1982 Annual Report

The Natural Energy Laboratory of Hawaii

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To:

The Honorable George R. Ariyoshi
Governor of Hawaii

The Honorable Richard S.H. Wong
President of the Senate

The Honorable Henry H. Peters
Speaker of the House of Representatives

Preface

Fiscal Year 1982 has been one of significant changes for the Natural Energy Laboratory of Hawaii (NELH). The Seacoast Test Facility (STF) completed at NELH in 1981 has produced high quality data continuously throughout the year, in spite of a mid-year interruption of the flow of federal funds. Continuing state support of this vital program has been widely acclaimed throughout the OTEC community.

Installation and operation of a milelong 12" diameter cold water pipe and pumping system have made NELH the only laboratory in the world that can provide a continuous supply of both warm surface seawater and cold deep seawater to a laboratory. This system can provide large volumes of flowing seawater at any temperature between the 10.5° C cold water maximum and the 24° C warm water minimum. This resource has already attracted several aquaculture research projects to NELH, and further expansion of such research appears likely.

The OTEC data collection program and the on-going cold water aquaculture of exotic plants and animals such as *nori*, lobster, salmon and abalone provide a significant basis for optimism regarding the future of NELH.

John P. Craven
Chairman
NELH Board of Directors

Contents

Introduction

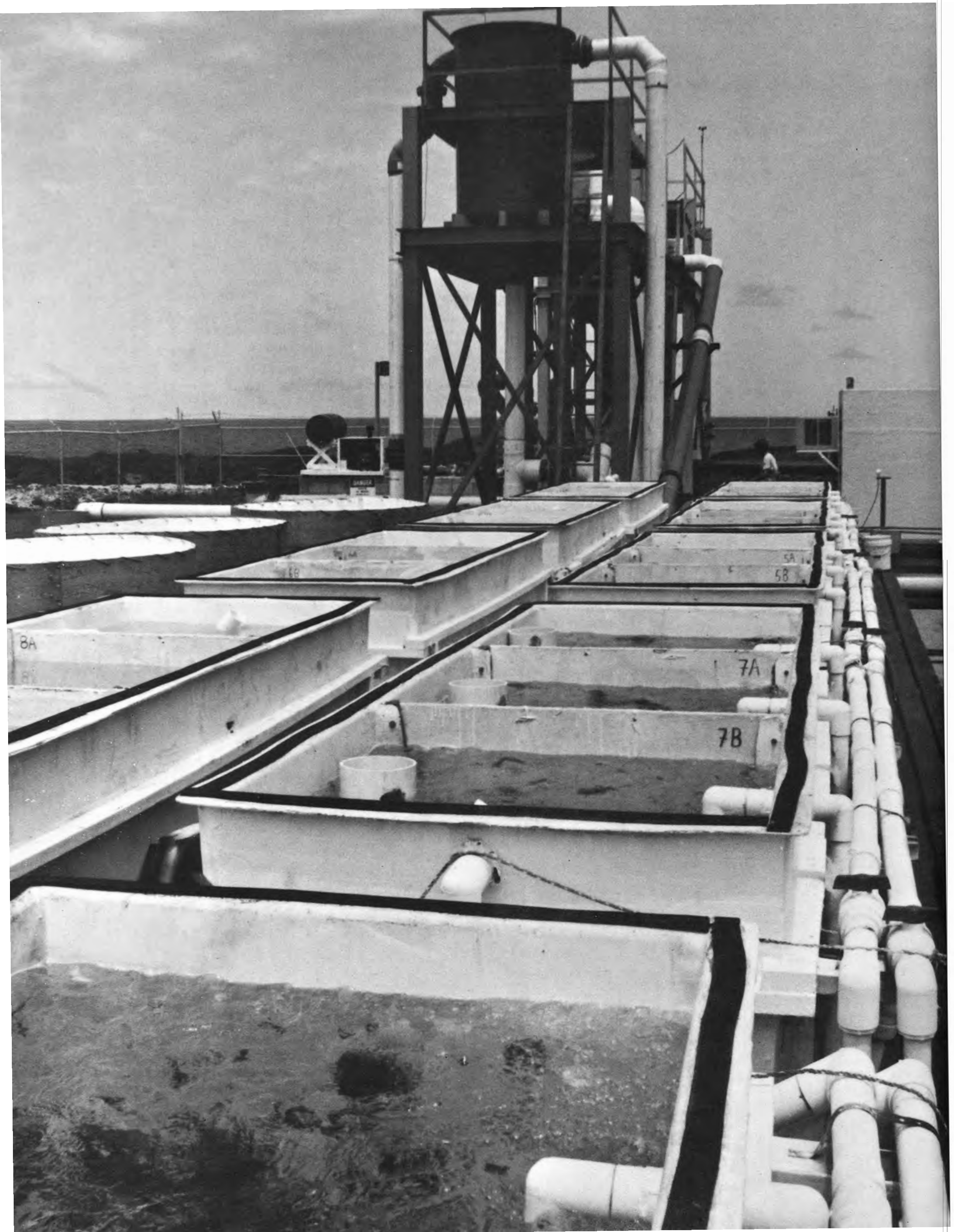
This report summarizes Fiscal Year 1982 activities and projects associated with the Natural Energy Laboratory of Hawaii.

NELH was created by the Hawaii State Legislature in 1974 as a facility for natural energy research. It is located on 328 acres of state-owned land at Ke-ahole Point, adjacent to the Ke-ahole Airport on the Kona Coast of the Island of Hawaii. This site was chosen because of the nearby availability of cold, deep ocean water; a warm ocean surface layer not subject to strong seasonal cooling; high annual solar radiation; accessibility to logistical support through airports, harbors, and highways; and the presence of adjacent, suitable undeveloped land. Among the nine sites investigated, Ke-ahole Point is unique in meeting all of these major criteria.

NELH is governed by a Board of Directors consisting of the Director of Planning and Economic Development of the State of Hawaii, the State Marine Affairs Coordinator, the Chairman of the Board of Land and Natural Resources, two officers or employees of the University of Hawaii appointed by the President of the University, and two County of Hawaii officials appointed by the Mayor of the County.

The Board is responsible for maintaining NELH property, reviewing and approving research proposals from prospective users, and planning and coordinating the development of the NELH site. While NELH personnel may become directly involved in research, the primary function of NELH is to serve as the facilities manager for the research activities of others. The Board has engaged the services of the Research Corporation of the University of Hawaii to provide administrative services. Plans call for the NELH to become self-supporting through collection of users' fees.

NELH welcomes research proposals from both the public and private sectors. With the approval of the Board, researchers may arrange to share existing facilities or construct their own. Areas of planned expansion are OTEC, OTEC aquaculture, solar ponds, and direct solar energy applications research. The Appendix contains the NELH Policy on Project Acceptance. Inquiries concerning NELH should be addressed to the Executive Director.



Summary of Activities

INSTITUTIONAL DEVELOPMENTS

Funding Changes

During fiscal year 1982, Federal support for the operation of the Seacoast Test Facility was interrupted, but NELH continued the OTEC biofouling, biofouling countermeasures and corrosion studies begun under a Department of Energy (DOE) contract through Argonne National Laboratory (ANL). The experiments have continued under the direction of Dr. Jorn Larsen-Basse of the University of Hawaii Department of Mechanical Engineering. Results, discussed elsewhere in this report, are attracting wide attention and praise for the high quality of the data.

Planning Workshop

In February 1982, the Hawaii Natural Energy Institute (HNEI) sponsored a workshop for discussing potential uses of the laboratory facilities. The many ideas presented by experts from industry, government and universities led to formulation of guidelines for new project development. They emphasize the importance of synergistic schemes combining energy production with aquaculture, agriculture and other projects including fresh water production and possible extraction of trace metals from sea water. Workshop participants stressed the importance of detailed study of the properties of the deep cold water that is continually being pumped through the laboratory.

Staff Changes

Some changes in the laboratory staff have helped NELH to meet the requirements of operating the OTEC experiments while developing new aquaculture projects. A laboratory director, appointed to work at Ke-ahole Point facilitating and coordinating the various programs, brings the total core staff of the laboratory to eight full-time employees, five of whom can provide direct project technical support.

FACILITY DEVELOPMENTS AND STATUS

Fiscal Year 1982 saw the installation at NELH of a unique cold seawater supply system pumping 340 gallons per minute of seawater from a depth of 2,000 feet into the laboratory. This system, installed by the State for aquaculture research, represents a major engineering achievement and a valuable scientific resource.

Cold Water Pipe Deployment

Deployment of this one-mile-long, 12" diameter polyethylene cold water pipe off Ke-ahole Point presented an unusually challenging engineering project. The pipe was assembled at Kawaihae Harbor and floated to Ke-ahole where it was deployed in two sections. Concrete anchors hold down the upper section of pipe extending from shore to 500-foot depth, while the lower portion floats off the bottom in a buoyant catenary from 500 feet down to the intake at 2,000 feet. Calm weather and much hard work made the November 1981 deployment successful and, after difficulties installing the submersible pump, the system began pumping deep cold water in late February.

Pumps

The submersible cold water pump, deployed at 30 foot depth about 100 feet from shore is made entirely from stainless steel. Though designed to produce 500 gallons per minute, the first pump actually pumped only about 340 GPM. Unfortunately, it failed in early June. The manufacturer agreed to provide two 500 GPM all stainless steel pumps at minimal cost. These will be installed in fiscal year 1983 with automatic switchover to allow one pump to serve as backup for the other.

Discussions with potential users have indicated that 500 GPM will satisfy NELH's cold water needs for the foreseeable future. Thus, plans to install three 750 GPM pumps to achieve (with redundancy) the pipe design capacity of 1,500 GPM have been set aside.

Warm Seawater Supply

The NELH warm surface seawater supply system, refurbished in fiscal year 1981, has operated continuously this fiscal year. This has permitted collection of the longest series of heat transfer data ever assembled for flowing tropical surface seawater. These heat transfer measurements have shown a much more rapid initiation of biofouling than indicated by previous experiments in Puerto Rico and on a buoy offshore of NELH. Though water quality analyses of nearshore and offshore waters indicated no significant differences, the location of the NELH warm water intake only about 15 feet from shore appears to be a likely source of the difference. A 300 foot extension to the warm water intake has been designed, and its installation in early fiscal year 1983 should provide a better understanding of the differences.

Aquaculture

Ten 600 gallon fiberglass tanks were built to support a project investigating the feasibility of raising salmon and rainbow trout using the deep cold water. Another ten 3 m^3 tanks with removable opaque covers were built to enable investigation of the feasibility of raising nori (Japanese seaweed), ogo (limu), and other valuable seaweeds. All of these tanks have individual plumbing for both warm and cold water, allowing a choice of temperature between the extremes.

Chlorination Study Facilities

Seven 1,000 gallon tanks and some smaller fish tanks, most of them chlorinated, with some serving as controls, were installed for a project sponsored by HNEI to investigate the effects of low chlorine levels on a marine food chain.

Facility Capabilities

As of June 30, 1982, the NELH had the following operational support capabilities:

WARM SEAWATER SUPPLY

2,000 gpm
24° C to 28° C

COLD SEAWATER SUPPLY

340 gpm (expandable to 1500 gpm)
9.0° C to 10.5° C

WATER CHEMISTRY LABORATORY

Flow
Temperature
Salinity
Suspended solids
pH and alkalinity
Nutrients
Dissolved oxygen
Biochemical Oxygen Demand (BOD)
Residual Chlorine

TECHNICIAN SUPPORT

Mechanical
Electronic/instrumentation
Diving

FACILITIES

Laboratory space (in & outdoor)
Shop and warehouse support
Office space
Offshore research corridor
24' workboat

RESEARCH ACTIVITIES AND RESULTS

OTEC Research

The biofouling, corrosion and biofouling countermeasures experiments, initiated as the primary focus of the Seacoast Test Facility, have several major goals. They will establish a high quality baseline of long-term heat transfer measurements in the presence of biofouling and corrosion by flowing seawater. Other important goals include analysis of the organisms causing the biofouling, developing an understanding of the corrosion mechanisms and their effects, and investigations of the efficacy of alternative OTEC heat exchanger materials and alternative techniques for controlling biofouling.

FACILITIES

These experiments under the direction of Dr. Jorn Larsen-Basse of the University of Hawaii Department of Mechanical Engineering are performed within the laboratory building in a series of 18 one-inch plumbing loops, through each of which a constant flow of approximately 6 ft/sec can be maintained. Each active loop contains a heat transfer monitor (HTM) which allows daily measurements of the heat transfer through the wall of a section of tubing within the loop. HTMs incorporate tubing of several different candidate OTEC heat exchanger materials, e.g. titanium and various alloys of aluminum and stainless steel. Different biofouling countermeasures can be tried in each loop, and deep cold water can flow through six of them, thus allowing a complex experimental matrix. The laboratory computer controls and analyzes all HTM measurements, producing a daily value for the resistance to heat transfer due to fouling (R_f). Sample coupons following each HTM are removed periodically for detailed analysis of both biofouling and corrosion products by research teams at the University of Hawaii.

HEAT TRANSFER

The warm water system, now in continuous operation for more than a year provided several interesting results. Loops allowed to foul freely showed immediate increases in resistance to heat transfer (R_f) within a day or two and then the R_f increased at a uniform rate, passing the point where OTEC heat exchangers become uneconomical after 12 to 15 days. Free fouling loops were then cleaned with a bottle brush which brought the fouling resistance down to its initial zero level, and the cycle was begun again (fig. 1). Results were the same throughout the year except for an expected increase in the fouling rate when the water temperature was higher. The heat transfer monitoring instrumentation at NELH is so much better than that available to earlier experimenters that the curves produced show clearly a temperature effect that had not been previously detected (fig. 2).

BIOFOULING COUNTERMEASURES

Biofouling countermeasures studies conducted on other warm water loops have established several useful results. The small sponge rubber balls slightly larger than the pipe diameter, which are marketed under the name "Amertap" and which are pushed through the pipes by water pressure, do not control the biofouling completely. Use of these balls in titanium and stainless steel loops does decrease the rate of fouling, but within about 60 days the R_f increases to levels unacceptable for OTEC heat exchangers (fig. 3). The study has also shown that these Amertap balls cause unacceptably high levels of corrosion in aluminum tubes. In consequence, they were only tested in titanium HTMs.

Chlorination appears to control biofouling completely in all candidate materials. Residual chlorine levels of .05 parts per million, generated electrolytically for one hour per day, effectively keep R_f near zero in both titanium and stainless steel (fig. 4). This result has persisted throughout the 14 months of operation achieved by the end of fiscal year 1982. In addition, chlorine applied to a loop which has fouled freely to a high R_f, causes a rapid decrease back to $R_f = 0$.

Aluminum loops have shown a residual R_f which is not removed by brushing. It was found that this residual R_f can be removed by treatment with chromic-phosphoric acid, indicating that it is caused by a layer of inorganic aluminum corrosion products. When the clean aluminum alloy is treated with chlorine, the R_f remains constant at the level due to this layer (fig. 5). These experiments indicate that the low R_f due to aluminum corrosion will still allow economical OTEC operation, and that chlorination will control biofouling of aluminum.

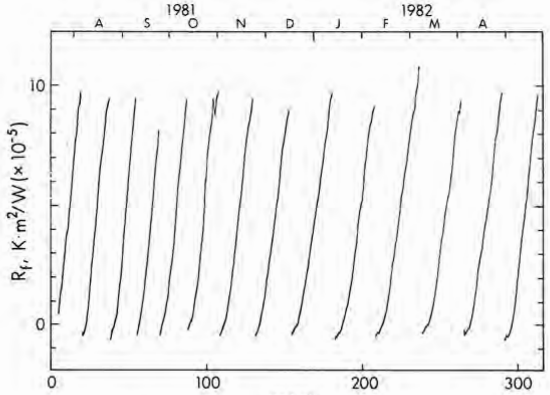


Figure 1. R_f vs time curves for free fouling titanium. R_f units are 10^{-5}x° C·m²/watt.

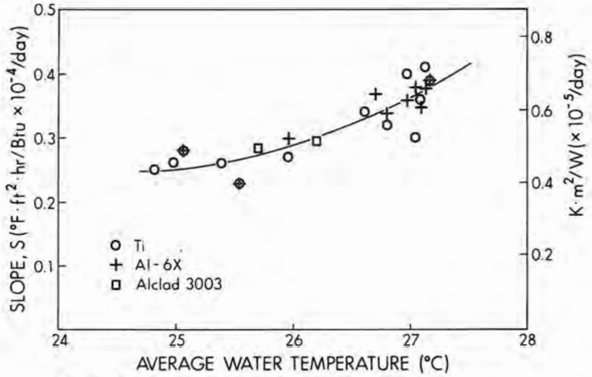


Figure 2. Fouling rate (s) as a function of average water temperature. Units for s are (° F·ft²·hr/BTU)X10⁻⁴/day (left hand scale) or (° C·m²/watt)X10⁻⁵/day (right hand scale).

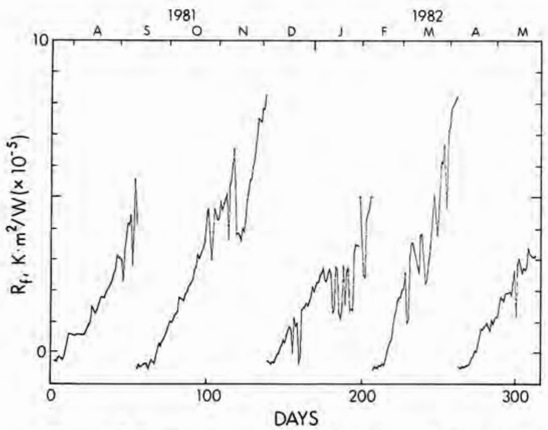


Figure 3. R_f vs time curves for titanium cleaned by 12 passes per day of sponge rubber balls plus occasional brush cleaning.

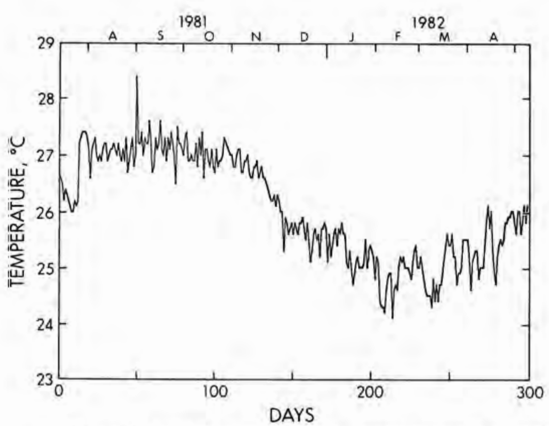


Figure 4. R_f vs time curves for titanium chlorinated at .05 PPM Chlorine for one hour per day.

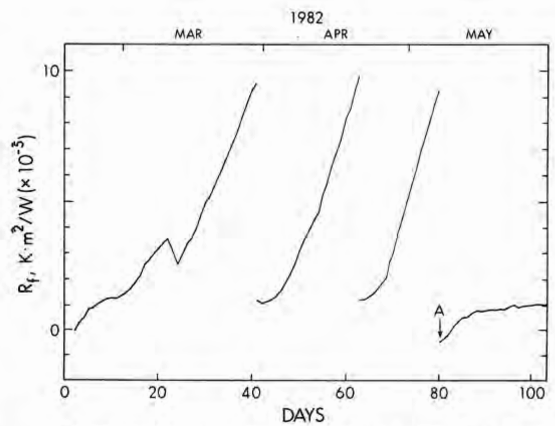


Figure 5. R_f vs time curves for free fouling Alclad 3003 (aluminum alloy coated with pure aluminum). The loop was acid cleaned at point A and chlorinated from then on.

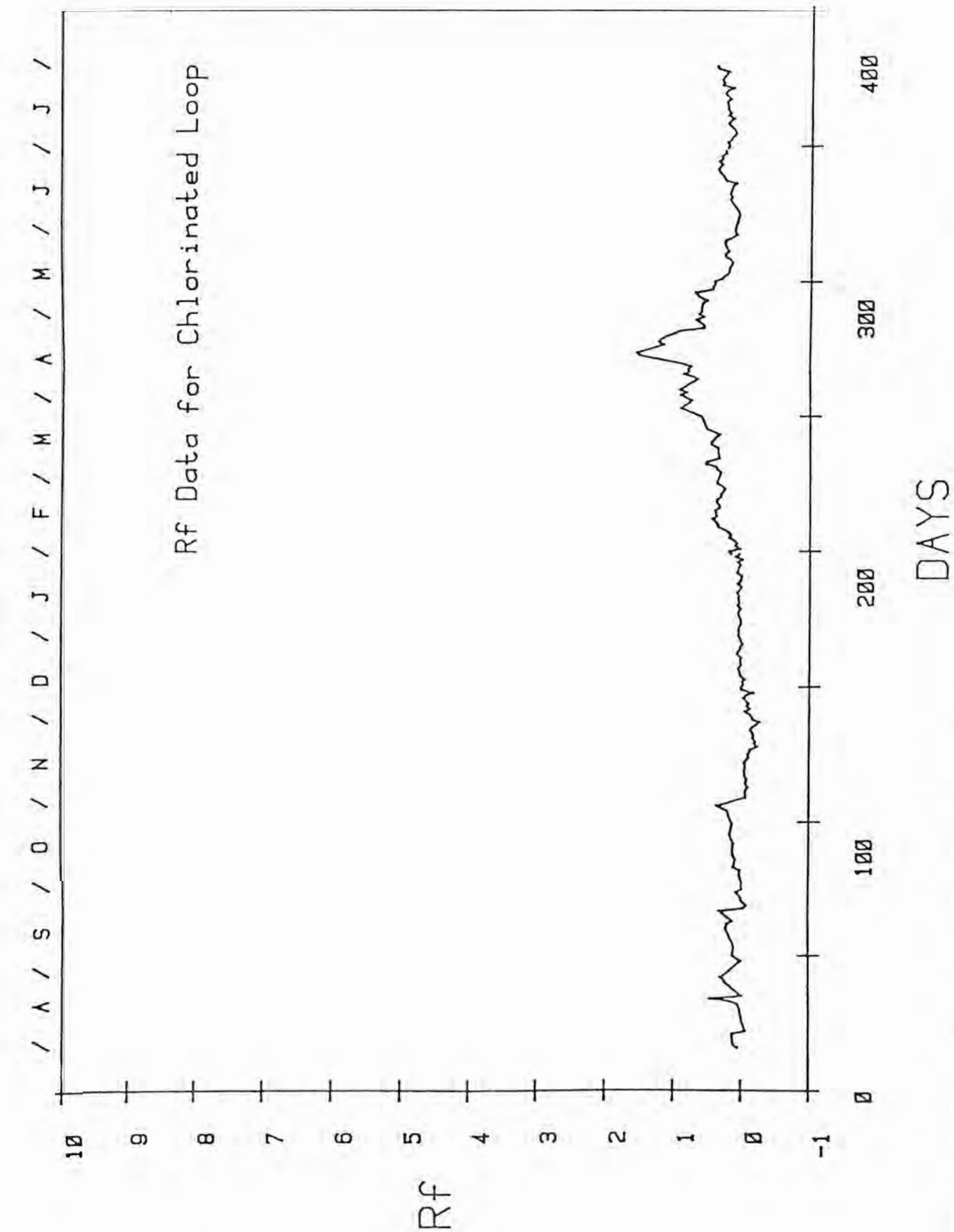


Figure 4. R_f vs time curves for titanium chlorinated at .05 PPM Chlorine for one hour per day.

NELH 1982 Annual Report - <u>Erratum</u>: p. 10

COLDWATER RESULTS

The cold seawater flowing through one rack of heat transfer monitor loops has provided an encouraging negative result. In the 104 days before the cold water pump failed, no change in heat transfer was observed. This finding will be confirmed and extended in fiscal year 1983 using the new cold water pumps. The lack of a biofouling problem in the condenser heat exchanger is indeed encouraging news to OTEC system designers.

CORROSION ANALYSIS

Examination of aluminum samples placed in warm and cold water loops for corrosion analysis has yielded results of great scientific interest and technological importance. The corrosion of the warm water samples with and without chlorination was minimal and uniform, indicating that the alloy tested could survive thirty years in a heat exchanger. Previous measurements with titanium and the stainless steel alloy used (AL-6X) indicated that these alloys do not corrode under OTEC conditions.

The cold water aluminum corrosion samples showed pitting corrosion. More study is needed to establish the seriousness of the problem for full scale OTEC condensers.

BIOFOULING ANALYSIS

Detailed analysis of the biofouling products by Dr. L. Ralph Berger, chairman of the University of Hawaii Department of Microbiology, has yielded valuable baseline information on the types of bacteria and microorganisms responsible for the fouling. The analyses have failed to indicate why the onset of fouling is more rapid in the NELH heat transfer loops than that found in previous experiments both offshore at Ke-ahole Point and in the Caribbean. Results from the warm water intake extension to be installed early in fiscal year 1983 should help in understanding this phenomenon.

CHLORINATION ENVIRONMENTAL IMPACT

Recognizing the promise shown by chlorination for control of biofouling in OTEC heat exchangers and the uncertain environmental impact that large-scale discharges might have, the Hawaii Natural Energy Institute has funded an experiment proposed by Dr. F.J. Sansone of the University of Hawaii Department of Oceanography and Dr. R.B. Spencer and Mr. F. M. Mencher of the Hawaii Institute of Marine Biology to test the effects of low-level chlorine discharges on a marine food chain. Several large tanks containing algae, brine shrimp and fish (Tilapia) are being chlorinated at 0.1 PPM continuously. At the conclusion of the experiment the organisms will be analyzed for uptake of the chlorine complexes and for possible detrimental effects on their systems. Many researchers have expressed interest in the results of this experiment, which is beginning early in fiscal year 1983.

OTEC Aquaculture Research

As noted above, potential by-products from aquaculture using the cold water discharge from an operating OTEC plant have prompted the State of Hawaii to fund facilities for research into cold water aquaculture. The unique cold seawater system at NELH has attracted several research projects investigating potential utilization of such cold water discharges.

FISH

The first two projects, with operational funding from University of Hawaii Sea Grant and the Ocean Resources Office of the State Department of Planning and Economic Development (DPED), have begun the culture of both fish and macroalgae at NELH. The fish culture project, under the direction of Dr. Arlo Fast of the Hawaii Institute of Marine Biology (HIMB), has successfully grown both salmon and rainbow trout in the deep cold water pumped to the Laboratory. These fish are hatched from eggs, some at HIMB and some in a freshwater spring in Hilo. They were transferred to NELH when they reached the smoltification stage. The salinity of the water in the 600 gallon fish tanks is gradually increased until, after about one week, it is the same as seawater. Taste tests indicate that the saltwater-reared rainbows (or "steelheads") taste as good as or better than their freshwater counterparts.

Preliminary results indicate that each 600-gallon tank can support about 300 pounds of fish if optimum flow rates and temperatures are maintained. Planned experiments are designed to determine the optimum flows, temperatures, fish densities and feed requirements. Additional research will determine whether unique properties of the deep water, such as different trace metal concentrations, might affect the fish. Future experiments proposed by Dr. Fast will investigate the smoltification process in more detail.

NORI

The macroalgae project, directed by Dr. Richard Spencer and Mr. Frederick Mencher has concentrated on growing the seaweed, nori, and has also produced encouraging results. The seaweed (*Porphyra tenera*) grown in the deep cold water exhibits very rapid growth rates, due in part to the elevated nutrient content of the water. The water temperature and light cycle have been maintained to mimic the environment of the harbors in Japan where the nori is traditionally cultured. A "tumble culture" technique involving high water flow and large volumes of air bubbled through the water has helped to provide conditions for maximum growth. This culture system has also supported the rapid growth of ogo (limu, *Gracilaria coronopifolia* and *G. bursapastoris*).

Preliminary results for nori growth show mass increases averaging about 35% per day during the first week using this system. Production rates increased with increasing biomass density to values around 40-60 dry gm/m^3/day in high density tanks containing 2-3 kg/m^3. Future experiments will investigate optimum conditions of temperature, water flow, nori density, light cycle and air flow for growth rates and quality. Though the nori produced by NELH must be processed to reach its normal marketable form (dried sheets) and the only present processing plants are in Japan, studies indicate that if a suitable cold water source could be ensured, the potential profitability of nori could justify the expense of Hawaii-based processing. In addition, a market might be developed for the raw nori, which has been readily accepted in local market tests.

MOLLUSKS

A California company has started a project testing the feasibility of growing certain gastropod mollusks in the deep cold water. Initial tests have been very successful and a pilot plant project will be constructed during fiscal year 1983.

LOBSTER

At the end of fiscal year 1982, Sanders Associates of Nashua, New Hampshire contacted NELH about the possibility of growing Maine lobster at the laboratory. Commercial prospects appear bright, and they hope to begin a pilot project in early fiscal year 1983.

Water Analysis

Throughout FY 82 many water samples were analyzed in conjunction with both the aquaculture projects and the biofouling studies. In particular, the effort to determine the cause of the rapid onset of biofouling led to a detailed study of the water characteristics both offshore and in the laboratory.

BASELINE DATA

These studies have provided much baseline data on various water parameters such as temperature, salinity, alkalinity, pH, nutrients and both particulate and dissolved carbon and nitrogen. Interruptions in funding, however, thwarted the continuous collection of these data.

CONTINUATION PLANS

The program planned for FY 83 will include a project to improve the baseline for water quality at NELH by providing continuous time series of various parameters. Weekly samples of both surface and deep water taken at the laboratory will be analyzed for all standard nutrients and water parameters by Analytical Services of the University of Hawaii. This will provide a year-long water quality baseline for future studies at Ke-ahole Point.

Other Research

ATMOSPHERIC CORROSION

An atmospheric corrosion project directed by Dr. Larsen-Basse and sponsored by the Hawaii Natural Energy Institute has collected data on the corrosion of several alloys in the marine atmosphere at Ke-ahole Point throughout the year.

SOLAR INSOLATION

Solar insolation data have been continuously recorded in cooperation with Dr. Paul Ekern of the University of Hawaii Department of Meteorology.

DEEP-SEA CABLE CORROSION

The DOE/Simplex Cable Corrosion Project, designed to analyze the survival potential in terms of macrofouling and corrosion of various materials used in the outer jacket of OTEC riser power cables, was completed during FY 82. Samples have been analyzed and returned to Simplex. A final report is in preparation.

OUTFALL ANALYSIS

Some analysis was completed on the effects of the NELH cold water outfall on the tidepools at Ke-ahole Point. Dr. Allison Kay of UH-Manoa has observed rapid growth of seaweed (*Ulva*) and sea hares (*Aplysia*) living in the nutrient-rich water. This research will continue when the new pumps are installed early in FY 83.

Future Plans

Many organizations have indicated interest in NELH as a site for research. Several projects are scheduled to begin early in FY 83.

DEMONSTRATION AQUACULTURE

Both the lobster aquaculture and the expanded marine mollusk programs noted above will start soon. Each project is basically a pilot plant demonstration of a process prior to commercialization.

SOLAR-PONDS

The design phase of a salt solar pond project proposed by SETS, Inc. of Honolulu, will begin soon with a design for an initial one-acre 30KW operating plant. These plants will use the cold water at NELH on the condenser side to provide a higher temperature differential than that available in similar projects elsewhere. Designers have proposed the acronym "SPOTEC" (Solar Pond OTEC) to describe this synergistic scheme. Estimates indicate that a 20-acre pond could provide sufficient electrical energy to run all the equipment already installed at both NELH and the Ke-ahole Airport.

NEW COLDWATER PIPE

The OTEC-1 coldwater pipe, consisting of three tubes of four-foot diameter polyethylene about 2200 feet long and now moored vertically about 14 miles northwest of NELH, is scheduled for recovery early in FY 83. The state will take possession of the pipe in Kawaihae Harbor. Present plans call for re-configuring the pipe into one four-foot diameter pipe 6000 feet long and re-deploying it down the slope off Ke-ahole Point in the Spring of 1983. This pipe will have a capacity of approximately 22,000 gallons per minute of deep cold water.

POSSIBLE OTEC PILOT PLANTS

The potential availability of the four-foot pipe and the larger volumes of water it can provide have prompted investigators from Argonne National Laboratories (ANL) and from the Solar Energy Research Institute (SERI) to propose the design and construction of operating OTEC plants at NELH. ANL has proposed a 1MW closed-cycle plant using the 48" pipe and the OTEC-1 heat exchangers, while SERI is investigating the possibility of an open-cycle plant. Neither plans nor funding are yet certain, but further federal participation at NELH appears likely.

DUMAND

The DUMAND (Deep Underwater Muon and Neutrino Detection) project plans to deploy a large array of sensors in the deep ocean off Ke-ahole Point in 1986. The power and data cables for the project will terminate at NELH, and plans are developing for a data collection and analysis facility at the Laboratory. Some exploratory experiments planned for FY 83 will investigate the effects of biofouling of the sensors in the deep cold water.

OTEC

The OTEC Heat Exchanger Biofouling, Corrosion and Biofouling Countermeasures Experiments will continue in 1983, building upon the baseline data collected in FY 82. Future participation has been proposed by Argonne National Laboratory. Planned new directions include studies of macrofouling in open troughs and investigations of some new heat exchanger configurations.

Small scale experiments investigating the efficacy of proposed open-cycle evaporators will begin early in FY 83. These will be conducted by Dr. Larsen-Basse with support from SERI.

CORROSION

Alcoa will begin an experiment early in FY 83 to test the corrosion properties of various aluminum alloys. Tubes of these materials will be installed in several loops for varying periods of time and later analyzed. The effects of chlorination on the aluminum corrosion will be studied.

Budget Summary

ABBREVIATIONS

ANL	Argonne National Laboratory
DOE	Department of Energy
DPED	Department of Planning and Economic Development
HIMB	Hawaii Institute of Marine Biology
HNEI	Hawaii Natural Energy Institute
NELH	Natural Energy Laboratory of Hawaii
RCUH	Research Corporation of the University of Hawaii
SG	Sea Grant
UH	University of Hawaii

INCOME & PROJECT SUPPORT SUMMARY

Funds Received FY-1982 (07/1/81-06/30/82)

	STATE	FEDERAL	OTHER
A. **Operational Support**			
Operational Support for NELH	$235,841/DPED		
B. **Site Studies**			
No funded projects this year			
C. **Site Development**			
Improvements to Interim OTEC Aquaculture Facilities	357,000/DPED		
D. **Ocean Energy**			
ANL Management & Operation of Seacoast Test Facility		$185,627/DOE	
E. **Mariculture**			
Salmon	11,000	14,635	$9,000
Nori	11,000	10,929	
Monterey Abalone Farms			3,015
F. **Other**			
UHM/Atmospheric Corrosion Test Project			200

Appendix

NELH POLICY ON PROJECT ACCEPTANCE

The criteria for acceptance of projects for pursuit at the NELH facilities shall be based upon the projects' relation to development of natural energy resources and also upon their utilization of those resources that are available at the NELH facility at Ke-ahole Point. Projects that are only tenuously related to alternate energy development and/or do not require the resources that are available at Ke-ahole Point shall be referred to the appropriate governmental agency for action and recommendations.

Illustrative examples include:

OTEC research

High priority, alternate energy development plus uses available NELH resource (deep cold seawater).

Solar pond power systems

High priority, alternate energy development plus uses available NELH resource (high solar radiation).

Cold water aquaculture

Medium priority, may be an adjunct to OTEC research plus utilizes available NELH resource (deep cold seawater).

Solar desalination

Medium priority, indirectly energy related and utilizes available NELH resource (high solar radiation).

DUMAND

Medium priority, tenuous relation to energy but needs proximity to undisturbed deep ocean.

Adopted by the NELH Board of Directors 21 December 1981.

STAFF

June 30, 1982

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Research Corporation of the University of Hawaii
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