Design of Solar Pond for Electricity Production

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Abstract

A solar pond is an area of land to be covered with water and receives thermal energy by insolation. The depth of water is ranging from (1-1.5) m. The area of the pond is 1.49 or 1.2 km on a side. Convection heat transfer is prevented by salting the water by the addition of NaCl or MgCl2 or NaHCO3 in the lower 40-50cm depth of the pond. Thus a density gradient of water is established. This would produce a temperature gradient and heat accumulation in the lower depth of pond. The temperature may reach up to 90C^o.Abinary/isobutanol power cycle incorporated with a goal of producing 10MWe electrical power. The increase of thermal power produced from solar pond will increase electricity production, the largest values of flow rate occur for the use of MgCl2 salt and the lower value for NaCl.

Introduction

The sun is radiating energy are a rate of $3.85X10^{23}$ kw with the earth intercepting about $1.72x10^{14}$ kw of it. The generally accepted value of the solar heat flux striking the outer atmosphere is about 1.38 kw per m^2.

As the solar radiation penetrates the atmosphere, some of it is absorbed by the atmosphere, so that at sea level with the sun directly overhead, the heat flux reaches the earth's surface is only about 990 W per m^2[Lunde,1980].

Considering these figures, we calculated the power received from the sun in Iraq as $4.507x10^6$ MW, which is far more than the total power consumption of the country. The construction of the devices for the collection and storage of solar energy in form suitable for use has been difficult and costly. The solar pond may offer a more economically effective means for the collection and storage of solar energy for eventual use of electricity production.

The solar pond (Fig.1) has three layers of water. Salt is dissolved in high concentrations in the lower depths or "Lower Convecting Zone LCZ or storage zone". The thickness of this layer is around 1.2 m [Jones,1985]. At the top of the pond, the "Upper Convecting Zone UCZ" is a layer free from salt whose thickness is 10cm.

Between these two layers is the "None Convecting Zone NCZ", in which salt concentration increases with depth. The thickness of this layer is 1.2 m. Because of the increasing salt concentration and therefore weight of the solution in this layer with depth, the normal tendency of the warmer water to rise to surface is prevented. The maximum salt concentration in the LCZ is (20-25)% by weight NaCl.

Solar pond has been analyzed by Tabor[Tabor,1981, Tabor.H,1980] ,Rabl and Nielsen[Rabl,1975] , Weinberger[Weinberger,1964] ,Akbararzadeh and Ahmadi[Akbarzadeh,1979] and Hawlarder and Brinkworth[Hawlarder,1981] among others.

Those investigators assumed one-dimensional models for both transient and steady state analyses to determine the mean temperature of the LCZ , the efficiency of the pond and the thermal storage capabilities of the ground. The starting point of these analyses was the energy equation applied to the LCZ of the pond where a balance was made between the net solar radiation absorbed by the fluid in the zone and the heat outflow to the above non-convecting zone. In several of these studies [Rabl,1975, Weinberger,1964, Akbarzadeh,1979], ground heat losses for large solar pond were consider to be negligible.

Thermal performance of solar ponds critically depends on a high transparency of the pond brine to solar radiation. Impairment of transparency may arise from dissolved colored substances, suspended particles or populations of algae and bacteria [Hull, 1990]. The solar pond concept for electric power generation is applicable whenever there is sufficient insulation and enough areas of land allow for contraction and operation of solar pond. These two factors are available in Iraq. Location of large pond system will be governed by local environmental conditions. Shadowing by hills, walls and trees should be avoided to ensure direct insulation.

Electric power plants that could found worldwide and operate on the solar pond concepts are the following:

- 5 MW plant in the Dead Sea area of Palestine with 250000 m^2 solar pond area [Sargent, 1983].
- 70 MW plant in the University of Texas at El Paso [WWW.solarpond].
- 2kW plant in Alice Springs of Australia [Jabri, 1996].
- 20kW plant in Bhavnagar of India [Jabri, 1996].

Main Design Parameters

The following parameters were assumed in the calculations:

- The power plant has an output of 10MWe.
- A binary fluid (isobutene) closed Rankine cycle is used. A direct-contact heat exchanger is envisaged.
- Negligible heat losses to the ground. This is in conformity with the investigators of [Rabl, 1975, Weinberger, 1964, Akbarzadeh, 1979]. The assumption may be substantiated if proper thermal insulation is provided for the base of the pond. However, proper thermal insulation should be incorporated.
- The salt concentration is 25% weight and the salt used is NaCl.
- All surfaces of the pond are lined to prevent leakage and ensure good heat absorption.
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Pond Size Calculation

An average annual insulation in Iraq was taken from Sayigh[Sayigh,1977] as follows:

The winter months were considered to be only five months (November, December, January, February and March). The average insulation is 325 cal/cm^2.day.

The summer months were therefore become seven with an average insulation of 550 cal/cm^2.day.

The average annual insulation is:

(5x325+7x550)/12=456 cal/cm^2.day

=19.09 MJ/m^2.day

This figure is checked againsed the data of Al-Jubouri and Ziyada[Al-Jubouri,1997] which was given as 19.054 MJ/^{2}.day.

Hence 19.09 MJ/m^2. dayx365days/year=6957 MJ/m^2.year.

Son and Letan[Wright,1982] estimated the ideal overall thermal efficiency of the solar-operated power plant. Due to the unforeseen circumstance that may face the constructors. we can estimate the thermal efficiency to be 2.5% therefore we need 10/0.025=400 MW thermal power from the pond.

400MWx365day/yearx24hours/day=3.5x10^9 kW-hr/year

1kW-hr=3.6MJ

3.5x10^9x3.6=12.6x10^9MJ/year

Therefore (12.6x10^9MJ/year)/(6957MJ/m^2year)=1811151m^2 is the area of the pond required

i.e. =1346m=1.346km on every side if the pond area is square

The above calculations were repeated for MgCl2 and NaHCO3 salts.

Heat Extraction

The power plant was chosen as 10MWe and a temperature difference of 10C^o comes from (90C^o outlet from the pond and 80C^o inlet). The density of the brine=1.2 g/cm^3 and its specific heat is 0.86 cal/gC^o.

1watt=14.3 cal/min.

Then we can say that the power=10MWex14.3=143x10^6 cal/min.

143x10^6 cal/min.=flow ratex1.2 g/cm^3x0.86 cal/gC^{o}x10C^o

Hence flow rate=143x10^6/1.2x0.86x10=13.8x10^6 cm^3/min.

This flow rate should be quite laminar so that the LCZ would not get distributed. With a pond width of 1346 m and a flow rate of 13.8x10^6 cm^3/min. , the velocity of a 20 cm thick layer would be:

Velocity=volumetric flow rate/cross section

=13.8x10^6 cm^3/min. / 1346x10^2 cmx20 cm

=5.126 cm/min.

This velocity is quite low which ensures layered flow without disturbances.

Power Plant

Consideration was given to a system of binary fluid cycle using a volatile hydrocarbon (e.g. pentane)[Wright,1982]. We in Iraq have a good of experience in this branch of technology.

The author has dealt with thermal systems using this type of fuel [Kendoush,2000, Rasheed ,1999]. Figure (2) shows the binary fluid cycle power plant. The most interesting part is direct-contact heat exchanger. This is in fact a tubeless heat exchanger where drops of pentane, whose boiling point at atmospheric conditions are 35.9C^o . The pentane vapor will be directed to the turbine which runs the electric generator. Note that the turbine should be of the axial-flow type [Wright,1982].

Direct Contact Condenser

This is also a tubeless condenser where the pentane vapor is allowed to get condensed by allowing the vapor to pass through nozzles into direct contact condenser in a counter flow arrangement. The condenser can be collected and returned through a pump to the direct contact heat exchanger. It should be mentioned have that it would be rather difficult to separate the pentane condensate from the cooling water. Loss of pentane would be inevitable in the direct contact condenser. The expected loss of pentane should be accounted for by daily compensation. This compensation reached around 7 tons/day for a 5 MWe power plant [Wright,1982].

Cooling Tower

The cooling tower used is envisaged to be an induced-draft evaporative cooling tower. Inputs the cooling tower equations include cooling water flow rate and temperature at the inlet, humidity ratio; output values include the cooling tower air flow rate, evaporation rate and overall heat load.

Results and Discussion

Results were obtained for using different salts (NaCl, MgCl2 and NaHCO3) in the lower layer of solar pond for electricity production.

Fig. (3) represents the relationship between solar pond thermal powers with electricity production. One can observe that the increasing in thermal power produced by solar pond will increase the electricity production.

Fig,(4) represents the relationship between flow rate of the circulated fluid with electricity production for using different salts. We can saw that the increase in flow rate will increase in electricity production and the largest values of flow rates occur for MgCl2 salt and the lower value of the flow rates happened for NaCl salt.

Conclusions

The following conclusions were reported from the present work:

1. The increase of thermal power produced from solar pond will increase electricity production.
2. The largest values of flow rate occur for the use of MgCl2 salt and the lower value for NaCl.
3. The increase in the flow rate will increase the electricity production.

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Table (1) Solar Pond with Sodium Chloride Salt (NaCl)

Solar Pond Area(m^2)	Flow Rate(cm^3/min.)	Thermal Power(MWt)	Electricity Production(MWe)
1811151	$13.6x10^6$	400	10
1630	$12.5x10^6$	360	9
1449	$11x10^6$	320	8
1265	$9.7x10^6$	280	7
906	$6.9x10^6$	200	5

Table (2) Solar Pond with Magnesium Chloride Salt (MgCl2)

Solar Pond Area(m^2)	Flow Rate(cm^3/min.)	Thermal Power(MWt)	Electricity Production(MWe)
1811151	$41.3x10^6$	400	10
1630	$37.2x10^6$	360	9
1449	$33.1x10^6$	320	8
1265	$28.9x10^6$	280	7
906	$20.6x10^6$	200	5

Table (3) Solar Pond with Sodium bicarbonate Salt (NaHCO3)

Solar Pond Area(m^2)	Flow Rate(cm^3/min.)	Thermal Power(MWt)	Electricity Production(MWe)
1811151	$21.6x10^6$	400	10
1630	$19.4x10^6$	360	9
1449	$17.2x10^6$	320	8
1265	$15.11x10^6$	280	7
906	$10.79x10^6$	200	5

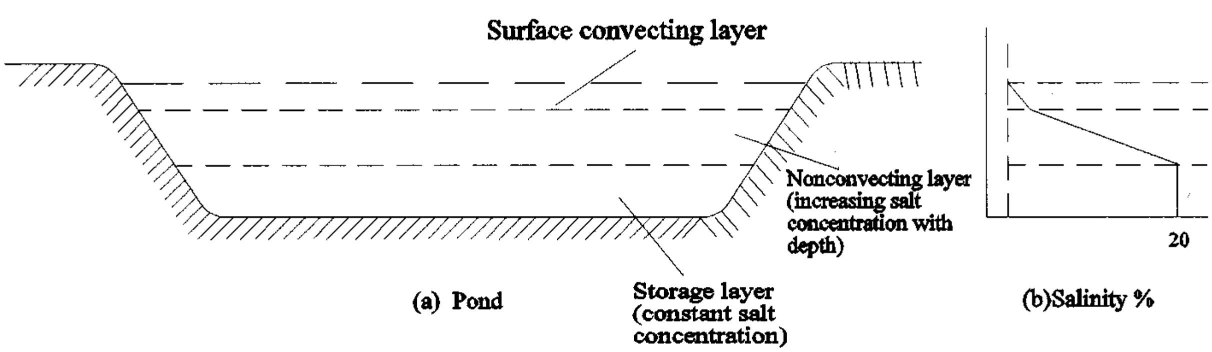

Fig.(1) Solar Pond a- pond layers ,b-salinity

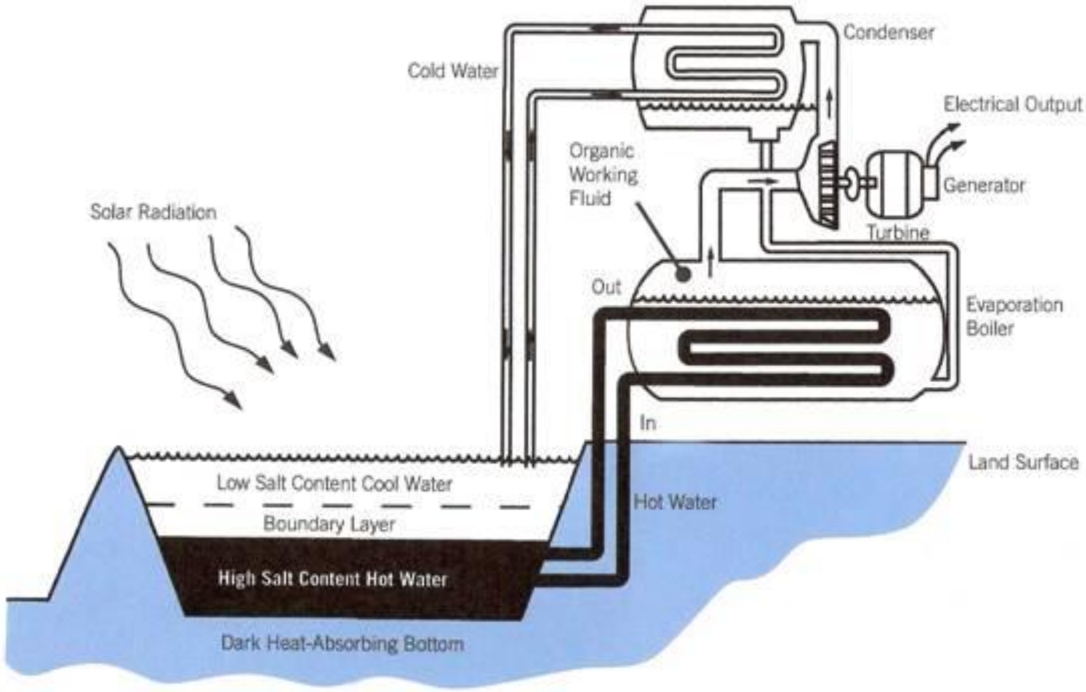

Figure (2) Solar Pond of Binary Fluid Cycle Power Plant

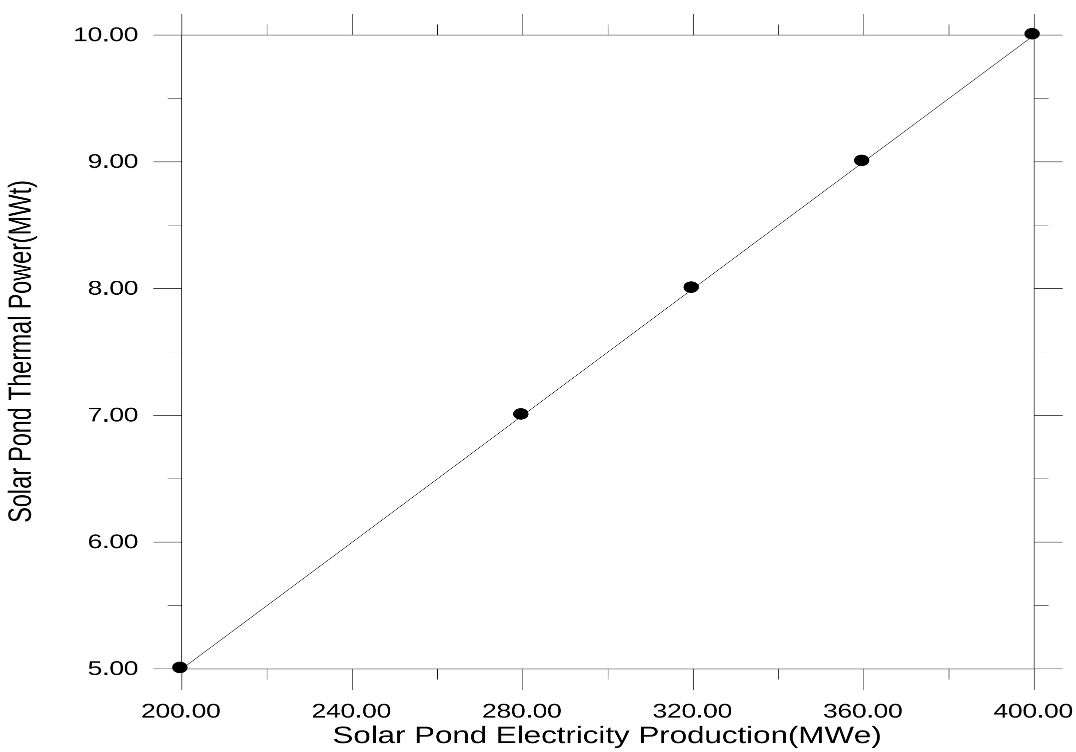

Fig.(3) Electricity Production from Thermal Power produced by Solar Pond.

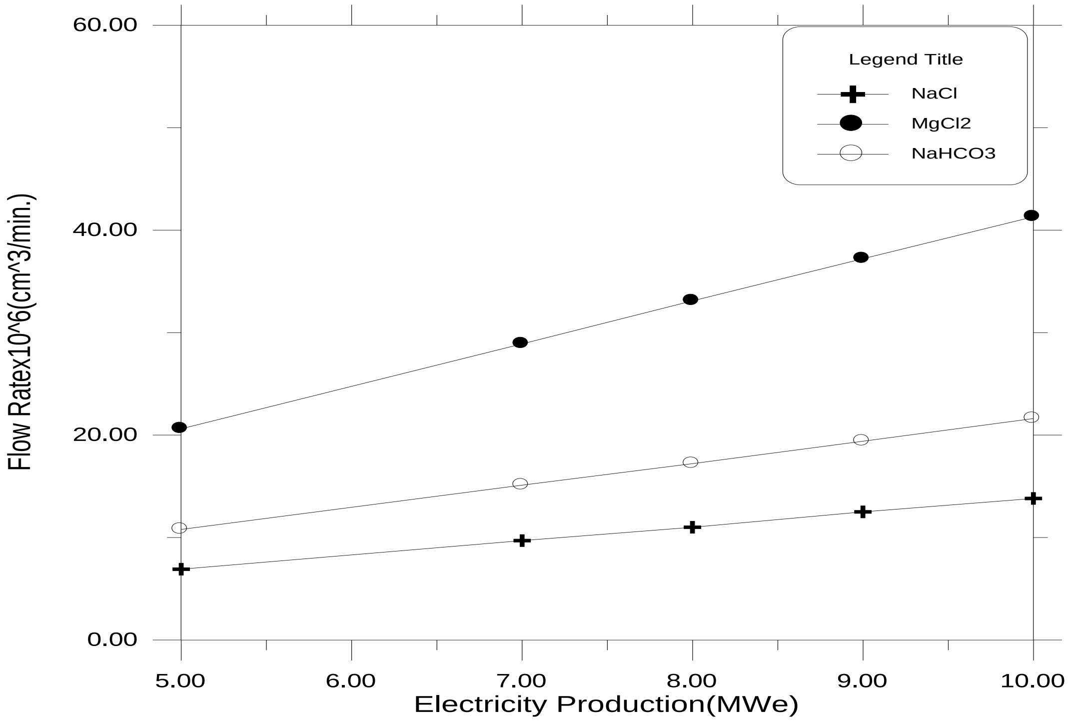

Fig.(4) Variation of Solar Pond Flow Rate with Electricity Production for using NaCl,MgCl2 and NaHCO3 Salts.