Energy

Plumbing the ocean depths: a new source of power

Temperature differences between surface and deep waters of tropical oceans can provide cheap power

Faced with a shortage of fossil fuels, rising costs of nuclear fission power plants, and long delays in introduction of nuclear fusion power plants, researchers in the U.S. are looking with renewed interest and a sense of urgency at nontraditional—and, in most cases, unproved—alternate energy sources such as tidal energy, geothermal energy, and solar energy In the solar energy field, for example, there are on-going investigative programs in satellite solar power stations, solar energy for buildings, solar thermal conversion, conversion of organic materials, photosynthetic production, wind power, and solar sea power—the technology that will be addressed herein.

The main difficulty in harnessing solar energy is collecting it. Land-based collection mechanisms require huge land areas and expensive materials for the direct or indirect conversion of solar energy into electricity or other forms of energy. But, in the case of solar sea power, the collection mechanism is the ocean. Solar energy, absorbed by the surface waters of tropical oceans, can be converted first into electric power by solar sea power plants (SSPPs), then converted by electrolysis into chemical energy, and transported by ship to the U.S. for distribution to heat homes, power transportation facilities, and form a basic ingredient in materials processing.

The concept of solar sea power is not new. In 1881, D'Arsonval pointed out the possibility of extracting energy from the tropical oceans by building a thermal engine operating on the temperature differences between surface water and deep layers of water.[1] And, in 1930, the French engineer Georges Claude actually attempted to build a 40-kW power plant off Cuba,[2] but his experiment failed for a number of technical reasons. More recently, Anderson and Anderson made detailed cost studies of such a sea thermal power plant[3] and estimated that a 100-MW plant could be constructed at a capital cost per kilowatt no higher than that for a conventional fossil-fuel plant.

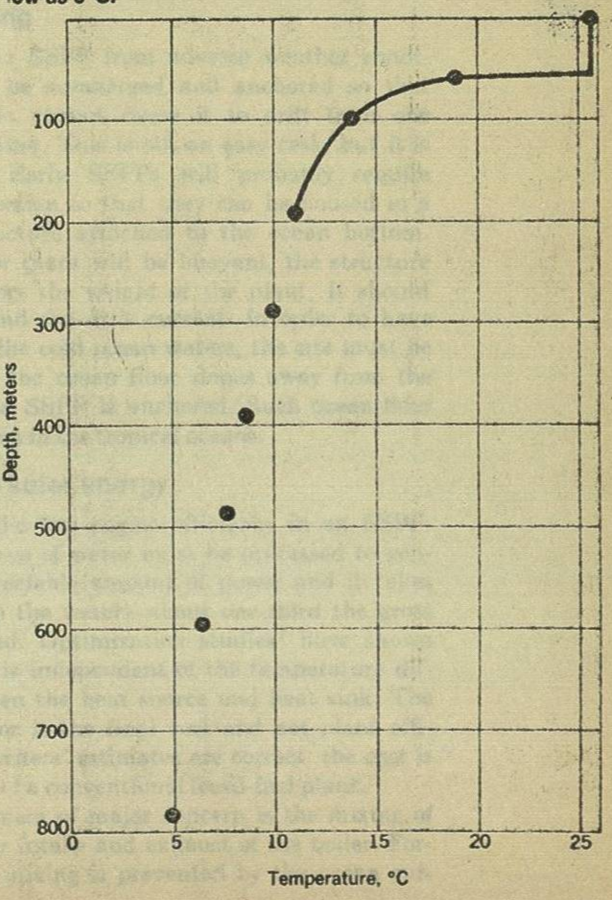
The scientific basis for an SSPP has not been questioned. But for engineers accustomed to thinking in terms of temperature differences of a few hundred degrees and super-heated steam, the available temperature differences for an SSPP seem miniscule. And other questions have been raised: corrosiveness of sea water, microbial fouling, plant anchoring, diluteness of solar energy in the ocean, and environmental effects. Each question will be examined in turn.

Abrahim Lavi, Clarence Zener
Carnegie-Mellon University

Insufficient temperature difference

Conventional fossil-fuel power plants operate with a temperature differential of 500°C between the heat source and the heat sink. In the ocean, there is at best a 20°C temperature differential between the warm surface water and the readily accessible deep cold water, as shown in Fig. 1. And of this 20°C, only 10°C can be used by the heat engine itself. The remaining difference is needed to drive heat from the warm surface water into the heat engine and then from the heat engine to the cold deep water. (A design concept for an SSPP operating on such a temperature differential is shown in the box on page 25.)

[1] Typical ocean temperature profile at various depths. The surface layer, which is about 200 meters deep, takes its heat from the sun and stays at about 25°C. The cold water at the lower depths comes from the Arctic region and can be as low as 5°C.



In an SSPP, a working fluid such as ammonia—or any fluid with a reasonably high vapor pressure at ambient temperature and with good heat transfer characteristics—must be boiled. Normally, to promote vigorous boiling, the working fluid must be superheated by from 5-10°C. But in an SSPP with only a small total temperature differential available, a 3°C superheat is the highest that can be afforded. One solution to the problem of a small superheat may lie in a technique that was used by the Linde Corporation in their refrigeration systems[4] where they encountered a similar problem. The solution came about through development of a method for cutting tiny, almost closed, channels on the surface of a metal. The channels become vapor-locked and, thereby, provide a steady stream of bubbles. Such a surface needs a superheat for boiling only one-tenth that of conventionally smooth surfaces.

Even with the boiling problem solved, the 20°C temperature differential might seem to create a cost handicap because it leads to a low efficiency—3 percent—compared to nearly 40 percent in a conventional plant. For a given kilowatt output, the SSPP boiler must process more than ten times as much heat as the boiler in a conventional plant. In particular, the SSPP boiler tube area must be more than ten times greater than that in a conventional plant. Although this requirement would seem to necessitate excessive cost, two basic physical phenomena enter the picture that tend to offset any cost increase and may even permit a cost decrease.

The first phenomenon is that the vapor pressure of a working medium rises rapidly as its temperature increases. This pressure increase must be offset by a corresponding increase in thickness of the boiler tubes. Since in an SSPP the maximum pressure anticipated is only about 150 psi (about one million N/m^2), compared to 3200 psi (about 22 million N/m^2) in conventional steam boilers, much thinner boiler tubes can be used.

The second phenomenon is the decrease in strength of metals with a rise in temperature that, in a conventional boiler, must be offset by an increased wall thickness or by the use of expensive alloys. Again, an SSPP benefits because the temperatures in use are small compared to those in conventional plants.

The increase in cost of boiler tubes because of either of these phenomena—or both—in conventional plants can be nearly catastrophic. For example, in the mid 1950s, the Eddystone power station was constructed in Philadelphia with a boost in peak temperature to 600°C. The drastically increased cost of the station required by the higher temperature was the death blow for plants above 500°C.

Corrosiveness of sea water

Because of the electric conductivity of sea water, metallic structures submerged in the ocean suffer electrolytic corrosion. A quantitative measure of the tendency of a metal to dissolve in water is its electrochemical potential. Those metals with a positive potential will dissolve spontaneously with the evolution of hydrogen. Those with a negative potential will not dissolve. Inexpensive metals such as iron have positive potentials while only expensive metals such as copper, silver, and gold have negative potentials.

Pure aluminum has the unique characteristic of forming a tightly clinging oxide coating which protects the metal from contact with water. Thus, in spite of its positive electrochemical potential, pure aluminum will not dissolve in sea water. The Aluminum Company of America has learned how to take advantage of this oxide coating on pure aluminum by bonding a layer of pure aluminum onto a high-strength aluminum alloy. Such a bonded structure is called Alclad. During the last several years, test data have been accumulated[5] demonstrating that Alclad tubing would have a long service life in SSPPs. It should be noted that life tests were conducted at elevated temperatures of up to 80°C where corrosive effects are much more severe than at the ambient temperature of an SSPP.

Microbial fouling

All surfaces submerged in sea water soon become covered by a film of microbes, a film that would ruin the heat transfer characteristics of boiler surfaces. The Woods Hole Oceanographic Institute has found, however, that an exceedingly small concentration of chlorine—less than one part in four million—is sufficient to prevent such microbial growth[6] and is far below that required to kill marine life.

When chlorine gas is added to sea water, it forms hypochlorous acid which can also be formed directly by electrolysis of sea water. The electric power required for the electrolysis is a small fraction of that generated by an SSPP. This electrolysis could take place in the input pipes of an SSPP. In fact, such electrolytic equipment has already been developed for use in the intake condenser pipes for power plants located on sea coasts.

Plant anchoring

To protect an SSPP from adverse weather conditions, it must be submerged and anchored so that oceanic currents cannot cause it to drift from one location to another. This is not an easy task, but it is surmountable. Early SSPPs will probably require careful site selection so that they can be housed in a permanent structure attached to the ocean bottom. Since the power plant will be buoyant, the structure need not support the weight of the plant. It should merely withstand the drift current. In order to have easy access to the cold ocean waters, the site must be selected where the ocean floor slopes away from the point where the SSPP is anchored. Such ocean-floor cliffs are common in the tropical oceans.

Diluteness of solar energy

Because of the low engine efficiency in an SSPP, immense volumes of water must be processed to generate any appreciable amount of power and it takes power to pump the water—about one-third the gross power generated. Optimization studies[7] have shown that this ratio is independent of the temperature differential between the heat source and heat sink. The important factor is the final cost and not plant efficiency. If the writers' estimates are correct, the cost is still below that of a conventional fossil-fuel plant.

Another problem of major concern is the mixing of the warm water intake and exhaust of the boiler. Fortunately, such mixing is prevented by the ocean cur-