EXPERIMENTAL SMALL-SCALE SALT-GRADIENT SOLAR POND FOR ENERGY PRODUCTION, DEAD SEA-JORDAN

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Abstract

A small-scale experiment for salinity-gradient solar pond has been constructed and operated at the Dead Sea area over a period of 3 months. The pond has a volume of $5m^3$ with dimensions of (L, H, W) as 2.0, 2.0 and 1,25 meter respectively. The two parameters temperature and salinity concentration profiles were evaluated through the measurements of the solar pond with respect to time. The experimental result shows that the bottom layer has a higher temperature and it reached a maximum temperature of 85 ℃ after 100 hour of operating.

In this experiment, the thermal insulation for the pond was successful to keep the boundaries isolated that made it possible to extract the thermal energy stored in the bottom zone during the daytime, continuously, while maintaining the stability of the solar pond. The total cost of the pond was about $35/m², in which the cost of the salt represents 45% of the total cost of the solar pond that is relatively cheap. Therefore, constructing the ponds close to the Dead Sea area is a cheaper alternative.

Resulting low cost of utilizing thermal energy that could be a valuable option for multistage flash desalination plant that is functioning below 100 ^oC. The operation of this pond reveals that solar pond technology in the Dead Sea area, as compared with other methods of using solar thermal energy for power generation, is more efficient especially for the utilities where direct thermal energy is required.

I. INTRODUCTION

During the last few years' great efforts have been exerted in developing alternatives of conventional energy sources as an alternative comprises solar energy, geothermal energy, wind energy and biomass. Among the solar energy systems, solar ponds have received worldwide attention in the last decade as an alternative means of supplying thermal energy for industrial process heat, thermal desalination, domestic water heating, space conditioning and electric generation.

The sun is the largest source of renewable energy and this energy is abundantly available in all part of the earth and especially in hot and arid regions such Jordan in the Middle East. Solar energy become as another source of energy supply. The solar energy potential in Jordan is enormous as it lies within the world solar belt with average solar radiation ranging between 5 and 7 KWh/m^2, which implies a potential of at least 1000 GWh annually [1].

One efficient way to trap this solar energy is through the use of salt-gradient solar ponds. They can be utilized for various applications, such as electricity generation, water desalination, drying and recover valuable salts. Collection and storage of solar energy in salt-gradient solar ponds are based on the fact that convection heat loss is suppressed by establishing a salt concentration gradient. This gradient increases the density of the lower layers of the pond and makes it stationary stable regardless of the temperature rise of these layers.

Thus a salt gradient solar pond, usually called a non-convective solar pond, collects and traps solar energy and stores it in a large body of brine. This solar pond technology, as compared with other methods of using solar thermal energy for power generation, is more efficient especially for the utilities where direct thermal energy is required such as in industrial processes, where the need is just for the thermal energy and not the electricity [2]. Solar ponds can cheaply fulfill the industrial demand without the need of expensive conversion of solar energy into electricity generation.

In this paper, a small-scale experiment for salinity-gradient solar pond has been constructed and operated at the Dead Sea area. The experiment intend to measure the temperature and salinity profile of the solar pond. Furthermore, to discuss the basic principles of solar pond design and the potential of the thermal energy extraction at the Dead Sea area.

II. IMPORTANT DATA

Jordan is considered as a developing non-oil producing country located in the Middle East. Its basic energy needs are obtained from imported oil and gas. Jordan imports 96 % of all its energy at a cost of US$ 3.6 billion or 13.5 % of the country GDP [3]. Domestic oil and natural gas production covers only 2% of its energy need. The total contribution of renewable energy in Jordan is less than 2% of the total energy mix. The master strategy of the energy sector in Jordan has set a target of 10 % of the country's energy supplies which is around 1,800 MW, from renewable sources by 2020. Jordan has made inspiring progresses in implementing its national renewable energy strategy.

In 2012, the government introduced regulations paving the way for solar net-metering, under which Jordanians can sell electricity produced by solar energy at a rate of US$ 0.2 KWh. Decentralized photovoltaic units in rural and remote villages are currently used for lighting, water pumping and other social services (1000 KW of peak capacity). In addition, about 15% of all households are equipped with solar water heating systems. Jordan has major plans for increasing the use of solar energy. As per the Energy Master Plan, 30% of all households are expected to be equipped with solar water heating system by the year 2020.

The Strategy calls for 600 MW of this new capacity to be provided by solar power. On the other hand, about 97% of the earth's water is found in the ocean, with a salt content of more than 30,000 mg/L. Water, with a dissolved solids (salt) content below about 1000 mg/L, is considered acceptable for a community water supply [4]. The concept of desalination refers to a wide range of processes designed to remove salts from waters of different salinities as collected from different areas see Table 1. All major water sources can be utilized as raw water supply for desalination, except the Dead Sea as considered as one of the saltiest place on earth. Salinity of the raw water affects the efficiency and the economy of the desalination plants: the more saline raw water sources, the costlier are the production.

Table 1: Salt concentrations of different world water sources [5-8]

Water Source or Type	Concentration (g/l, ppt)
Brackish waters	0.5 to 3
North Sea (near estuaries)	21
Gulf of Mexico and coastal waters	23 to 33
Atlantic Ocean	35
Pacific Ocean	38
Persian Gulf/Arabian Gulf	45
Mediterranean Sea	38.6
Red Sea	41
Dead Sea	~300

2.1 Chemistry of the Dead Sea

When the runoff goes into the Dead Sea, the salt content can fall from its usual 35% to 30% or lower [9]. Under normal conditions, the salinity of the Dead Sea is about nine times greater than the average salinity of the oceans. Depending on the season, the salinity of the uppermost 35 m of the Dead Sea ranges between 30% and 40% and the temperature between 19°C and 37°C. Below a transition zone, the bottom layer of the Dead Sea consistently has a temperature of about 22°C, with complete saturation of halite (NaCl). Because the water is saturated, salt precipitates out of solution onto the sea floor.

The Dead Sea is presently also saturated or oversaturated with respect to aragonite ($CaCO_3$) and anhydrite ($CaSO_4$) [10]. Mixing between the calcium-rich Dead Sea brine and a sulfate-rich seawater will result in gypsum precipitation ($CaSO_4 \cdot 2H_2O$) [11]. The Dead Sea salts are commercially important and their production increases the evaporation of water. Wisniak (2002) presented a description of the properties of the Dead Sea together with a chemical analysis of the processes utilized to exploit it commercially [12].

Several numerical models have been developed to determine the water balance [13,14]. Horizontal variations in temperature and salinity may occur in the Dead Sea, but these are usually neglected in modeling [15,16]. Due to the particular chemical composition of the water, the accepted definition of “salinity” is not useful for the Dead Sea and it has been replaced by an equivalent salinity, referred to as ‘‘quasi-salinity’’[17]. Carnallite ($KMgCl_3.H_2O$) is next to crystallize out, however, this is only expected to happen when the brine reaches a specific gravity of 1300 kg/m^3 [18].

Table 2 presents a comparison of elemental analyses of water from the Dead Sea, the Jordan River, and the Mediterranean Sea based on more than 40 years of data. Opinions vary slightly as to which salt content the water of the Dead Sea has. Gavrieli et al., (2005) [11] reported a density and salinity of the Dead Sea of about 1237 kg/m^3 and 342.4 g/l, respectively, whereas Vengosh and Rosenthal (1994) [19] reported the Dead Sea salinity to be about 332.06 g/l. Mixing of the water in the Dead Sea due to low waves and wind is slow compared to that in other water bodies e.g. Seas and Oceans.

The Dead Sea may thus be considered a stratified water body, based on 44 available data sets on potential temperature, quasi-salinity, and potential density. These data indicate that the depth of the upper layer of the Dead Sea is about 10% of the maximum depth; defined as the average between June 1998 and December 2007 at the Ein-Gedi 320 station (see Figure 1) (after [20]).

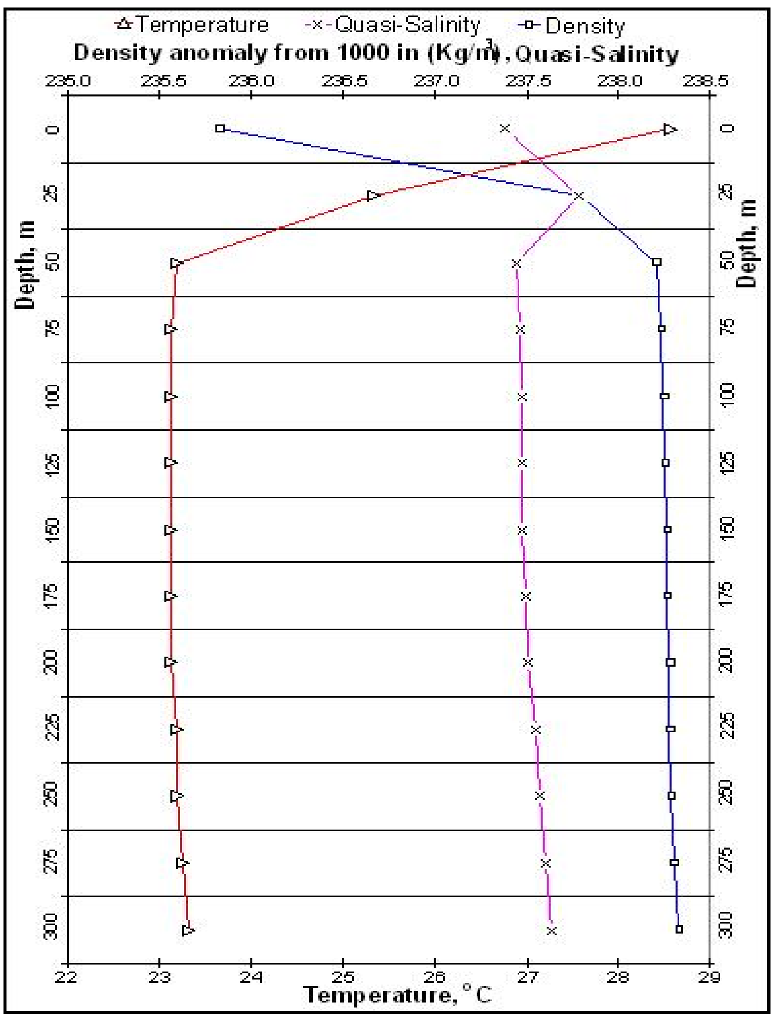

Fig. 1: Potential temperature, quasi-salinity, and potential density of the Dead Sea based on averages from June 1998 to December 2007 at the Ein-Gedi 320 station [21]

Table 2: Elemental analysis of water from the Dead Sea, the Jordan River, and the Mediterranean Sea concentration are expressed as g/l, [11,19,22-25]

Element	Dead Sea						Jordan River	Red Sea	Mediterranean Sea
	Ref. [11]	[19]	[22]	[23]	[24]	[25]	[22,23]	[25]	[24]
Cl	228.6	219.25	180.8	208.0	224.0	216.0	0.474	23.46	22.90
Mg	47.1	42.43	34.50	41.96	44.0	42.5	0.071	1.558	1.490
Na	34.3	39.70	33.50	34.94	40.1	34.3	0.253	13.34	12.70
Ca	18.3	17.18	13.00	15.80	17.65	17.1	0.080	0.685	0.470
K	8.0	7.59	6.30	7.56	7.65	6.65	0.015	0.466	0.470
Br	5.4	5.27	4.10	5.92	5.30	----	0.004	0.086	0.076

III. EXPERIMENT AND METHODOLOGY

An experimental salt-gradient solar pond was constructed at the Dead Sea area at the Jordanian part (see Figure 2) over a period of 12 months. The pond has a volume of 5 m^3 with an effective length, width and depth of 2.0m, 2.0m and 1,25m, respectively. To provide maximum solar radiation the pond was constructed with a black thermal plastic in 3 mm thickness and its bottom and sides were insulated by two layers of glass-wool with thickness of $1*10^{-3}$m (see Figure 3). The pond temperature was measured at different levels spaced 0, 15, 30, 60, 90, 120 cm from surface to the lower layers of the pond using highly accurate sensors with accuracy of ±0.1℃ for temperature range of 0-120 ℃. The temperature data was recorded using data logger every 30 minutes. The salinity was measured using portable conductivity meter; the measured data were transferred to computer in a daily basis.

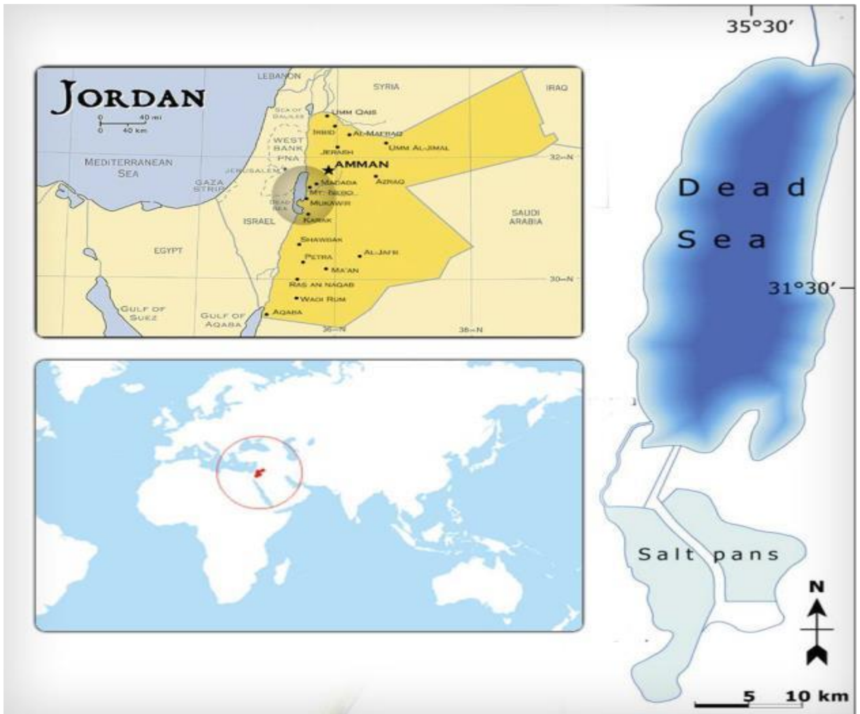

Fig. 2: Dead Sea area, location of solar pond

The pond was filled with Dead Sea water as it is about 9 times saltier than the ocean. A salt-gradient solar pond has three zones. The top zone is so called the surface zone, which is at nearly atmospheric temperature and has little salt content. The bottom zone is the hottest and is very salty. This zone collects and stores solar energy in the form of heat and is, therefore, known as the storage zone [26]. These two zones are separated by the gradient insulation zone. Within this zone the salt content increases as depth increases, thereby creating a salinity or density gradient. Water in a particular layer of this zone cannot rise, as the above layer has less salt content and cannot fall as the water layer below is heavier.

Fig. 3: Construction of experimental salt-gradient solar pond

Despite this significant amount of energy, the overall temperature of an ordinary pond remains uniform throughout the pond due to density driven gradients activated by convection heat transfer within the pond. In such ponds the energy going into the water at the bottom of the pond and gets wasted away because the water at the certain depth attains thermal equilibrium by mixing with heavy and colder water in the upper layer of the pond and forming a natural circulation loop. In this loop lighter but hotter water rises to the upper surfaces of the pond and the heavier but colder water at the upper surface moves down at the bottom of the pond [27]. Thus the solar energy in the pond spreads out and the average temperature of the water in the natural pond does not change more than few degrees from the ambient temperature.

However, in case of a solar pond, a method is devised such that the hot water in the bottom layers remains heavier than the cold water at the upper layers and therefore does not form a convection circulation loop to rise up. Thus, when the solar energy is incident upon the solar pond, it is trapped in the hot bottom layers, called lower layer of the pond. To achieve heavier (increased density) water in the bottom of the pond, sodium chloride was added to the bottom layers of the pond to increase the density of water at the bottom. The salt concentration is gradually decreased in the preceding upper layers [28].

The top layer has the least concentration of salt to achieve a perfect solar pond containing several intermediate layers of water with gradually increasing density from the top to the bottom layers of the pond. So the hot water at bottom of the pond is preserved through the formation of different convective zones, in the form of a thermal energy reservoir, this thermal energy can be extracted using different types of heat exchangers utilities [28].

IV. RESULT AND DISCUSSION

As a result of this study, temperature was measured in different layers of the solar pond, this result show that the bottom layer has a higher temperature and it reached a maximum temperature of 85 ^oC. The salinity and temperature profile with respect to the depth of the pond is presented in (Figure 4). As it can be seen in (Figure 4), the salinity was higher in the bottom of the pond most of the experiment time. The saline water moved to the lower layer of the pond where the temperature reaches the highest point after 100 hours of operating. Thermal insulation played a major role for the successful operation of the pond that was used in this experimental work.

This insulation is lowering the heat losses due to conduction through the thermal insulated boundary walls. However, this is due to relatively small dimensions of the pond and to the methodology adapted for the thermal insulation. Based on this, the estimated temperature drops during the period with no solar radiation, it is possible to extract the thermal energy stored in the bottom zone during the day time, continuously, while maintaining the stability of the solar pond.

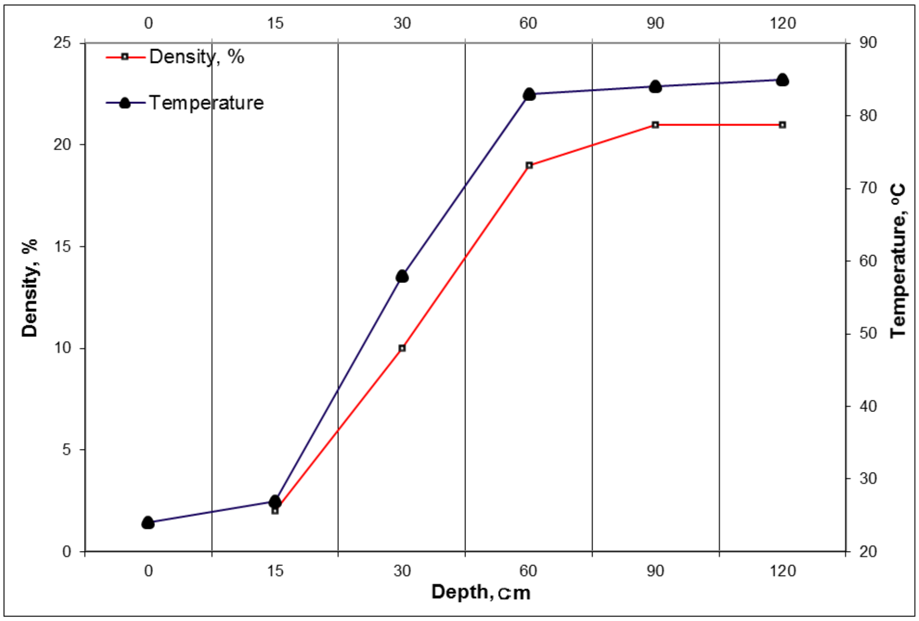

Fig. 4: The salinity and temperature profile with respect to the depth of the pond

Extraction of thermal energy (hot water) in the lower layers of the pond can be easily accomplished without disturbing the concentration gradient in the upper zone. This was achieved by installing the water outlet at the same height as the water inlet. Hot brine can be withdrawn and cold brine returned in a laminar flow. Considering the huge amount of salt produced in the Dead Sea area from its water, the market price for the salt used which is to be around $15/ton (price in 2013). The total cost of the pond was about \$35/m^2 and the cost of the salt represent 45% of the total cost of the solar pond. Therefore, constructing the ponds close to the Dead Sea area is a good alternative and economical option. The cost of solar pond is much less than that of the conventional flat plate collectors which is about \$130/m^2 (price in 2015).

The cost of solar pond is however; strongly dependent upon site specific factors and parameters such as local cost of salt and the initial installation cost (heat exchangers and pipes), operation cost, maintenance cost and pumping loses that associated with the heat transfer fluid. Also, the thermal performance is dependent on the site specific factors such as solar radiation, ground thermal conductivity and water table depth. This low cost of thermal energy could be a valuable option of desalination in practically for multistage flash desalination plant that work below 100 ^{o}C .

V. CONCLUSIONS

In this study, the operation of the pond reveals that significant amount of solar energy can be stored in pond which can be extracted through the installation of heat exchangers and can be used for several purposes. Thermal performance of the salt- gradient is artificially established in the pond with sodium chloride salt. As observed, a considerable amount of incident solar radiation can be trapped and stored as heat energy at pond at a long time period which can be additional source of energy.

Utilizing energy from solar ponds in Jordan will help the country meet the energy requirements and the increasing demand on energy. Solar pond technology is a viable option, both technically as well as economically for countries such Jordan as it will provide clean energy and reduces their energy bill significantly along with small payback period. In addition, it would be economically viable in a large commercial scale investment. Solar pond technology (spatially small size ponds), cheaper than other non-renewable energy sources, may still be a valuable option especially in circumstances where the unit cost of power is very high and access to a power grid is limited and for communities that prefer alternative renewable energy sources.

The effect of the wind on the solar radiation, wall shading effect as well as the variation of the thermo-physical properties of saline with temperature and concentration was not discussed in this research, longer operating time, therefore, further study is recommended.

VI. REFERENCES

1. Mohammed Awwad Al-Dabbas. Optimum Salt-Gradient Solar Pond in Jordan, Distributed Generation & Alternative Energy Journal, 2011, Vol. 26 (3) 45-65, DOI:10.1080/21563306.2011.10462198.
2. Jayatissa, N. Attalage, R. Hewageegana, P. Perera, P. Punyasena, M. Optimization of thermal insulation of a small-scale experimental solar pond. Sri Lankan Journal of Physics, 2012, Vol. 13 (1) 49-57.
3. Aljaradin Mohammad. Comparisons of Oil Shale Retort Water Treatment Methods. Journal of Water Management and Research (Vatten), 2012, Vol. 68: 37-41, [ISSN: 0042-2886].
4. Buros, O. K. The ABCs of desalting, report, 2nd ed., Int. Desalination Assoc., Topsfield, Mass, 2000.
5. OTV, Desalinating seawater. Memotechnique, Planete Technical Section, No. 31, 1999 (February), pp.1.
6. Gleick, P.H. Water in Crisis: A Guide to the World’s Fresh Water Resources, Oxford University Press, New York, USA, 1993.
7. Magazine, Water Condition & purification, (2005), January, Available at :< http://www.lenntech.com/WHO-EU-water-standards.htm> [Accessed on 11 April 2015].
8. Bashitialshaaer, R., and Persson K.M. China Desalination Cost Compared to Global Long-Term Estimation. International Journal of Sciences, 2013 Vol. 2(11), 63-72.

9. Salt Works (2001-2006). http://www.saltworks.us/shop/product.asp?idProduct=8
10. Gavrieli, I., Starinsky A. and Bein, A. The solubility of halite as a function of temperature in the highly saline Dead Sea brine system, Limnol. & Oceanogr, 1989, (34) 1224–1234.
11. Gavrieli, I., Amos B. and Aharon, O. The Expected Impact of the Peace Conduit Project (The Red Sea-Dead Sea Pipeline) On the Dead Sea, Mitigation and Adaptation Strategies for Global Change, 2005, 10: 3–22.
12. Wisniak, J. The Dead Sea a live pool of chemicals. Indian Journal of Chemical Technology, 2002, 9 (1): 79–87.
13. Al-Weshah, R.A. The water balance of the Dead Sea: an integrated approach. Hydrological Processes, 2000, 14 (1): 145–54.
14. Abu-Jaber, N. S. A new look at the chemical and hydrological evolution of the Dead Sea. Geochimica et Cosmochimica Acta, 1998, 62 (9): 1471–9.
15. Krumgalz, B.S., Pogorelsky R and Pitzer, K.S. Ion interaction approach to calculations of volumetric properties of aqueous multiple solute electrolyte solutions. Journal of Solution Chemistry, 1995 (24) 1025–38.
16. Krumgalz, B.S., Hecht, A., Starinsky A. and Katz, A. Thermodynamic constraints on Dead Sea evaporation: Can the Dead Sea dry up? Chemical Geology, 2000, 165: 1–11.
17. Anati, D.A. The salinity of hypersaline brines: concepts and misconceptions. International Journal of Salt Research, 1999 (8) 1– 16.
18. Steinhorn, I. and Gat, J.R. The Dead Sea. Scientific American, 1983, 249: 84–91.
19. Vengosh, A., and Rosenthal, E. Saline groundwater in Israel: it is bearing on the water crisis in the country. J. Hydrol, 1994, 156 389–430.
20. ISRAMAR, Israel Oceanographyic and Limnology Research, Israel Marine Data Center: http://isramar.ocean.org.il/(last update October, 2009).
21. Bashitialshaaer, R., and Persson K.M. The Dead Sea Future Elevation. Int. J. of Sustainable Water and Environmental Systems, 2011, Vol. 2, No. (2) 67-76.
22. Bentor, Y.K. On the evolution of subsurface brines in Israel, Chem. Geol., 1969 (4) 83-110. & Bentor, Y.K. Some geochemical aspects of the Dead Sea and the question of its age. Geochim. Cosmochim. Acta, 1961 (25) 239-260.
23. Abu-Khader M. M. Viable engineering options to enhance the NaCl quality from the Dead Sea in Jordan. Journal of Cleaner Production, 2006 (14) 80-86.
24. Katz, A., Starinsky, A. and Taitel-Goldman, N. Solubilities of gypsum and halite in the Dead Sea and in its mixtures with seawater Limnol. Oceanogr, 1981, 26(4): 709-716.
25. Eckstein, Y. Physicochemical limnology and geology of a meromictic pond on the red sea shore, Geological Survey of Israel, Limnology and Oceanography, 1970, Vol. 15, No. 3. pp. 363372
26. Mazidi M., Hassan M., Shojaeefard H. Two-dimensional Modeling of a Salt-gradient Solar Pond with Wall Shading Effect and Thermo-Physical Properties Dependent on Temperature and Concentration. Journal of Thermal Science, 2001, Vol. 20 (4): 362-370
27. Tejas Gawade, Varun Shinde, Ketan Gawade. Non-conventional energy sources: solar pond international journal of student’s research in technology & management, 2013, Vol. 1 (2): 156-162
28. Ahmad Aizaz, Rizwan Yousaf. Construction and analysis of a salt gradient solar pond for hot water supply, European Scientific Journal, 2013, Vol. 9 (36) 1857–7881.

VII. ACKNOWLEDGEMENT