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SOLAR POND WITH THERMOELECTRIC ENERGY CONVERTER

Analysis has been performed of solar energy recovery scheme based on a solar (saline) pond with thermoelectric converter. The feasibility of creating a thermoelectric generator with a solar pond as the energy source (STEG) with acceptable technical and economic features has been demonstrated.

Key words: solar energy, solar pond, thermoelectric generator.

Introduction

A solar pond is a water reservoir 2 to 3 m deep, filled with a salt solution. Owing to the fact that solubility of salts in water is increased with a rise in temperature, situations are possible when solution stratification takes place, i.e. in the bottom layer the concentration (and density) of solution is increased, and in the surface layer it is decreased. In so doing, three distinct zones appear in the water reservoir, namely an upper convective zone 0.1...0.3 m thick, consisting of fresh water, a gradient layer where salt concentration increases with increasing the depth, and a bottom convective zone with maximum concentration of salts (Fig. 1).

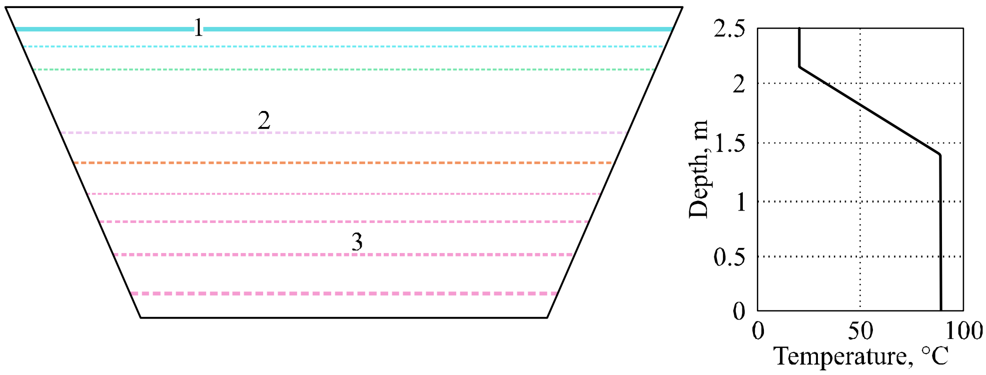

Fig. 1. Solar pond scheme [1]. 1 – fresh water; 2 – insulating layer with downward increasing brine salinity; 3 – hot brine layer.

Due to suppression of natural convection, the gradient layer possesses high thermal resistance (approximately three orders of magnitude higher than that of fresh water in vivo). As a result, the bottom layer is thermally insulated from the surface and capable of accumulating the energy of solar radiation. The temperature in the bottom layer can reach more than 100 °C. Thus, a solar pond is a concentrator and accumulator of solar energy at the same time. By estimates [2], a solar pond increases the density of solar radiation exergy many hundred thousand times, making this technology promising for creation of solar energy recovery systems.

At the present time, a number of power projects based on solar ponds with steam-vapour generators have been implemented [3]. In [4, 5], technical and economic analysis of such plants was performed which confirmed the advisability of using such systems. The specific power of such plants is of the order of 20 W/m^2 of water reservoir surface, which is 5...7 times higher compared to the existing hydroelectric power stations. In due time, research on the extent of possible use of Siwash salt bay was performed, by the results of which the energy potential of this bay was estimated as 10 GW of peak electric power. The scheme under consideration also fits well in the concept of integrated utilization of deep sea water [6] – the presence in the scheme of a low-temperature sink of thermal energy is capable of increasing considerably the efficiency of solar energy conversion system in general.

Alongside with known solutions, the use of thermoelectric generators in such systems can expand the area of application of such energy sources. This paper analyzes technical and economic features of solar energy conversion system of the type "solar pond-thermoelectric generator".

Scheme of a TEG with a solar pond as the energy source (STEG)

Let us consider the features of a thermoelectric generator utilizing a solar pond as a source of thermal energy, and sea water as a sink. Thermal energy accumulated in the bottom layer of the pond is removed by heat carrier pumped through the collector placed on the bottom. Heat carrier is circulated through STEG heat exchanger. The generator is cooled by water coming to process scheme of a centre for using deep sea water [6].

To analyze the scheme, we employ a method for calculation of TEG stated in [7] and the features of solar ponds [4, 5].

Initial data for the analysis:

– net power of STEG N_o = 100 kW;
– hot water temperature t_{hot} = 80 °C;
– cold water temperature t_{cold} = 8 °C;
– solar pond efficiency η = 30 %;
– intergral flux of solar radiation E_o = 2000 kWh/m^2 per year;
– thermoelectric module figure of merit z = 0.003;
– thermoelement height h = 0.5 mm;
– module size 40 × 40 mm;
– cost of one module – 3 $;
– specific cost of heat exchanger – 250 $/m^2;
– specific cost of solar pond – 30 $/m^2 [5];
– cost of grid tie inverter – 150 $/kW;

As was shown in [7], the features of such system for ocean thermal energy converter (OTEG) are essentially dependent on the hydraulic resistance of thermoelectric generator heat exchangers. In the case under consideration, due to a higher TEG efficiency, this dependence is not decisive. The estimate of TEG cost for the system at hand is given in Figs. 2 and 3.

The most capital-intensive part of STEG is a source of heat comprising a solar pond and a collector. To assure round-the-clock operation of STEG, the pond must possess the necessary heat capacity. Under the above conditions, the necessary solar pond area is 300...350 m^2/kW. Accordingly, the specific cost of heat source is 10...12 thousand $/kW, and the specific cost of the whole device is of the order of 13 thousand $/kW (without including the land area necessary for creation of a pond). Therefore, a 100 kW STEG will require a solar pond of the area about 3.5 hectares; the cost of such device will be approximately 1.3 mln $.

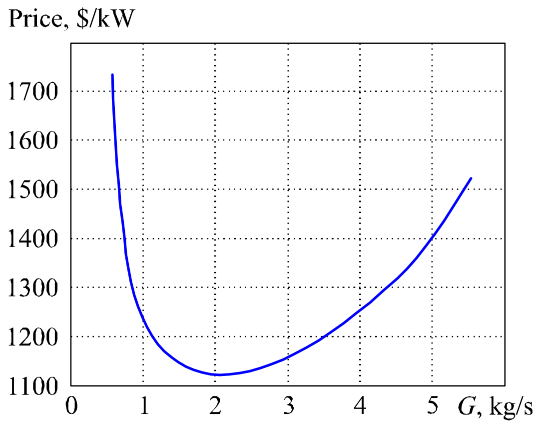

Fig. 2. Specific cost of TEG versus heat carrier flow rate.

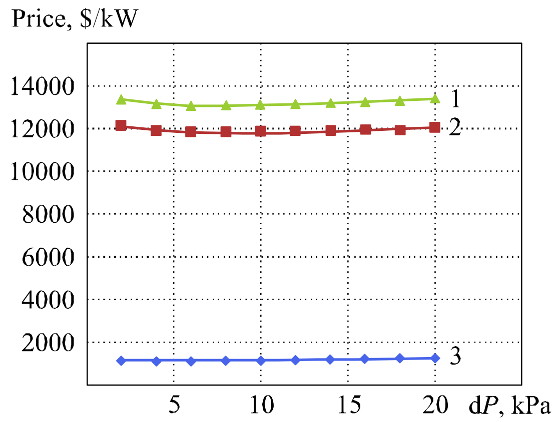

Fig. 3. Specific cost of STEG components versus the hydraulic resistance of heat exchangers.
1 – TEG cost, 2 – Solar pond cost, 3 – STEG cost.

The above data allow for using STEG in a base-load mode, i.e. at constant round-the-clock load. With full loading of STEG, electric energy generation will be about 900 thousand kW·h/year, which for standard depreciation periods of 20 years yields the electric energy cost of the order of 0.07 $/kW·h. With regard to maintenance costs, tax deduction and operating organization profit, this figure can increase maximum to 0.1 $/kW·h. Experience of using such systems suggests that with operation in a peak mode converter power can be increased by a factor of 3...5 with solar pond dimensions unchanged. Using STEG in a peak mode with the load coefficient of 50...70 %, the necesasry pond area (and capital expenditures) are reduced several times, and, accordingly, the cost of electric energy can be reduced to the level of 0.03...0.06 $/kW·h. For comparison, it should be noted that current feed-in tariff for systems of photoelectric solar energy conversion in the power range under consideration is 0.3...0.6 $/kW·h [8]. That is, the existing tariffs exceed by a factor of 5...10 the values obtained for STEG, proving high competitive ability of the scheme analyzed.

Conclusions

Analysis of thermoelectric system of solar energy conversion has shown the feasibility of creating STEG in the power range of 100 kW with technical and economic features acceptable for a wide commercial application.

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