Economic Study of Solar Pond Powerplants in Thailand

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ABSTRACT

This article presents an economic study of solar pond powerplants, in the range of 1 to 4 MWe, in Thailand. Production costs of plants of different capacities and related factors are discussed. The lowest production cost of Baht 3.36/kWh (1US$ = Baht 26.5) is obtained assuming 5% interest rate, 25% of capacity factor, and pond cost of US$10/m^2. This is higher than the average production cost of other powerplants in Thailand (Baht 1.3/kWh).

As Thailand is situated close to the equator where there is plenty of solar energy, one of the alternative resources to be developed for electricity generation, solar pond power plants have been investigated for application in remote areas where the electrical network is prohibitive.

This study shows that the price of electricity from this source is competitive to that from diesel plants (≈ Baht 5/kWh).

INTRODUCTION

The solar pond powerplant is one of the possible systems for generating electricity in the future. The pond functions both as a solar energy collector and as a storage sub-system. The cost of the complete pond system (including a solar pond, a heat exchanger, a pump and piping) ranges from US$14 to US$27 per square meter of surface area[1,2], depending on applications and on the condition of sites (Table 1).

Technical experiments using organic Rankine cycle turbo-generators in conjunction with solar ponds for generating electricity (binary cycle) have been done in several countries, such as: a 5 MW plant at the Dead Sea in Israel[2]; a 5 MW plant at the Salton Sea in Southern California, USA; and a 20 kW at the Alice Spring in Australia[3].

Electricity generating costs depend on the capacities of the plants[1,2] i.e.,

US$0.1-0.15/kWh for 5 MWe; and
US$0.04-0.09 /kWh for 20 MWe.

A well proven solar pond powerplant technology exists today, system standardization and mass manufacturing of electric generators will further improve reliability and reduce investment as well as electricity generating costs.

Table 1
Cost estimation of solar pond[1]

Items	A US$/m^2	B US$/m^2
Earth moving	5	5
Salt	5	5
Wave suppressors	2	2
Heat exchanger and piping	2	2
Liner	—	8
Insulator	—	5
Total	14	27

A – Soil condition does not need lining and insulation.
B – Soil condition needs lining and insulation.

ORGANIC TURBO-GENERATOR SYSTEM (BINARY CYCLE)

The organic turbo-generator system is based on the Rankine cycle and uses organic fluid as working fluid. It is advantageous in that at moderate and low temperatures it will have higher efficiencies than those of the steam cycle and will require no superheating.

The cost of such a system is about US$1,000-1,500/kW for system capacity of 1,000 kWe or more[2]. At present, the standard modules of 300 to 1,200 kWe are commercially available.

SOLAR PONDS – RESEARCH AND DEVELOPMENT

Solar ponds have been studied in Chile[4], in the U.S.S.R.[5], and in India[6]. Hirschmann has investigated the possibility of making solar ponds on natural salt flats to collect solar energy for electric power generation, industrial heat applications, and desalination. The work in U.S.S.R. mainly consists of theoretical studies and small laboratory experiments, with emphasis on attainable temperature and collection efficiency in very shallow ponds of less than 1 m depth. Jain[10] onsidered the main achievement of his work to be the measurement of heat extracted from the bottom layer of an experimental pond.

Solar pond research in the U.S.A. began at Ohio State University as the outgrowth of a search for a long term heat storage system, following a theoretical study of solar ponds for space heating[8].

The most impressive achievement of solar pond operation to date is probably the temperatue reached in a 2,000 m^2 experimental pond in Israel in 1976[2]. This pond, of approximately 0.8 m total depth, began heating in March and reached a temperature of 103°C in May. A decision was then made not to let it boil, and heat removal was begun, reducing the temperature to around 95°C during subsequent months. Heat-removal studies were a major objective of this experiment.

Akbarzadeh and Ahmadi[7] found that the mean heat flowing into the ground due to the

mean temperature difference between the bottom of the solar pond and the ground is about 10% of the average solar radiation after 10 days and becomes less than 5% after 30 days. Therefore, it is important not to insulate the bottoms of solar ponds in order to take advantage of the ground heat storage beneath the pond to reduce total cost.

ECONOMIC STUDY

Electricity Generating Cost

The average unit cost of electricity generation from different types of powerplants in Thailand is about US$0.05/kWh[9].

Assumptions

The following assumptions were made for the present study:

- Pond size 10, 20, 30, 40 ha
- Pond cost 10, 20, 25 US$/m^2
- Plant capacity 1, 2, 3, 4 MWe
- Plant cost US$1,500/kW for 1 MWe size; and scaling factor of 0.8 for other sizes,

$$I_A = I_B\ (A/B)^{0.8}$$

where:

I_A = plant cost of a capacity of A kW

I_B = plant cost of a capacity of B kW

- Plant life 20 Years
- Capacity factor* 15, 20, 25 %
- Operation and maintenance cost** for 1 MWe size US$100,000/yr, and scaling factor of 0.7 for other sizes,

$$M_A = M_B\ (A/B)^{0.7}$$

- Interest rate 5, 10 %
- Unit cost,

$$U = \frac{1}{P \times CF \times 8760}\ \left[\frac{\text{I.a.}\ (1+a)^n}{(1+a)^n - 1} + M\right]$$

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*Capacity factor = $\dfrac{\text{Average load}}{\text{plant capacity}}$

**Including the salinity cost

where:

U = Unit cost, US$/kWh
P = Plant capacity, kW
CF = Capacity factor
I = Investment cost, US$
a = Interest rate
n = Plant life, Year
M = Operation and maintenance cost, US$/yr.

Results

The results of the economic study are shown in Tables 2 – 5 and Figs. 1 – 4 which can be concluded as follows:

- Electricity generating cost of 1 MW plant (pond size of 10 ha) is about Baht 3.36-11.46/kWh.
- The lowest cost of Baht 3.36/kWh is obtained from the assumption of 5% of interest rate, 25% of capacity factor and pond cost of US$10/m^2.

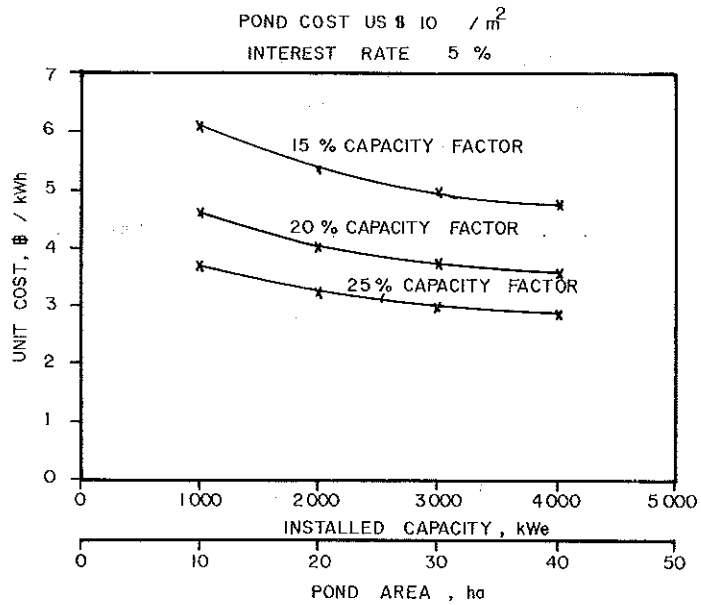

Fig. 1 Unit cost of solar pond powerplant.

Table 2
Economic study of solar pond powerplant 1000 kWe, pond size 10 ha.

Item	Pond cost – US$10/m²						Pond cost – US$20/m²					
Investment cost, US$												
Solar pond cost	1000000	1000000	1000000	1000000	1000000	1000000	2000000	2000000	2000000	2000000	2000000	2000000
Binary cycle cost	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000
Plant life, yr	20	20	20	20	20	20	20	20	20	20	20	20
Interest rate, %	5	5	5	10	10	10	5	5	5	10	10	10
Investment cost, US$/yr	200606	200606	200606	293649	293649	293649	280849	280849	280849	411109	411109	411109
O & M cost, US$/yr	100000	100000	100000	100000	100000	100000	100000	100000	100000	100000	100000	100000
Capacity factor, %	15	20	25	15	20	25	15	20	25	15	20	25
Elec. gen., kWh/yr.	1314000	1752000	2190000	1314000	1752000	2190000	1314000	1752000	2190000	1314000	1752000	2190000
Unit cost												
US$/kWh	0.23	0.17	0.14	0.30	0.22	0.18	0.29	0.22	0.17	0.39	0.29	0.23
Baht/kWh	6.05	4.53	3.63	7.92	5.94	4.75	7.66	5.75	4.60	10.28	7.71	6.17

Table 3
Economic study of solar pond powerplant 2000 kWe, pond size 20 ha.

Item	Pond cost – US$10/m²						Pond cost – US$20/m²					
Investment cost, US$												
Solar pond cost	2000000	2000000	2000000	2000000	2000000	2000000	4000000	4000000	4000000	4000000	4000000	4000000
Binary cycle cost	2611652	2611652	2611652	2611652	2611652	2611652	2611652	2611652	2611652	2611652	2611652	2611652
Plant life, yr	20	20	20	20	20	20	20	20	20	20	20	20
Interest rate, %	5	5	5	10	10	10	5	5	5	10	10	10
Investment cost, US$/yr	370051	370051	370051	541683	541683	541683	530536	530536	530536	776602	776602	776602
O & M cost, US$/yr	162000	162000	162000	162000	162000	162000	162000	162000	162000	162000	162000	162000
Capacity factor, %	15	20	25	15	20	25	15	20	25	15	20	25
Elec. gen., kWh/yr	2628000	3504000	4380000	2628000	3504000	4380000	2628000	3504000	4380000	2628000	3504000	4380000
Unit cost												
US$/kWh	0.20	0.15	0.12	0.27	0.20	0.16	0.26	0.20	0.16	0.36	0.27	0.21
Baht/kWh	5.35	4.01	3.21	7.08	5.31	4.25	6.96	5.22	4.18	9.44	7.08	5.66

Table 4
Economic study of solar pond powerplant 3000 kWe, pond size 30 ha.

Item	Pond cost – US$10/m²						Pond cost – US$20/m²					
Investment cost, US$												
Solar pond cost	3000000	3000000	3000000	3000000	3000000	3000000	6000000	6000000	6000000	6000000	6000000	6000000
Binary cycle cost	3612337	3612337	3612337	3612337	3612337	3612337	3612337	3612337	3612337	3612337	3612337	3612337
Plant life, yr	20	20	20	20	20	20	20	20	20	20	20	20
Interest rate, %	5	5	5	10	10	10	5	5	5	10	10	10
Investment cost, US$/yr.	530591	530591	530591	776683	776683	776683	771319	771319	771319	1129062	1129062	1129062
O & M cost, US$/yr.	215000	215000	215000	215000	215000	215000	215000	215000	215000	215000	215000	215000
Capacity factor, %	15	20	25	15	20	25	15	20	25	15	20	25
Elec. gen., kWh/yr.	3942000	5256000	6570000	3942000	5256000	6570000	3942000	5256000	6570000	3942000	5256000	6570000
Unit cost												
US$/kWh	0.19	0.14	0.11	0.25	0.19	0.15	0.25	0.19	0.15	0.34	0.26	0.20
Baht/kWh	5.00	3.75	3.00	6.65	4.99	3.99	6.61	4.96	3.97	9.01	6.76	5.41

Table 5
Economic study of solar pond powerplant 4000 kWe, pond size 40 ha.

Item	Pond cost – US$10/m²						Pond cost – US$20/m²					
Investment cost, US$												
Solar pond cost	4000000	4000000	4000000	4000000	4000000	4000000	8000000	8000000	8000000	8000000	8000000	8000000
Binary cycle cost	4547150	4547150	4547150	4547150	4547150	4547150	4547150	4547150	4547150	4547150	4547150	4547150
Plant life, yr	20	20	20	20	20	20	20	20	20	20	20	20
Interest rate, %	5	5	5	10	10	10	5	5	5	10	10	10
Investment cost, US$/yr.	685845	685845	685845	1003945	1003945	1003945	1006816	1006816	1006816	1473783	1473783	1473783
O & M cost, US$/yr.	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000
Capacity factor, %	15	20	25	15	20	25	15	20	25	15	20	25
Elec. gen, kWh/yr.	5256000	7008000	8760000	5256000	7008000	8760000	5256000	7008000	8760000	5256000	7008000	8760000
Unit cost												
US$/kWh	0.18	0.14	0.11	0.24	0.18	0.14	0.24	0.18	0.15	0.33	0.25	0.20
Baht/kWh	4.78	3.58	2.87	6.38	4.78	3.83	6.39	4.79	3.83	8.74	6.55	5.24

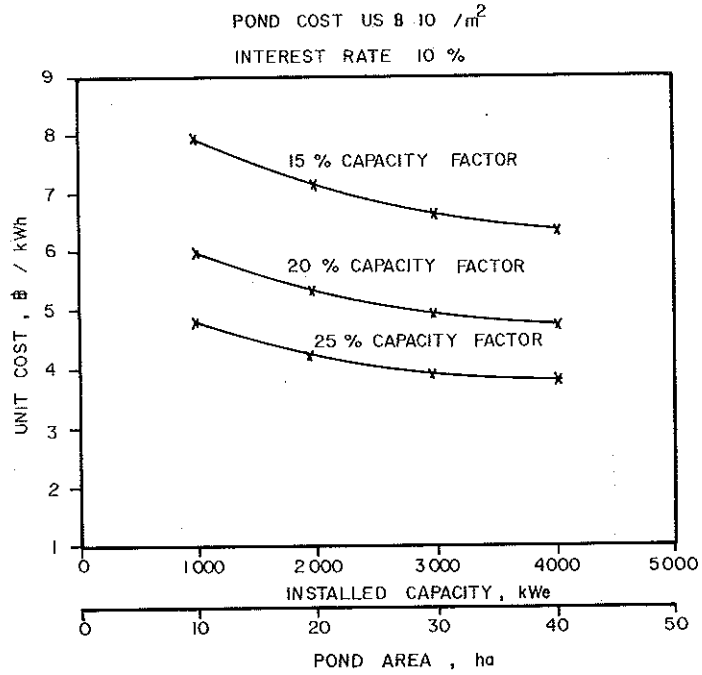

Fig. 2 Unit cost of solar pond powerplant.

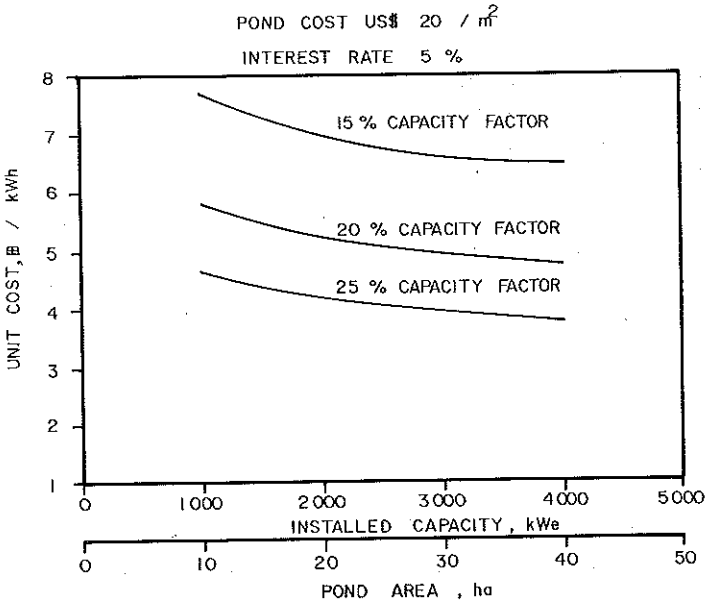

Fig. 3 Unit cost of solar pond powerplant.

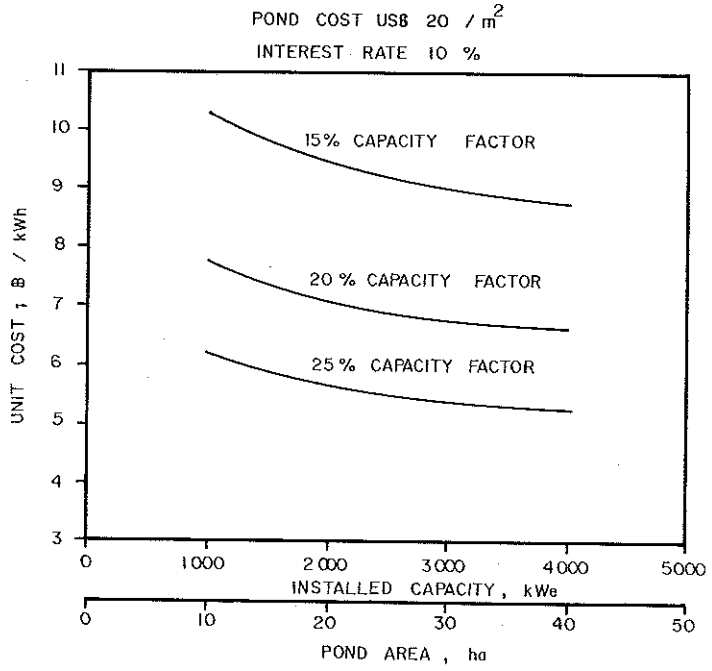

Fig. 4 Unit cost of solar pond powerplant.

CONCLUSION

The electricity generating cost from solar pond powerplants varies with investment costs of pond, binary cycle, capacity factor, operation and maintenance cost and interest rate. For a pond of 10 ha which corresponds to 1,000 kWe plant, electricity generating cost is Baht 3.63-11.45/kWh and pond cost is US$10/m^2.

This is higher than the average generating cost of other powerplants in Thailand (Baht 1.3/kWh)[9]. The generating cost is reduced by about 40% when capacity factor is increased from 15% to 25%. The interest rate is also an important factor. For the 1,000 kWe plant, the generating cost is increased by about 20% when the interest rate is increased from 5% to 10%.

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