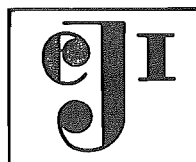


Project Planning for Small and
Medium Scale Industries No.23

Solar Pond Power

Generation Plant

January 1989



JAPAN CONSULTING INSTITUTE

This technical brochure was compiled to help in the drafting of a suitable plan for the construction of a Solar Pond Power Generation Plant.

The production scale and manufacturing process have been described in this brochure on the basis of a typical instance.

The profitability was estimated by fixing certain required conditions, which may differ from country to country.

We hope that the data contained in the brochure will help you to draw up the most suitable plan for the industrialization of your project.

In case a government or public organization requests the Japan Consulting Institute to conduct a feasibility study of the above industry for the purpose of establishing the most suitable plan, it is possible for us to carry this out free of charge.

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1. Introduction

Solar energy is one of the energy sources and is most easily available in the human society, but it has not fully been used so far. With the price increase of fossil fuel, however, solar energy has come to be reconsidered, and is now expected to contribute to regional development as an important alternative energy supply.

Solar energy utilization technology can be classified into

- (a) Heat utilization technology
- (b) Light utilization technology

(a) is most commonly used for warming water, and (b) is utilized for converting light into electricity. In this brochure, solar pond power generation, which uses solar heat, will be described.

The solar pond power generation plant is being put into practice in Israel, the USA and Australia. In the various countries including the USA, Taiwan, Egypt, etc., there are cases in which solar pond are only used to get hot water.

Solar pond power generation can advantageously be made in remote places where the construction of a conventional power plant is difficult but the conditions of solar radiation, climate and others are suitable for the solar pond power generation system.

Solar pond power generation has a scale merit and is not economically inferior to other power generation systems.

The solar pond power generation system has

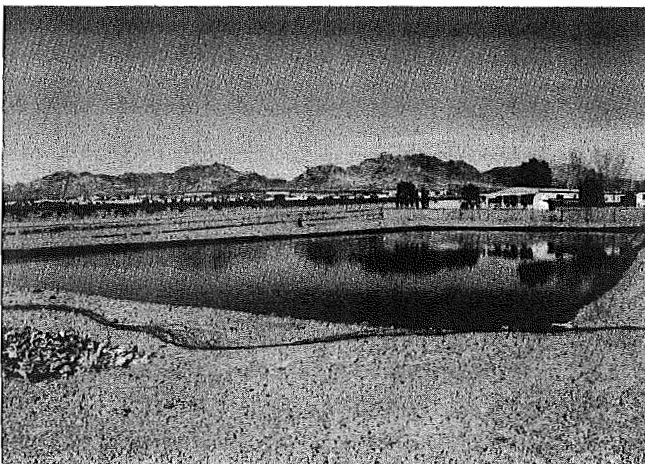


Photo 1. Solar Pond

the following merits.

- ① Running cost is low.
- ② Maintenance is easy and only a small quantity of spare parts is needed.
- ③ No fossil fuel is necessary.
- ④ Both the structure and operation of solar pond are very simple, and the system scarcely gets out of order.
- ⑤ Solar pond being a heat storing system, the power plant can be operated even on a rainy day, and is not so much affected by weather. Thus a high plant utilization factor can be achieved.
- ⑥ In addition to the generation of electric power, the heat generated by solar pond can be used for many other purposes.
- ⑦ Solar pond power generation does not affect environment because utilized energy is clean and the process is operated with a closed system.

2. Solar Pond Power Generation System

2.1 Concept of Solar Pond

Solar pond is a natural or artificial pond which can collect and store solar energy on a large scale without using such machines as a heat collector and the like. Solar pond can be classified into two types, one is with salt and the other without salt.

The solar pond having salt is also called a non-convective solar pond. The solar pond filled with salt water has a depth of 2 to 3 meters having concentration gradient, along which brine density increases with depth.

As shown in Fig. 1, the pond is composed of the surface convective layer, non-convective layer, and heat storage layer. Part of the sunlight reaching the pond surface is reflected, and the rest passes through the surface into the salt water of the pond, and is absorbed into the water according to each wave length. Solar energy reaches the bottom to be absorbed there most. In case fresh water is used as heat medium, the temperature of water rises, causing convection, and heat loss from the surface gets greater, making it impossible to store heat adequately. However, in the

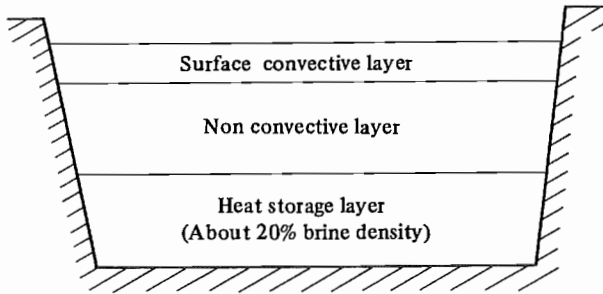


Fig. 1 Structure of Layers in the Solar Pond

case of the solar pond using salt, having brine density which increases with depth as shown in Fig. 2, convection can be prevented. The non-convective layer in the middle, which does not flow, plays the role of a thermal insulator and prevents the emission of heat from the heat storage layer at the bottom. Consequently, the heat storage layer at the bottom can effectively store the absorbed solar energy and can supply heat continuously and stably to a heat utilizing system even when sunlight is not available for about one week. The solar pond with salt water, by forming and maintaining a non-convective layer, functions the roles of a heat collector and a heat storage facility.

The solar pond stores heat when the sunlight is available. In tropical or subtropical regions of strong sunshine the temperature of the heat storage layer reaches as high as 80 to 90°C. Even in Alaska situated at a high-latitude region it is proposed that solar pond is used for heating purpose.

2.2 Outline of Solar Pond Power Generation System

The system of the solar pond power generation is shown in Fig. 4.

In the solar pond, sunlight is absorbed by salt brine which has density gradient. The heat is stored in the heat storage layer (design temperature 85°C) composed of high density brine with NaCl concentration of about 20%. The hot brine is used as a high heat source of Rankine cycle and is led to the preheater and evaporator of the cycle

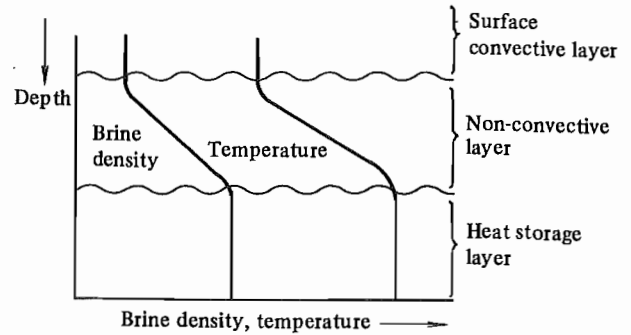


Fig. 2 Distribution of Density and Temperature of Solar Pond

to heat and evaporate flon R-11 (Trichlorofluoromethane, CCl_3F). The hot brine used for heat exchanger is returned to the heat storage layer to store heat again.

The flon, which was evaporated in the evaporator, drives turbine to generate electric power. Turbine exhaust gas is led to a condenser, where heat exchange is made with cold water (usual design temperature of 30°C) as a low heat source, and cooled to be liquefied. The liquefied flon is transferred to the preheater and evaporator by flon pump, and forms a closed circuit of flon.

Both river water and sea water can be used as the source of cold water, but in case they are not available nearby, the water in the surface convective layer of solar pond can be used as cold water.

The principles of solar pond and power generation cycle are both simple, and the mechanical structures are also simple. The total system is highly reliable and seldom gets out of order, and can be operated easily.

2.3 Relation between the Rated Power Output at Generator Terminal and the Area of Solar Pond

Fig. 3 shows the relation between the power output and the pond area. Fig. 3 is based on the temperature of 28.7°C and the annual average global radiation of 202 kcal/m²h. In case the condition is inferior to this, the pond area will become larger, and when the condition is better than this, the pond area will become smaller.

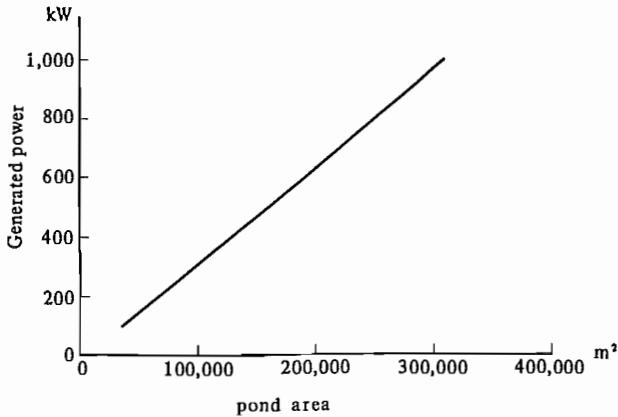


Fig. 3 Relation between Generated Power and Pond Area

2.4 Quantity of Salt (NaCl)

Salt of 0.5 tons/m² is needed.

3. Outline of a Model Plant

3.1 Selection of Plant Site

In selecting the solar pond site, it is necessary to take the following conditions into account.

- ① A large and flat area is available.
- ② Groundwater level is low.
- ③ As water for replenishment and flushing is needed, a water source for these purposes can be secured.
- ④ As the pond needs salt, low-cost salt is available.
- ⑤ Distribution line is needed near the solar pond power generation system so that the electricity generated by the system can be supplied.

3.2 Capacity of a Model Plant

1,000 kW (power output at generator terminal)

780 kW (power output at bus bar)

In this brochure the power generation scale of 1,000 kW (780 kW at the bus bar) was selected, considering that this scale will be suitable for developing and electrifying villages. The following figures were calculated on the basis of the annual average global radiation of 202 kcal/m²h and the atmospheric temperature of 28.7°C.

Consequently, the annual electric power output to be transmitted from the model plant will become as below.

$$780\text{kW} \times 24\text{hrs} \times 365 \text{ days} \times 0.93 \\ = 6,354,500\text{kWh}$$

Note: Plant utilization factor was set at 93%.

3.3 Area Needed for Solar Pond

Table 1 shows the areas of solar pond and evaporation pond required for a 1,000kW solar pond power generation plant.

The evaporation pond is used to recover the salt which was flushed out.

3.4 Heat Balance of the Power Generation System, and the Required Machinery and Equipment

The heat balance in the solar pond power generation system, and the required machinery and equipment are shown below.

(1) Heat balance

Fig. 4 indicates the plant heat balance at the 1,000 kW rated power output.

Table 1 Areas of Solar Pond and Evaporation Pond

Rated power output at generator terminal	Area of solar pond (surface of the water)	Area of evaporation pond (surface of the water)
1,000 kW	155m x 250m x 8 units Total: 310,000 m ²	51m x 75m x 4 units Total: 15,300 m ²

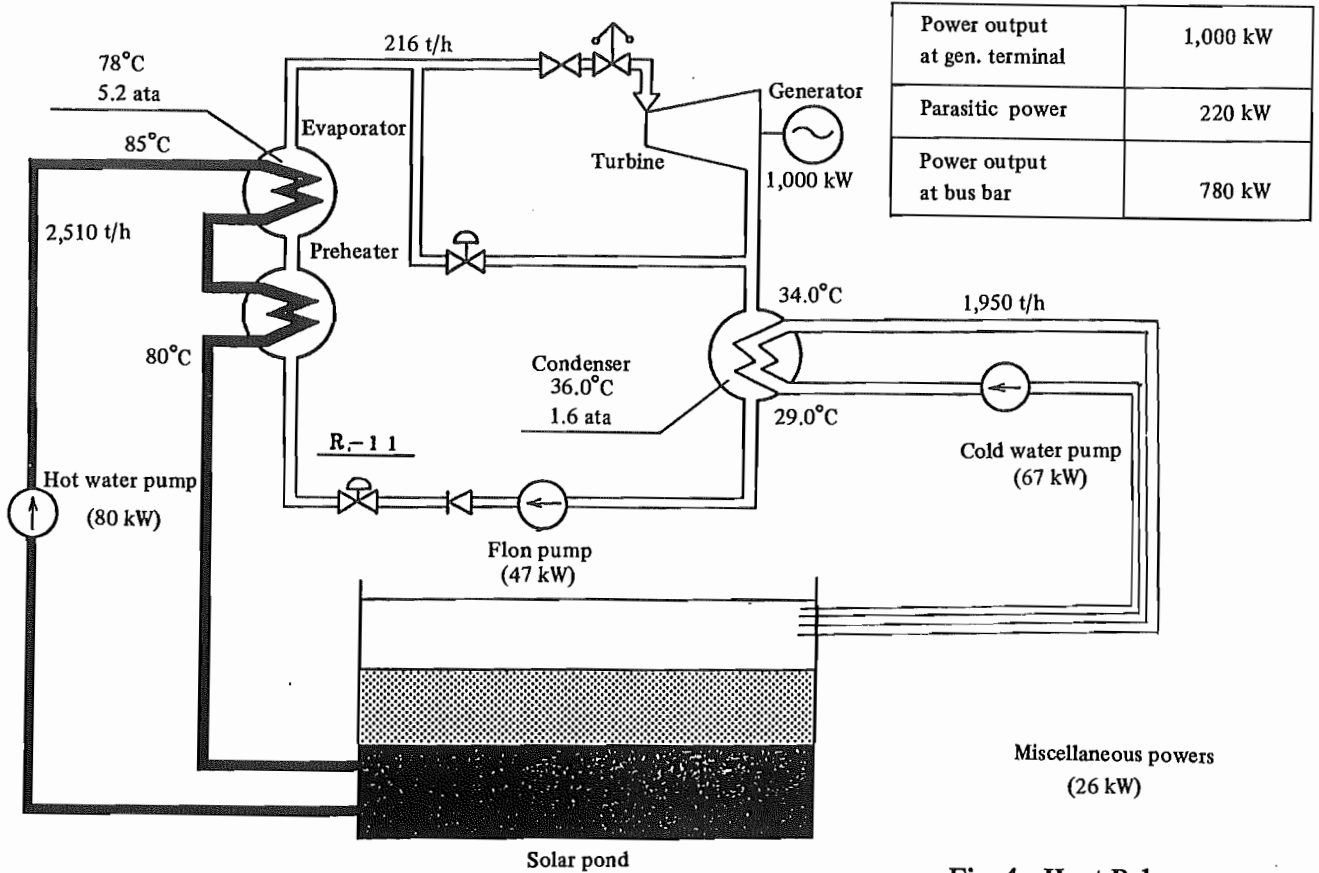


Fig. 4 Heat Balance

(2) Machinery and equipment

(a) Turbine

- ① Quantity 1
- ② Type Radial flow turbine
- ③ Rated power output at gen. terminal 1,000kW

(b) Generator

- ① Quantity 1
- ② Type AC three-phase synchronous generator
- ③ Rated power output at gen. terminal 1,000kW
- ④ Rated number of rotations 3,600rpm

(c) Turbine control devices

- ① Main gas stop valve 1
- ② Speed governor Inlet vane actuator

(d) Preheater

- ① Quantity 1
- ② Type Horizontal, shell and tube type
- ③ Rated hot water flow rate 2,510 tons/hr

(e) Evaporator

- ① Quantity 1
- ② Type Horizontal, shell and tube type
- ③ Rated hot water flow rate 2,510 tons/hr

(f) Condenser

- ① Quantity 1
- ② Type Horizontal, shell and tube type
- ③ Rated cold water flow rate 1,950 tons/hr

(g) Hot water pump

- ① Quantity 50% capacity x 2 units
- ② Type Horizontal, centrifugal pump

(h) Cold water pump

- ① Quantity 50% capacity x 2 units
- ② Type Horizontal, centrifugal pump

(i) Flon pump

- ① Quantity 50% capacity x 2 units
- ② Type Canned pump

3.5 Utilities and Chemicals

- (1) Quantity of water required for replenishing and flushing the pond

Natural evaporation occurs on the pond surface, and in case the evaporated quantity surpasses the rainfall, it needs to replenish fresh water so as to prevent the lowering of water level. It is also necessary to pour fresh water onto the pond surface to remove foreign matters floating there.

- (2) Chemicals

- (a) Hydrochloric acid (HCl)

In order to prevent the increase of algae in the pond, it is necessary to keep the salt water of the solar pond weak acidic at pH value of 5.5 to 6.5. For this purpose, it needs to control pH value by adding hydrochloric acid.

- (b) Copper sulfate (CuSO_4)

Copper sulfate is effective for the prevention of algae. Copper sulfate is added at a rate of 1 to 10 g/m² once every several months. Copper sulfate remains in the pond and its effectiveness will last for a certain period. Hence, the frequency of copper sulfate addition should be determined after checking the condition of algae increase.

3.6 Construction of Solar Pond

- (1) Method of construction

The construction procedure of solar pond is shown in Fig. 5.

- (2) Construction diagram and layout of solar pond

The construction diagram of solar pond is shown in Fig. 6 and layout in Fig. 7.

- (3) Lining material

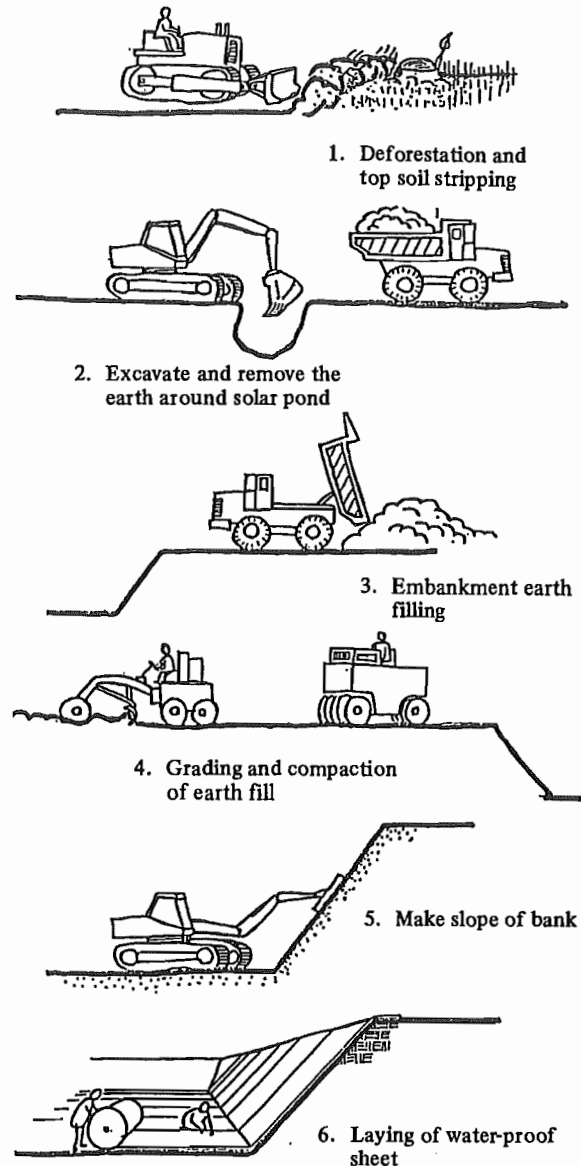


Fig. 5 Construction Procedure of Solar Pond

- (a) Selection of lining material

There are two lining methods, one is a “single layer direct method” in which a sheet is directly laid over compacted soil, and the other is a “plural layers method” in which a mortar base for a water-proof layer is made and over which the water-proof layer is laid. In foreign countries, especially in the USA, they commonly use the “single layer direct method”. In this brochure this method will also be adopted. As the proposed plant is supposed to be operated continuously for many years, it is necessary to select the

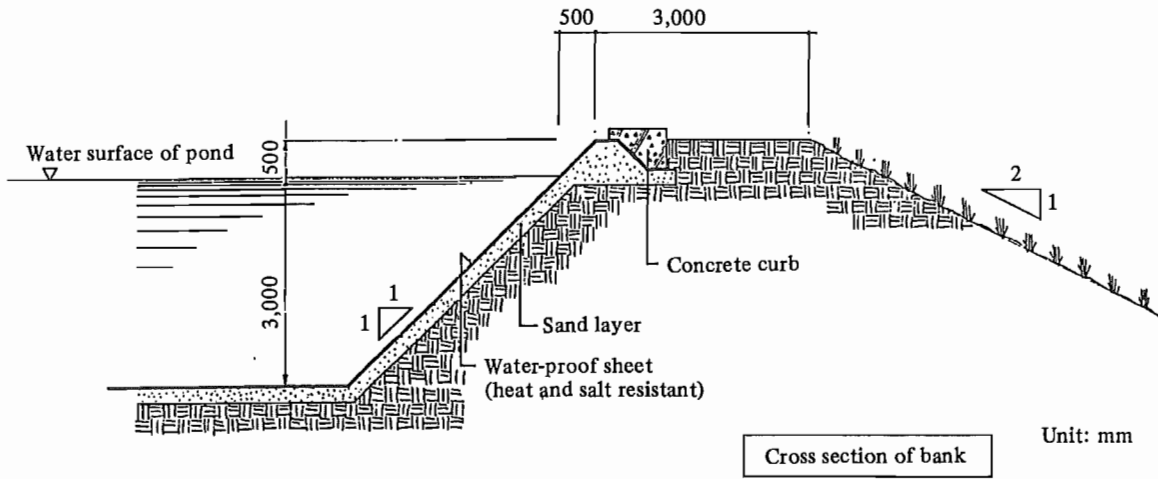
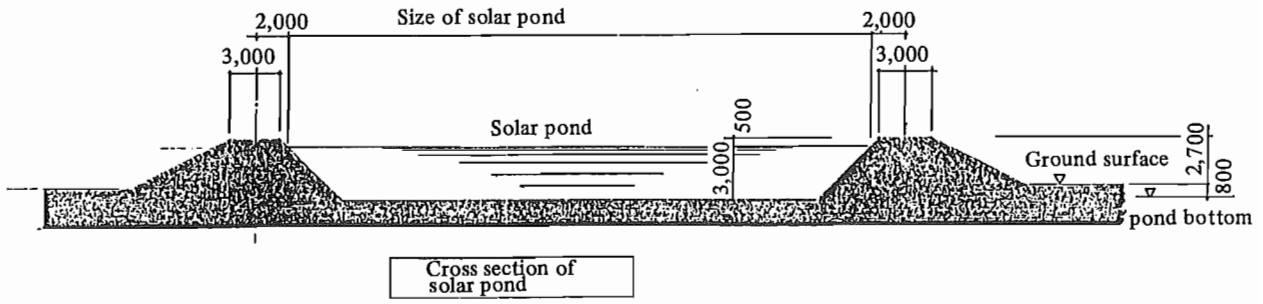


Fig. 6 Construction Diagram of Solar Pond

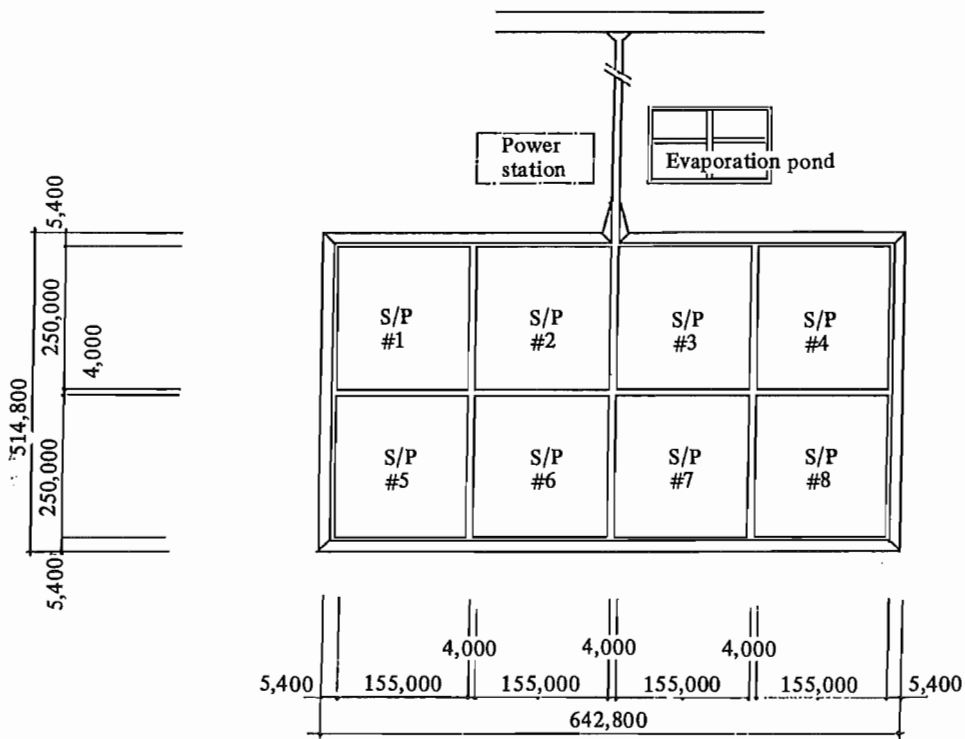


Fig. 7 Plan of Solar Pond

lining material while taking into consideration the following conditions.

- ① Excellent heat resistance (85 to 100°C)
- ② Excellent salt resistance
- ③ Excellent water-proof

In this brochure the lining material which satisfies the above conditions will be adopted.

(b) Method of laying the lining material

- ① Before compacting the ground, such matters as tree roots and grass which generate gas harmful to the lining

material, will be eliminated.

- ② The ground surface is compacted by a roller.
- ③ Fine sand or earth is put over the ground so that the lining material does not directly contact the ground.
- ④ In laying the lining material, good care must be taken not to damage the lining material.

3.7 Plant Layout and System Diagram

Fig. 8 shows the plant layout and Fig. 9 shows an outline of system diagram.

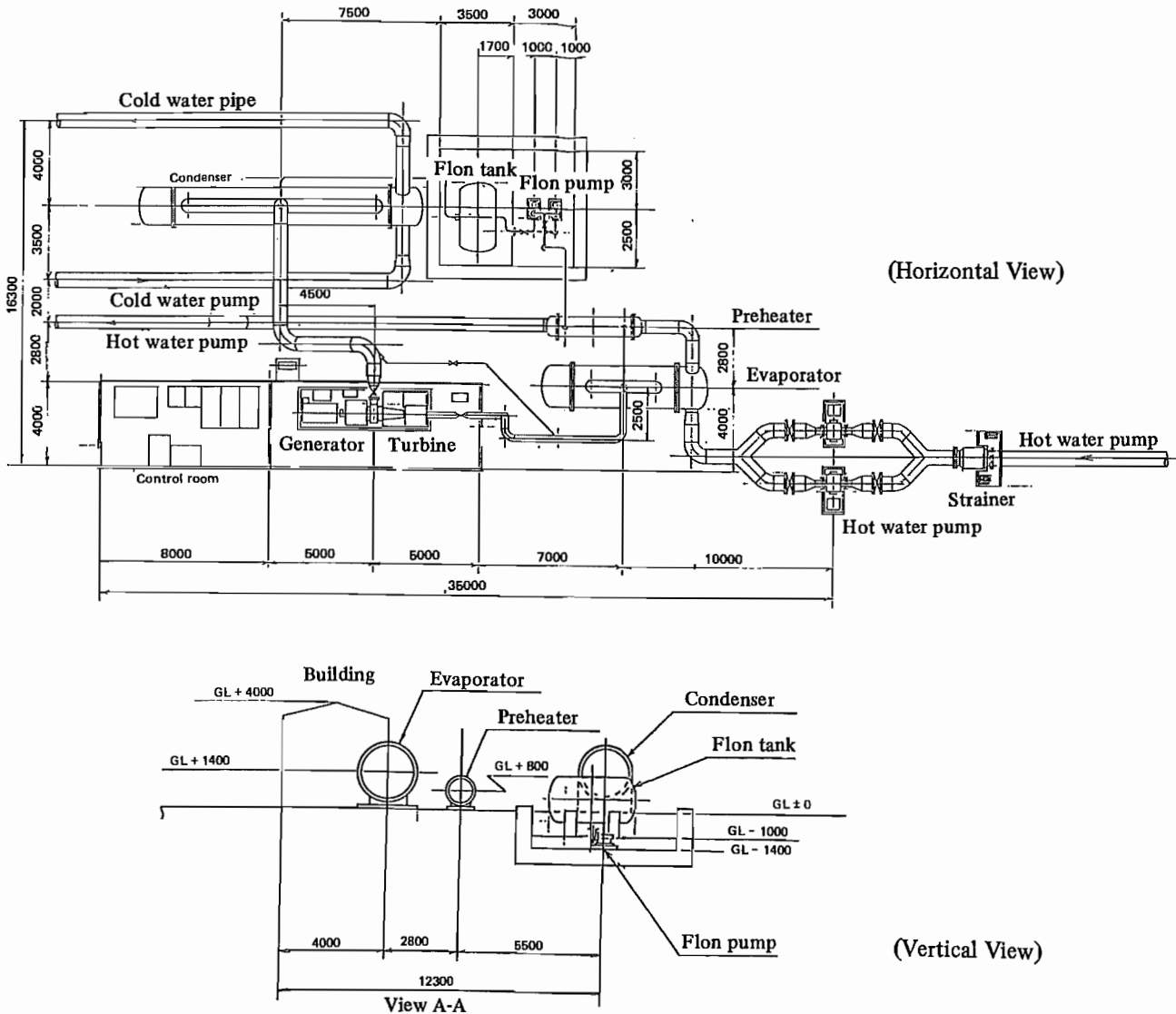


Fig. 8 Plant Layout

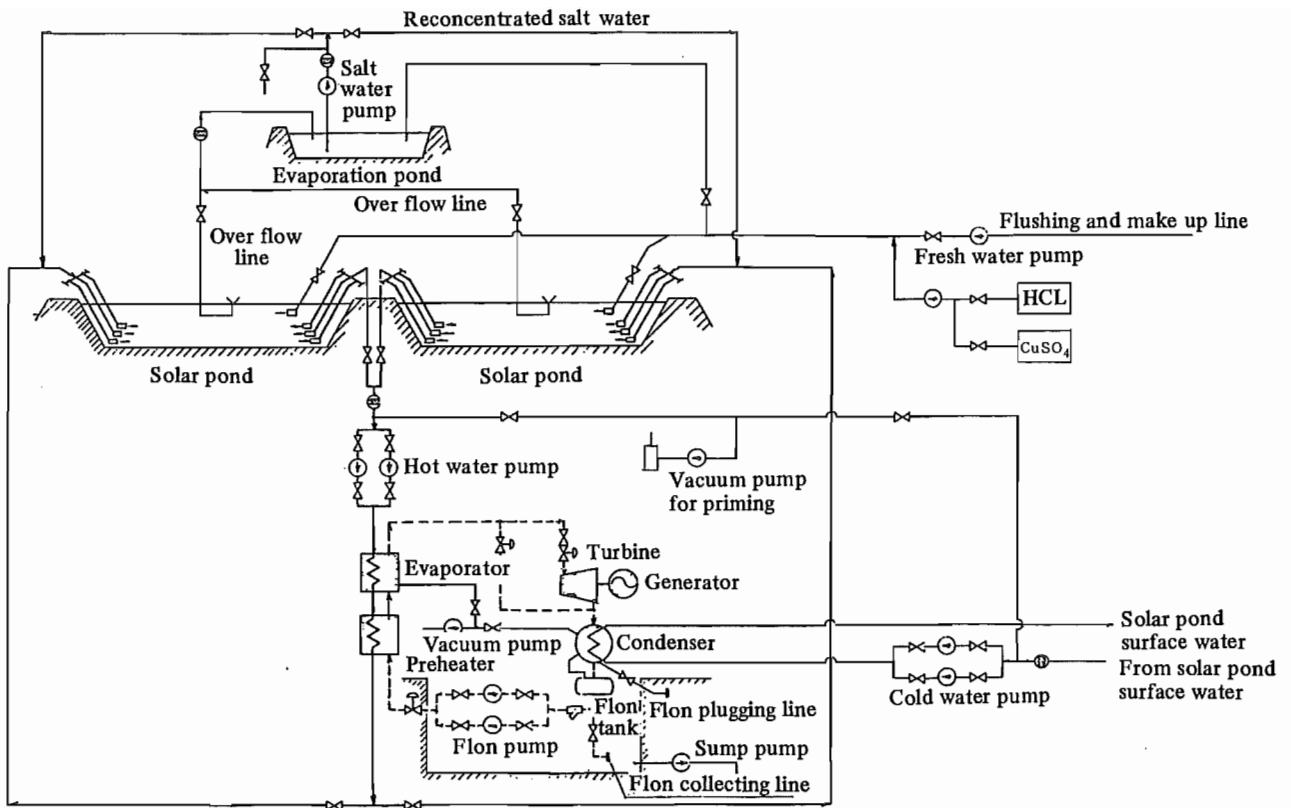


Fig. 9 Outline of the System Diagram of the Plant

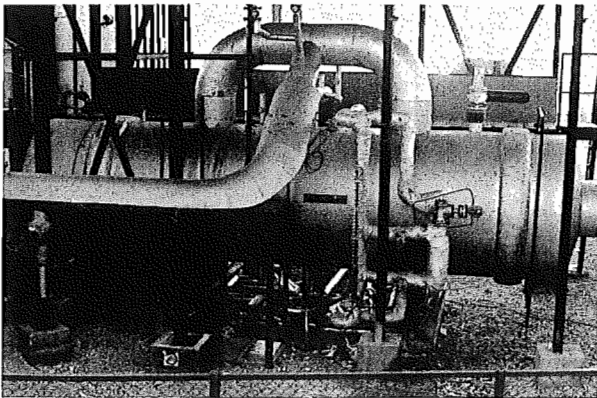


Photo 2. Evaporator

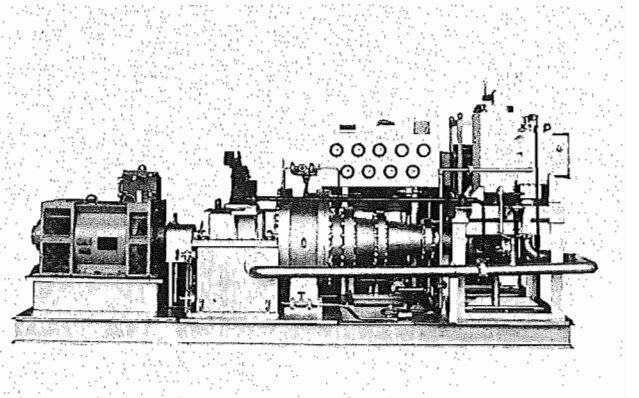


Photo 3. Turbine and Generator

3.8 Plant Area and Building Area

- (1) Plant area: 348,000 m²
- (2) Building Area: 72 m²

3.9 Number of Operators

The following number of operators are needed.

- Plant manager: 1 (also in charge of machinery and equipment)
- Mechanic: 1
- Electrician: 1

Prior to actual operation, the operators must acquire the knowledge on technology and the operational procedure (operation manual) through education.

4. Power Generation Cost

In calculating power generation cost the condition in each country must be used, but it being difficult to do so because the condition differs in each country, the calculation was made in this brochure on the assumption of the following basic conditions.

4.1 Basic Conditions for the Calculation of Plant Construction Cost and Power Generation Cost

- (1) Construction cost of the power plant
 - (a) Land cost is omitted.
 - (b) Construction cost of power plant building is US\$400/m²
 - (c) Machinery and equipment cost is based on FOB price of Japan, 1988.
 - (d) Spare parts cost is assumed to be 0.2% of the FOB price of machinery and equipment
 - (e) Construction cost of solar pond is US\$ 49/m²
 - (f) Freight and insurance cost is assumed to be 5% of the FOB price of machinery and equipment.
 - (g) Foundation work cost is assumed to be 1% of the FOB price of machinery and equipment.

- (h) Erection cost is assumed to be 5% of the FOB price of machinery and equipment.
- (i) Supervision cost is assumed to be 10% of the FOB price of machinery and equipment.
- (j) Commissioning cost is assumed to be 0.3% of the FOB price of machinery and equipment.
- (k) Training cost is assumed to be 0.1% of the FOB price of machinery and equipment.
- (l) Contingency is assumed to be 5% of the FOB price of machinery and equipment.

(2) Power generation cost

- (a) Annual sales amount of electric power is 6,354.5 × 10³ kWh
- (b) Labor cost is US\$2,400/man/year on the average.
- (c) Maintenance cost is assumed to be 0.1% of the FOB price of machinery and equipment.
- (d) Depreciation cost: Straight-line method will be adopted. Both machinery and equipment and building are 3% per year.
- (e) Insurance cost is assumed to be 0.1% of the construction cost of building and the FOB price of machinery and equipment.
- (f) Interest: Half of the plant construction cost will be covered by a long-term loan with a 10% annual interest rate.
- (g) Currency exchange rate: US\$1 = ¥130

4.2 Capital Required

The construction cost of power generation plant is calculated using the basic conditions cited in 4.1, and the result is given as follows.

(1) Construction cost of power generation plant	US\$
Land	—
Power plant building	28,800
Power generation facilities	
Machinery and equipment	5,900,000
Spare parts	11,800
Freight and insurance	295,000
Foundation work	59,000
Erection work	295,000

Supervision	590,000
Pond construction (including salt and water-proof material and evaporation pond)	15,500,000
Commissioning	17,700
Training	5,900
Contingency	295,000
Total	US\$ 22,998,200

(2) Capital required US\$ 22,998,200

4.3 Power Generation Cost

The annual power generation cost is calculated using the basic conditions cited in 4.1, and the result is given as follows.

	US\$
Labor cost	7,200
Maintenance cost	5,900
Depreciation cost	689,950
Insurance cost	5,930
Interest	1,149,910
Total	US\$ 1,858,890

Consequently, the power generation cost per kWh will be:

$$\begin{aligned} & \text{US\$}1,858,890 \div 6,354,500 \text{ kWh} \\ & = \text{US\$} 0.29/\text{kWh} \end{aligned}$$

4.4 Relation between Power Generation Capacity and Power Generation Cost

Fig. 10 shows the relation between power generation capacity and power generation cost at bus bar.

5. Conclusion

Most of the existing power plants use imported fuel. However, a general technology in the world has come to save fuel oil as much as possible, and moreover, it is very important that the abundantly available solar energy should be utilized effectively in place of fuel from the viewpoint of national security.

There will be great merits not to use fossil fuel as the energy source, and the foreign currency,

which is saved by introducing solar energy, can be utilized for other economic development.

The solar pond power generation system will be most appropriate as a power supplying source in such regions where the following conditions are furnished.

- Many fine days and large global radiation are obtainable.
- Salt can be obtained easily.
- A vast flatland is available.

As the solar pond has the heat collecting and heat storing functions, it is not directly affected by weather, and high-temperature hot water can be secured day and night, and the electric power almost close to the rated power capacity can be supplied.

Hence, the solar pond power generation will be a system which is suitable for the regional development and industrial promotion, as well as for improving people's living standards.

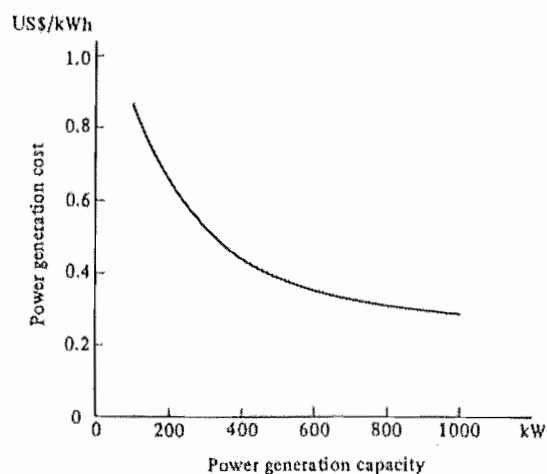


Fig. 10 Relation between Power Generation Capacity and Power Generation Cost

Project Planning for Small and Medium Scale Industries

- No. 1 Rice Milling Plant and Rice Bran Oil Manufacturing Plant
- No. 2 Plastic Woven Bag Manufacturing Plant
- No. 3 Container Board Manufacturing Plant
- No. 4 Plastic Blow Bottle Manufacturing Plant
- No. 5 Concrete Block Manufacturing Plant
- No. 6 Glassware Manufacturing Plant
- No. 7 Galvanized Iron Sheet Manufacturing Plant
- No. 8 Fishing Net Manufacturing Plant
- No. 9 Ice Making, Refrigeration and Cold Storage Plant
- No.10 Starch and Syrup Manufacturing Plant
- No.11 Instant Noodle Manufacturing Plant
- No.12 Surimi and Surimi-Based Food Manufacturing Plant
- No.13 Polyethylene Shopping Bag Manufacturing Plant
- No.14 Retreading Tire Manufacturing Plant
- No.15 Husk Fired Thermal Power Plant
- No.16 Fishmeal Manufacturing Plant
- No.17 Assorted Animal Feed Manufacturing Plant
- No.18 Sanitary Napkin Manufacturing Plant
- No.19 Sanitary Ware Manufacturing Plant
- No.20 Toilet Tissue Manufacturing Plant
- No.21 Powder Milk Manufacturing Plant
- No.22 Mosquito Coils Manufacturing Plant
- No.23 Solar Pond Power Generation Plant

Project Planning for Small and Medium Scale Industries No.23

Japan Consulting Institute (JCI)

Sumitomo Fudosan Kudanshita Bldg. 3 F
Kanda-Jinbocho 3-5, Chiyoda-ku Tokyo
101-0051 Japan

TEL +81-3-3222-8100
FAX +81-3-3222-8101
URL : <http://jei-plant.or.jp>

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