INVESTIGATION OF THE BIOFILTER
FOR INDOOR CULTURE OF CHANNEL CATFISH

by

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INTRODUCTION

The channel catfish (<u>Ictalurus</u> <u>punctatus</u>) has long been a favorite of fishermen in much of the United States. The fish is a good competitor for food and grows to over 10 pounds. The small number of large bones in the channel catfish and the excellent quality of lean meat make him one of the better rewards for patience and talent with a rod and reel.

The reproduction and the growth are directly related to the water temperature since channel catfish are cold blooded. The beginning of a young channel catfish occurs in the immature eggs within the female. In Kansas, when the water temperature in June reaches 70° (54), the eggs in the female enlarge, called ripening. The male begins his role in reproduction by cleaning a suitable spawning site, usually a hole in a bank. If the water temperature continues to rise, the male pairs with a female and ushers her to the spawning site. The female deposits upwards of 10,000 eggs. Immediate fertilization by the male causes the eggs to stick together to form an egg mass. The male then drives the female away for she will attempt to eat the eggs. The male guards the eggs and continually kneads the egg mass so the eggs in the center of the egg mass can recieve fresh water for exchange of oxygen and waste products. In about seven days from the time of spawning the eggs hatch into fry, very small catfish. The yolk material of the eggs is consumed five days later and the fry swim off to find additional food (43).

The alteration of the channel catfish from his natural habitat to a well managed commercial asset did not occur without some discouraging setbacks. Three primary problems encountered were inadequate techniques for: (1) obtaining the mass of eggs or spawn (2) hatching them under controlled conditions, and (3) lack of a feasible diet for newly hatched fish (51).

Mans' first attempt to alter the channel catfish's natural environment for his own benefit dealt with harvesting the spawn. At the Kansas Forestry, Fish and Game Commission hatchery, Doze (14) contributed knowledge to the first problem by placing kegs in brood ponds to provide spawning sites. Spawns were left to be hatched by the male fish. Clapp (10) further experimented with old tile, beer kegs, nail kegs, boxes, etc., to provide spawning sites. A popular spawning container (presently used by the Kansas Pratt fish hatchery and most Kansas fish farmers) is the ten gallon milkcan (29, 59).

Clapp (10) also brought about a second change in the channel catfish's environment by developing a hatching trough which permitted indoor hatching of the fertilized egg masses. The hatching trough was an important development because it enabled a greater percentage of eggs to be hatched, it separated the eggs from predator fish, and it provided an easy method to harvest the fry. The spawns were placed into wire mesh cylinders which were submerged in a twelve-foot long trough supplied with running water. A series of galvanized iron paddles, moved back and forth by a rod attached to a water wheel, were suspended in the water over the spawns. Motion of the paddles simulated the

kneading motion of the male fish tail over the eggs. Thus, spawns could be harvested and hatched in great numbers, but lack of a suitable diet slowed the development of cultured catfish.

Supplemental feeding was man's third change of the channel catfish's environment. If unfed in a natural lake or stream, young channel catfish tend to feed primarily on aquatic insects or on bottom arthropods, but beyond 100 mm in total length they are usually omnivorous or piscivarous (8). Feeding research in the last five years have enabled Kansas producers to rear a marketable sized channel catfish in three years using a pelleted feed (54,52,13,38,50).

The previously mentioned solutions to the three primary problems have enabled the catfish farming enterprize to grow to a 31-million dollar business in the United States (16). Although capital investment and risk are still high, the net return per acre under good management is higher than for grain crops or livestock. Most of the channel catfish are produced in the deep south where the longer, warmer summers increase the length of the growing season. However, Kansas is experiencing a rapid expansion of the channel catfish enterprize. Fish farming also has been advertized as a profitable second cash crop for the irrigated regions of the United States (41).

PURPOSE

The purpose of this project was to investigate a fourth

environmental change, the possibility of rearing channel catfish indoors under controlled environmental conditions. Indoor housing of some commercial animals, hogs and chickens, has proven to be an excellent management practice.

The benefits justifying an indoor controlled environment possibly would be:

1.) year around production

2.) independence from seasonal variations of weather

3.) reduced labor

4.) better working conditions for labor

5.) more effective management, sorting, feeding

6.) automatic feeding

7.) less time to produce a marketable size fish

8.) isolation from disease and unsuitable water

LITERATURE REVIEW

The review of literature was carried out over a two year period as the experimentation proceeded. The great majority of channel catfish are reared in ponds. Many publications offer aid to the producers (54,52,13,38,50,53). The publications are in close agreement on the following:

1.) Pond production is limited to 2,000 pounds/acre/season

2.) Growth is slow below water temperature of 65°F

3.) In Kansas, a one pound fish is produced in 3 years

4.) In southern states, a one pound fish is produced in 1 1/2 years

5.) Conversions of 2 lbs. feed to 1 pound live fish are possible

6.) Fish are fed at 2 to 4% of body weight daily

7.) Channel catfish production is expanding rapidly

The pond production limitation applies to all sizes of channel catfish. If indoor culture of catfish is to be feasible, higher production rates per unit area must be achieved. Two theories are offered to explain the production limit. One theory states that physical crowding or some needed minimal space requirement may control pond production. Another theory explains the limit on pond production as being controlled by the natural ability of the pond water to process fish wastes (48).

Simco and Cross (48) conducted an experiment to evaluate the effects of different degrees of physical crowding of fish in earthen ponds. A pond was subdivided by hardware cloth into four equal sized compartments. (Plate I) The stocking rates, initial and final weights, and feed conversion are also shown on Plate I. Water flowed freely through the partitions so that the fish in each section occupied water of similar quality; therefore the effect of crowding itself was tested. Good growth was obtained in all compartments. There was no evidence of antagonistic behavior, which indicated that the channel catfish could be confined at greater than normal population densities.

Further supporting evidence that channel catfish could be raised at high densities came from a new technique of rearing fish in cages (31,11). The cages consist of a floating plat-

EXPLANATION OF PLATE I

1966 Population Studies of

Simco and Cross (48)

THIS BOOK CONTAINS NUMEROUS PAGES WITH DIAGRAMS THAT ARE CROOKED COMPARED TO THE REST OF THE INFORMATION ON THE PAGE.

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PLATE I

NO. OF FISH	10	20	42	90
AVE. WT. OF FISH STOCKED	.077	.079	.076	.079
AVE. WT. OF FISH RECOVERED	1.00	.97	.88	.90
CONVERSION FEED/GAIN	1.95	1.93	1.96	1.94

80' 40' 20'

SIMCO AND CROSS
1966

form which supports a submerged frame covered with netting of hardware cloth. A more expensive floating food is usually fed to the fish in the cages because sinking pellets would pass through the bottom of the cages. Collins states (11) that fish in cages can pick up no extraneous food from the pond; therefore the feed must be a complete ration rather than supplemental food used for ordinary pond culture. The cages allow the fish to be grown and harvested in a body of water that could not be drained or seined.

Lewis (31), in regard to behavioral problems, found that fighting occurred at a density below 50 to 75 fish per cubic yard of water. The fighting damaged the fish to such an extent that mortality occurred. At densities above these levels, fighting decreased and was not evident at a stocking rate of 100 fish per cubic yard. Stocking rates for yearling fish are recommended at 150 fish per cubic yard.

The newest method of channel catfish culture involving high population densities, raceways, was borrowed from the experiences of the trout and salmon culturists. In a raceway, many fish are confined to a trough or tank through which large amounts of water are passed. The earlier trout and salmon raceways consisted of diverting a cold mountain stream through troughs. Japanese trout ponds have produced 56,000 pounds of trout per acre per year with flowing water and intensive feeding (32).

Carp are also reared in Japanese ponds using dilution

from streams. Production rates of $5,591.6kg/41.18m^2$ are possible(27). Kawamoto concluded that excretory substances from the carp may keep down production in the ponds. In summarizing the culture method, Kawamoto believes that for increased production of carp, removal of excretory substances is far more important than factors such as O_2 and CO_2 in the water.

The Pennsylvania Fish Commission is currently experimenting with a raceway shaped like a silo for trout production (42). 20,000 trout are housed in a 17 foot high, 7 1/2 foot diameter fiberglass tank holding 5,400 gallons of water. Ken Buss, Chief of the Commission's Division of Fisheries, emphasized that a major advantage of the silo is the cost savings of labor, maintance, and construction.

Raceways used for production of channel catfish require large amounts of warm (75°) water. Location of the raceways is therefore limited to a naturally warmed water supply.

J.E. Stearns (49), a retired biologist from Texas, is presently raising channel catfish in 20 foot diameter 2,488 gallon concrete tanks supplied with well water. Growth of four inch fingerlings to edible size takes six months. Floating trout food is fed. Two major drawbacks may limit the usefulness of raceways; the problem of maintaining the temperature of the inflow water and a possible pollution problem from the outflow which is discussed in the conclusions of this thesis.

The problem of ammonia in fish-rearing water has drawn considerable attention. In solution ammonia acts as a weak base.

It forms salts which hydrolyse to a considerable extent with acids. The toxicity of ammonia depends upon pH, CO_2, hardness of water, O_2, and temperature (25). The pH effect on toxicity of solutions of ammonia and ammonium salts depends on the concentration of molecular NH_3 or NH_4OH, the ammonium ion NH_4^+ being comparatively non-toxic. Neutrality or acidity favors the formation of ammonium ions; raising the pH increases the concentration of molecular ammonia.

Shelford (46) tested the effect of ammonia and its salts on the sunfish, Lepomis humilis, and found that the salts were far less toxic than the gas. A 7-8 ppm solution of the gas killed sunfish in about one hour; a solution of NH_4Cl of similar toxicity contained 700-800 ppm.

The buffering effect of alkalinity on ammonia was first verified by the information available on trout (25). For a bicarbonate alkalinity of 200 (ppm as $CaCO_3$), the ammonia threshold in ppm as N was about 12 ppm at a pH of 8.6. At a pH of 7.0, the ammonia threshold was raised to more than 100 ppm. The threshold values can increase 2 1/2 times at low temperatures; also the threshold values would be much lower in water deficient in oxygen.

Closely associated with pH is the concentration of CO_2. The effect of carbon dioxide on the ammonia toxicity of trout was investigated by Lloyd and Herbert (17). The investigation revealed that at a constant un-ionized ammonia concentration of .8 mg/l. as N, trout died in 50 minutes at a CO_2 content of

48 ppm; in 60 minutes at CO_2 of 21.5 ppm, in 100 minutes at CO_2 of 7.7 ppm, and in 24 hours at CO_2 of 3.2 ppm. Thus the higher the carbon dioxide content of the water, the lower concentration of un-ionized ammonia a trout can tolerate. Carbon dioxide has a very important effect on fish respiration in that the concentration in which it is present determines the extent to which the available oxygen can be utilized. For every species there is a CO_2 tension which seems to inhibit oxygen utilization completely so that the fish begins to be asphysiated at once. At 20°C the brown bullhead can tolerate up to 720 ppm CO_2, the blacknose shiner can tolerate 180 ppm, while the trout tolerance varies from 60-120 ppm. (25).

Kawamoto (28) investigated the effects of ammonia concentration on the oxygen uptake rate of carp. Carp was found to survive 1.2 ppm ammonium chloride. The oxygen uptake rate of the carp increased considerable above 20°C in a 1.2 ppm solution of ammonium chloride compared to normal conditions. The effect of ammonia on the respiration rate was explained by the alteration of the oxygen transfer ability of the blood. Kawamoto concluded that excretions of fish, whether urine or feces, largely inhibit the growth of fish. Therefore, fish culturists should never disregard the accumulation of the excretory products of fish especially in a pond and should always endeavor to remove the influence of these products.

In all literature dealing with accumulation of fish wastes, nitrogen as ammonia emerged as one of the major irritants. In

order to effectively reduce the irritant in a water treatment
system, literature on the nitrogen cycle was reviewed.

Nitrogen is found in all living matter and plays a major
role in the life processes of all plants and animals. Nitrogen
has many valence states. Changes of valence states can be
regulated by living organisms, primarily bacteria.

The changes that occur to nitrogen are explained by a
simplified nitrogen cycle. Nitrogen is contained in fecal matter
and urine. The first step in the nitrogen cycle is the breakdown
of organic nitrogen compounds into ammonia,called mineralization.
The amount of ammonia produced depends upon the organism in-
volved, the substrate, and the environmental conditions involved.

The next step in the nitrogen cycle is nitrification, the
oxidation of ammonia to nitrate form. The oxidation of ammonia
is considered as a two step process (1). The ammonia is first
oxidized to the nitrite form by the Nitrosomonas bacteria. The
nitrite form is further oxidized to the nitrate form by the
Nitrobacter bacteria. The nitrate form is the last oxidation
form and completion of the nitrogen cycle requires reduction to
occur.

Denitrification is the return step of the nitrogen cycle.
Denitrification refers to the biological reduction of nitrates
to volatile gases. The rate of denitrification is highly de-
pendent upon the partial pressure of oxygen. Denitrifiers will
utilize nitrates as a hydrogen acceptor only when the oxygen
supply is very limited (5). The nitrogen after denitrification

is released to the surrounding air since it is for the most part insoluble in water. The end path of denitrification reactions is not definitely known. A good supply of readily oxidizable organic compounds, high nitrate levels, and poor drainage favor soil denitrification (48). A near neutral or basic pH as well as a fairly high temperature also contribute to rapid denitrification (18).

The accumulation of waste products is not the only irritant to confined fish. Heavy metals such as lead, zinc, and copper are toxic to fish. Various water conditions vary the degrees of toxicity. An indoor fish culture system would involve pumps and piping that could produce toxic materials. The toxicity of of lead, zinc, and copper are greatly influenced by the amount of calcium in the water.

Zinc sulphate solutions are toxic to sticklebacks down to a concentration of about .3 ppm zinc when a very soft water is used for making up the solution (26). The addition of 50 ppm calcium chloride will reduce the toxicity of the zinc sulphate solution to a concentration of 2.0 ppm zinc. Similiar results occurred with rainbow trout (57,58).

A 1.0 ppm lead solution (lead nitrate) is fatal to sticklebacks in 18-28 hours. The addition of 50 ppm of calcium, as calcium chloride or calcium nitrate, will prolong the survival time to over 10 days (26). Similiar results occurred with copper. It is possible that the exact nature of the toxic action of heavy metal ions on fish depends on the nature and

quantity of their gill secretions. Some species produce relatively little gill secretions and experience rapid disintegration of the gill tissues from exposure to heavy metal salts. Some metals are actually precipitated on the gill surfaces and form a physical barrier to oxygen transfer (26).

The indoor culture of the channel catfish would require a container different than an earthen pond used for outdoor culture. Shell (47) evaluated the use of plastic, concrete pools, and earthen ponds for channel catfish research. Under similar conditions, fish in the concrete pools grew at a faster rate than those in the plastic pools, however fish grown in the earthen pond experience a five fold increase in growth rate. The difference was attributed to the soil in the bottom of the earthen pond. The difference may also have been attributable to the sources of water. Well water, which would have no aquatic life, was used for the concrete and plastic pools. Stream water, which may have supplied an abundance of aquatic life, was used for the earthen pond. The article states that experiments in plastic and concrete pools, in which the effect of a treatment depends upon the interaction of the aquatic enviroment, should not be applicable to earthen ponds unless demonstrated by comparable experimentation.

One main advantage of indoor confinement of fish is the ability to regulate the water temperature. Growth, food conversion, food consumption, and survival of the channel catfish at various temperatures was investigated by West (60). Replicated experiments of eleven tanks each were maintained at 21.0, 23.0,

25.0, 27.0, 29.0, 31.0, 32.0, 33.0, 34.0, 35.0, and 36.0°C.
Twenty fry were placed in each of the 22 tanks at the beginning
of the study. The tanks were 22 inches long by 16 inches wide,
and 14 inches deep. One air stone was placed in each tank. One
gallon of dechlorinated city water was added per hour to each
tank. Water temperatures were controlled by a thermoregulator
which was connected to resistance heaters submerged in each
tank. The fish were fed a liver paste three times daily. Max-
imum growth rate occurred between 29.0 and 30°C. Maximum food-
conversion efficiency occurred at 28.9°C. Food consumption per
gram of body weight increased with an increase in temperature
and decreased with age. The survival rate was in excess of 90
percent between 27.0 and 34.0°C.

Biochemical reactions in general, follow the van't Hoff
rule of a doubling of reaction rate for a 10°C increase in tem-
perature, over a restricted temperature range. The constant
temperature of optimum catfish production of about 80°F would be
an ideal temperature for a biological treatment system.

The potiential of the biofilter to reduce wastes has been
shown by a number of trickling filters used in municipal sewage
treatment plants. The trickling filter is the most widely used
biological waste treatment system for municipal wastes. Trick-
ling filters consist of a pile of rocks over which sewage or
organic wastes slowly trickle. In a biofilter, or trickling
filter, the water is intermittently sprayed over gravel that is
coated with a living film of micro-organisms actively feeding

upon the pollution in the water. The sewage is introduced onto the filter by a rotary distributor. The depth of rock in the filter varies from 3 to 14 feet with an average of 6 feet (59). The choice of filter stone size is dependent upon the waste characterists. A high organic load per unit volume of filter requires large stones so that the biological growth does not fill all the voids and clog the filter and allows air to circulate through the filter.

The final sedimentation tank which functions to remove large masses of biological growths which have dropped from the filter stones is an important part of the trickling filter. The removal of these settable biological growths accounts for 10 to 20 percent of the efficiency of the filter in removing organic matter.

Although classified as an aerobic treatment device, the trickling filter is not a true aerobic device but must be considered as a facultative system. At the beginning of filter operation, aerobic conditions exist. After start up, build up of micro-organisms creates an anaerobic layer at the stone interface (36). The predominant micro-organisms are bacteria; aerobic, facultative, and anaerobic. The great majority of bacteria in the filter are facultative, living aerobically as long as dissolved oxygen is present and anaerobically when the oxygen is depleted.

The removal of organic matter by the filter is a function of the micro-organism present, the organic concentration applied, the microbial surface area, the time of retention of the liquid

in the filter, and the temperature. For maximum organic matter removal, the filter should have as small a media as possible to yield the maximum surface area without harmful restriction of water and air passage. Some low rate trickling filters obtain a BOD reduction of 90% by recirculating municipal sewage during periods of low flows.

Green et. al. (19) experimented with a filter media of vertical stainless steel screens. Reductions of 49-95 per cent of organic matter and 40 per cent of ammonia were obtained by trickling effluent from settled sludge at 20 to 30°C. The reduction percentages are somewhat misleading because no absolute strength of the effluent is given. Assuming reduction figures are applied to a municipal waste with an average strength of about 300 mg/l BOD, the effluent would be of fairly high BOD if compared to water quality suitable for fish culture.

Chu (9) conducted a thesis experiment to determine the effect of a biofilter on water quality and fish production of recirculating water from aquaria housing goldfish. Four groups consisting of two-48 liter aquaria in each group were set up and maintained at the same temperature. Group 1 was fertilized with 50 gm fish feed, one liter of algae culture, and one liter of seined micro-organisms. Water in Group 1 was not filtered. Each aquarium in Groups 2 and 3 received the same treatment as those in Group 1, but they were also provided with a biofilter consisting of 39 cm diameter bucket with a perforated bottom filled 35 cm deep with washed gravel .5 to 5 cm in

diameter. A two cm layer of activated charcoal was spread on top of the gravel. Water flowed at six-liter per hour from each aquarium through a series of three 300 ml bottles that acted as settling tanks. An air lift pump lifted the water and sprayed the filter from above. Drainage from the filter returned to the aquarium. Group 3 also received 50 gm of powdered $CaCO_3$.

The water in Group 4 was changed twice daily to simulate a running water environment, but was not filtered. About 90 per cent of the water was replaced at each change. Five goldfish weighing 280 gms total were placed in each aquarium. The fish were fed trout food at the rate of 2.5% of fish body weight per day for 36 days.

In spite of constant aeration, the fish in Group 1 with no biofilter died by the 12th day. The oxygen was below two ppm and the ammonia was near 28 ppm. The fish in the other 3 groups grew well. Chu concluded that circulation of the water from aquaria through a biofilter reduced the concentration of organic wastes from the feed and fish while increasing the oxygen when compared with similiar aquaria without filtration.

Another labortory scale biofilter (35) used for rainbow trout had a total volume of 200 gallons and circulated 10 to 20 gallons per minute. Water temperature was maintained at 58°F by an electrical heater. The system incorporated a pressure sand filter which was back flushed weekly with 20 gallons of recirculated water. Fish were feed at the rate of 3 to 5% of live

body weight per day. Favorable growth weights were obtained with an above 80% survival rate. The system would support 25 pounds of trout but excessive nitrates would build up at that loading.

The Salmon-Cultural Laboratory at Longview, Washington, has developed a reconditioning system which makes possible at least a 95% reduction in the quantity of water required for rearing salmon (7). Ammonia is removed in the reconditioning system by percolating the water through gravel filters five feet deep at the rate of 1 gallon per minute per square foot of filter area.

The bacterial filters consisted of a 4-foot-deep layer of sharp rock covered by a 1-foot-layer of crushed oyster shell. The filters were 20' by 75'. Both the rock and the shell provide bacterial beds, but the bacteria on the rocks was stable and helped re-establish the shell bacteria when the oyster shell was "scrubbed" clean. Scrubbing of the filters occurred by back flushing with pressurized air and water every other day. The oyster shell provided mechanical straining and was credited for controlling pH by supplying clacium for calcium nitrate. Without a base available, nitrous and nitric acids were formed which lowered the pH to such an extent that the fish would die. The trickling filters converted from 50 to 100 percent of the ammonia present to nitrates in a single pass. Control of nitrates was accomplished by dilution with fresh water.

Make up water was added at the rate of 90 gallons per minute, or 5% of the circulated water. A make up rate lower

than 2% caused excessive nitrate build up. Sterilization of the make up water was accomplished by using pressurized sand filters and an ultraviolet irradiation unit. The water was maintained at not less than 6 ppm oxygen by aspirators. Each aspirator delivered 125 gallons of water per minute at 10 pounds per square inch. A one ton heat pump maintained the water temperature at 53°F.

Oxygen was found to be the limiting factor of population density when the water was warm. In colder water, density was limiting. Fish weighing one-tenth of a pound could be grown at 18 fish per cubic foot of water.

Of all the perils of fish farming, disease is probably the number one killer of fish. Very few people are qualified to diagnose and treat diseases effectively. The problem of controlling disease is more acute in a confinement system with a high density of fish.

One of the most prevalent diseases of fish, both in fresh and salt water is <u>Ichthyophthiriasis</u>, commonly called "Ich" or White Spot (56). The disease is characterized by the appearance of white spots, having a diameter of .5 to 1mm, on the fins and skin of the fish. The parasite is a protozoan which penetrates the mucous coat and the upper layer of the epidermis and feeds on red corpuscles. The irritation caused by the parasite is covered by a layer of skin which protects the parasite. When the parasite reaches maturity, it bores once again through the epidermis and leaves the fish for reproduction. The mature

THIS BOOK CONTAINS NUMEROUS PICTURES THAT ARE ATTACHED TO DOCUMENTS CROOKED.

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parasite sinks to the bottom and produces up to 1,200 offspring. The offspring must reattach itself to a fish within a few days or it will die of starvation. Chemical treatments are not effective while the parasite is on the host, therefore repetitive treatment is mandatory to kill the young parasites as they are hatched.

Sand filtration was once thought to be effective against the parasite. Johnson (24) concluded that the organism had passed through 2.5 feet of sand. Recommended treatments are quinine salts, methylene blue, mepacrine hydrochloride and mercurochrome.

Simple bacterial infections are common to small fish. Bacterial infections must be diagnosed by staining a slide prepartion under a microscope. Diagnoses of bacterial infections is quite complicated because of the number of other non-harmful bacteria present in an infection. Antibiotics and sulfur are recommended treatments (56). If very small fish become infected, their chances of survival are small due to their low energy reserve.

Treatment of the previously mentioned and other diseases with chemicals is difficult in a recirculating system. The difficulty is more pronounced in systems employing a biofilter since most treatments would be quite harmful to living organisms in the biofilter.

Two possible solutions to the disease problem were investigated. Ozonation is effective as a water sterilizer (39). However, it is quite toxic to fish and is expensive to manufacture and control for large quanties of water. Ultraviolet irradia-

tion may be a solution to disease control. Aquafine Corporation (3) states that Dr. Earl S. Herold, Curator of Aquatic Biology, Steinhart Aquarium, California Academy of Sciences, claims the ultraviolet sterilizers will kill 99% of the microscopic disease organisms found in an aquarium's water system. Electrical costs are less than one cent per 5000 gallons disinfected.

Two indoor fish production buildings were visited during the time span of the research project. The first visit was at Warsaw, Illinois. Marvin Hall (22) along with two other partners had built an indoor system utilizing a biofilter for their first attempt at production of channel catfish.

The system was composed of 16 galvanized tanks. Each tank was 2'x6'x16' and water inside was maintained at 18 inches deep by an overflow siphon. The outflow water was dumped onto a pea-sized gravel biofilter 4'x4'x8'. Underdrains from the biofilter led to a sump where a fractional horsepower pump returned the water to the tanks. Maximum population in the tanks at the time of the visit was 3,000 six-inch fish. The fish were fed sinking pellets.

Water temperature in the system was maintained by a water heater. An air heater was later installed to help maintain water temperature during very cold days.

Several problems had been encountered with the system. Solid wastes would plug the surface of the biofilter and the top 3" of the biofilter had to be disturbed daily to allow the water to percloate through the gravel. Plans were made to settle the

solids before passage through the filters.

A second problem became apparent when a power failure caused the death of numerous one pound fish in one tank. The problems were to be corrected and a second attempt at production of channel catfish was to be started.

The second visit was at the Skidaway Institute of Oceanography at Savannah, Georgia. James W. Andrews (2), (principal investigator) received a $105,000 grant from the Department of the Interior to study the interactions of environmental and dietary factors on growth, health, body composition and economical aspects of channel catfish in intensive running water production.

In his research, the fish were housed in 18 round fiberglass pools approximately 10 feet in diameter and 30 inches deep. Three different stocking rates of 200, 400, and 600 fish per pool were contrasted with three different dilution rates. The dilution water was pumped from 700 feet deep wells at a temperature of 65 to 70°F. Electric heaters on each tank controlled the water temperature at 75°F. Overflow water ran to a floor drain.

Growth rates for the first quarter of the experiment are very favorable except at the lowest dilution and the highest stocking rate.

In regard to nutrition, Andrews related that the supplemental feeds used for outdoor feeding would not be suitable for indoor intensive culture. He suggested floating trout food as a good ration.

Other experiments with channel catfish under way at Skid-away Institute were investigations of the amino acid and mineral requirements, various nutritional analyses and the effect of daylength and light intensity on growth.

Thus, there are some biofilters in use for cold water fishes. Information is lacking on the quantity and type of wastes that the filters must process. No information on catfish wastes was found. Many unknown factors must be investigated before design-ing a closed-circulation, controlled environment facility for the purpose of rearing channel catfish indoors.

PRELIMINARY EXPERIMENTATION AND OBSERVATIONS

Experiments conducted for this thesis took place in room 226 in Seaton Hall at Kansas State University. Manhattan city water was used in all the experiments. The water was partially dechlorinated in an elevated 250 gallon tank equipped with a paddle aerator. The water flowed by gravity through two activated charcoal filters to absorb any remaining chlorine. The activated charcoal filters also served as a precautionary measure against chlorine killing of fish in event of aerator failure.

The water then flowed through an eighty gallon hot water heater. Water temperature was controlled by a Honeywell Silicon Controlled Rectifier (S.C.R. unit). A sensing thermistor for the S.C.R. unit was located in a tee on the outflow pipe of the water heater. Since the S.C.R. unit was a modulating control instead

of an on-off control, outflow water temperatures could be held quite constant. Water from the heating system was distributed in the room to various experiments.

In order to become familiar with the problems associated with high density fish culture, preliminary observation experiments dealt with finding a suitable food for small fish and noting changes in water quality due to the feeding fish.

Four tanks each 3'x3'x1' were constructed by lining a wood frame with 6 mil polyethylene film. The polyethylene film was folded and taped in the corners to prevent small fish from being trapped. The capacity of each tank was held at 40 gallons. Dilution water was provided at the rate of 1/15 gal/min. A bubble aerator with an airstone supplied aeration for each tank. Two hundred fifty fry obtained from the Pratt Fish Hatchery were placed in each of the four tanks.

Four food sources were investigated. One tank was fed daily one gallon of water in which algae was cultured. The algae was grown in the glass jars by seeding with algae and then adding a small amount of 10-6-4- granular fertilizer. The jars were set in sunlight and became dark green in several days. By starting a new jar every day, five jars provided enough algae.

A second tank was fed a liver paste consisting of 1 1/2 pounds of homogenized beef liver, one 8-ounce box of high protein baby cereal, one 4 1/2 ounce bottle of strained spinach and 100 ml of water. A third tank was daily fed plankton seined with a plankton net from a catfish rearing pond. The fourth tank was

fed finely ground Z-14 commerical fish food developed by Dr.
Tiemeier and Deyoe (54). In all four tanks, an attempt was made
to keep food before the fish at all times. Growth measurements
were not taken due to the small size of the fish, but relative
growth rates are compared to fish of the same age reared at the
Tuttle Creek Fish Research Farm.

The fish which were fed algae died by the end of the tenth
day. Algae which exists in ponds appears not to be a direct
food of small fish, but it may serve the purpose of providing
nutrients to small microbes which the catfish might consume. The
two groups fed plankton and finely ground feed grew equally well.
However, their growth rate was slower than the outdoor growth
rate. The best results were obtained with the liver paste.
Growth at the two month interval was about equal to outdoor
growth.

Mortality on all groups of fish was 50% during the two months
feeding period. A white disc appeared on the forehead of the
diseased fish. A parasitologist diagnosed the deaths as the re-
sult of a bacterial infection. Since the fish were isolated
from any contaminated water, the infection was believed to have
orginated on the fish before they were transported from Pratt.
The tanks were treated with 2.5 ml of formaldehyde, but no
favorable results were observed.

Water quality studies were started on the tank of fish
which were fed the liver paste. The tank was completely drained
and refilled with fresh water. No dilution water entered the

tank. A bubble aerator supplied aeration. Water tests were analysed with a DR-EL model Hach Test Kit. The water, immediately after changing, tested 6 ppm oxygen, 2 ppm carbon dioxide, no nitrogen as ammonia, and .5 ppm nitrates.

The fish were fed as normal and 24 hours later the water was again tested. The oxygen had decreased to 2 ppm, the carbon dioxide had increased to 20 ppm, the ammonia had increased to 14 ppm, and the nitrates increased to 7 ppm. The procedure was repeated three times with the same results. Thus, the feeding of fish produced considerable ammonia and carbon dioxide.

Water at the end of the 24 hour period was slightly yellow in color and had a fishy odor probably attributable to the ammonia. Changes in the water quality could be visibly seen from watching the fish. Fish in this polluted water were quite sluggish and often very near the surface. A finger could be moved through the water touching the fish without alarm to the fish. The fish would also refuse to eat in the polluted water. Upon the addition of a stream of fresh water, immediately the fish would gather in the stream and become quite active. Upon changing of the tank with fresh water, the fish would again eat instantly. The build up of carbon dioxide and ammonia seemed to anaethetize the fish and the reaction could be natures' method of protecting the fish while in polluted water.

A simple test was undertaken to determine the value of aeration to the polluted water. A sample of the polluted water tested at 2 ppm O_2, 20 ppm CO_2, 14 ppm NH_3, and 1.5 ppm NO_3.

Severe aeration was applied to the sample for two hours. The water then tested 6 ppm O_2, 6 ppm CO_2, 18 ppm NH_3, and 4.4 ppm NO_3. The results show a decrease in the CO_2, but an increase in NH_3. The increase of NH_3 was attributed to the evaporation of water with no change in the amount of NH_3 since the solubility of ammonia is quite high.

Possible ways of reducing the ammonia were investigated. Chemical treatments were not considered because they appeared to be too costly and would require a technical chemical knowledge on the part of the operator. Anaerobic treatments were not considered because of the relatively small amount of wastes (low BOD) per unit volume in the water. Also the anaerobic treatment would strip oxygen from the water which would later have to be replenished to support fish life. The treatment of fish wastes by bacteria indicated in the literature review appeared to be the best method of renewing water for a closed recirculating system. Therefore, aerobic treatment using biofilters was considered as the best type of treatment process to pursue.

All large scale biofilters covered in the literature review had to be backflushed periodically. The backflushing required additional equipment and labor, therefore it was to be avoided if possible. It was reasoned that an ordinary downflow trickling filter would effectively treat the wastes, reoxygenate the water, and be self cleaning.

A biofilter consisting of a 6 inch diameter plexiglass tube 4 feet long filled with 1 1/2 inch rock was constructed. A

wood grid at the base of the tube supported the rock leaving approximately 50% of the bottom area open for water and air passage. A submersible pump circulated water from a 30 gallon plastic reservior to the top of the tube. The water then trickled through the gravel and returned to the reservior. The water was circulated at 1/2 gallon per minute.

To innoculate the filter, several rocks from the municipal trickling filter at the Abilene waste treatment plant were placed on top of the filter gravel and a shovelful of dirt was dumped into the bottom of the reservior. Daily, water which for 24 hours had contained 250 fish - the group fed the liver paste - was siphoned into the filter reservior. When the reservior became full, enough water was removed daily to admit the polluted water from the 250 fish. The water was circulated for one week and then the fish tank was connected directly to the filter. The changes in water quality as O_2, NH_4, CO_2, and NO_3 are presented in Table 1.

Changes in water quality occurred as expected for the first 15 days. The ammonia was converted into nitrates. The high nitrate level at the time of connection didn't visibly affect the fish. Figure I is a graph of the nitrate level. The reduction of nitrates during the latter 15 days of the curve was unexpected.

The reduction was explained as follows: the bacteria initially formed on the rocks were aerobic bacteria converting the ammonia to nitrates. As the growth thickened on the rocks, the bacteria on the stone interface became insulated from oxygen

TABLE 1.   Water quality of trickling filter.

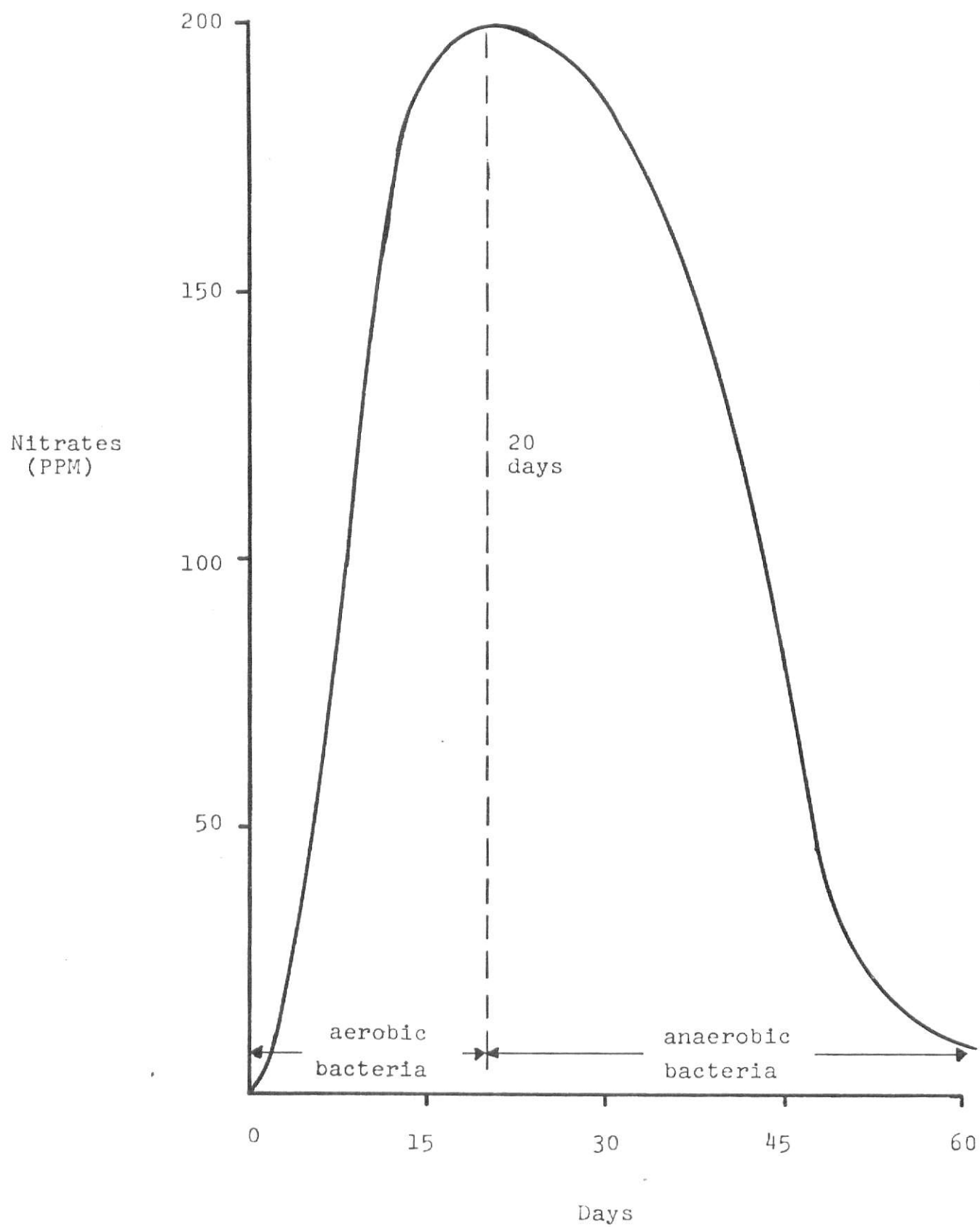| Date	O_2	NH_3	CO_2	NO_3
11/20/68	2	11.5	20	1.9
11/21/68	5	3.6	4	7.0
11/22/68	6	.3	4	3.3
11/26/68	6	.4	3	8.0
12/ 3/68	6	.5	4	53.0
12/11/68	5	2.0	6	211.0
12/18/68	5	2.0	8	80.0
12/23/68	5	1.1	12	48.0
12/26/68	4	2.0	16	14.3
1/ 2/69	4	2.0	18	2.6
1/ 8/69	4	1.6	20	8.8
1/13/69	5	1.3	22	14.3
1/23/69	4	.3	26	11.0
1/30/69	4	.4	30	12.0

Fig. 1. Nitrates vs. days for developing fish bio-filter.

by other bacteria growing on top of them. The bacteria on the
stone interface were forced to grow anaerobically. The outer
bacterial layer with an abundance of oxygen converted the ammonia
to nitrates.

The stone interface bacteria - due to the lack of oxygen and
the abundance of nitrates from the surface bacteria - anaerobical-
ly used the nitrates as a hydrogen acceptor. The nitrogen which
remained after stripping of oxygen from the nitrate molecule was
diffused outward through the layers of bacteria to the surround-
ing air.

After a month of recirculation, the dark brown bacterial
growth could be readily seen in the plexiglass cylinder. On
scattered places in the column, black areas could be seen and were
attributed to very thick bacterial masses where denitrification
might occur. Table 2 relates the growth of the fish while con-
nected to the biofilter. Random sampling of 80 fish was used to
obtain average weights.

TABLE 2.   Growth of fry connected to the biofilter.

Date	Ave. weight (lbs)
11/27/68	.0045
12/ 5/68	.0051
12/12/68	.0052
12/19/68	.0057
12/26/68	.0053
1/ 2/69	.0059
1/ 7/69	.0071
1/16/69	.0082
1/23/69	.0089
1/30/69	----

Growth of the fish was terminated on January 30, 1969 when the oil filled submersible pump developed a leak around the impeller shaft which killed the fish.

During the test, water in the filter system remained clear and produced no odor. Fish were quite active in the water and displayed no visible adverse effects. The growth data indicated that gains were possible with a biofilter.

Biochemical oxygen demand (BOD) is one important indicator of how much oxygen is needed to stabilize organic wastes. As the fish grew, the biofilter became darker with additional bacterial growth. No indication was obtained on the amount of wastes in terms of BOD that the trickling filter was removing and the waste production of channel catfish was not found in the literature.

BOD of many industrial and municipal wastes is known, and ranges of experimental values for wastes voided by most commercial animals have been published (34). Such data are used in designing waste treatments and as pollution-control criteria. The BOD that fed fish impose on their environments has not been investigated previously. Therefore, a system was designed to measure the BOD of wastes from two adult channel catfish.

Methods and Materials

Two fish were confined to a 250-gallon tank in which water was maintained at 75°F. Water flowing into the tank was measured accurately by a continuous fresh-water dosing system. A 3-foot high by 6-inch diameter plexiglass cylinder, filled to over-

flowing in a cyclic routine, gave a calibrated volume of 17.020 liters. Water overflowed (to a floor drain) till a timer signaled the end of each half-hour cycle, when one solenoid valve cut off water supply to the cylinder and another opened the cylinder drain line to the fish tank. After 15 minutes (adequate time for the cylinder to drain) solenoid valves returned to their original positions and the cylinder filled again (Fig. 2).

The tank was divided as shown in figure 3. Water level was controlled at 5 inches below the tank rim by a constant-level siphon. At that level, one tank volume was displaced every 24 hours.

One fish was placed in each end compartment. Both fish had been confined to the compartmentalized tank for the previous 1 1/2 years and were well accustomed to the environment. They were tame and trained to hand feed (Fig. 4). Hand feeding assured that the fish consumed all feed, so that BOD measurements would not be influenced by waste feed.

The feed was a paste rolled in balls readily accepted by the fish. It consisted of 4 oz. water, 40 gms. pulverized liver, and 80 gms. Z-14 fish pellets (54). The prepared paste was refrigerated in air-tight containers until used. Dry weights were checked periodically to determine feed conversion. The amount fed daily, as a percentage of body weight, average 2%.

Wastes from catfish occur in two forms: a soluble form that cannot be seen and a flocculate that settles readily in still water. Daily, using a hand-manipulated siphoning tube,
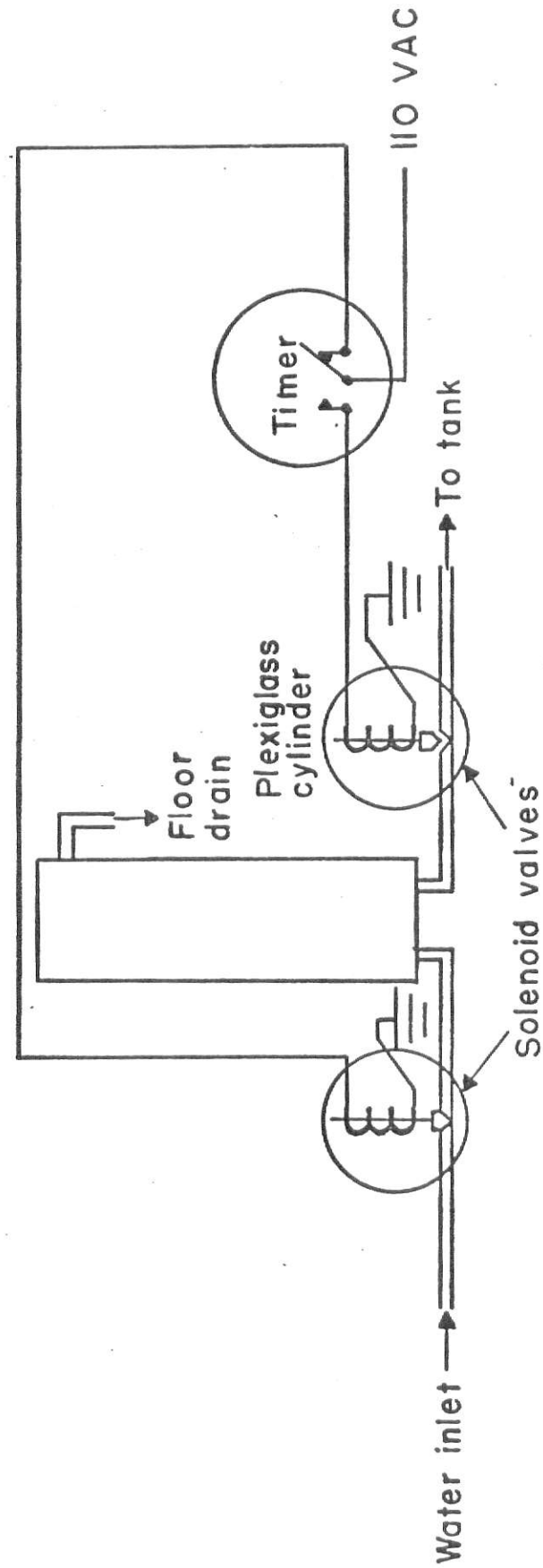
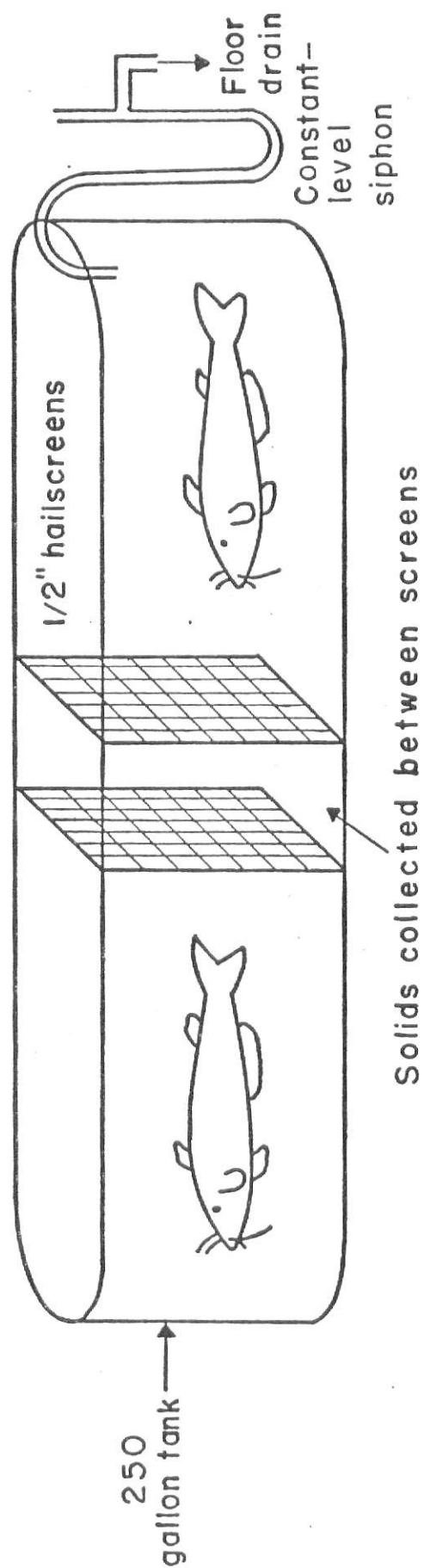Fig. 2. Schematic diagram of water measuring cylinder.

Fig. 3. Schematic drawing of BOD research fish tank.
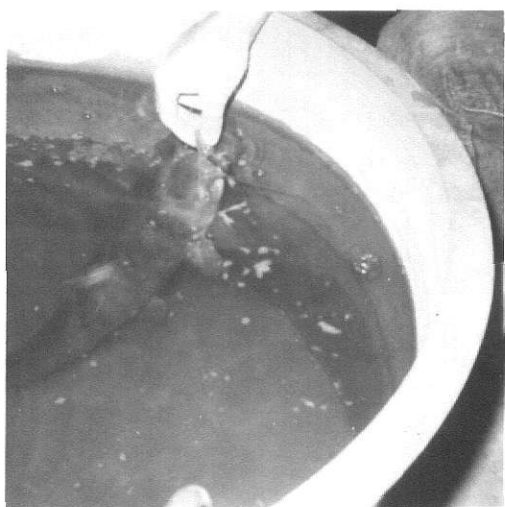
Fig. 4. Male fish accepting food.

TABLE 3. Measurements of settled solids and BOD wastes.

Volume of solids (ml/week)	Solid waste BOD (gms/week)	Soluble waste BOD (gms/week)	Total wastes BOD (gms/week)
2420	47.02	82.92	129.94
2540	62.46	76.34	138.80
2350	59.46	54.33	113.79
2250	51.50	43.41	94.91
1920	39.00	57.18	96.18
2220	39.25	80.16	119.41
2380	50.58	74.34	124.92
2630	69.48	88.64	158.12
2670	55.14	106.66	161.80
Avg. 2375	52.65	73.78	126.43
	42%	58%	100%

the flocculate was transferred to a 1000 ml graduated cylinder.
After settling to a constant volume (30 minutes), the volume was
recorded. The supernatant liquid was returned to the tank.

One day each week the total volume siphoned from the tank
(solids plus liquid required for transport) was recorded. That
mixture was allowed to settle and the solids volume recorded in
the usual manner. The mixture was then stirred vigorously and
samples taken for BOD tests. By equating the total BOD of the
entire specimen drawn from the tank to the volume of settled
solids, the BOD per unit volume of settled solids was obtained.
The method introduced a slight error because the BOD of liquid
containing the solids was included with that of the solids.

BOD of the soluble wastes was determined by sampling the
overflow from the tank once each week. In that humidity in the
laboratory was high, evaporation from the tank was considered
negligible and outflow was regarded as being equal to the measur-
ed inflow. Total BOD of the soluble waste was found by multi-
plying the strength of the sample volume by the inflow rate.
The dissolved oxygen, carbon dioxide, ammonia, nitrates, and pH
also were tested each week. The weekly water-quality tests
were run on a DR-EL Hach water-testing kit, and BOD was measured
by using a Hach BOD manometric test unit. The experiment was
terminated at the end of the ninth week.

Results and Discussion for BOD Production

Table 3 summarizes solid waste and BOD production, based
on weekly measurements, from two catfish maintained in a tank

under controlled conditions.

Oxidation of organic matter in the tank before samples were taken may have reduced the recorded BOD production of the fish. Ammonia and nitrates produced would indicate the treatment that may have occurred. The levels of ammonia and nitrate as well as other common water quality criteria are shown in Table 4. In that both ammonia and nitrate values were low (Table 4), it was concluded that treatment in the tank before sampling was negligible.

The feed conversion ratio for the female fish was higher than for the male fish (Table 5). Being more active than the male fish, the female fish would have metabolized a greater portion of her feed for energy production and less for weight gain; that could have explained the difference in the feed conversion ratios.

Compared with commercial animals, the channel catfish is a greater producer of BOD on a per-pound live-weight basis. Daily, the channel catfish produces 0.00490 pounds BOD (calculated from Table 3) per pound live weight. Comparable figures (34) for chickens, swine, and beef cattle are 0.0033, 0.00332, and 0.00102, respectively. On that basis, chicken and swine wastes have two-thirds and beef cattle wastes have one-fifth the pollution potential of catfish wastes. BOD production in a raceway containing 100,000 one-pound catfish would be approximately equivalent to the BOD production of a flock of 150,000 one-pound chickens, of a swine operation feeding 1,500 100 -

Table 4. Water quality in fish tank; based on weekly measurements.

ppm

Date	D.O.	NO_3	CO_2	NH_3	pH
10/ 9/69	6	.78	20	.5	7.2
10/16/69	6	.76	24	--	7.2
10/23/69	7	1.03	20	.2	7.2
10/30/69	7	.88	20	.2	7.0
11/ 6/69	7	1.50	28	.2	7.0
11/13/69	6	1.90	28	.4	7.2
11/20/69	6	1.80	36	.2	7.2
11/27/69	6	2.05	36	.4	7.2
12/ 4/69	6	2.39	24	.6	7.2
Average	6.3	1.46	26.2	.3	7.2

Table 5. Feed conversion ratios.

Fish	Initial weight (gms)	Final weight (gms)	Average weight (gms)	Gain (gms)	Dry weight feed (gms)	Conversion ratio
Male	2050	2526	2280	476	1118.46	2.35
Female	1250	1497	1374	246.9	847.26	3.34
			3654			2.89

pound hogs, or of a fed herd of 480 1,000-pound steers.

Treatment in the raceway could reduce the pollution load on the receiving waters, but the amount of treatment would be small because the water is detained so short a time in the raceway. The effect of the pollution on receiving waters would vary with different raceway operations. Therefore, each raceway operator should evaluate the liability of his outflow.

SUMMARY OF PRELIMINARY EXPERIMENTATION AND OBSERVATION

The trickling biofilter, as researched in the literature review and as experienced by preliminary experimentation, emerged as the best method to recondition water polluted with fish wastes. The trickling biofilter would have the following advantages:

1.) self cleaning - no labor or equipment required for backflushing

2.) water is reaerated and waste products are removed in the same structure

3.) denitrification occurs

4.) requires no chemicals or supervision

5.) possible food source for small fish

Consequently, it was decided to build a pilot scale trickling biofilter system to further explore the possibilities for use in indoor fish culture.

PROCEDURES AND EQUIPMENT

In the summer of 1969 a research system was designed and built to study fish confined to a recirculating water, fish production system. The system was designed to compare 3 types of biofilters.

1.) a 1 foot depth trickling filter

2.) a 4 foot depth trickling filter

3.) a 2 foot depth trickling filter followed by sand filtration

The 1 foot depth trickling filter consisted of a 2'x 2 1/2' x 1' box with a 1/2" hailscreen bottom. The box was filled with 1/2" expanded shale to support bacterial growth. Water was distributed over the filter by an oscillating lawn sprinkler. A 2'x 2 1/2'x 1' V-shaped sedimentation trough below the filter settled out the biological growths that dropped from the filter. Water from the settling trough flowed through a water jacket exposing the water to an 18 watt ultraviolet lamp before returning to a 50 gallon tank that served as a common reservoir to receive water from all the filters.

The 4-foot depth biofilter utilized a 6" plexiglass tube with a wood grid attached to the bottom. The tube was filled with 1/2" rock filled to a depth of 4 feet. Water entered the column through 3/8" plastic tubing and was distributed by splashing on an inverted evaporating dish. Effluent from the tube flowed directly to the common reservoir.

The 2-foot depth biofilters were constructed by using four
10-gallon plastic wastebaskets with holes drilled in the bottom.
The wastebaskets were filled with 1/2" rock. Water was dis-
tributed to each of the four wastebaskets by a manifold. An
aluminum pie plate punched with holes was placed on top of the
rock to disperse the water evenly over the rocks. After passage
through the 2 feet of rock, the water was allowed to settle in
a rectangular 3'x3'x 1' sedimentation tank which supported the
four wastebaskets. Constant level siphons conveyed the water
to sand filters. The sand filters were smaller plastic waste-
baskets filled with mason's sand. After percolating through one
foot of sand, the water returned to the common reservoir.

A 1/3 horsepower pump with the suction line attached to
the common reservoir discharged through 3 water meters to mea-
sure flows. The flow from the pump was divided among the
various filters and also to a line discharging directly into
each of two fish tanks. A 2000 watt resistance heater enclosed
in a 3" diameter, 2 foot long tube was installed in the line to
the fish tanks. The voltage to the electric heating element
which maintained the water temperature in the system at 80°F
was controlled by a silicon controlled rectifier.

A 1" plastic line conveyed water from the fish tanks to a
3'x 2'x 1 1/2' V-shaped settling trough. From the settling
trough water flowed by gravity to the common reservoir.

The fish tanks were 250-gallon galvanized oval stock tanks.
Each tank had a bubble aerator for additional aeration. Stand-

by power for the aerators in case of electrical failure was furnished by a relay controlled, 12 volt battery connected to a 12V-110V square wave Heathkit power inverter. The aerators normally operated on 120 AC. When the power was interrupted, the relay coil de-energized which closed 3 sets of contacts to operate the standby 12V inverter.

Dechlorinated tap water was supplied to the system at a rate of .225 liters per minute which was slightly in excess of that needed to make up for losses caused by evaporation and removal of solid wastes. The schematic of the system is presented in figure 5 and the legend relating the componets and water flows is on the opposite page.

Approximately 1500 fingerlings were obtained from the Tuttle Creek Fish farm in September. The fish were kept in a round 8' diameter stock tank diluted with 50°F fresh water until they could be transferred to the recirculating system. The fish lost weight during the time held in the stock tank but appeared healthy.

One hundred fish were placed in the south tank for 2 weeks to stimulate growth on the biofilter. An additional 500 fish were placed in the system one month after start up of the system. The remaining fish were transferred 2 weeks later on November 11, 1969 with a final population of 600 fish in the north tank and 435 fish in the south tank. The fish were fed Z-14, a commercial fish food developed by O. Tiemeier and C. Deyoe at the Tuttle Creek Research Fish Laboratory, at the rate of 3% of

Legend for figure 5.

Equipment

A. two-250 gallon fish holding tanks

B. 6" diameter, 4 foot depth, plexiglass tube filter

C. sedimentation trough

D. 50 gallon common reservoir

E. water meter

F. 1/3 horsepower pump

G. ultraviolet irradiator

H. 1 foot depth trickling filter

I. 2000 watt electric heater with SCR unit

J. four-2 foot depth wastebasket filters

K. oscillating lawn sprinkler

L. sedimentation reservoir

M. sand filter

N. gathering trough

Water flows.

1. 5.0 gallon per minute

2. 1.7 gallon per minute

3. 3.3 gallon per minute

4. 1.5 gallon per minute

5.   .4 gallon per minute
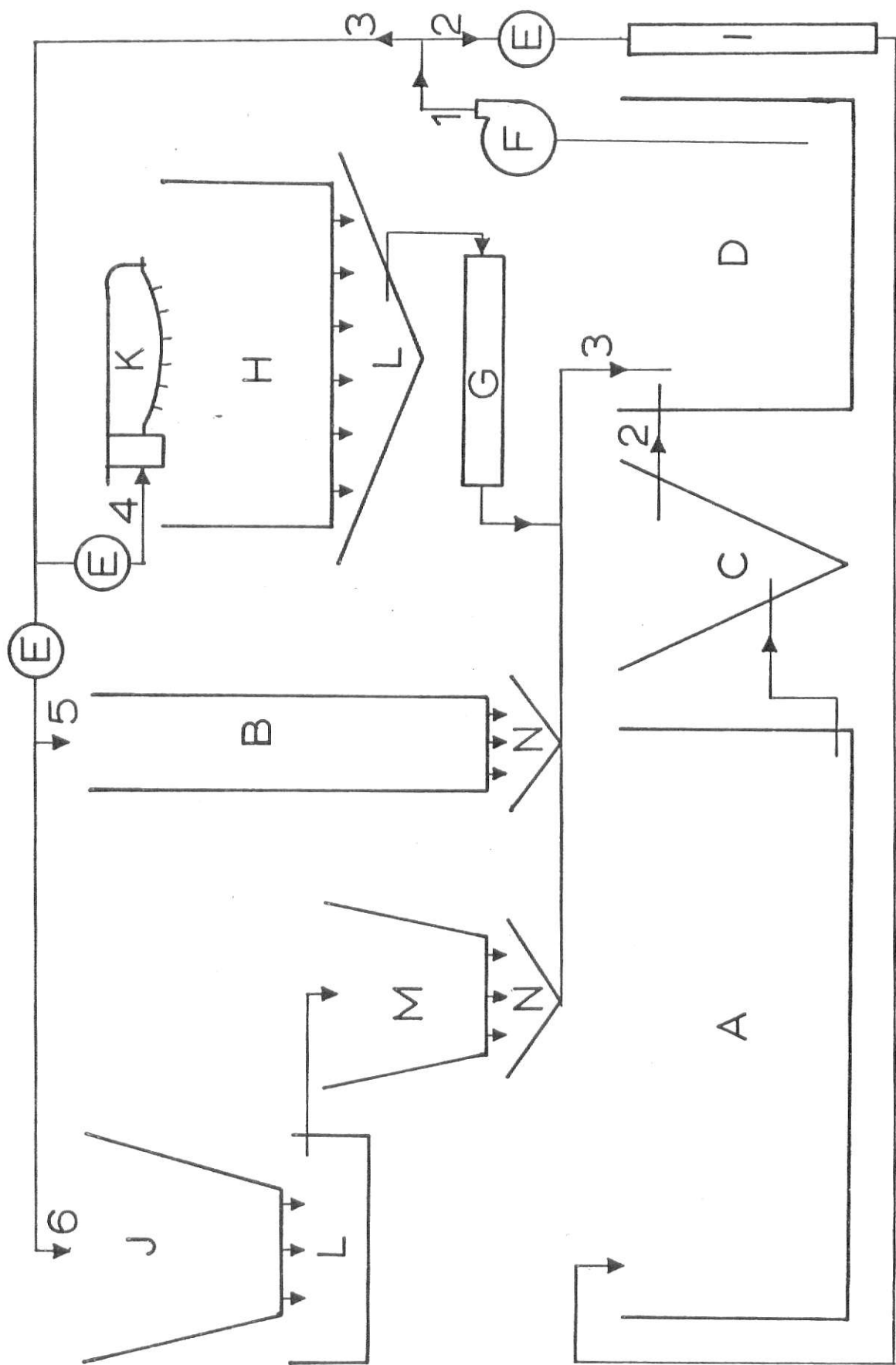
6. 1.4 gallon per minute

Fig. 5. Schematic diagram of experimental closed circulation system for catfish rearing.

body weight per day.

The fish ate well when first placed in the warm water of the experimental system. However, they lost vigor and after several weeks, the mortality rate became severe. Growth of the fish is shown in Table 6. Table 6 indicates a gain of weight on the fish, but it is not representative due to the high mortality which regularly caused the removal of small fish from the tank. Water quality remained suitable throughout the test period and is shown in Table 7.

The fish became reluctant to eat the Z-14 pellets, but appeared quite hungry when fed liver. Pursuing the theory that the food was limiting growth of the fish, different feeds were tried on the fish during the month of January.

On February 20, the fish were sorted. Weak individuals were destroyed and those that remained were divided into two sized groups. One hundred fifty of the larger fish were placed in the south fish tank; 121 of the smaller fish were placed in the north tank.

After reviewing formulas of several fish foods and some experimentation with the fish, a formula was devised which the fish readily accepted. The formula consisted of:

                20 oz. water
                 7 tablespoons Similac powder
               250 gms liver
                 8 oz. fish sticks
                50 gms of 35% protein baby cereal
               550 gms ground Z-14 fish feed
             3 3/4 oz. creamed spinach

The ingredients were blended and squeezed into strips by a caulking gun. The strips were air dried before fed to the fish.

Table 6 . Weight of fish in pounds.

Date	North tank no. of fish	North tank weight of 40 fish	South tank no. of fish	South tank weight of 60 fish
11/24/69	435	.71	600	1.11
12/ 1/69	423	.80	600	1.30
12/ 8/69	422	.86	600	1.25
12/15/69	420	.92	600	1.20
12/22/69	420	.93	580	1.30
1 / 6/70	415	.96	560	1.42

Feed experimentation

Date		Wt. of 25 fish		Wt. of 25 fish
2/20/70	150		121	
2/26/70	150	.83	119	1.37
3/ 6/70	150	.90	117	1.74
3/13/70	147	1.02	115	1.94
3/20/70	147	1.17	115	2.22
3/27/70	146	1.47	114	2.24
4/10/70	145	1.53	114	2.79
4/17/70	145	1.80	114	2.93
4/24/70	145	2.01	113	2.72
5/ 1/70	144	1.84	113	3.20
5/ 8/70	144	2.24	113	3.36

Table 7.   Water quality in ppm and pH.

Date	D.O.	NO_3	CO_2	NH_3	pH
11/ 6/69	7	2.10	16	.47	7.0
11/13/69	5	3.90	40	.79	
11/20/69	4	4.20	24	1.30	7.0
12/ 4/69	4	5.30	12	.95	7.0
12/11/69	4	3.94	24	1.49	
1 / 8/70	4	6.00	30	.50	
1 /15/70	3	6.80	35	.59	7.2
2 / 5/70	8	5.80	40	.54	7.0
2 /12/70	4	10.30	35	.54	
3 /20/70	7		28		6.0
3 /27/70	7	See	30	See	7.0
4 / 6/70	8	Table 8	36	Table 8	7.0
4 /16/70	7		28		6.5
4 /30/70	6		30		6.3
5 / 7/70	6		32		6.8

ILLUSTRATIONS

EXPLANATION OF PLATE II

Fig. 1. 2' deep wastebasket biofilters in background
connected by siphons to the 4 square 1' deep
sand filters. The Hach water testing kit is
shown on the table. Immediately below is the
resevoir tank containing the ultraviolet ir-
radiator.

Fig. 2. 4' deep plexiglass tube biofilter is shown on
the left and the 1' deep biofilter supported
by a collection trough is shown on the right.
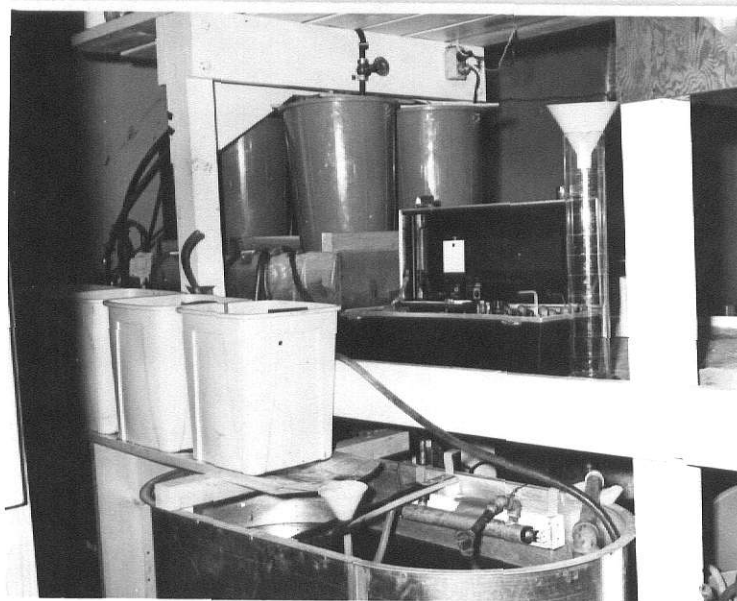
PLATE II

Fig. 1.

Fig. 2.

EXPLANATION OF PLATE III

Fig. 1. Pump with water meters is located
         on floor below table.

Fig. 2. Return line discharging into 250
         gallon stock tanks which housed the
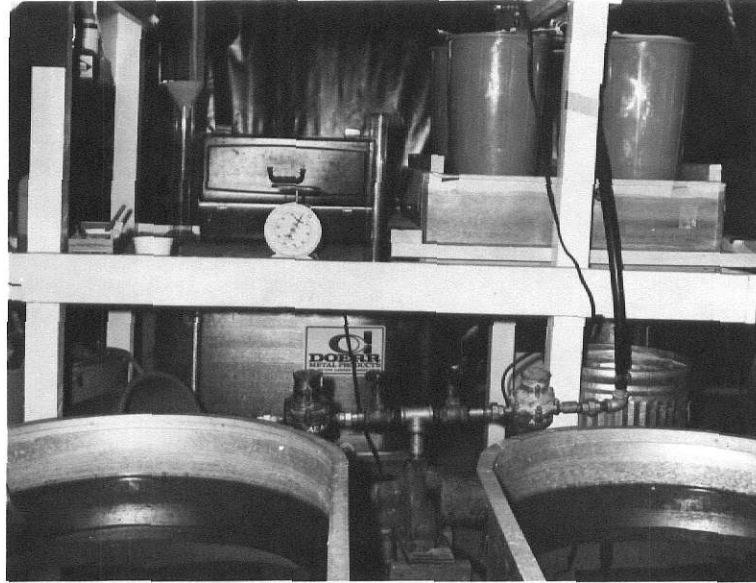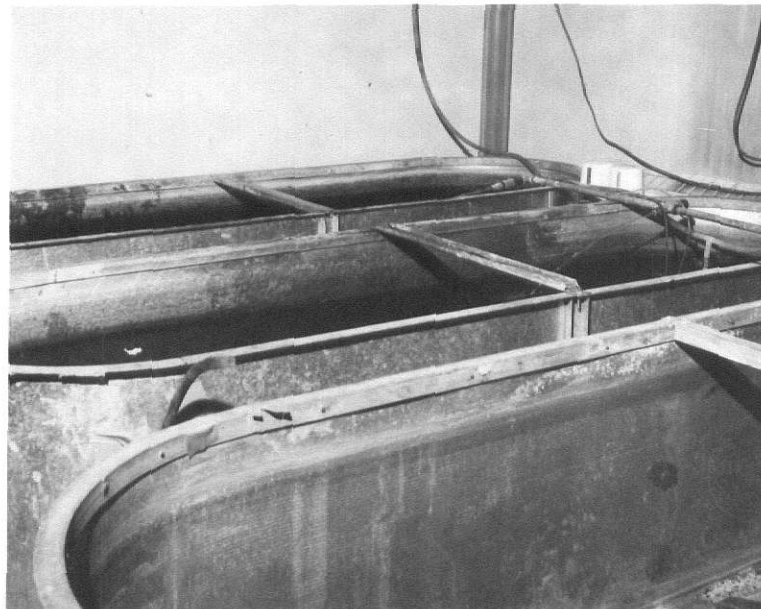   fish.

PLATE III

Fig. 1.

Fig. 2.

RESULTS

Growth rates using the above preparation fed at 3% of body weight per day produced the data shown on the lower half of Table 6. The fish in the second trial attained growth during the 2 1/2 month feeding period approximately equal to the growth experienced in one summer season in a Kansas outdoor pond.

Water quality in the fish tanks determined by weekly tests of dissolved oxygen, nitrates, carbon dioxide, and pH are presented on Table 7. The water quality tests, for the elements measured, produced no evidence of a detrimental condition in the water system. The carbon dioxide content of the water was fairly high (greater than 30 ppm) which could be bordering the limit for good growth. The Hach test kit produced a weak color change for the carbon dioxide test and could be responsible for the high values.

The ammonia and nitrate values remained low as experienced with the first biofilter. The effort to establish which filter was converting the ammonia to nitrates and which filter was denitrifying produced no positive results (Table 8). All filters, according to the data produced from the water testing, do not consistently nitrify or denitrify. The amount of nitrogen transformation that the water incurred in one pass through any of the filters was quite small and probably was beyond the

Table 8. Water quality in system
NITRATES (NO$_3$ as ppm)

Date	Reservoir tank	After sand filters	After 4' deep tube filter	After 1' deep box filter
3/20/70	3.60	3.48	3.95	
3/27/70	3.70	3.80	3.80	
4/ 6/70	3.60	2.90		2.65
4/16/70	3.30	3.70	3.65	
4/30/70	5.70	6.40	5.40	5.20
5/ 7/70	6.10	5.60	5.00	5.40

AMMONIA (NH$_3$ as ppm)

Date	Reservoir tank	After sand filters	After 4' deep tube filter	After 1' deep box filter
3/20/70	.07	0	0	
3/27/70	.29	.20	.20	
4/16/70	.44	.30	.30	.36
4/30/70	.41	.29	.30	.29
5/ 7/70	.27	.07	.02	.09

Table 9. BOD (mg/l) taken at various locations.

Date	Reservoir tank	After sand filters	Diff	After 4' deep tube filter	Diff	After 1' deep box filter	Dif
2/ 5/70	14	11	+3	6	8		
2/12/70	14	10	+4	10	4		
2/20/70	17			14	3		
2/27/70	12			8	4	11	+1
3/ 6/70	14	10	+4	12	2	12	+2
3/13/70	16	13	+3	9	7	15	+1
3/20/70	14	5	+9	18	-4		
3/27/70	16	6	+10				
4/ 9/70	16	16	+0	6	10		
4/23/70	18	2	+16	12	6	14	+4
Average Diff. from fish tank BOD		6.1		5.0		2.0	

accuracy of the testing equipment used.

The BOD measurements were fairly consistent (Table 9). The passage of the water through the 2' of rock followed by sand filtration provided the greatest reduction of BOD (6.1 mg/l) as compared to the level of BOD in the fish tanks. The next greatest reduction of BOD (5.0 mg/l) occurred after percolation through the 4' tube filter while the shallow 1' depth box filter averaged a reduction of 2.0 mg/l. The sand filters removed a high percentage of BOD while the filter was attaining a stable bacterial population. However, it soon became a trap for bacterial masses. Bacterial growth plugged the sand filters about every two weeks and they would have to be stirred or the top 3" of sand would have to be removed, washed, and replaced.

On the other hand, the 1/2" rock in the other two filters had large enough voids to allow bacterial masses to be washed downward through the biofilter which made the biofilter continually self-cleaning.

The solid wastes from the fish tanks were effectively settled in the sedimentation tank. About 1/3 gallon of settled solids were siphoned from the sedimentation tank daily. Suspended solids were usually low enough in the fish tanks that the fish could be seen on the bottom. Some sediments accumulated in the ends of the south tank and were occasionally removed.

CONCLUSIONS

Channel catfish are becoming a commercial source of food.

As with other commercial animals such as chickens, cattle, and hogs, the channel catfish excrete waste products. However, the channel catfish is inherently different in the respect that it has to use the same fluid medium (water) for waste treatment as well as an exchange medium for oxygen and carbon dioxide. Therefore, the medium in which the channel catfish lives must not become too heavily loaded with pollution from the fish itself or the gaseous exchange of the gills will be impaired to such an extent that the fish will die.

As was related in the literature review, production of channel catfish from a well managed acre of water is limited from 1500 to 2000 pounds per acre regardless of the size and number of the fish. One hypothesis to explain this limitation states that the treatment of the fish wastes by the natural ponds limits the poundage production of fish. It is interesting to utilize the results in this thesis concerning BOD production of channel catfish to investigate this hypothesis. Assuming the fish pond to be quite similar to an aerobic lagoon used by sanitary engineers to treat dilute wastes, such a lagoon designed to carry an average oxygen content capable of supporting fish life would be loaded at a rate of about 10 to 20 pounds of BOD per acre per day (36). A fish pond stocked at the generally recommended upper limit of 2000 pounds of catfish per acre would receive from the fish a waste loading of 9.8 pounds BOD per acre per day (according to calculations using the figure of .0049 pounds BOD per pound of fish per day from the results

of the BOD production of channel catfish). Thus, the BOD the pond would receive from the fed catfish is approximately the amount of BOD that the pond could effectively treat. This fact lends additional support to the hypothesis that nature's ability to recondition pond water is the factor limiting production of fish in ponds.

Bacteria treatment of fish wastes occurs naturally in fish ponds. The biofilter mentioned in this thesis is one method of compacting bacteria to process a large amount of waste. The basic idea of using the biofilter appears quite sound.

The 1/2" rock was the best filter material. It furnishes a low labor, low cost, self cleaning method of treating soluble fish wastes. Suggested design criteria for a biofilter would be as follows: 4 feet deep filled with 1/2" rock with a hydraulic load of 3 gallons/minute/square foot; at this hydraulic loading, 2 square feet of filter area is needed to support 50 pounds of fish.

The silicon controlled rectifier unit, which controlled voltage to the electric heater element, did an excellent job of regulating the water temperature. The water temperature was maintained within 2°C of the desired 27°C temperature.

No positive opinion was developed regarding the ultraviolet irradiation. However, no losses of the fish were specifically traced to a disease problem.

The biofilter shows excellent promise for the rearing of fish indoors. This is especially important in Kansas when

naturally heated water at a temperature suitable for fish growth is available only 4 months of a year. The ability of the biofilter to recondition water is attractive to indoor, winter time fish culture in that large amounts of heated fresh water do not have to be added to the system. The most immediate possibility for utilization of the biofilter appears to be in the area of rearing fry hatched from eggs spawned ahead of the normal spawning time. The fry could be grown in a biofilter unit until the fish could be transported to outdoor ponds when the temperature becomes suitable. By growing the earlier portion of the catfish's life in a controlled environment using a biofilter, Kansas should be able to produce a marketable sized fish in two years. Further experimentation could lead to a fish culture system in which spawning, hatching, rearing, and marketing of channel catfish would occur totally indoors under controlled environments.

SUGGESTIONS FOR FUTURE RESEARCH

In an exploratory research effort of this kind, the suggestions for future research for both the basic biofilter system and its applications could be many. Therefore, suggestions for future research will be limited to the basic system.

The nutrition knowledge of fish fed in closed recirculation systems is in its infancy. In recirculation systems the fish do not have access to possible normal food sources such as

algae or pond bottoms. Further work needs to be done to find a suitable diet. The catfish has a highly developed sense of smell and feed that his senses find attractive receives immediate attention. The use of a food that contains meat protein such as liver shows promise of acceptance. Feeding rates and time of feeding could also be investigated.

Further work needs to be done in the area of overall design. A method of continual removal and isolation of solids should be investigated. The less contact the solids have with the water, the less load will be placed on the biofilter resulting in better water quality. The design of the fish tanks could be studied to produce an optimum shaped tank that would be self cleaning and would influence the fish to be less sensitive and less reactive to occurances outside the tank. The biofilters themselves could be studied to survey the organisms present and to investigate inoculation of new organisms as possible food sources. The system once defined would need to be designed for the greatest utilization of space and to make the most effecient use of the energy involved.

Disease control will always be a problem as it is in other animal confinement systems. Pre-treatment procedures and methods of keeping the system disease free should be considered. Ultra-violet irradiation would be quite adaptable to the system if it were proven to be of benefit.

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INVESTIGATION OF THE BIOFILTER
FOR INDOOR CULTURE OF CHANNEL CATFISH

by

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ABSTRACT

Preliminary experimental studies dealing with channel cat-
fish in confinement were conducted to determine the food require-
ments of small fish. Four food sources were investigated: algae,
liver paste, powdered commercial feed, and plankton. The liver
paste proved the most feasible. Investigation of the water
quality during the food trials related a build up of carbon
dioxide and ammonia.

A small biofilter was loaded with fish wastes and proved
to be effective in reducing the carbon dioxide and ammonia levels.
The biofilter was also effective in reducing nitrates in the
system.

A technical paper was prepared from the measuring of the
BOD production of channel catfish. Two mature channel catfish
were hand fed in a temperature controlled tank with an accurate-
ly measured water dilution rate. BOD of solid and soluble wastes
was measured as well as DO, CO_2, NH_3, and pH. BOD of the
wastes, on a per pound live weight basis, was approximately 50%
greater than reported values for chickens and swine and five
times the reported values for beef cattle. Pollution implication
of intensive methods of catfish culture are discussed.

A pilot scale recirculating biofilter system was built to
rear fingerlings. Three types of biofilters were investigated;
one foot depth, four foot depth, and two foot depth followed by

sand filtration. The four foot depth proved the most desirable.
Nutrition problems were experienced. Using a supplemented
formula, good growth was obtained on the fingerlings. Water
quality measurements were taken on the biofilter systems.