

Solar Pond-based Rural Development Programme for Selected Coastal Regions — A Concept

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ABSTRACT

The concept of Ocean Coupled Solar Pond Power Station (OCSPPS) has been expanded. Supply of fresh water, extraction of salts and marine chemicals and improvement of coastal aquaculture are included as part of the project. This multi-purpose scheme is expected to aid speedy development of selected coastal areas. The programme involves design and construction of a solar pond in which brine in the lower layer is heated to 85°C by solar radiation and is used as the heat source for a closed cycle thermal energy conversion plant. The sink of the power plant is sub-surface seawater of temperature 15°C. The temperature difference of 70°C is utilized by the plant to produce electric power. Hot and cold waters from the plant are reused by a two-stage flash desalination unit to generate fresh water. The coolant water, being rich in salts and nutrients, is further utilized for culture of marine organisms and for production of salt and chemicals. The details of the multi-purpose scheme are presented. An attempt has been made to examine the relevant technologies available for the construction of such plants. The mechanisms of generation of power, fresh water, extraction of salts and marine chemicals and exploitation of the cold water for aquaculture are explained. A plan for implementation of the project is presented. The implementation of the scheme is expected to generate employment opportunities in the region and hence accelerate its overall development.

INTRODUCTION

Realisation of the link between the rate of energy consumption and development, finite nature of the conventional sources of energy and concern over the environmental damage caused by the large scale utilization of fossil fuels have contributed to an intensive search for new and alternative sources of energy. The search has been extended to oceans and a number of sources of energy — wind energy, wave energy, tidal power, ocean thermal energy and salinity power — have been identified [3,13]. Development of ocean energy has been one of the topics of many

ocean-related engineering conferences (such as Coastal Engineering, Offshore Engineering, Marine Technology and Ocean).

Sun is the basic source of most of the non-conventional sources of energy, such as wind and wave energy. Utilisation of these resources is economically feasible in selected regions where these sources are found to be concentrated. Direct use of solar energy, though it is time dependent and of low energy density, has also been attempted. Solar energy is required to be concentrated and sometimes stored before it can be put to convenient practical use on a large scale. A number of methods have been devised to overcome the drawbacks of solar energy. Some of these concepts which involve the sea are the OTEC, the solar pond and the OCSPPS. Ocean thermal energy conversion (OTEC) received special attention during the seventies [2,9]. OTEC has been the subject of a series of conferences. The non convecting salt gradient solar pond [11,12] and the ocean-coupled solar pond power station (OCSPPS) [5] are other two related concepts. The mechanisms of operation of these systems and their merits and demerits have been examined. The concept of an integrated development programme for selected coastal regions, with the help of an OCSPPS and its byproducts, is presented.

METHOD OF OPERATION

Solar pond power station (SPPS)

A salt gradient solar pond is a pool lined with a special black material at the bottom and containing layers of water of varying density, increasing from surface to bottom. The density layering of the pond is achieved by floating layers of salt solutions of less and less concentration from bottom to surface of the pond. The surface layer of the pond is almost fresh water, while the bottom layer has a very high concentration of salt. In a stabilised solar pond, a non-convective layer is maintained in between these two convective layers. When the pond is exposed to solar radiation, the bottom layer of the pond becomes progressively warmer. The rise in temperature in the bottom convective layer can be as high as 100°C, while the surface layer has a low temperature, about 30°C. The temperature difference between the surface and the bottom layers of the pond is utilised in SPPS for producing electric power, generally through a closed cycle thermal energy conversion plant.

In a closed cycle of thermal energy conversion, a warm fluid, like water, is pumped through an evaporator, in which an organic fluid like Freon that boils and condenses between the temperatures of the source and the sink, is evaporated. Coolant fluid, generally water, is pumped through the condenser where the vapour of the working fluid is condensed, thereby creating a pressure difference between the evaporator and the condenser. The pressure difference is used to run a turbine and the connected generator. A sketch of the closed cycle power plant used in an SPPS is shown in Fig. 1. This type of power plant is specially suited for power generation from a fairly low temperature difference between the source and the

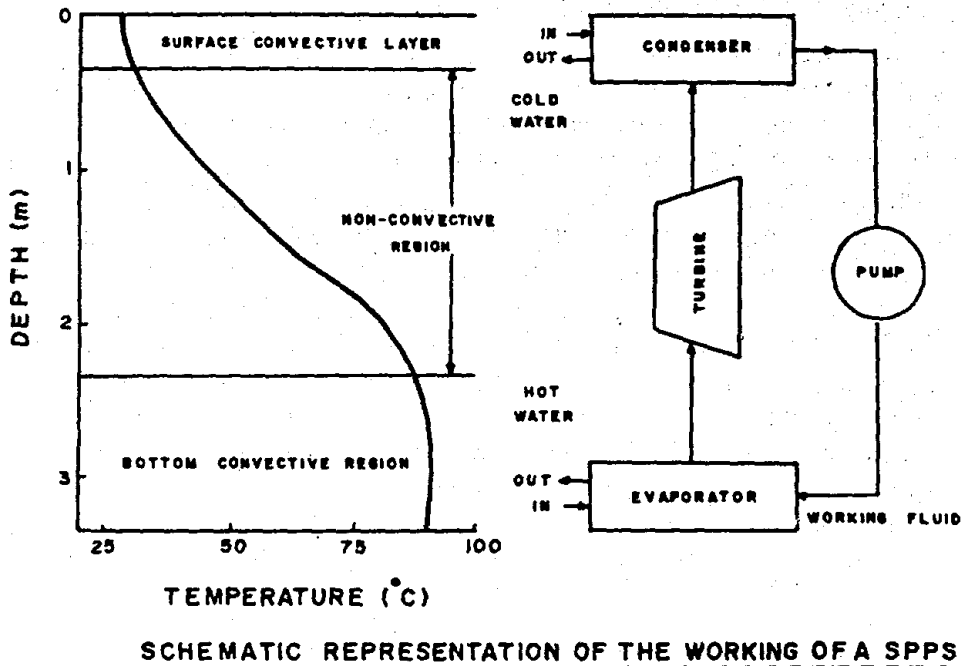


Fig. 1 — Schematic representations of temperature distribution inside a solar pond (left side) and use of the hot and cold waters by the closed cycle thermal energy conversion plant (right side) for power generation

sink. The technology of design and construction of this type of plant is well developed.

The power produced by SPSS is directly proportional to the surface area of the solar pond and the intensity of the incident solar radiation. The net (Rankine cycle) efficiency of energy conversion is about 8.8%. The concept originated in Israel, where a 5 kWe SPSS in 1977 and a 150 kWe station in 1979 [1] were tested. The cost of construction of the solar pond was estimated to be Rs 200/m² and that of the power plant, Rs 20 000/kWe.

Work on solar pond in India was carried out at the Central Salt and Marine Chemicals Laboratory, Bhavnagar, some of the IITs, IISc, Bangalore and the Tata Energy Research Institute, Pondicherry. NIO, Goa conducted field experiments on a 5 m² solar pond. This showed a rise in temperature of the near bottom layer from 35° to 72°C within a period of 15 days (Fig. 2). A national programme on the development of solar pond in India envisaged in 1983 for the testing of a 150 kWe SPSS by 1988 [4].

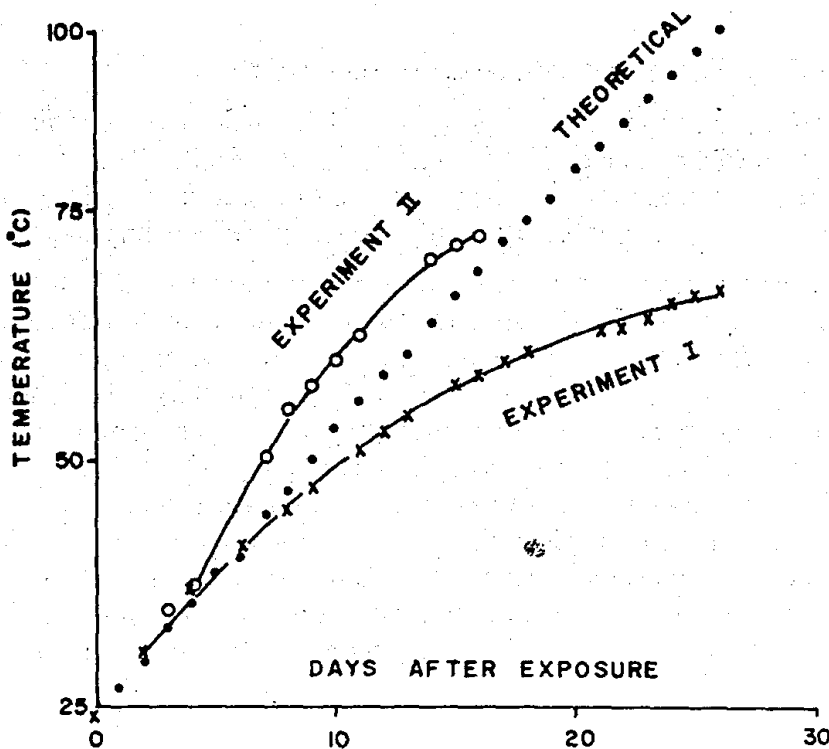


Fig.2 — Rise in temperature in the bottom layer of a small experimental solar pond at Goa [One of the experiments showed a temperature rise up to 72°C during the course of 15 days. The dots represent the rise in temperature possible as per theory]

Ocean thermal energy conversion (OTEC)

A temperature difference of about 20°C generally exists between the surface layer of the tropical oceans and the ocean layer at a depth of 1000 m. This temperature difference can be utilised to produce useful power by thermal energy conversion. Since both the source (warm water) and the sink (cold water) are of infinite size, power production can be very large and also steady. However, the net efficiency of thermal energy conversion is very low (about 1.8%). The concept was developed by French scientists. A number of small OTEC plants were tested. A plant of 10 kWe net (50 kWe gross) output was tested in USA [10], and in Japan a shore-based 100 kWe net output power plant was tested. The OTEC idea is still being pursued.

An inter-institutional groups has been working on OTEC problems in India since 1981, with the aim of establishing 1 MWe OTEC plant in one of the Laccadive Islands. The estimated cost of the OTEC plant was Rs 300 million. It was later decided to reduce the capacity of the plant to 100-200 kWe. The cost of the power to be produced was estimated to be about Rs 8/kWh, most probably because of the small capacity of the plant. The proposal was not pursued. A new proposal for establishing an OTEC plant off the Tamil Nadu coast is being considered now.

Ocean-coupled solar pond power station (OCSPPS)

A solar pond produces warm water in the bottom layer of the pond. The coolant water for SPPS can be obtained from the sea surface, if the plant is located near the sea. The surface seawater is cooler than the solar pond surface water and so efficiency of the thermal energy conversion in an SPPS is improved.

Seawater temperature in coastal areas off the east coast of India at a depth of 250 m is as low as 15°C [6,14]. If a large solar pond supplies warm water at about 85°C to a thermal energy conversion plant and the coolant water is drawn from 250 m depth in the sea, the temperature difference utilised is about 70°C. The theoretical efficiency of such a plant will be much high than that of OTEC and SPPS (Fig.3). The net power conversion (Rankine cycle) efficiency of such a plant will be as much as 11.7%. This concept has been developed by Gopinathan and Sastry [5]. The power generation can be carried out either by a closed cycle thermal energy conversion plant, as explained earlier, or by an open cycle plant which uses water itself as the working fluid. The open cycle plant can be designed to produce fresh water simultaneously with the electric power. In our scheme,

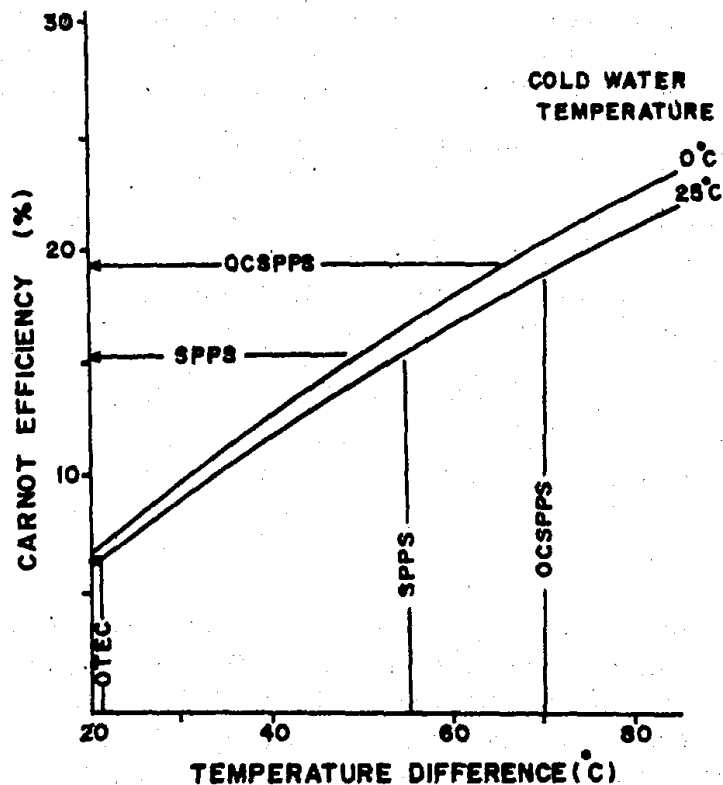


Fig.3 — Comparison of the Carnot efficiencies of OTEC, SPPS and OCSPPS, based on the thermal differences available for utilization

power production using the closed cycle is preferred, as this technology is fairly well developed. It is proposed that an experimental power station of about 1 MWe capacity may be set up in a selected coastal area. With electric power as its main product along with a number of byproducts, it can form the basis for an integrated rural development programme. A schematic diagram of an OCSPPS is shown in Fig.4 and the plan of implementation of the multi-purpose project is shown in Table 1. Ways and means of producing fresh water, marine living resources, salts and other marine chemicals are discussed below.

The OCSPPS-based multi-purpose scheme requires a pipe-line for bringing cold sea water from a depth of about 250 m. A plant of 1 MWe also requires about 30 ha of land for the construction of the solar pond. The ideal site for an OCSPPS in India may be found along the Tamil Nadu coast.

METHODS OF OBTAINING OTHER PRODUCTS

Fresh water

Fresh water is produced by the reuse of warm and cold waters from the power plant. A two-stage flash desalination plant can be used to produce fresh water. In

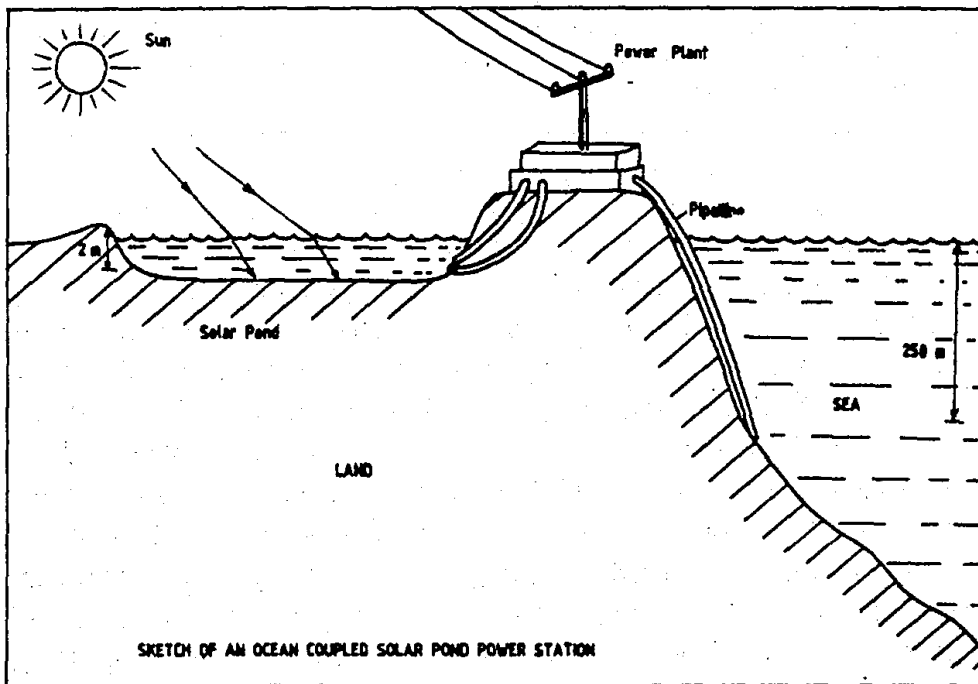


Fig.4 — Schematic representation of an OCSPPS [The heat source is the solar pond and heat sink is the sea]

Table 1 — Estimated Timeframe for Implementation of the Proposed Multi-purpose Project

S.no.	Activity	Year (s) after starting				
		1	2	3	4	5
1	Selection of site and work on experimental solar ponds	_____				
2	Environmental and bathymetric survey of the sea for cold water source	_____				
3	Construction, and stabilisation of the large solar pond	_____				
4	Design/procurement of energy conversion/MSF desalination systems and installation	_____				
5	Cold water pipe laying	_____				
6	Testing of power production and experiments to improve the efficiency of the plant	_____				
7	Intense R&D effort for aquaculture	_____				
8	Preparation of the aquaculture farms	_____				
9	Development of the salt pans and installation of machinery for extraction of marine chemicals	_____				

this plant, seawater is made to flash (boil at a temperature much below its normal boiling point) by reducing pressure above it. The proposed desalination unit is similar to a two-stage flash desalination plant fitted on modern ships. In such a unit, seawater is heated to 75°C by the waste heat (of the engine in the case of ships) and is passed to the first stage of the plant, where about 82% vacuum is maintained. The flashed water is condensed by seawater, which is pre-heated in the process and then sent for further heating and then to the first stage of the plant. The condensed water is collected. The water remaining after flashing is then passed on to the second stage, where 89% vacuum is maintained and it is again flashed. The vapour produced at this stage is condensed by the coolant water. The water remaining after flashing in the second stage is rejected. Repetition of the process produces fresh water continuously. A commercially available 40 m³/day plant requires about 100 m³/h hot water, an equal amount of coolant water and 15 kWe of power. The plant costs about Rs 200000/m³/day installed fresh water production capacity.

Aquaculture products

The typical characteristics of seawater from surface to 350 m depth, off the south east coast of India, are given in Table 2. The sub-surface water is cooler and has lower dissolved oxygen concentration, but it has a higher concentration of plant nutrients compared to surface water. It is generally known that primary production in upwelling areas is almost three fold higher than in other coastal areas [8]. Upwelling brings up nutrient-enriched subsurface water to the surface and makes it more productive. When artificially lifted sub-surface water is used to stimulate phytoplankton growth, the low dissolved oxygen may act as a limiting factor. But it may not affect the growth of large plants like seaweeds. However, the water may have to be oxygenated before it is used for general mariculture. Though an increase in the productivity of cultured organisms is very likely, more research is needed for quantitative assessment of the increased yield of the higher level organisms which are useful to man.

Salt and marine chemicals

Solar evaporation of seawater for the production of common salt is an age-old method. The coastal waters utilized for salt production are less saline than open ocean waters. During certain periods of the year, some of the tidal inlets along the east coast are choked with the formation of bars, thereby reducing the supply of brine to salt pans. The coolant water of the OCSPPS may be preferred for the production of salts and extraction of other marine chemicals because of its cleanliness and high salinity.

Table 2 — Depth-wise Distribution of Temperature, Salinity and Concentrations of Phosphates, Nitrates and Dissolved Oxygen in the Sea off Tamil Nadu Coast

Depth (m)	Temp. (°C)	Salinity (ppt)	PO ₄ -P (µg-at/l)	NO ₃ -N (µg-at/l)	Oxygen (ml/l)
			PO ₄	NO ₃ -N	
1	28.99	32.54	0.24	0.40	3.91
20	29.28	33.50	0.28	0.61	4.75
40	29.36	33.54	0.28	0.35	3.99
80	24.58	34.05	0.72	4.77	1.09
125	18.00	34.72	1.81	16.40	1.09
160	15.56	34.61	1.62	16.05	1.02
258	11.32	34.98	2.45	—	0.53
325	10.76	35.00	2.62	—	0.82

The detailed components of implementation of the entire plan are shown in Table 1. Important aspects of the work are:

- Selection of a suitable site for the OCSPPS and acquisition of about 1 km² land for the construction of a solar pond.
- Construction of an experimental solar pond to study the stability, efficiency and energy storage capacity under various environmental conditions.
- Selection of materials best suited for large scale construction of solar ponds.
- Oceanographic studies for understanding seawater characteristics and bathymetric survey for identifying the best pipeline route to lay the cold water pipe.
- Purchase of power and desalination plants, testing and installation.

CONCLUSION

OCSPPS has definite advantages over OTEC or SPPS, when the site of the plant is on the coast and the shelf width is narrow. The technical feasibility of constructing OCSPPS has been established. An OCSPPS can supply electric power and fresh water to a coastal area. The technologies of generation of power and fresh water are available. The byproducts of plants — salts, marine chemicals and also the products of aquaculture — will increase the employment opportunities in the vicinity of the plant, for both skilled and unskilled workers. The OCSPPS may be economically viable at sites where solar radiation is high and the continental shelf width is narrow.

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