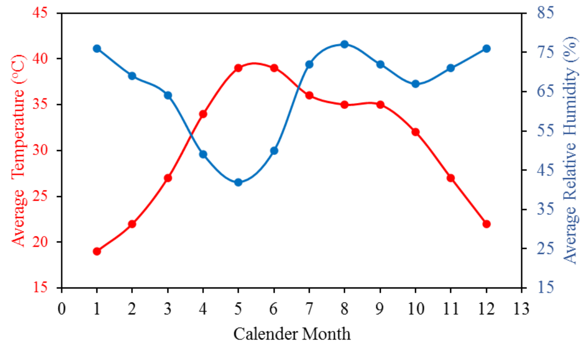


**Fig. 4. Annual distribution of temperature and relative humidity on a single plot for Lahore**

## 4. Results and Discussion

Following assumptions were considered for the analysis of the results:

- The pond comprises of 3 zones: UCZ, NCZ & LCZ
- There is no salt concentration in NCZ
- The salinity profile of NCZ is linear
- Salt injection to LCZ is considered to be negligible
- Diffusion of salt is assumed to be constant
- The wind affect is neglected due to vertical walls of the pond

Table 4 shows the variation in the temperatures of the UCZ and LCZ. The experiment was run for 100 hours, and the temperature was recorded every 5 hours. The peak temperature recorded for LCZ is 66°C and the pulsating variations was due to the variations in the ambient conditions. During the day the temperature of the surroundings increased and affected the temperature of the UCZ and LCZ also, while the temperature at night decreases and lowered the temperatures of UCZ and LCZ. The results of the experimentation are tabulated in Table 4. These results are plotted in Fig. 6 and Fig. 7.

**Table 4. Hourly variation of temperature for UCZ and LCZ**

| Time (hours) | UCZ Temperature (°C) | LCZ Temperature (°C) |
|---|---|---|
| 0 | 14.19 | 14.60 |
| **5** | 14.40 | 14.81 |
| **10** | 14.81 | 17.28 |
| **15** | 19.13 | 37.43 |
| **20** | 20.77 | 38.46 |
| **25** | 21.18 | 35.17 |
| **30** | 20.77 | 33.11 |
| **35** | 21.59 | 35.99 |
| **40** | 26.32 | 52.85 |
| **45** | 27.35 | 49.36 |
| **50** | 27.97 | 46.07 |
| **55** | 27.76 | 43.60 |
| **60** | 29.41 | 48.95 |
| **65** | 33.52 | 60.87 |
| **70** | 34.34 | 56.35 |
| **75** | 34.14 | 53.06 |
| **80** | 33.73 | 50.39 |
| **85** | 36.61 | 59.85 |
| **90** | 39.69 | 66.02 |
| **95** | 38.97 | 61.49 |
| **100** | 38.66 | 58.20 |

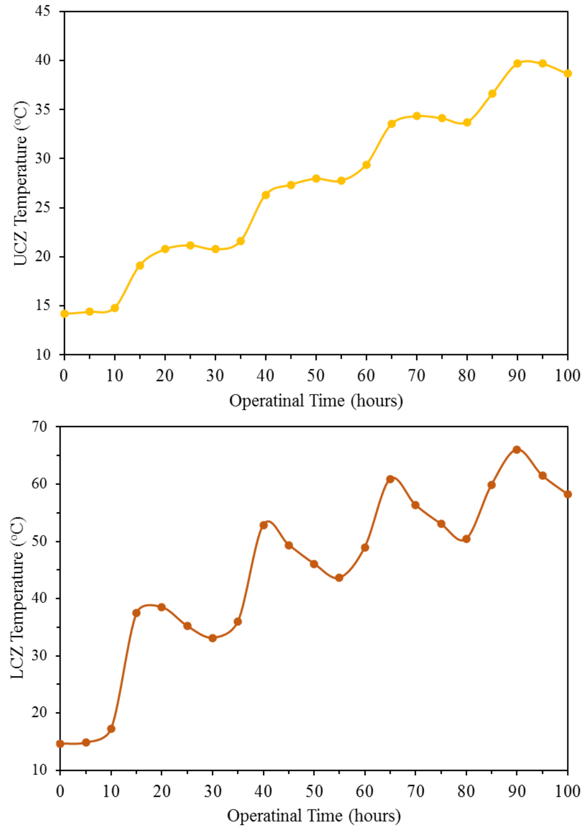


**Fig. 6. Hourly temperature distribution of UCZ (top) and LCZ (bottom)**

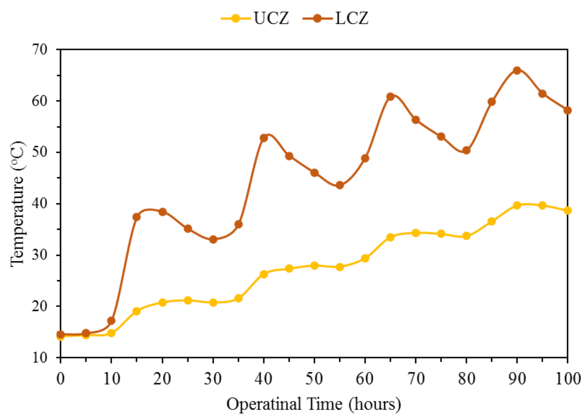


**Fig. 7. Hourly temperature distribution of UCZ and LCZ on a same plot for better comparison**

## 5. Conclusion

This study was an attempt to explore the potential of salinity gradient solar ponds in Lahore, Pakistan. A brief overview of the energy mix of Pakistan and the potential of solar energy in Pakistan was also provided. Average monthly variation in temperature and relative humidity was given. Unburied type solar pond was built, and experiment was run for 100 hours to record the temperatures in the upper convective zone (UCZ) and lower convective zone (LCZ). Halogen lamps were used to mimic the thermal heat from the sun. The results indicated that solar ponds could act as a storage medium for solar thermal energy. The maximum temperature of 66°C was recorded for

LCZ. The variations in the temperature were due to the variation in the ambient conditions which affected the heat loss. The study proved that solar energy has a promising future in Pakistan as one of the most prominent types of renewable energy, and solar ponds can be an effective way of capturing and storing solar energy. This energy can then be used for various domestic/commercial activities.

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