Water Heating Salt Gradient Solar Pond Performance in Libya

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Abstract: A solar pond is a body of liquid, usually brine, which collect the energy from the sun and store it as heat. The brine in the bond is introduced and maintained in such a way as to establish salt gradient of increasing concentration with depth to suppress natural convection.

In this study analytic and experimental studies were performed on a salt gradient solar pond to be used for water heating. An experimental solar pond with area of 22m2 and a depth of 1.5m was constructed in Ziwara city, Libya for this purpose. The results were conducted for one year of operation period, comparison were done for each two month operation, the results shows a good agreement with expectations, the salt gradient bond can work as energy storage, to be used in manufacturing and air conditioning applications.

Keywords*:* Salt gradient solar pond, Energy storage, air conditioning applications.

I. INTRODUCTION

The environmental problems that surround the world are large, varied and dangerous [1]. It harms humans, plants and animals. The most important of these problems are those resulting from human activities to produce energy by burning fossil fuels such as coal, oil, and natural gas [2]. Air pollutants caused by the combustion of these fuels have increased concentrations of contaminants such as carbon dioxide, which has caused global warming, causing high temperatures, resulting in climate change [3]. Climate change is beginning to cause real and intractable problems for the world's governments such as devastating floods [4], drought [5], high water salinity [6], and dust storms [7], rising sea water and melting Arctic and Antarctic ice [8].

Fossil fuels, especially oil, are drying up due to the arbitrary consumption of the last two centuries, while its composition took millions of years [9]. The change in prices has also caused a major economic recession and subsequent social problems [10]. This problem develops and is greatly exacerbated if we take into consideration the large spread of the use of cars and vehicles in transport and the emitted of dangerous pollutants into the environment [11, 12]. The shift from the use of fossil fuels with high environmental damage to clean and environment-ally friendly fuels makes it imperative to use renewable fuels as they are available in every country or community [13].

Agricultural countries can benefit from their agricultural products by converting them into biofuels such as bioethanol from sugar cane and corn [14, 15], biodiesel from plant zest, agricultural and animal residues and restaurant waste [16, 17]. Several studies have proven successful in using biofuels to reduce emissions from motor vehicles [18]. Many countries in the world are currently using wind power to generate electricity [19, 20].Many countries in the world have begun to produce hydrogen-powered cars. Hydrogen is clean combustible and available from water or through the steam reformulation process of methane [21, 22, 23]. Also, solar energy and its various applications are the most renewable energies with a variety of applications and are available in most areas of the Earth with a strong radiation suitable and long working hours [24, 25]. So, researchers consider that this energy is the most renewable energies used in the world soon [26, 27]. Applications of solar energy are based on a number of studies focusing on weather conditions and the topographic structure of the site for all seasons of the year [28, 29]. Many studies have focused on a clear vision of solar radiation and its intensity and angle of fall to determine the best solar applications suitable for it [30, 31].

Because the applications based on solar energy are greatly affected by the weather conditions in the application area, they are affected by wind [32], relative humidity [33], solar radiation [34, 35], temperature [36, 37], and dust [38, 39], as well as shadow [40]. Dust is the first enemy of solar applications which reduces the efficiency of any application [41, 42]. Solar application is influenced by the type and characteristics of accumulated dust [43]. Also, many researchers have studied the importance of cleaning the application of dust and the type of material used for cleaning [44, 45]. The researchers treated each effect of air effects on each solar application separately. They have developed solutions for the effect of relative humidity [46], solar radiation [47, 48], and high application temperatures [49, 50, 51], and the concern for dust has been notable for minimizing the harm to the efficiency of solar applications [52].

The uses of solar energy vary. The heat obtained from the sun through solar radiation can be used to heat water for domestic or industrial purposes [53, 54, 55]. They can also be used to heat the air in homes, offices, and even factories [56, 57]. This heat can also be used to heat houses in cold areas using a Trombe wall [58, 59, 60]. Trombe wall is also used for ventilation purposes [61, 62].Solar distillation is one of the most important solar applications [63, 64]. It is connected to water, the first cause of life on earth [65]. Solar distillation consumes a high percentage of fossil fuels to desalinate seawater and convert it into potable water for human drinking and agriculture [66, 67]. Using solar energy, researchers can produce fresh water from dirty, turbid water with promising potential [68, 69].

The solar chimney is one of the solar applications that produce electricity [70]. Many of them have been installed and operated around the world and operate with acceptable efficiency [71, 72]. Electricity is also produced using solar power stations [73]. Several stations have been demonstrated with high electrical capacities and work with excellent efficiencies [74]. Solar cells can be used to generate electricity for street lighting [75], communications towers [76], health centers in remote areas [77, 78], and running water pumps for watering plantings especially in remote areas [79, 80, 81 and 82], it is used to power lights in car parking [83]. These cells are used as a grid-connected or off grid [84, 85]. There are many solar cells operating around the world, and they are the most common solar applications acceptable to the public [86, 87].

Solar heat gradient ponds are not new, in many places where salt ponds exist naturally and where seasonal rainfall can add fresh water to the upper layers, significant heating can occur in the lower more dense layer [88]. It is believed that people collecting salt for human consumption and wading from pond to pond discovered this phenomenon around 80 years ago [89]. Bryant at the University of New Mexico produced a base temperature of 109°C. Solar heat gradient ponds are in operation in many countries including the US, Europe, India and Australia, (Alice Springs and Pyramid Hill in Victoria.) around 60 solar heat gradient ponds worldwide [90]. The great advantage of salt gradient solar pond is their unique ability to store thermal energy in the bottom layers of the brine. This attribute is useful for process like heating and power production by eliminating the intermittency factor [91].

A salt-gradient solar pond is a particular type of solar pond which relies on a salt solution of increasing concentration with depth. A salinity-gradient solar pond is an integral collection and storage device of solar energy and it can be used irrespective of season. Usually the gradient solar pond is filled with a solution of sodium chloride having a concentration varying from a very low value at the surface at near saturation at the bottom [92].

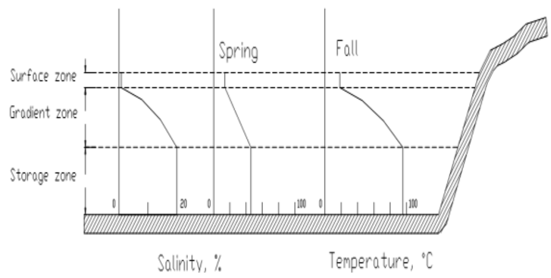

Fig. 1. Typical cross section and thermal and salinity profiles of a salt-gradient solar pond.

Figure 1 shows the cross section of a salinity- gradient solar pond with representative temperature and salinity profiles on the three typical regions. It is possible to see the lower warm and upper thin convective zones and the central gradient zone which has the function to insulate the storage zone [93].

Solar heat gradient ponds are typically around 2-3m deep and consist of layers of water; the bottom layer is hypersaline containing typically 15-20% dissolved salt, above this layer the salt content diminishes until the water layer at the surface is almost salt-free. This arrangement is known as a non-convicting salt heat gradient solar pond. Periodically the upper fresh layer may need to be skimmed off to avoid the pond overflowing [94].

A salt gradient pond can be operated with somewhat arbitrary upper layers but it is important to maintain the integrity of the lower layer for performance. The action of wind can cause considerable mixing of the fresh layer with the middle saline layer and devices are floated on the surface to prevent or reduce this surface effect [95].

The salt-gradient zone insulates the storage zone and inhibits the phenomena with which the heat water rises from the bottom to the surface and loses its heat to the external air. Heat stored in the bottom can be extracted to be used for several thermal applications for which the main advantages are as follows:

- Low investment costs per installed collection area.
- Thermal storage is incorporated into the system at the same cost.
- Very large surfaces to collect solar energy can be built [96].

A typical salt-gradient solar pond can absorb around 10 kWh/m^2/day and a 1-hectare (10,000m^2) solar pond can absorb around 100,000 kWh of thermal energy per day. Conversion efficiencies of around 10% would realize 1.75 million-kilowatt hours annually. Greenhouse gas avoidance of 1,600 tons perannum would also be achieved [97].

Only if the abundance of inexpensive salt and level land are verified is it possible to say that the use of solar energy is economic; therefore, it makes economic sense to locate the pond near an inexpensive salt supply such as salt works or an industry that produces brine as a by-product.
When these crucial factors are matched with the deliverables of a pond, this technology can be applied successfully in:

- Water heating.
- Agricultural processes as crop drying, shelter heating, greenhouse heating.
- Desalination.
- Electrical power generation.
- Production of marine chemicals [98].

II. LAND REQUIRED FOR PROPOSED DEMONSTRATION PROJECT

Solar pond construction considerations after the solar pond site selection and preparation, the most important elements of a solar pond are basically a containment volume obtained by earthwork, a filling of a salinity- stratified solution when the native soil does not provide low permeability a membrane liner and at the end a system for heat removal from the heat stored zone and associated equipment for pumping.

The usual technology used for building agriculture water retention basins can be employed to construct earth berms, installing membrane liners, insulation and mechanical systems, and these results in low construction costs. The solar pond site selection is very important; the ideal solar pond site should have several essential characteristics:

- Easy access to water to fill the pond and for operation and maintenance
- Access to salt and free salt available to reduce costs
- Dry soil to minimize thermal losses
- Free from moving water table to minimize heat losses
- Easily compacted soil and with good cohesion for wall and structural stability

Often some of these items are contradictory; in fact, for example, if the soil is good for draining, it has low cohesive properties and then it is difficult to compact for berm construction, but in any case it is possible to reach a compromise.

A suitable area of agricultural land that has become saline is selected where the salt scour (an area much like an ulcer, on the land where agriculture has subsequently become impossible due to Stalinization) and is around 300-500 meters in diameter.

The solar pond was constructed in Ziwara area in Ziwara city, its measures was 5m length, 4m width and 1.5m depth, constructed by brick and cement with 25cm thickness, consist of two layers of brick with 10cm thickness for each, separated by polyethylene thermal insulator 5cm thickness. The inner surfaces were attired with cement, and then painted by dia-eboccy used in damps pelvis painting to plug existing pores, and to increase solar radiant absorption. The bond's bottom was a concrete base of 25cm thickness, a pebbles layer was put under it, and its outer surface was covered by asphalt layer to prevent water leakage from and to the pond, and to give it the black color. The pond was supplied with transparency plastic cover used when it was necessary, at dusty and windy days, to avoid water mixing, and to prevent dirt falling inside it. The pond was supplied with several thermocouples type (Cr-Co) to measure water temperature on many elevations.

Salt solution was formed using local sodium chloride (NaCI); it was used because of its availability and cheap prices. The water salinity was checked in Ziwara Institute laboratories, Ziwara. Its quantity was calculated due to wanted concentrations in storing and gradation zones. The method mentioned in ref [98] was used to construct the solar pond salt layers.

Daily observations to the pond temperatures were recorded from first March 2017 to the end of February 2018. The salt concentrations in pond layers were tested periodically by taking several samples from a number of different depths in various periods.

A mesh system constructed from polyethylene pipes was used to withdraw the thermal energy from the pond, this material was used to prevent corrosion happens in metal pipes, because of the saline solution. The pipes diameter was 2.5 cm and 90m total length used, it worked as heat exchanger sunken in the bond solution, the outlet and inlet ports were connected to metal pipes linked to a water rotating pump outside the pond, the water was directed towards heat exchanger sunken in water box (1000 liter), the heat radiated from this exchanger was measured by knowing the temperature changing for known water quantity in the box.

II. RESULTS AND DISCUSSION

A solar bond was constructed with 1.5 m depth; this depth was divided into two equal parts for storing and gradient regions, 0.7m depth each, and 0.1m depth for surface region. These divisions were selected because of pond proportionally little height, increasing the total depth was unavailable because of groundwater rising in the pond area.

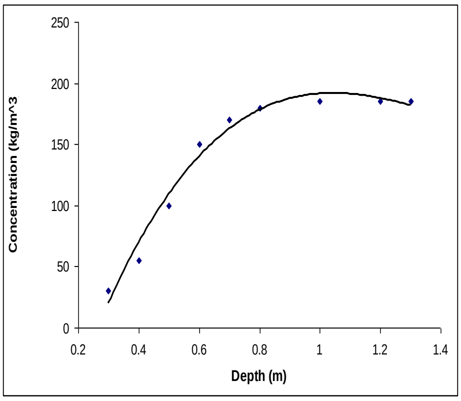

Figure 2, Salt concentration changes with depth

Figure 2 shows the change in salt concentration with pond depth, the changes were increased with depth increase to a certain limit then stable at this concentration.

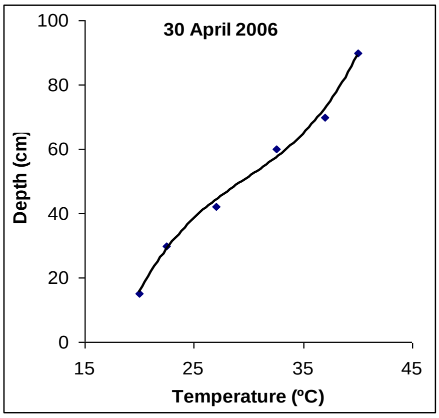

Figure 3: temperatures changing with depth

Figure 3 represents the temperature distribution inside the pond at 30 April, after two months from filling it with salt solution. The increase in heating rate represented by increasing temperature inside the pond could be described as slightly liner relationship. It clarifies the pond performance where the storage region temperatures began to rise, while the surface temperature still as it is.

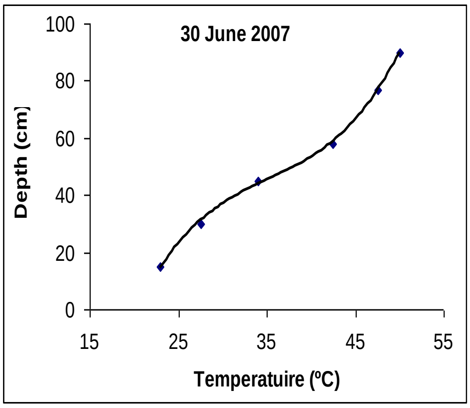

Figure 4: temperatures changing with depth

Figure 4 represents the temperature distribution at 30 June, that's means after four months from pond starting day, the temperature differences between surface and gradient layers increased, this difference increased more and more in storage region. The storing region temperature the most important variable reached 66.9ºC, this means the stored energy size increased, which can be used for other applications.

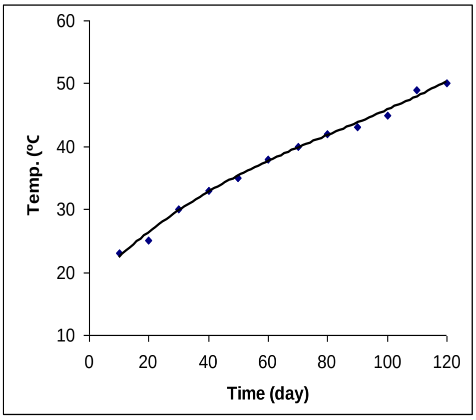

Figure 5, storage region temperature rise during operation period

The increasing temperatures in storing region for four months of pond working time represented in **fig.5**, there are variances in the figure, the stored temperature began above the usual level in many degrees, this due to pond filling preparations, and salt concentration arrangements, which last several days, the storing region started at that time collecting and storing solar energy as heating energy mode, which increased storage region temperatures, that means the actual time for pond starting was before first of March.

The temperature differences increased with time to reach its maximum value in the end of June. It was expected to achieve higher temperature degrees, but because of pond transparency decrement due to the dusty weather, and some falling dirt. Temperature increasing rate reduced with time prescription, this is also because of thermal losses through pond floor, and through gradient region by rise in temperature differences between this area and the surrounding areas.

Figure 6 compares between amounts of stored energy for the pond working four months period, heat storage energy increase with time due to increase in solar radiation from month to another, the increment rate reduced with time, due to thermal losses increase, and water density reduction by increasing its temperature. Increasing storage time increase the heat stored inside the pond, but also increased the losses. Calculations and measures must be taken to identify the best time to start withdrawing energy from the pond, depending on equilibrium between storage and lost energies.

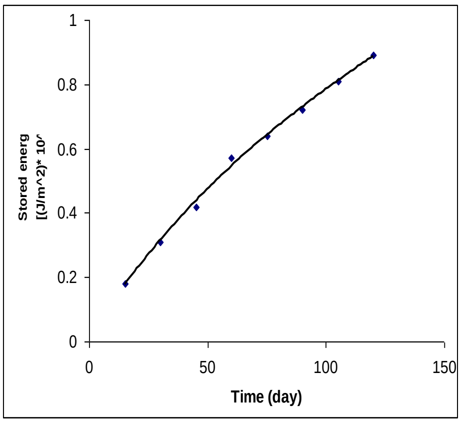

Figure 6, storage energy changing with time

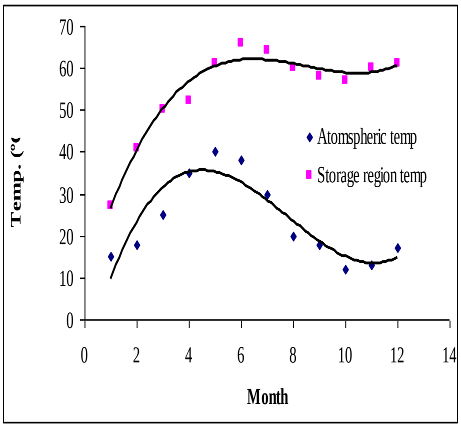

Figure 7 storage region and atmospheric temperatures changing for one year

Figure 7 represents temperature variation for storage territory, for one year working period start from first of March, where temperature start increasing to reach its maximum value (66.8ºC), at the middle of September, then it start reduces due to solar radiant reduction, and atmosphere temperature reduction, which increases the thermal losses to the surroundings in winter season. It can be observed that the minimum temperature for storage region reached was 54.3ºC at the end of December, this is an indication about the useful thermal energy which can be utilizes in many applications; specially that one does not require high temperatures like spaces worming.

Figure 8 represents the yearly changes in storage region temperature rate with thermal withdrawing. Calculations were done to evaluate heat needed to warm the water in the water box for two levels 15º and 20ºC. Heat suction bearings on the storage region temperature appear in reducing its values at warming months, to reach its minimum value at the end of January (47.1ºC). The figure represents also yearly changes in storage temperatures with warming load existence and for 20ºC warming load, the temperature reduced more than the former case, due to increase in the thermal heat drawnfrom the region, the minimum temperature reached was 38.8 ºC.

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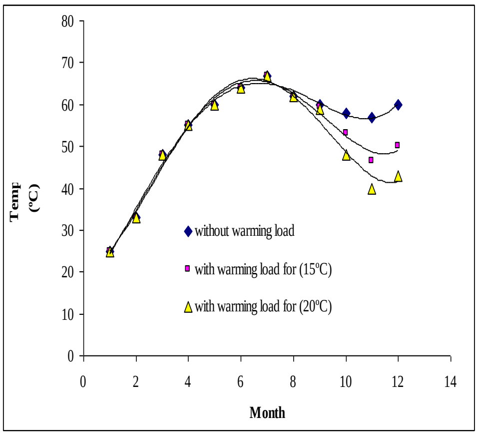

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The calculation were reviewed by changing warming load (considering the water heated in the box was used to warm square meters of space in a room), **fig. 9** demonstrate that every 1 m^2 from the pond manages to cover warming load for 2.9m^2 from heated room of 15ºC case, and 1.3m^2 from the room in case where warming temperature 20ºC, with assumption of the worst situation, the minimum temperature reached in storage region was 30 ºC.

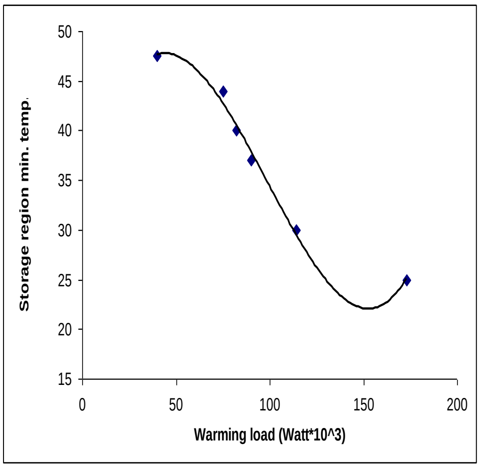

Figure 9, minimum storage temperature changing with warming load

CONCLUSIONS

1- Changing pond depths influence the temperature increase in storage region, and in storage energy amount.

2- The results show that the choice of gradient to storage heights percentage equal unity, gives the maximum storage energy amount at the end of working period.

3- The storage heat can be increased by taking some concentrations, like covering the pond surface with glass, or putting solar collectors to increase the declining radiant on the pond.

4- When operate for one year, the maximum temperature for storage region reached 66.8ºC. The minimum temperature reached was 54.8ºC in middle of Jan.

5- In case of withdrawing thermal energy the maximum temperature do not change, while minimum temperature happened at the same time.

6- Solar gradient pond can be used in many manufacturing and air conditioning applications, depending on its position and its diminutions.

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