THE DESIGN AND CONSTRUCTION OF THE UNIVERSITY OF DELAWARE MARICULTURE LABORATORY

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I. INTRODUCTION

During the fiscal year 1972, the University of Delaware College of Marine Studies undertook the design and construction of a marine laboratory. This laboratory was to provide the physical plant, services, and controls to support the demonstration of closed cycle mariculture. This effort was supported by a combination of University, Industry, and Government (Sea Grant) funds.

While the Eastern Oyster (Crassostrea virginica) was the marine animal of primary concern, particular care was taken to insure sufficient laboratory flexibility to facilitate the controlled environment culture of a wide variety of marine organisms and to support research efforts in related problem areas.

It became apparent very early in the program that the design of marine laboratories has been a very individual undertaking. Efforts to obtain step-by-step documented procedures describing critical parameters were fruitless. It was judged, from experience of others, that delegating the responsibility to consulting firms would not insure a satisfactory laboratory. Therefore, the resident multi-discipline research team (at that time two biologists and one engineer), with broad in-house support, designed and supervised the construction of this Mariculture Laboratory.

A predominant factor in the design approach to the Delaware Mariculture Laboratory was the availability of a two-story, concrete-block, building of 10,000 square feet facing the Delaware Bay near

Cape Henlopen. This building, along with a 1,200-foot pier and two 125,000-gallon concrete tanks, were committed to the project by Fish Products Company of Lewes, Delaware. The five-year period of this commitment biased decisions toward relative portability of equipment for subsequent relocation. As in most cases of laboratory construction, the needs and desires for the laboratory had to be satisfied within the confines of the funds provided. Fortunately, in this case the funds were sufficient to meet the essential needs.

Effort was initiated with a detailed inventory and evaluation of all facilities committed to the Mariculture Laboratory. Then a set of preliminary specifications was drafted by the biologists attempting to fit the intended process to the facility. These preliminary specifications also provided the starting point for the engineering design effort. An extensive facility survey was undertaken; major marine laboratories were visited on the East Coast, the West Coast, and in Canada. All information collected was carefully considered, while evolving design engineering specifications for the new laboratory. Using a combination of in-house capability and contractors, the selected equipment and systems were installed and put into operation.

The purpose of preparing and disseminating this information is to provide a guide for others faced with a similar task. The guide covers materials, methods, and equipment selected and a summary of costs and suppliers. If this paper gives rise to discussions and additional papers on alternate methods and approaches, it may be possible to consolidate the expertise that exists.

II. EXISTING FACILITIES AND EQUIPMENT COMMITTED

Certain properties were made available to the University by Fish Products Company of Lewes, Delaware. These properties consisted of a two-story, concrete-block, building of 10,000 square feet facing the Delaware Bay near Cape Henlopen; a 1,200-foot pier; and two 125,000-gallon concrete tanks. The building is approximately fifty years old and has been used for various processing and warehousing purposes. Most recently it was set up and operated as an oyster depuration plant. Aquapure, Incorporated, failed to achieve their desired profitability and abandoned the effort in early 1971.

Oyster depuration involves the purification of oysters taken from polluted waters. This purification occurs naturally when oysters are maintained in non-polluted waters for a period of not less than forty-eight hours. The process as well as design specifications are described by Furfari (1966). In this operation, seawater, at approximately 400 gallons per minute, was pumped in from Delaware Bay, heated by direct steam injection, and delivered to a 4,000-gallon redwood tank. From here the seawater was distributed by gravity through six ultraviolet treatment boxes, then to four 4,000-gallon concrete holding (depuration) tanks on the first floor. It was a flow-through system, and the overflow from each tank was channeled back to the bay. Oysters harvested from the polluted waters were stored in a refrigerated room prior to loading into the depuration tanks. After depuration, the oysters were processed and packed for market as frozen oysters on the half shell.

When the operation was abandoned, the buildings and equipment were acquired by the University intact, with the exception of two gas space heaters and a 100-HP oil-fired steam boiler. Figure 1 shows a floor plan illustrating the relative location of existing system components and provides a point of departure for a detailed discussion of the components.

A. Pump

The seawater pump was a 22-inch iron-centrifugal pump driven by a 20-HP G.E. motor. The suction line was 18 feet long, 4" diameter steel with a foot valve/strainer located about two feet off the bottom. The nominal water depth was 10 feet. The pump is shown in Figure 2.

B. Inlet Lines

The seawater was delivered to the depuration plant from a distance of 1,200 feet through a single inlet line. This line started as 4" steel at the pump and after a few feet was expanded to 6" steel. The 6" steel was tied into six inch transite for 1,000 feet, and back to 6" steel through the boiler room and up to the head tank.

C. Steam Boiler

Prior to delivery to the head tank, the seawater was heated by direct steam injection. A Clever-Brooks 100-HP, oil-fired steam boiler was tied in to the steel seawater line. Steam was injected directly into the seawater line through an open pipe without the benefit of an injector. Performance was reported poor and this step

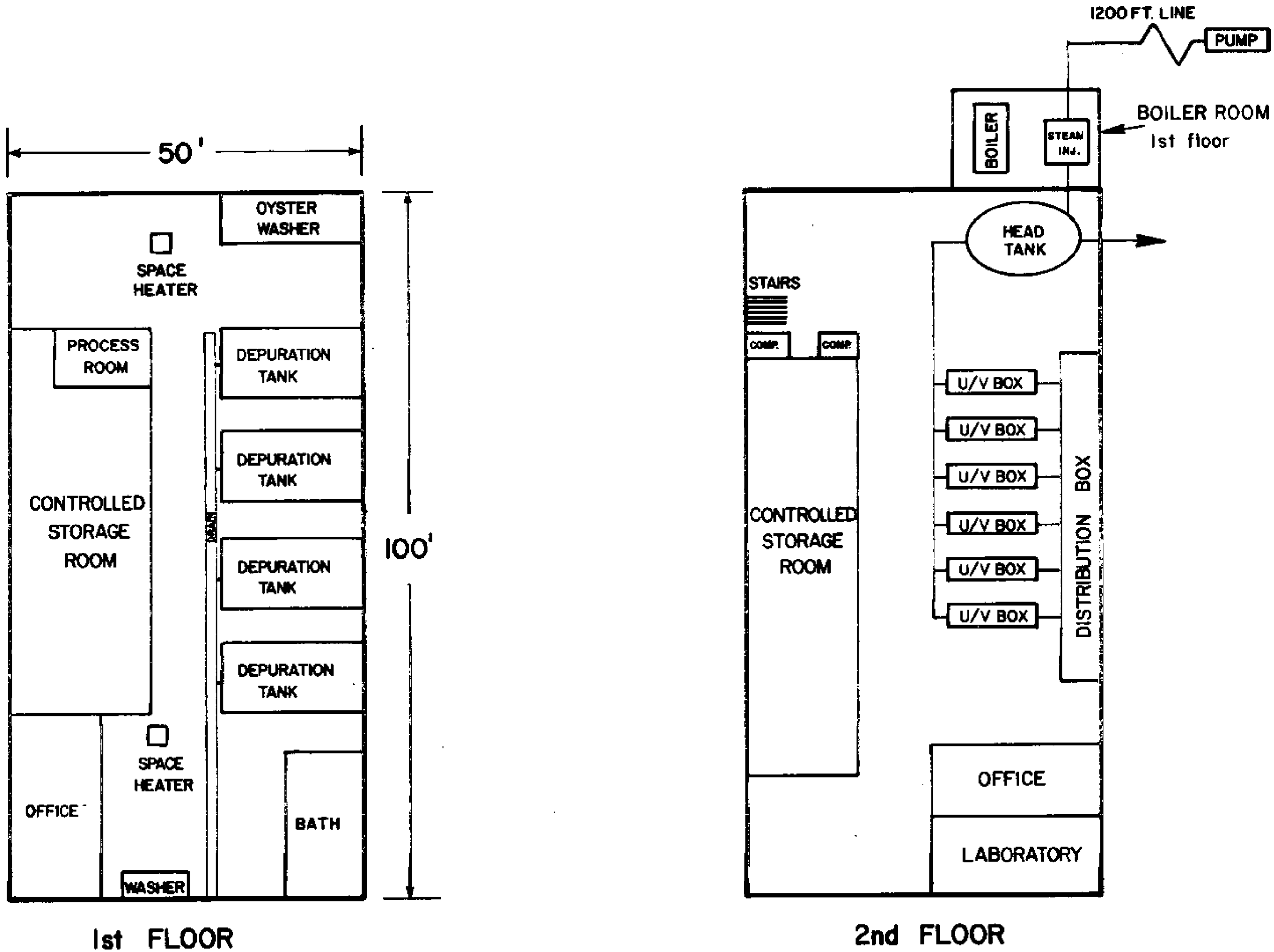


Figure 1. Existing Facility & Equipment

in the operation dangerous.

D. Head Tank

A head tank was located on the second floor of the building. This redwood tank was 10 feet in diameter and eight feet high. It was constructed of six-inch wide, two-inch thick tapered redwood slats supported by seven bands of 1/2-inch diameter steel rods. Figure 3 is a photograph of the redwood 5,000-gallon head tank. The incoming water was delivered to the tank by a 6" line supported by roof structural steel. Pumping capacity varied with the tide. The excess water pumped in at high tide was dumped by an 8" PVC pipe inserted through the side of the tank at the top and extending out through a second-story window. Approximately one foot below this level, two feet from the tank top, six 2" flanges were installed. Celflex flexible hose (by Yardley) was connected to these flanges and carried the seawater to the six ultraviolet treatment boxes (see Figure 4).

E. Ultraviolet Treatment Unit

The ultraviolet treatment units used in the depuration process were based on a design developed by the Public Health Service at Purdy, Washington, as described by Kelly (1961). These units were 7' long x 3' wide x 1' deep with 13 tubes (30w each) and a maximum flow capacity of 60 GPM for hydraulic considerations (see Figure 5). To achieve a 99.995% Coliform Kill, the seawater Absorption coefficient per centimeter at 2537 angstroms must not exceed 0.3. It further states that if the Absorption Coefficient is not measured,

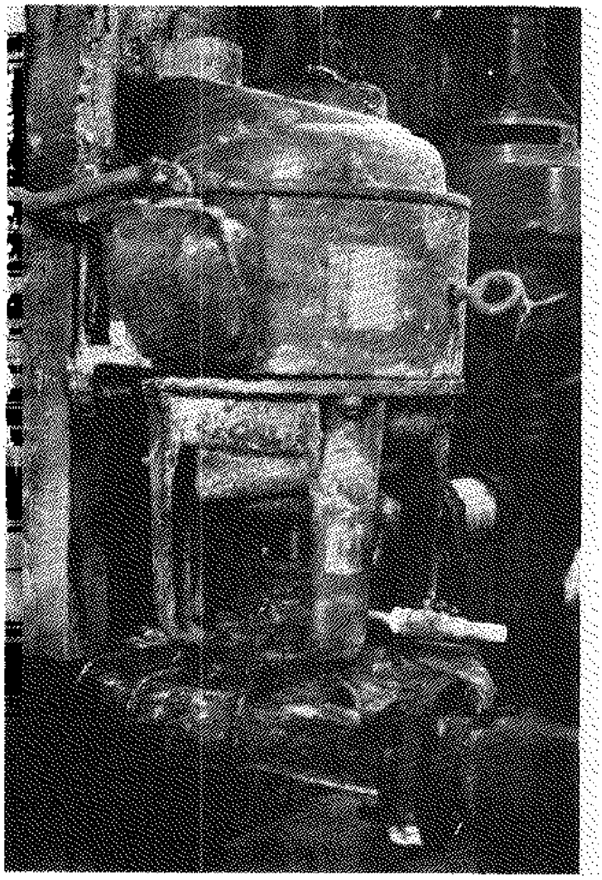


Figure 2.

Figure 3.

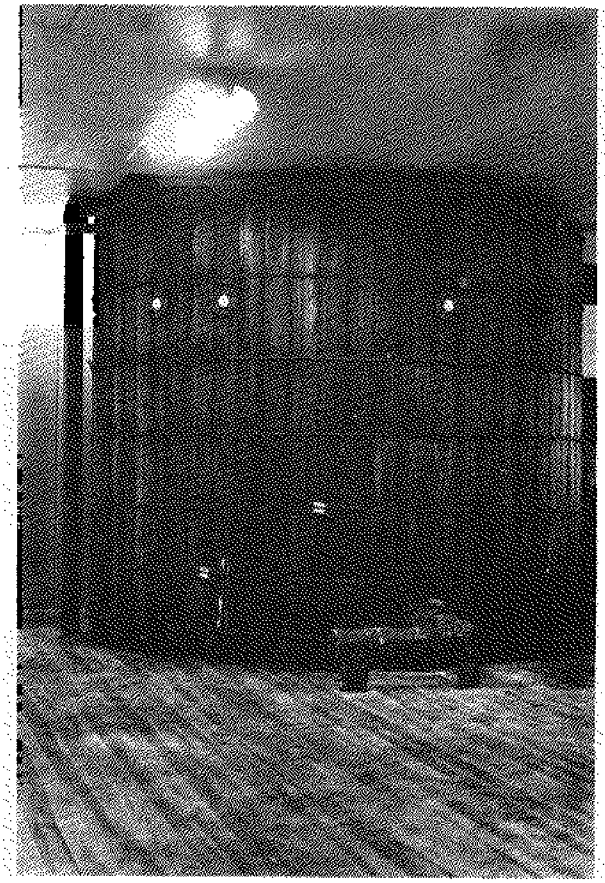


Figure 4.

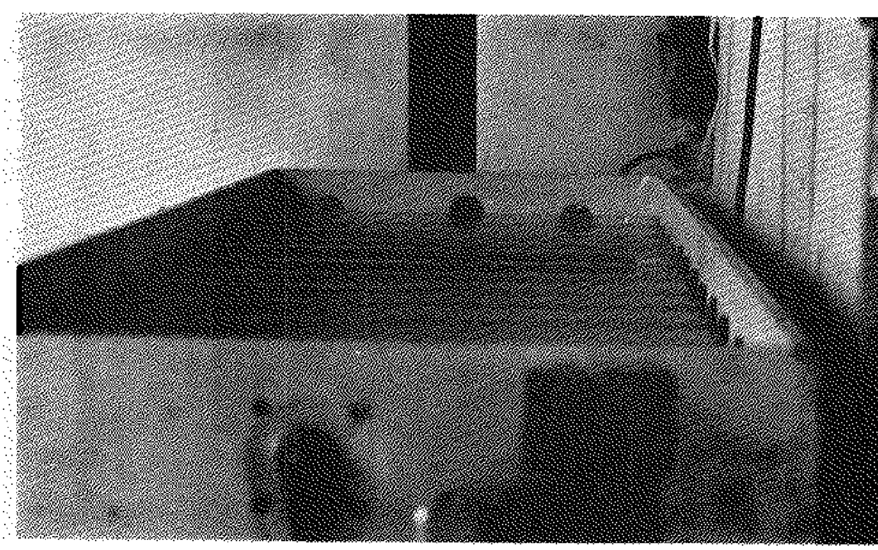


Figure 5.

the maximum allowable rate is 28 GPM.

F. Depuration Tanks

The seawater after UV treatment was delivered to the depuration tanks through a 60 ft. x 2 ft. x 1 ft. distribution box and vertical drop lines (see Figure 6). Each of four 4,000-gallon depuration tanks were fed by three 1 1/2" diameter PVC lines. The depuration tanks, 15' long x 13' wide x 3' deep, were of concrete block and mortar construction with a poured concrete floor. It is assumed that the block walls were pinned at the building wall and floor as well as at their corners by reinforcing rods. Waterproofing was accomplished by several coats of Mira Plate, a two-part epoxy polamide produced by the O'Brien Paint Company. This coating provided a smooth, hard, non-porous surface for ease of cleaning.

The seawater was delivered at the bottom rear of the tank and flowed out at the top of the front wall. The water was channeled and piped back to the bay. Depuration requires feces and pseudofeces to be washed out of the tank every 24 hours. Bottom drains were installed to remove this material, which is the focal point of any pathogenic micro-organisms that were in the gut of the animal.

G. Controlled Storage Rooms

There were two controlled storage rooms in operation as part of the depuration plant. A 15' x 40' x 8.5' room was provided on the second floor for holding oysters that could not be processed immediately. This room was insulated with four-inch rigid foam, 12 of xx between the studs. Galvanized sheet covering was used on the floor and up to a 3' height on the wall. These sheets were welded to provide a waterproof seal. The room was cooled by a pair of water-cooled compressors with a total capacity of eight tons. The operating temperature in this room ranged from 10°C to 20°C.

For holding depurated oysters prior to consumption or distribution, a 15' x 50' x 12' room was provided on the first floor. This room was of similar construction to the one above and was cooled by a pair of water-cooled compressors with a total capacity of 10 tons. The operating temperature in this room ranged from 0°C to 10°C (see Figure 7).

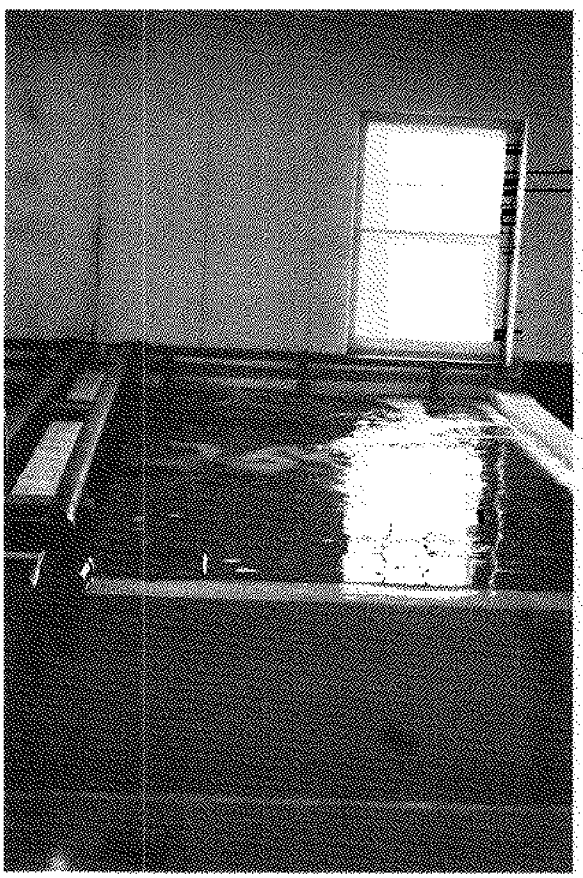


Figure 6.

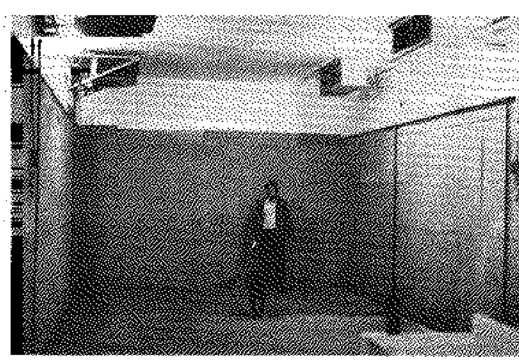


Figure 7.

III. BIOLOGISTS' PRELIMINARY SPECIFICATIONS

As an initial step in this project, the team biologists developed a preliminary set of specifications, attempting to fit the mariculture process to the existing facilities. These specifications provided a point of departure for the engineering design effort.

The recommendations presented here are based on known food, temperature, and water-flow requirements of larval, juvenile, and adult oysters. These suggestions are further tailored to meet a desired production requirement of 20,000 adults/yr.

In some areas the proposed system will have a definite over-capacity, e.g., larval-rearing capability will be much beyond what is needed for this project. Other phases of the operation will be limited in capacity by the volume of heated water that can be supplied in the winter. It is clear that insufficient funds are available to heat enough seawater to grow juvenile and adult oysters during the colder months. Therefore the process will be dependent on the recirculating system for achieving growth during the winter.

A. Brood Stock

Approximately 1,000 adults will be maintained as brood stock. Initially these oysters will be maintained in an open system. The animals will be conditioned according to the methods developed by the Delaware Shellfish Laboratory.

Process Specifications

Space required. . . . 15' x 12'

Air temperature . . .	15°C
Water supply	20 gpm at 15°C--12 months a year. This means heating from a minimum of 0°C and cooling from a maximum of 30°C.
	10 gpm at 20°C--12 months a year.
	15 gpm at ambient temperature.
Filtration	Removal of particles greater than 15 microns.
Tanks.	Two, wood or fiberglass, 22" x 10" x 72", not stacked (Figure 8A).
	Two, wood or fiberglass, 22" x 10" x 72", not stacked. Each tank with an aerated head box to correct super saturation (Figure 8B).

Proposed room arrangement--Figure 8C.

B. Larval Rearing

About 25 oysters will be used in each spawning. Each female can produce 50 to 100 x 10^6 eggs (10 to 25 x 10^6 is more typical for out-of-season spawning). Approximately 12 million fertilized eggs will be placed in each of eight 400-liter cones (30 larvae/ml). The developing embryos are kept at this density for 48 hours. By this time the larvae will have developed to shelled veligers and can be screened. The water will be run out of the cones through a 37-micron screen. The larvae will be caught in the screen and will be redivided among several cones so that the final density in each cone is 10 larvae/ml.

As larval development progresses, the cultures will be thinned out; the slower-growing larvae will be discarded, and by the time setting size is obtained, the density in the cones will be 2 larvae/ml. We will have the capability of rearing 8 x 10^5 larvae/cone to setting size. The larvae will be fed Monochrysis and Isochrysis to a density of 50,000 to 100,000 cells/ml, depending on the size and density of the larvae. The species of algae fed to the larvae will be alternated daily. Five to 10 liters of algae/cone/day are required to feed the larvae.

Process Specifications

Space required	40' x 15'
Air temperature. . . .	26°C
Water supply	15 gpm at 26° to 28°C; water to be filtered through 5-micron filter bags as it enters the tanks.
Tanks.	Eight 400-liter cones
	Ten 200-liter cones

Each cone should be supplied with an air line and air stone. There should be a seawater line, valve, and filter-bag-holder over each cone. The tables holding the cones should be high enough to permit easy drainage from underneath. The cone tables should be wide enough to allow room to walk around the cones. There should be a breaker-box under each cone. The tables should be positioned over a drainage trough.

C. Setting

The intent is to produce cultchless oysters in this project. Of the many techniques currently in use for producing such oysters, floating cultch (cork) and Filon sheeting offer the greatest potential

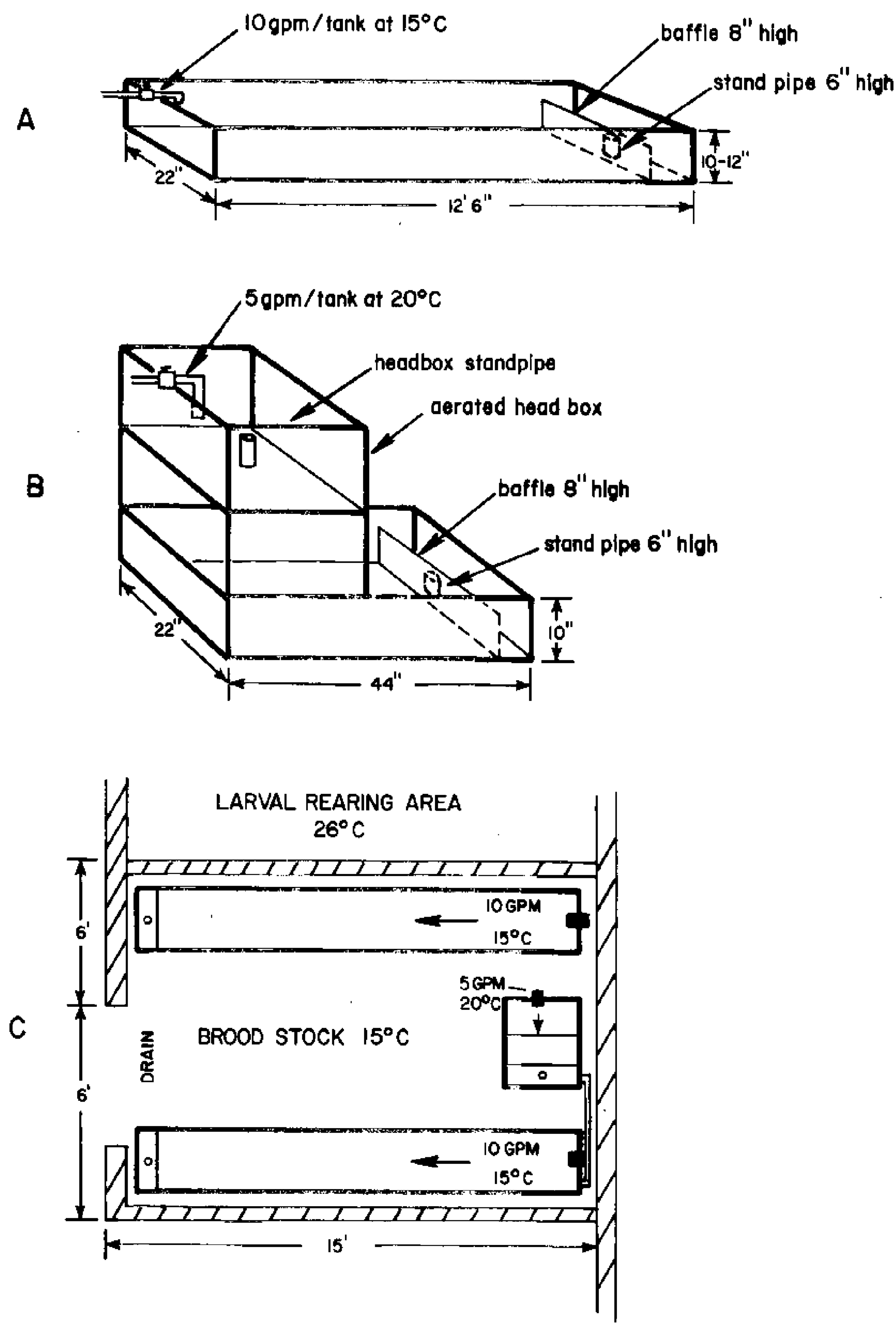


Figure 8. Brood Stock Tank Layout

for success.

Process Specifications

Air temperature. . . . 20°C (provided tanks are heated).

Water temperature. . . 15 gpm at 26°C (same as larval rearing room). The tanks should be equipped with heaters that would raise the temperature from 26° to 28° in a couple of hours.

15 gpm at 20°C (per tank); this would be used for 1 to 3 weeks after setting for the initial growth; during the winter newly set spat can be kept in standing 20°C water and can be fed from pure algal culture; the 20°C water would then be used only once daily to change the water in the tank.

Tanks . . . . Two large tanks of the same dimensions as the growing tanks already in place approximately 13' x 6' x 4' deep.

Four small tanks, plywood or fiber glass 4' x 4' x 12" deep; located in larval growing area, air temperature 25° to 27°C; if the tanks can be inexpensively and efficiently heated (without submersion heaters), they could be located in large 20°C room; each tank should be supplied with 5 gpm at 26°C for filling occasional use; plus 5 gpm at 20°C for initial growth; this water (20°C) could be diverted from some other area for the relatively short period of time (1 to 3 weeks) that we would need it.

D. Growing Tanks

New spat will be fed from pure cultures of algae in a static culture for the first few weeks after setting. This will assure that the high mortality among the early spat will occur before the oysters are placed in the recirculating system. Eight growing tanks modified from the four tanks now in the facility are envisioned. Oysters will be held in stacks of plastic trays in the tanks.

Process Specifications

Air temperature. . . .	20°C
Water temperature. . .	Ambient + whatever 20°C water is available.
Tanks.	The tanks are already in place; suggest splitting them down the middle with cinder block partitions.

E. Algae Culture

Methods of culturing marine algae for use in mariculture have been developed and standardized by a number of workers. Methods used in the Delaware lab were described in an unpublished report by Mr. George Reinsfelder. These are briefly outlined below.

Filtered seawater
Sal. 25 $\pm$ 2 ppt

*chlorinated 30 ppm

dechlorinated three carbon filter

small volume cultures (10 ml - 2L)	large volume cultures (20 - 400L)
nutrients added 1 ml/L	nutrients added 1 ml/L
autoclaved 15 lbs. 15 min.	inoculated, 20L carboy after 6 - 7 days
inoculated aseptically	inoculated, 100L tank after 6 - 7 days
flasks held on shaker table as inoculum	fed to larvae and spat

* An alternate sterilization procedure may be developed—ozone or the use of artificial seawater are being considered.

Process Specifications

Space required	Available in second floor cold room (approximately 15' x 40').
Air temperature. . . .	17° - 20°C
Water supply	15 gpm ambient temperature, for intermittent use; the water must be autoclaved, chlorinated, or sterilized in some other way before it is used, so its initial temperature is not critical.
Tanks and other facilities	Shelf space for 18 five-gallon carboys; about 40' of total shelf space; no more than 3 shelves high; shelves must be lighted and well ventilated to prevent heat build-up around the carboys.
	Lighted table space; lighted from above; about 10' x 3', for shaker tables, and other small-scale cultures.
	Large culture tanks, 75 to 100-gallon capacity, should be fiber glass, about 3' x 4' x 2' deep; well lighted from above; must be supplied with air or with some stirring device.
	An autoclave capable of handling 5-gallon carboys; must be available on site.

F. Seawater System (Preliminary)

A seawater system meeting the needs of the preceding preliminary specifications is shown on the following schematic diagram (Figure 9). The pump system is composed of four 100-gpm pumps, with a 6" line to a storage tank. Then the water is delivered via a direct pipe to the brood area, research area, algae area, and to each of the growing

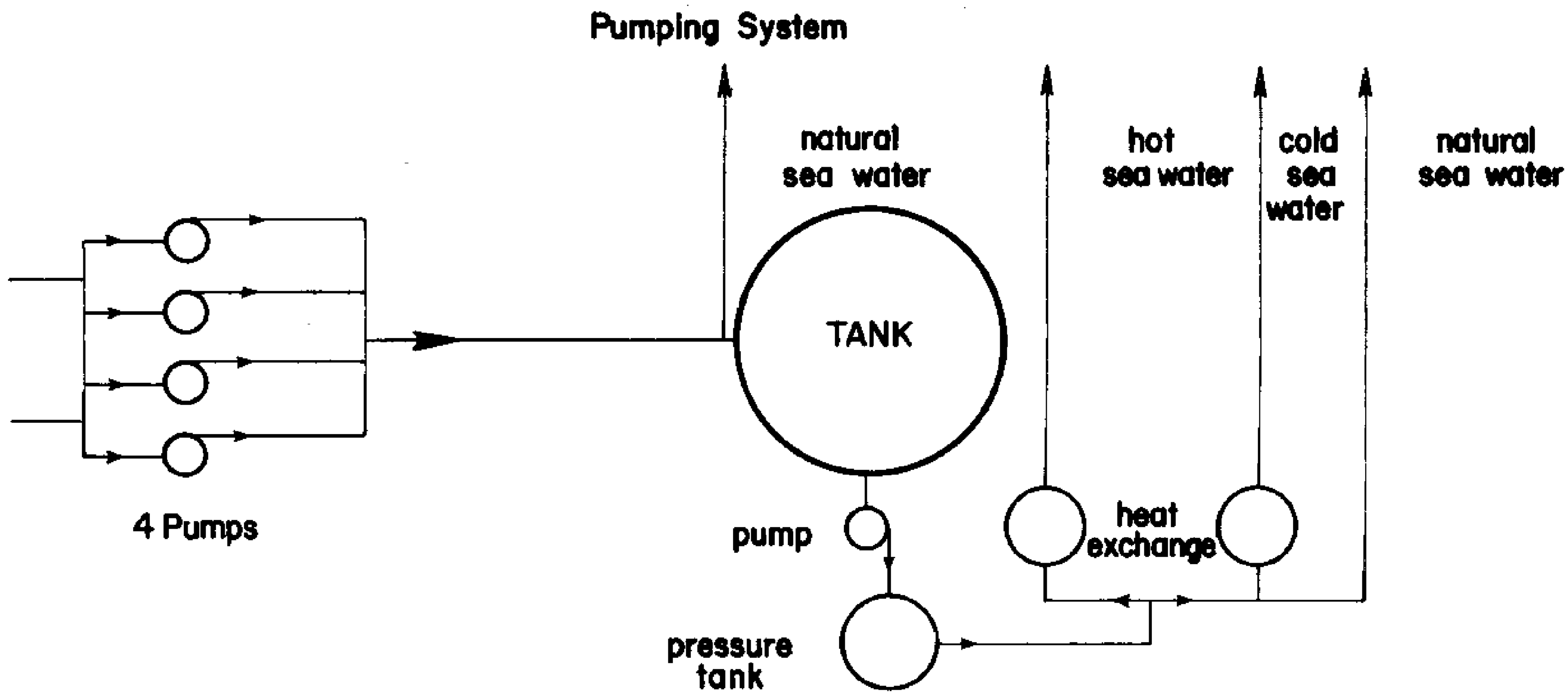

Pumping System
natural
sea water
hot
sea water
cold
sea
water
natural
sea water
TANK
4 Pumps
pump
heat
exchange
pressure
tank

Figure 9.

tanks. Pump inlets should be self-cleaning and have primary filtration. They should be controlled by a pressure switch with a built-in delay, with each switch set at a different pressure to bring the pumps on-off as required. The storage tank should be capable of being cleaned. A float control valve should be provided to control the water level at the desired depth. For the hot and cold running seawater, a pressure system is provided so both systems operate off the same pressure tank. The water and temperature requirement summary and floor plan layouts are as follows (Figures 10 and 11):

Brood Stock Area

Temperature - 15°C
Water supplied - 15 gpm at 15°C
- 5 gpm at 20°C
- 15 gpm at ambient condition

Larval Growing Area

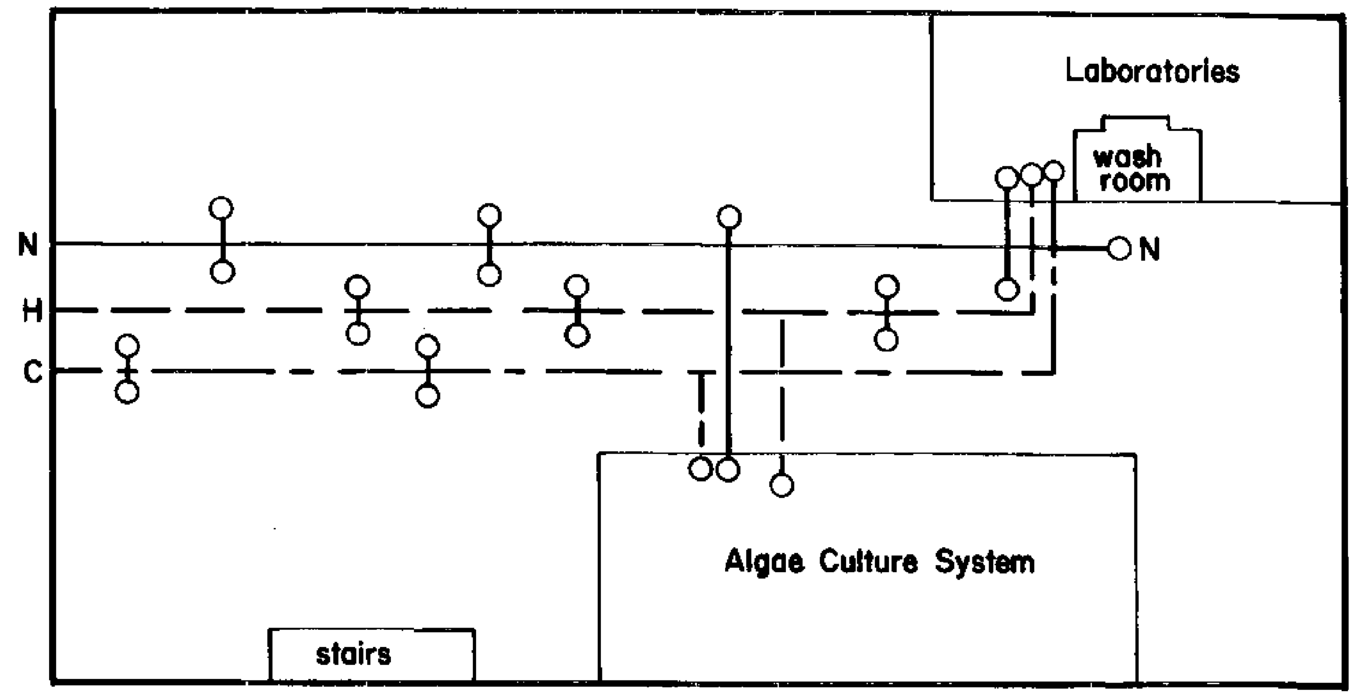
Temperature - 28°C
Water supplied - 15 gpm at 20°C
use an electrical water heater to bring the water temperature to 28°C

Setting Tanks (2)

Temperature - 26° to 28°C
Water supplied - 15 gpm at 20°C
use a heating unit incorporated into the tank wall to heat and hold at 28°C

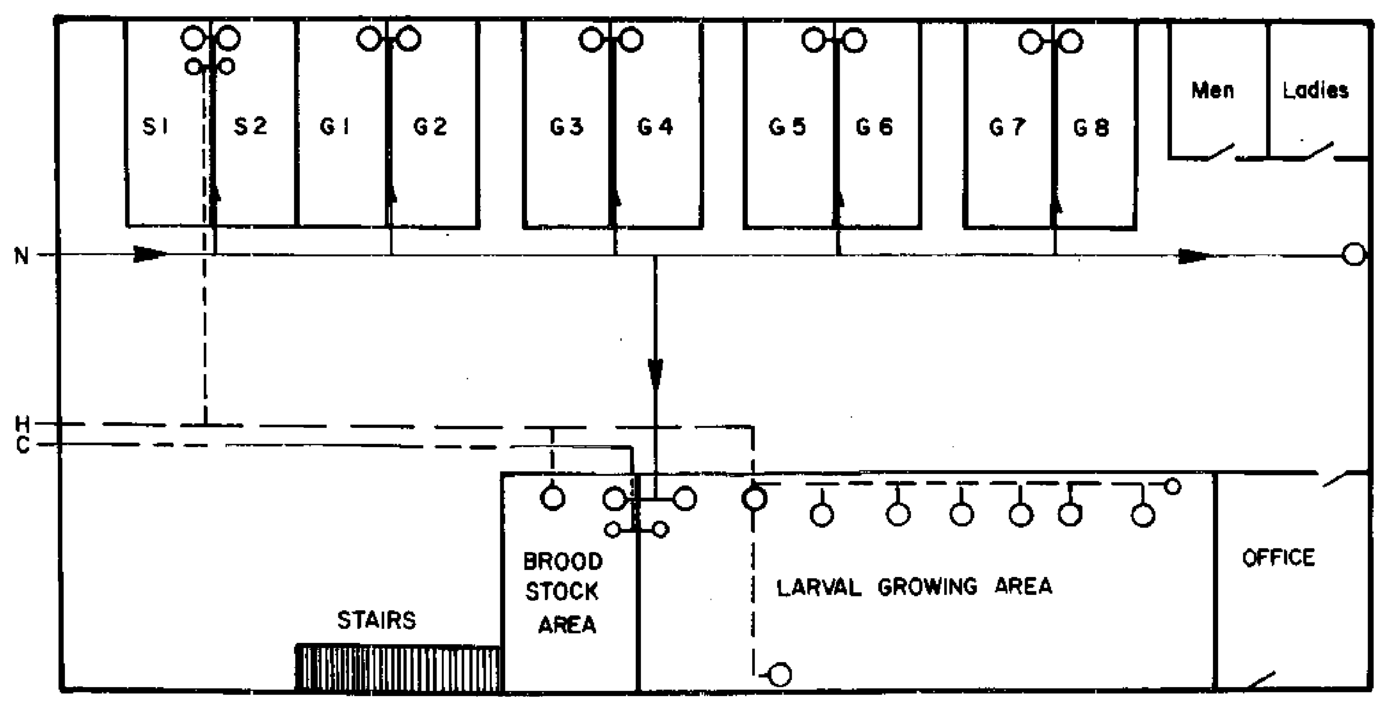
Growing Tanks (8, 2000 gallon/tank)

Temperature - 20°C
Water supplied - Ambient at 300 gpm possible; however when not needed could be used in research area with a 25 gpm rate to each growing tank, which would require 200 gpm for 8 tanks and 100 gpm for research area.



2nd FLOOR WATER SYSTEM

Figure 11.



1st FLOOR WATER SYSTEM

Figure 10.

Algae Culture Area

Temperature - 20° to 22°C
Water supplied - (1) ambient temperature - 20 gpm
(2) 15°C - 10 gpm
(3) 20°C - 10 gpm

Total Water

15°C - 25 gpm
20°C - 45 gpm
ambient - 300 gpm
370 gpm

would use 400 gpm

Research Area

Temperature - 15° to 28°C

Since more water is supplied to most areas than is required on a daily basis, by properly timing the filling of larval and setting tanks, water could be supplied to this area with no increase in pumping requirements.

Pipe Size - will vary with type of pipe used.

For Johns-Manville PVC pipe

400 gpm - 6"
100 gpm - 3"
50 gpm - 2 1/2"
15 gpm - 1 1/2"

Heating and Cooling

50 gpm x 60 = 3,000 gph

Heating: 0°C to 20°C, Δt = 20°C = 36°F
Cooling: 30°C to 15°C, Δt = 15°C = 27°F

3,000 gph x 8.34 #/g x 1 BTU/# x 36 = 817,320 BTU/hr

3,000 gph x 8.34 # x 1 BTU/# x 27 = 675,540 BTU/hr

Water Heating = 817,320 BTU/hr
Water Cooling = 675,540 BTU/hr

Cooling = 10 tons for air conditioning
Heating = 5 HP for building

IV. MAJOR MARINE FACILITIES SURVEY

To obtain the most current information concerning marine laboratories and seawater systems, the Delaware mariculture research team toured major marine facilities on the East and West Coasts of the United States and Canada. At each facility the team was informed of good and bad experiences encountered in its construction, operation, and maintenance. A short discussion of the findings at each laboratory is presented, including the names and titles of contacts. At the end of this section, a summary of the findings is provided. The sites visited are listed in Figure 12 and are discussed in that order.

A. University of Washington, Seattle, Washington.
Dr. Frieda Taub, Professor, College of Fisheries

The primary topic discussed at this facility was the continuous culture of algae and the potential of controlling protein level. It appears that maximum productivity can be achieved by maintaining a culture density near the peak of the exponential growth phase. Dr. Taub suggested a visit to the biological station at Nanaimo, British Columbia, where a new laboratory was being put into operation.

B. Lumi Indian Reservation, Bellingham, Washington.
Mr. Richard Poole

Richard Poole was visited at the Lumi Indian Reservation in the fall of 1971. At this time, ground was just about to be broken for a new oyster hatchery at their Bellingham site. The hatchery was to support a mariculture effort involving the growing of both rainbow

Figure 12

	Facility	Location	Contact
A	University of Wash.	Seattle, Washington	Dr. Frieda Taub
B	Lumi Indian Reservation	Bellingham, Wash.	Mr. Richard Poole
C	Fish. Res. Bd. Canada	Nanaimo, B. C.	Mr. Herbert Reinstein
D	Oregon State University	Newport, Ore.	Dr. Wm. McNeil
E	Cal. Fish & Game Lab.	Granit Canyon, Cal.	Mr. Earl Ebert
F	Fed. Water Qual. Lab.	Milford, Conn.	Mr. Warren Landers
G	University of R. I.	Narragansett, R. I.	Dr. A. N. Sastry
H	Woods Hole Ocean. Inst.	Woods Hole, Mass.	Dr. John Ryther
I	U. of Mass.	Wareham, Mass.	Dr. J. Zaradnyk
J	Mass. St. Lobster Hatch.	Martha's Vineyard, Mass.	Mr. John Hughes
K	Va. Inst. Mar. Sci.	Wachepreague, Va.	Mr. M. Castagna

trout and the Pacific oyster, Crassostrea gigas, in a large impoundment.

C. Biological Station, Fisheries Research Board of Canada, Nanaimo, B.C. Dr. Quayle, Station Director; Mr. Reinstein, Chief Engineer

Dr. Quayle was most cordial when contacted and arranged to have Mr. Reinstein act as a guide and to answer all questions. The laboratory was the most impressive of the visit, and the experience and candor of Mr. Reinstein was most valuable.

The specific difficulties involved the corrosion and pitting of stainless steel by seawater. 304 stainless had been used in the evaporator plates of cascade type heat exchangers. Resulting leaks allowed contamination of the seawater by freon and oil. This contamination was the cause of heavy mortality of marine organisms in several active, long-term research programs. 304 stainless was also used in the system condensers to allow seawater to be used as a coolant. As in the previous case, leaks developed and the system was shut down repeatedly by loss of freon as well as seawater contamination of the freon cooling lines and valves.

Many solutions were suggested, including the use of 316 or 317 stainless, copper nickel, meticulous cleaning procedures requiring considerable downtime, and coating the stainless to prevent seawater contact. After a very difficult period, the following decisions were made involving system modifications.

Seawater would not be used to cool condensers. A new cooling tower was added to handle the fresh water circulating through the condenser. The existing chillers were to be used to chill an intermediate fluid (water 30% propylene glycol). The intermediate fluid would be pumped to four new heat exchangers. The seawater exchangers would be the De Laval type with Titanium plates. The two freshwater exchangers would be identical but with 316 stainlees steel plates.

Additional items recommended at Nanaimo are listed below:

(a) Provide water reservoir with sufficient capacity to maintain system operation while changing over inlet lines, pumps, or filters.

(b) Utilize dual inlet lines on a set rotation schedule. Do not permit salt water to set (sit) in slack lines. Backflush with fresh water prior to period of inactivity. When putting slack lines back into service, provide vent to discharge water in lines, and freshen before starting to supply the laboratory.

(c) Use PVC pipe and valves wherever possible in the seawater system.

(d) When using fresh water from a municipal system, recognize the need to de-chlorinate.

(e) Maintain circulation in hot water lines, and take care to eliminate supersaturation of O_2 and N_2.

D. Oregon State University, Newport, Oregon.
Dr. William McNeil

Of definite interest at the Oregon State site was a dual tank filtration system designed to meet the requirements of a pilot oyster hatchery. The filters were Crystaleen Model #C-6 with a flow capacity of 20 GPM/sq. ft. with 3.1 sq. ft. effective area. The two filters are set in a series, the first with uniformly graded silica sand media of .45 mm effective size, and the second with media of .30 mm effective size. The filters were piped in such a manner as to provide independent backflush. The filter shell was fiber glass, and all piping connectors were PVC (Figure 13). The filter system was purchased from Howard Construction Corporation, Scottsdale, Arizona.

In addition to the sand filtration, the water is treated by an ultraviolet sterilizing unit, and chlorinated and dechlorinated before use in large-scale algae cultures.

E. California Fish and Game Laboratory, Granit Canyon, California.
Mr. Earl Ebert

After being exposed to the severe heat exchanger problems at Nanaimo, the setup at this laboratory appeared ideal. Simply an oil-fired hot water boiler provided closed cycle heated water which was pumped through the shell of a Pyrex brand shell and tube heat exchanger. Seawater, following sand filtration, was pumped to the heat exchanger tubes through PVC piping. The operation was reported to be completely satisfactory.

This was the first laboratory visited where extensive use was made of PVC seawater drop lines at several stations per work table. The heated, cooled, and ambient seawater lines were dropped to the station in a cluster (see Figure 14). The seawater was delivered by large submerged pumps to a 10,000-gallon head tank and from there was distributed to the laboratory stations.

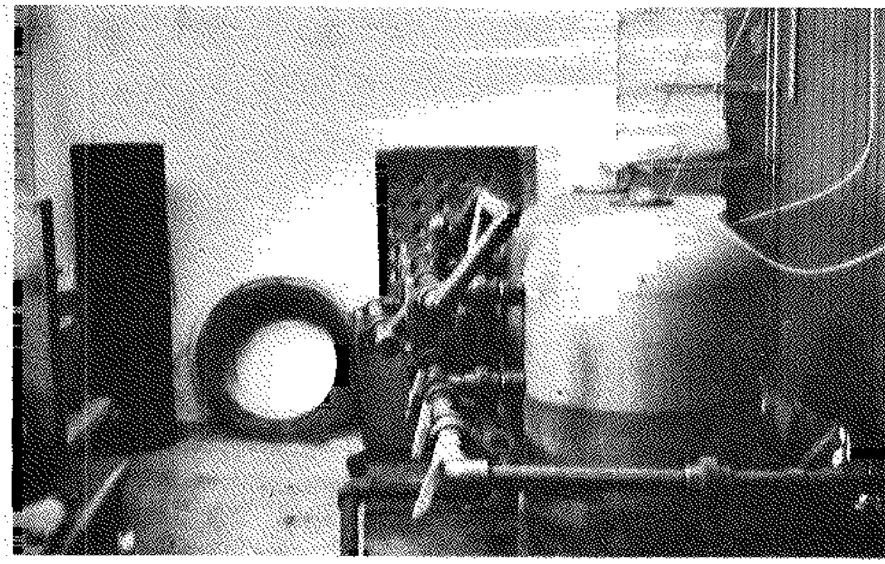


Figure 13.

Figure 14.

F. Federal Water Quality Laboratory, Milford, Connecticut.
Mr. Warren Landers

Of particular importance at this laboratory were the techniques used to handle the fouling of seawater lines. It was reported that in thirty years the laboratory has never been down for blockage due to fouling. The method involves an approach to all seawater lines throughout the laboratory identical to that recommended at Nanaimo for inlet lines. Basically it involves taking a portion of the laboratory seawater system out of service periodically on a rigid schedule for 24 hours. During this period, fresh water is flushed through that portion set aside and allowed to stand filled overnight. In the morning the fresh water is pumped out, the line is flushed with seawater and put back in service. All laboratory lines are thus maintained on a sequential basis.

It was also reported that continuing difficulty was experienced with pumps required to recirculate hot unused seawater back to the heat exchanger. Since failure of this pump might result in stagnating the flow, it was safer to put a constant drain on the hot water line at the farthest point in plumbing from the heat exchanger.

The algae culture facilities assembled by Dr. Rauna Ukeles were outstanding. Figure 15 shows the culture racks. The use of sawed PVC for inlet lines were reported to be very effective and easy to maintain (see Figure 16). Experiments in ozonation of seawater were being carried out. Initial results were very impressive.

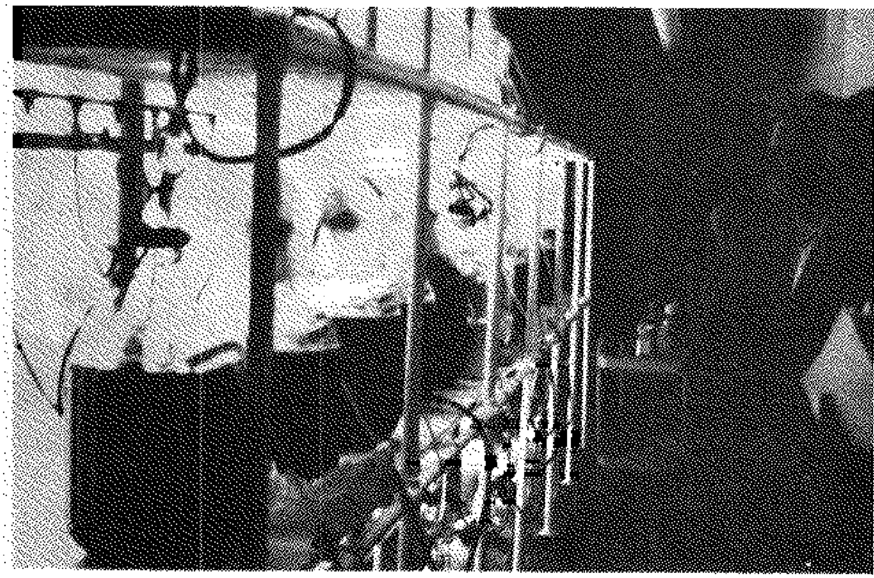


Figure 15.

Figure 16.

G. University of Rhode Island, Narragansett, Rhode Island.
Dr. A. N. Sastry

Dr. A. N. Sastry at the University of Rhode Island's School of Oceanography in Narragansett was visited. Discussions with Dr. Sastry mainly involved his experimental work with closed cycle culture of crustacean larvae. The visit also included a tour of the university's new aquarium building with its large flow-through seawater system.

H. Woods Hole Oceanographic Institution, Woods Hole, Massachusetts.
Dr. John Ryther

Dr. Ryther, a recognized authority in oceanography, is now involved in work to determine the feasibility of using the nutrients in sewage effluents to culture algae, which would then be fed to marine mollusks. At the time of the visit in the fall of 1971, Dr. Ryther was in the final stages of planning a new facility for the expansion of his work. That new facility was to include a substantial seawater system.

I. University of Massachusetts, Wareham, Massachusetts.
Dr. John Zaradnyk

Dr. John Zaradnyk was visited at the University of Massachusetts laboratory in Wareham, Massachusetts. He is particularly interested in hydraulically closed systems for delivering seawater to cultured animals.

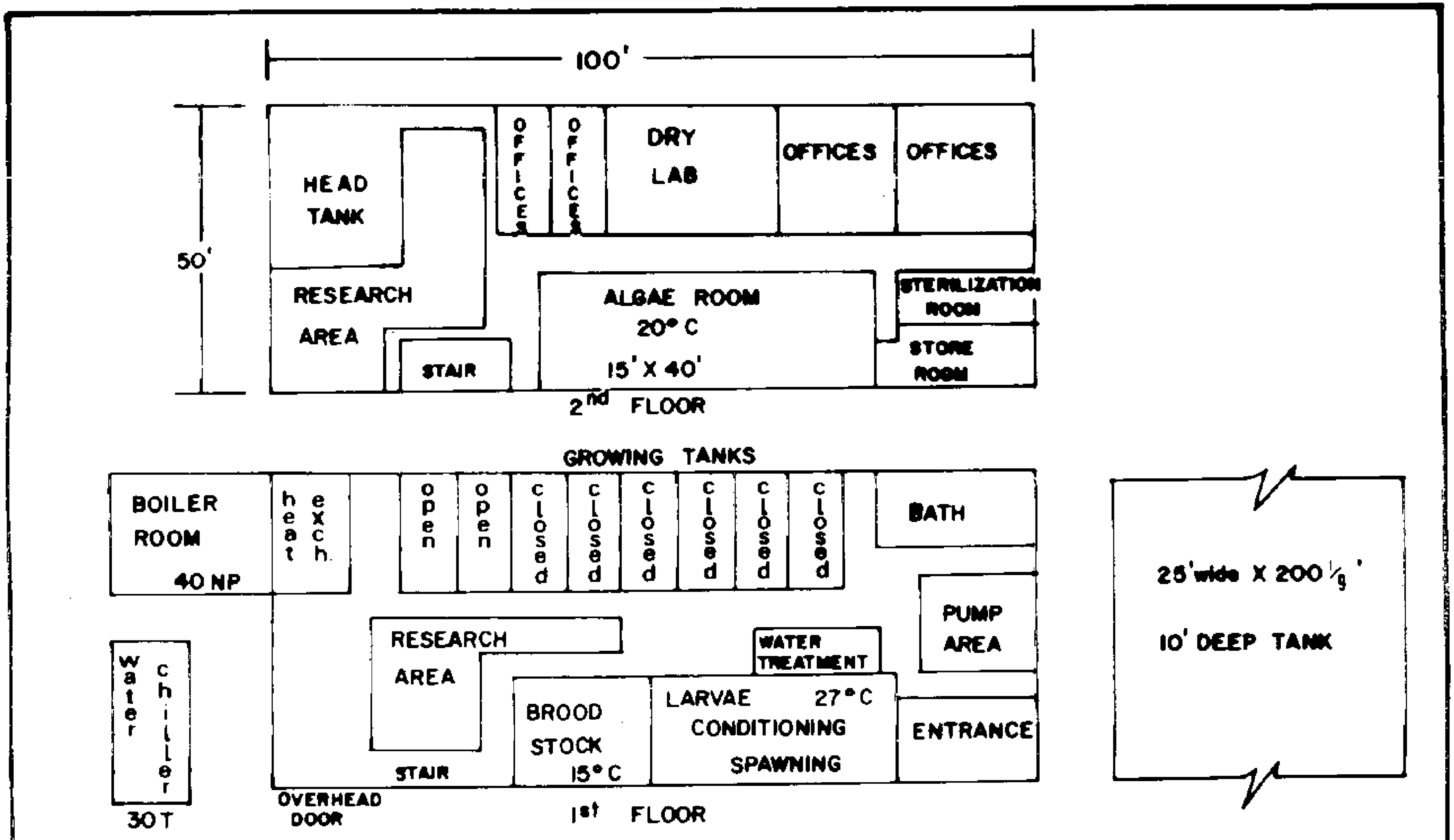
J. Massachusetts State Lobster Hatchery, Martha's Vineyard, Massachusetts.
Mr. John Hughes

Mr. John Hughes was kind enough to spend a day with us at the

Massachusetts State Lobster Hatchery on Martha's Vineyard. Mr. Hughes is not only an expert on the culture of lobsters, but is also quite knowledgeable in the construction and maintenance of seawater systems. He spent many years operating within a very tight budget and is therefore an extremely valuable man to contact if one is interested in constructing a seawater system within severe monetary limitations.

K. Virginia Institute of Marine Science, Wachepreague, Virginia.
Mr. Michael Castagna

The University of Delaware team not only toured the Virginia Institute of Marine Science's laboratory in Wachepreague, Virginia, but continued to draw on the expertise of Mr. Michael Castagna during the entire construction of its facility. Mr. Castagna's advice would be extremely valuable to anyone contemplating the construction and operation of a mollusk hatchery.



FLOOR PLAN
CMS MARICULTURE - LEWES, DEL.

Figure 17.

windows. The first floor had a 12-foot ceiling with exposed joists. The second floor was open to the steel roof, a height of 20 feet at the center, sloping to 9 feet at the sides. The roof was supported by structural steel trusses every 16' to 18'. The only approach considered for the first floor was bonding 2" thick styrofoam* to all exposed outside walls and installing storm windows. The styrofoam was to be tongue and grooved on all edges. On the second floor, it was considered desirable to install a drop ceiling. To determine the incremental cost increase, bids were requested comparing direct under-roof insulation to drop ceiling insulation. In both cases, a 4" total thickness of styrofoam was required. The lower 4 feet of all walls where insulation was installed was to be protected with 1/4" exterior plywood bonded to the insulation. The estimated insulation to accomplish the task was just under 12,000 sq. ft. of 2" styrofoam.

The bids received indicated that the drop ceiling insulation was no more expensive than the under-roof insulation. Further, styrofoam sheet costs essentially the same as polyurethane spray-on systems. There was a significant price difference between vendors responding. The prices ranged from $8,900 to $12,420. In this instance the low bidder was selected. We have been very happy with the effectiveness of this approach.

Figure 18 shows the work in progress and Figure 19 shows the

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* Dow Chemical. 2.2#/$ft.^3$, K = .185 btu/$ft.^2$/F°/in. thick

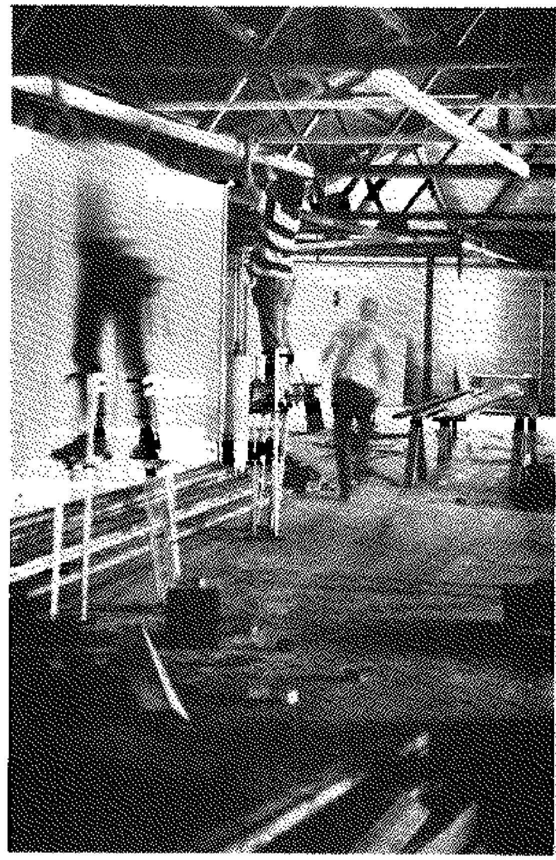


Figure 18.

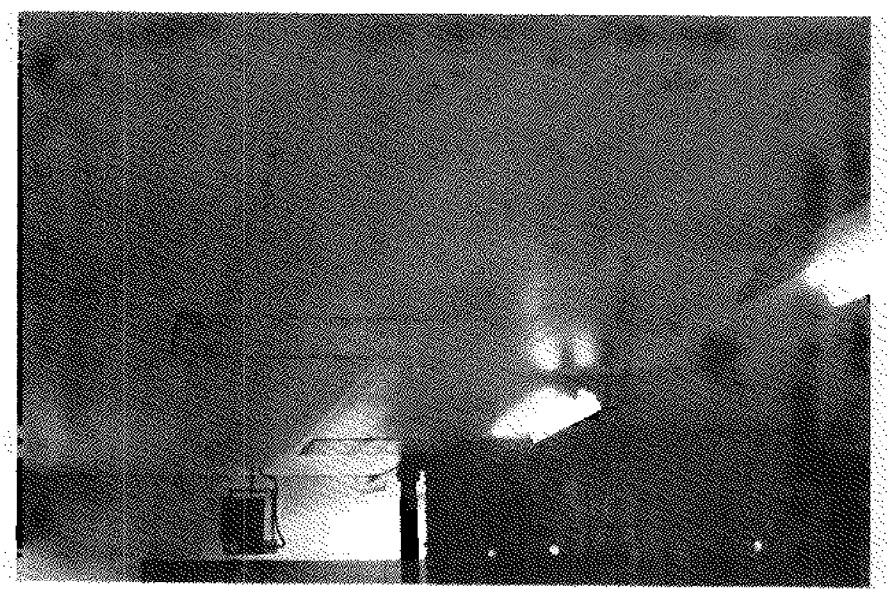


Figure 19.

finished product after lights were installed. The rule of the thumb, 25¢ per square foot material and 10¢ per square foot installation, reflects less than 1/2 the cost actually encountered. Based upon 2" thick foam, \$.75 to \$1 is more accurate.

A heat loss analysis was carried out and indicated a need for about 250,000 btu/hr at a 70°F differential. A comparison was made between the installation of a series of ceiling-mounted and baseboard electric heaters strategically placed throughout the laboratory and offices and the installation of hot water baseboard heat with an oil-fired boiler. Electric heat was selected because of a combination of low initial cost, flexibility, portability, and the five-year term of the existing lease. Some consideration was given to combining the requirements of building heat and seawater heat exchanger heat. If common freshwater was used, contamination of culture tanks with freshwater from copper lines and/or contamination of the heating system with salt water could occur.

With a conversion of 3.41 btu/watt, electric heating was installed with a capacity of 80,000 watts. The bulk of this was provided by seven Electromode-Singer ceiling-mounted, 3 phase, 240 volt, 10,000 watt heaters with built-in thermostat controls (Figure 20). An additional forty feet of Federal Electric baseboard units in 8 and 4 foot lengths at 250 watt/ft were installed in offices and laboratories (Figure 21).

In the absence of duct work that is an integral part of a forced-air heating system, individual units of various sizes are the only

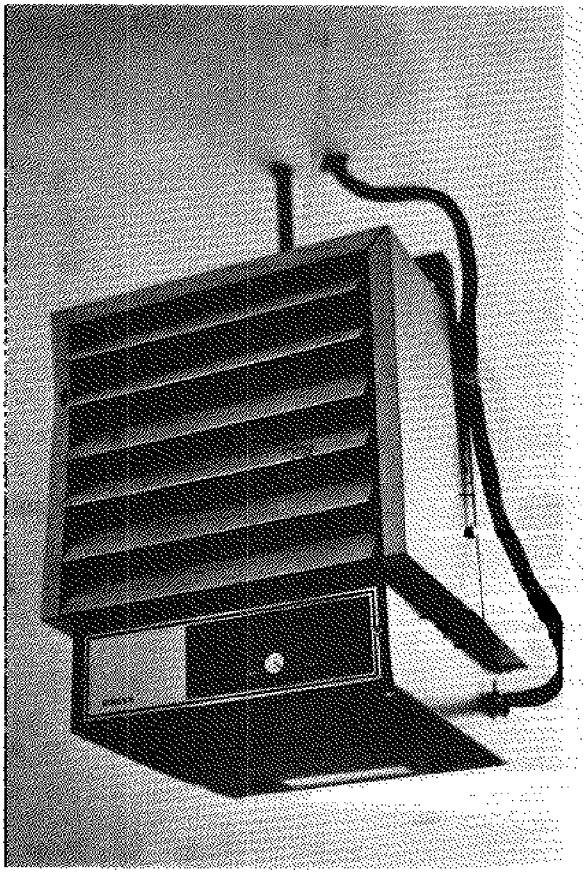


Figure 20.

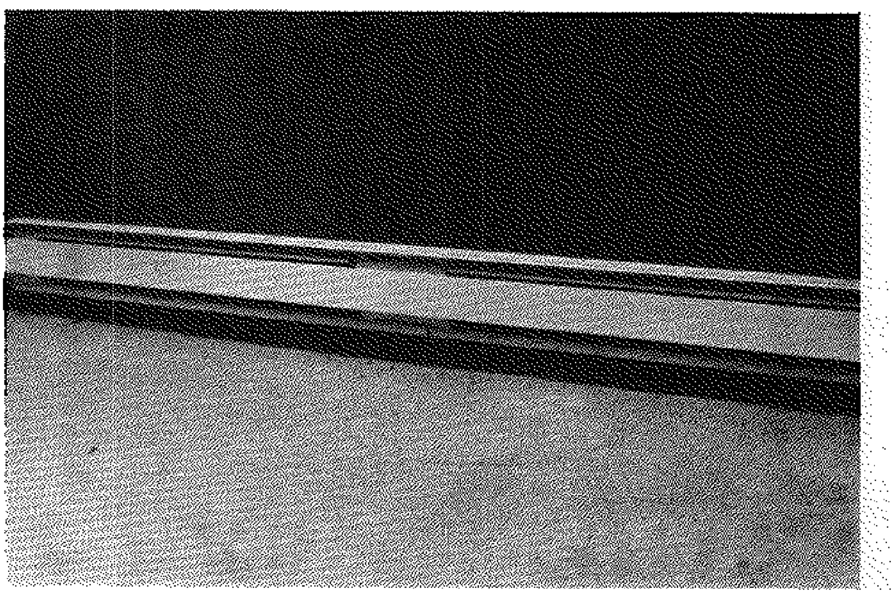


Figure 21.

choice. To provide the necessary cooling five 12,000 BTU and two 8,000 BTU air conditioners were purchased.

B. Seawater System--External

The seawater system is a dual pump, dual feed, 400 gpm system which delivers seawater to two 125,000-gallon settling and storage tanks and is provided with fresh water connections and valving for fouling control. All valves and lines are PVC except a 1000-foot 6" transite line. Figure 22 is a schematic of the Seawater System--External.

1. Suction Lines: The inlet point is approximately 1,100 feet from shore on a pier where the water depth varies from eight to twelve feet with the tide changes. The pump suction lines are 4" diameter PVC pipes, eighteen feet long, with PVC ball-type foot valves two feet from the bay bottom. The ball valves have a union-type end connector and removable screens which permit in-line service. The screen orifices are approximately 3/16" in diameter and require cleaning every two weeks during peak fouling periods in the summer. Divers remove the screen and install a clean one. The dirty screen is then cleaned and made available for the next exchange.

2. Pumps: There are two inlet pumps (Figure 23). One, which came with the facility, is a 22" centrifugal pump driven by a General Electric, 3 ph, 440 v, 25.8 amp, 20 HP motor. Particulars on this pump are not available. The second pump is Marlow Model 34-E1-15D modified by Coker Pump and Equipment Company to their specification no. Q-459-SS. Four of the pumps were purchased, and the other three form

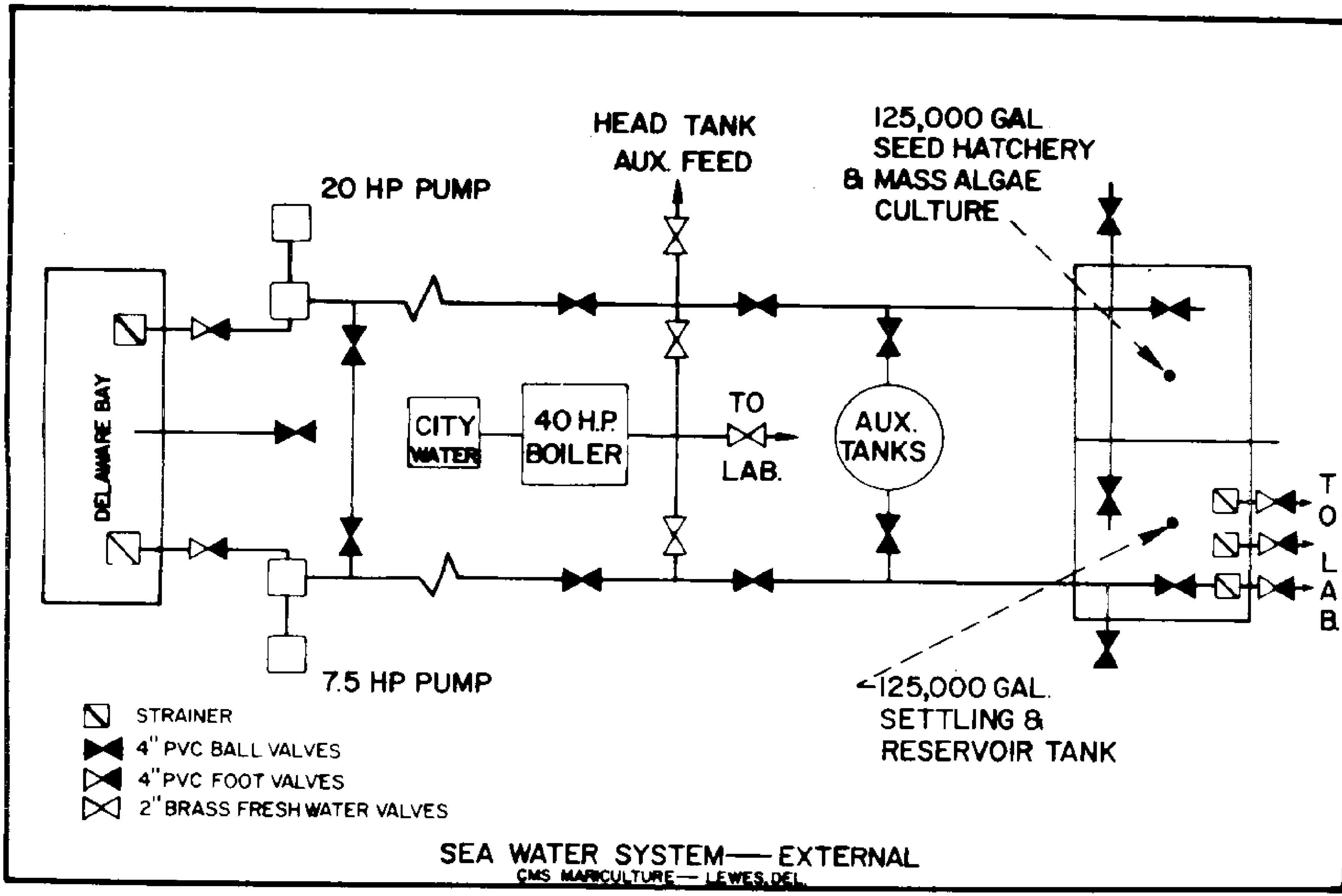

20 HP PUMP
HEAD TANK
AUX. FEED
125,000 GAL
SEED HATCHERY
& MASS ALGAE
CULTURE
DELAWARE BAY
CITY
WATER
40 H.P.
BOILER
TO
LAB.
AUX.
TANKS
TO LAB.
7.5 HP PUMP
125,000 GAL.
SETTLING &
RESERVOIR TANK
STRAINER
4" PVC BALL VALVES
4" PVC FOOT VALVES
2" BRASS FRESH WATER VALVES
SEA WATER SYSTEM — EXTERNAL
CMS MARICULTURE — LEWES, DEL.

Figure 22.

part of the Seawater System-Internal, discussed in the next section. It is worthy of special note that these pumps have a history of excellent performance at the Delaware Field Station. The first pumps of this kind were purchased by the Delaware lab in 1969 upon recommendation by the Chesapeake Biological Laboratory at Solomons Island, Maryland, and the University of the Pacific Biological Station in Dillon Beach, California. The pumps have been reliable in around-the-clock service. Specifications are listed as follows:

> For pumping 200 GPM of silty seawater against a differential head of 50 ft. TDH, liquid having a viscosity of 32 SSU at ambient temperature and specific gravity of 1.03. Pump requiring 7" NPSH with efficiency of 48%, unit requiring 4.8 BHP at the above conditions.
>
> Quan: Four (4) Marlow Model 34EL-15D (Coker Specification #Q-459-SS) Industrial Epoxy Coated, Size 3" flange discharge, end suction, single stage, single suction double ball bearing, self-priming centrifugal pump. Unit fitted with <u>316 Stainless Steel Shaft and Shaft Sleeve</u> thru seal area with <u>stainless steel metallic mechanical seal parts</u>. Pump furnished completely mounted and aligned on a channel steel base and connected by means of a flexible coupling with coupling guard to a 7.5 HP, 230.460 volt, 3 phase, 60 cycle, 1750 RPM TEFC U.S., Reliance, Louis-Allis, or G. E. motor.
>
> The Epoxy Coat is #203 Scotch Coat Epoxy.

The pumps are piped to allow interchange of pumps and inlet lines. There is a by-pass provided to adjust flow if required and to provide a dump point for routine hot freshwater backflush.

<u>3. Inlet lines</u>: One inlet line is 4" PVC, and the other is 6" transite (see Figure 24). The transite line was used in the Oyster Depuration Plant. Tests were conducted with a portion of this line, and no detrimental effects were noticed on oyster larvae. Use of this line saved 1,000 ft. of 4" PVC pipe. Wherever the line

was in a protected area, schedule 40 PVC was used. The factor expressing inches of expansion per 10°C temperature change per 100 ft. of PVC pipe is .33. Pipe expansion in the 1,000 foot run of PVC failed a glue joint due to temperature change, as the deformation took place in a localized area. Restrainers were installed to limit lateral movement to 2 feet. This effectively distributed the thermal expansion over the entire line, and no further difficulties were encountered. Several taps were placed in the inlet line to provide flowing seawater for auxiliary holding tanks.

4. Settling Tanks: Both inlet lines terminate at the pair of 125,000-gallon concrete tanks, just outside the laboratory (Figure 25). One of these tanks is primarily used for storage and settling, and the other is slated for use in seed hatchery and mass algae culture experiments. Each tank is 12 feet wide, 6 to 8 feet deep, and 200 feet long. In the opposite end of the storage tank from where the water is delivered, three suction lines and ball-type foot valves are installed and supply the three pumps inside the laboratory, providing the prime mover for the Seawater System--Internal.

C. Seawater System--Internal

This seawater system is a dual pump-head tank system, with all PVC valves and lines, that delivers and distributes up to 400 gpm of a combination of heated, cooled, and ambient seawater. It is provided with hot freshwater connections and valves for fouling control. Figure 26 is a schematic of the Seawater System--Internal.

1. Suction Lines: The pump suction lines are 4" diameter PVC

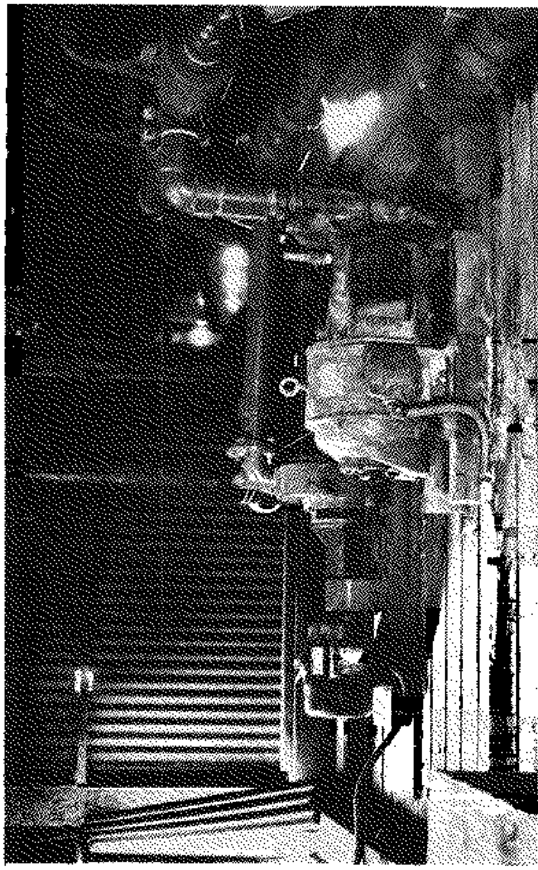


Figure 23.

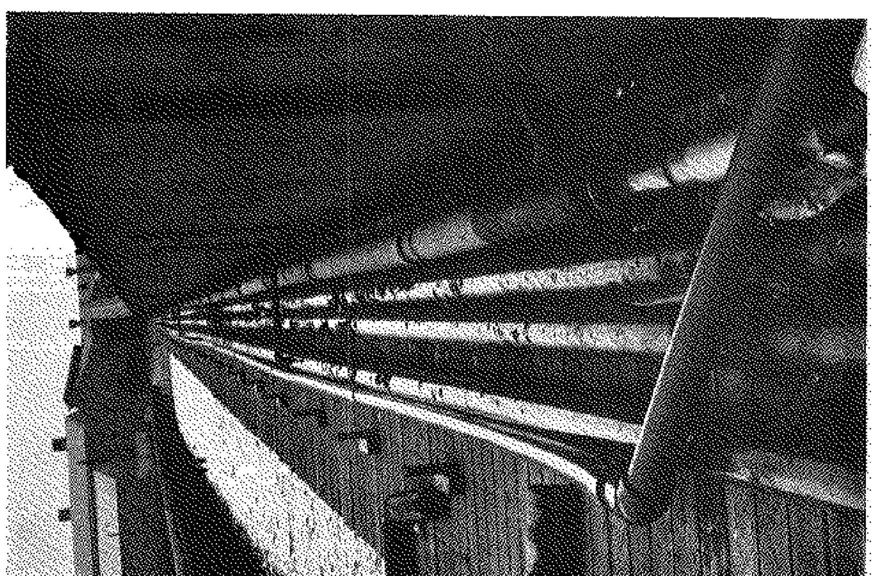


Figure 24.

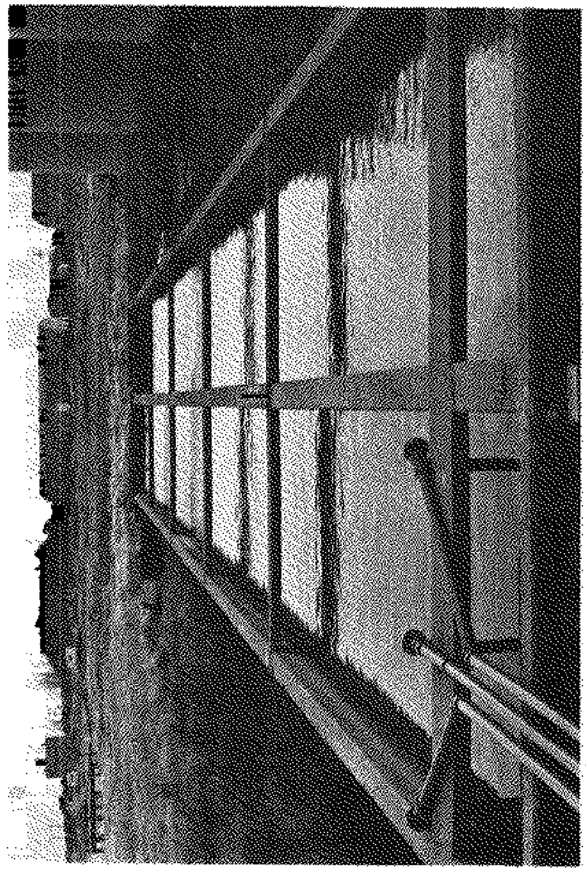


Figure 25.

pipes, eighteen feet long, with PVC ball-type foot valves two feet from the tank bottom. The ball valves have a union-type end connector and removable screens which permit in-line service. The screen orifices are approximately 3/16" in diameter and require cleaning every two weeks during peak fouling periods in the summer. Divers remove the screen and install a clean one. The dirty screen is then cleaned and made available for the next exchange.

2. Pumps: Three Coker modified Marlow pumps, described in detail in the previous section, provide the pumping capacity for internal distribution (see Figure 27). Each pump has an individual suction line into the reservoir. The pumps are interconnected with appropriate valves to allow any one or all three pumps to service the laboratory's water requirements. However, in normal operation the pump marked "1" in Figure 26 provides seawater at ambient temperatures at approximately 35#/in.^{2} to the water treatment area, to the algae room, to the brood stock room, to the hatchery, and to the research areas. The pump marked "3" on the schematic provides seawater for the hot and cold water lines as well as the open cycle. For several reasons it was desirable to operate the hot and cold water lines substantially below the 35#/in.^{2} of the ambient lines. First, the Pyrex Heat Exchangers, covered later, have a recommended operating pressure of 20 psi. The closed freshwater cycle water from the boiler and the chiller were set at the 20 psi figure. In the event of a ruptured tube in the heat exchanger, it was advisable to keep salt water out of the boiler and chiller if at all possible. As a step in this

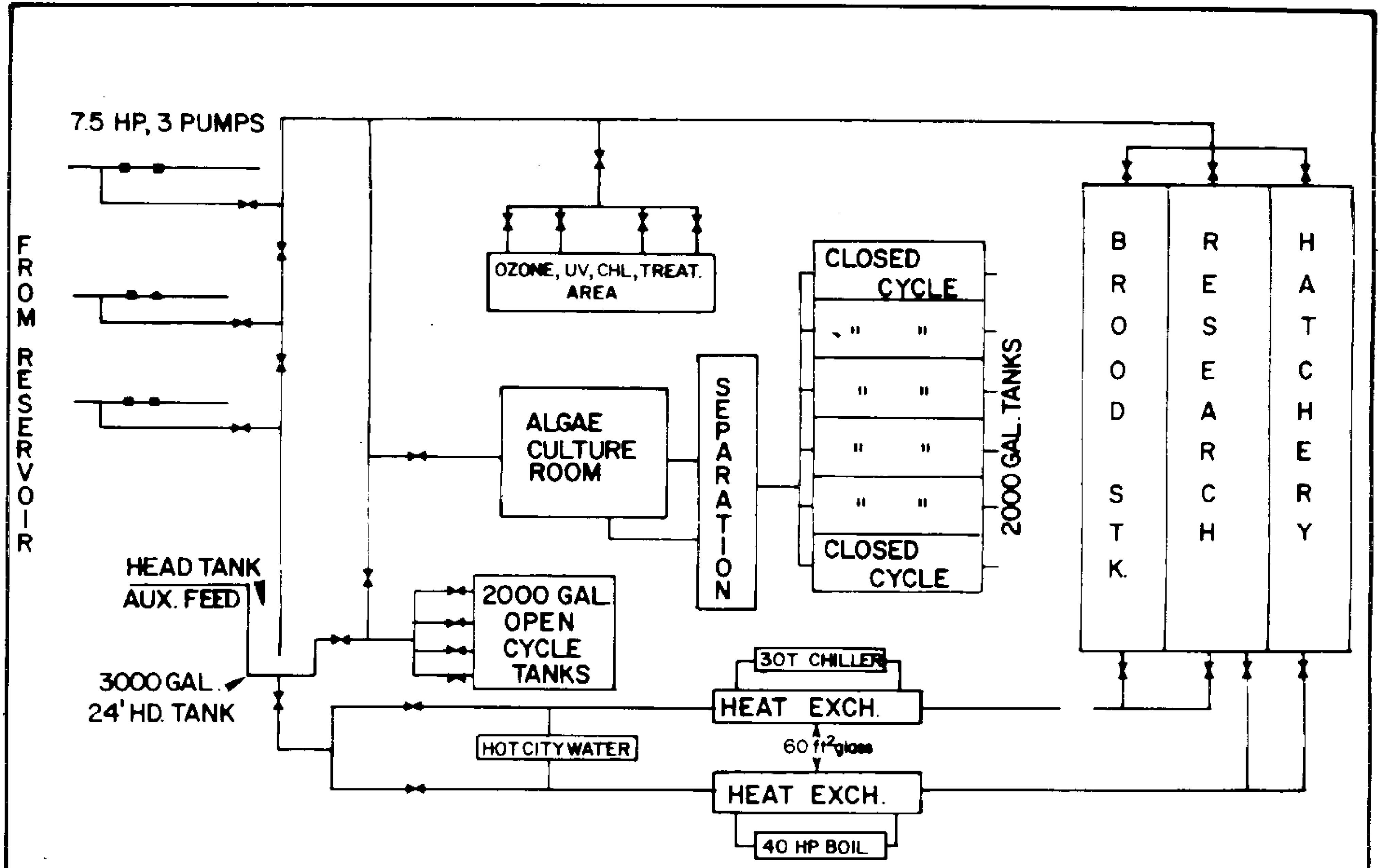


Figure 26. SEA WATER SYSTEM — INTERNAL
CMS MARICULTURE, LEWES, DEL

direction, the most desirable pressure in the hot and cold seawater system was set between 10 and 15 psi. The already existant redwood head tank provided an excellent means to establish the desired pressure. The water from pump #3 is delivered up to the head tank and through a bottom tap to the pair of heat exchangers and the psi line pressure established.

The capacity of the pump installed was far in excess of the needs of the hot and cold water system. Therefore, the seawater delivered over and above the hot and cold requirement became the seawater feed to the open cycle tanks (see Figures 28 and 29). This was accomplished by installing a standpipe in the redwood tank and connecting it to the open cycle feed lines. The head tank arrangement is shown schematically in Figure 30.

3. Heat Exchangers: The heat exchangers selected for this laboratory were Pyrex brand shell and tube type by Corning Glass Works, Corning, New York. Strong biases against metal heat exchangers had been built up by the difficulties encountered by the Nanaimo Biological Station and our own difficulties in maintaining epoxy coatings on the metallic shell of our Carbate (by Union Carbide) core heat exchanger, used at the laboratory since 1969. Therefore, the only decisions to be made concerned the number and size of glass shell and tube heat exchangers the lab would buy.

The projected requirements for heating 50 gpm at 20°C from a 0°C bay had been set. After consideration of required water for larvae of 26° to 28°C, it was decided to drop the idea of additional

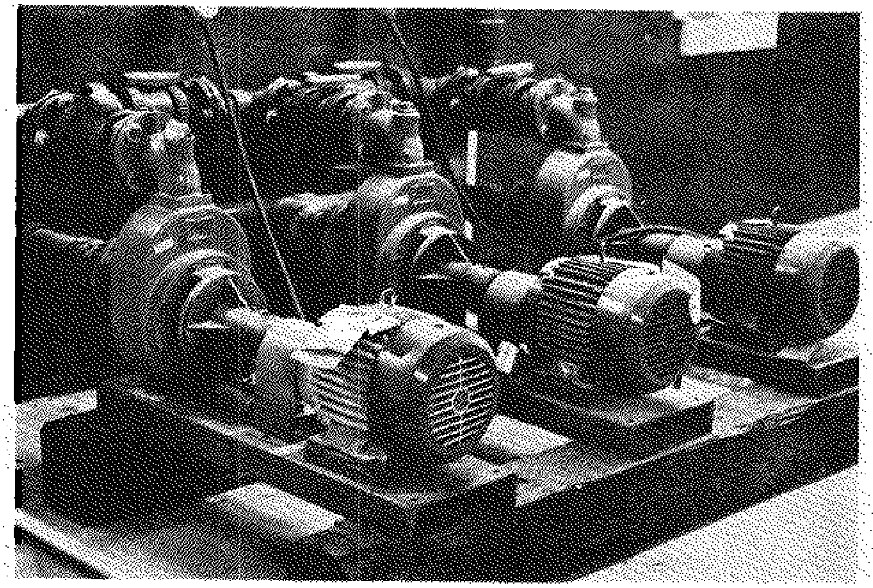


Figure 27.

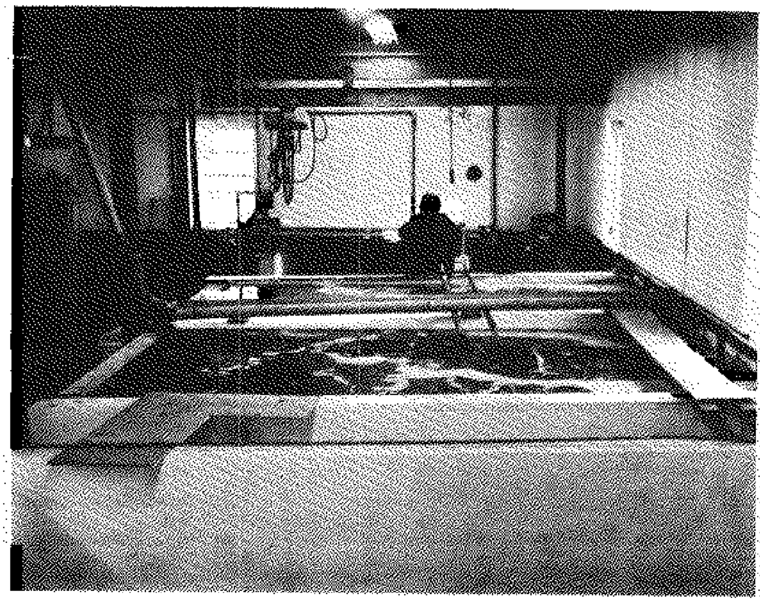


Figure 28.

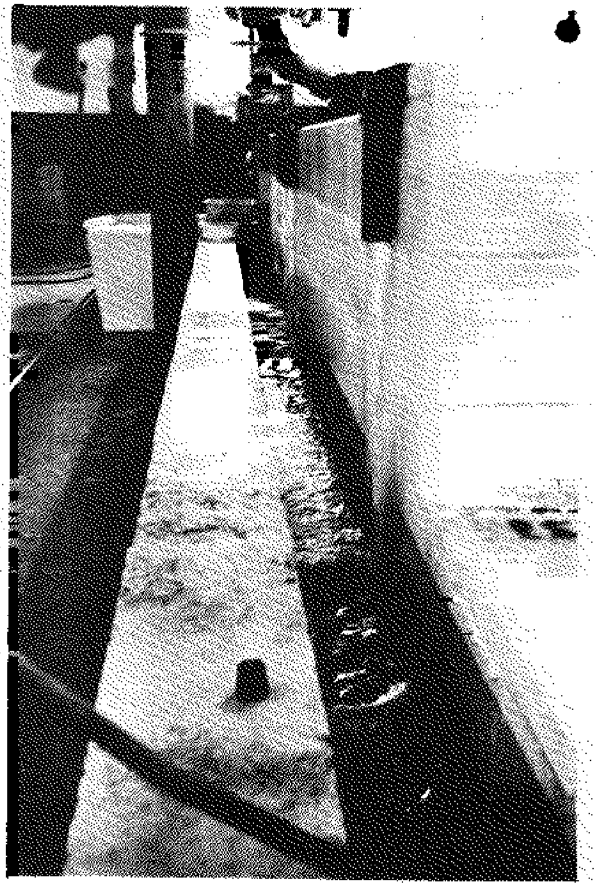


Figure 29.

tank heaters and to provide the seawater at the proper temperature directly from the seawater lines. An increase of the delivered water temperature from 20° to 30°C allows a drop in the flow rate from 50 gpm to 40 gpm while still exceeding the laboratory requirements for hot water.

The energy input to heat 40 gpm of seawater from 0°C to 30° is calculated as follows:

$$40 \text{ gal/min} \times 60 \text{ min/hr} \times 8.34\#/\text{gal} \times \frac{\text{BTU}}{\#\text{F}^\circ} \times 54^\circ \text{ F} =$$

Required Energy Input in BTU/hr = 1,080,864 BTU/hr

The tube wall conductivity coefficient of the shell and tube Pyrex heat exchanger is 260 BTU/hr/Ft.^{2}/F°.

The F° degree in the above coefficient represents the Δt between average boiler water temperature and average seawater temperature within the heat exchanger. The Ft.^{2} factor represents the surface area of the heat exchanger at the boiler-water/seawater interface. The product of the numerical product of these two variables must equal or exceed the numerical dividend of energy requirements/tube wall coefficient, or

$$\frac{1,080,864}{260} = \Delta t \times \text{Ft.}^2 = 4,153$$

Corning offers two basic sizes: a 60 sq. ft. unit and a 13 1/2 sq. ft. unit. If required, these units can be coupled or stacked to serve large capacity requirements. The required Δt for each of the units is shown below:

$$\Delta t = \frac{4153}{13.5} = 307^\circ\text{F}$$

$$\Delta t = \frac{4153}{60} = 69^\circ\text{F}$$

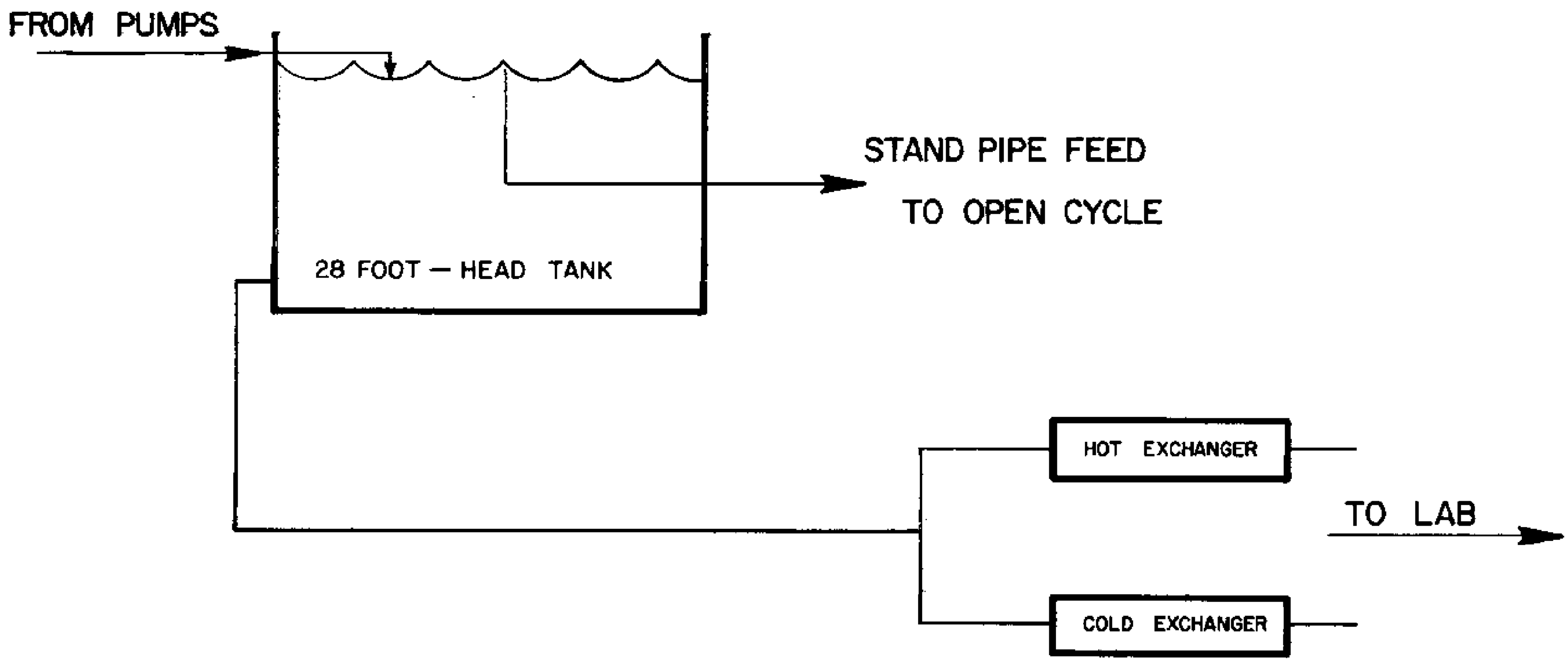


Figure 30. Schematic Diagram of Hot and Cold Water Feed System

With an average seawater temperature within the heat exchanger of $\frac{86°F + 32°F}{2}$ = 59°F, an average boiler water temperature of 128°F is indicated for the 60 sq. ft. unit, and 366°F for the 13 1/2 sq. ft. unit.

The 128°F range is well within the range of package hot water boiler systems, and the 60 sq. ft. unit was selected for the hot water heat exchanger. There is real capacity for expansion in this unit. The heat exchanger was purchased from Corning through Sentinel Glass Company in Hatboro, Pennsylvania. The exchanger and related fittings cost just over $2,000.

The estimated demands for seawater cooling were 50 gpm at 15°C from a 30°C bay. Initial investigation of the cost of water chillers of this capacity (675,540 BTU/hr) caused a restudy of the cooling requirement. The cost of cooling is very high, as will be shown later. It was decided that the laboratory needs could be met with 25 gpm at 15°C. The energy extraction to cool 25 gpm from 30°C to 15°C is shown below:

25 gal/min x 60 min/hr x 8.34#/gal x $\frac{BTU}{\#F°}$ x 27°F = Energy Extract in BTU/hr = 337,770 BTU/hr.

As before, the numerical product of heat exchanger $ft.^2$ and Δt must equal or surpass the numerical dividend of energy requirement/tube wall coefficient:

$$\frac{337,770}{260} = 1,300$$

and as before, the Δt requirement for the 13 1/2 $ft.^2$ unit and 60 $ft.^2$ unit are shown below:

$$\Delta t = \frac{1300}{13.5} = 94°F$$

$$\Delta t = \frac{1300}{60} = 21°F$$

With an average seawater temperature in the exchanger of $\frac{86°F + 59°F}{2}$ = 72.5°, the chiller water temperature average is 51.5°F for the 60 sq. ft. unit and a minus (-) 21.5°F for the 13 1/2 sq. ft. unit. So, as in the case of heating, the 60 sq. ft. Pyrex heat exchanger was purchased from Corning Glass Works. There was an appreciable savings because two units were purchased at the same time. The average cost for the heat exchangers and related fittings was just over $2,000 each. A photograph of the heat exchangers installed is shown in Figures 31 and 32.

4. Boiler: The boiler capacity requirement was established by combining the needs to heat seawater, to heat freshwater for line backflush, and to heat freshwater for domestic purposes. The calculated maximum heat input to satisfy the seawater heating requirement (40 gpm at a Δt 57°F) was 1,080,864 btu/hr. It was estimated that 200 gal/hr of hot water at 140°F would satisfy the direct backflush and domestic needs. The maximum Δt of this water would be 140°F - 45°F, or 95°F. The btu input rate is then equal to:

200 gal/hr x 8.34#/gal x 95°F x 1 btu/# F° = 155,000 btu/hr.

The combined input rate equals 1,235,864 btu/hr. Common practice rates boilers in terms of horsepower, with one horsepower being equivalent to 33,472 btu/hr. This is based on the definition of one horsepower as the evaporation of 34.5 pounds of water per hour from a temperature of 212°F into dry saturated steam at the

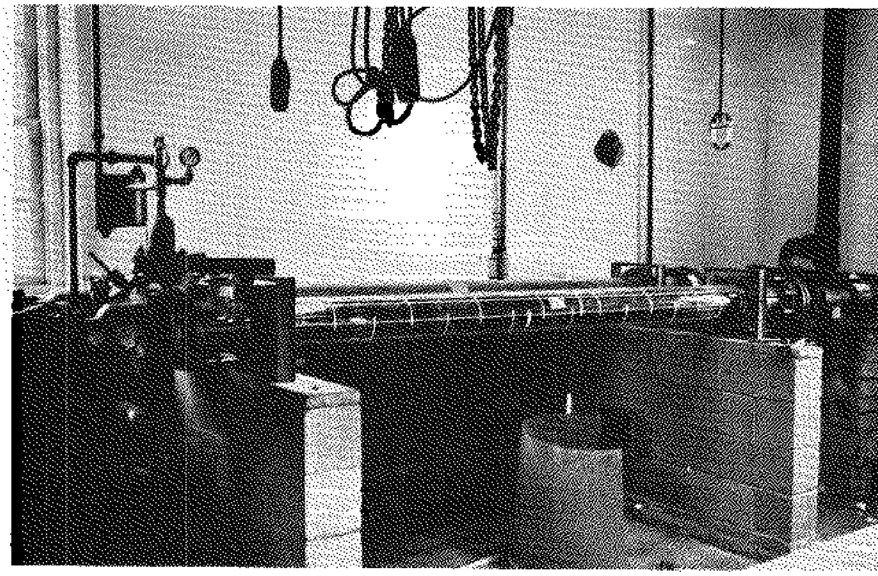


Figure 31.

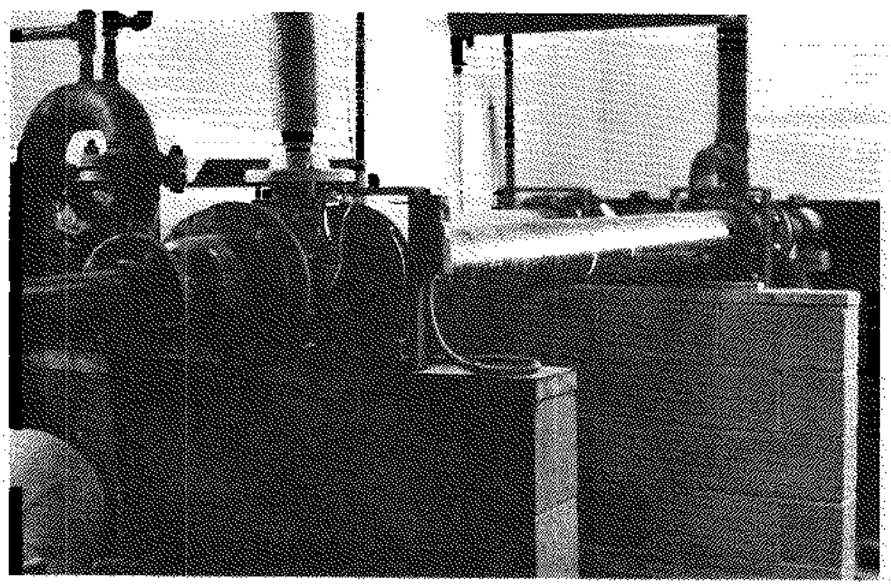


Figure 32.

same temperature (latent heat 970 btu/#) (Salisbury, 1967). The boiler capacity desired in normal terms was 37 horsepower.

The shell and tube type heat exchangers selected and the operating temperature range are fully compatible with water as a heat transport medium. A hot water boiler with a closed circulation loop, including the heat exchanger, operating at a low pressure, offers a very simple and reliable system. Steam was never seriously considered for this application. Oil was selected as the fuel to fire the boiler. Fuel oil competes favorably in the area with LP gas (oil .188 dollars/gal--140,000 btu/gal and LP gas .215 dollars/gal--91,503 btu/gal). Further, oil fuel tanks and feed lines were included with the building. Therefore the boiler description in general terms was a 40 HP, oil-fired hot water boiler including domestic hot water heating coil, with capacity for at least 200 gph at 95°F Δt.

A set of specifications was written (included in Appendix A), and after competitive bids, a Cleaver-Brooks Model Progress Series 100, 40 HP, 30 PSIG hot water boiler was purchased. Boiler output was 1,339,000 btu/hr when fired with CS12-48 #2 oil. The unit had a #S-7 internal hot water coil installed, with capacity for 1,000 gal/hr at 100°C Δt, and a McDonnel-Miller #247 make-up water feeder. In addition, a 500-gallon Domestic Hot Water Storage Tank was included (Figures 33 and 34).

<u>5. Chiller</u>: The chiller capacity requirement was established solely by the need to cool seawater. The calculated maximum rate

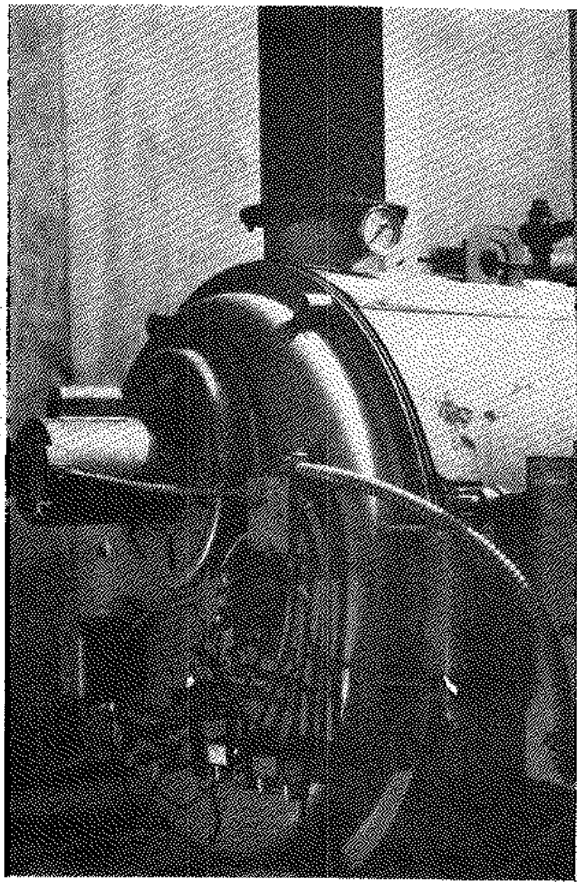


Figure 33.

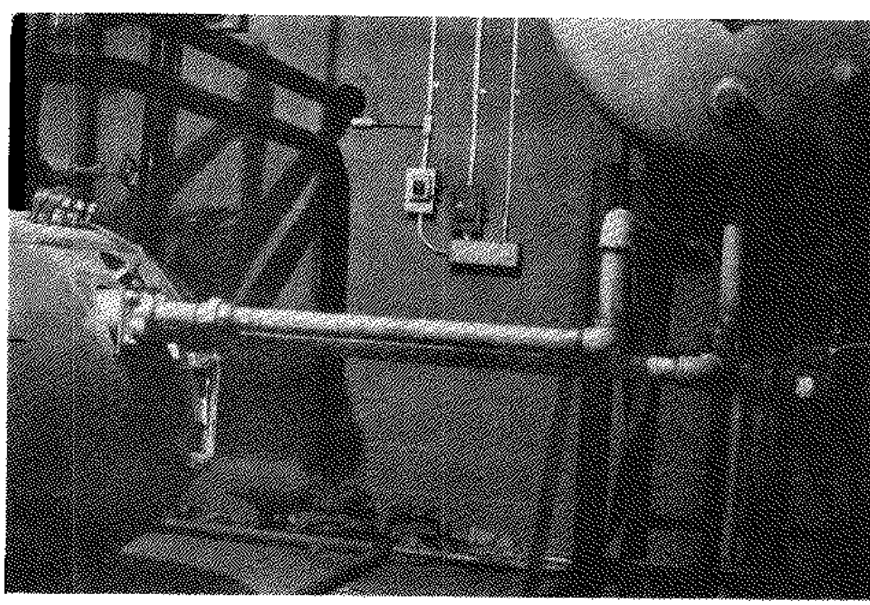
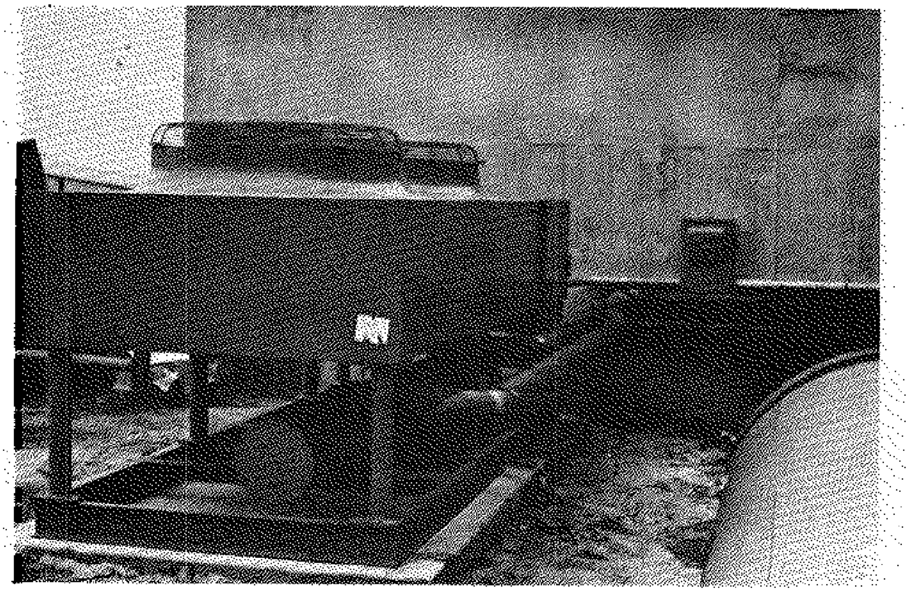


Figure 34.

of heat removal to satisfy the cooling requirements (30 gpm at Δt 25°F) was 330,000 btu/hr. Refrigeration system capacity is rated in tons, with one ton equivalent to 12,000 btu/hr. This is derived from the refrigeration effect of melting one ton of ice in 24 hours. The heat of fusion of ice is 144 btu/# or 288,000 btu/ton, which is the heat absorbed per 24 hours or a rate of 12,000 btu/hr per ton. The required 330,000 btu/hr is the equivalent of 27.5 tons of refrigeration. To avoid the excessive use of city water as a compressor and condenser coolant and the complications of a cooling tower, a packaged air cooled unit type was desired. The use of seawater as a coolant, even with stainless steel condensers, is discouraged (see discussion of difficulties experienced in other laboratories).

A set of chiller specifications was drafted and sent out as part of a bid package (see Appendix B). The basic chiller described in the specifications was offered with minor exceptions by Trane and one other manufacturer. Barcroft Incorporated of Lewes, Delaware, has had a 30-ton Trane air-cooled unit in operation for about three years and has been very satisfied with its performance and reliability. The University of Delaware, Newark campus, recently purchased 2 sixty-ton chillers from Trane. Tri-State Engineering of Salisbury, Maryland, the area Trane representative, had a good reputation for service and start-up assistance. Therefore a Trane Air-Cooled Cold Generator CGAC 30 RMB was purchased from Tri-State at a cost of $9,000. In this instance, reputation, service, and performance were used to justify the letting of the contract to the higher of two bidders.

The options selected allowed start-up and operation down to 0°F (RM Cold Start and Unipressure Control) and maximum low-range modulation with the hot gas by-pass (Figure 35).



6. Circulation Systems (Boiler-Heat Exchanger; Chiller-Heat Exchanger): Integral with the boiler-chiller-heat exchanger components is the means to circulate and control the circulation of heat-carrying freshwater (from boiler to the heat exchanger and from heat exchanger to the chiller).

The boiler to heat exchanger system is the simplest, in that closed cycle circulation is already included in the boiler and includes a surge tank and water make-up controls. Here one must select only the type and size of pumps, pipes, and controls. The pump characteristics must provide a sufficient flow from boiler to heat exchanger and back to the boiler to meet the heat transfer requirements without shocking the boiler. Boiler thermal shock occurs when boiler return-water is at too low a temperature as compared to boiler operating temperature. This Δt is dependent upon the type and construction of the boiler, and limits should be supplied by the manufacturer. For the boiler selected, the target maximum Δt was 30°F. The heat transfer desired, as indicated earlier, was 1,080,864 btu/hr. With the Δt of 40°F, the flow rate is given in the equations below:

$$\text{Flow gal/min} = \frac{\text{heat transfer btu/hr}}{60 \text{ min/hr} \times 8.34 \text{ \#/gal} \times \frac{1 \text{ btu}}{\text{\# F°}} \times 30°\text{F}}$$

$$\text{Flow gal/min} = \frac{1,080,864}{60 \times 8.34 \times 30} = 72 \text{ gal/min}$$

The total head against which the pump will operate is a summation of flow loss in the boiler, in the heat exchanger, and in the lines. The boiler loss was estimated at 4#/in.^{2}, the heat exchanger at 6#/in.^{2}, and the lines at 2#/in.^{2}. The total head was 12 #/in.^{2} or approximately 25 ft. of water. Booster pump capacity by Bell & Gossett (Bulletin A-105) indicated our need would be met by a PD37-5 3" flanged, 3/4 HP, 1 PH, 115/230 v pump. Three-inch steel freshwater lines were selected for minimum flow loss and for convenience to existing boiler and heat exchanger connections (Figure 36).

A Honeywell thermostat control was selected for sensing the seawater temperature. Stainless steel immersion wells were purchased

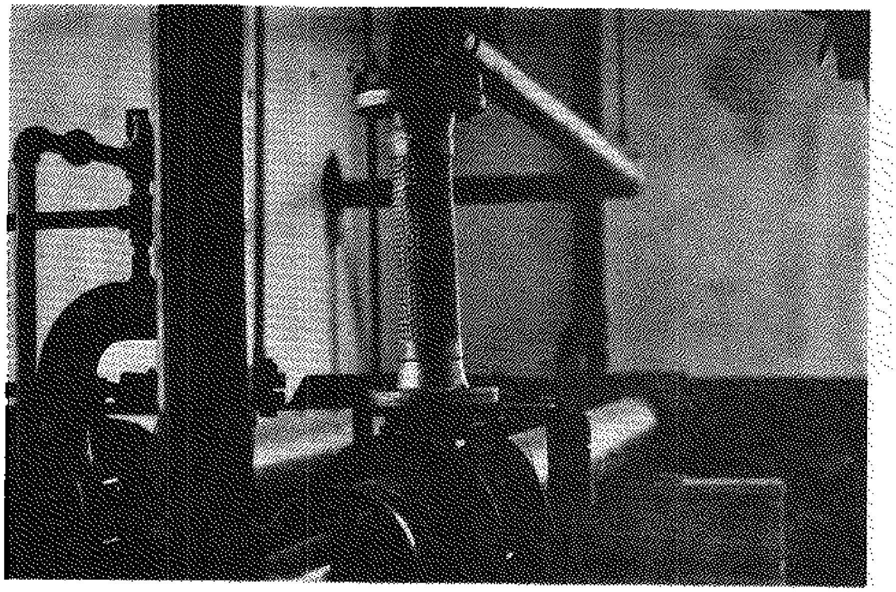


Figure 36.

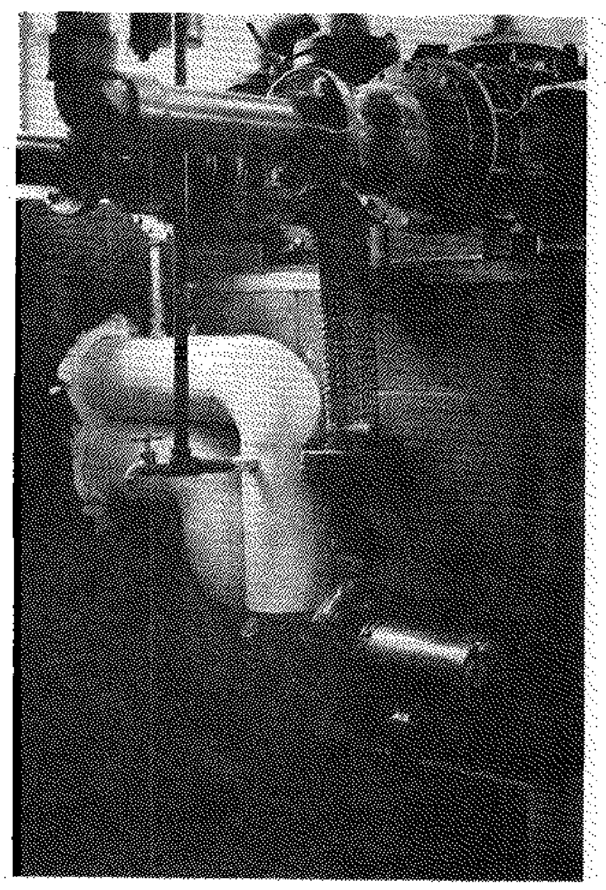


Figure 37.

and mounted via pump threads directly into the PVC elbow immediately outside the heat exchanger. The standard copper bulb then screws into the well. Glass immersion wells were requested but could not be located. The stainless steel wells will be replaced every 90 days.

The chiller to heat exchanger system (Figure 37) is essentially the same concept with variation in pump size and the addition of a surge tank for expansion and make-up water feed regulator and blow-off valves. The heat transfer desired for the chiller circuit was 337,770 btu/hr. The required flow rate of the circulation system based upon an 8°F Δt is shown below:

$$\text{Flow gal/min} = \frac{337{,}770}{60 \times 8.34 \times 8°\text{F}} = 85 \text{ gal/min}$$

The pressure drop for our CGAC30 Trane Chiller is 20 feet H_2O (catalog DS-352AC Table 4), about 12 ft. for the heat exchanger, and 4 ft. for the line loss. The total head, then, is 36 ft. of water. The Bell & Gossett booster pumps are weak in the high heat range, and therefore an Aurora 1 1/2 x 2 x 7 Series 320, 1 1/2 HP pump was selected (Aurora Bulletin A-40076). A surge tank, water-feed regulator, and blow-off valve were included in the package. Our initial control senses the chiller water circuit with 5-stage modulation. It is anticipated that next spring a switch will be made to direct sensing of the chilled seawater. The installation of this system, including all materials (temperature and pressure gauges included), was about $2,000.

D. Brood Stock Room

The 15-foot deep x 50-foot wide x 12-foot high controlled storage room (described in part G of Section III) was divided into two rooms. The Brood Stock room is 15 feet deep x 15 feet wide x 12 feet high, and the Larval Rearing room is 15 feet deep x 35 feet wide x 12 feet high. The partition was 2 x 4 studs with rigid styrofoam insulation covered with 1/4" plywood sheet.

The required temperature in the brood stock room was 15° Centigrade. A 3/4-ton Big Dutchman Egg Cooler window unit was purchased and easily maintained the 15°C temperature throughout the summer. The simplicity and reliability of these units make them very desirable. In addition, the independent cooling of the main laboratory, the algae room, and the brood stock room offers short-term protection for critical experiments requiring sub-ambient temperatures. Egg coolers are very similar to conventional window air conditioners but are designed to operate at lower temperatures.

The floor plan of the brood stock room is shown in Figure 38. Hot, cold, and ambient seawater lines were run to each of the four holding tanks. Each seawater line terminated at each tank with a 1 1/2" PVC valve. As in all internal seawater lines, these were made of PVC material. The holding tanks are 3/4" exterior plywood 2 feet wide x 8 feet long x 1 foot deep, coated with fiber glass. The size was selected for maximum utilization of standard 4 feet x 8 feet plywood sheet. Initially only marine plywood was used. However, the cost savings achieved by switching to exterior plywood

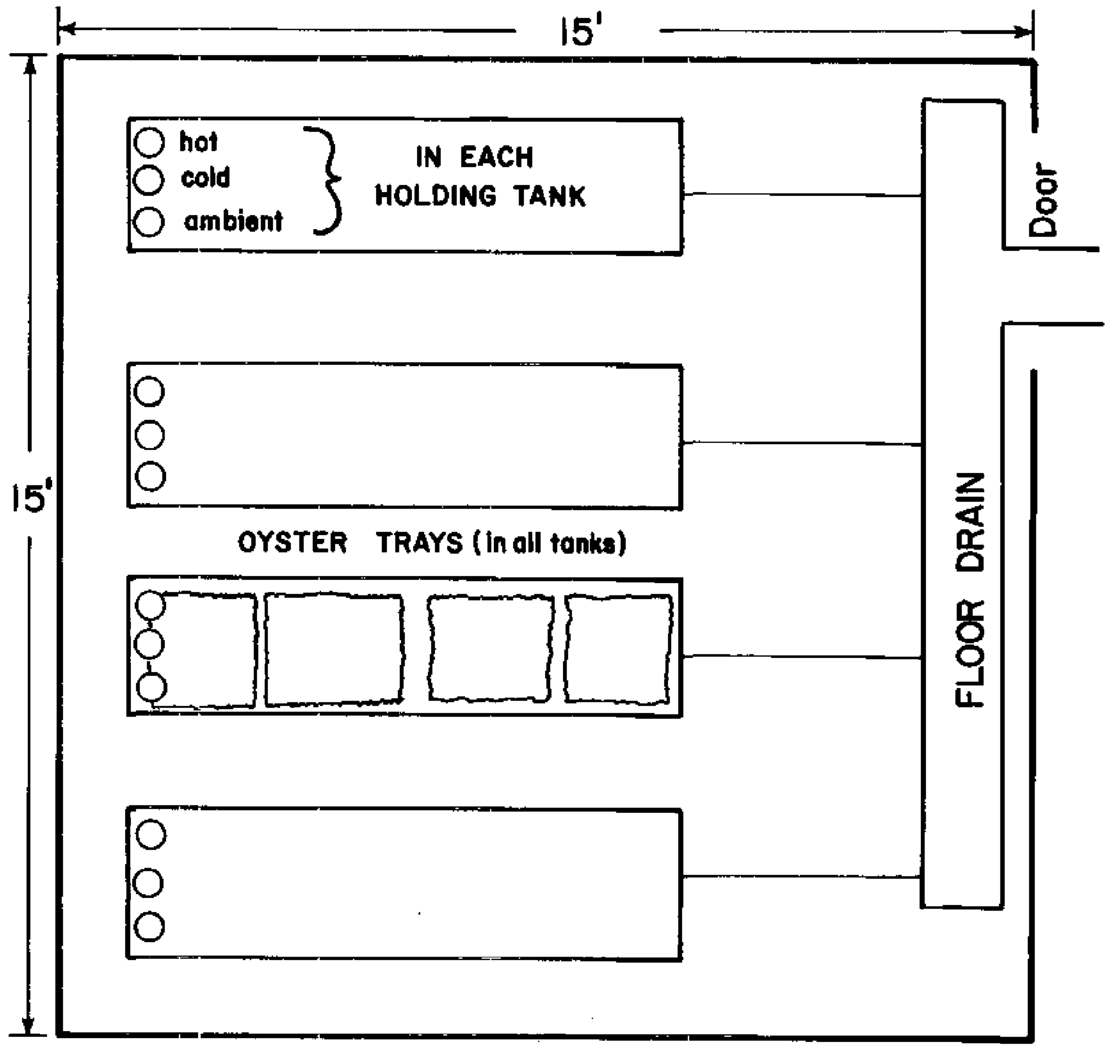
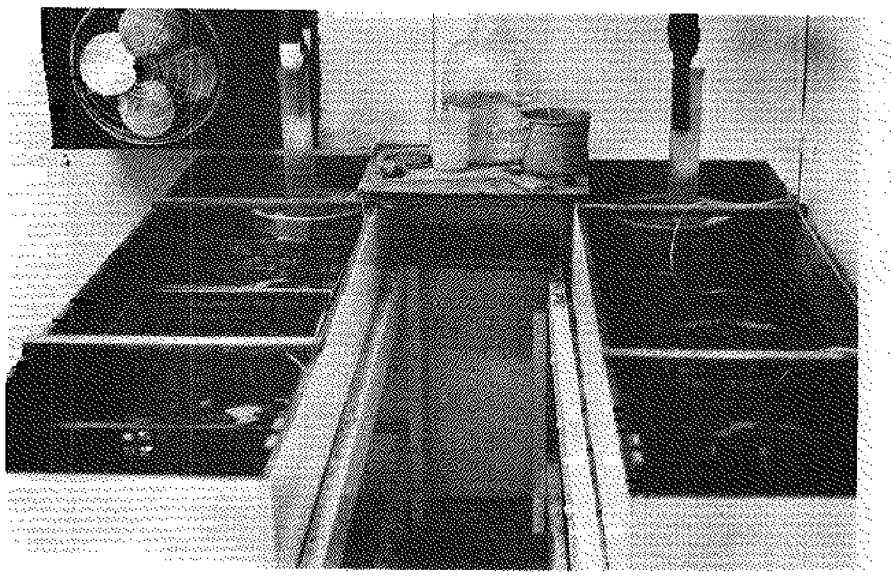


Figure 38. Brood Stock Room.

appears worthwhile since the fiber glass coating protects the wood from moisture penetration. At this time, the use of brass screws over cadplate or plain steel is preferred. This picture of the brood stock room shows the seawater drop lines at each tank position as well as the egg cooler location (Figure 39).



E. Spawning, Larvae Rearing, and Setting Room

This room is the 15-foot deep x 35-foot wide x 12-foot high portion of the original first floor controlled storage room.

The required temperature for spawning, larvae rearing, and setting is 28°C. The preliminary plan to raise and maintain the seawater at 28°C with individual tank heaters was abandoned in favor of maintaining the entire room at 28°C and delivering heated seawater to the

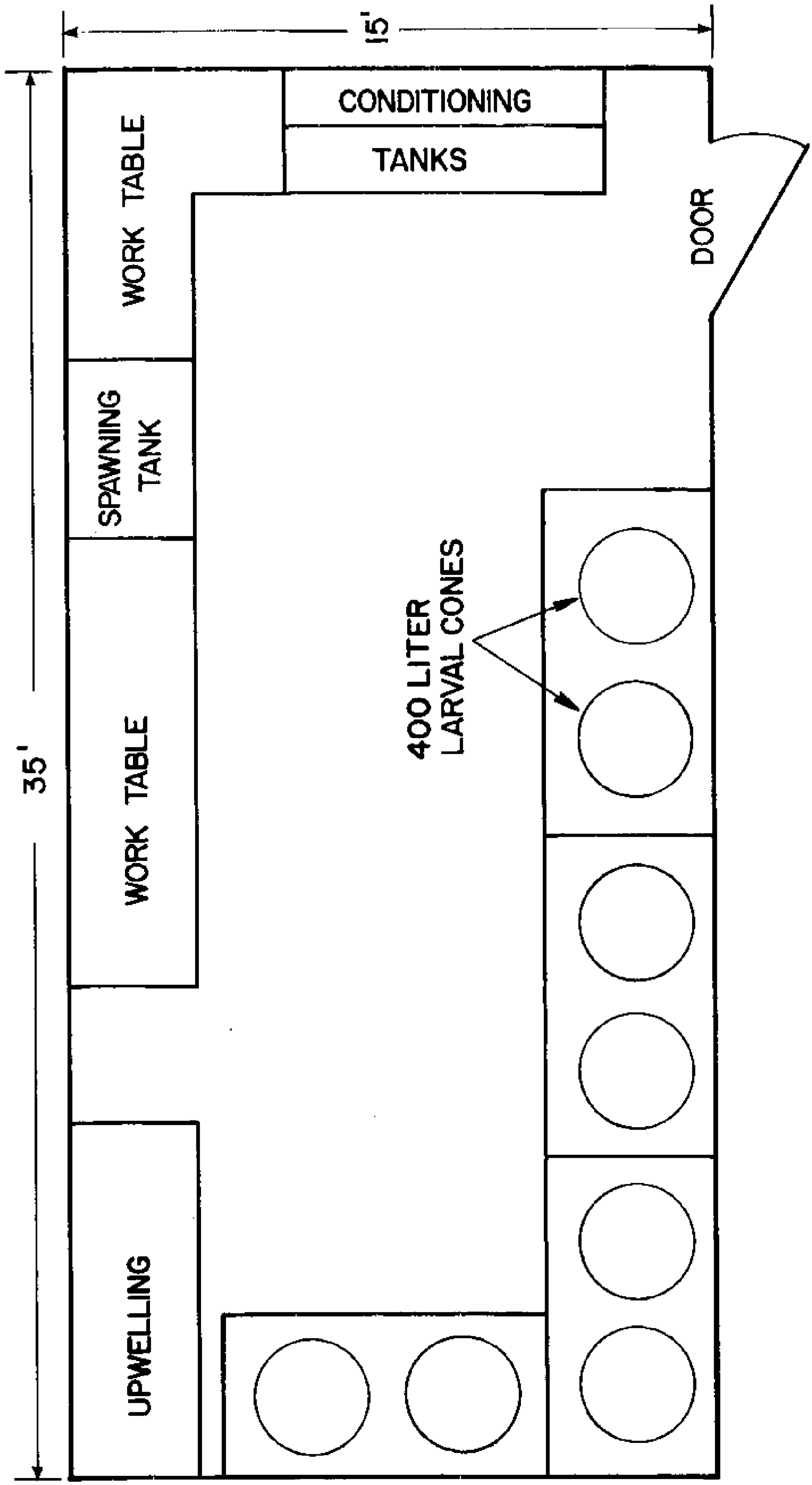


Figure 40. Larval Rearing Room.

larvae cones at 28°C. The heating requirement of the room was met by the installation of a 10 KW Electromode-Singer, ceiling-mounted electric heater. This is the same type unit that handles the main laboratory heating requirement.

The hot seawater lines were carried to each of the eight 400-liter fiber glass cones. The line terminated at each tank with a 1 1/2" PVC valve. A filter bag adapter is attached to each inlet line, and all water to the cones is filtered through a 5-micron filter bag. The cones themselves were purchased from an oyster hatchery on Long Island (Vanderborgh & Radel). In addition to the hot seawater lines to the cones, hot and cold seawater lines were provided for the spawning table and the setting tanks. Also, two ambient seawater lines were provided for general purposes. See Figure 40 for a floor plan

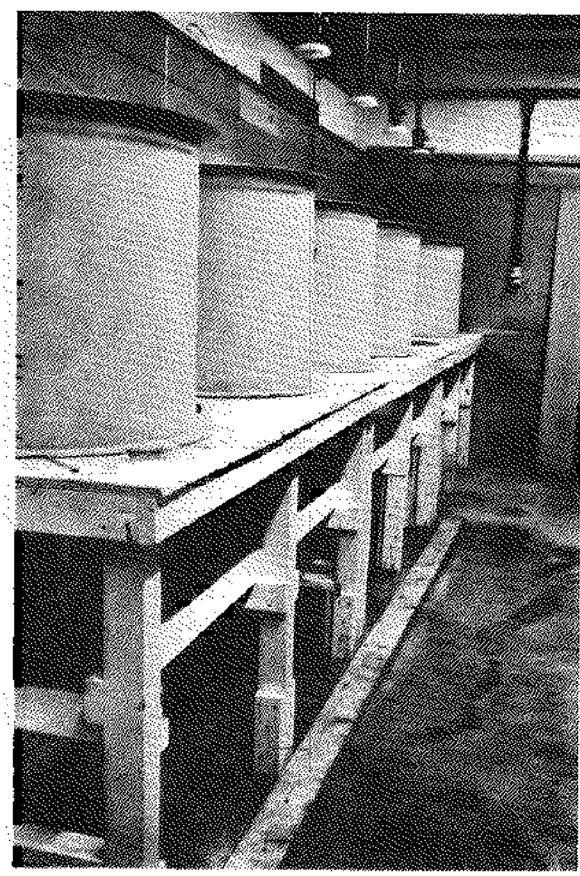


Figure 41.

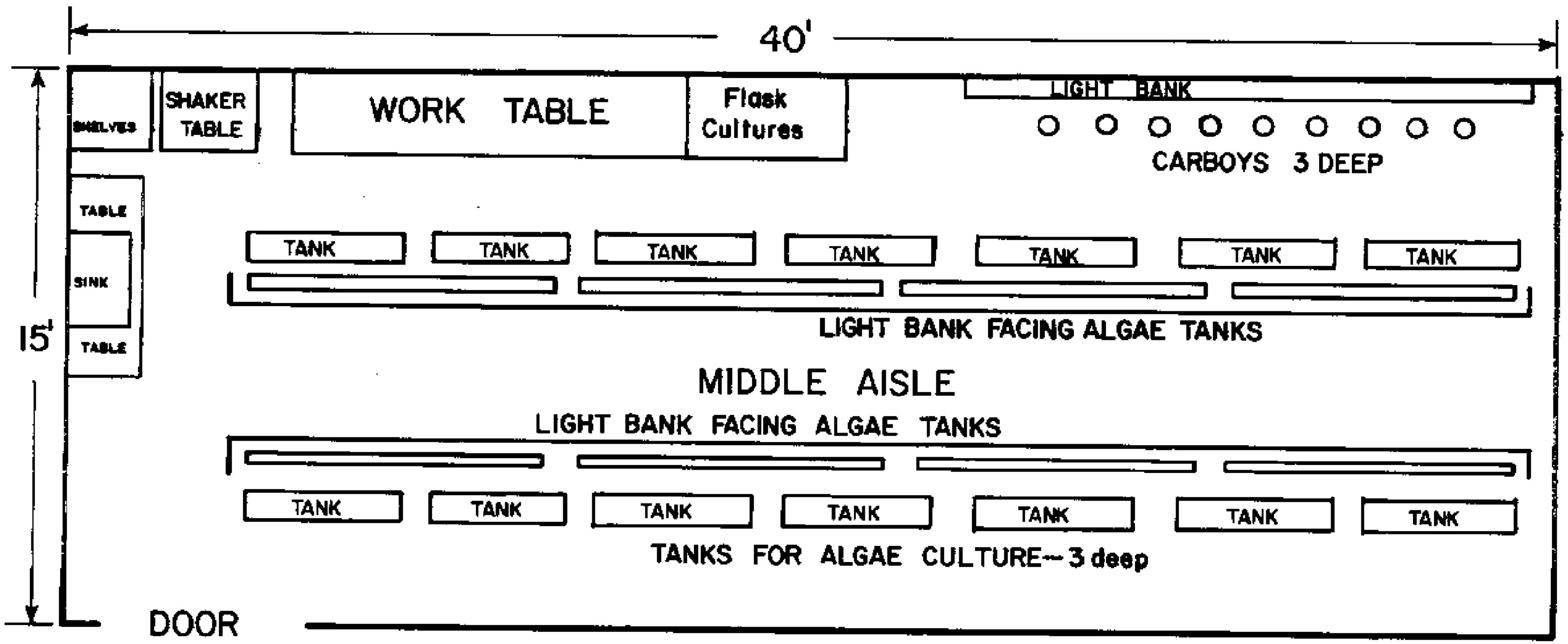


Figure 42. Algae Room.

of this room, and Figure 41 for a photo of it.

F. Algae Room

The entire second floor controlled storage room (40 feet wide, 15 feet deep, and 8 feet high) was converted into the algae culture room. This room is maintained at 16° to 18°C by a single 5-ton Brunner water-cooled compressor operating 5 evaporators. A second identical compressor is piped into the system as a back-up. It is brought on line by opening four manual freon control valves.

This room supports 39 two hundred-liter cultures, 36 eighteen-liter carboy cultures, and numerous flask and test tube cultures (see Figure 42).

The 200-liter cultures are grown in all glass commercial aquariums which are mounted on pipe racks clearly shown in Figures 43 and 44. The racks were an in-house effort, assembled in the algae room. The rack is made of 1" cadmium plated pipe (cut to length and threaded), tee's, crosses, unions, and floor flanges. The squareness and spacing were maintained by the degree of tightening of the connections. The two rails of each rack were secured to the floor and the ceiling and then tied together by angle iron cross straps, arc welded in place.

The light requirements were provided by floor-to-ceiling light boxes. Ten 8-foot x 8-foot sections are included, with each section having eight 2-bulb fluorescent fixtures, for a total of 160 eight-foot long, 75-watt bulbs. Plexiglas panels 4' x 8' were set between the tank racks and the light fixtures and sealed. The heat was

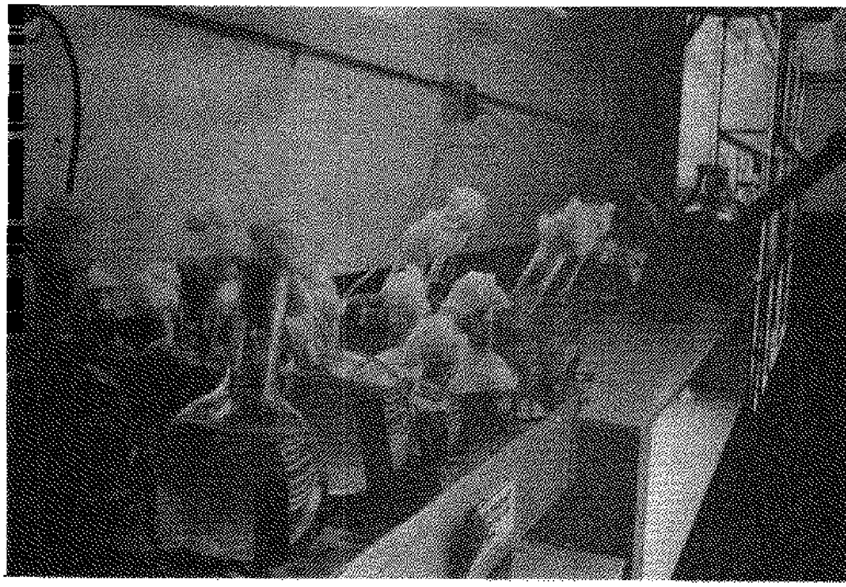


Figure 43.

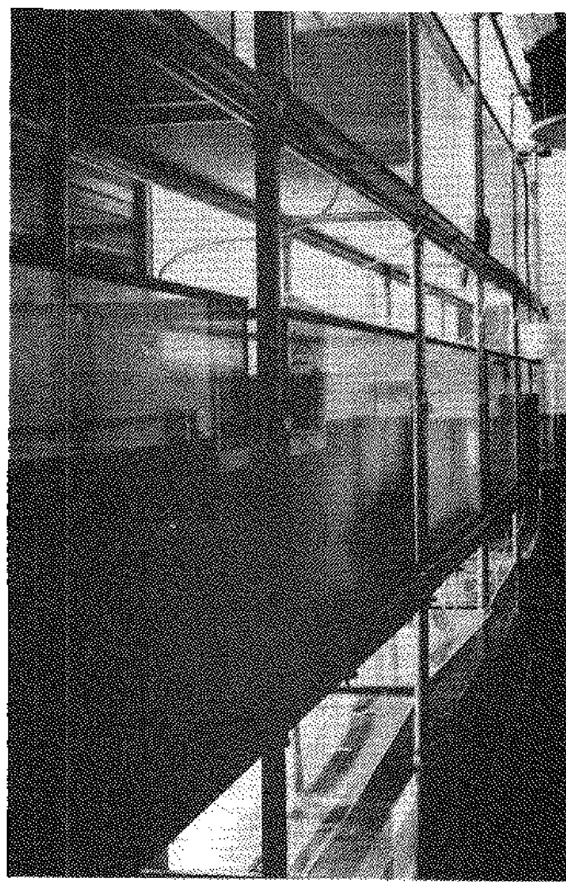


Figure 44.

removed from the light boxes by blowing general laboratory air through a plenum chamber to the bottom of each rack by five 60-scfm blowers. The maximum energy input expected from the lamps was 160 lights x 75 watts/light = 12,000 watts, or an equivalent of 12,000 watts x 3.41 btu/hr/watt = 40,920 btu/hr or 3.33 tons. An additional 10 percent was allowed for ballast loss. It was decided to vent the air from the lights directly into the algae room where it would be cooled by existing 5-ton compressors. See difficulties encountered and remedial action taken under discussion of laboratory operation.

G. Water Treatment Area

Approximately 120 sq. ft. of floor space was set aside on the first floor for comparative studies of seawater treatment. An ambient seawater line is provided which splits into four feeder lines, each terminating with 1 1/2" diameter PVC valves. A Welsback 7-408 ozone generator has been purchased with a companion dry air generator. This package will produce 4 gm of ozone per hour. A static mixer has been purchased from Kenics, Incorporated, to provide good mixing of the ozone and water. An ultraviolet treatment unit (described in Section III, part E) will be incorporated. Chlorination studies will be carried out in the 2' wide x 8' long x 1' deep fiber glass covered plywood tanks (see Figure 45).

H. Research Areas

Two areas were set aside to support allied research. On the second floor, a dry lab is provided with incubators, microscopes, etc.

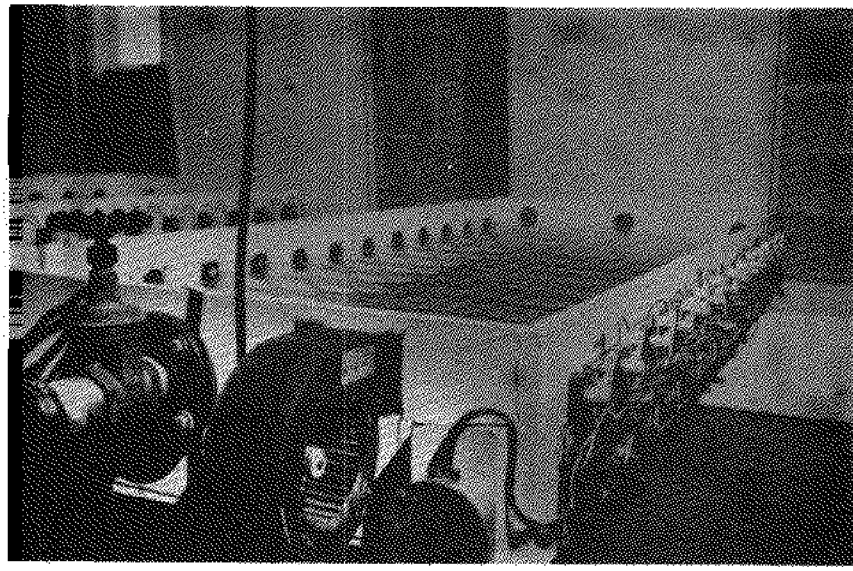


Figure 45.

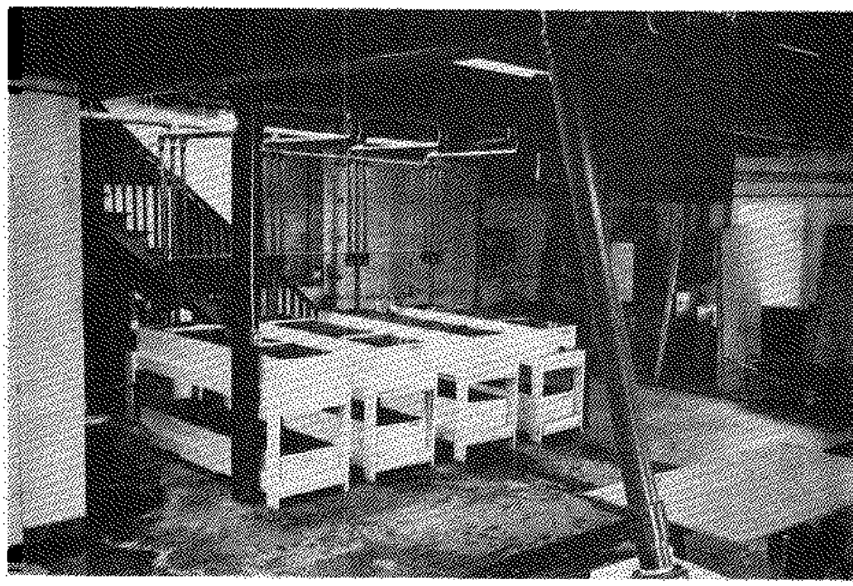


Figure 46.

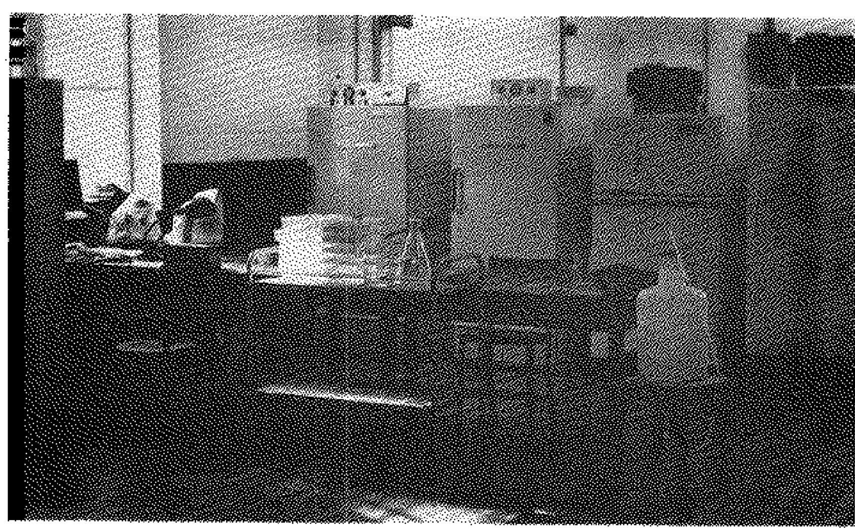


Figure 47.

Aquarium tanks are used to hold a wide range of marine animals. On the first floor, a wet lab is provided with eight 125-gallon plywood tanks. Four separate seawater stations provide ambient hot and cold seawater. Figures 46 and 47 are pictures of the research area.

I. Growing Tanks

The existing depuration tanks (4500-gallon) were divided by the addition of concrete block walls down the center of each tank. The block walls were pinned at the front, back, and bottom to the existing tank. This pinning was accomplished by drilling into existing concrete and installing steel rods that extended into the new blocks. A reinforcing rod was inserted through the new wall top to bottom and the blocks filled. The outside surfaces of the walls were plastered. After set up, the walls were smoothed with a disc sander and given two coats of Mirror Plate (a two-part epoxy) and a final coat of Torex 800 Enamel by Koppers, Inc. These special paints were supplied by Gibbs' Paint and Chemical Company of Lewes, Delaware.

Figure 48 shows the design of the first controlled environment recirculating culture system. The most important part of this 2,000-gallon culture apparatus is the 100 ft.^{2} biological filter. This consists of a false bottom (Figure 49) covered by a 3" layer of crushed clam shell which, in turn, is covered by a 3" layer of pea gravel (1/4 inch $Si\ O_2$). Water is circulated through the filter by three 35 GPM air lifts (see Figures 50 and 51). The filter functions in the ammonification, deamination, and nitrification steps of the

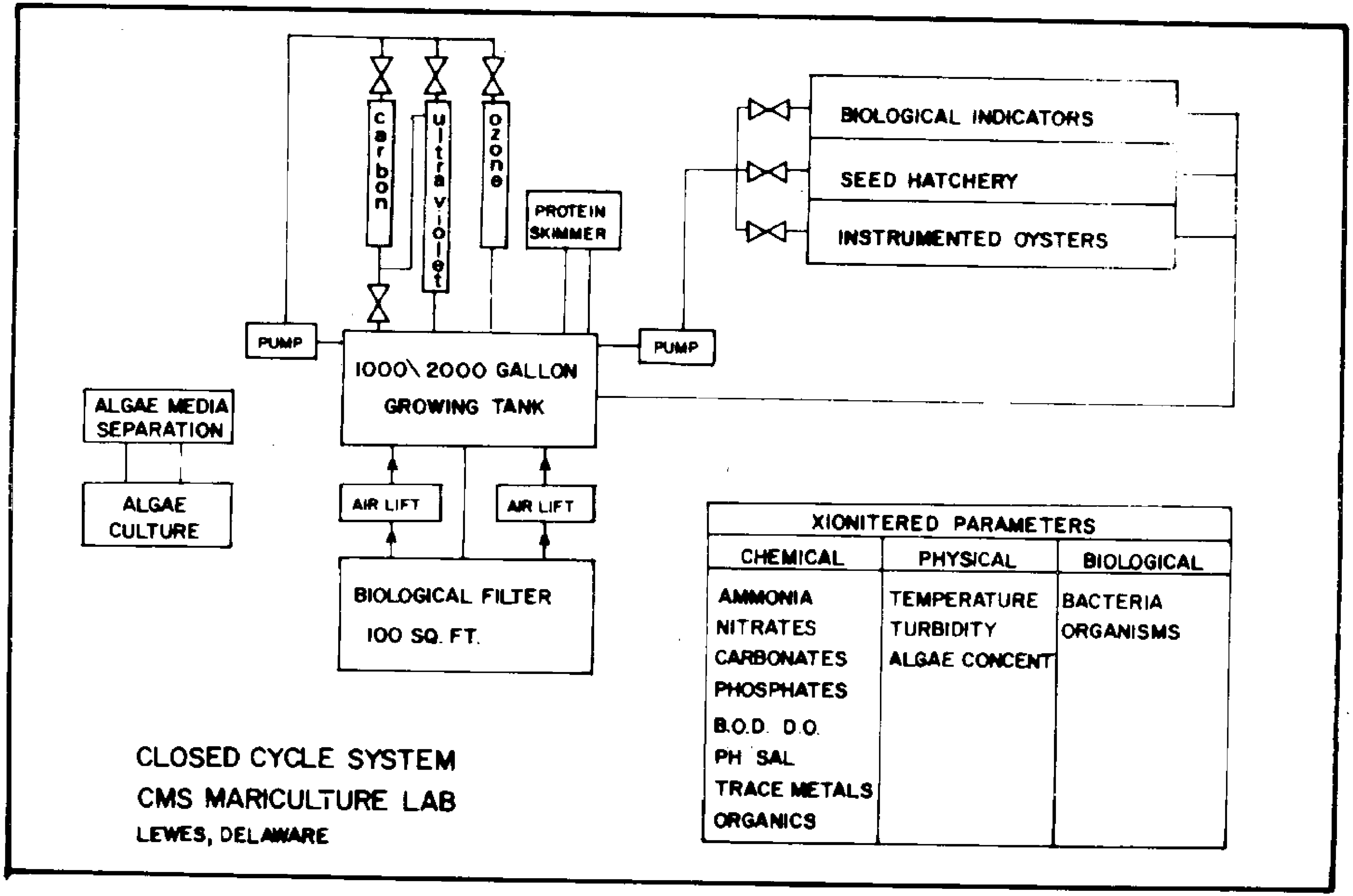
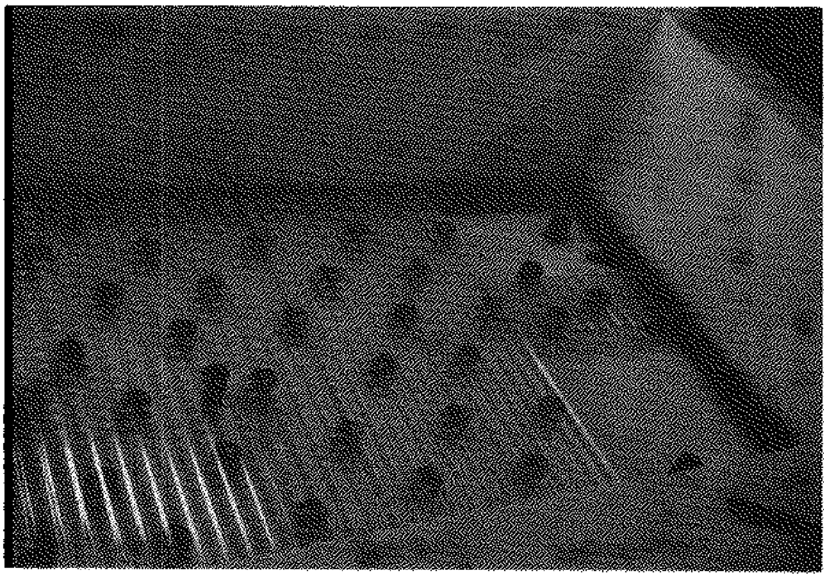

carbon
ultra violet
ozone
PROTEIN SKIMMER
BIOLOGICAL INDICATORS
SEED HATCHERY
INSTRUMENTED OYSTERS
PUMP
1000\ 2000 GALLON
GROWING TANK
PUMP
ALGAE MEDIA SEPARATION
ALGAE CULTURE
AIR LIFT
AIR LIFT
BIOLOGICAL FILTER
100 SQ. FT.
XIONITERED PARAMETERS
CHEMICAL
PHYSICAL
BIOLOGICAL
AMMONIA
NITRATES
CARBONATES
PHOSPHATES
B.O.D. D.O.
PH SAL
TRACE METALS
ORGANICS
TEMPERATURE
TURBIDITY
ALGAE CONCENT
BACTERIA
ORGANISMS
CLOSED CYCLE SYSTEM
CMS MARICULTURE LAB
LEWES, DELAWARE

Figure 48.

nitrogen cycle. The authors believe that Nitrosomonas sp. and Nitrobacter sp. are the bacteria in the filter most responsible for these processes. The filter was conditioned for three weeks by loading the system with 8 kg of fish and crabs. The animals were fed cut-up hard clams (Mercenaria mercenaria) at a ration of 50 g wet weight/day/kg animals in system. The levels of ammonia, nitrates, nitrites, phosphates, BOD, DO, pH, salinity, total organics, temperature, and turbidity are measured daily during the filter conditioning.

Figure 49.



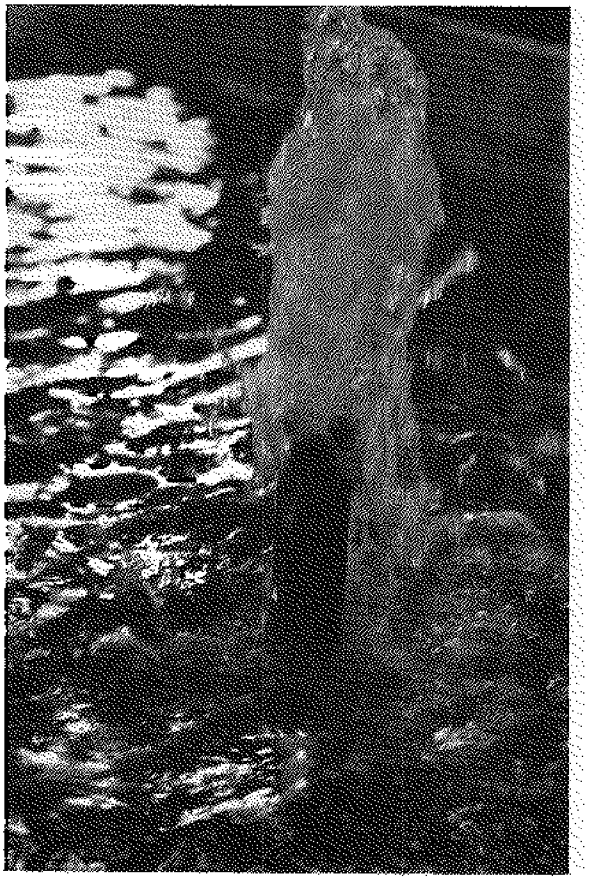


Figure 50.

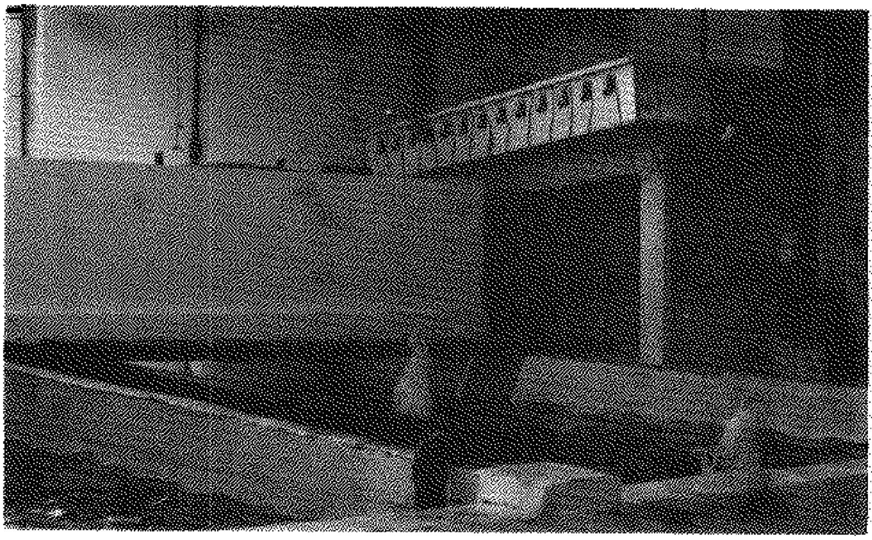


Figure 51.

VI. CONSTRUCTION AND INITIAL OPERATION

During the course of the construction and initial operation, several difficulties were encountered. A good deal of the effort was undertaken with in-house personnel, and expertise was developed as work progressed. Design modifications were required in some areas to give proper performance.

A. Pipe and Fittings

Without exception PVC pipes, valves, and fittings were used in the seawater systems. Cementing or solvent welding is simple and fast, and results in strong watertight joints. Initially, however, threaded connections and "Teflon" tape were used. Extreme difficulty was encountered in sealing 3" and 4" diameter pipe fittings. Any place where disassembly was a fixed requirement, flanges and blind flanges were used instead of caps and plugs. PVC piping systems can be easily disassembled by cutting through the existing line with a hand saw. Reassembly is accomplished with either flanges or couplings (valves).

High temperature PVC (CPVC) was considered but never used in the laboratory. The maximum operation pressures are 40#/in.^{2} in the ambient seawater lines and 15#/in.^{2} in the hot and cold water lines. The rating of 4" diameter socket (cemented) ends is 220#/in.^{2} at 75°F for schedule 40 pipe. Further, the hot seawater line maximum temperature is about 90°F. In this range, the PVC temperature corrective factor is .75 as compared with .92 for CPVC. There is no need for CPVC in a low pressure, low temperature (below 100°F) seawater system.

B. Drains

There was a strong tendency to take drains for granted, with water acquisition and distribution receiving the attention. When drains were considered, most proved to be undersized. Standpipes of 1 1/2" diameter were replaced with those of 2" diameter to handle 5 gpm properly. The channel drain for the brood stock and research areas is near overflow now with expansion of the research area certain. Consideration of drain requirements, including heavy safety margins, is essential.

C. Algae Room Cooling

The first failure of an algae room compressor brought out inherent weakness in the design concept; namely, physical acts were required to bring a back-up compressor on line, and a loss of freon knocked the whole system out. Further, the cooling air from the fluorescent lights vented into the algae room, while causing no trouble when the compressor was in operation, acted as a 13,200 watt heater in a heavily insulated room.

The system was modified as follows:

1. Each compressor was put on line with its independent freon system and evaporators. The capacity of each compressor is sufficient to handle the entire load; if one fails, the other thermostatically controlled compressor automatically takes the full load.

2. The direction and source of cooling air was reversed so that this load would not affect the algae room temperature. Now the air is drawn from the outside, past the lights where it is heated, and delivered to the main laboratory. In the summer the air from the lights will be directed outside.

3. As a final guard against algae-killing high temperatures, a temperature switch was installed. If the algae room temperature exceeds 72°F, all light banks are shut off.

D. Air Supply

Four Condé Dri-Air Pumps (Model 3, 3/4 HP, 17.0 scfm) were purchased and placed at various spots in the laboratory to handle specific air flow requirements. The only drawback is pump noise. The noise level of these pumps disrupts tour guide discussions and is generally considered a nuisance. The pumps are to be moved to a central location where a soundproof, well-ventilated cabinet will be built.

E. Pumps

Pump performance characteristics in terms of head should be available and used prior to any installation. Mismatches of pump and load are common.

VII. COST SUMMARY

Of particular importance in planning for a marine laboratory is the cost for equipment, material, and services. The costs incurred in our effort for equipment, material, and services are listed below. These data do not reflect the cost of six full-time University employees (2 biologists, 1 engineer, and 3 technicians), the lease of the buildings, the operating expenses, or the instruments.

PVC lines, fittings, and valves.	12,000
Pumps, seawater, 200 gpm, 7.5 HP (4)	3,500
*Boiler, 1,330,000 btu/hr	7,000
*Chiller, 360,000 btu/hr.	9,000
Heat Exchangers (2).	4,100
*Circulation Circuits	3,400
*Building Environmental Control	15,900
Light Fixtures	900
Plexiglas.	847
Filon.	250
Lumber, galvanized pipe, and fittings.	3,250
Culture Tanks, 55 gallon, (45)	2,250
Culture Tanks, 40 gallon, (6).	250
Air Pumps, 17 scfm, 3/4 HP (4)	668
Electrical Service	1,600
Plumbing Service	1,850
Masonry Service.	1,000
Carpenter Service.	2,100
Refrigeration Service.	1,300
Sinks, benches, etc.	1,800
Total	72,965

*Includes installation.

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APPENDIX A

Boiler Specifications

1. The boiler shall be a horizontal fire tube type. It shall be mounted on a heavy steel frame with integral forced draft burner and burner controls. The unit shall be pre-assembled, factory-tested, and ready for attachment of water, fuel, electrical and vent connections. The complete unit shall be approved by Underwriters' Laboratories and shall bear the Underwriters' label.

2. The boiler shell must be constructed in accordance with ASME Boiler Code and must receive authorized boiler inspection prior to shipment, ASME stamp required on the drum.

3. The boiler shall be designed to mix the return water rapidly with the boiler water. Forced internal thermal circulation shall be achieved by using an external factory-mounted circulating pump.

4. Observation ports for the inspection of flame conditions shall be provided at each end of the boiler.

5. The following items shall be installed on the boiler:

   a. Temperature Pressure Gauge. The combination gauge shall be mounted on the top of the boiler.

   b. Relief Valves. Water relief valves shall be of a type and size to comply with code requirements.

c. Temperature Controls. The temperature controls (for regulation of burner operation) shall be mounted on the boiler and the temperature-sensing elements shall be located adjacent to the hot water outlet.

d. Drain Valve. A drain valve shall be located at the rear drain connection.

e. Low Water Cutoff. The low water cutoff shall be wired in the burner control circuit to prevent burner operation if the boiler water falls below a safe level.

f. Make-up Valve. Boiler water automatic make-up valve shall be mounted including globe valve and check valve.

g. Blower and Damper. All air for combustion shall be supplied by a forced draft blower mounted in the front boiler door, above the burner, to eliminate vibration and reduce noise level.

1. The impeller shall be cast aluminum, radial blade, carefully balanced, and directly connected to the blower motor shaft.
2. The combustion air damper shall be located in the air inlet and shall be manually adjusted for proper air quantity.
3. Control Panel. The control panel shall be mounted on the right hand side, near the front of the boiler.

All electrical equipment shall be in conformity with the Underwriters' Laboratories requirements. Oil-, heat-, and moisture-resistant wire must be used throughout.

6. Firing Specifications - #2 oil

a. Burner. The burner shall be integral with the front head of the boiler and shall be the pressure-atomizing type approved for operation with CS12-48, Commercial No. 2 oil.

b. Oil System. The fuel oil piping on the unit shall include oil pressure regulating device, solenoid shutoff valve(s), pressure gauge, and fuel strainer.

An oil pump, with a capacity of approximately twice the maximum burning rate, shall be integral with the burner.

c. Flame Failure Device. A photo-electric cell shall shut down the burner in the event of ignition or flame failure.

7. Guarantees, Tests and Starting Service

a. Efficiency Guarantee. The boiler must be guaranteed to operate at an efficiency of 80 percent or greater.

b. Shop Tests. The packaged boiler must receive factory tests to check the construction, controls and operation of the unit. All tests may be witnessed by the purchaser if desired.

c. Starting Service. After boiler installation is completed, the manufacturer shall provide the services of a field representative for starting the unit and training the operator. This service shall not exceed two consecutive days.

APPENDIX B

Chiller Specifications

Water Chiller

The air-cooled chiller shall be designed to cool at least 76 gpm of water from 48°F to 40°F in ambient air of 95°F. This chilled water will be used to cool 20 gpm of sea water from an inlet temperature range of 55°F to 80°F, down to an outlet temperature of 50°F, utilizing a 60 sq. ft. glass heat exchanger rated at 242 BTU/ft 2/°F and presenting a pressure drop of approximately 10 ft. at 100 gpm.

The chiller shall be so constructed for operation down to 25°F ambient. The operation will be entirely automatic after manual start-up to maintain the 40°F water outlet temperature. It shall provide at least four steps of capacity modulation, including hot gas by-pass for further modulation of the lowest step. The unit shall be equipped for reduced voltage start-up. The chiller drop shall not exceed 20 ft. at 100 gpm. It shall have a full refrigerant charge.

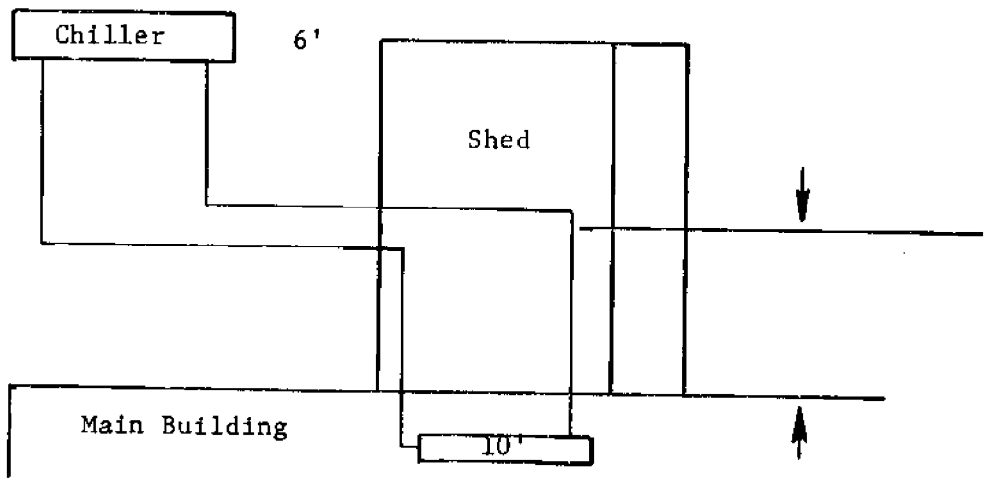
The unit shall be complete with a semi-hermetic reciprocating compressor with unloaded starting, multistep capacity control with hot gas by-pass, and forced feed oil system with fitters, magnetic plugs, and centrifugal cleaning. It shall incorporate a direct expansion shell-and-tube design, with seamless copper tubes expanded into tube sheets. Dual refrigerant circuit design, built per ASME Code unfired Pressure Vessels. ASME U-1 inspected. Designed for 225 psig working pressure on the refrigerant side, 200 psig on the water side.

The control panel shall have refrigerant controls and electrical equipment in separate enclosures. Refrigerant controls shall include electric temperature controller, dual pressure switch, differential oil pressure switch, ambient temperature cut-off and low temperature safety thermostat. Electrical equipment shall include part winding starter with time delay for 208-220 volt system, reduced voltage start accessory, control power transformer, noncycling pump-down relay and unit on-off switch.

The sheet metal and structure shall be galvanized and phosphatized steel with baked-on corrosion-resistant finish suitable for seashore environment.

Chilled Water Circuit

All material and components necessary to circulate, and control the circulation of, chilled water through the University-supplied 60 sq. ft. glass heat exchanger (242 BTU/sq.ft.F° with approximate back-pressure of 10' at 100 gpm) to cool 20 gpm sea water from an inlet temperature range of 55°F-80°F down to an outlet temperature of 50°F. Contractor shall provide all controls, gauges, pumps, valves, diffuser-strainer, pipe, pipe fittings, and insulation: the University will provide electrical and plumbing service as required. The heat exchanger inlet and outlet are equipped with adapters for 3" straight pipe.



A typical system is as follows:

Chilled water pump: Aurora type 321 (or equal) horizontal centrifugal pump bronze fitted construction with a capacity of 80 gpm at 40 ft. total head. The pump is to be furnished with case wearing ring and mechanical seal, with all metal parts to be 316 stainless steel and carbon washer. The pump is to be close-coupled to a Nema motor of 1 1/2 hp. 230/460/3/60 drip-proof enclosure with stainless steel motor shaft.

Chilled water circuit accessories: Suction Diffuser. Furnish on Suction Diffuser as manufactured by Bell & Gassett, Model DB, 3" flanged. Unit shall consist of angle-type body with inlet vanes and combination Diffuser-Strainer-Orifice cylinder with 3/16" diameter openings for pump protection: unit shall be equipped with disposable fine-mesh start-up strainer which shall be removed after 30 days of operation. Strainer-free area shall be no less than five times the suction area of the pump connection. Unit shall be provided with adjustable support foot to carry the weight of suction piping.

Check Valve: Furnish one check valve with linear-contoured disk and a calibrated adjustment feature permitting regulation of pump discharge flow and positive shut-off. Valve shall be designed to permit repacking under full line pressure. The unit to be installed on the discharge side of the pump in a vertical position with stem up. The valve shall be of cast-iron construction as manufactured by Bell & Gassett Model No. 3D-3 or equal.

Thermometers: Furnish 2 thermometers, mercury-filled, 20°F 120°F range, as manufactured by Taylor or equal. The units to have steel separable wells.

Miscellaneous: Furnish two 3" flexible connectors and two pressure gauges.

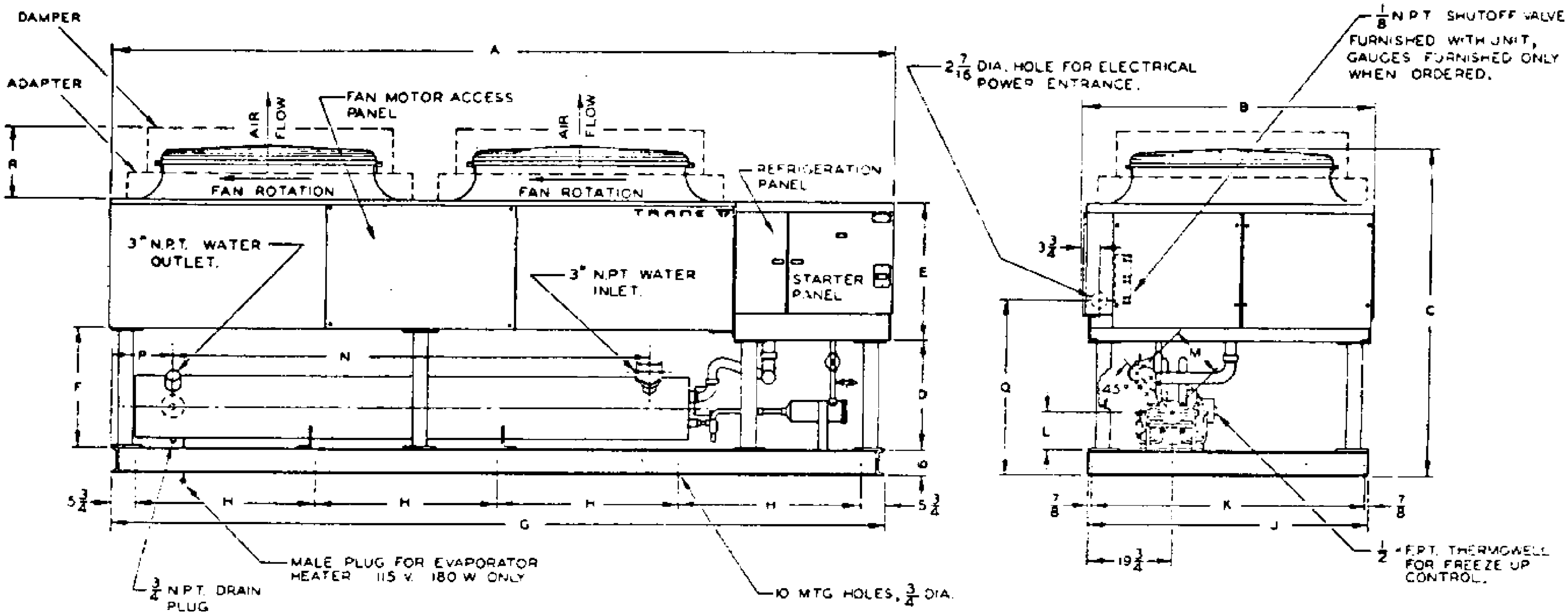
Insulation: Furnish sufficient insulation to cover entire chilled water piping, fittings and valves. Fiberglass pipe insulation of 1" thickness for 3" pipe shall have corrugated aluminum jacket laps and shall be oriented to shed water. Butt joint strips for each joint shall be furnished.

NOTE:
DISCHARGE DAMPER AND ADAPTER FURNISHED ONLY WHEN ORDERED.

FAN SPECIFICATIONS				
UNIT	DIA	RPM	PITCH	NO OF BLADES
CGAC 30 CGAC 30 RM	42"	550	27°	4
CGAC 35 CGAC 35 RM	48"	520	27°	4

NOTES

1. FOR SHIPMENT, ALL REMOTE BULB CAPILLARY TUBES TO BE COILED, TAPED TO FRAME AND IDENTIFIED, WATER INLET TEE OR BULB WELL IN CHILLER.
2. UNIT TO BE TESTED, CLEANED, DEHYDRATED AND SHIPPED WITH OPERATING CHARGE INSTALLED.
3. OIL LEVEL SIGHT GLASS FURNISHED ON COMPRESSOR.
4. LIQUID SIGHT GLASS FURNISHED ON COMPRESSOR.



MODEL	WIDTH A	DEPTH B	HEIGHT C	HEIGHT D	HEIGHT E	HEIGHT F	MOUNTING G	MOUNTING H	MOUNTING J	MOUNTING K	CHILLER L	WATER INLET CONNECTION OD	WATER INLET CONNECTION M	WATER INLET CONNECTION N	WATER OUTLET CONNECTION OD	WATER OUTLET CONNECTION P	POWER ENTRANCE Q	NET WT LBS	DISCHARGE DAMPER R
CGAC 30	168 7/16	62 3/16	66	8 5/8	30 5/16	24 9/16	167	38 7/8	59 7/8	58 [illegible]	8 [illegible]	3	[illegible]	39 9/[illegible]	3	[illegible] 1/4	33	3490	24 1/2
CGAC 30 RM																		3600	
CGAC 35	182 15/16	68 3/16	76	25 7/16	32 1/8	27 1/2	181/2	42 1/2	65 7/8	64 [illegible]/8	9 [illegible]	3	12	109 9/[illegible]	3	4 23/32	39 13/16	4490	24 1/2
CGAC 35 RM																		4600	

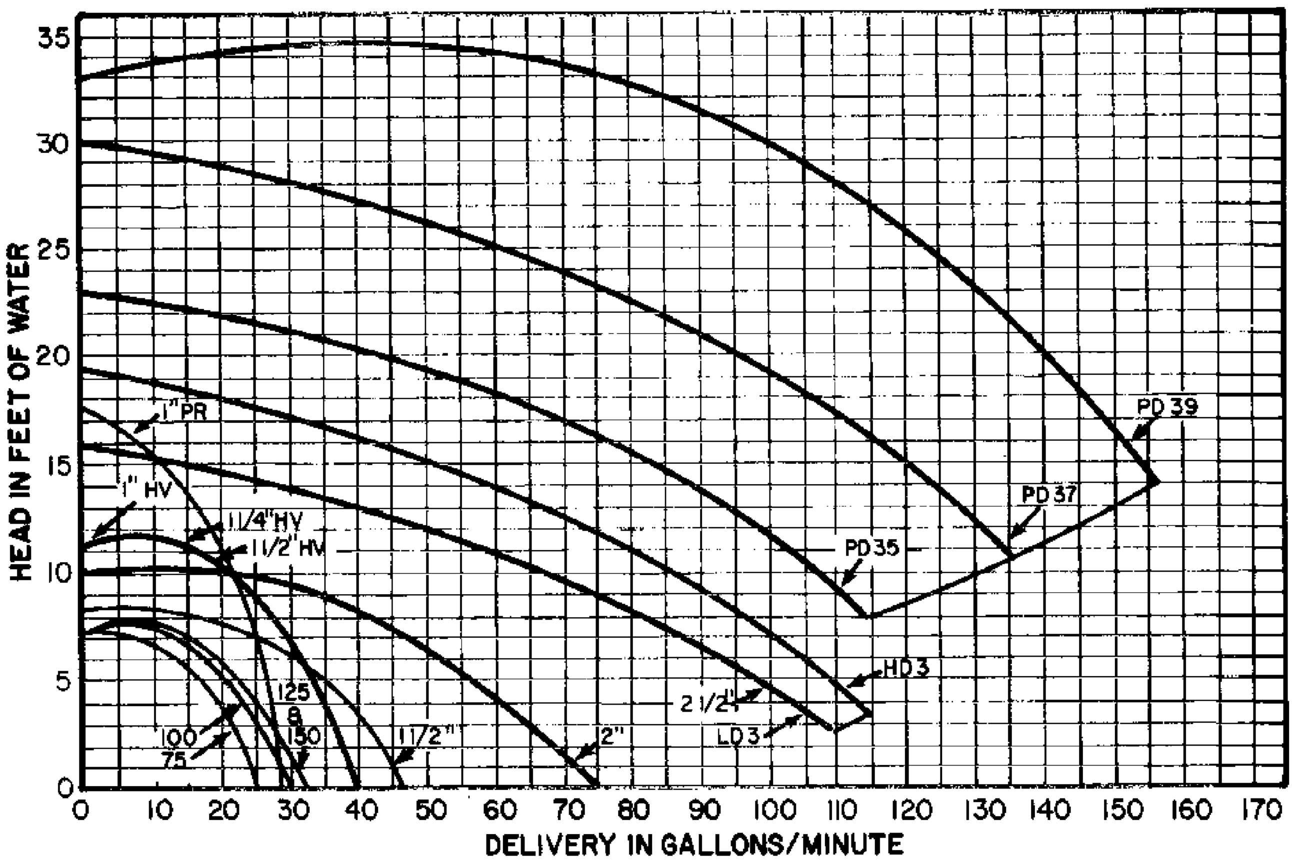
TRANE APPROVAL DRAWING

CGAC 30 CGAC 30 RM
CGAC 35 CGAC RM
COLD GENERAT
B 4321-9441 B

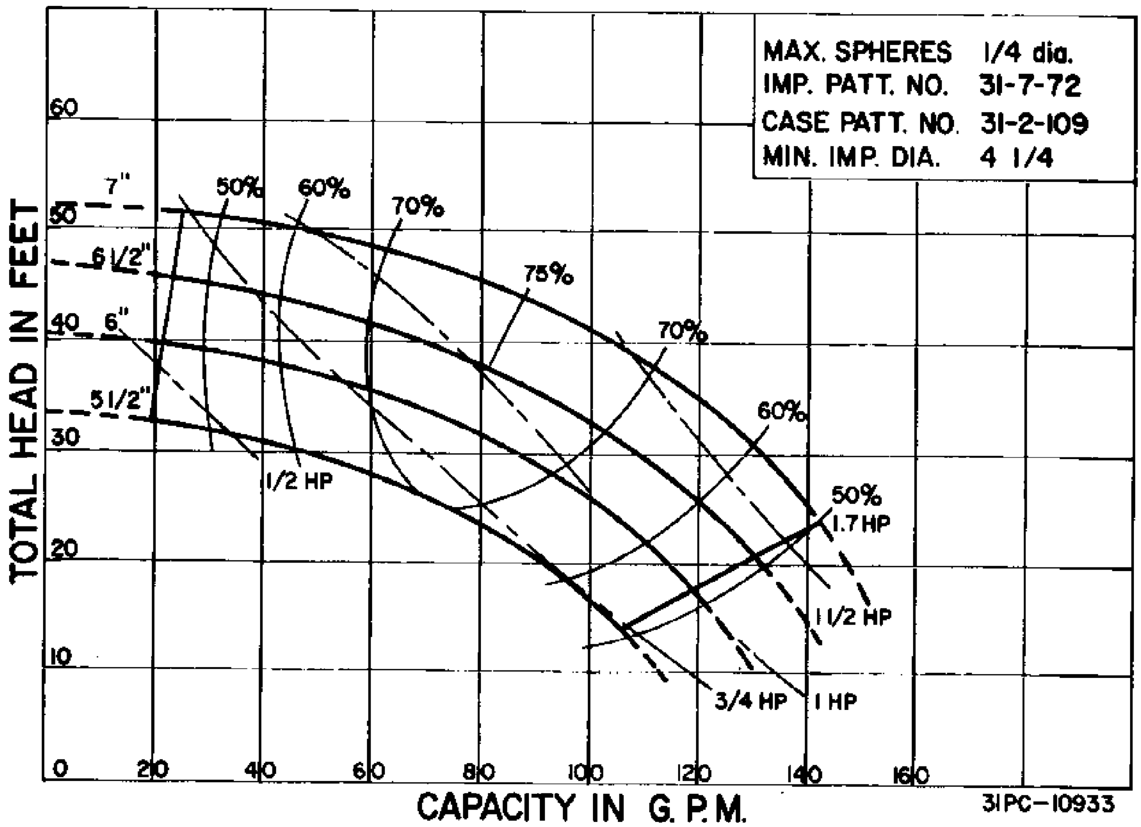
APPENDIX C

Pump Specifications

BOOSTER CAPACITY CHART



This chart is based on 1750 RPM, 60 cycle. For 25, 40 or 50 cycle motors, larger pumps will be necessary.


MAX. SPHERES 1/4 dia.
IMP. PATT. NO. 31-7-72
CASE PATT. NO. 31-2-109
MIN. IMP. DIA. 4 1/4
TOTAL HEAD IN FEET
CAPACITY IN G. P. M.
7"
6 1/2"
6"
5 1/2"
50%
60%
70%
75%
70%
60%
50%
1.7 HP
1 1/2 HP
1 HP
3/4 HP
1/2 HP
0
10
20
30
40
50
60
20
40
60
80
100
120
140
160
31PC-10933