SOLAR POND IS A NEW TECHNIQUE OF SUPPLYING THERMAL ENERGY

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Abstract

A performance study of using solar ponds for collecting and storing solar energy in a form of thermal energy was carried out. It displays various calculations for the required solar pond surface area for collecting the solar radiation, heat exchange pipe length and pipes surface area for extracting the heat from the pond and many other important design factors. These give an indication to estimate how big it must be the required pond and what output liquid temperature can be reached to achieve basic requirements for a certain project rely on heat supply. By doing such a project will save the environment and a lot of energy cost in addition of reduces the production of CO_2 to save the life on the earth. And in the same time it can be concluded thatreducing the required output liquid temperature from 70°C down to 60°C would save nearly third of the pipes needed in the same time third of the pond surface area. And this will confirm that the solar pond technology is working well with moderate output liquid temperature applications.

الخلاصة

تمت دراسة كيفية أداء البحيرات الشمسية في تجميع وخزن الطاقة الشمسية على شكل طاقة حرارية. وتظهر الدراسة حسابات لعوامل مختلفة منها مساحة البحيرة الشمسية اللازمة لتجميع الأشعة الشمسية وأطوال أنابيب التبادل الحراري ومساحة أسطحها الكافية لأستخلاص الطاقة الحرارية من البحيرة ونقلها الى المشروع المراد أستهلاكها فيه بالأضافة الى عوامل أخرى. مثل هذه النتائج تعطي أنطباع تقديري الى كبرمساحة البحيرة ومدى درجات حرارة السائل الخارج من البحيرة التي يمكن الوصول أليها واللازمة لعمل أي مشروع يعتمد على الطاقة الحرارية. وأن مثل هكذا مشاريع ستساهم في المحافظة على البيئة وتوفير تكاليف الطاقة بالأضافة الى الحفاظ على الحياة على الأرض كنتيجة لتقليل أنبعاث غاز ثاني أوكسيد الكاربون. وفي نفس الوقت يمكن أن نستنتج بأن تقليل درجة حرارة السائل الخارج من 70°م الى 60°م سوف يوفر ثلث أطوال الأنابيب المطلوبة وثلث مساحة البحيرة. وهذا يؤكد بأن تقنية البحيرات الشمسية تناسب جيدا التطبيقات التي تحتاج درجات حرارة معتدلة.

INTRODUCTION

After many conferences and meetings of various levels of scientists and political bodies, it becomes essential and a must that looking for alternative sources of energy to the conventional and fossil fuels e.g. nuclear energy, coal, gas and oil... etc. These sources of energy have a high potential of hazards on the environment and the human life on the earth and its atmosphere. So, making use of clean, free, lasting and renewable sources of energy, e.g. solar, wind and tidal energy, will mitigate the problem. In addition to consider these energy sources are environmentally friendly, they are cost competitive under a wider range of conditions as oil prices rise continuously [1].

Hence, solar energy is one of the promising sources of energy and available in abundance on this planet to avoid accumulation of CO_2 into atmosphere. It attracts the attention of a lot of researchers and scientists during the last a few decades [1-11].

Solar ponds represent a niche technology that makes economic sense. Specifically solar ponds provide low cost energy if all of the below points exist [2]:

- low-grade heat energy (i.e. < 100 °C temperatures) is required for an industrial process,
- salt to form the storage zone is readily available at low or no cost,
- low cost land is available, and

- the pond site is located in a high solar energy region.

Useful demonstrations of solar ponds include the production of industrial and agricultural process heat, pre-heating for higher temperature industrial processes, electrical generation and desalination [3].

Solar pond as a fairly new technology to collect and store solar energy is considered as a subject of this research. It seeks sustainable and environmentally benign methods to supply thermal energy for various applications. The first time the solar pond was discovered in the Middle East by Dave Grant in 1980 while he was working in an aquaculture project [4]. The incident solar energy is mainly transmitted through the water layers and absorbed by the lined darkened bottom and probably the sides of the pond. The accumulated heat will increase the water temperature in the lowest layer of the pond, which could reach 80-90^{o}C. Water in such temperature can be used for many purposes e.g. salty water desalination [5-8], aquaculture [4,9] and electricity generation [10]. An experimental and theoretical performance investigation was carried out on a small model of a research solar pond from which it was concluded that the temperature difference is a key driving force in heat transfer [11]. A solution mining facility at the Eddy Potash Mine, New Mexico, (USA) has been proposed that will utilize salinity gradient solar pond (SGSP) technology to supply industrial process thermal energy and to provide a safe, more economical secondary mining process. The project was intended to be the first of its kind in the USA to merge two innovative, cost-effective technologies that promise to improve industry productivity and economic competitiveness [2]. In the present paper author wanted to evaluate the essential requirements to estimate the required pond size and heat needed to run any project and associated pipe line length and their diameters in addition to the other technical factors, which form the fundamental aspects of the project's plan.

THERMAL TECHNOLOGY OF THE SOLAR POND

The solar ponds are unlike the conventional pond, where the energy is absorbed during the sunny hours that raise the water temperature and after the sun set it reduces gradually due to the convection currents and continuous water evaporation. Solar ponds are designed to be consisted of three layers of water with different salt concentration. The upper layer has the lowest salt concentration and that increases gradually toward the bottom of the pond. As a result, the water density is increased and hence preventing the convection currents [3-5].

The three layers are called: an upper convection zone, the stable gradient zone, and the bottom thermal zone (also referred to as the storage zone). In the gradient zone, salt content increases with depth. Water in the gradient zone cannot rise because the salt content of the water above is less and is therefore lighter, and the water below has a higher salt content and is heavier. Thus, the stable gradient zone suppresses convection and acts as a transparent insulator, permitting sunlight to be trapped in the hot bottom layer producing temperatures that can exceed 90^{o}C. Convection between layers is prevented by controlling density differences, thereby minimizing heat loses and maintaining pond. The most important zone of the solar pond is the Stable Gradient Zone (also called the Non-Convection Zone, NCZ or Middle Zone). That is because it allows most of solar radiation to penetrate into the storage zone but prevents the propagation of infrared solar radiation from escaping, as the water is opaque to infrared radiation[8,9]. So, heat will be accumulated at the storage zone. Hence, pumping brine from the storage layer through a heat exchanger or an evaporator removes the heat for industrial applications or any other application as shown in Figure (1).

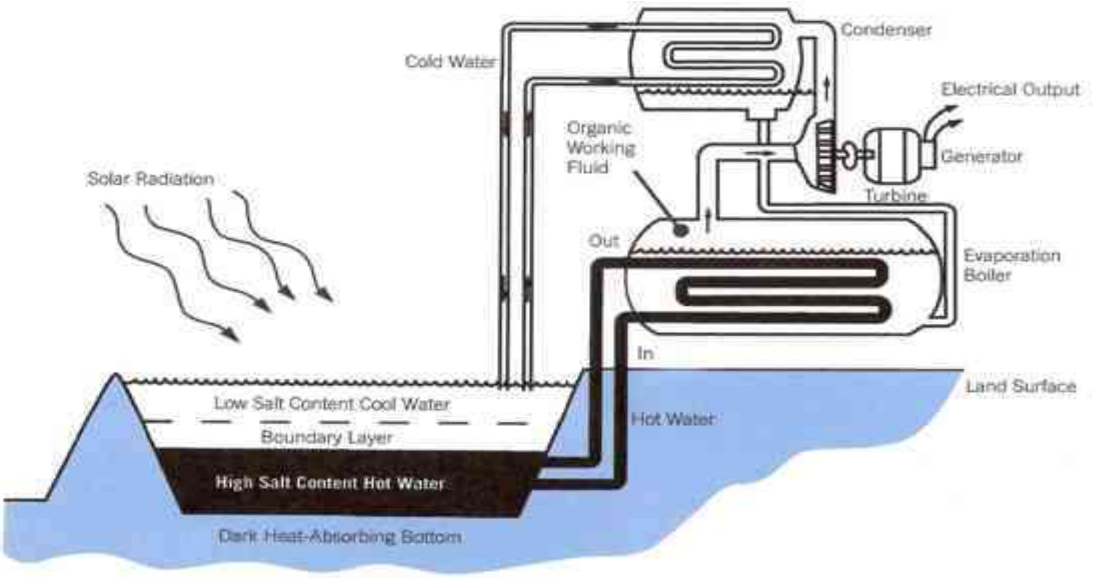

Figure (1): Schematic diagram demonstrates an electric power station connected to a solar pond.

THEORY

One of the important factors of using a solar pond is to know how much heat is required to be transferred from the bond to the suggested applicable project i.e. boiler of a turbine, desalination plant or dairy site...etc. This relies on several factors e.g. the expected maximum temperature of the salty water at the heat storage zone could be reached at the average daily incident energy, the surface area of the pond, the type of liquid needed to be used to transfer the required heat [12]. The liquid should have a relatively high specific heat capacity to extract the maximum heat through a closed pipe circuit. Hence, the required heat could be expressed as:

$$Q_{HR} = \frac{Q_{Fr-in} \times C_L \times (T_o - T_i)}{3600} \quad (1)$$

Where:

Q_{Fr-in}: Is the liquid flow rate inside the heat exchange pipes.

C_L: The liquid specific heat capacity.

T_o: The liquid outlet temperature.

T_i: The liquid inlet temperature.

Also, the pipes surface area (A_{pi}) and their length (L_{pi}) can be calculated from the Following expressions:

$$A_{pi} = \frac{1000 \times Q_{HR}}{U \times MTD} \quad (2)$$

Where:

U : is the over all heat transfer coefficient.

MTD : is the mean temperature difference which can be expressed as:

$$MTD = \frac{T_o - T_i}{ln((T_s - T_i)/(T_s - T_o))} \quad (3)$$

And the pipes line expression is:

$$L_{pi} = \frac{7000 \times A_{pi}}{11/(OD + ID)} \quad (4)$$

Where the pipes inner and outer diameters are ID and OD respectively. These pipes are carrying the circulated liquid which transfers the heat from the pond to the place where it is needed. Thus, the pond surface area can be determined from the following expression:

$$A_{sp} = L_{pi}/PD \quad (5)$$

Where PD is the pipes density distribution inside the pond [12].

RESULTS AND DISCUSSION

To predict some results from the above equations, the heat transfer circulated liquid considered as water with its known specific heat capacity of 4186.8 $Jkg^{-1}K^{-1}$. After employ a special program in Excel Language as shown in Figure (2) to solve the above equations, from The Centre for Osmosis Research & Applications University of Surrey, UK, the following tables and figures were obtained.

From tables (1,2) and figures (4,5) it can be seen that the more heat transferred required the more temperature difference between the input and output circulated liquid should occur. And as consequences for that are the more solar pond surface area and longer pipe line to circulate the liquid and to extract the heat from the heat storage zone of the salty water in the solar pond.

For any practical application to make use of the heat produced from a solar pond it can be seen that for the high temperature required of e.g. 70^{o}C the pipes length of 7138 m required if the returned circulated liquid with an input temperature of 25^{o}C. In the same time this would required 52.3 kW power to be transferred which give a good indication for one of the main costly system of a solar pond initial capital cost. Table (1) shows how big is the surface area of a solar pond is required according to the output liquid temperature. These technical results can have alternatives by changing the used materials of different properties, e.g. pipes material and diameters, circulated liquid...etc. Hence as a conclusion that reducing the required output liquid temperature from 70^{o}C down to 60^{o}C would save nearly third of the pipes needed in the same time third of the pond surface area.

NOMENCLATURE

A_{pi} : Pipes total heat transfer area (m^2).
A_{sp} : Solar pond surface area (m^2).
ID : Heat Exchange (HE) pipe inside diameter (m).
L_{pi} : HE pipes total length (m).
MTD: Mean Temperature Difference (^{o}C).
OD: HE pipes outside diameter (m).
PD: HE pipes density (m/m^2).
dp: Pressure drop in pipes (bar).
Q_{HR}: Heat Required (kW).
Q_{fr-in}: Liquid flow rate input (m^3/h).
Q_{fr-out}: Liquid flow rate output (m^3/h).
T_{sp}: Solar pond temperature (^{o}C).
T_i: Input liquid temperature (^{o}C).
T_o: Output liquid temperature (^{o}C).
U: Over all heat transfer coefficient ($W/m^2.^oC$).

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Table (1): Shows the direct relation between the required solar pond area and output liquid temperature for various input liquid temperature.

T_i (°C)	T_{out}(°C)			
	60	70	80	90
	A_{sp} (m^2)	A_{sp} (m^2)	A_{sp} (m^2)	A_{sp} (m^2)
15	587	811	1127	1667
20	540	764	1080	1620
25	490	714	1030	1569
30	436	660	976	1516
35	378	602	918	1458
40	316	540	856	1396

Table (2): Shows the predicted pipes line required to reach certain output water temperature at known input water temperature, when the other parameters are fixed.

T_i (°C)	T_{out} (°C)			
	60	70	80	90
	L_{pi} (m)	L_{pi} (m)	L_{pi} (m)	L_{pi} (m)
15	5872	8113	11272	16672
20	5400	7641	10800	16200
25	4897	7138	10297	15697
30	4360	6601	9760	15159
35	3782	6023	9182	14582
40	3159	5400	8559	13959

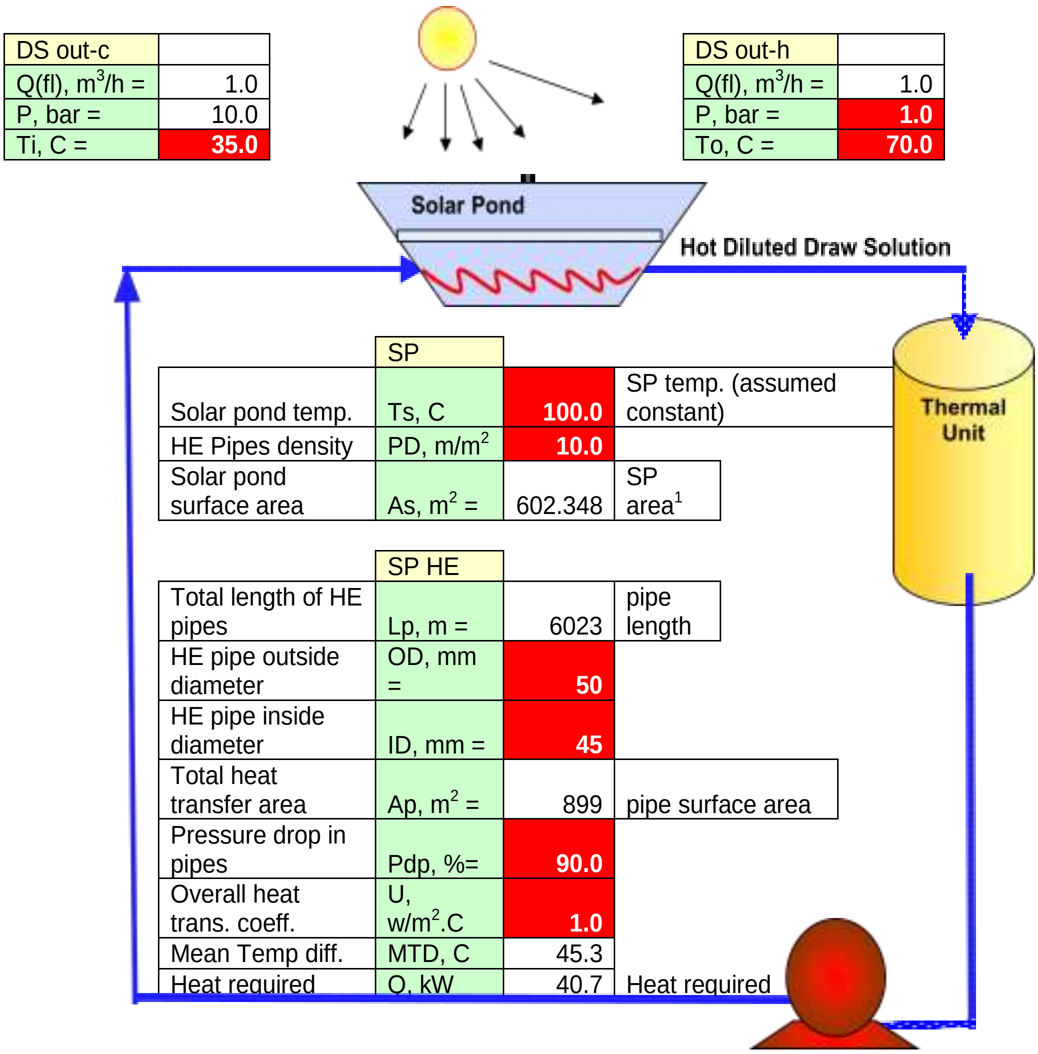

Figure (2): shows the program steps of results calculations.

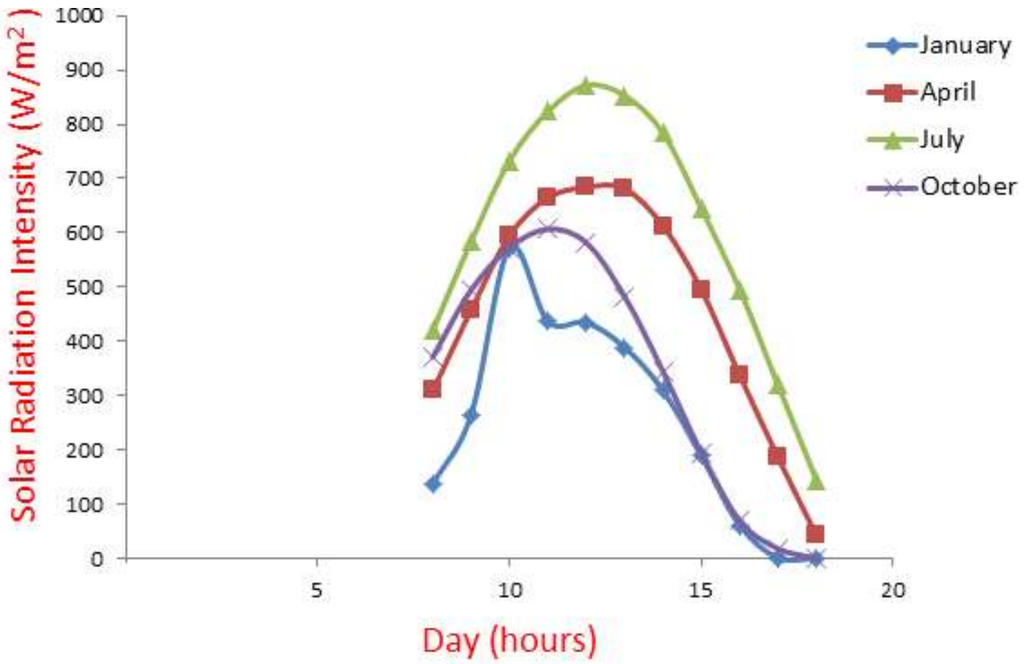

Figure (3): Shows the variation of monthly averaged solar radiation intensity with daily hours over the city of Karbala during the year 2010 [Weather station, Geographic Department, College of Education, Karbala University].

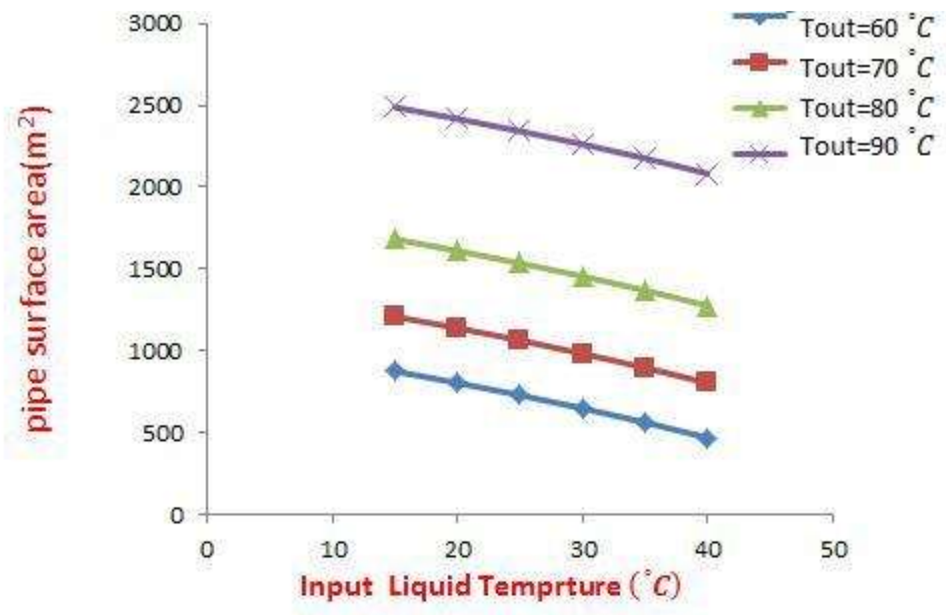

Figure (4): Shows the relation between input liquid temperatures with pipe surface area at various output liquid temperatures.

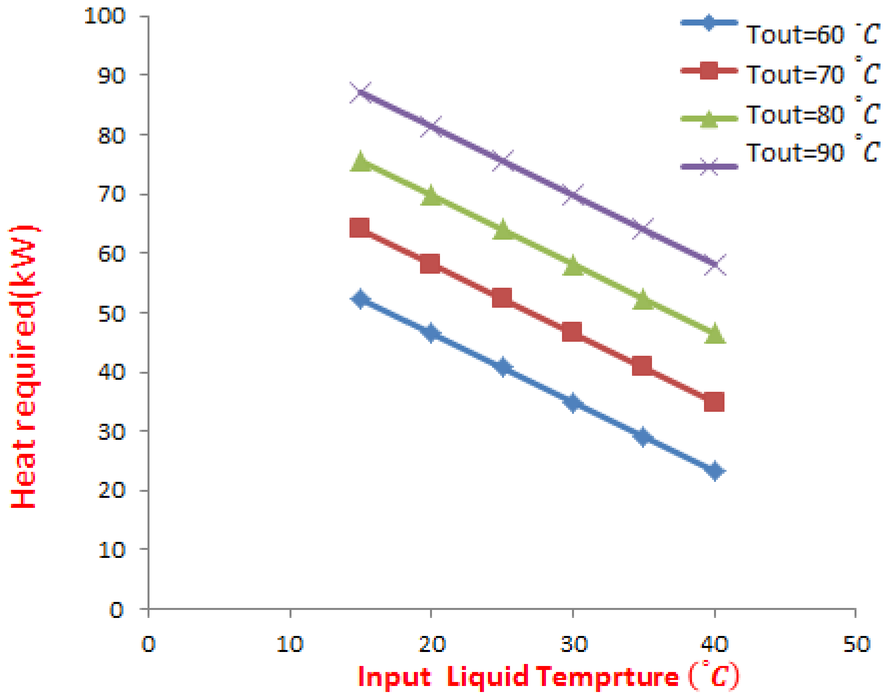

Figure (5): Shows the relation between the heat required and the input and output liquid temperatures.