AQUACULTURE USING COLD OTEC WATER

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ABSTRACT

The unique 2000 ft deep seawater pipeline installed at the Natural Energy Laboratory of Hawaii (NELH) supplies the only cold seawater available in large volumes anywhere in the tropics.

Not only does the low temperature of the cold seawater required for the OTEC process permit the tropical culture of species normally found only in colder areas, it also allows inexpensive yet precise temperature control throughout even an open culture system. The deep water also contains high concentrations of the dissolved inorganic nutrients essential to plant growth, while the near total absence of pathogens, plants and particulates makes the water particularly well suited for the culture of sensitive organisms and also for the development of pure culture strains.

THE NATURAL ENERGY LABORATORY OF HAWAII - A BRIEF HISTORY

The Hawaii State Legislature founded the Natural Energy Laboratory of Hawaii (NELH) in 1974. The enabling legislation set aside 322 acres at Keahole Point on the Big Island of Hawaii (Fig. 1) for research into renewable energy resources and also established a Managing Board of State, County and University officials to oversee its development.

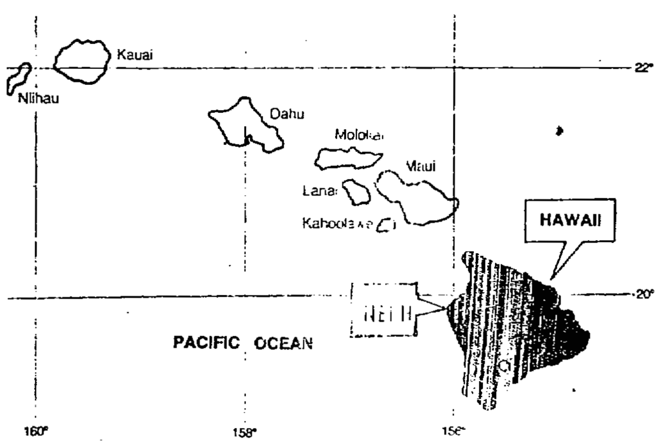

Figure 1. Site Location

From 1974 to 1979, the Federal Department of Energy (DOE) sponsored some experiments on Ocean Thermal Energy Conversion (OTEC) which were performed at NELH by researchers from various universities. During the same years, a comprehensive permitting program established all the permits necessary for performing research onshore and offshore at NELH.

Mini-OTEC, the world's first net power-producing OTEC plant, operated successfully under state and private industry sponsorship in NELH's offshore research corridor in late 1979. In the same year, construction began on the Seacoast Test Facility (STF), a joint state/DOE project aimed at providing laboratory facilities for studying OTEC processes. Only a small portion of the federal money earmarked for STF construction ever materialized, so the state increased its contribution and applied "creative engineering" to construct an operating laboratory for about one-half the original planned $16 million cost. This laboratory has met or exceeded all of the goals originally set for the full scale facility.[1]

The State of Hawaii operates NELH to encourage research, development and commercialization of alternate energy and related technologies. Since Hawaii by itself does not have sufficient financial or human resources to perform the needed research, the state's goal is to provide a facility where others from both the public and private sectors can perform the experimentation. It is planned that the facility will soon become self-supporting from user fees.

The DOE remains the major user of NELH facilities, now providing about 60% of the operational funding. The state has made efforts to broaden the NELH support base by encouraging the initiation of a range of new projects in aquaculture and related fields sponsored by both government and industry.

The state legislature has recognized the potential of these new projects, first by establishing "commercialization" as a legitimate goal of NELH and, most recently, by initiating the development of the Hawaii Ocean Science and Technology (HOST) Park adjacent to NELH. Laboratory users can now plan on both pilot scale commercial operations on land leased from NELH and eventual expansion to larger facilities in the HOST Park.

THE NELH COLD WATER PIPE

The initial STF design called for installation of three 32 in. polyethylene pipes: a mile-long deep pipe for cold water, a nearshore pipe for warm surface water and a discharge pipe for offshore discharge after experiments. These pipes were to run the 380 ft from the shoreline to a pump station at the laboratory througha trench excavated to 8 ft below sealevel. The trench was necessary since a static head is required over the intake pipes and the pumps to prevent pump cavitation caused by the suction head developed in sucking through a mile-long pipe.[2]

When funding was reduced, engineers developed a cheaper "interim" system, where the pipes run up over the sea-cliff at the shoreline. This design necessitates the installation of the deep water pumps offshore to provide the required static head.

The surface water pipe for this interim system was installed as part of the Phase I construction of the STF in 1980. Its four onshore 500 GPM pumps provide a total capacity of 2000 GPM, and water has been pumped through the system continuously since July of 1981.

When it became clear that DOE funding for the remainder of the STF would not materialize, the state took the initiative and installed the interim cold water supply system, using Capital Improvement Project funds earmarked for aquaculture. Pipe installation was completed in December 1981, and the system began pumping cold seawater in February 1982. Deep seawater has flowed onshore continuously since initial pumping problems were rectified in August 1982.

Figure 2 shows the design of the 12 in. diameter NELH interim cold water pipeline prepared by J. van Ryzin of Makai Ocean Engineering in Waimanalo, Hawaii. The offshore portion, made from slightly-buoyant high density polyethylene, is held on the bottom with concrete anchors down to the 500 ft depth, below which the bottom drops off more steeply. From that 500 ft transition point, the pipe floats in a buoyant catenary down to the 2000 ft depth where large battleship anchors hold the intake about 100 ft off the bottom. The pump station, located in about 30 ft of water approximately 100 ft offshore, contains three horizontally-mounted in-line submersible pumps arranged in parallel. Power for the pumps comes through armored cables from shore.

Experimental requirements dictated that the cold water pumps not dissolve iron ions into the water. Since fiberglass or plastic lined submersible pumps were unavailable, 316 stainless steel was specified for all wetted components. Pump performance has not yet met specifications, due to manufacturer inexperience with SS castings. Non-316 SS components have also been repeatedly discovered, in spite of certifications to the contrary. With the three pumps now installed, the system produces up to 1100

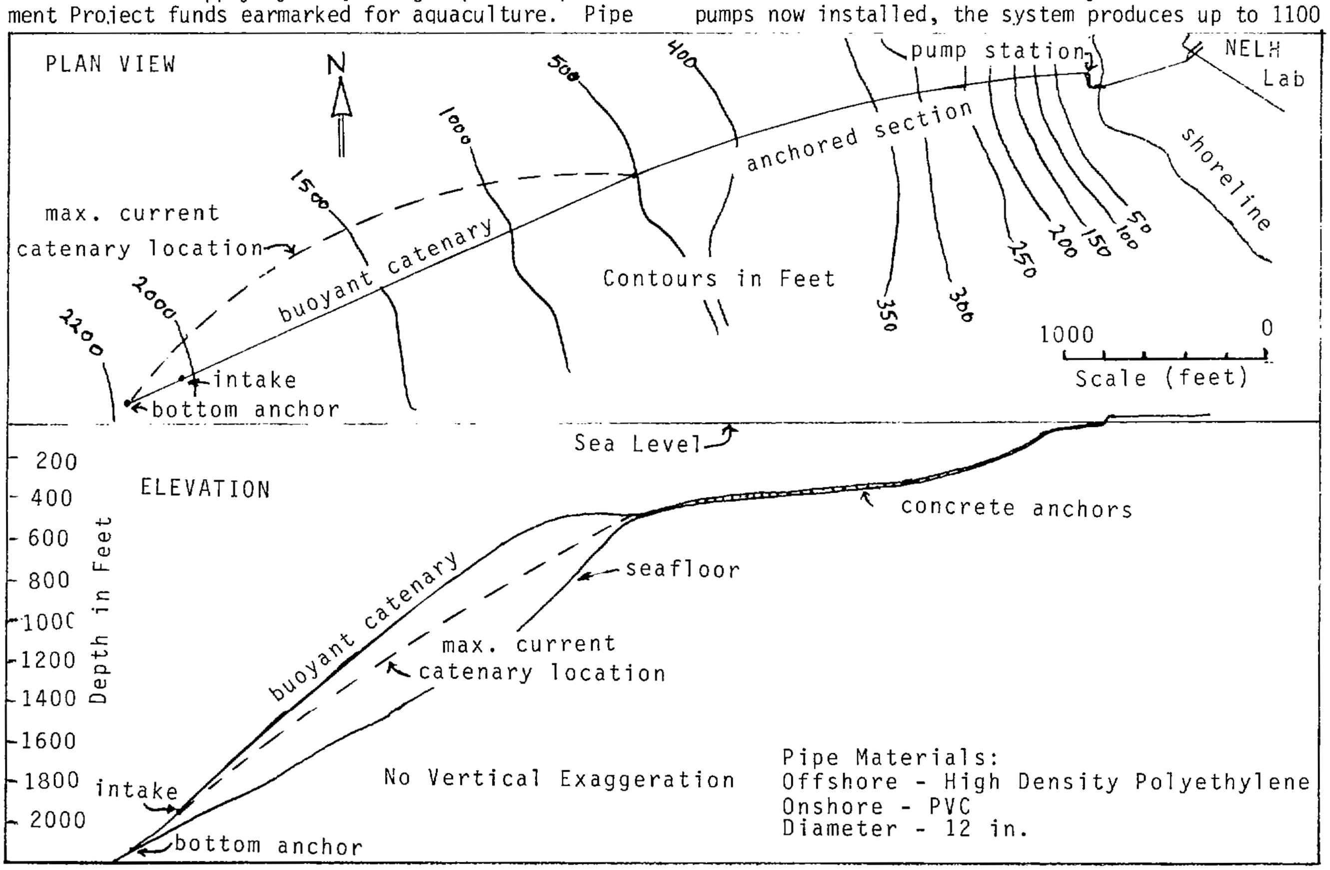

Figure 2. The NELH Coldwater Pipeline

GPM. Two new pumps planned for installation in September 1985 will together provide the 1300 GPM design capacity of the system. One of the present pumps will remain installed as a backup.

The NELH staff has developed techniques for installing and removing the cold water pumps in most wave and current conditions from a small boat. Maintenance becomes impossible, however, during extreme wave conditions which occur 20 to 30 days per year. In spite of the fact that system failures tend to coincide with extreme conditions, hard work and a generous amount of good luck have permitted nearly continuous operation for more than three years.

The polyethylene pipes survived the large waves generated by Hurricane Iwa in November 1982, but damage to the armored electrical cables resulted in several short-duration pump outages over the ensuing two months. No flow interruptions exceeding two hours occurred after that until large waves again broke the armored power cables in January 1985. A 37 hour outage at that time permitted installation of new specially designed caged-armor cables which should ensure continuous operation as long as the pumps operate and the pipeline remains intact.

The NELH cold seawater system is believed to be the only one in the world which continuously brings pure ocean water from 2000 ft deep in the sea to shore for experimentation and commercial ventures. Planning is underway for additional pipelines to be installed at NELH by both industry and government.

COLD WATER PROPERTIES

A regular sampling program has been maintained for the three years that cold water has been pumped, as part of the DOE-sponsored OTEC experiments. Weekly surface and deep water measurements of salinity, alkalinity, pH, dissolved oxygen, dissolved nutrients (NO_3,PO_4,& SiO_3), total dissolved nitrogen and phosphorus, total organic carbon, and total suspended solids supplement daily measurements of temperature and hypochlorite concentration.

Table I summarizes the results of these measurements. As was well-known from traditional oceanographic data, the deep water is significantly enriched over the tropical surface water in the dissolved inorganic nutrients which are essential to plant growth. The intake temperature of the cold water stays within the range of 5.5°C - 6.5°C (42.4°F - 43.7°F) throughout the year. The temperature delivered on shore is a function of the flow rate in the pipe: at 500 GPM the temperature is about 10°C (50°F), at 1000 GPM it is approximately 7.5°C (45.5°F).

Three properties of the cold water make it particularly useful for aquaculture:

1) Coldness - Not only does the cold water permit the culture of plants and animals which could not otherwise tolerate tropical temperatures, it also provides a simple, accurate and cost-effective means of year-round temperature control throughout a culturing system. Control of the rate of water

Table 1. WATER QUALITY DATA - NELH WARM AND COLD SEAWATER SYSTEMS

(Weekly Samples 1982-84)

PARAMETER	UNIT	WARM SEAWATER SYSTEM			COLD SEAWATER SYSTEM			RATIO - WARM:COLD
		max.	min.	mean	max.	min.	mean	
Temperature (in Lab)	°C °F	28.0 82.4	24.3 75.7	- -	10.0 50.0	7.5 45.5	- -	- -
Salinity	°/oo	35.05	34.33	34.71	34.37	34.21	34.29	-
pH	-	8.35	8.02	8.24	7.64	7.45	7.55	-
$NO_3 + NO_2$	μg-at/l*	0.50	0.05	0.17	41.70	36.80	39.62	1:230
NH_4	μg-at/l	0.76	0.20	0.47	0.76	0.06	0.34	-
PO_4	μg-at/l	0.34	0.03	0.15	3.17	2.69	3.00	1:20
Silicon	μg-at/l	11.52	1.80	3.46	84.96	69.13	77.58	1:22
Total Diss. Nitrogen	μg-at/l	7.84	2.51	4.12	48.00	37.32	42.16	1:10
Total Diss. Phosphorus	μg-at/l	0.66	0.19	0.35	3.26	2.72	3.03	1:9
Total Org. Carbon	mg C/l	1.20	0.51	0.91	0.99	0.07	0.58	-

*microgram-atoms/liter

flow, merely by opening or closing valves, permits maintenance of any temperaure between the input cold water (always less than 10°C) and the ambient air temperature (always at least 22°C). Temperatures can be maintained in this way even in open or shade-cloth-covered tanks or raceways. Note that by mixing the deep water with appropriate amounts of the flowing surface water also available at NELH, large volumes of seawater at any temperature between 10°C and 24°C (50°F and 75°F) can be obtained year-round.

2) Nutrients - The high nutrient levels of the cold deep water provide the opportunity for rapid growth rates in marine plants - either for plant production or as food for desirable animals.

3) Purity - Since the deep water comes from well below the photic zone, viable plant cells are scarce, allowing the culture of pure strains of algae without costly filtration. Bacteria and other pathogen levels in the deep water are also extremely low, permitting culture of very sensitive animal larval stages in the raw seawater.

AQUACULTURE RESEARCH PROJECTS FOR OTEC BY-PRODUCTS

Both research and commercial aquaculture projects have been conducted using NELH's cold water.[3] This section describes research projects, including those which require very large volumes of water, such as would be discharged from an operating OTEC plant. Such projects might prove very profitable in conjunction with an OTEC plant - even enough to significantly improve the overall economic viability of the OTEC process - but alone they might well be unable to support the tremendous capital investment required for installation of the required cold water supply system.

The next section will describe commercial projects which generally use less water per pound of product so that, especially for intrinsically valuable species, they may prove economically viable on their own. Such projects either use such small amounts of water that they can produce commercial amounts of product using only research volumes of water, or the product value is great enough so that pipeline installation costs become acceptable.

SALMON AND TROUT - When the cold seawater first became available early in 1982, Dr. A. Fast of the Hawaii Institute of Marine Biology (HIMB) obtained funding from the UH SeaGrant (UHSG) program and the state Department of Planning and Economic Development (DPED) to conduct an investigation into the possibility of growing salmon and rainbow trout in the cold deep water. This project continued through the end of 1984, and indicated significant potential for growing these finfish in the tropics.

Rainbow trout (Salmo kisutch) were already being grown successfully in freshwater in Hawaii, and they adapted well to the cold seawater at NELH. By maintaining high flows of aerated water, the researchers were able to keep nearly 400 lbs. of fish alive in each 600-gallon fiberglass tank. Eggs were hatched in freshwater and the fry raised to the smoltification stage, after which they were transferred to cold seawater where they grew rapidly as "steelhead".

Experiments with salmon, both "King" (Chinook - Oncorhyncus tshawytscha) and silver (coho - O. kisutch), initially gave low survival rates when the fish were transferred from fresh to salt water. Recognizing that environmental influences on the smoltification process were poorly understood, Dr. Gordon Grau initiated a separate experiment to study the effects of photoperiod and temperture on the smoltification process. Initial results indicate that photoperiod has little effect, but that lower temperatures decrease the time before smoltification.[4]

In further experiments with mature brood trout, the researchers manipulated the temperature and photoperiod to convince the fish to spawn in seawater. The eggs and sperm were then "milked" from the females and males and mixed together in freshwater. These fertilized eggs exhibited higher survival rates through the smoltification stage than had been obtained in previous experiments elsewhere.[3]

NORI - Another project initiated in the spring of 1982 with UHSG and DPED funding grew the seaweed "nori" (Porphyra sp.) under the direction of Dr. R. Spencer and F. Mencher. The nori, widely used in Japan and Hawaii for wrapping "sushi", grew well using a mixture of warm surface and cold deep seawater. Researchers experimented with various temperatures and photoperiods, and concluded that growth is best very near the conditions in the harbors where nori grows in Japan. Growth rates of about 35% increase in weight per day were achieved for the first 15 days in a tumble-culture using rapid water flow and bubbled air. More than 600gms dry weight per cubic meter were harvested after 39 days.[5] Japanese researchers are now investigating commercial nori culture prospects at NELH.

MAINE LOBSTER - Beginning in September 1982, Sanders Associates, an electronics company headquartered in Nashua, New Hampshire, performed a one year pilot test of their proprietary process for growing Maine Lobster (Homarus americanus) with partial sponsorship by DPED. Using mixtures of deep and surface seawater to control temperature at different stages of hatching and growth, they successfully grew the animals from eggs hatched in Hawaii to adults. Sanders determined that the high cost of the materials and the manpower required make the process unprofitable at the present level of wholesale lobster prices in Honolulu, so the project was terminated after one year.[6]

OYSTERS - Oysters (Crasostrea sp.) imported for a defunct project are now being grown by NELH staff. Initial attempts to culture various strains of algae to feed the oysters met with mixed success. Recently, rapid growth has been achieved by feeding the oysters with diatoms being filtered from the abalone farm's kelp tanks. This success has led to the importation of other oyster and clam species for similar experiments. Though commercial-scale growout of these mollusks in the tropics may require too much water and infrastructure to be economically viable, it does appear that the purity of the deep water may provide ideal conditions for commercial hatchery operations.

GIANT CLAMS - Dr. Murray Dailey, in cooperation with the Waikiki Aquarium, has begun a project with private and grant funds using the deep water at NELH to grow giant clams (Tridacna sp.) imported from Palau. These clams have economic potential both for their meat and for their shells which, at various stages of growth, have uses ranging from earrings to bathtubs. Since they subsist on algae which grow symbiotically within their bodies, they require no food beyond the sunlight and nutrients necessary for plant growth. The initial phase of this project, beginning in August 1985, includes research to determine the effects of the following variables: (1) the nutrient-rich water, (2) colder temperatures, (3) flow rate, (4) light spectrum and (5) spatial distribution.

CURRENT COMMERCIAL DEEP WATER AQUACULTURE PROJECTS

ABALONE - In May 1984, Hawaiian Abalone Farms (an affiliate of Monterey Abalone Farms of California) signed a long-term lease for 21.3 acres of land adjacent to the NELH compound and began development of a "Commercial Demonstration Module" of an abalone (Haliotus referens) production facility. This culminated more than two years of research at NELH which indicated the suitability of the deep cold water for abalone culture. The Company has since moved its production operations from Monterey to Kona and cleared the land for the demonstration module. They are presently installing a new coldwater pipe with their own funding, and plan to market abalone soon.

This company's research has demonstrated the useful properties of the deep cold water for aquaculture of marine mollusks. The purity of the water permits successful larval growout without expensive water purification. The high levels of dissolved inorganic nutrients in the deep water provide rapid growth rates and high protein content in both the microscopic diatoms the mollusks consume as larvae and in the giant kelp (Macrocystis pyrifera) which they eat as adults. Since the deep water is always colder than required for the various growth stages, temperature can be maintained in all systems by controlling water flow.

MICROALGAE - Cyanotech Corporation of Woodinville, Washington has recently constructed large raceways on land leased at NELH for the culture of various marine microalgae. Initial production includes Spirulina, a protein-rich microalga in great demand as a health food supplement. Though Spirulina is normally grown in fresh water, Cyanotech scientists have developed techniques for growing it in NELH's pure nutrient-rich deep seawater. The company is also growing other microalgae with very high concentrations of Beta carotene, a vitamin A precursor with a recently-discovered ability to prevent certain types of cancer. Future plans include development of other pharmaceutical products from microalgae.

The microalgae grow in oval raceways, some up to 550 ft long by 50 ft wide, with the water circulated by large paddle wheels.. The deep seawater is intentionally warmed to the higher temperatures needed for optimum algal growth during its slow passage through the pipes to the raceways. Once production in each raceway is initiated, the only water required is to replace evaporation losses. The high nutrient content of the water, its extreme purity and the high sunlight at Ke-ahole Point (the highest solar insolation measured at sea level in the U.S.), combine to provide ideal growth conditions for these microalgae.

COLD SEAWATER AGRICULTURE!

At the instigation of NELH Board Chairman John Craven, UH investigators have begun research on the possible use of the cold freshwater which condenses on the pipes carrying cold seawater to irrigate agricultural crops such as strawberries. With funding from UHSG, several beds were constructed at NELH and plumbed with various cominations of coldwater piping running both above and below the soil.

Initial results show that sufficient water condenses from the ambient air at Ke-ahole Point to provide adequate irrigation for strawberry growth. In addition, the strawberries grown using this cold condensed water consistently have about five times the sugar content of control plants watered with ambient temperature tap water. Varying the flow rate of the cold seawater also allows control of the root temperature of the plants, providing the possibility of rapid seasonal cycling for increased fruit production. The initial six-month pilot project conducted in 1984 demonstrated the usefulness of the coldwater agriculture concept, and further work is planned soon.

FUTURE PLANS

Recognizing the significant commercial possibilities developing from the coldwater research at NELH, the state government has begun development of the Hawaii Ocean Science and Technology (HOST) Park on 547 acres of land adjacent to the NELH property. Park sites, ranging in size from three acres to 100 or more acres, will be leased to companies wishing to take advantage of the unique natural attributes of Ke-ahole Point for production of aquacultural, energy or related products.[7]

Initially proposed by the Hawaii High Technology Development Corporation as an appropriate area of "High Tech" for Hawaii, the HOST Park has now received support from Governor Ariyoshi and the legislature. Design work is underway, and the infrastructure (including warm and cold seawater systems) will be completed in 1986.

In addition to the new pipelines planned for the HOST Park and for Hawaiian Abalone Farms, DOE is presently contracting for final design of a new 30 in. pipeline for OTEC research. Each of these pipelines will give some measure of redundancy to the NELH seawater system, providing the increased reliability which is particularly desirable for aquaculture research and development.

NELH will continue to provide research, development and pilot-scale "incubator" facilities for projects which may eventually expand into the HOST Park facilities. The capability of combining research with pilot scale production makes NELH a unique site for important stages of commercial development. New ventures can now utilize these unique advantages, knowing that full-scale development may follow at the HOST Park.

ACKNOWLEDGEMENTS

Chairman John Craven and the other unpaid members of the NELH Board are largely responsible for the success of the laboratory. The work reported here has been performed by many researchers and companies, all of whom deserve credit for their efforts.

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