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The Solar Ocean Energy Liaison

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Solar
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INCORPORATING
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# INDIA'S OCEAN ENERGY PROJECTS

**With over 4200 miles of warm-water coastline, India (the mainland and its island possessions) is endowed with one of the largest OTEC-resource bases in the world. This extensive coastline also provides access to another potential source of renewable energy: waves. The following two-part article describes how India is looking to the sea to provide a portion of its future energy supply.**

## OTEC

In mid-1980 an interdisciplinary working group was formed at the Indian Institute of Technology (IIT) in Madras to study OTEC. Their first report was a summary of the state of the art of OTEC. In their second study, the working group recommended focusing on the ammonia/closed-cycle option for early domestic applications. Their third effort involved the conceptual design of a one-megawatt plant using data from a specific site.

Based on information provided by the Tamil Nadu Electricity Board, a site near Kulasekarapatnam on the east coast of the state of Tamil Nadu was chosen. The site is protected from storms on the east by Sri Lanka. The thousand-meter depth contour is about 40 kilometers offshore, so a floating plant was proposed. A preliminary design was prepared for a one-megawatt floating closed-cycle plant utilizing shell-and-tube heat exchangers. The report was submitted in November 1981 to the Commission for Additional Sources of Energy (CASE) of the Indian Government.

An Ocean Energy Project Cell was then formed at the Ocean Engineering Center of IIT with funding from CASE. The purpose of the Project Cell was to continue investigations into OTEC for India and to coordinate the activities of an OTEC-project group consisting of the National Institute of Oceanography, Goa; Bharat Heavy Industries, Hyderabad; Engineers India Limited, New Delhi; Mazagon Docks Limited, Bombay; and IIT, Madras.

In April 1982 CASE requested that the project team investigate the feasibility of siting an experimental one-megawatt plant off the Lakshadweep (Lacadive) Islands. These coral-based islands are situated in the Arabian Sea about 500 kilometers from the southwestern state of Kerala. A project team visited the islands in August 1982 and found two suitable sites: one off the capital island of Kavaratti, and the other off Minicoy Island. The 1,000-meter depth contour is within two kilometers of the shore, and a delta-T of 20° to 22° Centigrade between the surface and the depth

(continued on Page 4)

## Waves

Due to the relatively low wave-energy potential in India compared to northern latitudes, a wave-energy system designed just to produce electricity is not seen as being commercially viable in the near future. However a multi-purpose wave-regulator system would have enough benefits to make such a system commercially attractive. Such a system has been proposed by Professor Indiresan, Director of IIT. The wave-regulator system would have the following objectives: to absorb wave energy by providing a long barrier and to convert the energy into electricity; to use the calm pool in the lee of the barrier for several purposes, such as a harbor, an aquaculture site, or a light-craft waterway for coastal transportation; and to protect the shoreline from erosion by wave action. To serve multiple purposes, the system would be deployed in about 10 meters of water about 200 meters from shore. Suitable locations exist at many points along the Indian coast.

### US PILOT PLANT PHASE II AWARD

The Department of Energy has announced that the Ocean Thermal Energy Corporation has been awarded the sole contract for Phase II of the US Pilot Plant Project. Phase II will involve preliminary design of a 40-megawatt OTEC plant for Hawaii. General Electric was the other bidder in the competition. The May 20th announcement was made as this issue was going to press. Details will be forthcoming.

A three-year project to investigate the potential for such a system has been funded by the Indian Government's Department of Ocean Development. The objectives are to gather systematic data of the wave climate around India, to study various wave-energy devices, and to select the most suitable system and site. Ten scientific investigators are working full-time on this project.

After a detailed report had been prepared on the state of the art of wave-

(continued on Page 2)

# OTEC IN JAPAN: HEAT EXCHANGERS

**(Note: The following article is the second in a two-part series on OTEC development in Japan.)**

One of the technical subjects being investigated most aggressively in the Japanese OTEC program is heat exchangers. These components have an added significance for the Japanese program (over other programs) due to their commitment to utilizing non-inflammable, non-toxic Freon as the working fluid in closed-cycle plants despite its poorer performance than ammonia. The objective of the heat-exchanger development program is to reduce the size and cost of the components while improving their performance using a Freon working fluid.

At the ASME-JSME Joint Thermal Conference held in Hawaii in March, Japanese researchers presented several innovative heat-exchanger designs. In addition, the final results of the heat-exchanger tests of the 100-kilowatt Nauru plant were discussed and are summarized below.

Heat-exchanger data for the Nauru plant are shown in Table 1. On the basis of preliminary laboratory experiments, a two-stage horizontal shell-and-tube evaporator was selected for use in the Nauru facility. The shell-and-tube construction facilitates sponge-ball cleaning. A two-stage configuration, in which a third of the working fluid is evaporated in the upper, first stage and the remainder in the lower, second stage, reduces the deterioration of boiling-heat-transfer performance caused by hydrostatic-pressure increases around submerged tubes. The titanium tubes were enhanced on the working-fluid side with flame-sprayed copper particles, creating a multiporous layer. The measured overall-heat-transfer coefficient at the rated warm-seawater velocity of two meters per second (m/s) was 4300 watts per meter-squared °Kelvin ($W/m^2K$), which is 1.4 times the design value.

A two-pass, vertical shell-and-tube condenser was employed at Nauru. The outer surfaces of the titanium tubes were fluted to increase the condensing-surface area. The vertical tubes were supported by four horizontal plates which also stripped the descending condensate from the tubes. A downcomer, or scupper, drained the condensate from each support plate to the bottom of the condenser. This configura-

(continued on Page 3)

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SOLAR OCEAN ENERGY

## NOAA'S REPORT TO CONGRESS PUBLISHED

The US OTEC lead agency, NOAA, has published its annual report to Congress for FY '82 called for by the OTEC Act of 1980. The 26-page document summarizes NOAA's OTEC activities in the areas of ocean engineering, licensing-system administration, and environmental assessment. The report also mentions the investigation into OTEC export potential which was initiated in FY '82 and will be completed this year.

In the area of ocean engineering in FY '82, NOAA has lent support to the DOE pilot-plant program and has managed the cold-water-pipe test project. Also in FY '82, NOAA issued the "Guide to Permits and Regulations Applicable to US OTEC Projects", and has responded to four pre-application consultations as part of its administrative function. The environmental questions addressed by NOAA over the last year include the potential effects of OTEC on fisheries and the regional influence of OTEC operations on the physical-chemical perturbations of water masses. NOAA's OTEC office has also chaired the GESAMP (Group of Experts on the Scientific Aspects of Marine Pollution) working-group meetings in which the environmental impacts of OTEC and energy production from waves, tides, and marine biomass were examined.

Copies of the Report to Congress are available from NOAA/OME, 2001 Wisconsin Avenue Northwest, Washington DC 20235.

## NOAA REVIEWS REGULATIONS

NOAA has announced that it is now conducting the periodic review of the OTEC licensing rules called for by the OTEC Act of 1980. Public notice of this review is detailed in the May 11th issue of the Federal Register (Volume 48, Number 92, Pages 21154 through 21156). The notice is intended to provide interested persons with an opportunity to review the existing OTEC licensing regulations and to submit written or oral data and comments concerning any licensing-related issues. A public hearing may be held in Washington DC if NOAA decides that one is warranted.

NOAA seeks to determine through this review whether any aspect of the regulations has contributed to the delay in filing of license applications by industry. Among the issues to be examined are the amount of and method for determining license-application fees, the duration of the licensing process, and the nature of the information to be submitted with a license application. NOAA also invites comments on any other relevant issues.

The deadline for submission of comments is July 1st, 1983. They should be sent to Richard D. Norling, NOAA/OME, 2001 Wisconsin Avenue Northwest, Washington DC 20235. For further information see the Federal Register or contact James B. Rucker, NOAA/OME, (202) 254-3483.

## BRITISH FIRM PLANS OTEC PROJECT

The British company Ocean Thermal Energy Conversion Systems Limited is in the final planning phase of a 10-megawatt OTEC project. The proposed facility will reportedly be a floating plant sited somewhere in the Caribbean.

If it is decided to construct the facility, and financing is available, the 2½-year construction period would begin in January 1985. This project would be the first major venture of OTEC Systems, which is eyeing the large number of developing countries possessing a good thermal resource as a vast commercial OTEC market. Further details on the company and the Caribbean project will be forthcoming.

**(continued from Page 1)**

energy devices and systems, models of three wave-energy devices were fabricated and tested. These are the oscillating-water-column (OWC) system, the single-float system, and the double-float system. Model tests were conducted in the two-meter-wide regular-wave flume and the four-meter-wide random-wave flume of the Ocean Engineering Center at IIT. After these preliminary experiments, the investigators decided that the OWC system is the best for application off the coast of India. A bottom-standing OWC system will also satisfy the multi-purpose function as proposed.

A Workshop on Utilization and Regulation of Waves was organized at IIT March 14th through 17th, 1983 with the assistance of the British Council and the Department of Ocean Development. Three ocean-energy experts from the United Kingdom—Professor A. Long, Mr. S. Salter, and Mr. G. Elliot—and members of various Indian organizations participated. The Workshop discussions led to the same conclusion: that the bottom-standing OWC system is likely to be the most suitable for the Indian coast. Whether the Wells turbine or the Francis-type air turbine is the best choice for the power take-off mechanism has yet to be decided.

A narrow-flume tank with a random-wave generator for testing small models in two dimensions is currently being designed. Simultaneously, efforts are under way to gather wave data with the assistance of the Central Water and Power Research Station in Pune. A four-meter-wide model with a complete air turbine and generator system will be tested for proving the overall system viability.

By the end of two years, a module of about 10 meters in length is expected to be ready for sea trials. Based on these trials, a decision on whether to install a 100-meter-long barrier module along the Madras coast will be made. Various organizations in India will be associated with the project as required.

**(continued from Page 1)**

tion helped to maintain a uniform condensate thickness on the tube surfaces. The measured overall-heat-transfer coefficient was about 3,000 W/m$^2$K with a cold-seawater velocity of 2 m/s, which is about 20% higher than the design value.

The Electrochemical Laboratory of the Ministry of International Trade and Industry (MITI) has developed an improved condenser-tube design, called the vertical spiral double-fin tube with drainage gutters (SDFG: see the July 1982 issue of OE). Experimental work has been conducted to define the optimum configuration of the tubes, varying fin pitch and shape and the number of gutters per tube. The objective of the SDFG design is to increase the speed with which the condensate is rejected from the tube surface. The SDFG is diagrammed in Figure 1.

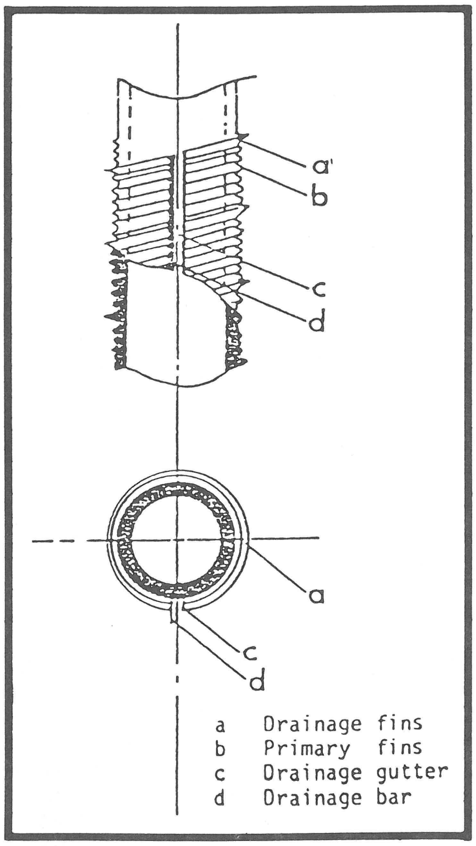

**Figure 1. Diagram of the spiral double-fin tube with drainage gutter for a vertical condenser.**

| DESIGN DATA | EVAPORATOR | CONDENSER |
|---|---|---|
| Number of Sets | 1 | 1 |
| Type | Horizontal shell-and-tube | Vertical shell-and-tube |
| Effective Heat Transfer Area | 371.4 m$^2$ | 437.6 m$^2$ |
| Heat Duty | 4024 kW | 3911 kW |
| Overall Heat Transfer Coefficient | 3000 W/m$^2$K | 2559 W/m$^2$K |
| Total Length | 8 m | 9.1 m |
| Shell Inside Diameter | 1.9 m | 1.5 m |
| Material: | | |
| Shell, Support plates | Carbon Steel | Carbon Steel |
| Tube sheets | Titanium-clad steel | Titanium-clad steel |
| Tubes | Titanium | Titanium |
| Water Boxes | Carbon steel with tar-epoxy coating | Carbon steel with tar-epoxy coating |
| Tube Specifications: | | |
| Outside Diameter | 25.4 mm (excluding sprayed layer) | 25.4 mm |
| Thickness | 0.7 mm | 0.6 mm |
| Total Length | 5.66 m | 6.916 m |
| Effective Length | 5.35 m (enhanced) | 6.0 m |
| Thickness of Cu Coating | 150 μm | NA |
| Groove Depth | NA | 0.5 mm |
| Groove Pitch | NA | 1.0 mm |
| Effective Length per Section | NA | 1.2 m |
| Number of Tubes | 870 | 914 |
| Tube-to-tube Sheet Joint | Welded | Welded |
| WORKING FLUID | | |
| Mass Flow Rate | 74000 kg/h | 74000 kg/h |
| Liquid Temperature | 13.1°C | 13.1°C |
| Vapor Pressure | 1.04 MPa (Boiling) | 0.747 MPa (Inlet) |
| Boiling Temperature | 24.8°C | NA |
| SEAWATER | WARM | COLD |
| Mass Flow Rate | 1.45x10$^6$ kg/h | 1.41x10$^6$ kg/h |
| Inlet Temperature | 29.8°C | 8.1°C |
| Outlet Temperature | 27.3°C | 10.6°C |
| Pressure Drop | 29 kPa | 37.3 kPa |
| Velocity in Tubes | 2 m/s | 1.97 m/s |
| Number of Passes | 2 | 2 |

**Table 1. Principal data on the Nauru demonstration heat exchangers.**

| Plate Type | | S | IP | P | No.1 | No.2 |
|---|---|---|---|---|---|---|
| Length | mm | 1255 | 1255 | 1450 | 1255 | 1450 |
| Width | mm | 415 | 415 | 235 | 415 | 235 |
| Thickness | mm | 0.8 | 0.8 | 1.0 | 0.8 | 1.0 |
| Number | | 60 | 50 | 100 | 54 | 168 |
| Total Surface Area | m$^2$ | 20.8 | 8.16 | 21.95 | 21.6 | 40.66 |

**Table 2. Specifications of plates.**

The working fluid condenses mostly on the primary fins and forms a thin falling film due to surface tension and gravity. The drainage fins collect the condensate falling from a group of primary fins located between the drainage fins. A vertical drainage gutter then channels the condensate from the drainage fins. The drainage bar increases the effectiveness of the drainage process. Primary-fin pitch was found to be a significant factor in performance, though the optimum surface design has yet to be determined. The results of experimental tests indicate condensing-heat-transfer coefficients 4 to 6.5 times that of a smooth tube based on actual surface area. The overall-heat-transfer coefficient based on nominal surface-tube area increased 3 to 3.5 times in comparison to a smooth tube.

Researchers at Saga University have been testing various plate-type heat exchangers at the Imari-2 facility on the shores of Imari Bay, Saga Prefecture. Shell-and-plate heat exchangers are less costly and more compact than their shell-and-tube counterparts. In the Imari-2 experiments, five titanium-plate designs were tested: three for the evaporator (smooth, impinging, and porous) and two for the condenser (called Numbers 1 and 2). Both ammonia and Freon (R-22) were used as working fluids in the tests. Plate specifications are given in Table 2.

The smooth plate (s) is fluted only on the working-fluid side. The impinging plate (IP) has working fluid impinging on the lower half of the fluted side, which is enhanced with an aluminum powder. The porous plate (P) is fluted and coated entirely with aluminum powder on the working-fluid side, but lacks the impingement.

The two condenser plates have similar surface conditions and differ only in their dimensions and working-fluid-port configurations. They both have large and small flutes in a "chevron" arrangement on the working-fluid side. The pitch of the small flutes is 1 millimeter, and that of the large flutes is 10 millimeters. Drainage channels are also provided. The Number 1 plate has triangular working-fluid ports, the vapor intake being about twice the size of the liquid-exit port. The Number 2 plate has round working-fluid ports which are the same size for vapor and liquid.

**(continued on Page 4)**

(continued from Page 3)

The performance tests showed that the porous plate has the highest overall-heat-transfer coefficient of the three evaporator designs. Values of 4,000 to 4500 W/m$^2$K and 3500 to 4,000 W/m$^2$K were reached for ammonia and R-22 respectively at a warm-water velocity of 1 m/s. On the condenser side, the Number 2 plate had a higher overall-heat-transfer coefficient than the Number 1 plate. Values of 3800 to 4500 W/m$^2$K for ammonia and 2,000 to 3500 W/m$^2$K for R-22 were recorded for the Number 2 plate. In addition, the cold-water head loss in the condenser was about 10 times greater for the Number 1 plate than for the Number 2 plate at the 1-ms velocity.

The Mechanical Engineering Research Laboratory of Hitachi Limited has been testing an innovative plastic-ceramic (P-SiC) plate heat exchanger. Some silicon-carbide (SiC) ceramics have a thermal conductivity of up to 230 W/mK, 15% higher than for aluminum, and are highly corrosion-resistant. If proven technically feasible, P-SiC heat exchangers could drastically reduce the overall cost of an OTEC plant.

Laboratory tests have been conducted using cold and hot water to determine convection-heat-transfer rates. An aluminum heat exchanger of the same basic design was simultaneously tested for comparison. A boiling experiment was also conducted on the P-SiC plates to study the feasibility of using them in OTEC evaporators.

A section of the plate-fin configuration is diagrammed in Figure 2. Table 3 gives the specifications of the tested heat exchangers. Figure 3 shows the relationship between the overall-heat-transfer coefficient (U) and mean Reynolds number (R$_{em}$) established in the experiments (points) in comparison to the calculated values (lines).

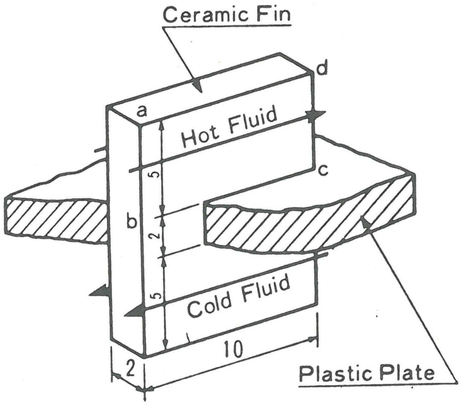

**Figure 2. Diagram of plastic-silicon carbide heat-exchanger unit.**

The boiling-heat-transfer coefficient was found to be about 10$^3$W/m$^2$K at a delta-T of 3° to 10° Centigrade. In OTEC plants with a delta-T of 2° to 3° across the plates, an overall-heat-transfer coefficient (U) of 3,000 to 5,000 W/m$^2$K is desired. However with the P-SiC heat exchanger, a U-value of only 800 W/m$^2$K at a delta-T of 2.8° Centigrade was obtained in the tests. These results indicate that a surface enhancement such as increasing boiling-side porosity is needed.

| Heat Exchanger | | Number 1 | Number 2 | Number 3 |
|---|---|---|---|---|
| Flow Configuration | | ---------Counter Current-------- | | |
| Plates: | | | | |
| Material | | ----Acrylic Resin---- | | Aluminum |
| Number of Plates | | 1 | 5 | 2 |
| Heat Transfer Area | m$^2$ | 7.84x10$^{-3}$ | 1.46x10$^{-1}$ | 5.84x10$^{-2}$ |
| Fins: | | | | |
| Material | | SiC | SiC | Aluminum |
| Number of Fins | | 112 | 2015 | 816 |
| Heat Transfer Area | m$^2$ | 1.12x10$^{-2}$ | 2.02x10$^{-1}$ | 8.06x10$^{-2}$ |
| Thermal Conductivity | W/mK | 230 | 139 | 113 |
| Configuration of Fins | | In-Line | ------Staggered------ | |
| Heat Transfer Area Based on Plates | m$^2$ | 1.04x10$^{-2}$ | 1.86x10$^{-1}$ | 7.45x10$^{-2}$ |
| Flow Area | m$^2$ | 4.00x10$^{-5}$ | 1.83x10$^{-3}$ | 7.30x10$^{-4}$ |
| Characteristic Length | m | 3.20x10$^{-3}$ | 5.29x10$^{-3}$ | 5.71x10$^{-3}$*<br>4.44x10$^{-3}$* |
| Volume of Heat Exchanger | m$^3$ | 1.21x10$^{-4}$ | 2.24x10$^{-3}$ | 8,94x10$^{-4}$ |

*Top-Hot side; Bottom-Cold side

**Table 3. Specifications of the P-SiC and aluminum heat exchangers tested.**

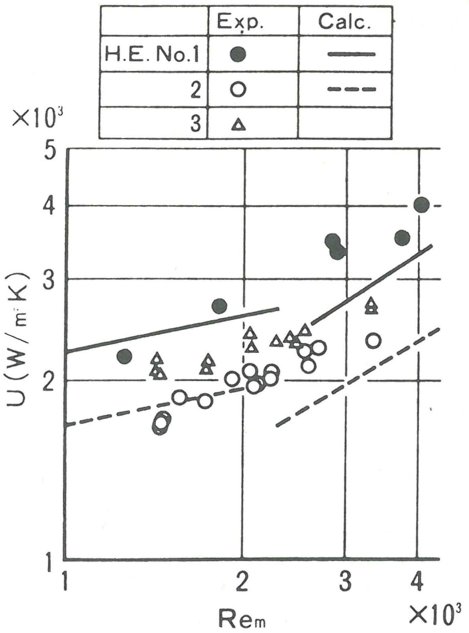

**Figure 3. Calculated values (lines) and experimental values (points) of overall heat-transfer coefficients (U) and mean Reynolds number (R$_{em}$) for P-SiC (Numbers 1 and 2) and aluminum (Number 3) heat exchangers.**

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of 1,000 meters persists all year round, making either site suitable for a shore-based plant.

A polyethylene cold-water pipe 1.5 meters in diameter was proposed, but further studies on pipe deployment were found necessary. Detailed pipe-design and deployment investigations, as well as bathymetry and oceanography studies, are now under way. A feasibility report will be submitted to CASE for a final decision on implementation of the project when these studies are complete. According to Dr. M. Ravindran, Director of the Ocean Energy Project Cell at IIT, operation of the plant could commence within 54 months after approval of the plan.

An aquaculture operation, utilizing the nutrient-rich cold-water discharge, is proposed for the large lagoons on the western sides of the island sites. The aquaculture project is expected to contribute significantly to the overall project revenues.

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## US GOVERNMENT PROCUREMENT INVITATIONS AND CONTRACT AWARDS

Listed below are procurement invitations and contract awards related to OTEC in particular and ocean resources in general culled from the Commerce Business Daily. This is not to be construed, however, as a complete list.

**Apr 25: Continued Research in Physical, Chemical, Biological, Geological, Optical, Acoustic Oceanography and Ocean Engineering:** Contract N00014-79-C-0004, April 4th, 1983 (no RFP), for $1,613,800, awarded to the Oregon State University School of Oceanography, Corvallis, Oregon 97331. Office of Naval Research, 800 North Quincy Street, Arlington, Virginia 22217.

**May 10: Operation of OTEC Seacoast Test Facility at Keahole Point, Hawaii:** Negotiations are being conducted with the Research Corporation of the University of Hawaii, 1110 University Avenue, Honolulu, Hawaii 96826. Argonne National Laboratory Procurement Department, 9700 South Cass Avenue, Argonne, Illinois 60439.

**May 10: Expansion of Research on Pacific Oceanography:** Contract N00014-80-C-0252, April 19th, 1983 (no RFP), for $113,721, awarded to the Regents of the University of Washington, 201 Administration Building, AG-20, Seattle, Washington 98195. Office of Naval Research, 800 North Quincy Street, Arlington, Virginia 22217.