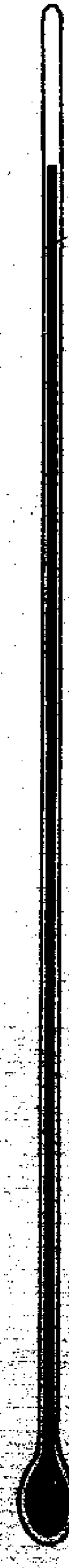
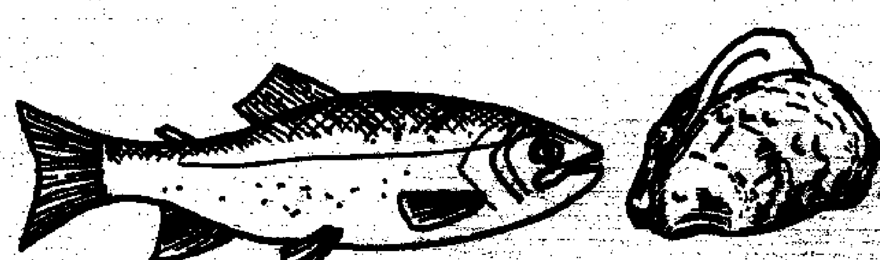


UTILIZATION OF THERMAL EFFLUENT IN AQUACULTURE:

IDENTIFICATION OF RESEARCH AND DEVELOPMENT NEEDS



Workshop Proceedings: University of Massachusetts Aquacultural Engineering Laboratory
Wareham, Massachusetts, October 23, 1975
Co-hosted by M.I.T.-U. Mass. Joint Sea Grant Program and New England Marine Advisory Service

PROCEEDINGS

Workshop

on

"Utilization of Thermal Effluent in Aquaculture:

Identification of Research and Development Needs"

October 23, 1975

University of Massachusetts Aquacultural

Engineering Laboratory, Wareham, Mass.

Co-hosted by

M.I.T.-UMass Joint Sea Grant Program
and
New England Marine Advisory Service

PREFACE

The purpose of the workshop was to stimulate information sharing among professionals. Participants were researchers, managers, and administrators who know through experience what the problems are in the utilization of thermal effluent in aquaculture. The program was organized to promote informal communication. During the morning, speakers reported to the assembled participants their conclusions on what they view as pertinent research findings and their assessment of the obstacles to and needs for continued research and development (R & D) in the utilization of thermal effluent. Presentations were brief, and purposefully did not deal with research methodology or the delivery of substantiating statistical evidence. Instead, each speaker presented the nub, or essence, of what he deemed relevant to the utilization of thermal effluent in aquaculture. Participants met during the afternoon to exchange R & D information and to discuss the presentations, which have been compiled into this Proceedings.

The New England Marine Advisory Service (NEMAS) is an association of advisory, extension, and education programs in the northeast. Designed to support and augment the member programs' marine advisory efforts, NEMAS is headquartered at the New England Center for Continuing Education in Durham, New Hampshire, and provided regional coordination to the M.I.T.-UMass Joint Sea Grant Program in this workshop. Current NEMAS members are: the Universities of Connecticut, Rhode Island, Maine, Massachusetts, and New Hampshire; Massachusetts Institute of Technology; State University of New York; Maine Department of Marine Resources; Massachusetts Department of Natural Resources-Division of Marine Fisheries; National Marine Fisheries Service; New England Aquarium; New England Center for Continuing Education; Southern Maine Vocational Technical Institute.

CONTENTS

THE ESSENCE OF THREE APPROACHES USEFUL IN RELATING AQUACULTURAL DEVELOPMENTS IN THE UTILIZATION OF THERMAL EFFLUENTS

by

John W. Zahradnik

Aquacultural systems have been the focal point of this laboratory since its founding in 1967. These complex operations have been the subject of our efforts in our teaching, applied research, and extension or public service programs.

As a result of these endeavors we have come to look upon the use of thermal wastes from three vantage points which can be termed the long range, the medium range, and the close range, depending on the boundary conditions which one desires to assign to the problem.

A Long Range View

The long range view has been set forth by McWethy and is presented in tabular form on page 3. This view can be characterized as a general one applicable to the development of any comprehensive, new technology. It can be further characterized as depicting a simple linear process of development, the various steps representing milestones. What might happen between the various milestones is not obvious, and this long range view can easily mislead the naive into believing that new technology develops in a simple linear fashion. Nevertheless, this scheme can provide an extremely useful framework of reference especially for planning purposes, and perhaps after today the status and planning of thermal effluent use in aquaculture can be properly described.

A Medium Range View

This approach has been described by Chestnut and is presented in graphical form on page 4. Those familiar with engineering systems analysis will recognize this as the system-sub-system, input, output, feedback way of depicting the developmental process. This approach is narrower in its scope than the overall milestone view of McWethy already reviewed, and it represents a high degree of resolution yielding a process to solve detailed problems. It is realistic in that, to a degree, it provides for recycling trial solutions as experience with the system under development accumulates. It recognizes our own inability to solve problems perfectly, at least not all of them at the first attempt. This medium range view can also be helpful to us today in placing certain developments in their proper perspective and in relating developments one to the other.

A Short Range View

As one attempts to define and to redefine the problems into portions small enough for the resources available to solve in a year or two, we have found the flow diagram on page 5 to be useful. This approach, while basically a linear concept, stresses parallel efforts and recognizes the necessity in some cases of several pilot plant stages. Most important, however, this scheme of process development recognizes two basic types of pilot plants. One of these is the pilot plant operated to determine operational parameters such as food concentrations, temperatures, oxygen levels, and those variables desirable to be maintained somewhere near their optima. The other of these is the pilot plant operation to determine scale-up criteria useful in the design of additional large scale operations. Failure to recognize these two distinct types of pilot plants in aquacultural developments is common. Sometimes the same pilot plant, if properly designed, can be used to determine both operational parameters and scale-up criteria. In addition, pilot plants need not represent all aspects of the prototype: they can represent only certain critical features, thus greatly reducing costs.

As with the other two schemes of reference, McWethy's and Chestnut's, this one likewise is helpful in relating some of the ideas which will follow.

STEPS IN A PHASED PROJECT PLAN FOR
DEVELOPMENT OF A NEW TECHNOLOGY

from McWethy (1974) *

PHASE 0 - ADVANCED RESEARCH AND TECHNOLOGY
- CONCEPTUAL SYSTEMS
- COMPONENT AND SUBSYSTEM ANALYSIS
- SYSTEM MODELING AND ANALYSIS
- REQUIREMENTS ANALYSIS AND SELECTION
- IMPACT ASSESSMENT

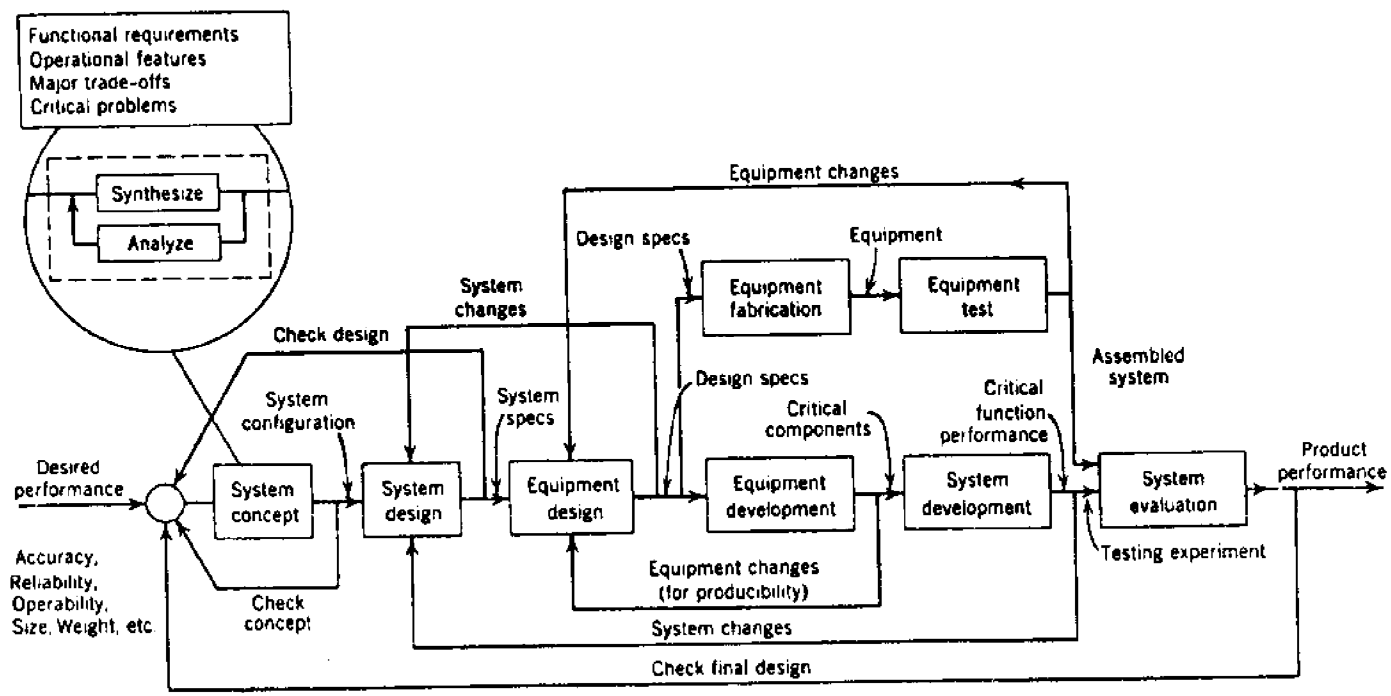
PHASE 1 - COMPONENT AND SUBSYSTEM DEVELOPMENT
- SYSTEM ANALYSIS AND OPTIMIZATION
- SYSTEM DEFINITION
- PRELIMINARY SYSTEM DESIGN
- SOCIO-ECONOMIC AND ENVIRONMENTAL ANALYSIS
- ENVIRONMENTAL IMPACT STATEMENT

PHASE 2 - SYSTEM DESIGN
- SYSTEM PROOF-OF-CONCEPT EXPERIMENT CONSTRUCTION
- TEST
- EVALUATION

PHASE 3 - PROTOTYPE DEVELOPMENT, DESIGN, AND LARGE-SCALE FIELD DEMONSTRATION

PHASE 4 - COMMERCIAL DESIGN AND OPERATION

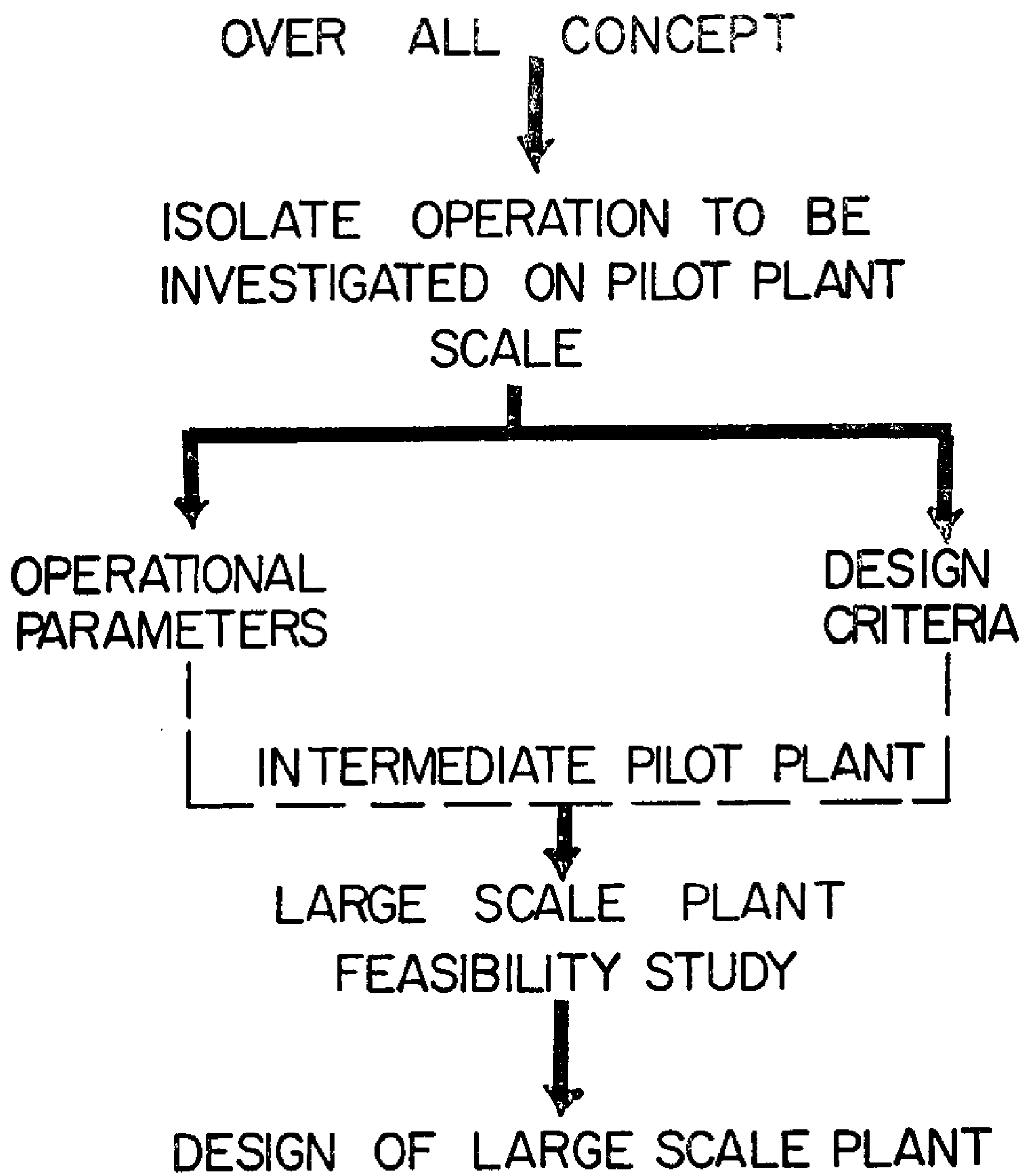
* McWethy, Patricia J. 1974. Process for determining the federal role in stimulating development of ocean energy technologies. Proceedings Tenth Annual Conference, Mar. Tech. Soc., Sept. 22-25, 1974. Washington, D. C., 455-481.



System engineering process.*

* Chestnut, H. 1965. System Engineering Tools. John Wiley & Sons., New York.

PROCESS DEVELOPMENT



THE USE OF WASTE HEAT FOR AQUACULTURE

by

Frank Gottlich

My part in this Advisory Service meeting is to discuss, as a representative of a public utility, my position on the use of waste heat for aquaculture.

Before I respond in this regard, I would like to comment from the point of view of an engineering oriented person. Consideration should be given to the current needs and costs of fuel, future electric generation capacity, and the national problem of oil imports and balance of payments. I would say that a significant amount of effort is needed in cycle efficiency improvement with the ultimate reduction in available waste heat. With concerted effort, it should be possible, by means of small improvements in generating efficiency, to reduce significantly our energy imports.

Presently, we are spending, overseas, $50,000 a minute for foreign oil, by the importation of 40% of our total consumption. If we consider Massachusetts alone, approximately 51 million barrels of oil per year are used for electric generation. An increase in efficiency of 10% would be a saving of 5 million barrels of oil and a reduction in cost of approximately $60 million. Extrapolating this on a national basis, we see it would mean a significant savings in dollar outflow and oil importation.

I recognize that this is not the theme we are discussing, but, nevertheless, it is one that needs to be kept foremost in our thoughts if we are to make meaningful strides in energy independence and economic stability.

Do we need thermal effluent utilization for aquaculture? I believe there are definite advantages, from both a short and long range point of view, for the utilization of such waste heat. We all recognize that there are many areas in the world that are underfed and that world food supplies could be augmented by aquaculture programs. In fact, there are many such processes ongoing in the world at the present time.

From an economic point of view, the utilization of any waste product is a fundamentally correct move, provided the cost of implementation justifies the expected return. Therefore, I believe that thermal effluent utilization certainly should have a place in our society, and aquaculture is one of the means of utilization.

Can aquaculture become viable on a commercial scale? I understand that some current installations in our region, such as the oyster rearing program at Long Island Lighting Company and the Coho Salmon rearing facilities that are mentioned in Maine, are economically viable. However, from a Boston Edison point of view, I can not be definitive as to the economic viability. The two projects that we are involved with, "Coho Salmon" and "Lobster," are two different concepts. The salmon hatchery proposal is designed to create a new species in Massachusetts Bay which will be geared mainly to sport fishing and not a commercial enterprise. The lobster hatchery is at present in a technical feasibility study stage. However, this concept and study are aimed toward the commercial aspect of raising and selling about 3 million lobsters per year. Although not put into practice yet, that I am aware of, it has been estimated that lobster farming can be a very profitable business venture. I will comment briefly on these projects later on.

One possible aspect of aquaculture that has some benefits for a utility is the acquisition of discharge permits. Section 318 of the Clean Water Act applies to the approval of pollutant discharges in a special manner. This section of the Act states that a permit to discharge specific pollutants may be approved if they are associated with an approved aquaculture project under Federal or State supervision. However, I am unaware of any utility companies applying under this section of the Act at the present time.

So far, I have been talking about the potential positive aspects of aquaculture. In any such project related to an operating plant, there are some practical problems to be considered. For instance:

(1) Discharge of heavy metals in cooling water. This would have an adverse effect on the quality of reared species or possibly their survival.

(2) Influence of plant operation on life cycle. Plant operation may severely influence life cycle or require supplemental heat. 100% reliability of continuous operation is not achievable nor is it practical. Plants must be shut down for emergency repairs or annually scheduled shutdowns.

(3) Use of biocides in cooling water. Effluents from plant operation usually require the use of chlorine compounds or contain boiler water treatment chemicals which can have an injurious effect on marine species.

(4) Variations in discharge temperature caused by load swings. In addition to shutdowns, all plants will have load variations on a daily or weekly basis that cause variations in the temperatures of water that would be used in aquaculture projects.

(5) Available land for use other than generation. The ideal concept in plant design is to utilize available large volumes of water. Available land near these water source sites is scarce, in this region, and is usually obtained with a concept of ultimate plant expansion. In the case of nuclear plants, there are NRC restrictions whereby any activities within a certain distance from the plant must be under complete control of the plant site owners.

(6) Oil spills. One must realize that it is against the law to spill oil. However, accidents such as pipe breaks can occur. The resultant oil spill could create another hazard to aquaculture.

(7) Radioactive waste discharge. Radwaste discharges occur on a controlled frequency in a nuclear plant. Their levels and content are well below any

biological risk. However, certain species may concentrate elements that would make the species questionable for human consumption. This would be a significant deterrent to a project unless documented evidence of no effect is submitted and is approved by the FDA.

(8) Chemical discharges. I have previously touched on chemicals used for biocide or water treatment. As an example some recent studies have shown that morpholine can eliminate "finger printing" in salmon. Morpholine or similar chemicals in minute quantities are used in about every fossil and some nuclear plants as a water treatment chemical.

(9) Supersaturation of dissolved gases. Frequently high quality seawater is in a condition of saturation of dissolved oxygen and nitrogen. Its passage through the plant with increases in temperature results in conditions of supersaturation. A detrimental condition to many marine species may result.

Each one of the above items, and probably many more, can create problems with aquaculture from a point of view of the effective use of thermally enriched water.

Regulatory requirements may also be restrictive to any planned aquaculture work. Let me list some of the regulatory agencies involved in approval of any such project:

- U. S. Environmental Protection Agency (Discharge Permits)
- Food and Drug Administration
- Federal Power Commission
- U. S. Environmental Protection Agency (Hazardous Materials Branch)
- Bureau of Marine Fisheries
- U. S. Army Corps of Engineers
- State Impact Statement
- State Division of Marine Fisheries
- State Division of Water Pollution Control
- State Department of Public Utilities
- State Department of Public Works
- Local Conservation Commission and Health Departments

For each of these there is a need for contact with the agency, a review of their regulations, and the obtaining of a permit if deemed necessary. This is a time-consuming, expensive, and detailed requirement that can be frustrating at times, yet necessary.

One major issue which is the source of many of our industry problems is financing. Expenditures by a utility are closely controlled and necessarily so, since our obligation is to supply reliable electricity to our customers in the least costly manner consistent with environmental standards, while providing investors with an adequate return on their investment. Therefore, any funding of research must be closely scrutinized.

However, let me say that upon a comprehensive evaluation some funds may be available. Funds for research may be also obtainable through research organizations such as EPRI and Federal agencies such as ERDA, EPA, and the Department of Commerce.

As is often the case, many otherwise desirable projects may not be implemented for financial reasons if they require the raising of significant amounts of capital.

I am sure you are aware of the potential biological problems that can arise in any aquaculture program: proper or optimum food, waste products, disease, genetics, containment, water quality, and just the normal growth aspects from an abnormal environment. I know you are well versed in these potential problems.

If I were to sum up the statements that I have made and draw a conclusion, I think it would be that the ultimate implementation of an aquaculture project requires a significant amount of pre-planning back in the initial conceptual stages prior to major funding of the project. In general, the content of such a pre-planning program should include the following analyses: site evaluation, regulatory issues, legal problems, socio-economic factors, marketing potential, cost studies, biological issues, as well as the factors involved in a conceptual design particularly related to the species under consideration.

If you will allow, I would like to point out, briefly at this time, some of the particulars of the two aquaculture projects that Boston Edison and others are involved with at present.

Within a few months, we hope to have completed a feasibility study on a Coho Salmon Hatchery proposed for our Pilgrim Station. The study has been funded by the Boston Edison Company and the State Division of Marine Fisheries who in turn obtained support from NOAA. The preliminary concept is the accelerated growth of Coho Salmon from eggs to release size in approximately six months. In addition, a salinity acclimation program is planned. Plans call for the installation of a fish ladder for the returning adults which will be used for stocking purposes. The majority of the salmon will be released in Massachusetts Bay for the development of a new sport fishing species. Upon completion of the study by Kramer, Chin and Mayo of Seattle, a determination will be made whether to proceed with the project or not. The decision will be based on the potential for success, cost of project, availability of funds, and evaluation of project worth.

I would also like to refer to our Lobster Hatchery Feasibility Study. This is a similar project being funded by Boston Edison, Northeast Utilities and Westinghouse Electric Corporation. This study, in its feasibility stage, will also look at the various aspects of creating a Lobster Hatchery. The concept considers using waste heat from a power plant and producing 3 million marketable lobsters per year. The program will be long range, five to ten years away. However, to restate the approach taken, it is a feasibility study or analysis that will review and evaluate all aspects of the enterprise from licensing through plant design concepts. This evaluation and review includes all the factors of marketing, cost analysis, legal, regulatory, biological, site evaluation, pilot plant, and production facility.

I hope I have given you some necessary input needed for this workshop. I would be happy to supply you with any further information that I may have.

Thank you very much.

OYSTER DEVELOPMENT IN POWER PLANT DISCHARGE

by

George H. Vanderborgh, Jr.

The age of aquaculture, using thermal effluents, is here. For the past six years, Long Island Oyster Farms has been using (on a commercial scale) the effluent of Long Island Lighting Company's power station to grow seedling oysters in a warm water lagoon. The only factors stopping rapid growth in the beneficial commercial use of thermal discharges are possible government regulations that do not take into account the total biological effect of the effluent.

There has been great talk about the harmful effects of thermal effluents, when in many cases these are due to local weather conditions, other environmental problems, and inadequate design. With proper design and proper planning, thermal effluents can be used beneficially and discharged into a natural environment without causing overall harmful effects, but, in a sense, beneficial effects. Beneficial use of warm water power plant discharges can be a great boon to the aquaculture industry. With the shortage of protein that is facing the world, and projects for more and more warm water discharges from power plants being planned, beneficial use of this water to provide needed protein is in evidence.

Due to the low-grade heat (20° to 30° above ambient) that is produced by the power plant effluent, for economy it is also essential that the water be used directly out of the plant discharge and not through a heat exchanger system. In utilizing thermal discharge, the people in the aquaculture industry must recognize that the major job that utilities have is to generate power, and nothing in the aquaculture project should change this or cause problems to arise due to emergencies in the power plant. Slight modifications of the effluent can be worked on between the utility and the farmer. However, the farmer must recognize the effects that possible plant shutdowns, plant cleaning systems, and extreme weather conditions might have on the effluent.

Initial development work to utilize Northport Power Plant lagoon water for growing oysters was a joint effort of Long Island Lighting, New York State Department of Environmental Conservation, and Long Island Oyster Farms. Long Island Oyster Farms has been growing oysters in hatcheries for over ten years. Our biggest problem in our operation was getting enough warm seawater and food to grow our juvenile oysters. Since the small juvenile oyster will pump about five gallons of water a day, and we were raising millions of animals, it was necessary for us to provide a source of warm, plankton-rich seawater. Long Island Lighting Company's discharge seemed like an ideal place to start. The Conservation Department had two objectives in mind: to revive the oyster industry in New York State, and to monitor the effect of the warm water discharge. Growing juvenile oysters in this discharge encompassed both of New York State Conservation Department's objectives. As a result, we now have a thriving oyster industry on Long Island and a good, safe effluent in the warm seawater discharge lagoon, which flows into Smithtown Bay.

Long Island Oyster Farms' hatchery is located on a 10-acre warm water lagoon, with a weir at the end to allow a maximum drop of tide of 3 feet (normal drop 7 feet). We started working this location when one unit was in operation in 1967. The size of this unit is 389 MG. This unit has a Δ T of 25°F. to 28°F. At the present time there are two more units in operation, both the same size as the first unit. There is also a dilution system with two pumps to be used so the temperature of the effluent does not exceed 90°F. A fourth unit is now being constructed of similar size. All of the units' tubes are mechanically cleaned. The depth of the lagoon is about 8 feet, and the holding time in the lagoon for any of the water is less than an hour. The lagoon has recently been inspected by the New York State Department of Environmental Conservation. They saw no reason why this system could not be continued in the future, as the effluent seemed to have a total beneficial use to the shellfish industry and the fishing enthusiasts in Smithtown Bay, although our State's written rulings are that a discharge pipe be put into Long Island Sound with diffusers at a cost of $40,000,000. However, this ruling was not made by any data obtained at the site, but rather what the State thought best fitted the Federal guidelines. The government now seems to be taking case by case, studying the environmental effect of each power plant's cooling water discharge. This practical approach will probably make it possible for us to continue to operate in this dilution lagoon.

Having worked for over six years at the Northport Long Island Lighting Company Power Plant lagoon, we might say we have monitored the water through the use of bioindicators, oysters, and other shellfish, continuously. This has taught us the techniques that we can use to adapt to the changing power plant effluent. We have had extreme temperature conditions, and in one case the temperature of the water went down more than 28°F. in less than an hour. There have been times when the turbidity of the water was so great that one could not see five inches below the surface. We have learned to work with the techniques we have developed to meet this type of change. There have been certain cleaning chemicals, however, that the power plant was using which did cause problems. When the plant was notified of these problems, they were able to substitute different cleaning solutions and also alter their method of cleaning without an increase in costs so as to make the effluent better for growing oysters.

In the heated power plant effluent, due to the increase in temperature, fouling organisms grow at a very rapid rate. One of the main problems we had to solve was how to handle the fouling economically. The handling of fouling varies from season to season and year to year. There is no easy solution, but, with good farming techniques and by applying the principles that worked in the past, we have been able to overcome the fouling problem.

The oysters are spawned in our hatchery over a ten-month period by keeping them in various water temperatures to simulate certain seasons. The oyster will reproduce when the temperature of the water reaches 68°F. While continuously and slowly building up oysters to this temperature, we are able to keep a constant production for ten months of the year. After spawning, the larvae are placed in tanks where they will swim for the next two or three weeks. They are fed daily, and they are drained and screened four times a week. At any of these drainings, if the oyster develops improperly, looks weak, or the growth rate does not meet certain standards, either a total batch or a partial batch (smaller ones) might be discarded. We usually discard about 90% of our animals in the first two or three weeks. This gives us a fast growing, hardy oyster. These oysters are next placed in screens in our hatchery and again fed a controlled diet for about four weeks. During this time, they are continually screened and sized. After they reach a size that can be retained in a 20-mesh screen, they are put out into the warm water of the lagoon to begin the nursery period in their lives. These screens are placed in racks that are lowered into the fast moving waters of the warm water lagoon. While in the lagoon, where the oysters grow very rapidly, the screens are kept clean by washing, and the juvenile oysters are screened at weekly intervals. They will stay in the warm water lagoon from four to six weeks, at which time they are at a size of a natural year-old oyster. These oysters are all single and are then placed on specially prepared bottoms. They will be ready for market at anywhere from 24 to 36 months, thus cutting the growing time to about half that of a natural oyster. Oysters produced by this method are better shaped, have better shell growth, and are fatter than natural oysters. This project is not an experiment, but a full-scale commercial operation used by Long Island Oyster Farms (the largest oyster company in New York State) for growing its seed oysters. We are now starting out to look for other animals, such as scallops, clams, shrimp, and many fin fish, which also might be benefited by warm water lagoons.

There have been changes in the area around the power plant effluent in Smithtown Bay. Algae growths have improved, fishing around the discharge is much improved, and the overall effect on the ecology of the area appears beneficial. The warm water lagoon seems to be taking the place of the wetlands, many of which have been lost on Long Island through harbor developments. These warm water discharges, when properly used and designed, may lead to the greater improvement and total production of marine animals.

PROPOSED MARINE TEMPERATURE CRITERIA AND GUIDELINES FOR THERMAL MIXING ZONES

BY

Don C. Miller

Water quality criteria serve to define limits to the discharge of specific pollutants and so to afford protection of aquatic systems and their indigenous species of fish, shellfish, and wildlife. For some discharges, such as heated water, water quality criteria may be exceeded in a mixing zone immediate to the discharge point. Aquaculture projects conducted within a thermal mixing zone of an industrial or municipal plant source may exceed aquacultural effluent guidelines within the project area, but should not contribute to pollution outside the designated project area (40 CFR, Part 115). This paper will not address regulatory questions pertaining to aquaculture project areas per se. Rather, the present discussion is more general, focusing on some considerations on thermal mixing zones and receiving water criteria for thermal discharges.

Proposed EPA marine temperature criteria, which are to be met at the periphery of the mixing zone, are as follows:

(1) the maximum acceptable increase in the weekly average temperature due to artificial sources is 1 C (1.8°F) during all seasons of the year, providing the summer maxima are not exceeded;

(2) daily temperature cycles characteristic of the water body segment should not be altered in either amplitude or frequency;

(3) summer thermal maxima should be established which recognize the upper thermal limits for communities

of the water body in question. Existing studies suggest the following regional limits:

	Short-term Maximum	Maximum True Daily Mean*
Tropical Regions (south of Cape Canaveral and Tampa Bay, Florida, Puerto Rico, and Pacific tropical islands)	35.0 C (95°F)	31.1 C (88°F)
Cape Hatteras, N.C., to Cape Canaveral, Fla.	32.2 C (90°F)	29.4 C (85°F)
Long Island (south shore) to Cape Hatteras, N. C.	30.6 C (87°F)	27.8 C (82°F)

(*True Daily Mean = average of 24 hourly temperature readings)

Baseline thermal conditions should be measured at a site where there is no unnatural thermal addition from any source, which is in reasonable proximity to the thermal discharge (within 5 miles) and which has similar hydrography to that of the receiving waters at the discharge.

These criteria will assure that temperatures of a water body segment will not become elevated to the point that neither community interactions, nor reproduction, recruitment or migrations of important indigenous species would be adversely affected. Such life-cycle events are known to be cued to environmental temperature, with slight changes in the long-term temperature regime having the potential of causing appreciable shifts in the distribution and abundance of some species. Natural cyclic temperatures should be maintained, as these conditions have been demonstrated to provide increased thermal tolerance when compared to constant thermal regimes. Finally, it is recognized that thermal elevations which are stressful to the indigenous species can occur naturally during the summer. Thermal addition from artificial sources during such periods would not be appropriate, hence the recommended thermal maximum.

General guidelines and limitations for mixing zones are currently under consideration by EPA. The following discussion includes some of the points being discussed, but should not necessarily be construed as present requirements or policy. Mixing zones are not interpreted as "write-off" areas, where acutely lethal conditions are permitted. The NAS-NAE Committee on Water Quality Criteria[1] has recommended that the total time-toxicity exposure history within a mixing zone must not cause deleterious effects in affected populations of important species, including the post-exposure effects. Depending on the

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[1]Committee on Water Quality Criteria, Environmental Studies Board, National Academy of Sciences-National Academy of Engineering, Water Quality Criteria, 1972. U. S. EPA R3-73-033. 1973. Washington, D. C.

species evaluated in such tests, this recommendation could contribute significantly to assure long term protection of the adjacent receiving waters. Mixing zone water quality should not contribute to alterations in community balance outside the zone, which would adversely affect the indigenous species of fish, shellfish, and wildlife.

Questions of mixing zone location and size must be considered at the time of plant siting and design. Ideally, a plant discharge should be located in a region of relatively low biological value within a water body segment. It may be possible to predict relative biological value of a series of sites for some coastal or fresh water systems. However, it is highly questionable whether this could be done for estuaries in light of their diverse biological functions of high value to man.

Some items to be considered in allocating mixing zone sites include: (1) potential biological loss; (2) total area of mixing zones on the waterway, both existing and proposed; (3) relative size of the discharging plant, with recognition that larger discharges may need a proportionally larger mixing zone; and (4) some size restriction for biologically adverse discharges which attract aquatic life. Finally, it is recommended that the major axis of a mixing zone should be parallel with prevailing currents to minimize impact on planktonic and weakly-swimming pelagic organisms.

DYNAMIC MODEL OF A HEATED FINISHING PLANT FOR OYSTERS

by

Sara Callaghan

Due to a growing interest in, and potential for, commercially raising oysters in a heated finishing plant in conjunction with warm effluent waters from electric generating stations, this research project was undertaken. To aid in forecasting the economic potential of a large scale operation, a mathematical model, using the System Dynamics technique, was developed to represent the many combinations of physical and economic factors in an operation of commercial magnitude. Combinations of four policy variables were investigated: (1) system capacity (5,000, 25,000, and 50,000 bushels); (2) sea water flow rate (75, 150, 300 l/oyster-day); (3) temperature change above ambient (2.78, 5.56, 8.34, and 11.12°C); and (4) the addition of supplemental nutrient supply.

Figure 1 on page 18 is a schematic which depicts the overall design of the proposed oyster finishing plant. Thermal effluent from a power plant flows on one side of a sheet piling or steel bulkhead-type heat exchanger. The raw sea water flowing on the other side is warmed and flows into pond containment structures which contain the oyster propagation units. More detailed information regarding the design and benefits of the steel bulkhead-type heat exchanger is included in the presentation by John Huguenin at this workshop.

One of the most significant parts of this project was to determine what the actual components of a commercial system would be and to try to place a cost estimate on each component (see Figure 2, page 19). Information regarding the operation of each component as an individual subsystem was generated from a wide variety of interdisciplinary sources. With all the model's assumptions, combinations of policy alternatives, and capital and operating costs in mind, the model was exercised through its time cycle -- ten years. Particular attention was paid to production capabilities and potential economic viability of the aquacultural configurations studied. Never before have the design and operating parameters of a complete commercial system for growing oysters been evaluated in this manner.

This study was designed in part to help answer some of the major questions brought before this workshop. With regard to the financial viability of a commercial thermal aquacultural scheme for oysters, results of the model runs demonstrated that given a proper mix of input variables, <u>the system could indeed show economic potential</u>. For example, results indicated that none of the 5,000 bushel configurations appeared economically feasible. However, with the increase in capacity from 5,000 to 25,000 bushels, all criteria used to predict potential economic viability appeared promising. Breakeven for those 25,000 bushel systems employing supplemental nutrient supply ranged from a reasonable 12 to 30 months. A calculated 10 Year Return on Cash Input Ratio ranged from 5 to 18. Here economies of scale were clearly noticeable. Then the promising trends that had been apparently tied to increasing capacity began to break down when expansion to the 50,000 bushel capacity system occurred. Diseconomies of scale were very evident, and the 10 Year Return on Cash Input Ratio for those schemes having algae culture subsystems was lowered to a range of 1 to 9. When the variable combinations discussed above were considered without the use of heated effluent water (i.e., at ambient temperatures), all financial indicators reflected unprofitable operations, and the 10 Year Return on Cash Input Ratio was near or below one. The conclusion may then be drawn that thermal effluent utilization is needed if an operation of the magnitude described is to show potential. However, it must be acknowledged that the full potentiality of the use of warm effluent water on the culture of oysters can be achieved, for the most part, only with the supplementation of natural plankton with cultured nutrient sources.

Results of the study did indicate several areas worthy of further research:

(1) Input data could be more refined and boundaries of the model expanded to include such subsystems as the marketing sector.

(2) Further insight into the true economics of the system would be possible once appropriate costs of capital and discount rates used for the industry are determined so that the effects of inflationary and deflationary pressures may be considered.

(3) The model may be used as is to monitor the economic implications of alternative engineering designs in the same production scheme.

(4) The model would require only slight modification if used to represent aquacultural production schemes of species other than the oyster.

(5) Further pilot plant studies are warranted to investigate the effects on oyster growth of the addition of supplemental nutrient supplies containing artificially cultured algae. Incorporation of any new growth data, such as that recently generated by Ernesto Lorda, would certainly serve to increase the overall validity of the model.

For a complete discussion of the above research, see Callaghan, Sara. 1975. A Dynamic Model of a Heated Finishing Plant for Oysters. M. S. Thesis, University of Massachusetts, Amherst, Massachusetts. This thesis is available through the University of Massachusetts Library. Interlibrary Loan Office.

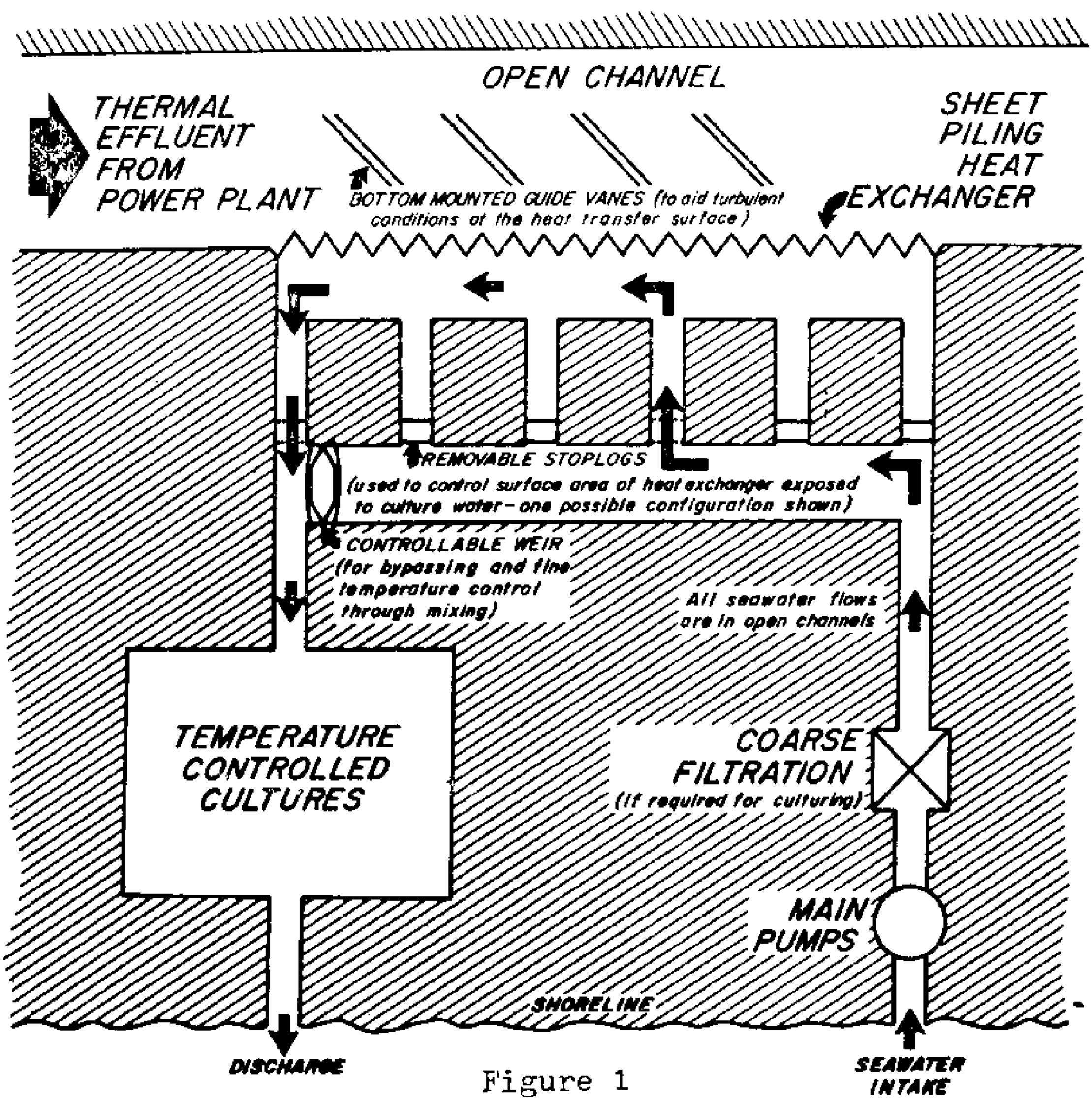


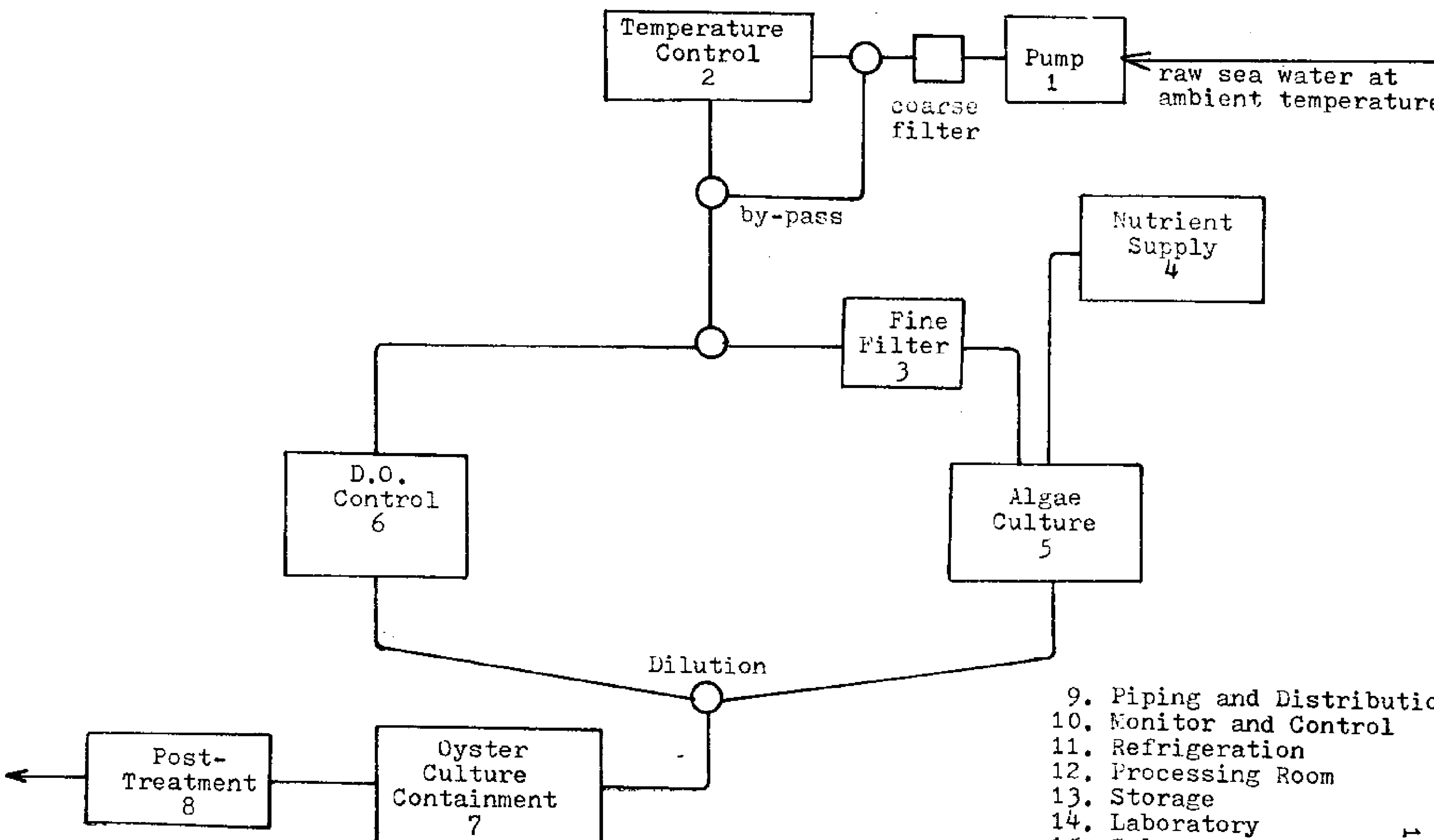
Figure 1

SHEET PILING HEAT EXCHANGER
SCHEMATIC FLOW DIAGRAM

UMASS Aquacultural Engineering Laboratory 5/75

Figure 2

SYSTEM COMPONENTS AND ASSOCIATED COST CATEGORIES



9. Piping and Distribution
10. Monitor and Control
11. Refrigeration
12. Processing Room
13. Storage
14. Laboratory
15. Salary
16. Administrative
17. Maintenance

12

OBSTACLES TO AND NEEDS FOR CONTINUED R&D FOR THE UTILIZATION OF THERMAL EFFLUENT IN AQUACULTURE

by

Al Price

Let me state at the outset that the use of thermal effluents in aquaculture is not a new concept. Biologists and aquaculturists have, over the past 25 years, been repeatedly attracted to the idea of using the thermal waters from electrical generating facilities in aquaculture. Proposed applications have been for their use in hatcheries, to increase the rate of growth, and to extend the growing season of the various marine species considered for culture.

The increasing demand for electricity by our civilization and the consequent construction of additional generating facilities in coastal areas will dramatically increase the number of thermal releases available for application in marine aquaculture systems. If present governmental planning is implemented, it is probable that a large part of this future generating capacity will be thermonuclear. Thermonuclear generating facilities are of particular interest in considering the use of thermal effluents for aquaculture because of the use of large volumes of water for cooling in such installations. The rise in temperature above ambient of the water which is associated with the cooling of these plants is generally compatible with the biological requirements for accelerations in gametogenesis, increased growth rates, and the extension of the growing seasons of many marine species.

If we conceptualize an electrical generating station as primarily engaged in the conversion of matter, through combustion, fission, and in the future fusion, into heat energy, and the processing of this heat via steam into usable form of energy, electricity, we find that the process is about 33% efficient. Approximately 66% of the heat generated in this process is at present released into the environment as waste.

Since fuels used in the release of energy are becoming more valuable as their availability decreases, the utilization of the waste heat in the production of protein through aquaculture should be examined as a method of increasing the net efficiency of the economic and energy cycles involved in the generation of electricity.

One might well ask why the use of thermal effluents in aquaculture has not become a more common occurrence.

Power companies are public utilities that are in business to generate electricity in order to supply public demand and to yield a fair return to their stockholders. In order for such a public utility to see the development of aquaculture using the thermal waste from this process as a viable concept, they (as any prudent business organization) will require that the use of the waste heat they generate be demonstrated to benefit their interests. This has yet to be accomplished to their satisfaction, and so their interest in aquaculture using thermal effluents remains primarily at a public relations level.

Electrical generating facilities in the past have been designed and sited to serve a single function--the generation of electricity, with little or no consideration given to the use of waste heat for aquaculture. Waste heat has been seen by utilities and regulatory agencies as an undesirable by-product which must be dissipated as quickly as possible, rather than as a resource to be used efficiently.

I believe that it is possible to see this waste heat as a resource that could be usable in a multi-species aquaculture system which takes advantage of the thermal gradients implicit in the dissipation of the significant amounts of heat necessary to minimize the thermal impact on receiving waters. If such a system could be demonstrated to produce a cost saving to utilities (as opposed to the expense of cooling towers), aquaculture using thermal effluents would become a more viable consideration in the planning, site selection, engineering, and construction of electrical generating facilities.

A great deal of engineering has been applied to the conversion of energy as heat into electricity. One would expect that an equal application of engineering to the utilization of the waste heat generated in this process would prove beneficial by increasing the overall efficiency of this energy cycle, through the production of protein. Two important areas into which further research and development effort should be directed are engineering and biology.

We know that raceways are more efficient in protein production per given acre than ponds. More work needs to be done on stocking densities and on the specific biological requirements of different densities and species which can be used in such systems. This information is important in developing engineering and design criteria.

More work is needed on the modeling of uptake and depuration of contaminants of plant origin, such as heavy metals and radioisotopes, in the different species which are candidates for use in such systems.

Disease and its control is an important factor which bears further investigation, as does the control of fouling organisms which may also thrive in heated waters and adversely affect the growth rates and market quality of organisms cultured in heated effluents.

Genetic studies and breeding programs to develop strains of plants and animals which can adequately adapt to and take optimal advantage of the projected environment in aquacultural systems using waste heat should be developed.

Studies should be undertaken to estimate the probable impact of such systems on the environment, and methods of minimizing it should be designed into the system both through the engineering of the physical plant and biologically by intelligent selection of species for culture.

In summary, I would like to say that I feel we are some way from seeing the commercial, and by commercial I mean profitable, use of thermal effluents for aquaculture on any level other than the present opportunistic ones that attempt to take advantage of unmodified effluent waters as they are discharged into the receiving waters. These opportunistic utilizations of existing thermal effluents will generate data which can move us closer to the constructive use of what will become the larger and larger quantities of waste energy which are now referred to as thermal effluents.

To develop this resource efficiently will require the participation of many disciplines--biologists, engineers, chemists, physicists, sedimentologists, and oceanographers--as well as cooperation of industry, government, and the appropriate regulatory agencies at both the state and federal levels. Whether such an effort is possible, only time will tell, but the benefits of increased efficiency in the production of protein through the utilization of waste heat should not be ignored.

ON THE POSSIBLE CULTURE OF THE AMERICAN OYSTER IN HEATED RAW SEAWATER

by

Ernesto Lorda

A study on oyster growth under varying flow rates and temperature conditions has been being conducted at the University of Massachusetts Aquacultural Engineering Laboratory facility in Wareham, Massachusetts, since December, 1973. This experimental work, supported by the MIT Sea Grant Program as a part of a joint UMass-MIT research program, is intended to provide design criteria for small to intermediate size culturing systems and to generate the necessary data to evaluate the feasibility of using heat from thermal effluents in order to enhance oyster growth.

Although this work has not yet been finished, some problems encountered during the operation of the pilot plant, as well as some preliminary results, will be briefly discussed.

Two specific problems which are believed to be typical of oyster culture systems using both raw seawater and additions of heat are water supersaturation and blooms of zooplankton.

It is a well-known fact that supersaturation of seawater occurs when its temperature is raised under certain conditions. Supersaturated seawater impairs normal oyster growth and may have lethal effects if oysters are exposed long enough, for the noxious effects are cumulative.

Occurrence of supersaturation and its level depend upon many factors. Net increment of temperature, elapsed time per unit volume within which the change in temperature occurs, and available water-air interface during the heating process can be considered the most important.

During the operation of the pilot plant, supersaturation of the seawater occurred, and levels as high as 125% saturation were measured when incoming water at 34-36°F. ambient temperature was heated up to 68-70°F.

It is feasible to prevent the occurrence of high levels of supersaturation in small culturing systems by strongly agitating the water during the heating process by means of coarse air bubbles. Bubble size must be carefully chosen in order to avoid foam formation, which would strip the water of part of its phytoplankton content. "Foaming" increases as the bubble size decreases, and efficiency in preventing supersaturation decreases as bubble size increases. Initial bubble size of 3/16 inch diameter was found to be a good compromise.

Most likely, this method to prevent or alleviate the supersaturation of the heated seawater would not be economically feasible in large culturing systems. However, if a thermal effluent were to be used as the source of heat, the two following factors would minimize the supersaturation problem: the temperature gradient available as source of heat would be only 20°F.; and because large masses of water would be heated, the heat transfer process would be rather slow and it would take place in an open system with both large water-air interface and large residence time.

Unfortunately, nothing is yet known about the levels of supersaturation that the special heat exchangers for this type of operation would produce. Experimental data relating growth performance and low levels of supersaturation that oysters can tolerate are not available either.

The second problem that might plague large culturing systems is the bloom of zooplankton. A bloom of copepods occurred in the heat exchanger of the pilot plant during the spring of 1974. Many of these planktonic species can complete a reproductive cycle in about two weeks with proper temperature conditions, and they feed voraciously on phytoplankton.

This problem can be solved in small systems, either by prefiltering the incoming raw seawater as soon as the water ambient temperature rises above 50°F., or by emptying and rinsing the heating system often enough to keep the population of copepods from building up within it.

None of the above methods would be practical in huge heating systems like the ones that would be necessary in order to tap heat from a thermal effluent. In addition, the dimensions of such a heat exchanger would increase the occurrence of pockets of poor water circulation where copepods would thrive undisturbed.

Some of the preliminary results from the mentioned experimental work will be discussed now.

A mathematical model to predict oyster growth as a function of initial size, varying water temperature, and varying supply of raw seawater was developed on the basis of the experimental growth data collected during the first 18 months of the experiment.

Although this model has some obvious limitations because of the local conditions under which the experiment was conducted and because of the lack of control on the actual food supply (number of phytoplankton cells per unit volume of water), it describes successfully the growth response of the oysters to the complex interaction between the three above mentioned variables and the oyster metabolism.

One of the parameters in the model allows one to establish a temperature-flow rate relationship that will facilitate the programming of optimal flow rates of raw seawater and produce maximum growth at each different temperature.

This relationship was expressed as the ratio temp./flow rate per gram of oyster biomass, and it was estimated to be about 1.0 : 0.195 . This means that at 70°F. the optimal flow rate is about 14.0 liters/day/gram, while at 50°F. it is only 10.0 lit.

Expected growths were computed for various conditions and growth periods, and it seems that optimal flows of raw seawater at constant temperature of 68-70°F. will allow one to grow seed oysters to legal size in a little less than one year and that almost twice as much time would be necessary to achieve similar growth if water temperature were kept at only 20°F. above ambient temperature.

Since only a temperature gradient of 20°F. is available in a thermal effluent, these preliminary estimates show that, if a thermal effluent were utilized as a source of heat, it would take about two years to grow legal size oysters with only algae in raw seawater as a food supply.

Although these results are not yet final conclusions, experimental evidence suggests that if thermal effluents are to be used as a source of heat in oyster culture, addition of phytoplankton cells to the water would be necessary in order to achieve the type of growth that would be economically sound.

INDIRECT USE OF POWER PLANT THERMAL EFFLUENTS IN MARINE AQUACULTURE

by

John E. Huguenin

While a direct use of power plant thermal effluents mixed with ambient temperature seawater is the most efficient approach, this may not be permissible for large scale applications. Power plants add, in generally miniscule amounts, a considerable variety of different substances to the water. These may include metals from piping, chlorine, processing and cleaning residues, and low level radioactive materials. Many of these substances have at least the potential for ecological effects and possible impacts on culture organisms. Unfortunately, the mere possibility of a health hazard when substances are added, either intentionally or unintentionally by man, is sufficient cause for condemnation of foods grown in their presence under the authority of the Delaney Amendment to the Food, Drug and Cosmetic Act of 1938. There is some evidence to indicate that this provision will be strictly interpreted by the F.D.A. with regard to power plant aquaculture. Under these conditions, it is clear that a major investment in a direct use system may involve substantial legal/political risk.

The potential legal/political problems with direct water use in cultures bring up the possibilities of indirect use through some sort of large heat exchanger. Many different types of heat exchangers have been successfully used in marine culturing experiments (Huguenin, 1976). However, most of these are relatively expensive even for small scale culturing. For the more conventional types of heat exchangers which could be built big enough for large scale applications, it is clear that their costs would not be economically justifiable. These costs are due to the need for additional pumping, in large quantities, of either or both the culture water and thermal effluent, difficulties of access for cleaning, materials restrictions, and supersaturation problems with pressurized systems. A promising alternative to conventional heat exchangers involves a recently proposed concept of using industrial interlocking steel sheet piling as the heat exchanger material in a counterflow system (Huguenin & Ryther, 1974). This concept (see figure on page 18) provides some distinct advantages which are listed below.

(1) Hydraulic pressure drops are negligible on both the power plant and culture water sides. This eliminates the need for any additional pumping and may even be compatible with tidal pumping of culture water.

(2) Very large heat transfer areas dictated by small temperature differences as well as the required high flow rates can be accommodated. The concept is flexible and amenable to large scale applications.

(3) Water temperature control can be achieved through use of alternate water entry positions to the heat exchanger surface and by final mixing.

(4) There is easy access to the heat exchanger for inspection and mechanized cleaning. Flow and temperature control devices are highly visible, easily understood, and inherently reliable.

(5) The use of open channels substantially reduces the probability of problems due to the supersaturation of culture water.

A cost analysis, including the heat exchanger, channels, weirs, and excavation, indicates that, for a power plant which raises its water 20°F., a heat exchanger system to raise the culture water 5°F. would cost approximately $4,000 for a flow of 1,700 GPM and $2,000,000 for a flow rate of 688,000 GPM. A similar system to raise the culture water to about 20°F. would cost around $15,000 at 1,700 GPM and $10,000,000 at 688,000 GPM. Using an existing model (Callaghan, 1975), it is clear that the economic benefits achieved through faster growth, due to increased winter water temperatures, more than compensates for the fixed and operating costs associated with the heat exchanger systems. Thus, the sheet piling heat exchanger system, as a component, appears to be economically viable and is the best alternative if an indirect system is necessary.

References

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THE USE OF THERMAL EFFLUENTS IN AQUACULTURE: RESEARCH NEEDS

by

William B. Kerfoot

The use of thermal effluent in aquaculture poses a variety of unique problems in water quality management. Conventional power plant operations are designed with the user populations in mind and lack the continual control of flow necessary to deliver the year-round constant ambient temperatures required for successful aquaculture. Intermittent operations of heat exchangers may also lead to stagnant water conditions promoting the release of slugs of transition metals acutely toxic to the cultured organisms or capable of long-term accumulation in tissue to levels sufficient to interfere with marketing. The evaluation of the capacity of alternative heat exchangers and control systems to minimize temperature fluctuations and avoid pulses of contaminants should be given high priority, particularly since the design of such systems would also serve to lessen environmental impacts of thermal discharge even in the absence of aquacultural facilities.

The low level at which trace contaminants can affect culture systems, particularly algae and shellfish, places a burden on existing methods of analysis to supply the monitoring necessary. To reach the level of contaminants required to detect background copper concentrations in seawater, organic extractions of seawater with MIBK-APDC (Methyl isobutyl ketone - Ammonium pyrrolidine dithiocarbonate)[1] are recommended prior to direct analysis by atomic absorption spectrophotometry. Non-flare techniques, such as the increasingly popular graphite furnace, are subject to similar interferences, producing "smoke" ion clouding and salt particles which seriously limit reliability unless pre-extractions of samples of seawater are obtained. Current analytical equipment is also directed toward individual or "batch" sampling, rather than fulfilling the necessity for continuous monitoring.

Attention should be directed toward the following areas:

A. Research aimed at evaluating and assessing the temperature stability and metal toxicity of alternate heat exchangers and their adaptability to aquacultural needs, particularly with direct heat exchangers where the

[1] "Methods of Chemical Analysis of Water and Waste," U. S. Environmental Protection Agency, 1974, suggests modified form with PDCAL Chloroform.

water flow used for aquaculture comes in direct contact with metallic heat transfer surfaces -

(1) Greater knowledge of surface area versus leaching rates under continual and intermittent operation

(2) Chronic accumulation and toxic effects to algae and shellfish induced by heat exchanger operation

(3) Evaluation of the expected levels of contamination and their acute or chronic effects on cultured organisms

B. For monitoring -

(1) Greater development of low-cost multi-element continual monitoring devices with rapid data return

(2) Development of limits of ranges of constituents found associated with "successful" grow-out operations

(3) Production of an inventory of <u>sources</u> of trace pollutants associated with thermal water flow systems, their origins, and contributions to ambient levels

IN RETROSPECT

by

John W. Zahradnik

One way of relating the presentations made in this workshop is to view their substance in terms of the three vantage points delineated at the outset of our deliberations. To review for a moment, these vantage points were the long range "milestone" concept of McWethy, the medium range concept of Chestnut, and the short range process development concept generated in this laboratory.

In attempting to relate the presentations, one becomes aware that the status of the use of thermal effluents in aquaculture is very much species dependent. For the oyster, the situation is different from the lobster. Therefore, we have a mix when we attempt to place the status of the use of thermal effluents on McWethy's chart or on Chestnut's systems analysis scheme.

However, it is possible to take a composite view and make a general assessment since the degree of precision is not critical.

It appears that on the whole with the exception of one species, the oyster, most aquacultural uses of thermal effluents are in phases 0 and 1 of McWethy's milestone chart. The exact meaning of this assessment can be better appreciated by referring to page 2.

In terms of Chestnut's systems engineering process, again with the exception of the oyster, the status of thermal effluents in aquaculture lies in the system concept, system design, and equipment design processes.

The short range scheme of process development utilizes the concept of partial pilot plants being evaluated for operational and design criteria. Most of the current development in the use of thermal effluent in aquaculture is in this category.

In addition to placing the development of thermal effluent usage in aquaculture in perspective, the presentations and discussions yielded another significant insight. That is the so-called "opportunistic" utilization of thermal effluents whereby only a part of the life cycle of an aquacultural species is spent under the influence of a thermal effluent. This opportunistic utilization bypasses a great number of the problems involved and reduces both the risk and capital costs, although it does not maximize the potential benefits of heated waters.