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Ocean Thermal Energy Conversion Experiment Slated For Hawaii

Solar Energy Research Institute is ready to test feasibility of open-cycle OTEC system to generate electricity in 165-kW unit

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An experiment to test conclusively the feasibility of open-cycle ocean thermal energy conversion (OTEC) to generate electricity has been designed by Solar Energy Research Institute, Golden, Colo. Following five years of gathering data and modeling systems, and with funding from the Department of Energy, SERI will conduct the experiment, as yet unscheduled, at the Natural Energy Laboratory of Hawaii.

NELH has been involved in ancillary studies of OTEC for some time and already has in place some of the equipment needed for the experiment. The design calls for a 165-kW, open-cycle system. That size is considered the smallest that can be used satisfactorily to validate the basic design and also permit scale-up to projected commercial systems with generating capacities in the range of 5 to 15 MW.

Interest in open-cycle OTEC systems was revived in 1978, when DOE funded analyses of the concept with an eye to cost-effectiveness. Work by several groups, including Westinghouse, the University of Massachusetts, Colorado School of Mines, and SERI, concluded that OTEC energy production could be cost-effective. The Westinghouse study assumed a 100-MW floating platform but predicted that operations with capacities as low as 35 MW could be effective. Some uncertainties centered on costs for

conventional equipment that had to be adapted to unconventional conditions encountered in OTEC systems.

Since 1980, SERI has been pursuing research directed at obtaining better data than were available to the earlier investigators. Research also aimed at refining open-cycle designs. Another look at the Westinghouse analysis, with the new data in mind, showed that all of the original conclusions were still valid but conservative. The institute now believes that OTEC plants with capacities in the range of 5 to 15 MW can be economically viable in the near term and that open-cycle modules in the 2- to 5-MW range can be built now with existing turbine and cold-water-pipe technology.

The principal locations of practical interest to the U.S. for OTEC installations are the Gulf of Mexico, Hawaii, Guam, and Puerto Rico. OTEC refers to the recovery of thermal energy from the surface layers of the oceans in suitable parts of the world. The energy is mostly absorbed from solar radiation. Usable surface temperatures are largely confined to the tropical oceans, between 20° north and 20° south latitude. In that region, the temperature difference between the surface and a depth of about 1000 meters is roughly 20 °C, with some seasonal variations.

Warm water (the heat source) for OTEC operation is immediately available from surface water intakes. Cold water must be obtained from considerable depth to maximize the temperature differences, since this difference helps to determine steam flow through the turbine. This means pumping water from depths of as much as 1000 meters. Such depths pose considerable engineering problems in the deployment

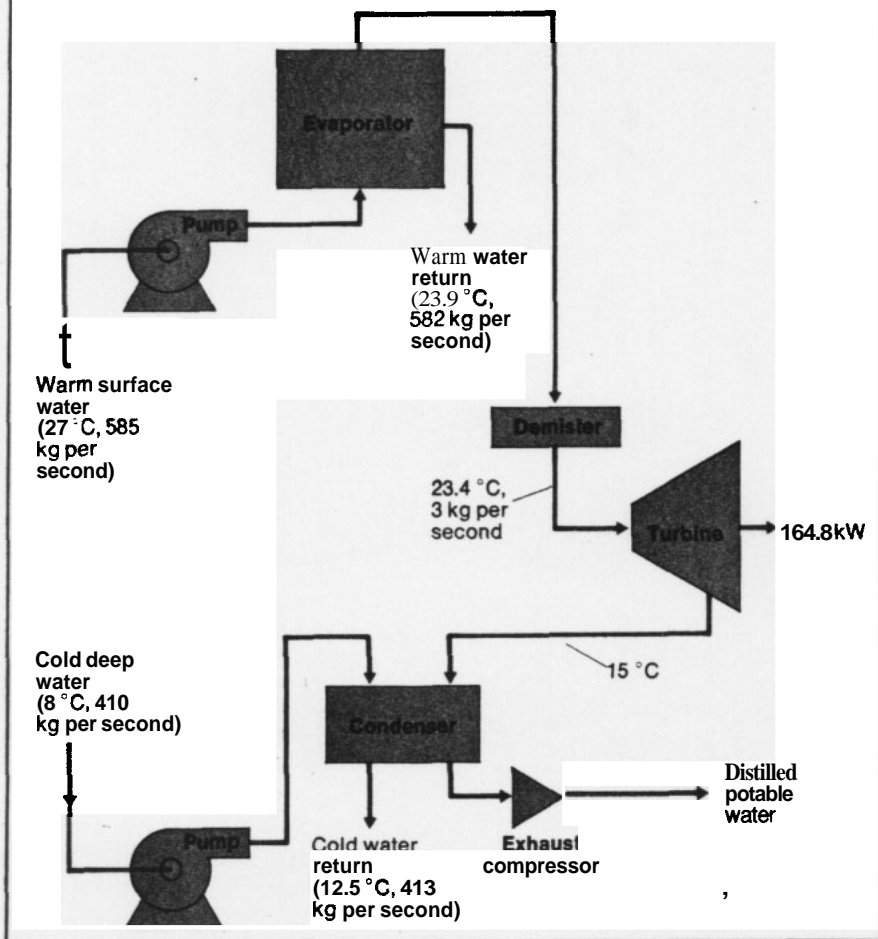
and maintenance of very long intake pipes. At various times, cold-water intakes have been made of such materials as steel pipe and concrete conduits. The best materials have proven to be large-diameter polymer pipes that have densities approaching that of seawater.

OTEC systems are primarily electricity producers. They may be shore bound, mounted on the continental shelf, or mounted on moored floating platforms. For onshore or platform-mounted OTEC plants, the cold-water pipes may be anchored to the bottom in many locations. For offshore, barge-mounted plants, deploying and maintaining the cold-water pipe becomes more difficult. The output from an OTEC plant varies, among other things, as the square of the temperature difference between the surface and a given depth.

According to Terry Penney, section manager in SERI's thermal sciences research branch, some of the more critical issues now facing OTEC designers revolve around integrating all the parts of the system and evaluating the multiordered coupling among heat, mass, and momentum flows in the system. That's a classical problem in plant design that engineers usually face as they approach commercial demonstration. It's also the impetus for preparing the new experiment, utilizing the smallest operating system necessary to determine the design parameters for larger commercial operations.

The experimental apparatus is designed to be installed at NELH on the Kona Coast of the island of Hawaii. A DOE facility has been operating at NELH since 1981, obtaining biofouling, corrosion, and related data. The facility is equipped to conduct tests of flash evaporators and

Opencycle experiment designed to generate 165 kW



condensers and to gather data on seawater deaeration, a major problem with OTEC systems.

Penney notes that SERI's OTEC experiment is designed to investigate five major problems. Heat and mass transfer will be studied in an evaporator that will produce 0.5 kg per second per square meter of steam with a 3.1 °C flashdown and less than a meter of hydraulic head loss. The condenser for the system is envisioned as a two-stage unit with matrix packing to provide vapor/liquid contact. The flow conditions in the packing are extreme when compared with those usually encountered in conventional chemical engineering practice. The projected load on the condenser is 0.8 kg per second per sq m of cross-sectional area with an entering temperature difference of 7 °C. Both evaporator and condenser are direct-contact types.

Steam flow dynamics are critical in low-pressure design, particularly

in the turbines. Flow velocity in all parts of the system will be kept below 125 meters per second and steam will encounter only one return bend in the system. The mist eliminator is of special low-loss design, and pressure losses there are projected to be less than 100 pascal.

Seawater hydraulic losses are projected to be from 2 to 6 meters, and studies indicate that up to 90% of the gas dissolved in the seawater can be released before it reaches the evaporator or condenser. Deaerating the seawater is a major problem, particularly in very closely designed systems. The mechanism of deaeration is still not well understood, but provisions are being made to monitor the deaeration closely during the experiment.

SERI researchers are probably the most anxious about operating a steam turbine at a very low pressure drop with steam of varying enthalpy and flow rates. About 10% of the power produced is expected

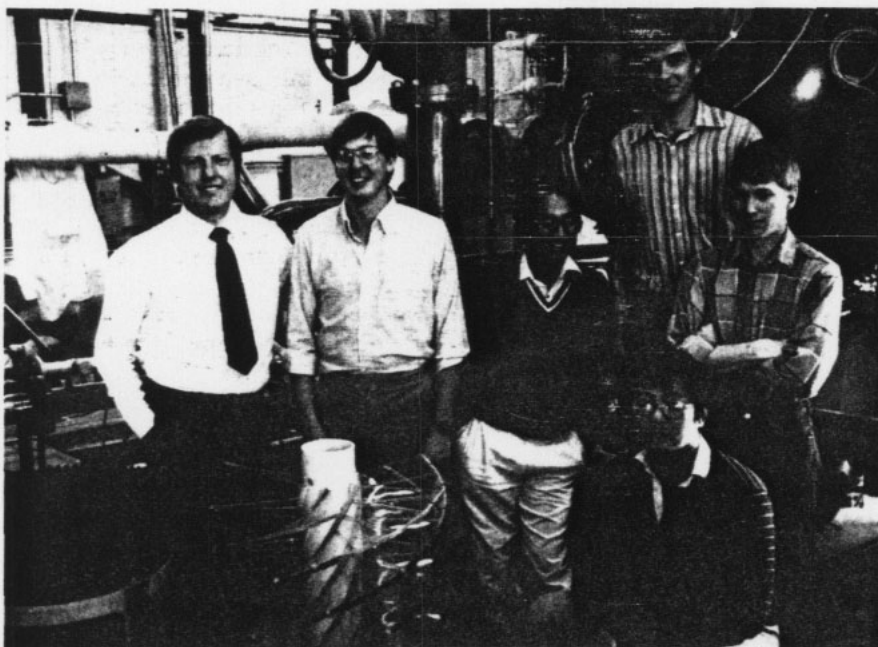
to be used in purging noncondensable gases. Another 20% may be used in pumping seawater. Steamside pressure losses thus may be equivalent to 25% of the power produced. All of these effects are magnified because of the low steam pressures and the high water-pumping rates in the cold-water pipe.

In the SERI design, a 30-inch cold-water pipe will deliver about 6500 gal per minute from a depth of about 1000 meters. That likely will allow generation of gross power, of 165 kW with a turbine wheel 1.4 meters in diameter. The apparatus will be constructed in two phases. The first phase includes building the condenser and evaporator followed by tests and performance comparison with the models. The second phase involves assembly of turbine and additional heat-transfer modules. After that, the entire system will be operated to evaluate the integration effects.

The first open-cycle design was patented in 1932 by the Frenchman Georges Claude. Following some development in the 1930s, the concept lay dormant until interest revived following the oil price increases in the mid-1970s.

SERI senior engineer Desikan Bharathan explains that although Claude's ideas have become synonymous with open-cycle systems, the closed cycle was popular for a long time. Closed-cycle systems employ a second fluid, confined between the ocean water heat source and sink. That had the advantages of higher pressures and better thermodynamic characteristics. But the energy losses were too great, and the secondary fluids then available, usually ammonia, were hard to confine. Bharathan says that most OTEC efforts in progress are now concerned with open-cycle systems. They are more difficult to develop but are more reliable and require less equipment development.

One of the biggest problems that OTEC designers have faced has been a lack of reliable data on seawater itself—in particular on the absorption and desorption of noncondensable gases in deep waters. A persistent problem in OTEC systems will be degassing cold water brought from considerable depths.



SERI's Penney (left) and Bharathan (third from left) with coworkers Jay Althof (second from left), Brian Parsons (top right), Sung Ho Jo (seated), and Ken Penner; in background is SERI vacuum test chamber

Bharathan lists four types of OTEC systems so far proposed for consideration. One is the closed, Rankine cycle, which uses an enclosed secondary working fluid. That type was demonstrated to be technically feasible in 1979 with a Mini-OTEC unit in Hawaii. The Mini-OTEC system was barge-mounted. The first commercial shore-based, closed-cycle plant was started up in 1981 in the Nauru Islands (Republic of Nauru) with the cooperation of Tokyo Electric Power Services Co. It is intended to produce power but not fresh water.

About half the costs of closed-

cycle plants go for heat exchangers, the most critical components for closed cycles. Some of the main problems in closed-cycle systems have been biofouling and corrosion in the heat exchangers. Most of the development work in closed cycles has been devoted to achieving higher heat-exchange efficiency and minimizing the fouling and corrosion. So far, success has been minimal.

The second type, open-cycle systems (Claude cycles), use the steam directly as the working fluid to drive turbine generators. That eliminates the need for most of the heat exchangers, but it requires very large

turbines because of the low steam density. Most development effort with such systems has been devoted to achieving more-efficient turbines and to work on direct-contact heat exchange, gas desorption problems in seawater, and gas exhaust.

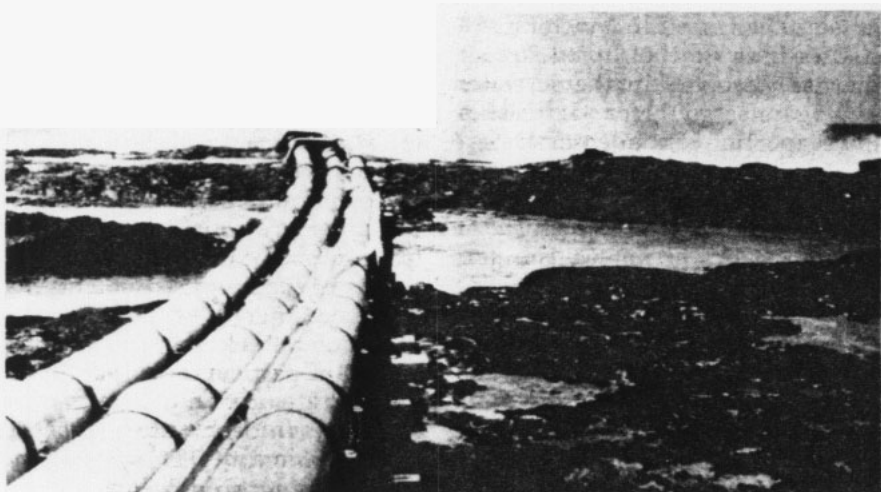
The SERI experimental system represents the furthest advance in open-cycle systems to date. At the same time, however, the most advanced low-pressure turbine designs have been produced in France. Adaptation of existing French designs for certain types of low-loss turbines would be the most appropriate for the SERI experiment.

The third system proposed for OTEC is the staged open-cycle system, which, in theory, is more efficient than simple systems. The staging is envisioned to occur between different annular sections of the turbine. At present, however, such special turbines are still too complex and costly to warrant their use in operational system designs.

The fourth concept is the mist-lift system, which utilizes the work of expansion that is derived from evaporating a two-phase mixture. This increases the potential energy of the warm water used to drive a hydraulic turbine. The concept has yet to be demonstrated technically on a practical scale with seawater.

Most present attention is focused on the relative merits of open- and closed-cycle systems. Although closed-cycle systems have the distinction of being first in commercial use, they have experienced operating problems. In open-cycle systems, many of the individual units can be made from inexpensive polymer materials, and there is little chance of significant biofouling. Also, there is little chance of chemical pollution of any kind because no intermediate working fluid is present. However, water discharged from an OTEC plant may be deficient in dissolved gases and could require aeration before being returned to the sea.

One attraction of open-cycle OTEC plants is that they produce fresh water as a by-product. The greatest drawback to open-cycle plants at present is the need for better turbines, which must be housed in vacuum shells. □



OTEC cold-water pipe installed at NELH