

## Review on Solar Ponds in Libya

(PAST EFFORTS, CURRENT CHALLENGES AND FUTURE PROSPECTS)

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**Abstract:** Solar and renewable energies applications got a great interest and attention in the last few decades. Problems related to CO<sub>2</sub> emissions, air pollution, Ozone layer depletion, global warming and environment issues raise the necessity for getting a clean and safe energy. For this purpose, the Center for Solar Energy Studies (CSERS) in Libya conducted a huge research work in different applications for solar and renewable energies. One of these important activities is the Solar Gradient Solar Pond technology. It is an effective solar energy collection and storage system which presents a relatively simple and economic method of providing low grade energy with the advantage of annual storage cycle.

This paper presents a general review on researches and studies on solar ponds that were conducted by CSERS research team. Tajoura's Experimental Solar Pond (TESP) is designed as an experimental facility enabling the investigation of various aspects of pond performance. It is constructed by the Center for Solar Energy Studies, in joint cooperation with a Swiss company, with a surface area of about 830 m<sup>2</sup>, and a depth of 2.5 m, coupled with an evaporative pond of 105 m<sup>2</sup> area and 1.5 m deep, equipped with all necessary equipments and measuring control system.

The paper also shows the experience of operating MSF desalination unit coupled with TESP solar pond. Finally, other factors affecting the solar pond's thermal stability were also discussed.

### ورقة مراجعة عن البرك الشمسية في ليبيا

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ملخص: حظيت تطبيقات الطاقة الشمسية والطاقات المتجددة باهتمام كبير في العقود الأخيرة. فالمشاكل المتعلقة بانبعاثات ثاني أكسيد الكربون وتلوث الهواء ونضوب طبقة الأوزون والاحتباس الحراري وقضايا البيئة أظهرت الحاجة الملحة إلى ضرورة الحصول على

طاقة نظيفة وأمنة. ولهذا الغرض، قام مركز دراسات الطاقة الشمسية في ليبيا بعمل بحثي كبير في التطبيقات المختلفة للطاقة الشمسية والمتجددة. واحدة من هذه الأنشطة الهامة هي تقنية البرك الشمسية المتدرجة الملوحة، فهي عبارة عن منظومة فعالة لتجميع وتخزين الطاقة الشمسية، باعتبارها طريقة بسيطة واقتصادية نسبياً لتوفير الطاقة عند درجات حرارة منخفضة مع ميزة دورة التخزين السنوية.

تقدم هذه الورقة استعراضاً عاماً للبحوث والدراسات المتعلقة بالبرك الشمسية التي أجراها فريق البحث التابع لمركز دراسات وابحث الطاقة الشمسية، وتم تصميم البركة الشمسية التجريبية بتاجوراء كمرفق تجريبي يتيح التحقيق في مختلف العوامل المؤثرة على أداء البركة، تم إنشاؤها من قبل مركز دراسات الطاقة الشمسية، بالتعاون المشترك مع شركة سويسرية، بمساحة حوالي 830 متراً مربعاً، وعمق 2.5 متر، إلى جانب بركة تبخيرية مساحتها 105 أمتار مربعة، وعمق 1.5 متر، مجهزة بجميع المعدات اللازمة ومنظومة للقياس والتحكم.

تطرقت هذه الورقة أيضاً إلى خبرة تشغيل وحدة تحليل مياه تعمل بالتبخير الوميضي المتعدد المراحل بواسطة البركة الشمسية التجريبية بتاجوراء. وأخيراً، تم أيضاً مناقشة العوامل الأخرى التي تؤثر على الاستقرار الحراري للبرك الشمسية بشكل عام.

**Keywords:** *Solar Pond, Evaporation Pond, Salt Diffusion, Thermal Storage*

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## 1. INTRODUCTION

### 1.1 The concept of a solar pond

A solar or salt gradient solar pond (SGSP), is usually artificial, although a few occur naturally where dissolved salts create a trap that can be tapped both for heat and to produce electricity. The water and bottom material of an ordinary pond, whether fresh or saline, absorbs heat from the sun but loses it as the heated water expands and rises to the surface as shown in Figure 1-a. The addition of salt makes water denser and heavier. If the salt is added at the pond bottom, a salt gradient is created between the surface and the deeper waters.

A typical artificial solar pond as shown in Figure 1-b has three gradients or salinity zones. The surface zone, upper convective zone (UCZ) up to 0.5 m deep, has the lowest salinity. In the middle zone, non

convective zone (NCZ), 1~1.5 m deep, salt content increases with depth. The salt gradient zone NCZ is the key to the working of a SGSP. It allows solar radiation to penetrate into the storage zone while prohibiting the propagation of long wave radiation because water is opaque to infrared radiation. The zone suppresses global convection due to the imposed density stratification. It offers an effective conduction barrier because of the low thermal conductivity and the zone thickness, which averages over 1.0 meter. The storage zone, lower convective zone (LCZ) at the bottom, which may be several meters deep, has the highest salinity and therefore the densest, heaviest water. It is in this bottom layer that trapped heat is stored.

A solar pond is an effective solar energy collection storage device which presents a relatively simple and economic method of providing low grade energy with the advantage of annual storage cycle.

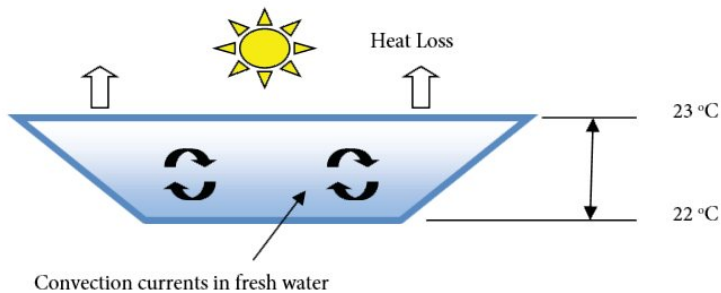
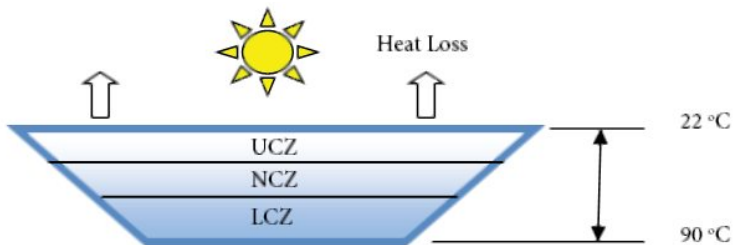


Figure (1-a). Schematic diagram of an ordinary pond [7].

Figure (1-b). Schematic diagram of a Solar Pond [7].



## 1.2 Advantages and disadvantages

Solar ponds as in many other engineering systems have many merits and drawbacks that may affect their design, construction and operation in addition to their thermal performance and control. The main advantages and disadvantages are summarized as follows;

### 1.2.1 Advantages

- Unlike solar panels, solar ponds can generate energy at night or during cloudy weather. Solar ponds can also store heat in the bottom layer for later use to produce electricity when needed without the help of any type of storage devices such as a battery which can be limiting and costly.
- Solar ponds can use what are usually thought as waste products, such as brine, to help create the salinity gradient.
- Each solar pond is built to site and can be expanded if needed.
- Materials are readily found to construct the pond.

- They are environmentally friendly because they are able to produce thermal energy without producing any waste products.
- Ponds are easily expandable if space is available.
- They have long life spans.
- Cheap to construct.
- They can be used in winter even when the top layer of the salt-gradient pond becomes covered in ice.
- Salt crystals have to be removed but can be an economically valuable by-product.
- No fuel has to be burned in order to produce thermal energy.
- Cost of energy produce is competitive with natural gas and coal
- No storage tanks or collectors needed.

### 1.2.2 Disadvantages

- Requires a reasonable amount of flat land. It can be difficult to find the empty land needed to make the pond big enough to be used. In addition, lots of salt is also needed.
- Low conversion efficiency of solar to thermal energy of about 15-20%.
- Cannot be built above moving ground water that is close to the surface.
- Liner may be needed to contain salt brine.
- Temperature limited due to varying seasonal cycles.
- As water evaporates, it needs to be replaced.
- Salt crystals have to be removed – can be a problem.
- Burrowing animals must be kept away to prevent damage.

### 1.3 Factors affecting pond stability

There are many factors that affect the pond thermal stability and its performance during daily operation of the SGSP as shown in Figure 2; the main factors are summarized as follows:

#### • Salt diffusion

Based on the working principle of a SGSP, it is necessary to build a salinity profile in such a way that allows high concentration brine to be at the bottom layer and low concentration brine to be at the upper layer of the pond. Between these two layers a salinity gradient profile has to be built. Naturally, salt diffuses from high salt concentration layer to low salt concentration layer, diffusivity of the salt is affected by pond temperature and the salinity profile. The annual rate of this natural diffusion of salts from high to low concentration was estimated to be in the range of 20-30 (kg/m<sup>2</sup>-yr). As a result, salt diffusion negatively affects thermal stability and efficiency of the pond.

#### • Evaporation and precipitation

Evaporation and precipitation are important factors, which together constitute the net evaporation rate. Net evaporation rate is defined as the evaporation rate minus the precipitation rate. Wind, ambient air temperature and surface water or brine temperature affect evaporation. In the SGSP, evaporation increases the salinity of the UCZ which is flushed away by using the flushing water to offset the evaporated water and to flush away the surface water to decrease the salinity of UCZ.

- **Wind mixing**

Wind effect causes mixing in the top region of the solar pond. Wind driven wave's currents cause turbulence and induce eddy diffusivity that reduces the salt concentration gradient, and thus it may result in a complete convection in this region leading to a corresponding increase in the thickness of the mixed surface layer.

- **Clarity**

Solar pond as a solar collector depends mostly on its performance and efficiency in transmitting light across the gradient zone to the storage zone. Water transparency is one of the most significant factors affecting pond performance. There are many factors that decrease light transmissivity in the SGSP, like unrefined salts, which contain impurities and nutrients, dust, bird excretion, leaves and many others. Some of these impurities settle easily to the pond bottom, others float or suspend at some levels in the gradient. Some particulates mostly organic favor formation and development of bacteria and algae.

- **Dust**

One factor that is expected to significantly influence the pond performance is the dust accumulation at the bottom of the pond. Strong wind and storms are mostly the main reasons for sand accumulation. Clarity of the pond gradient and reflectivity of the pond bottom are expected to be mostly affected by this dust. This problem and its effects on the SGSP are still being subjected to further research and study.

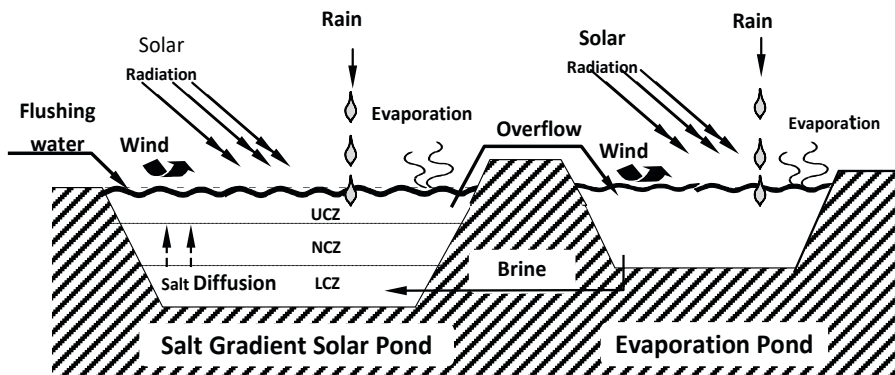


Figure (2). Main factors that affect the solar pond thermal stability [7].

## 2. RESEARCH ACTIVITIES AND STUDIES ON SOLAR PONDS IN LIBYA

### 2.1 Solar energy in Libya

LIBYA is located in the Sun Belt area that is characterized by high insolation and duration. An estimated daily average of solar radiation falling on the ground level to about 8 kilowatt - hour per square meter during the month of summer (June). According to measurements, as shown in Figure 3, the average annual solar radiation per square meter of horizontal surface ranges between 19.8 MJ / m<sup>2</sup> per day coastline to 25.2 MJ / m<sup>2</sup> per day southern regions of Libya or average of 2,470 (kW.h / m<sup>2</sup>/year). The duration of sun brightness during the year reaches approximately 3100 hours on the coastal strip and 3900 hours on the southern regions. In other words, 95% purity of the skies or clear days each year is available, in addition to the favorable climate of air temperature and relative humidity. There is no doubt that these data call for the need for attention to this energy source and to exploit the use of appropriate technologies to the largest extent possible.

Libya also has very huge areas of 1,759,540 square meters; more than 90 percent is arid desert or semi-desert. In addition, the cheaper cost of land makes the extended applications of solar energy very economical when compared to the same applications in other countries.

In fact, Figure 3 gives the annual energy obtained from direct vertical solar radiation and without taking into account the diffuse radiation, and therefore, the total value of the solar radiation is much higher than that and consequently encourages exploitation in all possible applications.

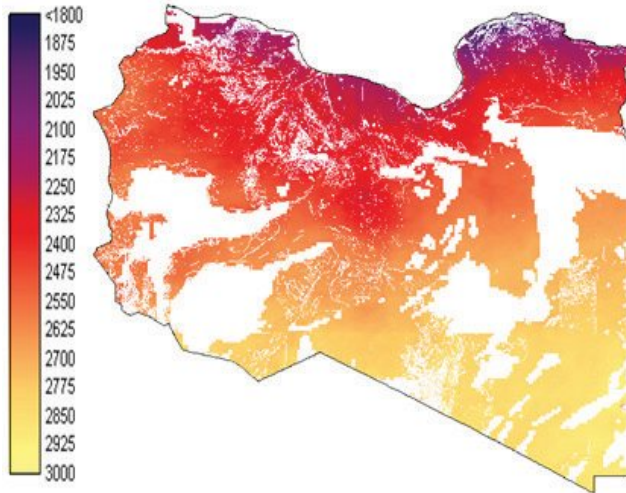


Figure (3). The intensity of the solar radiation levels in Libya, ( $\text{kWh}/\text{m}^2 / \text{year}$ ) [4].

## 2.2 Center for Solar Energy Studies experience

### 2.2.1 Tajoura's Experimental solar pond

Tajoura's Experimental Solar Pond (TESP), Figure 4, located to the east of Tripoli, is constructed by the Center for Solar Energy Studies (CSERS), in joint cooperation with a Swiss company, with surface area of about  $830 \text{ m}^2$ , and a depth of 2.5 m, coupled to an evaporative pond of  $105 \text{ m}^2$  area, 1.5 m deep. It is designed as an experimental facility enabling the investigation of various aspects of pond performance.

Tajoura's Experimental Solar Pond is an artificial solar pond. It consists of main pond, evaporation pond, control room and its accessories (hydraulic system, measuring system and data acquisition system). Figure 5 shows the general layout of Tajoura's Experimental Solar Pond at the site near Tripoli.



Figure (4). General view of Tajoura's Experimental Solar Pond [3].

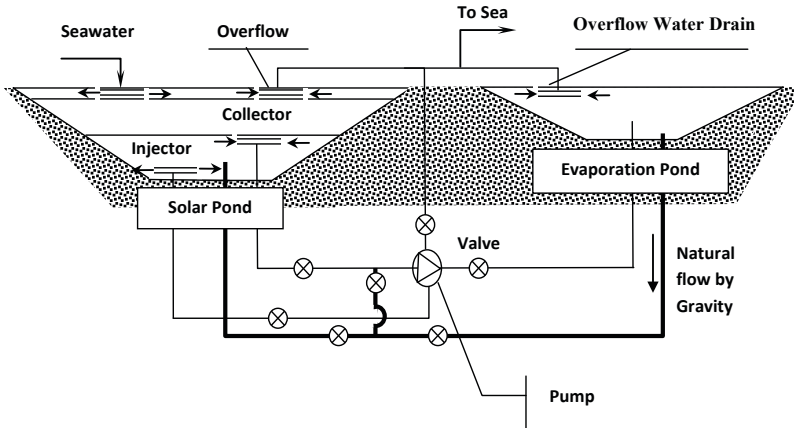


Figure (5). General layout of the hydraulic system [3].

### (I) Main pond

The main pond has an active area of 600 m<sup>2</sup>; the dimensions of the main pond are summarized in Table 1 as follows;

Table (1). Main Pond Dimensions.

Solar Pond Dimensions	Original Design
Depth	2.5 m
Surface ( top level surface layer )	830 m <sup>2</sup>
Active surface ( top level storage layer )	600 m <sup>2</sup>
Storage volume	530 m <sup>3</sup>
Total volume	1610 m <sup>3</sup>
Thickness of upper convective zone	0.30 m
Thickness of non convective zone	1.20 m
Thickness of storage zone	1.00 m

### (II) Evaporation pond

The evaporation pond is designed to generate the salt which is lost by upward diffusion from the LCZ of the main pond to the surface where it is flushed away, some 10 tons per year of salt must be replaced for a pond having a surface of 600 m<sup>2</sup>.

The dimensions of evaporation pond are depicted in Table 2 as follows:

Table (2). Evaporation Pond Dimensions

Solar Pond Dimensions	Original Design
Depth	1.5 m
Surface	105 m <sup>2</sup>
Volume	105 m <sup>3</sup>

### (III) Hydraulic system

The Hydraulic System consists of the following components;

#### a. Pump and valve group

The pump and valve group is the heart of the solar pond system and is composed as follows:

- Centrifugal pump, made of polypropylene (pp), flow rate 10 (m<sup>3</sup> / hr).
- Manually operated valves V1-V6, made of pp.
- Electrically operated valve V7, made of pp.
- Fittings and pipes made of pp.

#### b. Outside components

The outside components are specially designed and developed for the purpose of the solar pond system.

- Main injector made of polypropylene (pp).
- Main collector made of (pp).
- Flushing water injector made of (pp).
- Over flow of the solar pond made of (pp).
- Rain water drain and over flow of the evaporation pond made of (pp).

#### c. Piping

The locations and the sizes of the pipes are designed as in the related drawings. All pipes are made of (pp), except the short connection to the movable outside components. For this purpose EPDM Rubber hoses are provided.

### (IV) Measuring and control system:

The heart of the measuring system is a data logger (data taker DT 500), which is programmed to fulfill the following functions:

- Measuring all the fixed channels: Every minute the channels are measured and the hourly average is stored.
- Climate: sun irradiation, air temperature, wind speed.
- Water: pond top temperature, pond bottom temperature, evaporation pond temperature.
- Soil: temp1.....temp10.
- On times: main pump, water supply evaporation pond, surface rinse pond.
- Alarms: 12 Vdc °k, measure valve time , circuit breaker, water level, battery voltage.

As a further step, the software package has the capability of measuring the energy extraction rate by taking the values of the following parameters:

(Water flow out, water temperature in, water temperature out, energy output)



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## Measuring water temperature and salt concentration at all levels

At the beginning of every hour, the measuring procedure is reset. The measuring valve is set to the evaporation pond. The values are taken only after 4 minutes to ensure that the measuring system is filled with water of the correct temperature and concentration then, the measuring valve is set to the level 1 ( lowest ), the values are taken after 2 minutes, because the concentration of the level 1 ( storage layer ) is about the same as that of the evaporation pond , but the temperature is much higher, the measuring valve is advanced to the next level once a minute , the values are taken after 1 minute, because the concentration and the temperature decrease only slightly from one level to the next, then measuring stop after level 29 ( highest ) and restart at the beginning of the next hour.

For maintenance purposes it is possible to select a level (valve) manually with the level switch depending on the level switch position.

### (V) Cooling of the storage layer

The main pump is turned on and off in function of the storage layer temperature and the water is pumped into the evaporation pond. Because the evaporation pond has no salt concentration layers, it is cooled by convection, the cooled water flows back into the storage layer of the solar pond; in addition the main pump is turned on for few minutes at midnight to prevent damage on the bearings and the sealing.

### (VI) Feed storage layer with salt from evaporation pond

When the salt concentration in the evaporation pond is high enough, the valve which feeds fresh water into the evaporation pond is turned on and from the bottom of the evaporation pond the water with high salt concentration flows into the storage layer of the solar pond.

### (VII) Rinse solar pond

The valve which rinses the surface of the solar pond is turned on constantly.

### (VIII) Security

All the valves and pumps are interrupted when , the 12 Vdc supply (or the grid) is interrupted, a (or several) circuit breaker is open or a ( or several ) water level (solar pond , evaporation pond , vessel) is too high .

### (IX) Design of the salt gradient

The salt concentration in the UCZ is maintained by flushing with fresh water or seawater (salt is diffused upwards from the gradient zone and is produced also by evaporation at the surface). For Tajoura's Experimental Solar Pond, the salt concentration of the UCZ layer of 30 cm thickness has been chosen to be 40 (g/kg).

The salt gradient of the NCZ, 1.2 m thickness was designed on the basis of its stability criteria assuming a temperature difference between UCZ and LCZ of 85 °C.

Depending on varying weather conditions and other prevailing physical conditions, the value is chosen to be 204 (kg/m<sup>3</sup>) which equals 180 (g/kg) in order to obtain a stable and safe salt gradient.

The thickness of the LCZ was chosen to be 1.0 m. With an increased thickness the heating up time would be longer. The LCZ thickness can be increased to approximately 1.3 m, in order to increase the storage capacity.

For storage zone thickness of 1 m initially, the salt concentration value of 220 (g/kg) is chosen. The summary of the salt concentration profile is given in Table 3 by the following values:

Table (3). Designed Salt Gradient for TESP [3].

Layer	Thickness (cm)	Salt Concentration (g/kg)
UCZ	30	40
NCZ	120	40 ~ 220
LCZ	100	220

### 2.2.2 Theoretical and field studies

A normal procedure prior to the design and practical implementation of an engineering system is to study the affect of various parameters on the system behavior. This step will ensure the correct working order and less problematic operation of the system when practically implemented.



Figure (6). Starting up and maintenance work activities at TESP [3].

The research program on solar ponds in Libya started in 1987. There are a lot of studies and researches, theoretical and experimental. Since then, the research team in the Center for Solar Energy Study (CSERS) and part time researchers from other universities and organizations take part in these activities. In this section, a summary of the main theoretical and field studies will be presented.

Agha et al [1] [2] & [3], presented the starting up and maintenance work activities for Tajoura's Experimental Solar Pond (TESP). In their reports, they illustrate all steps and activities accomplished as shown in Figure 6. They presented the maintenance work including the work plan, the work done and future needs in addition to cost. Before they started their maintenance work in 1999, the project has been running for just one month during (the month of April, 1994), after construction and erection by the Swiss Company. Then the solar pond lost its thermal stability.

As a result it lost the ability to collect and store solar energy. The pond is left for four years without any care and concern. This resulted in the evaporation of more than 1,500 cubic meters (more than 90%) of the pond water in addition to the accumulation of dust and dirt. Furthermore, all electromagnetic valves, pipes and fittings were blocked by rigid and solid salts and in a state of total obstruction. The main maintenance work activities are (cleaning, inspection of polypropylene liner, import of salt, construction and maintenance of salt gradient).

The salt gradient establishment was completed in August 18, 1999. The storage zone of the pond achieved a temperature of 62 °C in October 20, 1999, as shown in Figure 7, after which the temperature dropped, presumably due to the low solar radiation intensities and decrease in ambient temperature. At about the same time, a Copper Sulfate was added to the pond with the purpose of controlling the algae growth. The addition of Copper Sulfate to the pond resulted in a less clear water and, therefore, less net radiation reaching the bottom of the pond.

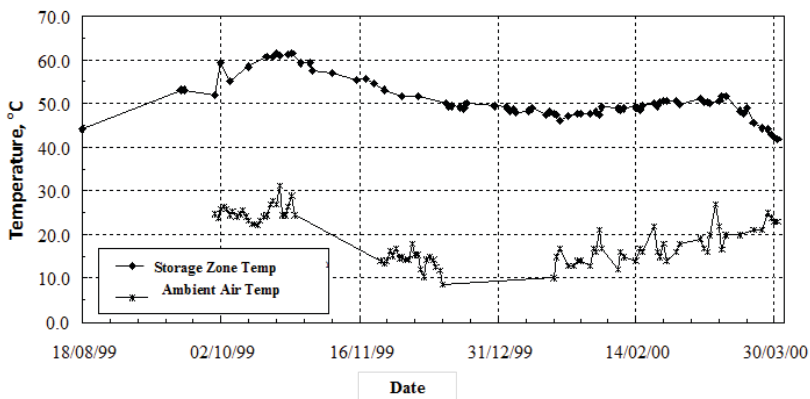


Figure (7). Daily records for storage zone and ambient air temperatures at TESP [3].

The pond continued to be thermally stable up to the end of March 2000. By that time some problems severely impaired the pond operation, as they lead to a serious drop in its collection and storage efficiency. These problems are excessive erosion of the gradient zone, the formation of sizable localized convective zones within the gradient zone, the deterioration of pond clarity and the high rates of surface evaporation.

The gradient was re-established on January 24th, 2001, and the pond continued to be in fairly good thermal stability conditions for more than one year (up to February 2002). At that time, internal convection zones were developed within the gradient zone due to large quantities of dirt and tree leaves fall on the pond surface and the maintenance team was not able to control the problem. In their paper [6], Agha et al analyzed

the measurements taken on the pond from August 1999 till February 2002, through the discussion of the measurements of both salt concentration and temperature profiles. The stability criterion of the pond was also presented by showing the daily level of stability margin as a function of time. The heating up period of the pond and its comparison to the predicted theoretical performance was presented and discussed. It should be noted that a good agreement between the predicted and measured storage zone temperature was found.

On overall, the Tajoura's Experimental Solar Pond has demonstrated that solar ponds for low grade heating applications, such as desalination, space heating and grain drying, can be designed in a simple manner that requires minimal maintenance duties. More time is needed to refine operation procedures; however, enough data have been collected such that the basic design used for the pond can be replicated without significant modifications.

In 1999, Ramadan [7], investigated the design methodology and maintenance strategy for a salt gradient solar pond coupled with an evaporation pond. It was aimed to establish a physical understanding of the problems associated with the operation and maintenance of solar ponds and thus develop a guide for a systematic operation and maintenance of solar ponds. As the internal conditions of the solar pond are not closely coupled to those of the external environment, a criterion needs to be developed that allows the designer to effectively specify the system required and to realistically appraise the benefits associated with its use. This is intended to be postulated through a relationship between the salt diffusion rate, area of the solar pond, area of the evaporation pond, and the rate of surface flushing has to be explored.

Results of the study provided an insight to the designers of solar pond systems and the operation engineers of such systems through the following parameters; the effects of the local weather conditions on the thermal stability of the SGSP, recommendations on how to minimize their effects on future designs, the best method for salt gradient maintenance, a day to day operation for solar ponds and a guide for a systematic operation and maintenance of solar ponds.

Agha and Ramadan [8], presented the stages of maintenance and operation of Tajoura's experimental solar pond. In addition, the project aims to identify the potential and advantages of solar ponds under local conditions and suitability for thermal applications, where it will be possible to assess the future role of solar ponds and the extent of their contribution to the thermal energy production of low-temperature techniques. The paper also presents the difficulties faced by the operating team, actions and majors that have been taken to overcome them.

Agha et al [9], presented the results of a simple mathematical model for predicting the ratio of the Evaporation Pond (EP) area to that of a SGSP area. The EP idea provides a very attractive method of salt recycling by evaporation, especially in areas of high evaporation and low rates of rain as it is the case for North Africa.

The model was applied for two types of surface water flushing (fresh water and sea water) under the prevailing conditions of Tripoli-Libya (Lat=32.86 °N) and for measured evaporation rates. The proper size of EP was estimated and presented under different design conditions. The considered design conditions include summer, autumn and spring designs, while the winter design was excluded due to the low rates of net evaporation during the winter season. The results showed that the EP of TESP was under-sized and could only provide about 30% of that salt required by a SGSP. Under the summer conditions and for the case of surface flushing by fresh water, the area ratio was estimated at about 0.17, whereas for the case of using seawater, this ratio increased enormously to about 14.4.

The paper also presents the design, the construction, and the method used in the establishment of salt concentration profile of Tajoura's Experimental Solar Pond (TESP) (Tripoli-Libya). The preliminary calculations on the TESP project have shown that the SGSP requires about 35 ~ 70 kg<sub>salt</sub>/day whereas the

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evaporation pond can provide a maximum of about  $26 \text{ kg}_{\text{salt}}/\text{day}$ . For  $830 \text{ m}^2$  SGSP area, the model predicted an evaporation pond area of about  $141 \text{ m}^2$  for fresh water surface flushing and  $11592 \text{ m}^2$  for seawater surface flushing under the prevailing conditions of Tripoli - Libya (summer design) (Lat. =  $32.68^\circ\text{N}$ ).

Agha et al [10], illustrated in a previous study [9], a simple mathematical model for predicting the ratio of the Evaporation Pond area to that of a Salt Gradient Solar Pond.

In their paper, the model was elaborated and applied for two types of surface water flushing (fresh water and seawater) under the prevailing conditions of Tripoli-Libya (Lat.= $32.86^\circ \text{N}$ ). The time required for the salt concentration to increase from seawater concentration to high concentrated brine, which could be injected at the bottom of the solar pond, was also predicted. The time required to increase the salt concentration from 3.5% to 35% was estimated to be about 120 to 180 days during the summer season, and about 220 to 260 days during the winter season.

The daily variations of brine concentration in the EP of TESP and those based on different designs were predicted and discussed under different scenarios for the first three years of operation. The quantities of brine provided by the evaporation pond and that required by SGSP were predicted for both cases of surface water flushing (fresh water and seawater) under the different design conditions. The results showed the predicted quantities of salt that could be contributed by EP (as percentage). It was found that EP provided 20% to 40% during the first year and 45% to 95% during the third year, depending on the selected design. Comparing the percentage of salt provided for different designs, it was clearly found that the autumn design presented a favorable condition. It also provided a reasonable percentage reaching 79% in the case of fresh water surface flushing and 93% in the case of seawater surface flushing.

Under the prevailing weather conditions of Tripoli, the results had shown that in addition to the higher flushing quantity required during the summer, flushing was needed more frequently. It was predicted that the number of flushing varied between five times per month during the summer to two or three times per month during winter. Also, the study predicted that the quantity of sea-water surface flushing was bigger than that of fresh water.

Under the assumption of  $16.6 \text{ (kg/m}^2\text{-year)}$  for the natural rate of upward salt diffusion (assumed by TESP project team), it was predicted that the brine (or salt) must be injected to the LCZ every 49 days (or earlier) to keep the pond stable. The quantity of the brine to be injected, its concentration and timing were predicted and discussed. For example, for EP concentration of 26%, the quantity of the brine to be injected to LCZ was about  $3.4 \text{ m}^3$  (for TESP).

Finally, the research project presented a guide for a systematic maintenance and daily behavior for different designs. Such a guide is very useful in the operation and maintenance of such systems. Also, simulations of day to day monitoring were achieved.

Ramadan et al [11] investigated the differences between Evaporation Pond (EP) and Evaporation Surface (ES) both as a source for salt brine generation by evaporation. The effect of (EP) depth on the area ratio and daily variations of salt concentrations for three years of operation was shown. Results show that evaporation can be a reasonable method for salt brine generation. Reducing the depth of (EP) improves the capability of (EP) for brine re-concentration. It also increases the (EP) surface area for the same quantity of saline water used. Therefore, ESs are more powerful than Eps in salt re-concentration.

Agha et al [12], presented a research project in the field of water desalination through the use of TESP. The Center for Solar Energy Research and Studies has installed a multi-stage flushing (MSF) desalination plant using low grade heat energy that is collected in the TESP as a source of energy for this system. The aim of their project was to identify the possibilities and advantages of solar ponds under local conditions and their

suitability for the techniques of MSF desalination units. Thermal energy at relatively low temperatures is suitable for blending with several solar thermal systems. Solar ponds come in the forefront of these systems as they have the ability to provide thermal energy at a temperature ranging between 60 and 80 degrees Celsius throughout the year. To ensure the operation of the desalination unit, it has been designed to be operated by the available heat energy that is collected by TESP at an operating temperature of 80 ° C. The average daily production of the unit is 5 cubic meters.

The project was designed and constructed under CSERS's Solar Pond Program – an idea mooted and formulated by a group of scientists within CSERS. The design and construction of the project has been carried out in a joint cooperation with a Swiss company. Currently, the project is operating and is maintained by CSERS's solar pond research team. A Multi-Stage Desalination Unit with a daily capacity of 5 m<sup>3</sup> was installed to utilize the thermal energy collected and stored in TESP.

The application of the Tajoura Experimental Solar Pond is to deliver the required thermal energy for the operation of an MSF desalination unit. To realize this, a heat exchanger was installed, wherein the circulating hot brine, extracted from the bottom of the pond, heats the seawater. This hot seawater then enters the end heater where the effective transfer of the required energy from outside takes place. The seawater temperature is therefore raised again by few degrees and is then directed to the evaporation chamber of the first stage. There is a small fraction of the seawater evaporates (“flashes”) due to the sub-atmospheric pressure in the stage it has entered.

Through the evaporation process, the seawater temperature drops few degrees. The vapour migrates to the condenser chamber where a first fraction of distilled water is produced through condensation on the outer surface of the tubes. The seawater flowing inside the tubes recovers the energy, which is lost by this condensation. Both, the distillate and the remaining seawater are directed separately to the next stage where flashing occurs again because of the lower pressure prevailing in that stage. More distillate is therefore produced in the adjacent condenser chamber. This process is repeated in the following stages and the accumulated distillate is withdrawn from the last stage.

The design capacity of the desalination unit is 5 m<sup>3</sup>/day. The daily thermal energy supplied by the solar pond to the desalination unit at nominal operating conditions is about 375 kWh per day and at a temperature of about 70°C.

This project is the first in the country. It successfully demonstrates the use of solar pond technology to get potable water from seawater. CSERS's technical program will culminate with the demonstration of a seawater desalination plant coupled to a salt gradient solar pond. The program is designed to accumulate the technical know-how in designing, installing and operating such systems, as well as to generate economical data necessary to the commercialization phase. The expected results will respond to local needs, national and regional objectives.

### **(I)- MSF desalination unit**

A 5 cubic meter per day Multi-Stage Flashing (MSF) desalination unit with 14 stages available at the Center was used in this project, Figure 8. This unit is coupled with a solar pond of TESP as shown in Figure 9. The technical specifications for this plant are shown in Table 4. The plant is capable to operate over a wide temperature range of low grade thermal energy input without loss of efficiency. The maximum design operating temperature is 80 °C, and the preferable range of operation is between 70 – 80 °C.

## **3. PROBLEMS AND DIFFICULTIES**

In view of close monitoring, day to day operation and accumulated work experience for the research

team at TESP, in addition to what already mentioned above in section 2, many problems and difficulties were encountered and noticed by the research team. These problems can be summarized as follows;

- **Wind mixing** (erosion of the NCZ, increasing the salinity of UCZ, huge amounts of water needed for surface flushing. Fall of dust, dirt and dry leaves and flowers of trees on the pond surface, affect the clarity of the pond).
- **Turbidity of water** (algae, bacteria and suspended dust particles and other impurities were the cause of turbidity in TESP water layers).
- **Salt import** (huge quantity of salt required for salt gradient establishment for TESP, 260 Tons result in transportation problems, high cost and mixing problem).
- **Salt gradient establishment and maintenance** (not easy task, need skilled staff, continuous monitoring and supervision, very sensitive to prevailing and physical conditions. The evaporation pond of TESP is undersized, small amounts of brine offered, not enough for salt gradient maintenance).
- **Dust** (heavy particles, accumulated at the storage layer, negatively affect the absorptivity of the liner. Light suspended particles; affect the clarity of the pond water. Sand filter is needed).
- **Thermal performance** (low conversion efficiency 15-20%, seasonal temperature variations).
- **Cleaning** (salt crystals (solid), dust and other dirt cleaning - can be a problem).
- **Competition** (more researches and investigations still needed, not offered in commercial scale yet, other thermal conversion systems such as solar water heaters, concentrated solar power...etc are commercially available)



Figure (8). A view of the MSF desalination unit [4].

Table (4). Technical specifications of MSF plant [4].

Item	value
Average daily production of fresh water	5 m <sup>3</sup> /day (0.208m <sup>3</sup> /hr)
Max working temperature	80 ° C
Sea water temperature	20 ° C
Thermal energy consumption	15.6 kW

Designed specific consumption of electric power	4.8 kWh/ m <sup>3</sup> .
Rate of flow of sea water (nutrition and cooling)	2.3 m <sup>3</sup> /hr
Flow rate of saline solution	2.1 m <sup>3</sup> /hr
Concentration of the Mediterranean sea waters	35,000 ppm.
Specifications of desalinated water	< 100 ppm

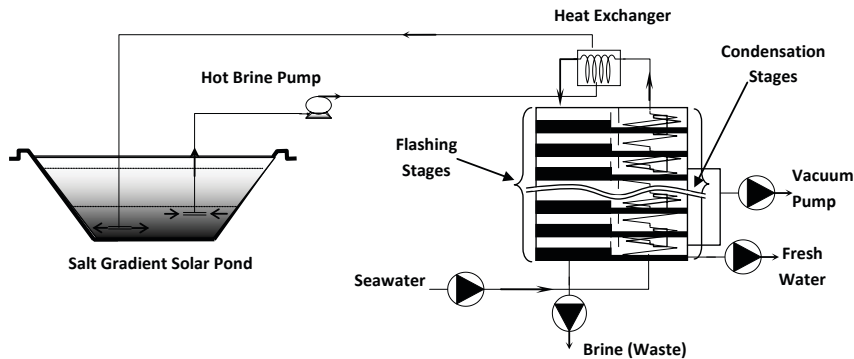


Figure (9). Schematic drawing of MSF Desalination Unit coupled with TESP [4].

It should be noted that the research team tried to solve some of the problems mentioned above. Sometimes, financial problems hamper the operation routine and disturb the work plan. Moreover, some devices and equipments were not available. For example, solar radiation measurement device through different layers of TESP, turbidity measuring device and sand filter.

#### 4. THE FUTURE OF SOLAR PONDS' RESEARCH IN LIBYA

Based on the above review, it is clear that although solar pond technology looks simple and attractive, many drawbacks and problems negatively affect solar ponds operation, thermal stability and performance and in some situations limit their use. Extensive research activities and studies in solar pond technology have been carried out in Libya. When comparing with other solar thermal conversion technologies, there is a general feeling that developments and advances in these technologies are much faster than that of the solar pond. This is clearly understood due to their commercial spread and use. New designs and improvements make them economically competitive and feasible.

As a result, the decision maker will not confuse when he put in choice whether to continue with research on solar ponds or on other technologies. Nowadays, due to the financial problems and limitation of budget in addition to the above experience, authors feel that the future of research and studies on solar ponds in Libya will be decelerated or even stopped for near future. Other technologies will get more care and concern.

#### 5. CONCLUSIONS

Many researches and studies were conducted on Salt Gradient Solar ponds in Libya. An artificial Salt Gradient Solar Pond was built and constructed by CSERS in Tajoura, Tripoli in cooperation with a Swiss company. Understanding the physical behavior and problems associated with the operation and maintenance of solar ponds were of the main objectives of those studies and researches. The above review gives a close insight into the research work carried out by the CSERS research team about solar Ponds and their applications. They



investigated all factors and parameters that are known to affect the solar pond performance. In addition, MSF desalination unit was also operated by the heat energy supplied by TESP.

The research team in CSERS got the experience and skills of operating and maintaining solar ponds and majors to overcome their operating problems.

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