SECOND ANNUAL WORKSHOP:

COMMERCIAL AQUACULTURE USING WATER RECIRCULATING SYSTEMS

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SECOND ANNUAL WORKSHOP: COMMERCIAL AQUACULTURE USING WATER RECIRCULATING SYSTEMS
LaDon Swann, Editor

Second Annual Workshop On: Commercial Aquaculture Using Water Recirculating Systems

November 15-16, 1991

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Sponsored by:
Illinois State University
Illinois-Indiana Sea Grant Program
and the North Central Regional Aquaculture Center

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Illinois State University

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Illinois-Indiana Sea Grant Program
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Ms. Jean Reipe, Purdue University

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Welcome

R. D. Henry
Illinois State University
Normal, Illinois

On behalf of Illinois State University Department of Agriculture, Illinois-Indiana Sea Grant Program and the North Central Regional Aquaculture Center, I would like to welcome each of you to the *Second Annual Workshop on Commercial Aquaculture Using Recirculating Systems*. During the next two days we will do everything we can to make your stay at Illinois State University as educational and enjoyable as possible.

Illinois State University and the Illinois Indiana Sea Grant Program sponsored a similar workshop last year. A lot has happened at Illinois State since then. The ISU aquaculture program has received two major grants which will allow the program to expand. The objective of the expanded program will remain the same, that is to ascertain the economic feasibility of commercial recirculating systems.

This year's workshop promises to be bigger and better than last year's workshop. The lineup of speakers is very impressive with nine universities, one state agency and one private business represented. Each speaker has taken the time to prepare a written copy of their presentation in advance so that you can have the proceedings which you received during registration. Take the time to introduce yourself to our speakers and ask questions of them.

In addition to hearing excellent presentations on various aspects of recirculating systems, there is a small but thorough trade show offering you a chance to visit several of the largest aquaculture equipment suppliers in the U.S. Refreshments for one of our breaks were provided by Bio-Products, Inc. Each sponsor has made a commitment to aquaculture and we are very appreciative for their help in sponsoring this workshop.

Tomorrow afternoon we will tour Illinois State University's recirculating facility. During this tour, you will have a chance to see various commercial recirculating systems operating. Many of the concepts presented today and tomorrow morning will be in operation at the facility. Ask as many questions as you like during the tour.

Finally, keep in mind that this workshop is yours. There are some excellent resources here for you. Use them to their fullest so that you can increase your knowledge of recirculating systems.

Behavior and Physiology of Nitrifying Bacteria

James E. Alleman, Ph.D. and Kurt Preston
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Purdue University
West Lafayette, Indiana

Background

Hidden literally in the shadows of every successful aquaculture operation lies a reclusive bacterial clan whose lifestyle spans the extremes of bizarre and beautiful. Few humans will ever see these magnificent creatures, miniature residents of life's trailing edge, yet without their help your fish would be downright miserable if not altogether lifeless.

The group, collectively known as nitrifiers, actually includes two discrete microbial partners tied faithfully to a life of biochemical harmony. Together, they play a critical role in every earthly ecosystem, both aquatic and soil, scavenging potentially toxic nitrogen compounds from their surroundings, including: ammonia (NH_3) and nitrite (NO_2^-). Linked in `bucket-brigade' fashion, this nitrifying family successively transforms these nitrogenous chemicals through a delicate set of biochemical oxidations, eventually producing a soluble nitrate (NO_3^-) end-product.

Given their subtle and minute nature, the role of nitrifying bacteria in these reactions escaped detection until late in the nineteenth century. However, mankind had long been fascinated with nitrifications's mineralized crystalline product (i.e., nitre or saltpeter). Over a period extending nearly two millenia, ancient philosophers, alchemical wizards, and modern chemists alike tried desperately to find this enigmatic crystal's true source, driven largely by the explosive discovery of gunpowder.

Oblivious to nitre's bacterial origin, let alone its true composition, this potent crystal seemingly coalesced from unseen atmospheric spirits, an earthly offspring magically impregnated with nature's thunderous `menstruum.' In fact, nitrogen's own name (a.k.a. nitre-genesis) bears witness to this original hypothesis, forever perpetuating the quaint legacy of nitre's supposed aerial origin.

Our current understanding of these bacteria has improved considerably, though, over the past century. Shortly after discovering its biochemical source, researchers identified two separate bacterial companions responsible for nitrification. Each partner critically depends on the other, and each finds nourishment in seemingly barren substrates. Both of these bacteria qualify as lithotrophic microbes (translated from Greek, `*rock eaters*'), feeding on chemicals which no other bacteria would possibly use as their primary energy source.

Aside from this particularly spartan diet, using chemicals often regarded as potential toxins, their intermediate and final products are similarly unusual. Perhaps most notably, the lead organism actually makes, and then reingests, a dangerous mutagenic substance (hydroxylamine, NH_2OH) whose noxious character hardly seems commensurate with normally healthy metabolic activity.

Based on our overall perception of its unusual lifestyle, therefore, the conventional wisdom for nitrifiers provided in most textbooks describes a fragile, highly sensitive life form. However, evidence collected over the past few years strongly refutes this image. In fact, recent discoveries about these unusual microorganisms suggest a far different behavior, as robust, metabolically agile microorganisms.

This article will consequently explore our current knowledge of nitrifying bacteria, detailing their metabolic behavior, qualifying their environmental likes and dislikes, and highlighting recent insights on their unique lifestyle. In addition, a set of recommended guidelines will be provided to enhance and promote their successful use within aquaculture systems.

Nitrifier Physiology

Bacterial Groupings and Genetics

The nitrifying bacterial clan includes two distinctly different subsets, based on their consumption of either ammonia or nitrite. Table 1 provides a breakdown of these affiliated bacterial genus and species members, covering a total of eight separate nitrifying bacteria, including: five species of ammonia-oxidizers (often called `*nitritifiers*'), and three nitrite-oxidizers ( `*nitratifiers*').

TABLE 1. Taxonomy of Nitrifying Bacteria

```
Taxonomic              Preferred Environs        Motility Potential
  Group              Fresh    Saline   Soil       Motile     Non-Motile
                  Water    Water   and Mud
-------------------------------------------------------------------------
 Nitritifiers
Nitrosomonas europaea     *              *          *          *
Nitrospira briensis     *              *          *          *
Nitrosococcus nitrosus                 *          *          *
Nitrosococcus oceanus            *                *          *
Nitrosolobus multiformis  *                      *
-------------------------------------------------------------------------
 Nitratifiers
Nitrobacter winogradsky   *        *       *       possibly in    *
                                           continuous
                                            culture
Nitrospina gracilis              *                          *
Nitrococcus mobilis                *                 *
-------------------------------------------------------------------------
```

Ironically, studies recently completed (Wood 1986) on the genetic makeup of these respective subsets do not show strong evidence of a common genetic structure between these '*nitritifier*' and '*nitratifier*' subsets. Accordingly, each appears to have evolved from a distinctly different ancestral lineage.

On the other hand, the ammonia-oxidizing '*nitritifier*' actually appear to have much more in common with an aerobic heterotrophic (i.e., organisms who subsist on organic carbon) bacteria with a similarly fastidious diet, methane. This latter group is generically referred to as methanotrophs (i.e., methane oxidizers). Their metabolic correlation has been reinforced with five supporting observations: 1) similarities in the structure of their genetic coding (i.e., DNA composition), 2) similarities in their substrate-oxidizing *monooxygenase* enzymes, 3) similarities in the structure of their cell membranes, each being extensively intruded or corrugated, 4) apparent similarities in their desired substrate forms (e.g., both consuming unionized forms having molecular weights of either 16 or 17),and 5) the fact that `*nitritifiers*' can co-metabolize the methanotroph's substrate, methane.

General Metabolic Pathway

After a full century of intensive study, modern microbiologists still do not fully understand just how the nitrification sequence first begins. Specifically, there is lingering confusion over the `*nitritifiers*' initial substrate form.

Most textbooks indicate that nitrification starts from ionized ammonium- nitrogen, NH_4^+-N. Suzuki's (Suzuki, et al., 1974) work, however,strongly suggested that the lead `*nitritifying*' organism used unionized ammonia, $NH_3$, in a gaseous state, based on an analysis of the organism's response to elevated substrate levels. Furthermore, this behavior appears consistent with its genetic `methanotrophic' cousin, who similarly ingest gaseous methane.

Assuming that ammonia is, in fact, the starting point, Figure 1 provides a complete overview of the currently accepted nitrogen transitions through a normal nitrification sequence, covering both ammonia and nitrite oxidizers. These biochemical reactions are all respirative, with oxygen used by the organisms as a sink for electrons drawn from their reduced nitrogen substrates.

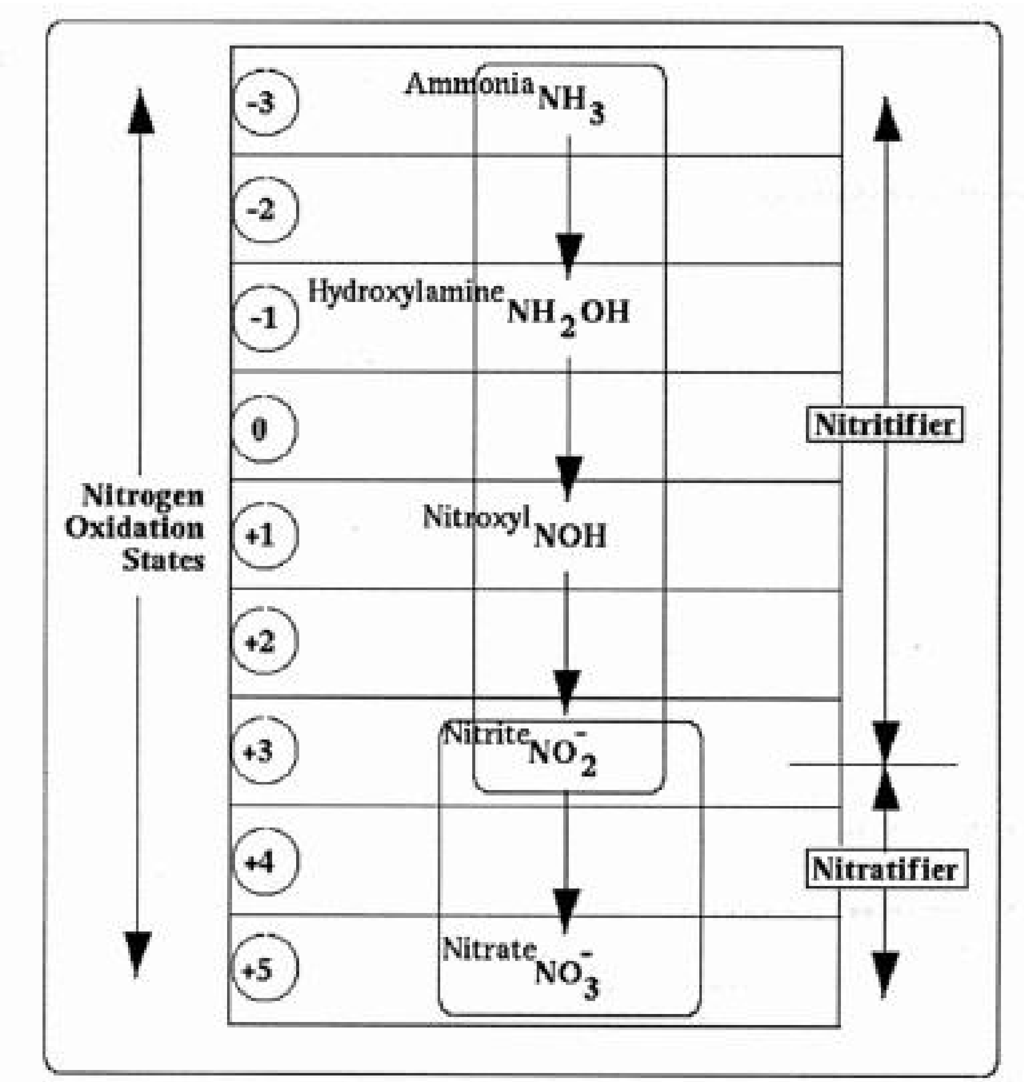

Figure 1. Conventional Nitrification Pathway

Admittedly, though, the chemical intermediates found along this sequence seldom appear at measurable or significant levels. For example, intermediate nitrite levels rarely reach the milligram per liter range (Alleman, 1985). In turn, the entire process could usually be considered a single-step jump, from NH_3 to NO_3^-.

Under certain conditions, however, it is conceivable that the complete nitrification reaction could become disrupted, with elevated levels developing for one or more of the intermediates. A variety of stress conditions might promote this type of disruption, including oxygen deprivation or toxin presence. These factors, and their resultant impacts, will be discussed in subsequent sections of this paper.

Nitrifier Growth

Nitrifiers and heterotrophs maintain distinctly different growth and substrate uptake patterns. As with all bacteria, their kinetic rates depend on substrate availability. At maximal activity levels, both are able to consume several times their body weight in substrates each day. Nitrifiers, though, convert far less of their consumed substrate into new cell mass. The latter characteristic is quantified on the basis of cellular yield, which for nitrifiers is considerably less than that of heterotrophs.

Table 2 provides an overview of the generally accepted kinetic coefficients for each of these groups, including: `*nitritifiers*', `*nitratifiers*', and heterotrophs.

TABLE 2. Kinetic Characteristics of Nitrifying versus Heterotrophic Bacteria. (see *Sharma and Ahlert, 1977* and Gee et al., 1990)

Bacterial Group	Specific Substrate Uptake (mg/mg-cells-day)	Specific Growth (mg/mg-cells-day)	Yield Constant (mg/mg)	Saturation (mg/L)
Nitritifiers	6-->20	0.5-->2.0	0.05-->0.08	1
Nitratifiers	10-->40	0.2-->1.0	0.02-->0.05	1
Heterotrophs	20-->30	10-->15	0.4-->0.5	75-->125

Another important characteristic is that nitrifiers are able to shift into their maximal activity range at a distinctly lower substrate concentration (i.e., at approximately one percent the concentration required by heterotrophs). For nitrifiers, this characteristic might be considered analogous to a `*light switch*' phenomenon, working either full-on or full-off, without much of a metabolic intermediate.

Nitrifier Movement and Adhesion

Many of the nitrifying bacteria use whip-like flagella to propel themselves through water, akin to an oar which drives a Venetian gondola. However, the environmental engineering literature often suggests that nitrifiers prefer a sedentary, stationary existence, attached to a solid surface rather than freely swimming. In fact, nitrifying reactor systems inherently rely on this adhesive preference. Nitrifiers could only be retained inside process reactors when attached either to a surface biofilm or as part of settleable activated sludge floc.

For most bacteria (i.e., heterotrophs), attachment stems from their exterior coating with a sticky, exocellular polysaccharide, typically referred to as `slime.' However, in the case of nitrifiers, we simply do not know if they have this sort of adhesive coat.

Recent observations, though, strongly suggest that their attachment does not involve this sort of surface slime. Indeed, nitrifiers attached to one another in dense clusters have been seen to rapidly detach in pursuit of a free-swimming migration. If slime had been the agent for attachment, it is quite unlikely that these organisms could have mustered enough energy to pull away nearly so quickly, if at all.

Aside from the inherent mechanism for attachment, another uncertainty exists as to the rationale behind their personal preference for one mode over another, either free-swimming or attached. Unstressed nitrifiers apparently prefer a free-swimming lifestyle, perhaps endowed with sufficient energy to pursue the luxury of independent locomotion (Hyman, 1991). As environmental stress (e.g., abnormal environmental conditions, lack of substrate availability, predator interaction, etc.) develops, though, nitrifiers may elect to conserve their energy by limiting movement.

These `stress' conditions assuredly exist within nitrifying process reactors, involving reduced substrate presence, sub-optimal environments, and routine predation by higher life forms. In fact, the success of these reactors probably depends on this stress and the nitrifier's resultant shift toward surface attachment, as it is the only means by which an otherwise inevitable loss of free-swimming nitrifiers can be avoided.

Nitrifier Death and Decay

Bacterial decay and death during prolonged resting or inactive periods occurs due to the natural onset of entropy. Aerobic bacteria may attempt to retard and prolong this tendency toward disorder through a process known as endogenous respiration, whereby a nominal energy flow is secured for limited maintenance purposes. This energy provides for resynthesis of critical metabolic material, as well as facilitating such activities as transport, motility, and pressure and heat control.

Our best estimate for the collective impacts of decay, endogenous metabolism, death, and predation on nitrifiers presently ranges from 0.05 to 0.12 $days_{-1}$. Correspondingly, these rates imply that resting, non-active nitrifiers will deteriorate at rates of 5 to 12% per day.

However, these values were typically inferred from heterotrophic bacteria rather than specifically measured for nitrifiers. Hence, conclusive data to clarify our understanding of nitrification-related decay and death is lacking.

Cell decay should certainly be expected with these organisms, but it is questionable whether their physiology would yield endogenous respiration activity during substrate-limited periods in a fashion comparable to that associated with heterotrophs. Indeed, energy procurement for these resting nitrifiers would probably depend more so upon external substrate availability than the mobilization and uptake of nitrogenous substrates found inside these cells. Resting nitrifying bacteria might consequently be expected to decay at a far lower pace than that which would be expected for heterotrophs. Correspondingly,indications within our contemporary literature that nitrifiers decay at a rate comparable to that of heterotrophs appear to be erroneous. In fact, unpublished values appear to be considerably lower (at about 0.01 to 0.02 $days^{-1}$; Alleman, et al., 1991).

Slow decay and death rates for nitrifiers should, however, be considered a positive attribute. They can be shifted (e.g., taken off-line) into a dormant or resting state for extended periods with less concern about retaining their viability.

Nitrifier Behavior

Oxygen Tension

Nitrifiers need oxygen for normal metabolism. Every milligram of nitrogen passed through their full nitrification pathway (starting at ammonia and concluding at nitrate) requires approximately 4.5 mg of dissolved oxygen to scavenge electrons drawn from their nitrogenous substrates.

Should the available dissolved oxygen drop much below a few milligrams per liter, though, nitrifier metabolism will markedly slow down. However, even without access to any oxygen whatsoever, they can sustain some measure of respirative metabolism using nitrate or nitrite as an alternative electron acceptor (i.e. in lieu of oxygen). In short, they can, if necessary, both nitrify and denitrify, an incredible biochemical feat somewhat analogous to having their cake and eating it too.

Although both nitrifying bacteria appear to have this denitrifying capability, the biochemical balance between nitritifiers' and `*nitratifiers*' may, itself, become disrupted by oxygen deprivation. Specifically, `*nitritifiers*' exposed to low oxygen conditions seemingly generate higher levels of intermediate hydroxylamine. In turn, the presence of this chemical will disrupt, and possibly terminate, the activity of their companion `*nitratifiers*,' resulting in a short-circuiting of the normal nitrification sequence.

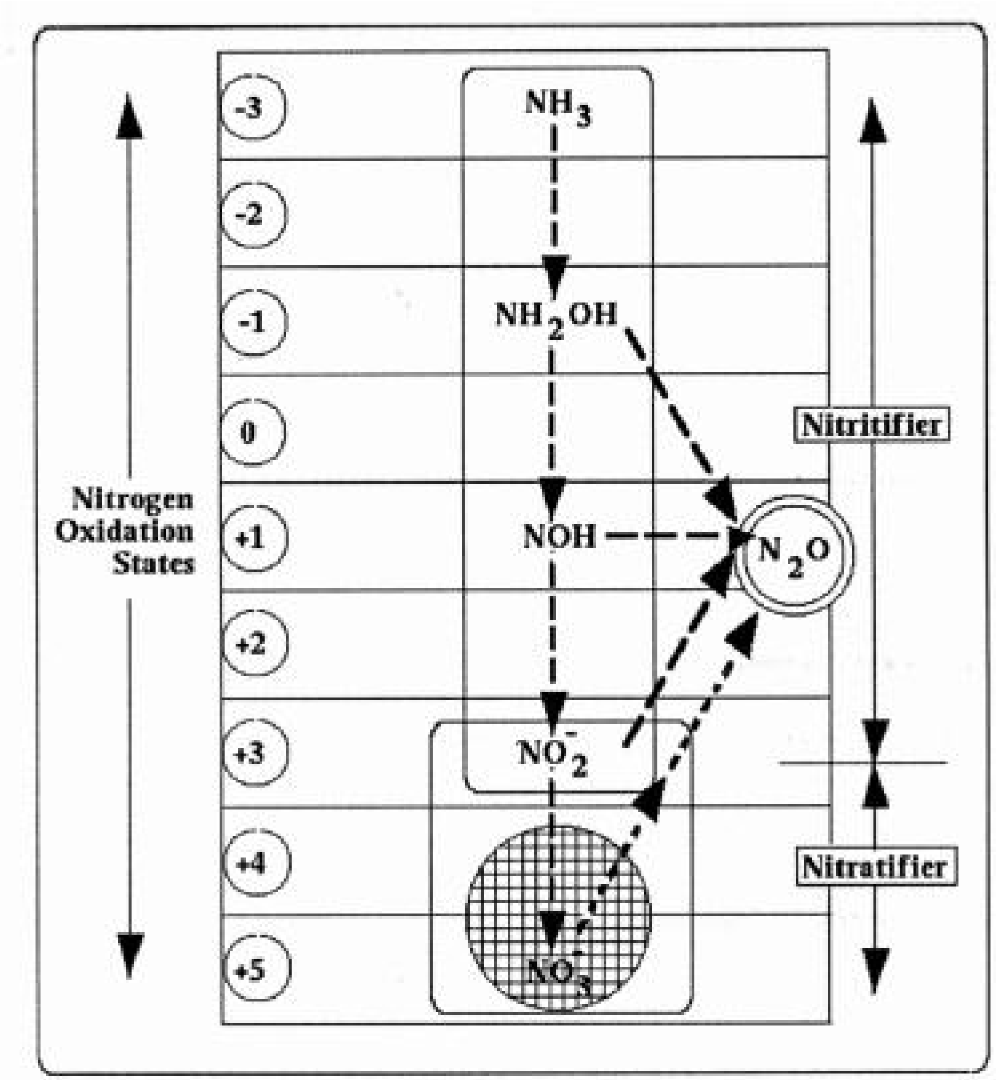

Figure 2. Nitrifier `Denitrification' Pathway

Having only discovered this denitrification capability within the last few years, our awareness and understanding of the nitrifier's denitrification capability is frankly tenuous. At this point, it appears that nitrifier denitrification often falls short of complete nitrate or nitrite reduction to dinitrogen gas. Instead, their `denitrification' behavior seemingly generates a gaseous nitrous oxide product, which in turn might well represent an important contributor to the greenhouse phenomenon.

pH and Alkalinity

Nitrifying bacteria prefer an alkaline environs, with optimal pH levels ranging from the mid-seven's to mid-eight's. For `*nitritifiers*,' their apparent preference for the high end of this range seemingly reinforces the hypothesis of their initial NH_3-N substrate form.

Aside from the ambient pH itself, nitrifiers appear able to handle rather sizable dynamic transients in this parameter. However, after acclimation, it would be best for their activity if the pH were kept as consistent as possible. Concerns expressed over alkalinity stem principally from its correlation and impact on system pH. Alkalinity levels adequate to stop pH from dropping below the preferred alkaline range should be adequate.

Temperature

Nitrifiers prefer moderate temperatures, ranging from 20 to 30°C. As temperature declines into the teens, their metabolic activity will decline. At temperature levels above 35°C, however, they enter a region of potential life-threatening stress, perhaps due to enzyme disruption. `*Nitratifiers*' specifically have an upper threshold of about 40°C, at which point their activity completely stops, while the permissible upper threshold for `*nitritifiers*' appears to be approximately 5°C higher. In either case, attention should be given to stabilizing reactor temperature, relative to avoiding extremes and short-term transients.

Salt Osmotic Pressure

Nitrifiers have a sizable range of tolerable osmotic pressures, ranging from fresh to saline, depending on the particular genus form. Furthermore, many nitrifiers seem able to rapidly switch from one salt level to another with little impact on their activity. Within most nitrifying reactor systems, however, it is likely that they will become acclimated to an osmotic pressure which varies relatively little over time, even given the dynamics associated with makeup water addition. In turn, this parameter should not represent a particularly important concern.

Light

Ammonia-oxidizing `*nitritifiers*' are sensitive to a region of the light spectrum known as near-shoulder' ultraviolet (Alleman, 1987). The exact cause of this negative impact is unknown, but may have some relationship with a superoxide radical produced in conjunction with stagnant membrane oxygen. For those `*nitritifiers*' affected by light, though, darkfield repair is possible, during which these bacteria rehabilitate over a period of hours in the presence of an available energy producing substrate.

Inhibitors

The technical literature for nitrifiers has extensive references to the impact of specific chemicals on their efficacy, including, for example: thiourea, allythiourea, acetylene, N-Serve (Dow Chemical Corporation), heavy metals, metal chelators or binders (particularly those of copper), carbon disulfide, free ammonia, and free nitrous acid. Individuals interested in further details regarding this impacts should refer to the following citations: Blum and Speece (1991), Doster (1988), Pantea-Kiser (1987), and Sharma and Ahlert (1977).

Co-Metabolism Capabilities

As mentioned earlier, the `*nitritifiers*' employ an initial enzyme known as `*ammonia monooxygenase*' (AMO) which bears a surprising similarity to the methanotroph's `methane monooxygenase' (MMO). The importance behind this match stems from the fact that MMO is able to catalyze the oxidative breakdown of several hydrocarbons, including halogenated versions thereof.

Remarkably, recent studies of the AMO-bearing `*nitritifiers*' have shown that they too have this sort of ability, acting along a co-metabolism route in which their AMO becomes expended on an alternative substrate other than its intended ammonia form (Rasche, et al, 1990; and Hyman, et al., 1988).

In turn, `*nitritifiers*' may well have the ability to degrade industrial and hazardous wastes, at least to some extent. Unpublished estimates of this activity suggest that `*nitritifiers*' might be capable of degrading as much as one-tenth the weight of their daily nitrogen uptake in the form of co-metabolized hydrocarbons (Hyman, 1991).

Admittedly, aquaculture systems will not likely encounter or rely on this unusual capability. However, here again the recently derived insights on nitrifier behavior suggest that they are far more complex and robust that what they are usually given credit for.

Promotion of Nitrifier Performance

Reactor Scheme

An attached growth approach to nurturing nitrifier growth and retention would be recommended for aquaculture systems, in lieu of a suspended growth strategy. Stationary plastic packing material (nested sheets, random beads or saddles, etc.) represents a attractive media form, low in weight, high in specific surface area (e.g.,~ 30 ft^2 per ft^3 for many commercially-available media types), and chemically inert. Another option would be to use moving plastic media, such as rotating sheets or fluidized sand. Whatever the approach, attached cells can be retained in the reactor without having to deal with settling and recycle complications. This reactor configuration would be less prone to upset by hydraulic surges. However, the media must be consistently wetted to avoid spalling of dried biofilm. Furthermore, it would be highly recommended that some portion of this attached growth media be easily removable from the reactor to allow for visual inspection of the media and qualification of its related characteristics (e.g., film depth, film smell, etc.).

Reactor Operation

The principal operating parameter for these nitrifying units will be hydraulic loading. Unfortunately, recommended values vary considerably depending on media type. Working strictly on a `grass-roots' basis, though, one to two cubic foot of media could initially be used per 100 gal of tank volume, with a hydraulic loading rate of approximately one gallon per minute per square foot of cross-sectional media surface area.

Ammonia-Nitrogen

Routine measurements should be made of the total NH_4^+ +NH_3-N concentration in the bulk fluid. Simple `eye-ball' colorimetric analysis using Nesslers reagent (*Standard Methods*, 1975) would be adequate, with a desired result either having no color at all or a very, very faint yellow. Ideally, the bulk concentration should be consistently below 0.1 to 0.2 mg N/L; a pale yellow color on the Nesslers test would indicate an unacceptably high ammonia-nitrogen level, in the ~ 1 mg N/L range.

Nitrite-Nitrogen

Routine measurements should be made of the NO_2^--N concentrations in the bulk fluid. Hach Chemical Company markets a convenient reagent `pillow' (*NitriVer*) which can be used for this test. Ideally, very little, if any, nitrite should be found in these systems. Elevated nitrite levels (above a 0.1 mg N/L concentration) will signal a metabolic upset within the full nitrification sequence.

Nitrate-Nitrogen

Here again, routine measurements should be made of the NO_3^--N concentrations in the bulk fluid. Hach Chemical Company also sells reagent `pillows' (*NitraVer*) for nitrate. Nitrate will be expected to build up in the tanks, although diluted relative to the addition of dilution and makeup water.

Temperature

Reactor temperature should be routinely monitored; values of ~ 20 --> 30°C are satisfactory. However, temperatures above 35°C must be avoided, as this level begins to approach a region of fatal stress for the `*nitratifier*.'

pH

The pH level should be routinely monitored. Slightly alkaline values are preferable, within a desired range of ~ 7.5 to 8.2. pH levels above 9.0 to 9.5, or below 6, must be avoided since either extreme may harm the nitrifiers.

Alkalinity

Alkalinity levels may be infrequently checked as a complement to the aforementioned pH measurements. Bicarbonate alkalinity levels of ~ 100 to 200 mg as $CaCO_3$/L should be adequate.

Light Exposure

Ideally, the nitrifiers should neither be exposed to sunlight or room light of a color other than red (e.g., darkroom lighting). When grown as an attached biofilm, though, considerable shading provided by bacterial layering will shelter the lower organisms from stressful light. Hence, this recommendation against light exposure is somewhat conservative.

Oxygen Tension

The dissolved oxygen of water leaving the nitrification system should be routinely measured, and kept above 2 to 3 mg/L. Assumedly, the dissolved oxygen in the fish tanks will be much higher, and with reduced loading levels on the attached nitrifying bacteria, oxygen depletion should not be much of a concern.

Biofilm Color

Nitrifying biofilms (on media occasionally drawn from the nitrifying reactor) will tend to have a brown to orange-brown color, which intensifies into a reddish brown as the fraction of nitrifiers increases. Dark brown or blackish colors will denote problems with films that are deficient in oxygen or simply too thick.

Biofilm Depth

Thick films (on media occasionally taken from the nitrifying reactor) much beyond a few millimeters will signify impending problems, particularly if the lower strata of the film appears dark black.

Biofilm Smell

The biofilm should smell earth and musty, much like the bottom gravel found in a home aquarium. Sour or disagreeable smells, in particular, are tell-tale indicators of sub-optimal environmental conditions (i.e., probably septic).

Biofilm Microscopy

If a microscope is readily available, routine visual inspections of the nitrifying biofilm would be recommended. Admittedly, it will be hard to pick out the nitrifiers. Instead, one should look for nuisance organisms which signify less than optimal environmental conditions inside the film. Filamentous bacteria, such as gliding *Beggiatoa*, are a prime example, as they tend to grow in low dissolved oxygen conditions unfavorable to the nitrifiers. Good films will normally include a diverse population of bacteria and higher life forms; in fact, it is likely that the nitrifiers will be far outnumbered within these mixed cultures.

Summary

Ammonia toxicity to fish contained within aquaculture systems can be reliably alleviated with biological nitrification, whereby excreted ammonia is successively oxidized to nitrite and nitrate. Given sufficient space and time, these nitrifiers can routinely scavenge ammonia from a recirculating flow passed over their attached media habitat. However, these microorganism have certain environmental preferences which must be routinely satisfied, including: elevated dissolved oxygen, neutral to slightly alkaline pH, and moderate temperature. Attention must also be given to their interaction with other bacteria, and specifically those who thrive on residual organic matter. These latter microbes can overwhelm the slower growing nitrifiers, overcrowding their niche and stifling their metabolism. These problems, however, can be minimized by providing additional media able to accommodate both groups by spreading their population over a greater, and effectively more viable, surface area.

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Biological Filtration: Design and Operation

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There is considerable confusion concerning the term biological filtration, because it can mean different things to different people. Biological filtration will be used in this paper to mean the process by which ammonia is first converted to nitrite and then to nitrate. This process is also called nitrification. Other papers given at this workshop cover the microbiology of the nitrifying bacteria. Hence, this paper will concentrate on filter design considerations. It should also be noted that anyone can construct a biofilter. After all, a simple biofilter is nothing more than some solid particulate media held in a container over which water containing waste is pumped. The challenge to the designer is to produce a biofilter that removes the ammonia and nitrite at the required rate, requires little maintenance, is cost effective and efficient, and is integrated into the system in which it is operating. Designing a biofilter to meet all of these requirements is not a trivial exercise.

Filter Configurations

There are five general filter configurations commonly used in aquaculture production systems: submerged, trickling filters, biodisks, biodrums, and fluidized beds.

Submerged Filters

Figure 1 shows a schematic diagram of a submerged filter. The filter consists of a container filled with porous media. Water enters the filter, passes over the media on which the bacteria grow, and out of the filter. The media may be almost any material that will allow the water to pass through easily and is non-toxic to the nitrifying bacteria that grow on the media surface. Some of the more common media types include rock, sand, and plastic media of various designs. The inflow and outflow must be designed to handle both the normal flow through the filter and the backwash flow. Because the backwash flow is considerably higher than the normal flow, it usually determines pipe size.

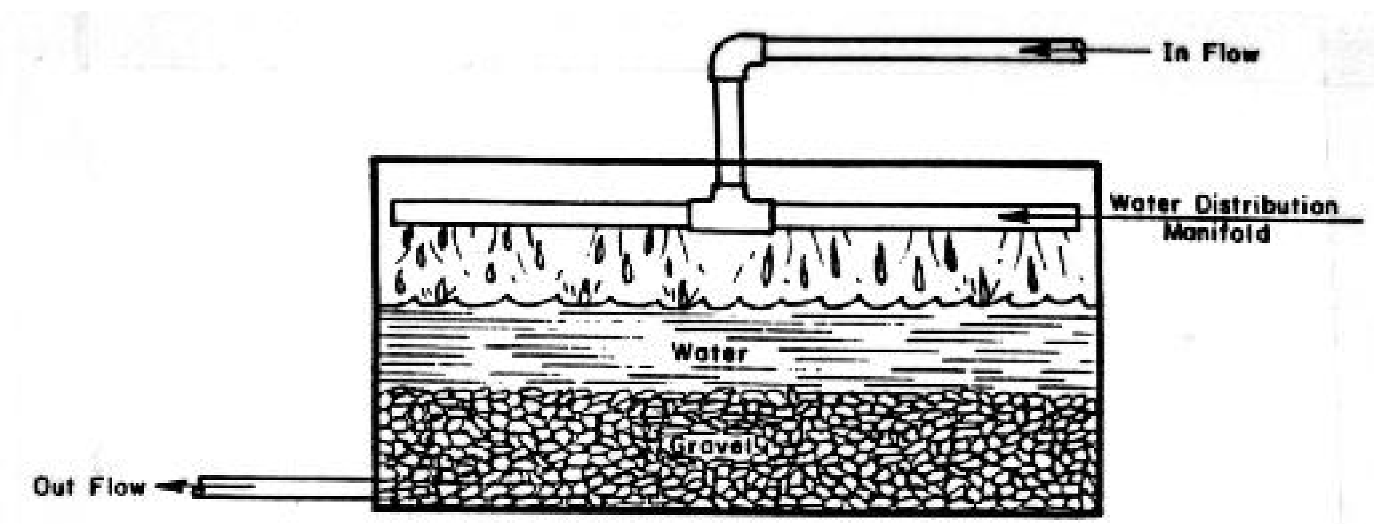

Figure 1. Schematic diagram of a submerged downflow biofilter.

The distinguishing feature of a submerged filter is that the media is always submerged completely below the water surface There are two common operational modes for submerged filters. When the water flows from the top of the filter downward and out the bottom filter it is called a downflow filter. When water flow is from bottom to top it is referred to as an upflow filter. Occasionally submerged filters are operated such that water flows horizontally through the filter. This mode is called a cross flow filter.

Trickling Filters

Trickling filters look the same as a submerged filter except the media are kept damp, but not submerged. Wastewater is allowed to trickle down through the filter, but the flow is maintained low enough that the media is not flooded. This allows air to circulate through the filter at the same time as the wastewater is moving downward through the filter.

Biodisks

Figure 2 shows a schematic drawing of a biodisk. The filter is composed of a series of circular plates each of which is attached to a common shaft. Plate spacing along the length of the shaft is minimized while maintaining enough space for wastewater to circulate between plates after a bacterial film has been established on both sides of each plate. The shaft passes through the center of each plate and is mounted in bearings attached to each end of the wastewater container. The mounting is located such that the plates are submerged in the wastewater to approximately one-half of their diameter. The shaft and plates attached to it are rotated by a power source, usually an electric motor. Flow through a biodisk is usually parallel to the shaft.

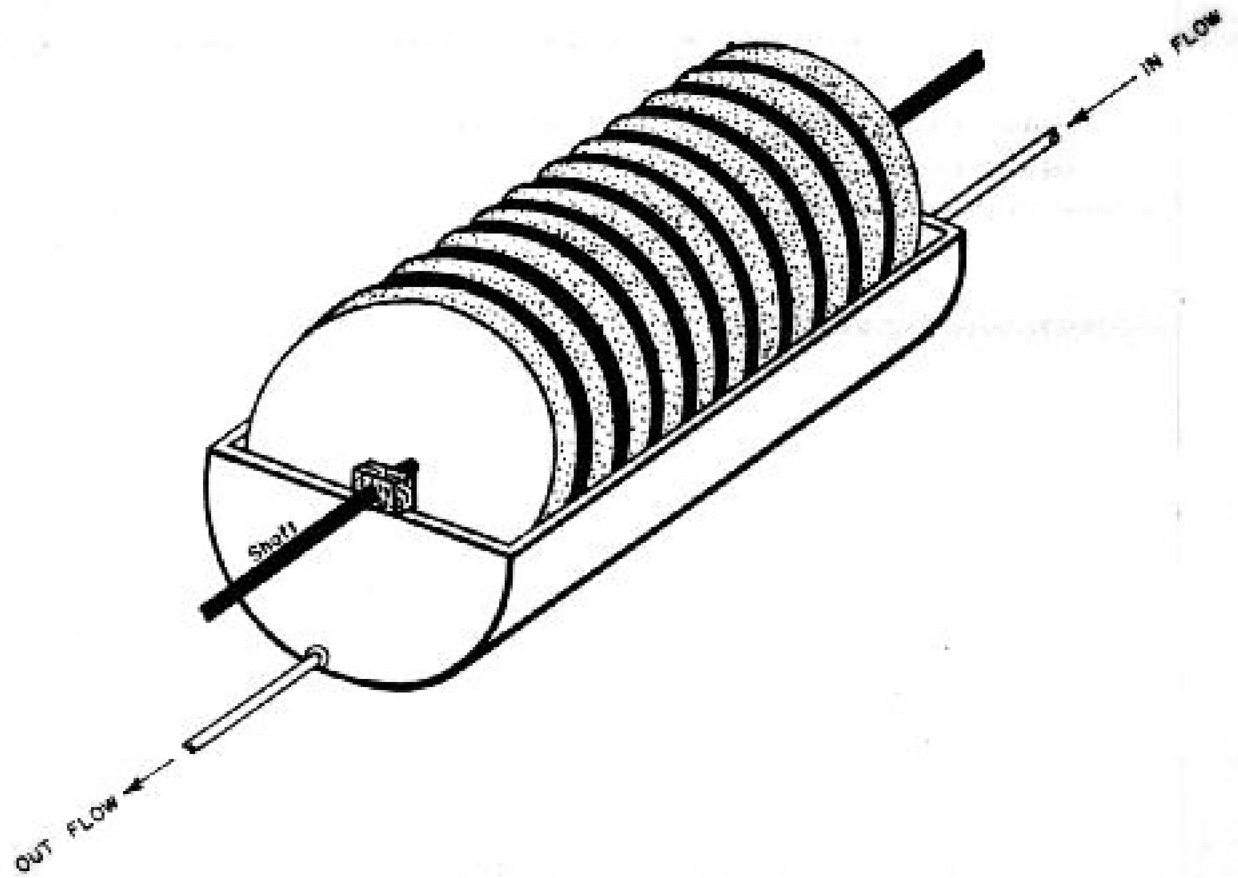

Figure 2. Diagram of a biodisk.

Biodrum

Figure 3 shows a schematic of a biodrum. Biodrums look and operate similar to a biodisk except the disks are replaced by a cylindrical drum. The cylindrical drum surface is porous, typically some type of mesh material, and the drum is filled with some type of solid media having a high specific surface area (area of all of the pieces of media in the drum) per unit volume. Plastic media, such as plastic rings or balls, are usually used as media rather than rock (which is heavy) to reduce drum weight and, hence, the structural support needed for the drum.

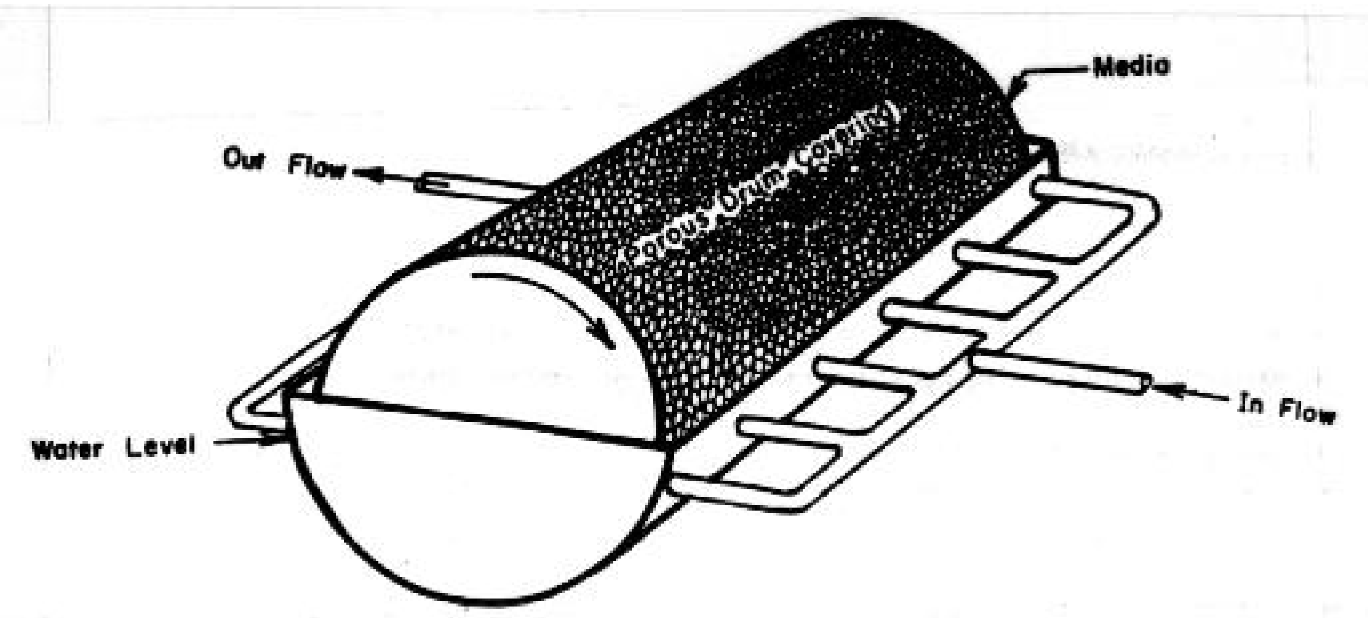

Figure 3. Biodrum schematic diagram.

Fluidized Beds

Figure 4 shows a schematic of a fluidized bed filter. The filter consists of a closed container that is partially filled with a particulate media, typically sand. Wastewater enters the filter through the bottom, passes through a distribution plate, moves through the media and exits from the top of the filter. The distribution plate serves two functions; 1) it supports the media and prevents it from clogging the inlet when the filter is not operating, and 2) it helps distribute the wastewater evenly across the horizontal area of the filter. During operation sufficient water flow is maintained to suspend the media particles in the upward flow. This is called fluidizing the bed and is the reason these filters are referred to as fluidized beds. Too low a water flow rate will not fluidize the bed, while too high a flow rate will flush the media out of the filter. Nitrifying bacteria grow on the fluidized particles and remove ammonia as it moves past.

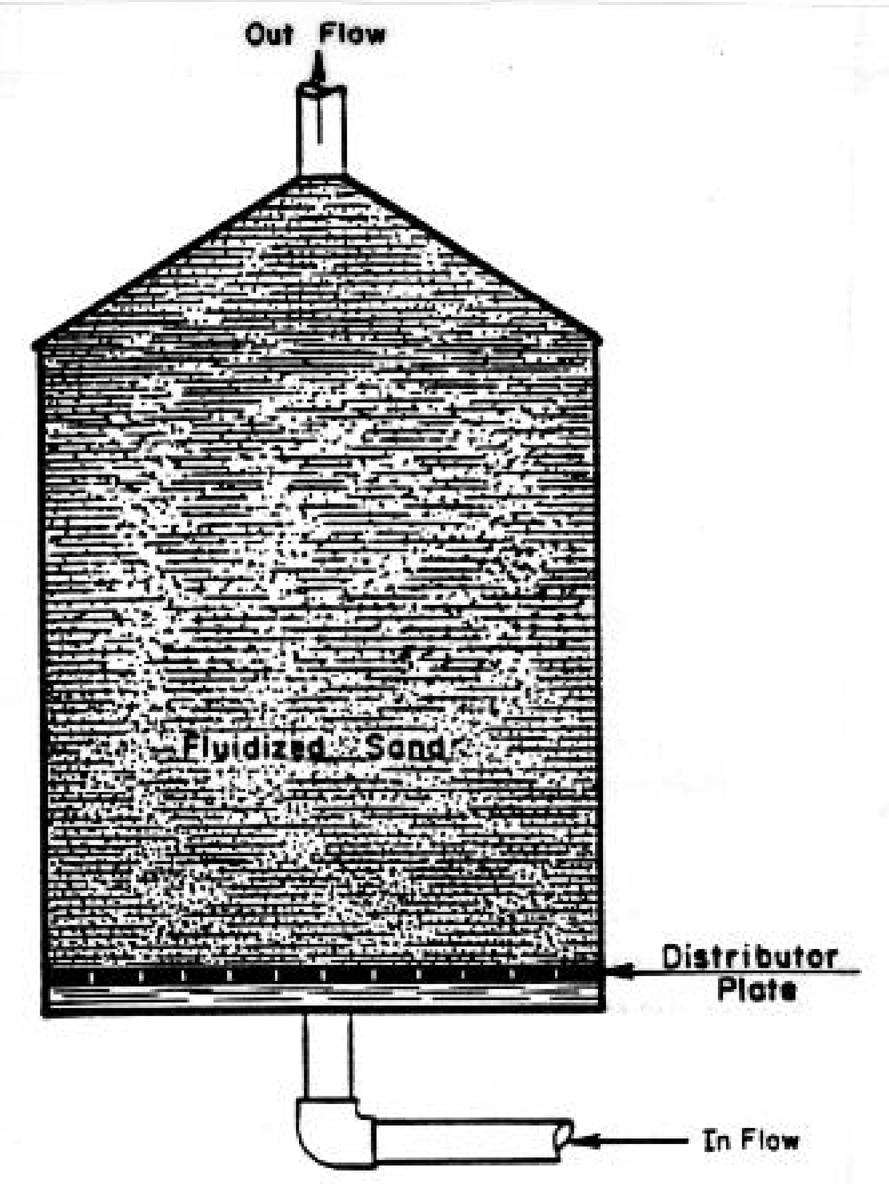

Figure 4.Schematic diagram of a fluidized bed biofilter.

A bead filter, Figure 5, is a special form of a fluidized bed. In bead filters the media consists of small plastic beads, typically less than 2-4 mm in diameter, that float. The beads are held in the container by a screen at the outlet and the water passes upward through the bed of beads. The filter is cleaned by stirring the beads mechanically (with a propeller), by the use of air released into the water stream, or by closing down the flow and letting the beads fall to the bottom of the container. The solids trapped in the beads are washed out during cleaning and discarded.

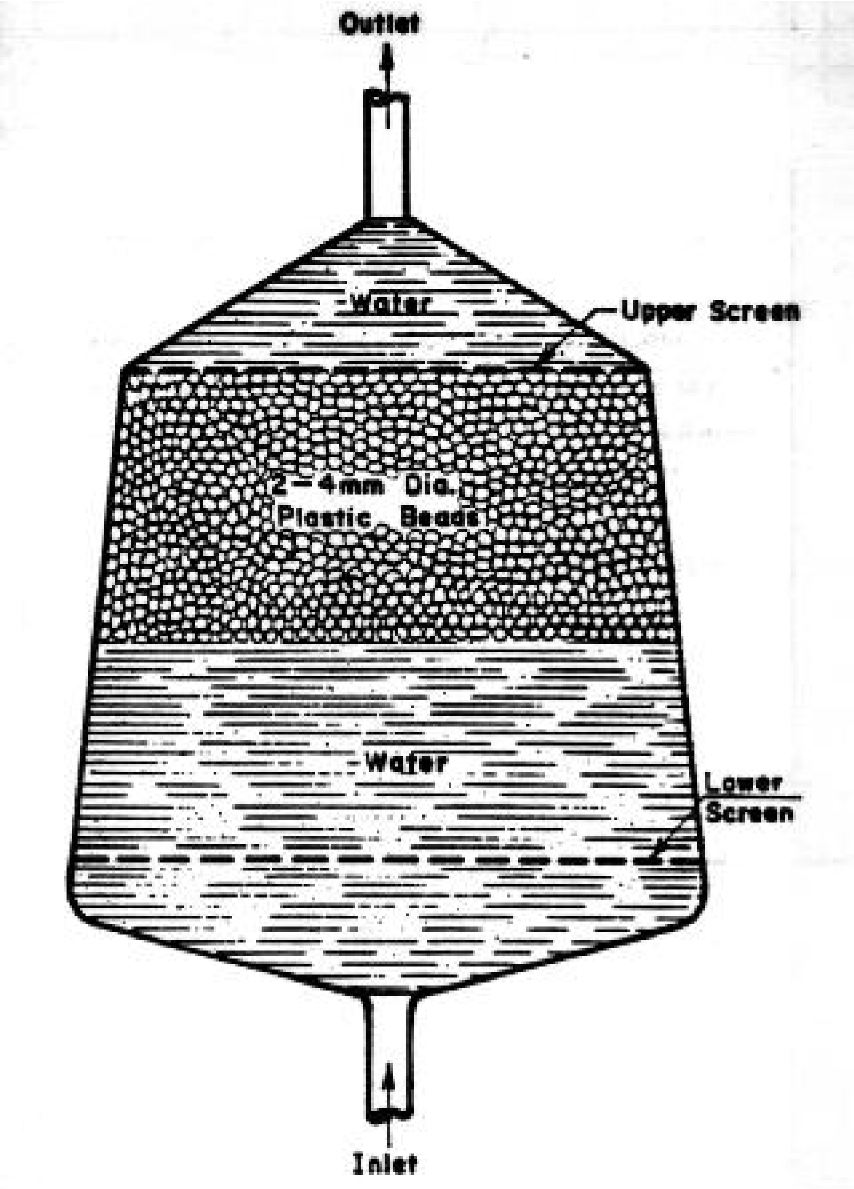

Figure 5. Schematic of a bead filter.

Comparison of Filter Types

Oxygen Supply

The water passing through the filter is the only oxygen source for the bacteria in a submerged filter. This is a major design constraint on submerged filters, because water flow rate is often determined by the bacteria's oxygen demand. Filter oxygen demand is high, sometimes exceeding that of the cultured crop. Oxygen supply in trickling filters, biodisks, and biodrums is primarily from the air. Air contains 210,000 ppm of oxygen while cool, oxygen saturated water contains less than 15 ppm of oxygen. This large oxygen concentration difference between air and water is why it is much easier to supply filter oxygen demands from air contact than by water flow. Fluidized bed filters and bead filters require a relatively high water flow rate to fluidize the bed. Thus, the water flow is usually more than sufficient to supply the needed oxygen.

Oxygen availability to bacteria in rotating biological contactors (RBC's), including biodisks and biodrums, depends on rotational speed of the RBC. Selection of proper rotational speed will assure that the bacteria do not dry out while out of the water, nor do they run out of oxygen while they are in the wastewater. Maximum RBC rotational speed is limited by the bacteria scour velocity. At some velocity, the scour velocity, friction between the water and the media is great enough to strip the bacteria layer off the filter media. Obviously, peripheral disk or drum velocities that exceed the scour velocity will destroy the nitrifying capability of the RBC.

Energy Usage

Energy requirements of biofilters is an important concern in aquaculture. Energy requirements in submerged and trickling filters are primarily due to pumping water vertically into or out of the filter. Submerged filters can, if designed correctly, operate with from less than one to a few psi (pounds per sq inch) pressure drop across the filter, Trickling filters usually require pumping the water the full height of the filter. Thus, the taller the filter the more energy consumed during operation.

Energy consumption in RBC's is essentially the power required to rotate the RBC. The faster the RBC is rotated, the higher the energy consumption. Increased rotational speed generally increases mixing in the tank containing the RBC. Increased mixing is sometimes desirable because it increases aeration and/or suspension of solids. However, increased mixing increases energy consumption by the RBC. Thus, a design compromise must be made between increased mixing and/or aeration by the RBC and minimizing energy consumption. The pressure loss across an RBC is very low, usually in the range of 1 inch or less of water.

Fluidized bed filters require relative high water velocities to fluidize the media. Energy loss due to the water flowing through a pipe or filter increases with the square of the velocity. Thus, doubling the water velocity through the same pipe increases the energy loss by four times. A similar energy loss is experienced when water velocity through a filter increases. Thus, a designer must balance energy usage against other desirable features of a specific filter.

Bead filters generally have fairly high water velocities through them. Thus, energy consumption in these filters is primarily due to pressure loss through the bead bed.

Clogging

Filter clogging is undesirable, because it restricts water flow through the filter. Restricted water flow reduces filter ammonia removal capacity, may cause the filter to run over, and almost surely will cause oxygen starved areas to develop in the filter. Oxygen starved, anaerobic, areas produce hydrogen sulfide and other toxic and smelly compounds that can cause direct fish kills in the system. Clogging also increases energy loss across the filter which can lead to increased operating costs.

Clogging is caused by an accumulation of organics, dead bacteria, and other particulate debris in the porous passages in the filter. Downflow submerged biofilters are probably most subject to clogging of any of the biofilter designs. Upflow submerged filters and bead filters exhibit somewhat less clogging followed in order by fluidized beds, biodrums, and biodisks. Upflow and downflow submerged filters, bead filters, and fluidized bed filters are designed to facilitate periodic backwashing to remove the accumulated particulates. Biodrums and biodisks rarely clog.

Sludge Disposal

All biofilters produce some solids, primarily dead bacteria cells. The amount of sludge produced by the various types of filters is essentially the same, although the particle size and or shape may be different. This material must be removed from the system or it will increase the oxygen demand of the wastewater.

Filter Break-In

Biofilters are essentially masses of living organism, primarily bacteria of several species. As such, the filter does not react instantaneously to changes in the environment. Ammonia loading on a filter (i.e., pounds of ammonia entering the filter per day) is the environmental parameter of most interest to culturists. When the ammonia load increases, due to an increase in the number of animals in the system or an increase in the amount of feed fed, the filter requires time to adjust to the new conditions. The amount of time depends on the rapidity and the magnitude of the change, the more rapid or the greater the loading change the longer time is required to restabilize the filter. Changes in other environmental parameters (e.g., temperature) will have similar effects.

Figure 6 shows what are termed break-in curves for a new biofilter. These curves demonstrate the lag in response of a biofilter to a loading change. In the case shown in Figure 6, a constant load is placed on a new filter. The load can be generated by placing some fish in the system, by daily feeding of ammonia chloride or other means. The ammonia concentration first starts to increase because ammonia is continuously being added to the system, but there is no bacteria to remove it. The ammonia provides a plentiful supply of food so nitrifying bacteria that usually are ubiquitous in the environment attach themselves to the filter media and thrive. However, it takes many bacterial generations to produce a large enough bacteria population to consume the ammonia faster than it is being added to the filter The time required for the bacteria to reproduce results in a lag between a loading change and restabilization of a low ammonia concentration. At some point the population of bacteria that convert ammonia to nitrite, Nitrosomonas, is great enough that ammonia consumption exceeds ammonia production. The ammonia concentration falls to a low level, but the level of nitrite increases due to its production by Nitrosomonas. The plentiful supply of nitrite encourages growth of Nitrobacter, the genus of bacteria that converts nitrite to nitrate. As the Nitrobacter population increases the nitrite concentration begins to fall as it is being consumed at a greater rate than it is being produced. Once the nitrite concentration falls to a very low value, the filter is considered to be broken-in or conditioned. The nitrate concentration in the system will slowly increase with time unless there is some means incorporated into the system to remove it (e.g., a denitrification system).

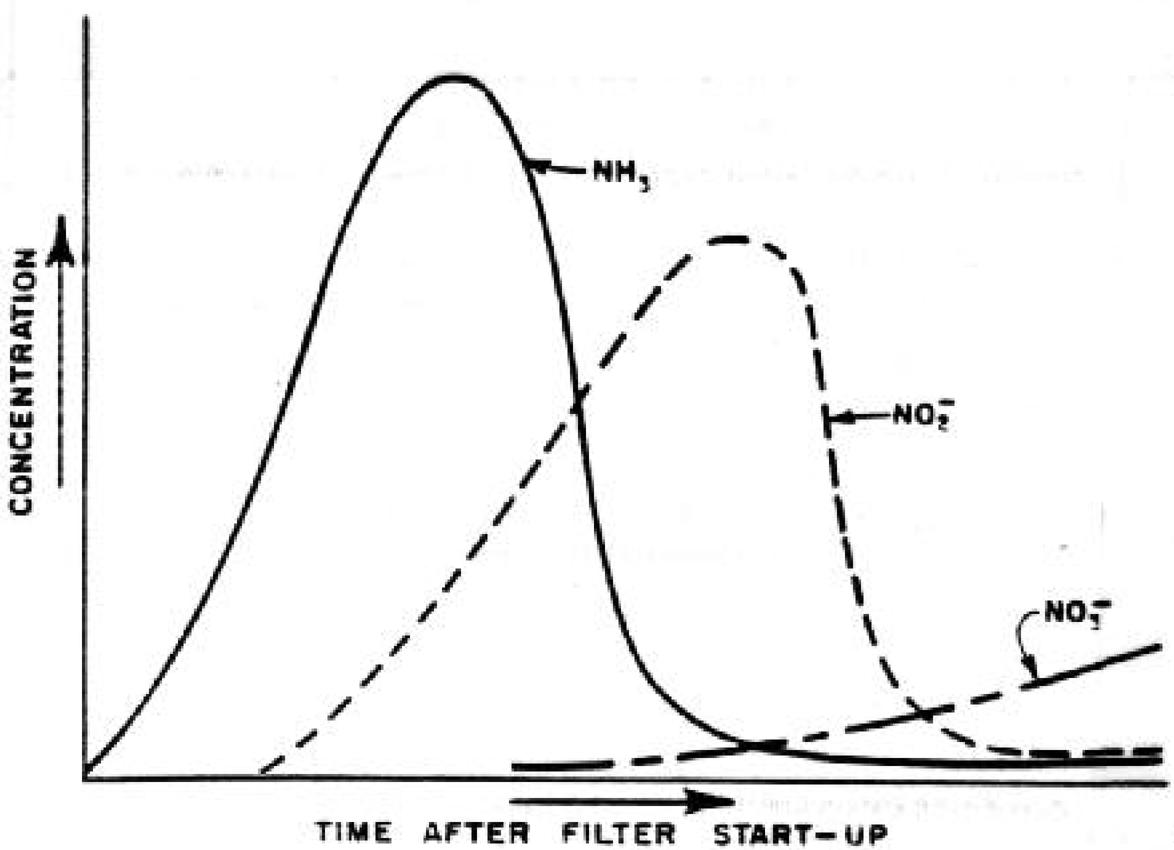

Figure 6. Typical start-up curve for various nitrogen forms in a biofilter.

The break-in process in a new filter usually requires 30 to 60 days. In some systems the ammonia concentration may fall after a few days, but the nitrite peak may persist for a month or more. In other systems it may take much longer for the ammonia peak to pass. Researchers do not completely understand why there are such differences in the break-in pattern from one filter to another. Thus, when breaking-in a filter it is imperative that both the ammonia and nitrite concentrations be monitored to determine when the filter is broken-in.

There is a considerable volume of literature discussing the merits of adding "seed" to the filter to decrease the time required for break-in. Many of the results are variable. However, it appears that in new filters adding 10-30 percent or more media from an operating biofilter will decrease the break-in time drastically, sometimes as much as 60 to 90 percent (Carmigaina and Bennett, 1977; Bower and Turner, 1981; Hochheimer and Wheaton, 1991). However, both the broken-in filter and the new filter must be operating under similar environmental conditions in order for the addition to be effective. For example, using media (and bacteria attached to it) from a filter operating in a saltwater system as seed in a filter that will be operating with fresh water will not decrease the break-in time. The use of commercially available dry or wet "seed" formations has shown variable results. Although the reason for the variable results is not clear, it probably is related to the differences in the environmental parameters under which the "seed" was grown compared to the conditions in the specific filter being tested.

Biofilter Design

Design Date

Biofilter design requires some knowledge of the other components of the culture system. For example, what aeration system, what solids removal methods, and what arrangement of the system components will be used in the overall system. This data impacts on the operating conditions of the biofilter and will, thus, influence its design.

There is also a body of data needed that details the water quality requirements acceptable to the species being cultured. Acceptable ranges of pH, temperature, ammonia concentration and other variables must be known. The largest weight of fish the filter will support at any time during the life cycle of the crop must be determined. Feed to be used and feeding rates anticipated, water temperature and range of water temperatures expected, and the range of oxygen demand by the fish all need to be determined prior to designing a biofilter. Waste production rates by the particular fish species are also needed for the range of fish sizes expected in the culture system. This should include solids production as well as ammonia production.

Design of any filtration system is based on the principle that the filter must remove wastes at or above the maximum rate at which the crop produces them. If the production system has sufficient volume of water in it, there is some potential for short term (i.e., a few hours) waste removal rates to be slightly less than the hourly maximum production rate. However, filters should almost always be designed for the maximum short term ammonia production rates.

Filter Design Example

Problem -- Design a biofilter to remove the ammonia produced by 10,000 pounds of trout held in a recycled system having 95 percent recycle of water. The trout average 2.2 pounds each at the time the filter will experience the maximum ammonia load. Assume the following information:

System temperature is constant at 54°F (12° C)
Make up water has an ammonia concentration of 0 mg/L

Filter media data

Media type	Plastic rings
Media diameter	2 inch
Void fraction	0.9
Specific surface area	50 ft^2/ft^3
Weight	2 lbs/ft

Length of a 2.2 lb trout 18.5 inches
(Manual Fish Culture, 1970)

Fish feed will be trout pellets 2% body wt. per day

Minimum oxygen concentration leaving filter 5 mg/L = 5 ppm

Solution

I. Ammonia Production (AP)

From Liao and Mayo (1974)

AP = 0.0289 (Feed fed/day)
AP = (0.0289)(10,000 lbs)(2% body wt/day)
AP = 5.8 lb ammonia produced/day

II. Ammonia Removal By the Filter (AR)

From tables in Speece (1973) or Wheaton (1977)

At 54°F (12°C) ammonia removal = 0.00012 lb/ft^2 day

III. Specific Surface Area Needed (SSA) if Have Only One Pass System

$$SSA = \frac{\text{ammonia produced}}{\text{ammonia removed/ft}^2\text{ day}}$$

$$SSA = \frac{5.8 \text{ lb/day}}{.00012 \text{lbs/ft}^2 \text{ day}}$$

SSA = 48,333 ft^2

Note that this method of determining SSA does not account for recycling, retention time and other filter variables.

IV. Calculate Oxygen Consumption of Fish

From Liao (1971)

$O_c = K_2 T^a W^{1b}$

where O_c = oxygen consumption rate in (lb 02/100 lb fish day)
K_2 = rate constant
T = temperature (°F)
a,b = slopes
W = fish size (lb/fish)

The constants K_2, a and b come from tables in Liao (1971) or Wheaton (1977).

$O_c = 3.05 \times 10^{-4} (54)^{1.855} (2.2)^{-0.138}$

O_c = (3.05 x 10^{-4}) (1635) (.9)

O_c = 0.4472 lb O_2/100 lb fish day

The total oxygen demand by the fish is:

O_{TOTAL} = (0.4472 lb O_2/100 lb fish day)(10,000 lb fish)
O_{TOTAL} = 44.72 lb O_2/day

V. From Liao et al. (1972) The Carrying Capacity Can be Calculated.

$$L_c = \frac{0.14(C_e - C_m)}{O_c}$$

where L_c = carrying capacity (lb fish/gal/min)
C_e = dissolved oxygen concentration at temperature T and altitude E_1 (ppm)
C_m = minimum oxygen concentration allowable in the filter (ppm)
O_c = oxygen uptake rate (lb O_2/100 lb fish day)

Assume oxygen saturation is 10 ppm from tables and minimum oxygen concentration is 5 ppm (given).

$$L_c = \frac{1.2\ (10\text{-}5)\ \text{ppm}}{0.447\ \text{lb}\ O_2/100\ \text{lb fish day}}$$

L_c = 13.4 lb fish/gal/min

Required water flow rate (U):

$$O = \frac{10{,}000\ \text{lb fish}}{13.4\ \text{lb fish/gal/min}}$$

O = 746 gal/min

VI. Initial Ammonia Concentration at Discharge Point

$$C_i = \frac{\text{ammonia produced/day}}{\text{flow rate/day}}$$

$$C_i = \frac{5.8\ \text{lb ammonia/day}}{(746\ \text{gal water/min})\ (60\ \text{min/hr})\ (24\ \text{hr/day})\ (8.33\ \text{lb/gal})}$$

C_i = 0.65 x 10-6 lb ammonia/lb water

C_i = 0.65 ppm

Allowable ammonia concentration (C_2) is 0.75 mg/L (Liao et al., 1972) or 0.75 ppm.

VII. Allowable ammonia concentration factor due to recycling is:

$$C = \frac{C_2}{C_j} = \frac{0.75}{0.65} = 1.15$$

VIII.The Filter Efficiency Needed to Remove the Ammonia Produced can be Calculated from Liao et al. (1972).

$$E = \frac{1 + CR - C}{CR}$$

Where R = percentage (as a decimal) of water recycled
E = percentage (as a decimal fraction) of metabolite removed by a single pass through the filter
C = concentration of metabolite at any rearing unit outlet divided by concentration occurring at rearing unit outlet in a single pass system (ammonia concentration factor)

$$E = \frac{1 + 1.15\,(.95) - 1.15}{1.15\,(.95)}$$

E = 0.86

Therefore, the filter must be 86% efficient, a rather severe requirement for a filter.

IX. Total Ammonia Load on the Filter (W_A) is higher than a one pass system because of recycling.

W_A = (ammonia load from single pass) C
W_A = (5.8 lb ammonia/day) 1.27
W_A = 7.37 lb ammonia/day

X. Filter Retention Time Needed to Achieve an Ammonia Removal of E is Given by (Liao et al., 1972).

$$t_m = \frac{Ep}{9.8\,T - 21.7}$$

t_m = filter retention time (hours)
E = filter efficiency (in percent)
T = water temperature (0C)

$$t_m = \frac{86}{(9.8)\ (12) - 21.7} = 0.90 \text{ hours}$$

$$t_m = 53.8 \text{ min}$$

XI. Volume of filter needed is:

$Vol = O\ t_m$ (I/void ratio)

Vol = (746 gal/min) (53.8 min) (1/0.9)(0.1337 ft^3/gal)

Vol = 5962 ft^3

XII. Specific Surface Area is Thus

SSA = (Vol) (surface area/unit vol)

SSA = (50 ft^2/ft^3)(5962 ft^3)

SSA = 298,100 ft^2

The above SSA was found using a calculated retention time and filter efficiency after the method developed by Liao and Mayo (1974). Compare this with the Specific Surface Area (SSA) calculated in step three of the problem. This SSA was calculated assuming an ammonia production rate and an ammonia removal rate with no recycling. The production was calculated using data from Liao et al. (1972) and the ammonia removal from data by Speece (1973). The difference in SSA needed by the two techniques is 298,100 ft^2 versus 48,333 ft^2. Converting this to volume using 50 ft^2/ft^3 gives a volume of 5962 ft^2 versus 967 ft^3, a difference of over 6 times. In looking at the size of these differences it is important to realize that data for trout and catfish is very good compared to available data for other species.

XIII.Calculate filter dimensions

Using a 6 ft depth for the filter (assumed value based on the media specified)

Vol = (depth) (length) (width)

5962 ft^3 = (10 ft) (length) (width)

596 ft^2 = (length) (width)

Assume a length of 15 ft
then width = 40 ft

XIV. Check Oxygen Supply to the Filter

Stoichiometric oxygen requirement is 4.57 lb oxygen/lb ammonia converted to nitrate (Wheaton, 1977).

There are 5.8 lb ammonia that need to be converted per day. Therefore, the oxygen requirement for the filter is:

O_2 = (5.8 lb ammonia/day) (4.57 lb O_2/lb ammonia)

O_2 = 26.5 lb oxygen required by filter/day

Oxygen available across the filter is (0_2A):

O_2A = (water flow rate) (change in oxygen conc. across filter)

O_2A = (746 gal/min) (10 ppm - 5ppm)

O_2A = 746 gal/min (5 x 10-6) 8.33 lb/gal

O_2A = .03 lb/min

0_2A = 44.6 lb oxygen available/day

Therefore, at the flow rate used (746 gal/min) there is plenty of oxygen available to the filter if the water enters the filter at 10 mg/L and leaves at 5 mg/L (i.e. 44.6 lb/day > 24.24 lb O_2/day).

Discussion

The above problem has been solved in two ways. The specific surface area (SSA) calculated in Step XII of 298,000 ft_2 is about six times the 48,333 ft_2 that was calculated in Step III. These two different techniques give widely differing results because the values calculated in Step Ill do not consider the effects of recycling and retention time as does the method used in Step XII. Because the two filters are so much different in size, the difference in capital cost of the two filters is considerable.

It should be noted that the basic data used by the designer will greatly influence the size of the filter. For example, if Wortman's (1990) rather than Speece's (1973) data for ammonia removal per unit SSA was used in Step II, the resulting design would require 45 percent less SSA than the design shown. However, Wortman's (1990) data was developed for biodrums, not a submerged or trickling filter.

The important point here is to realize that the data available to biofilter designers is limited and there is much variation in the data that is available. There is a considerable amount of required design data that is not available at all. Lack of the needed data makes biofilter design part art and part science. Experience on the part of the designer tends to improve the "art" component of a designer's design.

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Suspended Solids Filtration In Water Recirculation Systems

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Introduction

Finfish aquaculture in recirculating systems has several unique problems as compared to extensive aquaculture in ponds or single-pass raceway systems. Among these are maintenance of dissolved oxygen, oxidation of dissolved nitrogenous wastes, and solids removal. Suspended solids can build up in recirculating systems to the level where the entire system will fail -- the biofilter will clog and suffocate the nitrifying bacteria and water flows will be disrupted. Particulate waste removal is the most problematic component of water reuse systems in aquaculture (Tetzlaff and Heidinger 1990; Lewis et al. 1981).

Three general method are used to remove suspended solids: sedimentation, centrifugal concentration, and mechanical filtration. Each of these has some inherent benefits and detriments.

Once particulates are removed from the aquaculture system, they must then be disposed of in a manner which conforms to the numerous state and federal regulations.

Particulate Waste -- The Problem

Particulate wastes in recirculating aquaculture systems come from three major sources: the fish, the feed, and heterotrophic organisms (bacteria and fungi). However, all of these result from the incomplete utilization of feed by the fish. Poor feed utilization results from: 1) poor quality of feed with a high percentage of "fines", 2) poor feeding techniques where some feed is made unavailable to the fish (washed down the standpipe), 3) overfeeding, 4) improper feed type for the fish -- some fish will chew food pellets that are too large, releasing particulates through the gill covers, and 5) a poor match between the nutrient requirements of the fish and those contained in the feed.

The aquaculturist can control the first four of these. In purchasing feed, you get what you pay for. Some low quality feeds can come with 15% "fines"; others have insufficient binding agents added so the pellets begin to fall apart as soon as they get wet. There is also some degree of "fine" production by automatic feeders. Early designs of feeders which use blowers to move feed to tanks were particularly prone to this problem. The feed pellets would grind against one another and produce a high percentage of "fines". These can contribute significantly to the suspended particle load of a system.

Poor feeding techniques, overfeeding, and pellet size are all problems which are associated with poor animal husbandry. The aquaculturist should be aware of any system flaws which allow the loss of feed before the fish can use it. Adjustments in the size of the screen covering the tank effluent may be required. Feeding less feed, but more often, prevents feed from breaking down before it is consumed by the fish. Elimination of the second problem, overfeeding, requires considerable knowledge about the animal one is rearing. Information such as optimum and maximum feed consumption as they relate to the temperature of the system, the size of the fish, and the conversion ratio of feed to fish should be known. Most of the feed given a fish beyond the amount it can use is released into the water as particulate waste. This is detrimental for the recirculating system and is also economically inefficient. The use of improper sizes of feed also results from insufficient knowledge. Many fish have pharyngeal pads which they use to move food to their stomachs. These pads are usually equipped with teeth. Fish will use these teeth to grind pellets that are too large to swallow. The resultant particulate waste can be seen as small clouds exiting their opercula. Thus, improper feed sizes should be avoided. Since there is often a several-week delay between the time feed is ordered and delivered, the aquaculturist must be able to predict the growth rate of his fish. With new systems and new animals experience is required.

Particulate matter caused by an unbalanced diet is more difficult to control. Only the salmon and trout have their nutritional requirements well known, although channel catfish nutrition is becoming better understood. For many of the other species being cultured, little is known of the basic requirements, such as optimum protein, carbohydrate, and fat levels, and which proteins can be digested. When the feed contains too high a lipid level, or lipid that are undigestible, the fish produce feces with a high level of fat. The resultant particulate waste is then less dense than water. Particulate waste removal systems that rely on the difference in density of the waste and water are thus ineffective. The result is lower food conversions and higher levels of particulate waste entering the system.

Acceptable food conversion rates for finfish range from 1.5 to 2.2. These ratios are based on dry weight of feed to wet weight of fish. Since fish are 71- 76% water, a food conversion of 2:1 is really 7.7:1 when expressed as dry weight of feed to dry weight of fish. Thus 87% of the feed given to a fish is not converted to flesh. The rest of the feed is released into the water as metabolic products and particulate waste. The greatest amount of waste is carbon dioxide and other dissolved inorganic products although settleable solids are also significant.

Piper et al. (1982) state that 0.3 kg of settleable solids are produced from each kg of feed supplied to the fish. Thus an aquaculture operation holding 25,000 pounds of fish and feeding 3% per day is producing 225 pounds of particulate waste per day. Liao and Mayo (1974) found that 70% of the total ammonia production of a system is in the particulate waste. Clarke and Phillips (1989) note that a salmon production facility will produce 40 kg of particulate nitrogen, 7-10 kg of solid phosphorus, and 250 kg of particulate carbon (organic material) per 1000 kg of fish produced. A large biological oxygen demand (BOD) and chemical oxygen demand (COD) is also produced by the particulate waste. Efficient removal of the particulate waste thus greatly reduces the oxygen and nitrification requirements of the system. The high organic content of the particulate waste permits heterotrophic bacteria populations and fungi to grow rapidly. Their growth creates high BOD in the system and the end products of their digestion release ammonia into the water.

Few studies have examined the physical properties of the particulate wastes produced in aquaculture. Generally it is agreed that most of the wastes produced by the fish have a density only slightly greater than water -- wastes resulting from uneaten feed will be slightly more dense. The size of the particulates can be highly variable, although Clarke and Phillips found that most of the waste coming from a salmon smolt facility was in the range of 50-100 micrometers. Actions such as pumping homogenize the waste, producing finer particles that are harder to settle out or filter.

Removal of Particulate Waste

Removal of particulate waste from a recirculating aquaculture system can be accomplished through settling, centrifugal separation or filtration. All of these general methods will work. The problem arises when they have to work efficiently and economically. An effective particulate removal system should: 1) concentrate the wastes so that water loss from the system is minimal, 2) remove the waste rapidly so that heterotrophs do not have time to develop and use dissolved oxygen and release ammonia, 3) not require large energy inputs which increase operating costs, and 4) not result in major pressure losses which require additional pumping or potential loss of water flow. No system totally fulfills these goals.

Settling Systems

The simplest type of particulate waste removal system is the settling basin. The velocity of the effluent water is slowed in a large tank or pond and the particulate wastes are allowed to settle to the bottom for later removal. The design of settling basins involves four inter-related factors: 1) retention time, 2) water velocity and flow distribution, 3) the density of the particulate waste, and 4) water depth (Piper et al. 1982).

Retention time is simply the time it takes to exchange the water in a container at a given flow rate. Longer retention times give the particulate waste more time to settle to the bottom. Thus, the larger the settling basin, the more waste that will be removed. The retention time needed to settle wastes depends on their settling rate which, in turn, depends on the density of the particle and the amount of water turbulence in the Basin. Depending on these factors retention times vary from 15 minutes to 2 hours (Piper et al. 1982).

Slow water velocities and laminar flow patterns enhance the settling process. Piper et al. (1982) recommend that the influent water to a settling basin should be directed through perforated diffuser plates to create laminar flow. They recommend plates with greater than 50% open area. Without diffusers, a channel effect can occur resulting in very reduced retention times for some of the wastes.

The speed which a particle settles is controlled by its mass (weight), density (weight/volume), size, and the viscosity of the fluid. The theoretical settling rate can be modeled using Stoke's Law of physics. Basically, this law states that: 1) denser particles settle faster, and 2) particles with larger diameters settle faster. Unfortunately the particulate waste produced in aquaculture is usually small, and has a density near that of water. Clarke and Phillips (1989) state that their salmon smolt operation produces particles in the range of 50-100 microns. Assuming that the density of the 100-micron particles is 1.4 (40% denser than water), these particles would settle at a rate of 0.01 cm/sec. or take 4.3 minutes to settle one inch. This calculation does not account for the effects of water movement which helps to keep particles in suspension.

Piper et al. (1982) note the importance of settling basin depth on the effectiveness of particulate waste removal. A shallow basin may allow water currents to resuspend particulates. A basin that is too deep will not allow the particles to reach the bottom during the retention time and thus be flushed out. These authors recommend a depth of 1.5 feet for a settling basin. Davis (1972) and Liao and Mayo (1972), however, recommend settling basin depths of greater than 3 feet.

Once the particulate waste has settled out, it must be concentrated and removed. If the waste is not removed rapidly, nutrients can be released through leaching and bacterial action. These will increase the ammonia load on the biofilter, provide nutrients for heterotrophic bacteria, and raise the BOD and COD in the system. Sludge is generally removed from settling basins either by de-watering the basin and scraping, or by vacuum pumping. De-watering the system requires that a method be installed to by-pass the settling basin during cleaning, and that the basin be drainable. Some settling basins have mechanical sludge scrapers installed in the bottoms to facilitate cleaning.

Based on the above information, it is obvious that settling basins are not efficient particulate waste removal systems for large in-door facilities. A system running 500 gallons/minute would require a 1 5,000-gallon settling basin. Piper et al. (1982) discuss the use of two 30 ft X 100 ft basins, 4 feet deep, to handle a 600-gallon/minute influent. In this system, 85% of the wastes settle out.

In a small aquaculture facility settling basins may be more realistic. A settling basin could be incorporated below the rearing tanks and thus reduce the space requirements for the basin.

Several modifications of the basic settling basin are commercially available. They incorporate a series of parallel plates or tubes to create areas of no turbulence, allowing for more rapid settling of particulate waste. These units require less settling time, and thus permit a much smaller unit. These plate or slant-tube settlers are still controlled by the physics of the particulate waste -- the particles must be sufficiently dense to settle.

The benefits of settling systems are: 1) low cost, 2) ease of operation -- they operate on gravity and produce no loss in pressure, 3) low energy requirement, and 4) low water requirements when properly designed. The detriments of these systems include: 1) large size which precludes their use in in-door facilities, 2) relative inefficiency -- small or low-density particles will not settle out, and 3) the continued contact of the waste with the culture water which allows ammonia and other nutrients to leach into the water.

Centrifugal Systems

Particulate waste concentrators which operate on centrifugal force have been used in manufacturing for many years, but have only been used for the treatment of particulate waste from aquaculture for about 10 years. Centrifugal concentrators are also known as swirl separators, hydrocyclones, and vortex concentrators. They operate on the principle of spinning particulate-laden water so that the denser particulate waste is forced to the wall of a cone by centrifugal force. Influent water enters a closed cone tangentially, causing a swirling motion in the cone. Particulates are forced to the wall of the cone where they settle and are removed with a continuous effluent of water. This waste effluent can compose as much as 5% of the total system flow. Scott and Allard (1983) restricted this water loss to less than 3.8% of total flow. The cleaned water exits the cone through an effluent pipe in the top of the unit.

The effectiveness of these units depends on: 1) the amount of centrifugal force placed on the particles, and 2) the density of the particles in relation to that of water. The centrifugal force in the cone is dependent on the velocity of the entering water. Pumping is usually required to obtain sufficient water velocity to force the particulates to the cone wall.

The same factors that affect the ability of a particle to settle in a settling basin affect the ability of a centrifugal concentrator to remove it, namely; the mass, the diameter, and the density of the particle. Thus those particles with densities similar to that of water are not removed. In addition, the pumping of the waste water to produce sufficient velocity homogenizes it, producing particles with smaller diameters.

The efficiency of these units has been evaluated by Scott and Allard (1983, 1984) and Enqvist and Larrson (1986?). Scott and Allard (1983) found that this type of particulate removal system would remove 56% of the net dry solids circulating in their system. In 1984, these authors further evaluated centrifugal concentrators in a recirculated trout culture system. They found that 90% of the particulate wastes produced by the trout were larger than 77 micrometers in diameter and that the concentrator removed 70% of these. With smaller particle sizes, the concentrator was less efficient, removing only 10% of the waste entering it. Enqvist and Larrson (1986?) examined a centrifugal concentrator in a single-pass salmon hatchery. They found that a centrifugal concentrator removed 66% of the total solids, 33% of the BOD, 18% of the total nitrogen, and 40% of the total phosphorus.

The main benefit of centrifugal concentrators is their compact size. This makes them adaptable to in-door culture facilities. However, there are numerous weaknesses in this system. Centrifugal concentrators require high water velocity to produce the force to separate the particles. This necessitates pumping, and thus homogenizing the waste. It also requires that pumps produce a higher pressure than is necessary to just move the water. This is energy inefficient. These systems also require a continuous waste effluent of up to 5% of total system flow. Scott and Allard (1984) their concentrators to reduce this loss. The concentrator waste effluents were directed through 100-foot coils to reduce flow and pressure. However, they still had continuous water loss and thus needed a freshwater make-up supply. This fresh water would have to be purchased or pumped from well and then potentially heated. A 3% make-up on a 500 gallon/minute system totals 21,600 gallons/day, This increases the costs production. It is possible to retreat the effluent of the concentrators to reduce this water loss. As an example, the effluent from a centrifugal concentrator would be 15 gallons/minute from a system running 500 gallons/minute (3%). The 15 gallons/minute could be directed to a settling basin for further concentration of the sludge. At this flow rate, a settling basin of only 900 gallons would provide a 1-hour retention time.

Mechanical Filtration

Mechanical filters can be divided into two subgroups; media filters and screen filters. Both operate by acting as a physical barrier to the particulate waste. The main advantage of mechanical filters over the previous two systems is that filters do not rely on the density of the particle -- floating objects are filtered equally as well as heavy objects. Filtration is only limited by the size of the particle. Unlike sedimentation basins and centrifugal separators, mechanical filters require a cleaning cycle which utilizes energy.

Media Filters

Media filters are typically composed of a container holding a fixed volume of the filtering media. Sand is the most common filtering media, although very small systems (aquaria) may use diatomaceous earth. Manufactured media consisting of very small beads is also being used. Media filters can be pressurized or open-flowing. Open-flow filters are very limited in the amount of water flow they can handle. The maximum for sand filters is about 1 gallon/minute for every square foot. This discussion is therefore limited to pressurized systems.

Pressure sand filters consist of a closed chamber holding the filter sand. Raw water is pumped into a diffuser and filters through the sand. Cleaned water exits through the bottom of the filter. These filters are very effective at removing particulate waste. They are capable of filtering particles as small as 15 micrometers.

There are, however, numerous problems with pressure sand filters. They have high costs involved with backwashing, and create significant pressure losses. As particulate matter is removed from the culture water, it accumulates on top of, and in, the sand media. When this happens, water pressure on the upstream side of the filter increases and water flow decreases on the downstream side. The SIUC Fisheries Research Laboratory had one pressure sand filter explode from high pressure when using a extremely fine-grain medium. As the filter clogs, flows to the system can be restricted significantly and even totally stop.

The only means to prevent clogging is frequent backwashing of the medium. Backwashing involves reversing the direction of the water flow and providing adequate pressure and volume to suspend the sand while flushing the particulate material to waste. A pressure sand filter typically requires approximately 20-40 volumes of water to backflush -- a 60-gallon filter thus requires 1,200 gallons of water.

A second common problem encountered with these filters is adhesion of the media by heterotrophic bacteria. Growth of these bacterial populations within the filter create viscous masses of sand, bacteria, and particulate waste that are not removed by normal backwashing. Water flow is inhibited by these masses, reducing the efficiency of the filter. Chlorination, combined with mechanical agitation, is required to eliminate the bacterial masses. The filter must be taken off line during this procedure.

These problems make pressure sand filters one of the most effective, but least efficient methods for removing particulate waste from a recirculated system. They require high capacity pumps both to push the raw water through the filter and to backwash the filter, and require large amounts of water for backwashing.

Screen Filters

For this discussion, screen filtration includes any mechanism where particulate matter is trapped on a thin porous membrane. The filter membrane may be composed of woven wire or other material, a perforated plate, or a set of parallel wires with fixed distances between them. Screen filters can have a stationary filter plate or a moving membrane. The moving membrane filters often take the form of a rotating drum or plate. Screen filtration systems vary from a simple plate or bag placed in a tank to complex automatic systems costing in excess of $50,000.

Three factors govern the effectiveness of all screen filtration systems: 1) the efficiency of particulate removal, 2) the rate of clogging, and 3) the ease and efficiency of cleaning. Traditionally screen filter systems used in industrial applications have not been successful when applied to aquaculture using water reuse, The efficiency of particulate removal is governed by the mesh size of the screen, the amount of open area compared to the area screen (% open area), and whether the system forces soft particulate material through the mesh. Microscreens are commercially available with extremely small mesh sizes.

The major limitation with screen filtration has been the rapid growth of bacteria and fungi on the screen and ineffective backwashing techniques to remove that growth. This is particularly true in warm-water aquaculture systems. Moving screen systems may also have a tendency to grind soft particulate matter until some of it will pass through the mesh.

Of the many proprietary screen filtration systems on the market, the Triangelfilter by the Swedish company, Hydrotech, is gaining popularity among fish culturists. The design of the Triangelfilter is based on a slanted filter plate. The slanted plate allows the input water to help in cleaning the filter screen. Wastewater flowing over the top of the plate pushes some of the sludge down the slanted screen to a sludge collection trough. When the filter screen begins to clog, a spray arm washes the screen. Water loss from the Triangelfilter is designed to be 0.2-0.5% of input flow. An additional 1000 gallons per day is used for backwash, although much of this actually enters the system. Thus for a 500 gallon/minute system, the total water use would be 2,400-4,600 gallons. This would require an input of 1.2-3.2 gallons/minute of new water. The manufacturers recommend a post-Triangelfilter settling basin to further concentrate the sludge. Use of this would further reduce the water requirements. The Triangelfilter has been evaluated in salmon hatcheries in Sweden by Enqvist and Larrson (1988?), and Canada by Goldberg et al. (1988). In these applications the filter removed 80-100% of the total dissolved solids, 27-70% of the total nitrogen, 67-79% of the total phosphorus, and 75-82% of the BOD. Variations in the efficiency of the filter were attributed to the size of fish being reared and the speed with which the particulates were being removed. Smaller fish produced finer waste which reduced efficiency of the filter -- self cleaning circular tanks reduced sludge breakdown and increased the efficiency.

I have not found an evaluation of this filter in a warm-water fish culture operation using water recirculation. The rapid growth of bacteria in warm water may cause bio-fouling of the filter screen similar to that seen on other screen filtration systems. If this occurs, an expensive retrofit for steam cleaning would be required.

Screen filtration systems vary considerably on the amount of energy input required to operate them. Rotating drums and disks have the greatest power consumption. Some systems require high pressure pumps or steam generators for backflushing. These add to the production costs. Another consideration is the head loss in the filter. All screen filters should be capable of operating on gravity. However, the physical dimensions of some systems results in some head loss. The Triangelfilter screen has a 16-inch head loss at maximum flow rate. This amount of head loss makes this system marginal when considering air lift pumping.

Waste Disposal

Depending on the food conversion ratio, a fish culture operation will produce approximately 0.5-1.5 tons of particulate waste (dry weight) for each ton of fish produced. However, when it leaves a particulate filter this material is mixed with a lot of water. Goldberg et al. (1988) measured 348 mg/L of total suspended solids in the sludge effluent of their Triangelfilter. The dry solids level was thus only 0.0035%. Using a post-filter settling basin as a sludge concentrator, the percent dry matter can be increased to 8-10%. The fish culturist must thus dispose of 0.5-1.5 tons of waste mixed in 5-15 tons (1,200-3,600 gallons) of water for each ton of fish. Based on the data of Clarke and Phillips (1989) this mixture will contain 210 pounds of nitrogen, 30-40 pounds of phosphorus and 500 pounds of particulate carbon. A commercial aquaculture operation thus creates a large quantity of nutrient rich manure.

This waste can be disposed of by field application, sending it to a municipal sewage treatment facility, drying and burning, or discharging it to a lagoon. Because of the high costs of vacuum de-watering and the regulations governing incineration of sludge, this option is unlikely.

The other methods of disposal of this waste are regulated by one or more government agencies, including the U.S. Army Corps of Engineers, the U.S. EPA, the state EPA, the Department of Conservation, and the Department of Agriculture. If a fish culture operation produces more than 20,000 pounds of aquatic animals per year, or discharges wastewater for more than 30 days per year, a National Pollution Discharge Elimination System (NPEDS) Permit is required. Although a federal program, NPEDS permit application are obtainable from the Illinois EPA. Basically, applications requesting permits to discharge waste into any "navigable water", including streams, rivers, lakes, natural ponds, and wetlands will be denied.

Field application of this waste will fall under two guidelines, both administered by the Illinois EPA. If a vegetative filter system in employed, the information in the "Design Criteria Regarding Runoff Field Application Systems" guidelines must be followed. Since a iart~culate filtrat~on system is a type of wastewater treatment system, the guidelines of the "Land Application of Sludge Permit" and the "Design Criteria for Field Application of Livestock Waste" must be followed. These rules basically are the same that a swine producer must follow.

Because of the high nutrient content of aquaculture sludge, Piper et al. (1982) suggests that the waste could be sold to fertilizer manufacturers. This may entail the use of expensive de-watering systems and thus may not be economical. Moving the waste also requires an Illinois EPA "Special Hauling Permit" for each vehicle used to transport the sludge.

Construction of a lagoon or other waste treatment facility requires another Illinois EPA permit, "Construction and/or Operating Permit, Division of Water Pollution Control." Treatment works which may, or may not, have discharge may need this permit.

The rules governing discharges from aquaculture in Illinois are still being refined. Currently, the major concerns are the release of non-native species and the high levels of phosphate and solids.

The Department of Lands, Forest and Water Resource Services in British Columbia have developed rather strict, but straight-forward rules for aquaculture operation. Their rules are based on the weight of fish currently being reared and are defined as pounds of pollutant/100 pounds of fish/day.

With the new state and federal incentives that are available, construction or restoration of wetlands to process the waste may be a disposal method worth evaluating.

Discussion

Particulate waste removal a major, if not the major, problem with recirculating aquaculture systems. The high nutrient load and BOD associated with particulate wastes have caused more biofilter systems to fail than any other cause.

The main difficulty in efficiently and economically removing this waste is the similarity in density of the waste and water. This similarity prevents systems based on gravity or centrifugal force from removing much of the waste.

Of the current technology available, screen filtration seems to offer the best removal of particulate wastes. However, because most of the technology was developed for salmonid production, the problem with bio-fouling of the filter screens by rapidly-growing bacteria has not been addressed. Current methods for filter cleaning are expensive, either using considerable power or water.

Designs for recirculating fish culture systems should incorporate criteria for the efficient transport and removal of particulate waste, including: self-cleaning tank designs, gravity flow to the particulate filter, rapid or frequent cleaning of the filter, and rapid isolation of the filter sludge from the culture water. These criteria minimize the breakdown of the waste into particles that are difficult to remove, and isolate them from the culture water so that nutrients cannot leach from the sludge, and place additional burdens on the biofilter and oxygenation system.

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Types of Aeration and Design Considerations

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Introduction

Dissolved oxygen (DO) is probably the single most important environmental factor in aquaculture. If DO concentrations are low fish will not eat well, they will not grow well, and they will be susceptible to disease. Furthermore, where concentrations are very low, many or even all of the fish may die from lack of oxygen. In order to have good feed conversion efficiency, high survival, and adequate profits, fish farmers must maintain plenty of DO in waters of culture systems. Aeration is necessary to supplement natural sources of DO.

Although aeration is widely used, there are many mistaken ideas about aeration and few aeration practices have been thoroughly investigated. In this lecture, I will provide some basic information on DO and on the practice of aeration.

Improvements in management procedures such as aeration are very important for fish prices will probably continue to be low. This will increase the demand for fish, but it will force farmers to become more efficient managers. Just to illustrate how a small factor can be important to profit, consider that an improvement in the feed conversion efficiency of 0.1 unit could potentially increase profits by $25 to $40 per ton of fish produced.

Solubility of Oxygen in Water

Approximately 20% of the volume and pressure of gases in the air is oxygen. When water is in contact with the atmosphere, oxygen from the air will enter the water until the pressure of oxygen in water and air are equal. This condition is known as equilibrium or saturation. The concentration of DO at equilibrium increases with increasing pressure and decreases with increasing water temperature and salinity. The equilibrium (saturation) concentrations of DO at different temperatures and salinities are provided in Table 1 for standard sea level barometric pressure (760 mm mercury or 29.92 inches of mercury). To obtain the DO concentration at saturation for any other location, multiply the appropriate DO value from Table 1 by the ratio local barometric pressure:standard sea level pressure.

Sources of Oxygen

Natural Diffusion

When water contains less oxygen than the saturation concentration, oxygen from the atmosphere diffuses into the water. In culture tanks, diffusion is a slow process. It is not an important source of oxygen except when DO concentrations are low and there is a high degree of turbulence.

TABLE 1.THE SOLUBILITY OF OXYGEN (MG/LITER) IN WATER AT DIFFERENT TEMPERATURES AND SALINITIES FROM MOIST AIR WITH PRESSURE OF 760 MM HG. AFTER COLT (1984)

**Tem-
per
ture**

(°C)	0	5	10	15	20	25	30	35	40
0	14.60	14.11	13.64	13.18	12.74	12.31	11,90	11.50	11.11
1	14.20	13.72	13.27	12.82	12.40	11.98	11.58	11.20	10.82
2	13.81	13.36	12.91	12.49	12.07	11.67	11.29	10.91	10.55
3	13.44	13.00	12.58	12.16	11.76	11.38	11.00	10.64	10.29
4	13.09	12.67	12.25	11.85	11.47	11.09	10.73	10.38	10.04
5	12.76	12.34	11.94	11.56	11.18	10.82	10.47	10.13	9.80
6	12.44	12.04	11.65	11.27	10.91	10.56	10.22	9.89	9.57
7	12.13	11.74	11.36	11.00	10.65	10.31	9.98	9.66	9.35
8	11.83	11.46	11.09	10.74	10.40	10.07	9.75	9.44	9.14
9	11.55	11.18	10.83	10.49	10.16	9.84	9.53	9.23	8.94
10	11.28	10.92	10.58	10.25	9.93	9.62	9.32	9.03	8.75
11	11.02	10.67	10.34	10.02	9.71	9.41	9.12	8.83	8.56
12	10.77	10.43	10.11	9.80	9.50	9.21	8.92	8.65	8.38
13	10.52	10.20	9.89	9.59	9.29	9.01	8.73	8.47	8.21
14	10.29	9.98	9.68	9.38	9.10	8.82	8.55	8.29	8.04
15	10.07	9.77	9.47	9.19	8.91	8.64	8.38	8.13	7.88
16	9.86	9.56	9.28	9.00	8.73	8.47	8.21	7.97	7.73
17	9.65	9.36	9.09	8.82	8.55	8.30	8.05	7.81	7.58
18	9.45	9.17	8.90	8.64	8.38	8.14	7.90	7.66	7.44
19	9.26	8.99	8.73	8.47	8.22	7.98	7.75	7.52	7.30
20	9.08	8.81	8.56	8.31	8.06	7.83	7.60	7.38	7.17
21	8.90	8.64	8.39	8.15	7.91	7.68	7.46	7.25	7.04
22	8.73	8.48	8.23	8.00	7.77	7.54	7.33	7.12	6.91
23	8.56	8.32	8.08	7.85	7.63	7.41	7.20	6.99	6.79
24	8.40	8.16	7.93	7.71	7.49	7.28	7.07	6.87	6.68
25	8.24	8.01	7.79	7.57	7.36	7.15	6.95	6.75	6.56
26	8.09	7.87	7.65	7.44	7.23	7.03	6.83	6.64	6.46
27	7.95	7.73	7.51	7.31	7.10	6.91	6.72	6.53	6.35
28	7.81	7.59	7.38	7.18	6.98	6.79	6.61	6.42	6.25
29	7.67	7.46	7.26	7.06	6.87	6.68	6.50	6.32	6.15
30	7.54	7.33	7.14	6.94	6.75	6.57	6.39	6.22	6.05
31	7.41	7.21	7.02	6.83	6.64	6.47	6.29	6.12	5.96
32	7.29	7.09	6.90	6.72	6.54	6.36	6.19	6.03	5.87
33	7.17	6.98	6.79	6.61	6.43	6.26	6.10	5.94	5.78
34	7.05	6.86	6.68	6.51	6.33	6.17	6.01	5.85	5.69
35	6.93	6.75	6.58	6.40	6.24	6.07	5.91	5.76	5.61
36	6.82	6.65	6.47	6.31	6.14	5.98	5.83	5.68	5.53
37	6.72	6.54	6.37	6.21	6.05	5.89	5.74	5.59	5.45
38	6.61	6.44	6.28	6.12	5.96	5.81	5.66	5.51	5.37
39	6.51	6.34	6.18	6.02	5.87	5.72	5.58	5.44	5.30
40	6.41	6.25	6.09	5.94	5.79	5.64	5.50	5.36	5.22

Inflowing Water

Water entering culture systems contains DO. The amount of oxygen from this source depends on the DO concentration and volume of inflowing water. For example, if water containing 9 mg/l DO enters a culture tank at 200 liters per minute, the oxygen input rate is 1 ,800 mg/min or 1.8 g/min. In 24 hr, 2,592 g or 2.59 kg of oxygen would enter the tank.

Photosynthesis

Photosynthesis by phytoplankton is usually the most important natural source of oxygen for ponds. Phytoplankton remove carbon dioxide from the water, produce organic matter (carbohydrate), and release oxygen during the day:

$$6CO_2 + 6H_2O + \text{Radiant energy} = C_6H_{12}O_6 + 60_2$$

DO concentrations will often increase above saturation during daytime.

However, photosynthesis is not a significant factor in indoor, water recirculating systems.

Aeration

When DO concentrations are below saturation, aerators can put oxygen into water. The amount of oxygen from aeration depends upon the type and number of aerators and upon the concentration of DO in the water. Aeration is an important source of oxygen when DO concentrations are low.

Losses of Oxygen

Diffusion

When DO concentrations are above saturation, oxygen diffuses from the water into the atmosphere. Diffusion is a slow process, but surface turbulence and mechanical aeration can greatly increase the rate of diffusion of oxygen from supersaturated waters. Water recirculating systems will seldom be supersaturated with DO, so diffusion normally is not a major loss of oxygen.

Outflowing Water

DO is lost when water is discharged from culture systems. The loss is unimportant, for incoming water normally has a higher concentration of DO than outflowing water.

Respiration

All living things in aquaculture systems use oxygen in respiration to release energy from food.

$$C_6H_{12}O_6 + 60_2 = 6CO_2 + 6H_2O + \text{Heat energy}$$

Unlike photosynthesis, which occurs only during daylight, respiration occurs 24 hours per day. Phytoplankton are not abundant in water recirculating systems but bacteria are present in large numbers. The amount of oxygen used by bacteria decomposing organic matter varies with the concentration and composition of organic matter in water. However, water passes through fish rearing units of recirculating systems very quickly and oxygen consumption by bacteria is probably not great within the rearing unit.

Fish use about 150 to 300 mg oxygen per kg of fish per hour; however it is difficult to estimate their respiration rate. The best way of assessing the oxygen demand of the fish grow-out unit is to assume that for each kilogram of feed applied, 0.2 kg of oxygen will be required (Boyd and Watten 1989). This takes into account the oxygen used by fish and bacteria. Of course, additional 'y,gen will be needed by bacteria to break down organic matter which accumulates in the waste treatment part of the culture system.

Effects of Dissolved Oxygen on Fish

The influence of DO concentrations on fish is summarized below:

DO concentration	Effect
Less than 1.5 or 2 mg/l	Lethal if exposure lasts more than a few hours.
2 to 5 mg/l	Growth will be slow if exposure to low DO is continuous.
5 mg/l to saturation	Best condition for good growth.
Above saturation	Can be harmful if supersaturated conditions exist throughout water volume.

Concentrations of DO can fall so low that fish are killed. However, adverse effects of low DO more often are expressed as reduced growth and greater susceptibility to disease. In systems with chronically low DO concentrations, fish will eat less and they will not convert food to flesh as efficiently as in systems with normal DO concentrations.

Aerators

Most intensive, recirculating aquaculture units consist of a rearing unit and some type of water treatment unit. Water flows through the rearing unit where it is contaminated with uneaten feed and fish excrement and its DO content is reduced by fish respiration. Water leaving the rearing unit passes into the treatment unit where it is purified by various physical, mechanical, and biological processes before being passed through the rearing unit again. In some places, recirculating systems are located outdoors and employ large earthen ponds as biological water-purification units. Such systems do not differ substantially from conventional pond aquaculture systems, because phytoplankton are a dominant component. The phytoplankton remove ammonia and release oxygen in photosynthesis, but they also produce large amounts of organic matter in photosynthesis. Because of low light intensity, indoor, recirculating systems do not contain a significant amount of phytoplankton. Organic matter in the system can be traced back to the feed, and the natural supply of oxygen is small.

Oxygen can be added to an indoor, recirculating system at almost any point. However, the part of the system most sensitive to low DO concentration is the rearing unit. If DO concentrations are low in the rearing unit, fish will be stressed. They will not eat and grow well, they will be susceptible to disease, and they may die.

Any place in the system where water flows abruptly to a lower elevation affords the opportunity for gravity aeration. Water may fall over a weir, fall through perforated trays, spray from a nozzle, splash over an inclined surface, flow through a container packed with porous media, etc. This type of aeration is called gravity aeration. Because head loss provides the energy for gravity aeration, there usually is no operating cost associated with it. However, gravity aerators are not very efficient, and the practice of pumping water to a higher elevation just to provide head for gravity aeration is not as economical as many other kinds of aeration (Soderberg 1982).

Recently, there has been considerable interest in pure oxygen contact systems for increasing DO concentrations in fish culture systems. In these systems, U-tubes, packed columns, spray chambers, and many other devices are used to effect transfer of pure oxygen into water which is then passed through the grow-out unit (Boyd and Watten 1989). Pure oxygen contact systems have certain advantages which will not be discussed here, but their economy is not obvious. Until more is known about operating pure oxygen contact systems, mechanical aerators seem more practical.

Principles of Mechanical Aeration

Aerators are mechanical devices that increase the rate at which oxygen enters water. There are two basic techniques for aerating pond water: water is splashed into the air or bubbles of air are released into the water. Hence, we have "splasher" and "bubbler" aerators.

Splasher aerators include vertical pump, pump-sprayer, and paddle wheel aerators. A vertical pump aerator consists of a motor with an impeller (propeller) attached to its shaft. The motor is suspended below a float with a center opening and the impeller jets water into the air at low velocity. A pump-sprayer aerator employs a centrifugal pump to spray water at high velocity through holes in a manifold and into the air. A paddle wheel aerator splashes water into the air as the paddle wheel rotates (Boyd and Ahmad 1987).

Bubbler aerators include diffused-air systems and propeller-aspirator-pumps. In a diffused-air system, an air blower or air compressor is employed to deliver air through an air line, and the air is released through air diffusers located on the bottom or suspended in the water, The propeller-aspirator-pump aerator has a high velocity, uncased impeller at the end of a hollow shaft and housing. In operation, air flows down the shaft by the venturi principle and is released into the water in fine bubbles (Boyd and Ahmad 1987).

Performance

The ability of an aerator to transfer oxygen to water is expressed as the standard oxygen transfer rate (SOTR) and the standard aerator efficiency (SAE). The SOTR is the amount of oxygen that an aerator will transfer in 1 hour to clear freshwater at 20°C which contains 0 mg/I DO. SOTR usually is expressed as pounds of oxygen per hour. The SAE is simply the SOTR divided by power input; it normally is expressed as pounds of oxygen per kilowatt~hour or pounds of oxygen per horsepower. Power input may be expressed as power applied to the aerator shaft (brake power) or the electricity consumption by the aerator (wire power); it is best for practical purposes to express SAE in terms of the rated horsepower of the aeration unit. Standard conditions employed for presenting SOTR and SAE values seldom exist in aquaculture systems. As DO concentration and water temperature rises, actual oxygen transfer rate and actual aeration efficiency decrease with respect to SOTR and SAE. For example, at 30°C and 4 mg/I DO, an aerator would transfer only about 50% of the oxygen suggested by SOTR and SAE. Nevertheless, SOTR and SAE are important for they permit comparisons of efficiency among aerators.

The nomograph, Figure 1, may be used to obtain correction factors for converting SOTR or SAE to actual oxygen transfer under pond conditions.

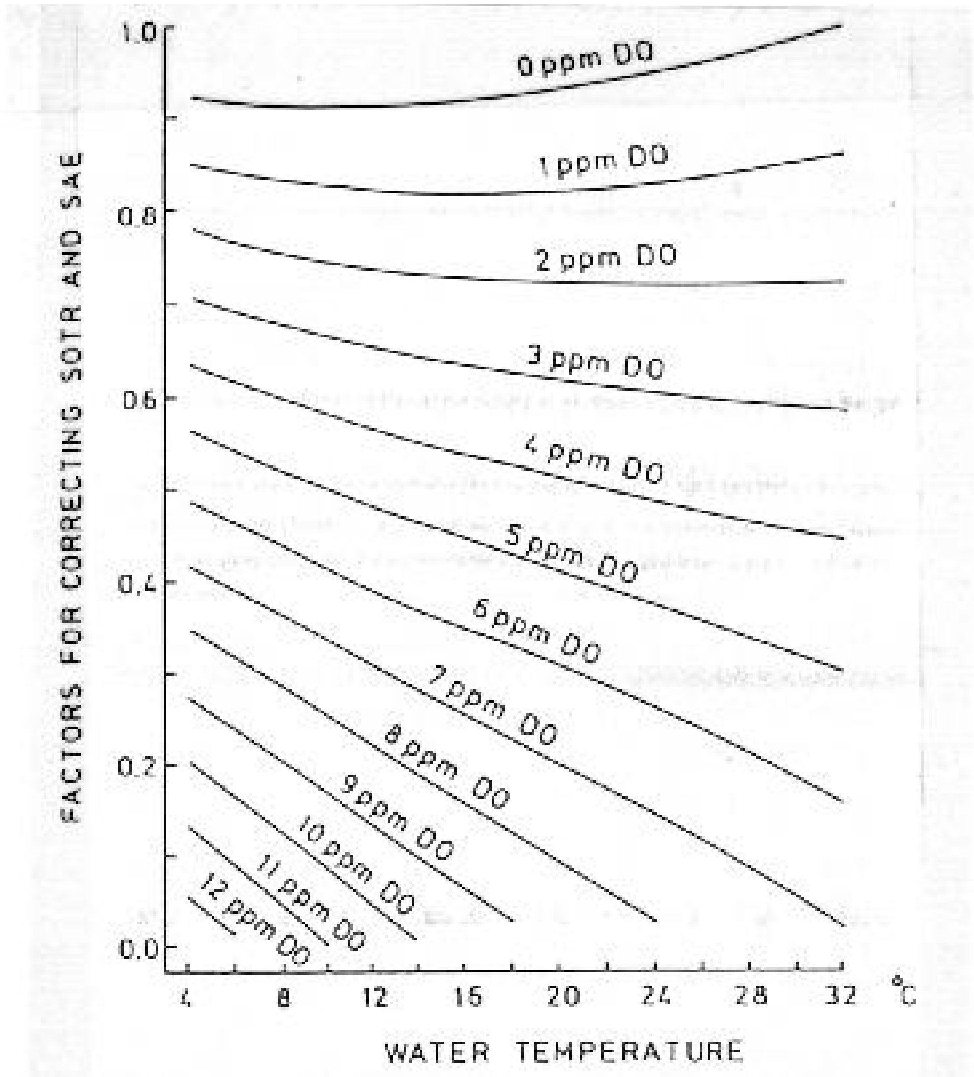

FIGURE 1. Nomograph for estimating correction factors for SOTR and SAE

Researchers at Auburn University evaluated the performance of many aerators and studied the effect of design features and operating conditions on performance. Results in terms of pounds of oxygen transferred per kilowatt of electrical power used are summarized below:

	SAE lb O_2/hp-hr	
Aerator type	**Average**	**Range**
Paddle wheel, all types	3.1	1.6 - 4.3
Propeller-aspirator pump	2.3	1.9 - 2.6
Vertical pump	2.0	1.0 - 2.6
Pump sprayer	1.9	1.3 - 2.8
Diffusion	1.3	1.0 - 2.3

Although research has shown paddle wheel aerators to be highly efficient, they are too large for use in most indoor, recirculating systems. Small vertical-pump aerators, propeller-aspirator-pump aerators, and diffusion aerators are better suited for recirculating systems. SAE values for 0.5 to 2.0-hp vertical pump and propeller-aspirator-pump aerators typically ranged from 1.0 to 2.6 lb $O_{/hp-hr}$. For design purposes, I suggest using an SAE of 2 lb O_2/hp-hr. These types of aerators are designed to operate in a set manner. They only have to be assembled, placed in the aquaculture system, and put into operation.

Diffusion aeration systems are much more complicated. Choices must be made about air pressure, air flow rate, type of diffuser, depth of diffuser, and number of diffusers. The performance of diffusion aeration systems is quite sensitive to the combination of operating variables as illustrated in Table 2 with data collected under different conditions for a particular system. Low air flow rates provided higher SAE values, and at low air flow rates depth of water over the diffuser and the number of diffusers had little effect on SAE. At higher air flow rates, SAE tended to increase with water depth, and increasing the number of diffusers enhanced SAE.

Although SAE is important for comparing aerator efficiency, other factors should also be considered in selecting aerators. These factors include: compatibility with culture system, purchase price, durability and operation lifetime, problems in obtaining service, and personal choice. Also, SAE is simply a measure of efficiency. The SOTR must be considered in determining if an aeration system is large enough to supply the desired quantity of oxygen.

TABLE 2. POWER REQUIREMENT IN HORSEPOWER, STANDARD OXYGEN TRANSFER RATE (SOTR) IN POUNDS OF OXYGEN PER HOUR, AND STANDARD AERATION EFFICIENCY (SAE) IN POUNDS OF OXYGEN PER HORSEPOWER~HOUR FOR A DIFFUSION AERATION SYSTEM OPERATED AT DIFFERENT DEPTHS AND AIR FLOW RATES.

Diffuser depth	Air flow rate	Six diffusers			Twelve diffusers		
(ft)	(ft^3/min)	hp	SOTR	SAE	hp	SOTR	SAE
3	1	0.04	0.13	3.48	0.03	0.13	3.98
	2	0.08	0.22	2.66	0.07	0.24	3.22
	3	0.14	0.29	2.15	0.12	0.34	2.82
	5	0.29	0.42	1.46	0.28	0.38	1.38
	7	0.48	0.54	1.13	0.46	0.48	1.05
	9	0.77	0.66	0.86	0.74	0.61	0.83
5	1	0.06	0.21	3.63	0.06	0.19	3.45
	2	0.12	0.36	3.04	0.12	0.39	3.40
	3	0.19	0.50	2.60	0.18	0.42	2.28
	5	0.39	0.74	1.92	0.36	0.64	1.78
	7	0.62	0.92	1.49	0.59	0.82	1.40
	9	0.91	1.10	1.21	0.89	0.88	0.99
7	1	0.07	0.29	3.91	0.07	0.28	3.87
	2	0.15	0.49	3.18	0.15	0.52	3.42
	3	0.24	0.64	2.64	0.24	0.71	2.93
	5	0.46	0.80	1.72	0.45	0.93	2.05
	7	0.72	0.97	1.34	0.72	1.21	1.69
	9	1.03	1.17	1.13	1.05	1.54	1.46
9	1	0.09	0.35	3.78	0.09	0.31	3.34
	2	0.19	0.63	3.34	0.19	0.64	3.39
	3	0.29	0.88	3.04	0.28	0.89	3.17
	5	0.54	0.97	1.79	0.54	1.30	2.40
	7	0.84	1.24	1.48	0.83	1.66	2.00
11	1	0.11	0.33	3.02	0.11	0.35	3.23
	2	0.23	0.61	2.66	0.22	0.77	3.46
	3	0.36	0.82	2.30	0.34	1.14	3.31
	5	0.64	1.22	1.92	0.63	1.69	2.67
	7	0.95	1.57	1.65	0.94	2.18	2.32

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Design Example

A simple way to determine the amount of fish biomass that can be supported by an aeration system will be described. Suppose that a 2-hp aeration system that has an SOTR of 4 lb of oxygen/hr is to be used in a rearing tank that receives 18°C water containing 5 mg/l DO. The aeration system should keep the DO concentration above 5 mg/l at all times. From Fig. 1, the correction factor from estimating the actual oxygen transfer rate from the SOTR at 18°C and 5 mg/l DO is 0.44. Thus, the aeration system will transfer 1.76 lb of oxygen/hr or 42.2 lb oxygen/day to the water. This is enough oxygen to permit the application of 211 lb feed/day. If fish are fed at 3% of body weight per day, the estimated maximum, permissible standing crop is 7,000 lb of fish. However, this would provide no margin of safety. I suggest a safety factor of at least 1.5 (a safety factor of 2 would be better). The maximum permissible standing crops of fish would be 4,700 lb and 3,500 lb for safety factors of 1.5 and 2, respectively.

Airlift Pumps in Recirculating Systems[1]

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Abstract

Properly sized and operated airlift pump systems will reliably move water to minimize stratification even in 20-A ponds. Their simplicity, low cost, and effectiveness makes airlift pumps especially suitable for use in water reuse systems and hatchery operations. Basic components of an airlift pump system typically include a regenerative or sliding vane blower, an air distribution system of polyvinylchloride pipe, tubing to pipe adaptors, tubing, orifices to control delivery of air, and airlift pumps arranged as single units or in parallel as panels.

Introduction

Airlift pumps have been used to move liquids since at least 1797 (Ivens 1914). Small water reuse systems such as aquaria for hobby fish use airlift pumps to move water through the filter system. The simplicity of airlift pumps makes them a first choice for use in aquaria (Castro 1975, Spotte 1979). However, maintaining an even flow of air and water from multiple pumps connected to a common air source has been a problem. The water flow is usually adjusted with a series of small valves which control air delivery to individual pumps. In larger systems it is difficult to properly balance air flow with a series of valves, but, systems properly designed with fixed orifices to regulate airflow will work reliably. The objective of this paper is to describe construction and operation of airlift pumps for aquaculture and specifically for use in recirculating systems.

Components

Air pump

An airlift system requires a pump or blower to deliver air, a series of tubes and pipes for air distribution, a valve or orifice to control air flow, and a vertically mounted tube as the actual airlift pump. In very small systems, such as in one or two aquaria, air is commonly supplied by diaphragm-type pumps. However, in larger systems either regenerative or sliding vane-type blowers are preferred (Parker 1983). Due to the very shallow depth (3-6 ft.) of most aquaculture facilities it is not necessary to provide air at high pressure; instead, it is more efficient to deliver a larger volume of air (60 cfm/hp) at a relatively low (less than 1 psi) pressure.

Air Distribution

Moving large volumes of air at low pressure requires relatively large diameter pipes. For systems installed on ponds, 3-, 4- and 6-inch diameter lines are commonly used for the main distribution with smaller diameter pipes (2-inch) as laterals. The actual pipe diameter required i s a function of the length and number of bends in the line. As a rule of thumb, when a regenerative blower is hot enough to burn your hand then insufficient air is passing through it. Air passing through the blower will keep it cool and the pipes in the air distribution system will remain cool if properly sized and operated. For smaller systems such as those in a hatchery building or laboratory a 2- or 3-inch pipe will be adequate for the main distribution line with laterals of 0.5- to 1-inch pipe.

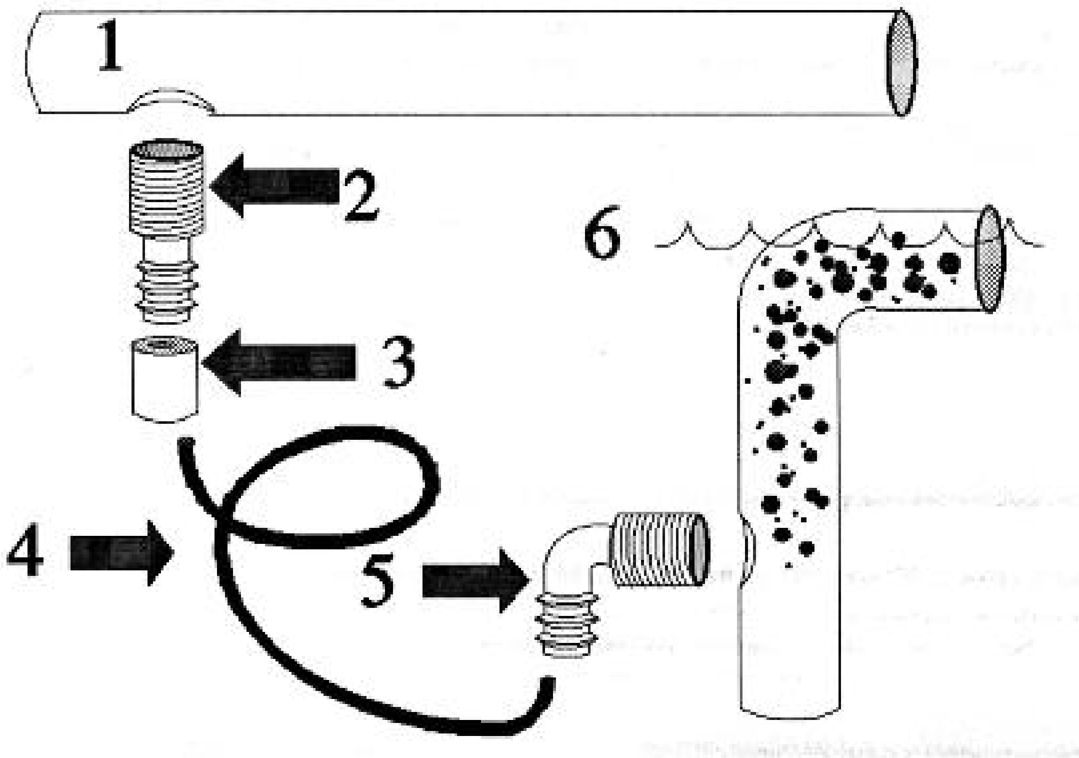

Figure 1.Connection of components for an airlift pump: (1) PVC pipe for air distribution from the air pump or blower; (2) male thread by slip-fit tubing adapter and (3) plug with orifice; (4) airline tubing; (5) 900 tubing adapter and (6) airlift pump in operation indicating optimum placement for maximum water flow and presence of air bubbles in the body of the airlift. (Drawings not to scale).

Connecting tubes

For larger systems, airlifts of 3- or 4-inch diameter are connected to the main distribution line or laterals by 0.5-inch tubing. Black coiled polyethylene tubing of 0.5-inch diameter is commonly used, However, garden hoses and clear vinyl tubing such as tygon tubing are very adequate. On smaller systems with airlifts of 2-inch diameter or less the clear vinyl tubing of 0.25- to 0.5-inch is preferred. These connecting tubes should be as short as possible to minimize friction and back pressure.

Pipe-to-tubing connectors

Valves are not needed in a properly designed air delivery system. Air flow is regulated by properly sizing the components and by use of orifices (Item 4, Fig. 1) to restrict air flow from the system. When schedule 40 polyvinylchloride (PVC) pipe is used for the air distribution system connections for tubing can be made by drilling and taping the PVC pipe (Item 1, Fig 1) to accept male tubing adapters (Item 2, Fig. 1). An orifice placed in the tubing connector at the distribution pipe will regulate air delivery to the airlift pump. Orifices have been made by plugging the tubing connector with a short segment of PVC rod or other material (wood, steel, or other plastics) and then drilling a small hole usually 1/16 to 1/4-inch diameter in the plug. A set of small drill bits ranging from 1/64 to 1/4 inch with size gradations of about 0.015 to 0.070 inch are useful for drilling the orifices. These drills are known as wire size drills and a number 80 drill bit is 0.0135 inches in diameter whereas a number 1 drill bit is 0.2280 inches.

Airlift pumps

The body of the airlift pump is usually a 1- to 4-inch diameter PVC pipe. Small diameter airlifts move more water per volume of air injected than large diameter airlifts (Parker and Suttle 1987). In ponds airlift pumps 3 inches in diameter are preferred whereas in tanks airlifts of 1 to 2 inch diameter are commonly used. The airlifts are constructed from a piece of PVC pipe fitted with a 900 elbow at the top, a means for attachment, and a port for injection of air. Alternately, heavy-walled PVC and polyethylene pipes cut on a 450 angle have been reassembled and welded to form a 900 bend at the upper end. Diffusers have proven to be of limited value due to the problems of fouling and are not recommended.

Several small diameter airlifts placed side-by-side (Fig. 2) or constructed from parallel tubes (Fig. 3 and 4) in a panel will pump more water than will a single large diameter tube. The air and water are more uniformly mixed in small tubes but separate to form a two-phase flow in large tubes. The low density air slips around the high density water in large pipes resulting in substantial noise but little water movement.

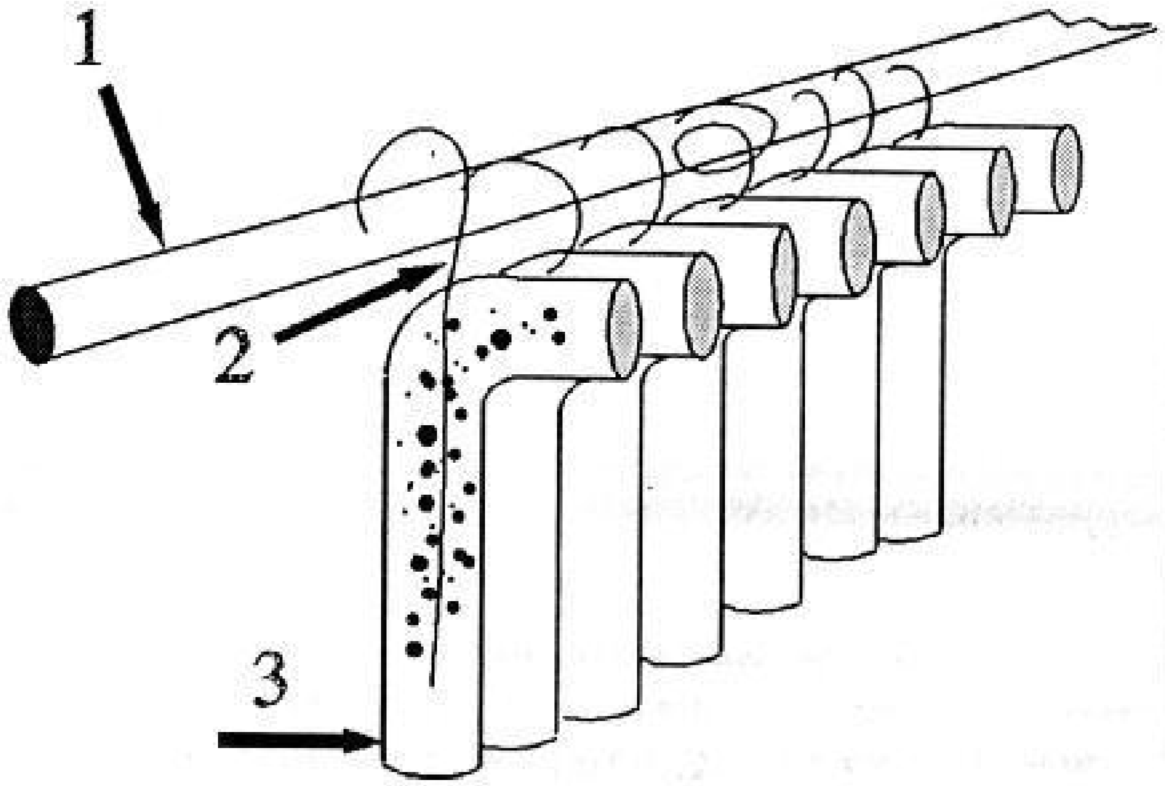

Figure 2.Airlift tubes arranged side-by-side showing (1) air distribution line from air pump or blower, (2) tubes connecting airlift pumps to distribution line, and (3) airlift pumps with bubbles depicted in the first tube.

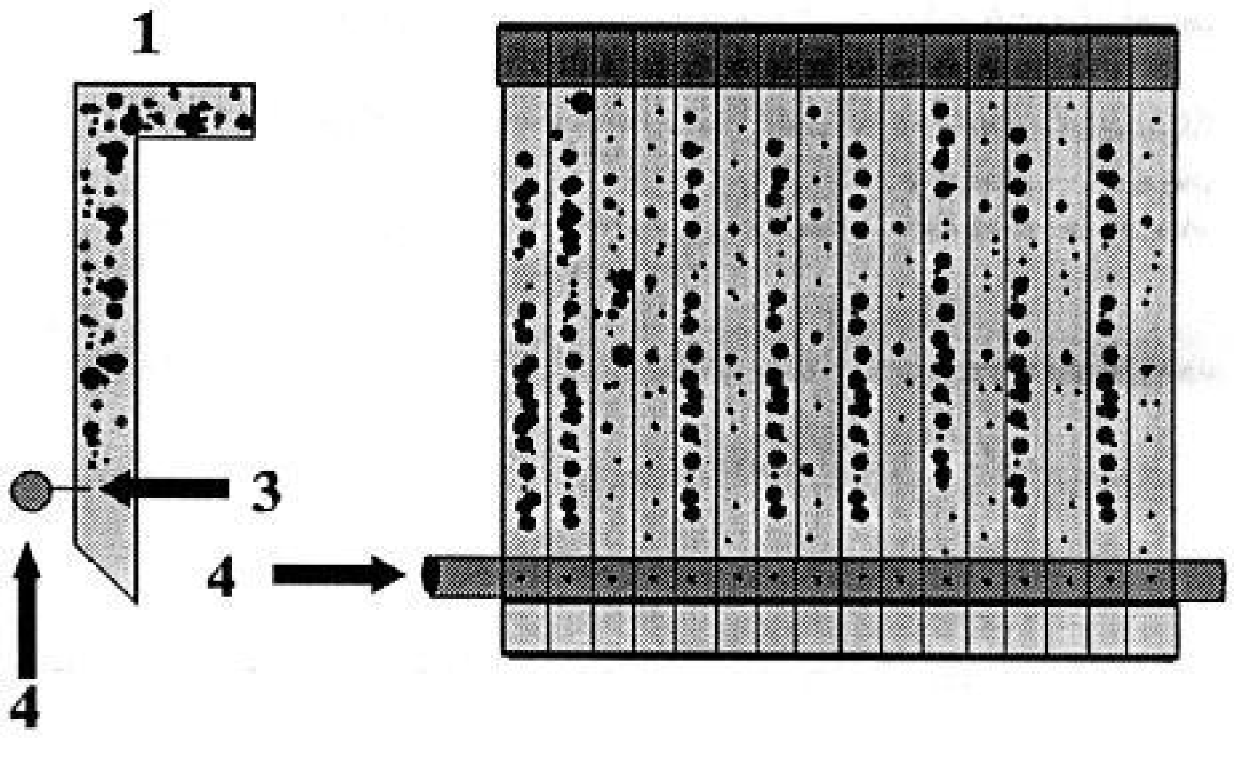

Figure 3.A pond airlift (1) end view, (2) front view, (3) point of air injection into the pond, and (4) Air delivery line Note internal partitions in the panel to minimize side-to-side slippage of air and water.

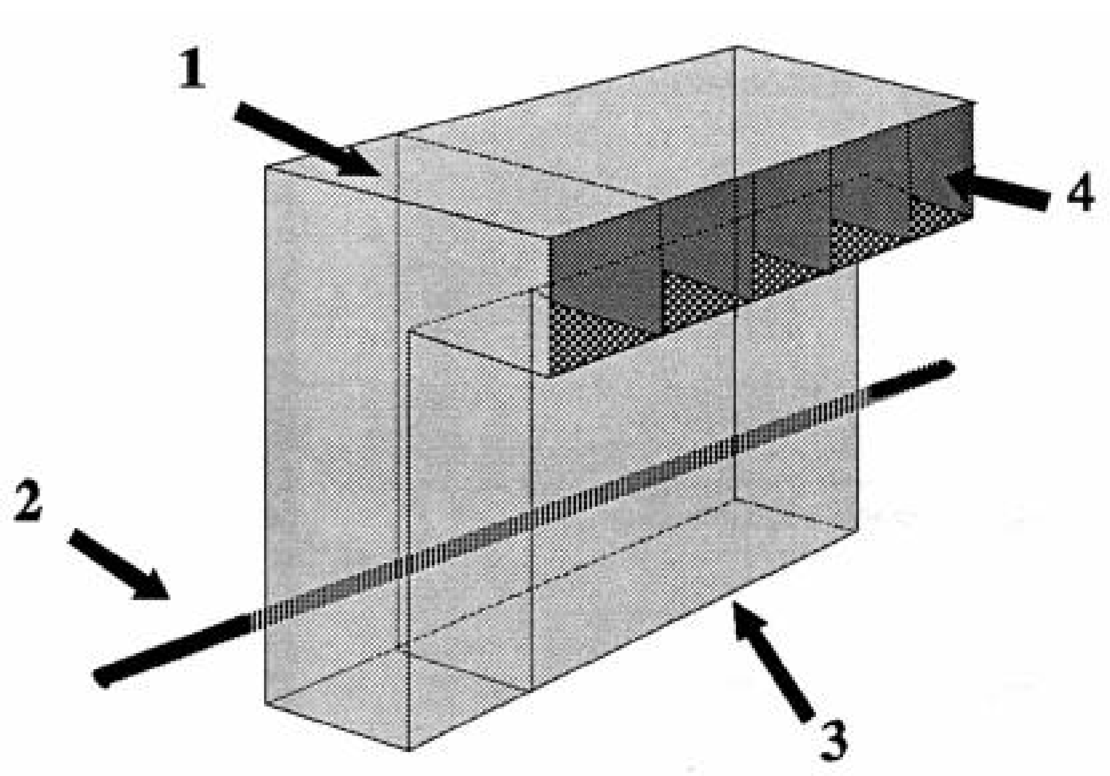

Figure 4.Three dimensional view of a panel air lift: (1) one internal partition shown; (2) air delivery line; (3) water intake port and (4) water discharge port.

Installation of an airlift system

In ponds, airlifts are usually placed along one side and one end, preferably the deep end to establish a circular flow throughout the pond. Ten, 3-inch diameter airlifts per acre have been used to eliminate stratification in ponds (Parker and Suttle 1987). Each airlift received 3 cfm of air and pumped about 55 gpm. A 1-hp regenerative blower will operate 20 airlifts at 30 inches of water pressure. To minimize hardware distribution throughout the pond, airlifts have been arranged in groups of five to ten and supplied with air from a 2-inch lateral line branching from the main distribution line.

Air distribution for indoor systems is commonly arranged in a box-type pattern (Fig. 5) running around the walls of the building with laterals branching to the interior areas. This arrangement facilitates placement of air outlets along the walls or in tanks and provides relatively uniform air pressure as needed. Alternately a central main line down the center with laterals to the sides works very well but air pressure may be less uniform than with the box-type distribution system (Fig. 6).

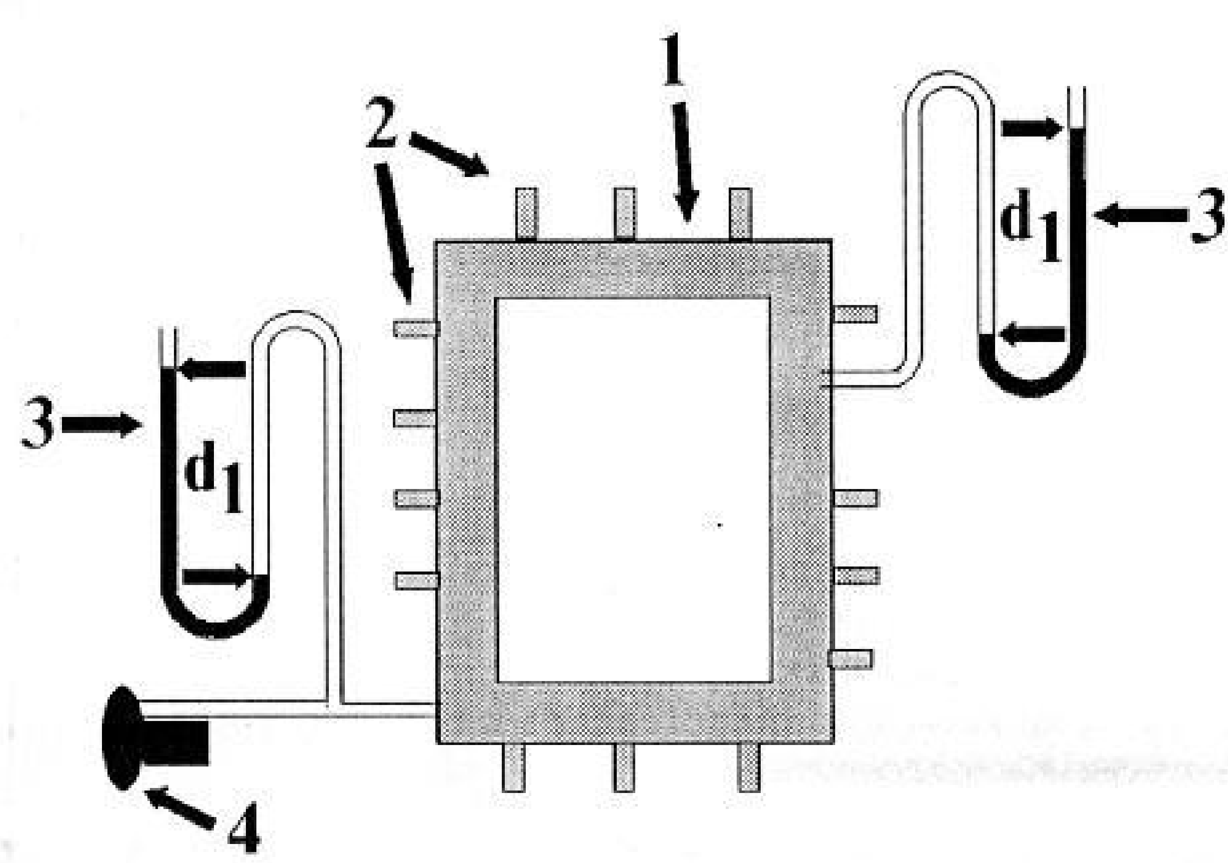

Figure 5.Air distribution system arranged in a box-type pattern to equalize air pressure throughout the system: (1) main air distribution line; (2) outlets for airlifts (or air stones in small tanks); (3) water manometers indicating equal pressure (d1) on front and (d2) on back side of system and (4) blower providing pressurized air for the system.

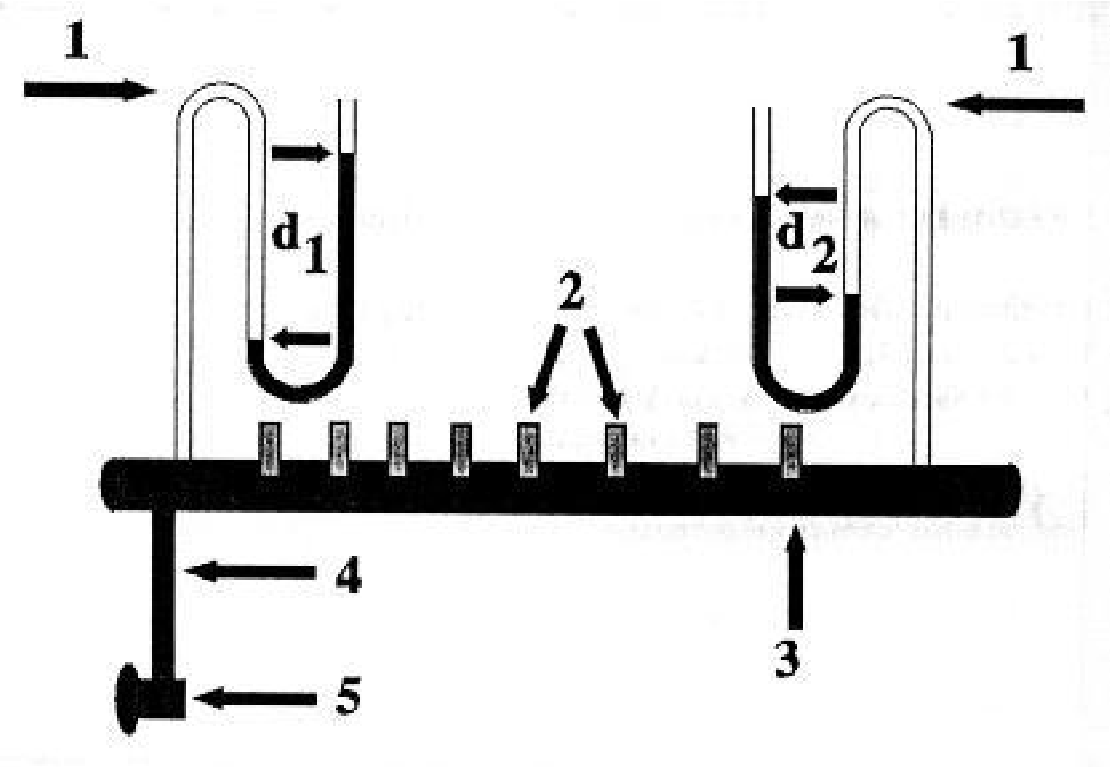

Figure 6.Air distribution system with a single straight manifold: (1) water manometer indicating high pressure (d1) at the head end of the manifold and low pressure (d2) at the tail end of the manifold; (2) outlets for air pumps (or air stones in small tanks) (3) main distribution line or manifold; (4) discharge line from air pump or blower and (5) air blower.

Operation

The number of air outlets on a system (e.g. the number of airlift pumps which can be operated) is a function of the internal resistance (friction loss of pressure) in the system and the water depth at which air is injected If the maximum depth of air injection is 24 inches then the air pressure in the distribution line must be at least 24 inches of water (0.8 psi); however air at 30 inches of water pressure is preferred. Water pressure IS easily measured with a water manometer (Fig 7) constructed from a piece of clear vinyl tubing looped into a large U shape and half filled with water. Tubing of 1/8 and 1/4 inch diameter is commonly used for manometers and can be connected to PVC pipe by drilling, taping and inserting a 1/4-inch male thread tubing adapter. When not in use the 1/4-inch threaded hole can be plugged. A properly sized and constructed air delivery system for air lift pumps will maintain a constant pressure of about 29-30 inches in the distribution line even when all airlifts are removed from the water. The orifices, not the depth of water, regulates the pressure.

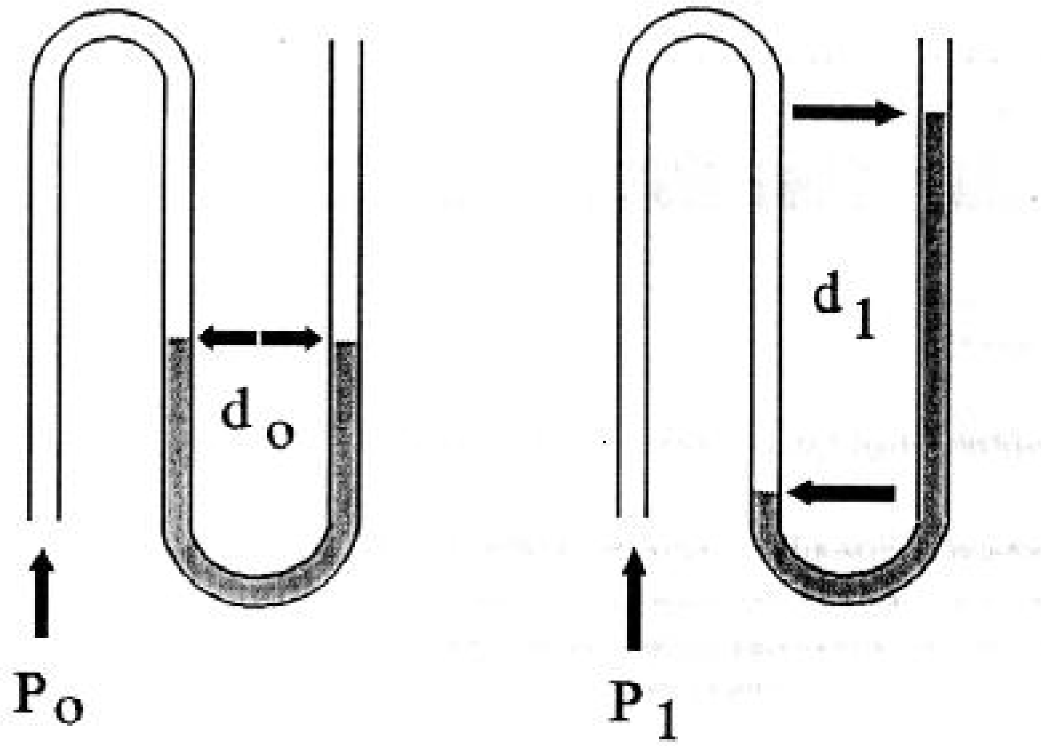

Figure 7.Water manometers constructed of vinyl tubing and half filled with water: (Po) no air pressure applied (blower is off) and there is no difference (do) in the height of the water column in the U-shaped manometer, (P1) air pressure is applied (blower is on) and water columns are different heights. This difference, dl, is typically measured in inches and reported as inches of water pressure.

To lift water from deep tanks or ponds the length of the airlift tubes may vary (Fig. 8) but the point of air injection must remain constant. When an air outlet is not being used it should remain open to exhaust air through the orifice. If the outlet is blocked the pressure in the distribution line and the back pressure on the pump is increased. The increase in pressure is accompanied with an increase in temperature and high temperature contributes to failure of bearings in the blower and motor.

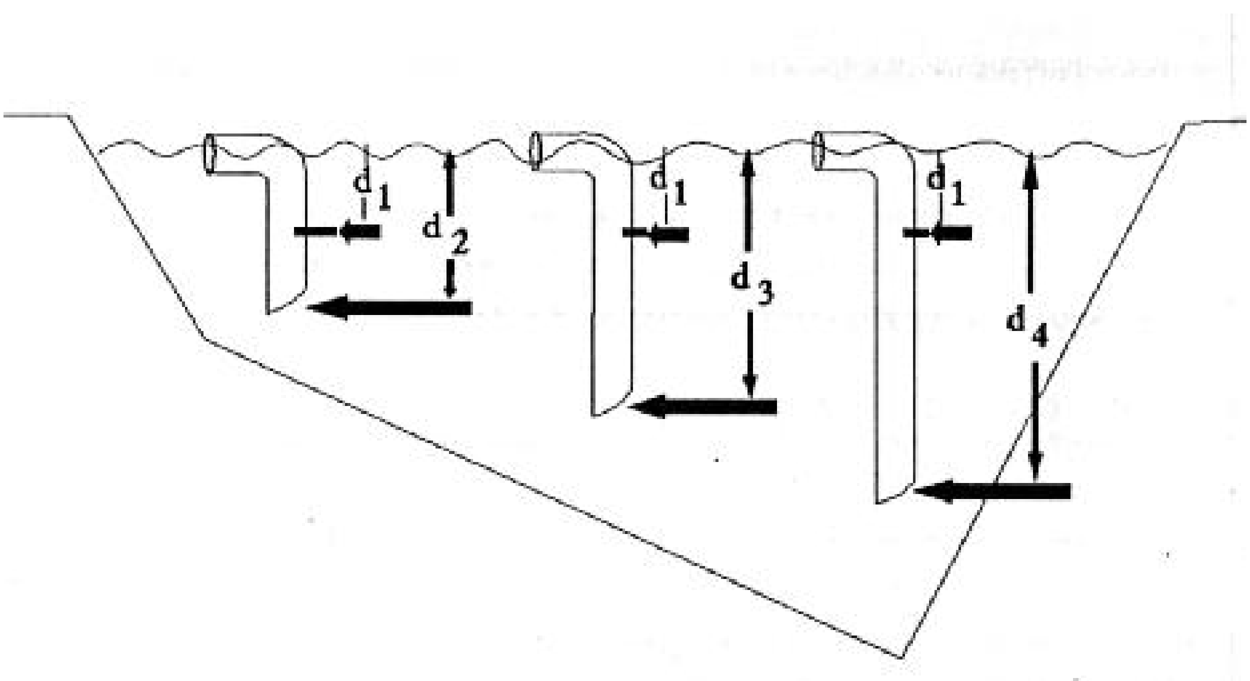

Figure 8.Placement of airlifts to lift water from various depths in a pond or tank. Note: the point of air injection (dl) is constant for all airlifts even though the length of the lift tube varies from short (d2, shallow) to long (d4, deep).

Pilot Systems

The low pressure required to operate air lift pumps makes them easy to assemble and test prior to final installation. Hub-type connections on PVC pipe can be slipped together without glue and will usually stay together due to friction long enough to conduct preliminary test of a system. If a fitting does separate, it can be temporarily held together with tape or by drilling a small hole through the pipe and coupling for insertion of a nail or small screw. Before installing a permanent system, it is recommended that a pilot system be evaluated to become familiar with the principals of regulating low pressure air in aquaculture. Pilot systems have ranged in size from a 10-hp regenerative blower delivering air to airlifts in a 20-A pond down to very small systems using a discarded automobile smog pump (a sliding vane pump) providing air for a few tanks or aquaria. Once the principles are understood and the pilot system is operating properly the component parts can be permanently assembled.

Acknowledgments

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Footnotes

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The Application of Pure Oxygen in Recirculating Systems

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Introduction

Pure oxygen (LOX) or high purity oxygen (PSA) can oxygenate fish culture water in excess of 100% saturation DO, something not possible with atmospheric air (21% O_2) without exceeding total gas pressure (TGP) over 100 percent

In aquaculture, especially intensive aquaculture, oxygen availability to the fish has been recognized as the first limiting factor. In intensive aquaculture, under conditions of high loadings (weight of fish per unit flow) and high densities (weight of fish per unit of space), only pure oxygen can meet the demands. This is even more critical in recycling systems where organic matter and nitrification exert significant additional oxygen demands on the system.

Oxygen Required

The aeration system must be designed to deliver the amount of oxygen required. In a recycling system it is difficult to determine the oxygen required, yet such information is important (Losordo, 1991). The major consumers of oxygen can be identified as the biomass, organic matter (BOD), and the biofilter. Each of these are functions of many physical and biological variables.

In this paper fish, specifically the rainbow trout, will represent the cultured organism The oxygen consumption rate (metabolic rate) is primarily a function of water temperature and fish size. These same parameters are used to determine optimum feeding levels. Consequently oxygen consumption is a constant relative to feed fed. For salmonids, as a group, this value is from 200 to 250 g of oxygen per kg of feed (Westers, 1979). For esocids (tiger muskies), a coolwater, non-active fish, it is 110 g (Pecor, 1978), and for the common carp, a warmwater species, it is 230 g (Huisman, 1974). Although probably only 30% is actually utilized as "feeding metabolism" (Machiels, 1987) the feeding level, for practical application, can be related directly to the metabolic rate of the fish (Westers, 1979). Nevertheless, these values, as well as others used in this paper, are not absolute. This, of course, is characteristic of biological functions in general in contrast to those of the science of physics.

For rainbow trout, 250 g of oxygen is required per kg of feed. Equation 1 determines the daily oxygen (g) requirement per kg biomass, equation 2 expresses it as mg/L DO per 1.0 % BW feeding level.

$$gO_2/\text{kg fish} = \frac{\%\ BW \times 250}{100} = 2.5\ g \qquad (1)$$

$$\text{mg/L/kg fish} = \frac{\%\ BW \times 250}{1.44 \times 100} = 1.74\ \text{mg/L} \qquad (2)$$

The oxygen demand placed on the unconsumed feed and the feces is a function of the system design. The objective is to rapidly remove the suspended and settleable solids. Accordingly it will be assumed that the

BOD_5 loading is reduced by 70 percent. Wimberly (1990) determined that the solid waste trapped in the biological filter requires a substantial amount of oxygen. For channel catfish he determined this rate at approximately 2.3 times the BOD_5. The author furthermore indicated that the average BOD,sub>5 excretion rate for channel catfish, fed 1.0 % BW, was 2.3 g O_2/kg fish. If the same values are applied to rainbow trout and a 70 percent removal is assumed, the daily oxygen requirement (g) for solid waste per kg fish is:

$$gO_2/kg\ fish = (2.3)\ 2.3 \times 0.30 = 1.59\ g \qquad (3)$$

The oxygen required to oxidize one g of ammonia to nitrate is 4.18 g. If it is assumed that 1.0 kg feed generates 30 g of total ammonia nitrogen (TAN), then 1.0 kg feed requires 125.4 g of oxygen for the nitrification process in the biological filter. Equation 4 determines the daily oxygen (g) demand for nitrification per kg biomass per 1.0 % BW feeding level.

$$g0_2/kg\ fish = \frac{\%\ BW \times 30 \times 4.18}{100} = 1.25\ g \qquad (4)$$

Understandably, the entire processes are more complicated than presented here. Simple, direct mathematical expressions (stoichiometric values) have been applied to very complicated processes which are influenced by a great many factors and interactions.

In the example above, the total daily oxygen demand for the system is 5.34 g per kg biomass fed at 1.0 % BW per day. For a feeding level of 2.0 percent the demand would be twice that or 10.68 g O_2/kg/day. It has been suggested by Rosati (1990) to assume a one to one ratio of oxygen to feed. This appears to be a reasonable approach for design purposes.

Oxygen Dynamics

The advantage of pure oxygen lies in the fact that DO levels exceeding 100 percent saturation can be achieved without causing TGP to exceed 100 percent (Westers1 1990). Today's trend in aquaculture is towards high density rearing. In salmonids, densities in excess of 100 kg/m^3 have been obtained. At such levels, pure oxygen must be used unless very large volumes of water are introduced into the rearing unit. Equations 5 and 6 show the relationship of density (D) or space with loading (Ld) or flow.

$$D = \frac{Ld \times R}{.06} \qquad (5)$$

$$Ld = \frac{D \times .06}{R} \qquad (6)$$

D is density expressed in kg/m^3 Ld is loading expressed in kg/L/min, R is the rearing unit water turnover rate in number per hour and .06 represents 1.0 L/min x 60 min or 60 L which is 0.06 m^3.

At a density of 90 kg/m^3 (5.6 lbs/ft^3) and an R of 1.5, the loading is 3.6 kg/L/min (30 lbs/gal/min). The required incoming DO level (DO_{in}) can be determined with equation 7.

$$DO_{in} = \frac{(Ld \times gO_2/Kg\ feed \times \%\ BW)}{100 \times 1.44} + DO_{out} \qquad (7)$$

The value 1.44 represents 1 .44g (1.0 L/min @ 1.0 mg/L x 60 min x 24 hr - 1,440 mg/day). At the 1.0 % BW feeding level, and a minimum DO_{out} of 5.0 mg/L, the DO_{in} is:

$$DO_{in} = \frac{(3.6 \times 250 \times 1.0)}{100 \times 1.44} + 5.0 = 11.25 \text{ mg/L} \qquad (8)$$

Per cubic meter rearing volume with an R of 1.5, the intake flow is 25 L/min. With DO_{out} at 5.0 mg/L, 180 g 0_2 (25 x 5 x 1.44) is available for BOD and biofilter. The BOD requirement is 1.59 g/kg fish (eq. 3) and the nitrification process requires 1.25 g/kg (eq. 4). For 90 kg fish this adds up to a demand of 225g O_2. With 180g O_2 available, the deficit is 75g O_2. But to maintain a biofilter effluent level of 2.0 mg/L, an additional 72 g O_2 must be made available (25 x 2 x 1.44), for a total of 147 g or 4.1 mg/L DO, in addition to the 5.0 mg/L. In other words, the DO_{in} to the filter should be at 9.1 mg/L to satisfy BOD and nitrification. To accomplish this the DO_{in} to the system as a whole should be at 11.25 + 4.1 or 15.35 mg/L. Since 2.0 mg/L should be in the recycled water, 13.35 mg/L must be added to the system. This requires the application of pure oxygen.

Table 1. Supplemental DO_{in} mg/L required for rainbow trout maintained at five rearing densities (D) during a doubling of the metabolic rate (from 200 to 400 mg/Kg/hr) for brief periods of 5, 10 and 15 min. DO_{out} = 5.0 mg/L Act. DO_{out} = 3.0 mg/L R is 1.5, flow is 25 L/min/m^3 volume

1	2	3	4			5			6			7		
D	H_20 Vol.	O_2 reserve	mgO_2 req. at activity over time (from res.			mg 0_2 diff. with reserve during time			mg/L DO suppressed during act. period			mg/L DO suppl. req. during act. period		
kg/m^3	L	mg	5 min	10 min	15 min	5	10	15	5	10	15	5	10	15
30	970	4850	500	1000	1500	4350	3850	3350	4.50	4	3.50	0	0	0
60	940	4700	1000	2000	3000	3700	2700	1700	4	2.90	1.80	0	.40	2.90
90	910	4550	1500	3000	4500	3050	1550	50	3.40	1.70	.05	0	4.70	7.10
120	880	4400	2000	4000	6000	2400	400	-1600	2.70	.50	0	1.90	9	11.30
150	850	4250	2500	5000	7500	1750	-750	-3250	2.10	0	0	6.40	13.20	15.50

Col. 3 is 5 x Col. 2
Co. 4 is {(200 x D ÷ (60 min)} x min. (5; 10; 15)
Col. 5 is Col. 3 - Col. 4
Col. 6 is Col. 5 ÷ Col. 2
Col. 7 is {(3 x Col. 2) - (Col. 5)} ÷ (25 x min)

Note: Higher exchange rates (R) result in proportionally less suppl. DO required. For R = 4, for instance, multiply values of Column 7 by 0.375 (1.5 ÷ 4)

It is well known that fish, when they become excited, by feeding or fright, can double their metabolic rate for short periods of time. This greatly increased demand on oxygen can result in depletion and death. This problem can be especially acute under conditions of high rearing densities since there is little reserve oxygen available. Table 1 illustrates this for five different rearing densities. For the low density of 30 kg/m^3, even 15 minutes of hyperactivity will not depress the DO below 3.5 mg/L, while at 90 kg/m^3, 10 minutes of hyperactivity will depress the DO down to 1.7 mg/L and 1 5 min of such sustained activity would, theoretically, result in 0.05 mg/l DO, Higher densities cannot even support 5 minutes without depressing DO below 3.0 mg/L, a level considered safe for short term exposure for rainbow trout, the species considered here.

For high rearing densities, the oxygen capacity of the aeration system must be designed above that required for the routine needs. The biofilter, too, must not go anoxic since this will kill the bacterial culture. However, since the DO_{out} of the rearing unit, in this example, exceeds by 4.1 mg/L the minimum of 5.0 mg/L required, the situation is not as critical as it appears. Nevertheless, it is advisable to continuously monitor the DO_{out} and select a minimum safe (for fish as well as biofilter) level that will trigger delivery of supplemental oxygen.

Oxygen Application

Pure oxygen can be added to the water in many different ways, such as U-tubes, packed columns, aeration cones and various diffusers (Colt and Watten, 1988). A recent technique is the low head oxygenator (LHO) consisting of a series of chambers in a box. The water enters the top of the box through holes while, at the same time, forming a water seal. Sealing is important to prevent oxygen gas from escaping. For this reason the packed column has been converted to a sealed column, a technique described in detail by Westers (1990). This approach requires a head of five feet, while the LHO was specifically developed to avoid this. It can operate rather efficiently with a head of one foot or even less.

Two sources of oxygen are commonly used, LOX (liquid oxygen) and PSA (pressure swing adsorption) generated oxygen. Their advantages and disadvantages are described in some detail by Colt and Watten (1988).

Since the papers of Westers and of Colt and Watten referenced above, as well as others, can be found in the publication "Oxygen supplementation, a new technology in fish culture" which is available at no cost from the U.S. Fish and Wildlife Service as Information Bulletin #2 from P.O. Box 25486, Denver Federal Center, Denver, CO 80225, I will not repeat the information here, but instead recommend the reader obtains this document which contains 17 papers related to the technology of oxygen injection, water quality aspects, biological aspects, and monitoring technology. It is a valuable resource for anyone considering the use of pure oxygen.

Information on the LHO, a technique of more recent origin, can be obtained from Zeigler Brothers Inc., P.O. Box 95, Gardners, PA 17324-0095, phone 717-677-6181.

Oxygen Consequences

It has been pointed out that the oxygen requirement can be related, directly, to the feed. Since feed is the source of all "pollutants", oxygen can be used to predict those components. More oxygen means more pollutants that require removal from the system.

In the example, with rainbow trout, 250 g of oxygen are required to metabolize one kg of feed. Therefore, 250 g of oxygen which represents 1.0 kg of feed, results in the generation of 30 g TAN, 300 g solids and 325 g of CO_2.

Carbon dioxide is very soluble in water and difficult to remove. The toxicity of CO_2 is aggravated by low DO and low pH. These conditions must be avoided through oxygenation and buffering, either natural (high alkalinity water) or artificially by adding lime or sodium bicarbonate.

Lack of CO_2 control can be a weak link in recycling systems. An open packed column works well but requires lifting the water an additional five to six feet above the existing design. It could be combined with a trickling biofilter. Rotating biodrums or discs also accomplish some CO_2 degassing in contrast to fluidized filter beds and other types of upflow filters. Since the air contains only 0.03% CO_2 (300 mg/L), excessive CO_2 released from the water can increase the atmospheric CO_2 level in a closed environment (building) to manyfold this level, making it increasingly more difficult to "absorb" additional CO_2, thus reducing the efficiency of the degasser. Since recycling systems are, generally, indoors, the building should be outfitted with exhaust fans, either directly exhausting the degasser itself or exchanging the building air at the proper rate.

What level the carbon dioxide must be reduced to in the culture water depends on a great many factors, such as species, dissolved oxygen level, pH and most likely, other water chemistry characteristics. The literature is not clear on this issue (Westers, 1991) and thus it represents an important topic for research.

Oxygen Economics

Oxygen requirement has been expressed in terms of food fed and, consequently, it can be expressed in terms of fish produced.

Table 2 provides cost figures for O_2 in cents per kg of fish produced. These costs are based on 50 percent and 75 percent absorption efficiencies, as well as three feed conversions (FC), three oxygen costs, and three ratios of oxygen to feed.

The cost of oxygen, whether LOX or PSA, should fall somewhere between 30 and 50 cents per 100 cubic feet. This includes the energy requirement, maintenance, equipment depreciation and the rental cost of LOX storage.

Table 2. Cost of oxygen in cents per kg fish produced based on two absorption efficiencies, three O_2 costs, three feed conversion ratios (FC), and three 02 consumption ratios (kg O_2 to kg feed).

Ratio O_2 Feed	**O_2 cost in cents per kg**	**per 100 ft^3**	**Oxygen Cost (cents) per kg of fish produced: .75% Absorption FC 1.0**	**1.5**	**2.0**	**.50% Absorption FC 1.0**	**1.5**	**2.0**
	7.5	30	4.9	7.5	10.0	7.4	11.2	15.0
.50	10.0	40	6.7	10.0	13.3	10.0	15.0	20.0
	12.5	50	8.4	12.5	16.8	12.6	18.8	25.2
	7.5	30	7.5	11.1	15.0	11.2	16.8	22.4
.75	10.0	40	10.0	15.0	20.0	15.0	22.6	30.0
	12.5	50	12.5	18.7	25.0	18.8	28.2	37.6
1.00	7.5	30	10.0	15.0	20.0	15.0	22.6	30.0
	10.0	40	13.3	20.0	26.6	20.0	30.0	40.0
	12.5	50	16.6	24.9	33.3	25.0	37.4	50.0

An 800 cubic feet per hour (95 percent purity) PSA oxygen generating system at one of Michigan's state fish hatcheries delivers oxygen at a cost of 49 cents per 100 cubic feet (Hall, personal communication).

This includes the following:

1. Two 40 H.P. rotary screw air compressors $22,400

a. Depreciation (20 years) $ 1 ,600
b. Maintenance $ 3,530
c. Energy @ 7 cents/kwh $16,188
Total $21,318

2. Four 200 ft^3 PSA oxygen generators $47,200

a. Depreciation (30 years)	$ 1,573
b. Maintenance	$ 8,261
c. Energy	$ 1,417
Total	$11,251

3. 800 ft^3 O_2 per hour @ 95 percent purity x 8,760 hours equals 6,657,600 cubic feet of oxygen per year. At a total cost of $32,569/yr the cost per 100 cubic feet is $.49

It was pointed out that the application of pure oxygen allows for high density rearing on moderate flows of water. Since more fish are reared per unit space and generating oxygen is cheaper than pumping water, pure oxygen can be an economically sound approach to intensive fish culture, despite the apparent high cost per fish produced. One must carefully consider all aspects.

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Current Status On Profits In Recirculating Systems

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Introduction

What are called "commercial recirculating aquaculture systems" have drawn a lot of attention in recent years from current aquaculture producers as well as those interested in becoming producers or investors. Why is there this interest in commercial recirculating aquaculture systems (CRAS)? Is it a passing fancy that will fade away like the Edsel or "junk bonds"? Or, is it an appropriate technology for commercial aquaculture production whose time has come or is coming like pen raised salmon, raceway raised trout, and pond raised catfish?

What do the proponents of CRAS see as its advantages or potential advantages over other commercial fish production systems and/or the wild capture of fish? Here are some of those suggested advantages or potential advantages:

** has few geographic limitations on location of production

** allows for better quality control of product than other commercial production systems or wild capture fisheries

** allows for better control of diseases and contaminants

** provides much better control of predators than pond systems

** reduces waste management problems through reduced volume of waste water

** through control of the fish production environment, provides opportunity to time production to the market's signals rather than the seasons of the year.

What do the protagonists offer as reasons why CRAS are not or will not be successful in large enough numbers to be significant to the aquaculture industry ? Here are some of the suggested disadvantages or potential disadvantages:

** the cost of reconditioning and recirculating the water will be too costly

** the high densities of fish (pounds of fish per volume of water) will cause higher stress and therefore higher incidence of disease

** the cost of supplemental oxygen will be too high

** the cost of special feeds will be too high

** the cost of total energy requirements will be too high

** the cost of removing nitrogen and controlling carbon dioxide will be too high

** the required capital investment is too high

** many have tried and failed.

Who is correct? Do we have the technology to design a CRAS that can produce one or several species of fish at a volume, quality and cost that is profitable? I believe the answer is "MAYBE". I believe the scientists, farmers, investors and entrepreneurs who began the pond raised catfish industry over a quarter century ago had the same enthusiasm, similar questions and similar problems to address. Mississippi is the leading catfish producing state today. The first pond built in Mississippi specifically for the commercial production of channel catfish was built in 1965 in Sharkey County. That pond covered 40 acres and produced 10,000 pounds of catfish in January 1966 (Wellborn, 1988). Mississippi had 95,000 acres of commercial catfish ponds in 1991 (USDA, 1991), better than a 9 percent compound annual growth rate over 26 years. In the early years raising catfish in ponds was probably more expensive than dropping a hook and line in the river, however, the catfish raised in ponds were a different product. Fish raised in recirculating systems will similarly be a different product than wild caught or pond raised fish.

Commercial Aquaculture Recirculating Systems Cost Studies

Thomas M. Losordo, J. E. Easley and Philip Westerman of North Carolina State University, Raleigh, NC, have been conducting research on recirculating systems for commercial production for several years. Utilizing information from a producer survey and their own research experience they developed a "best case" simulation model of catfish (and hybrid striped bass) production in a 9 tank intensive culture system (Losordo, et. al., 1989). The model system was designed for periodic harvesting, year round and was expected to produce approximately 400,000 pounds of fish per year. The capital investment required was estimated to be approximately $345,000 with 50 percent coming from equity and 50 percent coming from debt.

That simulation model demonstrated the technical feasibility of raising 6 inch stocker catfish to a harvest weight of 1,25 pounds in 30 weeks (210 days). Overall estimated production costs for the "best case" scenario were $ .95 per pound. (The "best case" scenario for hybrid striped bass was $1.67 per pound.) The breakdown of the costs per pound, as reported in that 1989 study, are shown in the two left most columns in Table 1.

The research on commercial recirculating systems at NCSU has continued as they continue to develop "non-biased and non-proprietary studies of the biological, economic and engineering aspects of recirculating systems." (Losordo & Westerman, 1991) This recent report covers an 11 tank system (3 nursery tanks and 8 growout tanks) designed for continuous production and regular periodic harvesting throughout the year. Total annual production is estimated to be over 96,000 pounds of tilapia. The complete production system, including building related costs, required an initial investment of $188,634. The base case simulation (with atmospheric oxygen) indicated that fish production costs were approximately $1.27 per pound. (The authors note that using pure oxygen would increase the estimated costs of production to approximately $1.30 per pound. The two right most columns in Table 1 show the breakdown of the production costs per pound as reported in that 1991 study.

Table 1. NCSU Estimated Production Costs From Simulation Models of Recirculating Systems For Catfish (1989) and Tilapia (1991).

ITEM	CATFISH (1989)		TILAPIA (1991)	
	% of Cost	Cents/lb.	% of Cost	Cents/lb.
Feed	32.3	30.7	20.58	26.14
Labor	7.9	7.5	13.33	16.93
Recirculation	3.1	3.0		
Heating	15.0	14.3	2.60	3.30
Oxygen	2.7	2.6		
Aeration			5.68	7.21
Pumping			5.44	6.91
RBC Energy			1.34	1.70
Elec. Demand			.79	1.00
New Water			.08	.10
Fingerlings	6.8	6.5	7.57	9.61
Depreciation	9.3	8.8	14.35	18.22
Maintenance	7.9	7.5	7.41	9.41
Operating Interest	2.0	1.9	1.18	1.50

Cost of Borrowed Capital	7.2	6.8	10.96	13.92
Cost of Equity	5.7	5.4	8.68	11.02
TOTAL COST PER POUND		$0.95		$1.27

Research on the viability of commercial recirculating aquaculture systems is also being conducted at Illinois State University. A 1990 report (O'Rourke, 1990) contained production cost estimates based on a simulation model of tilapia production in a recirculating system similar to one located on the ISU Research Farm. That simulation was for a system designed to produce on a batch basis approximately 34,000 pounds of tilapia per year. The complete production system, including building renovation cost, required an initial investment of $78,650. The base case simulation indicated that tilapia production costs were approximately $1.68 per pound. Table 2 shows the breakdown of the production costs per pound for that simulation.

Table 2. ISU Estimated Production Costs From Simulation Model of Recirculating System For Tilapia (1990).

ITEM	**TILAPIA (1990)**	
	% of Cost	**Cents/lb.**
Feed	17.2 %	$ .29
Wages	17.5	.29
Water	0.7	.01
Electricity	6.0	.10
LP Gas	5.7	.10
Liq. Oxygen	11.9	.20
Testing Supplies	.6	.01
Insurance	1.7	.03
Fingerlings	6.7	.11
Depreciation	9.5	.16
Maintenance	5.9	.10
Property Tax	.6	.01
Operating Interest	5.3	.09
Interest on Investment	8.4	.14
Miscellaneous	2.1	.03
TOTAL COST PER POUND		$1.68

Other Sources of Data For Costs and Profits

There are several private companies and groups who have cost of production estimates for commercial recirculating aquaculture systems. In some instances the cost data is based on actual commercial scale production experience with the systems. In other instances the cost of production estimates are based on how the systems are expected to perform when constructed and stocked. In both cases the cost data is generally not available to the general public but is shared with bonafide prospective investors. This lack of publicly available cost data is not unusual . This is the usual situation when new technology applications are emerging in a commercial setting. However, it does suggest that one must carefully and thoroughly evaluate such data to appreciate the applicable risks and uncertainties in a commercial enterprise.

Several universities, other than ISU and NCSU, are conducting research related to the commercial viability of recirculating aquaculture systems. These efforts will produce additional data on the biological, engineering and economic aspects of such systems. Some of this data will seem slow in coming to the public because this kind of production system research requires several years to conduct and verify the findings. Until more public, independently derived data is available farmers/investors may find it useful to evaluate investment opportunities in recirculating systems in a capital budgeting framework. The remainder of this paper is dedicated to describing a capital budgeting approach that may be useful, when accompanied by rigorous examination of performance claims, in deciding whether or not to invest in a (any) particular commercial recirculating aquaculture system.

The Capital Budgeting Approach To Investment Analysis

When one considers investing in assets to expand their current business or to expand into a new product market there are several basic questions they seek answers to. Should I make the investment? Will the investment pay off? Is this the best use of my capital?

These questions obviously apply to those considering investing in a commercial recirculating aquaculture system. Answering the questions is complicated by the fact that such investments typically require a substantial initial investment of capital with potential returns on that investment occurring over several years. Those future returns on the investment are uncertain and risky to some degree. The degree of that uncertainty and risk is related to the characteristics of the individual investment opportunity. For example, investing in a 10 year treasury bond is considered to be almost risk free. There is little doubt about the payment of interest on the bond and the return of the original investment when the bond matures. On the other end of the spectrum, investing in a new swine confinement enterprise is considered to be relatively more risky. That is due to the fact that market prices for the pork produced, the operational efficiency of the enterprise and the costs of the inputs over the years are uncertain. The swine confinement investment must offer the investor an opportunity to earn a significantly higher expected return if it is to attract investment capital away from less risky opportunities.

An investment in a commercial recirculating aquaculture system has the same general risks and uncertainties as other livestock enterprises; uncertain future market prices, uncertain and risky operational characteristics and uncertain input costs. Further, some of the technology used is relatively new in this type of commercial enterprise so even less is known about its technical performance. Investment in such risky ventures calls for a rigorous analysis and a logical framework within which to make the investment decision.

The net present value method of evaluating investments is the preferred framework because it takes into account the time value of money. It explicitly recognizes that a dollar today (present value) is worth more than a dollar to be received at some future time. The present value of that dollar depends on when that dollar will be received (or spent) and the appropriate interest rate representing the time value of money. The net present value method allows one to compare alternative investments of different durations and different levels of risk on a uniform basis. A hypothetical capital budgeting problem will be utilized to illustrate the application of the net present value method in evaluating investment opportunities in commercial recirculating aquaculture systems.

Net Present Value Method Demonstrated

The net present value method for evaluating a capital budgeting project can be applied in several steps:

1. Determine the net investment required to initiate the project.
2. Estimate the incremental operating cash flows expected over the life of the project.
3. Estimate the non-operating cash flows expected at the end of the project.
4. Determine the appropriate cost of capital or discount rate of interest.
5. Calculate the net present value of all cash flows.
6. Evaluate the impact of changes in the estimated cash flows on the net present value.
7. Compare this investment with alternative investment opportunities.

This approach is applied to a hypothetical commercial recirculating system investment opportunity called the

Superfish Recirculating Project. The investment and operating costs are derived from a previously reported simulation model (O'Rourke, 1990) and are not meant to be taken as representative of any specific recirculating system. Tables 3 through 9 contain the data utilized in this illustration.

Step One

The initial capital investment required for the Superfish Recirculating Project is shown in Table 3. An acre of land and an existing building are purchased. The land and building (former swine nursery) are purchased for $10,000 and refurbishing the building costs $10,000. The market value of the land alone is estimated to be $2,000. The equipment for the Superfish system will cost $60,000 installed. It is estimated that an additional $2,000 in net working capital will be required due to an increase in inventory of feed, oxygen and other items. The total initial investment requirement is estimated to be $82,000. This cash outflow is assumed to occur at the beginning of the Superfish project.

Table 3.Initial Investment Outlay (Year 0) for Superfish Recirculating Project.

Item	Outlay
Land	$2,000
Building	$18,000
Equipment	$ 60,000
Total Fixed Assets	$ 80,000
Change in Net Working Cap.	$2,000
Total Investment	$82,000

Step Two

Estimating the incremental operating cash flows for the Superfish project begins with estimates of the annual operating expenses of the system. This is usually the most difficult step in the net present value method. It requires making estimates of output level and prices received, quantities and prices of inputs, depreciation schedules for equipment and buildings, and income taxes attributable to the project. Some of these estimates will be uncertain, especially where there is little historic data on which to base them.

The estimated cash operating expenses, shown in Table 4, are categorized as fixed or variable. This gives one the opportunity to apply different assumptions on the impact of inflation on these categories of expenses and lets some expenses vary directly with the assumed level of output. Interest expense is not included since the cost of capital is expressed in the discount rate used to calculate net present value. If interest cash expenses were included it would be double counting. The estimated annual cash operating expenses for the Superfish project are $17,000 fixed expenses and $28,000 variable. We will discuss in a later section the impact of changes in these expenses on the evaluation of the project.

The allowable depreciation charges on equipment and buildings, while not a cash expense, must also be considered. Depreciation expenses are tax deductible and therefor have an impact on cash flow. An increase in depreciation expenses will reduce the amount of taxes due by an amount equal to the incremental depreciation times the marginal tax rate for the project (or the business initiating the project). Table 5 shows the allowable Modified Accelerated Cost Recovery depreciation rates assumed appropriate for this illustration. The equipment has all been assumed to qualify for the five year asset depreciation category. This is a simplifying assumption. In an actual analysis the depreciation allowed on each major asset should be carefully estimated.

Table 4.Estimated Cash Operating Expenses for Superfish Recirculating Project.

ITEM	DOLLARS FIXED	DOLLARS VARIABLE
Feed		$10,000
Wages	$7,000	3,000
Electricity	$2,500	$ 1,000
LP Gas	$3,500	
Liq. Oxygen		$ 7,000
Insurance	$1,000	
Fingerlings		$ 4,000
Maintenance	$2,000	$ 2,000
Miscellaneous	$1,000	$ 1,000
TOTALS	$17,000	$28,000

Table 5. MACRS Depreciation Rates for Superfish Recirculation Project.

Year	1	2	3	4	5	6
Building	1.5%	3.0%	3.0%	3.0%	3.0%	3.0%
Equipment	20%	32%	19%	12%	11 %	6%

The net operating cash flows need to be estimated for each year of the projects life. This is another important decision for the person doing the analysis. The life of the project will affect the project net present value either positively or negatively depending on the magnitude of net cash flows in the later years of the project. To simplify this illustration it was assumed that the project would end at the end of the sixth year, This may not be terribly unrealistic given the possibility that technological improvements may lead to the decision to sell the Superfish assets in favor of another system by that time.

Table 6 shows the calculation of net operating cash flows for the six years of the project. The basic data comes from Tables 4 and 5. Several assumptions are embodied in the calculations. The sales price is assumed to be at $2.00 per pound in year one and is assumed to increase by 3 percent each year thereafter. Variable expenses, which are 40 percent of sales revenue, and fixed costs also are assumed to increase by 3 percent per year. Earnings are calculated on an accounting basis and taxes, at an assumed rate of 30 percent, are deducted. The net operating income after taxes plus the depreciation represent the net operating cash flow for each year.

Table 6. Net Operating Cash Flows For Years 1 Through 6 of Superfish Recirculating Project.

	Year 1	Year2	Year 3	Year 4	Year 5	Year 6
Sales (lb.)	35,000	35,000	35,000	35,000	35,000	35,000
Price	$2.00	$2.06	$2.12	$2.18	$2.25	$2.32
Net Sales	$70,000	$72,100	$74,263	$76,490	$78,786	$81,149
Variable Cost	28,000	28,840	29,705	30,596	31,514	32,460

Fixed Cost	17,000	17,510	18,035	18,576	19,134	19,708
Depr (build.)	270	540	540	540	540	540
Depr (equip.)	12,000	19,200	11,400	7,200	6,600	3,600
Expense Subtotal	$57,270	$66,090	$59,680	$56,912	$57,788	$56,308
Earnings Before Tax	12,730	6,010	14,583	19,578	20,998	24,841
Tax (30%)	3,819	1,803	4,375	5,873	6,299	7,452
Projected Net Oper. Income	8,911	4,207	10,208	13,705	14,699	17,389
Add back Depreciation	12,270	19,740	11,940	7,740	7,140	4,140
Cash Flow From Operations	$21,181	$19,947	$22,148	$21,445	$21,839	$21,529

Step Three

There are usually some non-operating cash flows at the end of a project. (Table 7) For the Superfish project, it is assumed that the owner sells the assets of the business at the end of year six. As was mentioned before this is a simplifying assumption but perhaps not an unrealistic one. The land is assumed to have the same value on the market as in the beginning of the project. The building is assumed to have a salvage (market) value of $5,000 significantly below its book value (depreciated value) of $14,490. This results in a calculated loss (non-cash) of $9,490 and a cash savings of $2,847 in taxes. The equipment is assumed to have a salvage value of $10,000 which is above the book value of zero dollars. This is reported as ordinary income whish results in a $3,000 higher tax payment ($10,000 x 30 percent). The net total cash flow from salvage values is the sum of the net salvage values for the land, buildings and equipment. For consistency it is assumed that the increase in net working capital from the beginning of the project is recovered by selling the now unneeded inventory items. The net non-operating cash flow for the end of year six is $18,847.

Table 7. Terminal Year Non-operating Cash Flows for Superfish Recirculating Project.

	Land	**Building**	**Equipment**
Salvage (ending market) Value	$2,000	$ 5,000	$10,000
Initial Cost	$2,000	$18,000	$60,000
Depreciable Basis	---	$18,000	$60,000
Book Value (ending)	$2,000	$14,490	$ 0.0
Capital Gains Income	---	---	---
Ordinary Income (Loss)	$ 0.0	($9,490)	$10,000
Taxes	$ 0.0	($2,847)	$ 3,000
Net Salvage Value (Salvage Value - Taxes)	$2,000	$ 7,847	$ 7,000

Net Cash Flow From Salvage Values = $16,847

Net Cash Flow From Working Capital = $2,000

Step Four

Determining the appropriate cost of capital is the next important step in the net present value method. The cost of capital or discount interest rate used should reflect the cost of capital to the business or the investor and perhaps a risk premium if the project is judged to be riskier than the average project for the business or the investor. If the project is to be financed by both debt and equity capital, the cost of capital rate should reflect the different after tax costs of debt and equity weighted by their proportionate shares. If the debt and equity shares are assumed to be equal (50 percent each) and if the before tax cost of debt is 14 percent and the cost of equity is 20 percent then the appropriate cost of debt would be calculated as follows: (14 x (1.0 - .3) x .5 + (20 x .5) = 14.9 %. The appropriate cost of capital will be related to rates of return on alternative investment opportunities, expected future rates of inflation, the relative riskiness of the project, and the attitude of the investor toward assuming risk.

Step Five

It is now possible to calculate the net present value of the Superfish project. Table 8 shows a consolidated listing of the net annual cash flows for the project. The cash flows are all assumed to occur at the end of the appropriate year with the exception of the initial investment which is assumed to occur at the beginning of year 1 (called time zero). For illustrative purposes a discount rate of 15 percent is used to calculate the net present value of the project. The calculation shows a net present value of $6,639. Accepting the project would be justified because the present value of the future cash inflows is greater than the present value of the initial cash outflow.

Table 8.Consolidated Cash Flows for Superfish Recirculating Project.

YEAR	**CASH FLOW**	**PRESENT VALUE (@ 15.0%)**
0	($82,000)	($82,000)
1	$21,181	$18,418
2	$19,947	$15,083
3	$22,148	$14,563
4	$21,445	$12,261
5	$21,839	$10,858
6	$21,529 +$ 2,000 +$16,847 --------- $40,376	$17,456

NET PRESENT VALUE (15%) = $ 6,639

INTERNAL RATE OF RETURN = 17.7%

If the appropriate discount rate was 12 percent the net present value of the project would be $15,054. If the appropriate rate was 16 percent the net present value of the project would be $4,086. And, if the appropriate discount rate was 17.7 percent the net present value of the project would be $7.00.

The discount rate at which the net present value of the project is zero is called the internal rate of return. While many investors like to see the internal rate of return it is not the most consistent criteria to use in making accept/reject decisions on investments. The net present value method is the preferred criteria. Table 9 contains the present value factors for several interest rates and years. This data can be used to examine the impact of alternative discount rates on the net present value of the Superfish project.

Table 9.Present Value of $1 .00 to be Received at the End of n Years.

$PVIF_{k,n} = 1/(1 + k)^n$

(n) Years in The Future	**DISCOUNT RATE 8.0 %**	**10.0 %**	**12.0 %**	**14.0 %**	**16.0 %**
1	.9259	.9091	.8929	.8772	.8621
2	.8573	.8264	.7972	.7695	.7432
3	.7938	.7513	.7118	.6750	.6407
4	.7350	.6830	.6355	.5921	.5523
5	.6806	.6209	.5674	.5194	.4761
6	.6302	.5645	.5066	.4556	.4104
7	.5835	.5132	.4523	.3996	.3538
8	.5403	.4665	.4039	.3506	.3050
9	.5002	.4241	.3606	.3075	.2630
10	.4632	.3855	.3220	.2697	.2267

Step Six

It has been mentioned above that the estimates of operating cash flows and terminal cash flows are uncertain. One should examine the

impact of reasonable changes in those cash flows on the net present value of the project. One approach to doing this is to develop worst case and best case scenarios and the associated cash flows. Calculate the net present value for each scenario as well as the base case and, if possible assign some (subjective) probability to each. The resulting weighted average net present value may be a better criteria because it now reflect more of the risk and uncertainty of the project (at least on a subjective basis).

Step Seven

As a final step one should compare the impact of accepting the project, Superfish in this case, on their opportunities for other investments. An actual investment in a commercial recirculating aquaculture system may tie up capital for long periods of time. In doing this one loses the opportunity to invest in other project or securities. There is also a lose of flexibility in that it may be difficult to reduce the investment in such a system without a lose. Aquaculture enterprises are riskier than many other investment opportunities; therefore one should expect a higher rate of return on such an investment. In calculating the net present value of risky enterprises one should probably use a higher discount rate than normal.

Conclusion

The author reported some the limited publicly available economic data on commercial recirculating aquaculture systems. There are indications, not covered in this paper, that technological and biological advances and the expected increased demand for high quality fish products will improve the potential for economically viable recirculating systems.

The net present value method of evaluating capital investment opportunities was described and illustrated. It is suggested that it is the preferred criteria for making capital investment decisions. This approach may be helpful for those individuals who are faced with making such decisions now. Caution and rigorous analysis of investment opportunities in commercial recirculating aquaculture systems is suggested.

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Direct Retailing Your Aquaculture Products

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Introduction

You are ready to harvest your first crop of 100,000 pounds of "widget fish." "Where will I sell them?" It is surprising how many producers ask this question so late in their production cycle.

Assuming that all you have to do is produce the fish and people will buy them will lead to certain failure of any aquaculture enterprise. Midwest farmers in traditional farming enterprises, such as corn, soybeans, beef, swine and poultry use well established markets that have been highly refined over the last few decades. For example, go to any rural town regardless of its size and you will find a grain elevator or stockyard. Aquaculture, unlike other agriculture enterprises is still in its infancy, especially in the Midwest, and as a result large scale processing plants, solely for farm-raised products are nonexistent. Fish and shellfish farmers are forced to use alternate, less established, markets for their products. Alternative markets have advantages and disadvantages The main advantage in alternative markets is producers become wholesalers, and in some cases retailers. Consequently, producers have more control over the prices they receive for their products and they retain some portion of the profit that would otherwise have gone to the "middleman." The main disadvantage is that considerable time must be spent time analyzing and developing their markets and in some cases processing their product,

How many beginning aquaculturists have made the statement, "**with the huge fish markets in Chicago, St. Louis, Louisville and Indianapolis, selling my product will be no problem**." While it is true that massive quantities of fish are marketed in those areas, it is necessary to keep in mind that those markets are usually for high volume producers. New farmers producing relatively small quantities (less than 100,000 pounds) of food species should develop their markets with the attitude that they will sell within a fifty mile radius of their farm. The focus of this paper is to discuss some general marketing concepts as applied to food fish and to present some ideas on how to sell your aquaculture products locally. Since food fish production offers the greatest potential for aquaculture expansion in the Midwest, most of this paper will specifically address marketing of food fish. Besides food fish, there are other types of aquaculture, that should be mentioned. These are: sportfish, bait fish and ornamental fish. Many of the same marketing principles will apply to the other types of aquaculture products.

Know Your Competition

If you are considering aquaculture as a business because you think there is limited competition, then you should reconsider aquaculture. The seafood industry is well established and very competitive and will become even more so in the near future. Midwestern producers have to compete with wild-caught and farm-raised products of both domestic and foreign origin. By understanding current sources of seafood, the new producer will be more knowledgeable and better able to build a production and marketing program that will be responsive to market opportunities and able to endure adverse price fluctuations.

Native wild

Competition from commercial fisheries for yellow perch, walleye and crawfish exists in and around the Great Lakes. Each of these fisheries is in jeopardy of being severely restricted due to over fishing. Nevertheless wild-caught yellow perch and walleye are usually sufficiently cheaper than farm-raised products to offset any perceived quality differences in the eyes of buyers. Ocean-caught fish such as cod, pollock, perch, and salmon account for a significant portion of the U.S. seafood consumption and are often a cheaper or more reliable source of fish than lake fisheries or farmed species. Wild caught minnows, in particular fathead, from Minnesota also compete with farm-raised bait fish.

Foreign wild

Competing with seafood imports poses the greatest challenge to the aquaculture industry. Total edible seafood imports in 1990 totaled $5.2 billion, most of which was wild caught. [Of the 15.5 pounds of seafood consumed annually per person in 1990, less than 20 percent was farm-raised.] Competition between farm-raised species and foreign wild is greatest for catfish from South America and walleye from Canada. Farmers considering walleye production should also realize that Canada has a well established commercial walleye fishing industry which includes many bodies of water that can be opened to fishing in order to maintain their market share by "flooding" the market. Prices could be reduced to the point that marginal farmers who cannot compete with the wild imports would be forced out of business.

Farmed domestic

Farmers in the Midwest raising food species such as channel catfish and rainbow trout will have to overcome competition from industries in southern and western states which have been producing these species for several decades. Moreover, shipping costs only allow prices for locally grown products to be about 10-20 cents per pound higher. The established aquaculture industries will force small-scale producers in the Midwest to rely more heavily on direct marketing until significant infrastructure is established to provide Midwest farmers competitive feed and fingerlings prices. It is encouraging that a restaurant survey completed by Cornell University found that some restaurants are willing to pay anywhere from a 10-25 cent per pound premium for locally grown trout.

Farmed international

The competition from species farmed internationally is greatest for salmon from Europe, and increasingly from Peru and Chile. Tilapia is another product which is being farmed internationally in large numbers and could be imported cheaply into the United States. Organizations that are currently working hard to establish markets for Tilapia in the U.S. may be benefiting South American and Asian producers who could take advantage of the growing U.S. market for Tilapia.

Selecting a Species

When deciding which species of fish or shellfish to farm keep in mind two things. **First, choose a species which is recognized as being marketable**. A good example is common carp. Common carp is easy to farm and is a candidate species if you live in Asia or have a strong Asian market in your area. Otherwise, it is probably advisable to consider other species more widely accepted. Of the 60 or so candidate species for food fish aquaculture there are currently only two, channel catfish and rainbow trout, for which established industries have developed in the United States. Other species such as Atlantic salmon, Coho salmon, crawfish, hybrid striped bass, Tilapia, yellow perch, and various sunfishes offer considerable potential in the Midwest.

Second, attempting to farm species having incomplete production information or production peculiarities is a very risky venture. Although species such as walleye and lobster have wide public appeal and are very marketable in the Midwest, each have production problems. Using walleye as an example, existing producers recognize that fingerling survival is low due to their cannibalistic nature. Furthermore, most walleye are produced by state fisheries agencies and are released as fingerlings. Few have been grown to marketable food size using commercial diets. This has resulted in little available nutritional information for market-size walleye. Faced with these production obstacles a producer could easily fail to reach production goals. In any new business and especially aquaculture, cumulative short term setbacks could lead to loss of investment of the farm.

Special mention of Tilapia is in order at this point. Tilapia are extremely hardy fish. They tolerate poor water quality and are easy to spawn. The only production drawback is their intolerance to low temperatures. A second, more serious problem with Tilapia is in marketing. Because Tilapia grown in the U.S. are non-native, the public does not recognize them as being a high quality food fish. If adequate marketing research and promotion is provided then Tilapia does offer great potential in recirculating systems.

Variety may be important to small scale producers. Many marketing outlets prefer buying small quantities of more than one species. Production of more than one species may offer a competitive advantage over single species operations.

The Four P's in Marketing

Product, price, promotion and place are classical points in traditional marketing and will apply to marketing aquaculture products too. After potential producers determine their competition and choose the "best" species for their area, serious planning and research needs to go into each of the four P's.

Product

Market size and product form are two very important aspects of an aquaculture product. Different customers often have different ideas on what is the "best" size or form. Market size will vary according to species and product form. Channel catfish are usually sold at a size of 1.25 to 1.5 pounds. At this size, two dressed fish will yield one serving of two fillets of about 4.5 oz. each. Yellow perch or bluegill are examples of fish which are served at a smaller size. Market size for either of these species is around 0.50 to 1 .0 pound. Each successive degree of processing of fish results in different product forms. The following is a discussion of definitions and specific information concerning various product forms. Your local and or state department of health officials should be contacted to determine permit requirements before any type of processing is undertaken,

Live fish are sold to live haulers who stock fee fishing lakes or farm ponds.

Fish in the round are put on ice and sold just as they come out of the water.

Drawn have the entrails removed.

Dressed are sold completely cleaned but with the head intact.

Headed and gutted fish have the head and entrails removed. Fins and tails may be removed or left intact. Species such as channel catfish have the skin removed. For trout and other salmonids the skin and scales are left intact but gills are removed.

Chunks are cross sections of large dressed fish having a of backbone as the only bone. They are similar to beef or pork roasts.

Steaks are slices of dressed fish smaller than chunks. Larger catfish (2 lbs or more) are usually sold as steaks.

Nuggets are the belly flap after it is cut free from the fillet. Channel catfish nuggets are becoming more common in supermarkets. Part of this popularity may be a result of the lower cost of nuggets.

Fillets are boneless pieces of fish and can be obtained either as flank or butterflies.

1. Flank fillets are the two sides of the fish cut away from the backbone. It usually has no bones or waste.

2. Butterfly fillet includes the two flank fillets held together by the belly flap. Trout or yellow perch are examples of fish which are sold as butterfly fillets.

Fillet size will depend on a particular individual preference. Usually, fillets are cut to prescribed proportions which yields a single serving (6-8 oz.) from one or two fillets. As a rule, whole fish need to average around 1.25 to 1.5 pounds depending on the dress-out percentage of each species. For example, 1.5 pound channel catfish, hybrid striped bass, Tilapia or trout will have a fillet dress-out percentage between 35-40 percent.

Deboned fish have the bones removed but the body left intact.

Breaded fish, canned fish, fish sticks, and fish strips are value added products and were not defined because all involve a high degree of processing.

Smoked fish is a value added processing method which is becoming more popular, especially during the holidays. Two smoking methods (hot and cold smoking) have commonly been used. Hot smoking is more like flavorful cooking of brined fish, and never produces enough drying to ensure safe keeping. Hot smoking involves temperatures of 250° to 300°F for a period of 4-5 hours. Cold smoking, on the other hand, preserves fish by drying. Cold smoking times may be as short a 24 hours or as long as three weeks at temperatures never exceeding 80°F.

Regardless of the product form you choose to offer, it is very important to establish and maintain a reputation as a reliable supplier. Be sure to gain an accurate understanding of each customer's needs regarding both volume and frequency of purchases before you ever deliver the first fish. Remember that it is much more risky for a customer to depend on you for fish supplies than to rely on a local fish wholesaler or other established business. Therefore, you need to take extra care to be reliable. This can be a major problem area for new or small-scale producers. One approach could be to join together with other producers to form a marketing cooperative.

Price

How much do you charge for your product? Real life implementation of this simple question, however, is not so easy. Pricing a product is an agonizing, lengthy decision and your price will likely need periodic adjustments to reflect new market realities.

So where do you start in thinking about price? Well, the lowest price you would ever want to charge is the price per pound that just equals your costs per pound, including both fixed and variable costs. The highest price would be what you could talk one or two people at most into paying for your fish. Your base price needs to be somewhere between, taking into consideration such factors as how you are going to position your product in the food fish market (is it a Chevy Chevette or a Cadillac Eldorado?), who your customers are (individual consumers, upscale restaurants, food wholesalers, etc.), what species and prices competitors are offering, and the quality perceptions, if any, associated with your chosen species. As you may have figured out, pricing is <u>not</u> an independent decision. Many systems of determining the price of your product are in use by marketers. From a small- scale retail marketing standpoint only the most relevant systems will be discussed.

Cost-plus pricing simply adds a constant percentage of profit above the cost of producing a product.

Example 1;
If you want 20% of gross sales to be profit:

$$\text{price} = \frac{\text{unit cost per lb.}}{\text{1 - percentage}} = \frac{\$1.00}{1 - .02} = \$1.25 \text{ per lb.}$$

The problem with cost-plus pricing is that it is sometimes difficult to accurately assess fixed and variable costs. This pricing system works fine in the absence of severe competition But, if alternatives to your fish exist, you could price yourself out of a market with higher than average production costs or fail to obtain additional profits with lower than average costs.

Return on investment is similar to cost-plus pricing. It begins with an estimate of your annualized investment in your fish enterprise. Tack on the percentage return you want to achieve and divide this new total by your annual production or expected sales, whichever is lower. Thus if you sell all you expect at the calculated price you will earn your target profit.

Example 2:
Annualized investment $10,000, desire 20% return.

$$\text{Price} = \frac{\text{A.I.} \times (1 + \text{percentage})}{\text{pounds produced or sold}}$$

$$= \frac{\$10{,}000 \times (1 + 0.20)}{7{,}500}$$

$$= \$1.60 \text{ per lb.}$$

Keep in mind that the same drawbacks to cost-plus pricing apply here.

Competitive pricing is probably the easiest and in retail marketing the most common form of pricing. In this system, producers gather market information on the prices and quantities of competing products and price their products accordingly.

Penetration pricing is the offering of a product at a relatively low price in order to gain wide acceptance in the marketplace quickly. This pricing method is often used for unfamiliar species such as Tilapia.

Skimming is the opposite of penetration pricing. It involves the introduction of a product at a relatively higher price for more affluent, quality-conscious customers Then, as the market becomes saturated, the price is gradually lowered. This strategy is currently being used by many hybrid striped bass producers.

Discount pricing offers customers a reduction from advertised prices for specific reasons. For example, a fish farm advertises in the local newspaper that prices will be 25 percent cheaper if they bring the advertisement from the paper. Another example would be when the producer advertises on the local radio that customers mentioning the advertisement from the radio will receive a preset discount.

Loss-leader pricing is the offering of a portion of your product at a reduced price for a limited time. The goal is to attract more customers to your place of business so that they might make purchases of non-discounted products as well. This pricing method is often seen in supermarkets to introduce a new product or to create consumer excitement.

Psychological pricing involves establishing prices that look better or convey a certain message to the buyer. For example, instead of charging $3.00 per pound the producer charges $2.99 per pound. This will make the product appear to be more of a bargain. Or, Instead of charging a price close to production costs the producer charges in a higher price range that buyers associate with higher quality or more desirable fish species.

Perceived-value pricing is positioning and promoting a product on non-price factors such as quality, healthfulness (clean water, no contaminants), prestige, etc. Then the producer must decide on a price that reflects this perceived value. This would be a good strategy for farm-raised versus wild-caught fish or any species you could pitch as having non-price attributes.

Product line pricing, in the case of food fish, means offering a variety of species and/or product forms. You would price the various products based more on targeting certain customers with certain products than on production costs.

Promotion

Producers promote their products to create customers. The best way to create new customers is to develop excellent promotion. Regardless of the advertising method chosen the producer should expect to spend a portion of their time promoting their product. There are two general methods of promoting aquaculture products, **generic** and **personal promotions**. Generic promotion is commonly performed by large marketing groups such the National Fish and Seafood Promotional Council (NFSPC). Because groups such as NSFSP are involved in generic advertising and do not focus on specific farms, we will discuss personal promotions.

What are the methods available to a small-scale retail marketer? One of the most common promotional methods is word of mouth. You convince a friend to buy from you. If satisfied with the quality and or price of your product, the buyer will pass along word of your operation to others. The multiplying effect can be tremendous, but often times word of mouth is not sufficient. Other common channels for advertising include: radio, newspaper ads, magazines, handbills, flyers and posters.

Promotion is usually aimed at the consumer. The promotional message must be clear, to the point and be focused. A small ad in the farm produce of the classified section of your hometown newspaper might read, "farm-raised striped bass raised indoors free of contaminantes, are highly nutritious and priced to sell, State Road 38 and 900 East in Tipp City, Sat. 8-12." What form of promotion you take as a new producer will depend on the scale of your operation, available resources, availability of your product, and geographic location of your farm. In addition to public advertisement, you should consider some on-site product promotion, both visual and verbal. This should accent the non-price attributes of your product which will convince the consumer to be a repeat customer.

Place

There are many places, many markets, for farmers to sell their food fish products directly, both at the retail and wholesale levels. A number of considerations (species, form, location, ability to process, etc.) must be taken into account when deciding where, what type of market, and specific business or locations, to market your fish. Farmers may sell their product directly to the consumer (retailing) or to other businesses which then sell to the consumer (wholesaling). The promotional principles discussed earlier usually apply to retailing directly to the consumer since most establishments where you may wholesale have their own forms of promotions.

Direct Retail Sales to consumers are a good place to start if supplies are small or uncertain.

Farm side sales are a good place to start if the farm is located within a short distance to urban areas. Specific dates can be reserved to make transactions. For example, Saturday morning from 8:00 am. till noon. Equipment such as change, accurate scales, ice and transport bags, if not essential, will certainly make the purchases more convenient for the consumer.

Farmers markets are widely utilized in southern states by fish producers. Here in the Midwest the concept of selling fish at existing farmers markets is new. As a result, the producer usually has to convince the manager of the farmers market that the product will be live and safe for human consumption. Hauling tanks are positioned to create a stand or booth similar to other forms of produce. Equipment needs will be similar to farm side sales.

Roadside stands are often used to capture a percentage of the traffic flow along busy highways. Several states including Illinois and Indiana offer directories of roadside stands. Obviously location is important in alerting upcoming traffic to the opportunity they are approaching. Offering fresh produce either yourself or in conjunction with another farmer may increase your customer level. Equipment needs are similar to those for farmers markets.

Wholesaling your fish to other wholesalers or retailers may be an excellent route to market your fish depending on the species (probably not catfish) and your supply situation. Some wholesale customers such as restaurants have a strong preference for steady, year-round supplies but even this generalization does not hold true in every individual case. It would probably be worth your while to set up an appointment with the manager of every restaurant, grocery store, and food wholesaler within that 50-mile radius of your production site. Find out, beforehand if possible, individual preferences for species, product form, size, volume, availability, and prices. Have a strong sales pitch prepared and a sample of your product. Pricing in the wholesale market will likely be based on individual negotiation so be sure to be armed with a negotiation strategy. Some managers will immediately be interested, others won't. For those who are interested, the accurate, sensitive positioning of your product to fit their individual needs and your ability to convince them of your product's attributes could gain you a customer on a trial basis. Once that customer is gained, you must be extremely diligent to be a reliable supplier of the size, form, quantity, and quality of product that the customer expects. You must work hard to earn a good reputation and to maintain it.

Live haulers can be used if the producer does not own a transport tank. Live haulers will sell fish to fee fishing operations, farm pond operators, or processing plants. Selling in this manner would not require any investment on your part of time or equipment to process, transport, or sell your fish.

Restaurants can be a good place to start with smaller quantities of fish because they are usually willing to try new species (and suppliers) to fill their "catch of the day" specials or other such short-term menu items. The typical restaurant will take 10 to 80 pounds of a fish species per week (Oha, 1991) depending on product form (another advantage of producing multiple species and/or product forms). For regular menu items, restaurant managers tend to prefer weekly deliveries over monthly (Riepe 1991). One point to keep in mind when thinking about businesses to contact is that more businesses serve food than those that you would immediately identify as a "restaurant." Don't overlook the country club, VFW, or corner pub. You might be just the type of supplier or have just the right fish they want. Once you successfully gain a restaurant customer then you still have an education program to do. How many times have you asked your waiter, when dining out, about the seafood item on special and were given a "song and dance" because he/she knew nothing about it? Educating the head of the serving staff and providing a short brochure or other printed information may be a key to continued success.

Supermarkets offer one of the best places to sell larger volumes of food fish products. It is quite likely that unless a supermarket is locally owned and operated that you would have to supply all or many of the stores in a chain. This may be a good situation for some producers, but others may have difficulty with the volume or other requirements. But here again, it is probably best to research and interview to determine whether or not producer and customers are compatible. Staff education is likely to be important here also in keeping customers. Staff may need information not only about how the fish are produced and their quality and such, but also about how to prepare them. Since the average consumer simply puts "fish" on the shopping list, a knowledgeable and enthusiastic staff member will be extremely valuable in marketing your product.

Specialty stores include ethnic groceries and health food stores. Fish is a more important part of people's diets in some cultures than others. Health food stores may be willing to try your product because the perceived quality of farm-raised products is usually higher than wild caught . Asian markets usually are more willing to purchase whole fish.

Regulations

Regulations for marketing aquaculture products locally will either focus on permits allowing retail marketing at the farm, farmers markets, roadside stands or the setup and use of small-scale processing facilities, In either case the producer should contact their local health department. The accreditation procedure for small-scale processing plants will involve assurances by the processor that the equipment can be disinfected and that the product can be properly refrigerated.

Inspection

Seafood inspection will soon occur. The United States Department of Agriculture (USDA) and the Food and Drug Administration (FDA) have been competing for the right to perform the sea food inspection. As the inspection procedure is currently proposed FDA will be the lead agency and will use the Hazard Analysis Critical Control Point (HACCP) method for inspecting seafood, This method involves random inspections at critical points along the processing line instead of inspecting every fish.

Summary

In this paper general background information was provided on direct retail marketing strategies. Marketing is as important, and in some respects more important, than actual production. Assuming that all you have to do is produce the fish and people will buy them will lead to certain failure of an aquaculture enterprise.

New farmers raising relatively small quantities (less than 100,000 pounds) of food species should develop their markets with the attitude that they will sell within a fifty mile radius of their farm.

The seafood industry is very competitive and will become even more competitive in the near future. Midwestern producers have to compete with wild-caught and farm-raised products from domestic and foreign origin.

When deciding which species of fish or shellfish to farm keep in mind two things. First, choose a species which is recognized as being marketable. Second, attempting to farm species having incomplete production information or production is peculiarities a very risky venture.

Product, price, promotion and place are classical points in traditional marketing and will similarly apply to aquaculture products. The product refers to the degree of processing undergone by the fish or shellfish. Producers promote their products to create customers. The place or location chosen to sell your product will depend on the location of you farm and the method of advertising that you chose to undertake. Three places to direct market your food fish products (farmside, roadside stands, and farmers markets) were discussed. Four places (live haulers, restaurants, supermarkets and specialty stores) to wholesale your food fish product were discussed.

Regulations for marketing aquaculture products locally will either focus on permits to retail market at the farm, farmers markets, roadside stands or setup and use of small scale processing facilities. As the inspection procedure currently is proposed FDA will be the lead agency and will use the Hazard Analysis Critical Control Point (HACCP) for inspecting seafood.

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Wholesaling Your Product to Fish Brokers

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Introduction

There are many important factors that an aquaculturist must consider when it comes time to develop marketing Strategies for selling his product. Species type, seasonality, and marketing costs are all elements that should be carefully thought out when deciding which species to culture and what marketing strategy to employ.

Procedure For Selling Fish Products to the Seafood Industry or Chicago Fish House

When an aquaculturist is ready to sell his product, he simply needs to call the fish buyer with information on the species and its size, and then offer his product for sale at a certain price. If this meets with the buyer's specifications (what its customers are requesting), then the buyer will conduct the whole transaction over the phone.

The producer will be asked to box and pack his commodity in fresh or chemical ice and make arrangements for shipment by truck or airplane. Delivery is preferred no more than one day from the harvest date for maximum freshness.

The Chicago Fish House and most seafood buyers use no contracts and makes no long-term commitments on 99% of what they buy in fresh fish. Its buyers operate on a day-to-day and week-to-week basis through phone transactions.

Once the product arrives at the dock, the receiver examines it for freshness. Among the qualities looked for are firm flesh, bright and colorful skin, bulging clear eyes, and clean red gills. If there is a problem, the fish is sent to the Government Inspector for further examination. If there is a concern, a certificate of inspection will be issued and is available to the seller.

If the delivered product is not acceptable, it will be returned to the seller. However, this change in timing can certainly affect the selling price. For instance, if a product delivered to the Chicago Fish House on Thursday did not meet required standards, then the buyer would not have time to find a replacement to sell to its customers for the weekend, therefore losing money.

What Species are Hot; What are Not

Game fish seem to be in great demand these days by retail and institutional customers because they are not easily obtainable as some other species, and are a favorite food of many fish eaters. Game fish are those fish not allowed for commercial harvest, but for capture by sport fishermen. They include walleye, pike, lake perch, crappie, sunfish, striped bass, largemouth and smallmouth bass, and bluegill.

I recommend that fish farmers in the Midwest not get involved in the production of catfish and salmon. There are already large quantities available from people throughout the U.S. A midwestern farmer could possible find a small niche in a local market, but there would probably be little potential to expand.

Factors Affecting Price Paid to Producer

The Chicago Fish House and other fish buyers will only pay what the market will bear, so that they can make a profit. The idea is to buy for less than they will sell it for.

Seasonality comes into play in determining price. In the winter, the market for fresh fish is often higher because there is less available. People can't go out and catch their own, and the commercial fisheries don't harvest as much as in other seasons. Production of fish is highest in the spring and the fall so prices paid to producers are generally lower. The summer market is unstable because people go on vacation and eat out more. Price determination all boils down to supply and demand.

Transportation Considerations

The seller must make transportation arrangements and pay the freight when dealing with any seafood buyer. There is an occasional exception that a fish broker will pay some of the shipping costs if there is great demand and little supply.

A seafood buyer will accept any quantity of fish if there is enough customer demand. They buyer takes as little as 50 lbs. of fish or as much as 4,000-5,000 lbs. of fish.

The aquaculturist must be aware that freight charges are assessed per pound or per hundred weight of the product. I recommend that if, for instance, the freight charge is $100 for 1,000 lbs. or less, then the producer should try and get the buyer to take 1,000 lbs. if he has that much stock on hand. If the buyer will not take the minimum shipment, then the seller must pay the increased freight charge or increase the price of the fish to cover shipping costs.

Other Marketing Considerations

A bill on seafood inspection is still pending in Congress. If it passes, the aquaculturist will have to understand what the criteria will be required for his product to pass inspect on.

Many institutional and retail customers are touchy about receiving a product that has received chemical additives by the producer or through the environment. Aquaculturists should carefully consider what they use. Artificial chemicals such as antibiotics used in feeds during fish production can create problems. Even though these chemicals serve to control disease or improve fish size, they will adversely affect the product's marketing potential. This applies even if the volume of chemicals is low.

In addition to chemical additives, the fish producer should also take care to avoid any pollution hazards such as industrial, agricultural, and other outside chemical pollutants that may harm the crop.

The Future Role of Farm-Raised Species in The Operation of The Chicago Fish House

I have seen farm-raised species play a greater role in my operation every year. In the last ten years, farm-raised fish went from 10% to 25% of the species we stock in our fish cooler and distribute. In the next 10 years, it could jump to 50-60% of our business.

The benefits of buying farm-raised fish are a raw material supply I can count on and it provides more stability in pricing. Aquaculturists who have a desirable product and a good marketing plan can expect to reap the benefits of this industry now and in the future.

Remodeling Existing Farm Structures for Commercial Fish Culture

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A fish production system using recirculated water may be thought of as analogous to a hog confinement system. In both systems a farmer needs a method to house the animals, control ambient environmental parameters (temperature, noxious gases, etc.), feed the animals, remove waste products, sort animals, control reproduction, harvest animals, treat diseased animals, etc. The primary difference between the two forms of livestock is that the production environment for fish is controlled and manipulated to a much greater degree than is the production environment for hogs. (Other differences between these two forms of livestock are that commercial-scale culture system variables for fish are relatively unknown compared to hogs, indoor food fish production generally involves greater financial risk than confinement hog production, and the market infrastructure for farm raised fish other than catfish is still relatively undeveloped compared to hog marketing systems.) The purpose of this paper is to discuss the criteria used to evaluate the remodeling of an existing farm structure for use as a fish culture environment.

This paper was written based on the assumption that commercial fish culture in recirculating systems is a profitable enterprise. However, some fish producers have found that profits were less than anticipated. Each potential producer is encouraged to expend their initial efforts on budgets and profit/loss statements before using capital for fish production. Entrepreneurs who currently own farm structures may be able to use those farm structures to gain the comparative advantage needed to make fish culture profitable.

A culture building must contain the equipment required to preform the following function:

1. manipulate the ambient environment, especially temperature
2. contain water
3. remove ammonia or convert it to a less toxic form
4. separate solid wastes from culture water
5. treat and dispose of solid wastes
6. add oxygen
7. remove carbon dioxide
8. feed fish
9. monitor system components and alert farmer to component failure
10. allow fish containment, manipulation and harvest.

The cost of remodeling verses new construction must be evaluated. Some producers consider remodeling advantageous if the remodeling costs are one-half or less the price of new construction. Turn-key pole building shells can be purchased for approximately $15 per square foot (assuming a 40' x 70' building without a concrete floor, without insulation). Some producers prefer remodeling older farm structures for aesthetic or nostalgic reasons. Other advantages of remodeling older buildings verses new construction is the ability to begin use of the building with minimal investment, and the ability to do most of the remodeling with home labor rather than hired labor.

Humstone (1988) presents a 10 point preliminary checklist to begin evaluation of the feasibility of remodeling an existing barn:

1. evaluate framing. Check posts, beams, sills, rafters, and joists to be sure they are solid and free of rot.

2. evaluate the foundation. Check for cracks, settling, and shifting. Look for loose or missing mortar.

3. evaluate the roof. Check the roof covering and flashing. On the inside, look for water stains and rot on sheathing and beams.

4. evaluate the exterior walls. Eyeball the length of the barn at eave level to checks walls for straightness. If the foundation has shifted, walls may have sagged and pulled out.

5. evaluate the building interior. Note the location and existence of drains and gutters. Check the condition of existing floors. Note the amount of free-span space.

6. evaluate the building location. Is the barn conveniently located with good access to and from other buildings and the farmyard, and access to water and electricity? Can delivery and livehaul trucks easily access the fish tanks? Is there room to add on if you want to expand your operation in the future?

7. evaluate the building size. Is the barn big enough for its intended purpose? Is there adequate ceiling clearance and space between interior posts? Is there room to install the equipment you need?

8. evaluate doorways. Will doors need to be enlarged or moved?

9. evaluate the building ambient environment. Is the barn airtight and insulated? Can heating and ventilation systems be installed?

10. evaluate utilities. What is the condition of the plumbing and wiring? Will it need to be updated? Can feeding, water flow and manure handling systems be installed if necessary?

If after running through a preliminary checklist the project looks feasible, the following detailed considerations need to be studied while planning for the remodeling:

Water Supply

The most important consideration for fish culture is the supply of water. Even in a recirculating system, substantial quantities of water are required. A well designed recirculating system consumes 10% or less of its total water volume per day. If a culture system contains 50,000 gallons, the producer must plan for a consumption rate of at least 5,000 gallons per day. If a pipe was running 24 hours per day to supply only this use, approximately 3.5 gallon per minute (GPM) must be supplied. In reality, flow rates must be as high as is practically possible in a fish production building. Supply rates for farmsteads which include fish production as a major farm component is at least 20 - 40 GPM. Piping must be sized to accommodate this flow rate. Water well capacity may also be evaluated to assure adequate supply. Well capacity can be increased by pulling the existing pump and installing a larger pump (cost of labor and 1 hp pump are approximately $700). Often, water supply lines throughout the building are made of surface mounted 2" PVC. This piping is inexpensive, easy to install, easy to service and of high capacity.

Some consumption devices such as sand filters require large volumes of high pressure water for backflushing. The surge requirements of these devices may dictate the capacity of the building plumbing. For example, a sand filter sized to filter the wastes from a heavily loaded 6,000 gallon system may require 60 GPM at a pressure of 40-50 psi during backwashing. The total consumption of this filter may exceed 700 gallons in a 12 minute time period. Large pumps and large piping is required to handle hydraulic loading at this level. To economize on plumbing, a reservoir tank may be installed.

The quality of incoming water needs to be considered in planning the facility. Incoming water should meet these values (concentrations are give in parts per million) (from the US Fish and Wildlife Service, 1982 and Boyd, 1990):

VARIABLE	WARMWATER FISH
dissolved oxygen	6-saturation
carbon dioxide	0-10

total alkalinity (as $CaCO_3$)	50-400
pH	6.5-9.0
total hardness (as $CaCO_3$)	20-400
calcium	10-160
iron	0-0.5
hydrogen sulfide	<0.005
un-ionized ammonia	<0.05
total dissolved gases	<105% total gas pressure
salinity (value for catfish)	100-8,000
temperature	appropriate for species

Culture water may need to be treated to meet these requirements. Planning must allow for the treatment and storage of incoming water to allow the oxidation of iron, gas exchange, settling, warm-up, etc.

Drainage

A 50,000 gallon system reusing 90% of its culture water must plan on disposing of 5,000 gallons per day. A building must have a drainage system to allow this amount of water to flow into a disposal system. Floor drains must be of a size to accommodate large flows.

Floor Construction

Floors in a culture room are often concrete to allow easy accomplishment of husbandry activities. Floors should be sloped towards drain. Level floors will actually have some slope and it may be away from floor drains. Reinforcement must be used in the floor to allow the floor to withstand the heavy loading resulting from culture tanks. When constructing floors, give consideration to casting concrete tanks directly into the floor.

Light

Laboratory and hatchery areas should be equipped with lighting at a level of 2.75 watts per cubic foot of floor space. Culture areas may receive less lighting. A hatchery manager should have the ability to manipulate photoperiod to correspond with culture activities. UV light at high intensities may be harmful to larval fish. Algal growth on biofilters may be stimulated by high light intensities. Since algae out competes nitrosomonas and nitrobacter bacteria, biofilters should not be exposed to high light intensities. Vapor-proof lamps should be used near culture tanks.

Doors

When evaluating the remodeling of a building, consider the placement and size of doors. A building suitable for aquaculture must have doors allowing access by trucks, forklifts, etc. In addition, tanks and filters will need to be replaced - a large door may be required to install a 5000 gallon rectangular tank.

The flow of materials throughout the structure should also be evaluated during remodeling. Plan for conveyors, alleyways, augers, etc as required to move fish, feed, supplies or equipment. Avoid the temptation to "make-do" with inefficient, high-labor techniques. Once a system grows to a commercial scale, a producer will have difficulty performing repetitive, heavy tasks such as harvesting fish, loading and unloading livehaul trucks, and unloading and moving feed without mechanized equipment. Bulk bins and auger conveyors may be used for feed handling. Some feed equipment companies such as Choretime currently market tested and proven automatic feed delivery systems for fish farmers.

Electrical Service

A recirculating aquaculture system will be a consumer of large amounts of electrical power. The facility may be supplied with its own electrical drop. A 200 amp power supply should be installed even if current needs are less than 200 amps. Three phase power is required for pumps larger than approximately 2 HP. Both 110 and 220 volt service should be installed. All wiring should be installed according to the National Electrical Code by a competent electrician.

Wiring throughout the facility should be exterior quality. Each circuit should be protected by a ground fault circuit interrupter. Underground feeder (UF) cable should be surface mounted throughout the facility. Wire size must be based upon current and anticipated loads. Planning is required to determine the location of large pump motors so individual circuits can be installed for those motors.

Heating

Extensive heating is required for the culture of all warmwater species such as tilapia and limited heating is required even for coldwater species to allow for optimum fish growth and for operator comfort. The ideal heating plant would be inexpensive, efficient, easily installed into a retrofitted building, and easily maintained. Infrared heaters fit these requirements best. LP or natural gas is a less expensive fuel than electricity so its use is preferred. See Appendix B for a comparison of heat sources. Avoid the use of unvented gas heaters in northern climates. Building ventilation rates must be increased to compensate for the increased indoor pollution created by these heaters and the economic efficiency of the heater is quickly lost due to these increased ventilation rates.

The most applicable heater for a retrofitted building is a tube style infrared gas heater. Tube style infrared gas heaters are easily vented through a 6" hole cut into the side of the building. Their efficiency is higher than 90%. A tube-style heater is easily installed in a remodeled barn by ceiling hangers.

A major advantage to tube-style infrared heaters is they can be used to heat culture water directly. Infrared heat heats the surface it strikes so an infrared heater suspended over a tank will heat that tank rather than heating air between the heater and the tank. Submerged electrical heaters are short-lived, potentially dangerous and consume expensive fuel.

Convective air furnaces (hot air furnaces) have the advantage of being readily available, easily repaired, and easy to install. Modern, high-efficiency gas furnaces can be vented directly through building sidewalls without the use of an extensive chimney system but older furnaces require an extensive exhaust gas venting system which can be cost prohibitive. Supplemental water heating devices are often required when warmwater fish are cultured in buildings heated by convective air furnaces.

Radiant floor heaters can be cast into the concrete when floors and tanks are being cast. These heaters are safe, do not become biofouled and do not build-up scale but their inaccessibility is an obvious disadvantage.

See Appendix A to determine the size of heater required. Add 25% to the heater size to allow for the heating of water. For a general approximation, a 100,000 BTU infrared gas heater at the Illinois State University aquaculture facility is more than adequate to supply air and water heat for a 1000 square foot building with 10,000 gallons of culture water.

Insulation

Insulation must be installed in most barns when they are retrofitted for fish culture. Insulation is important because it allows the control of both temperature and condensation. The form of insulation installed is determined by cost, ease of installation and health consideration. Fiberglass insulation is the most common and likely the most cost-effective per unit of R-value. Batts may be installed in walls and over ceilings and blown or loose fill fiberglass may be used over ceilings. Unfortunately, fiberglass batt insulation is often difficult to install in pole type buildings. Rigid board insulation is made from cellulose fiber, fiberglass, polystyrene, polyurethane, and polyisocyanurate. Sheets are 1/2 to 2" thick by 2 or 4' wide. Sheets are usually rated at high R-value per inch of thickness but they are also more expensive per unit of R-value when compared to fiberglass batt insulation. Despite its relatively high cost, board insulation is a good choice for remodeling a barn into a fish culture building because the insulation is easily installed into most existing barns styles, board insulation can be moisture resistant, and board insulation has a high R-value per inch. Some board insulations are flammable are release toxic gases when burned.

Foamed-in-place insulation are composed of polystyrene or polyurethane. If "open-celled", foam insulation is not moisture resistant. Closed cell foam is moisture resistant. Foam insulations are easily installed into existing buildings by spraying. Some foam insulation have been found to release formaldehyde gases as they age. Safety and cost problems need to be compared against the ease on installation and high R-values of this type on insulation.

Concrete is an excellent construction material but it has a very low R-value. Its primary function is to provide structural strength but from a thermal perspective it is little better than an excellent wind break. See Appendix B to determine wall R-values.

Air Moisture Control

Is excessive humidity a problem in a fish culture building? Not from the perspective of the fish - the primary inhabitants of the building. In other confinement livestock buildings, managers are concerned about air quality because it impacts on the health of the building inhabitants but in fish confinement buildings air quality must deteriorate to severely debilitated condition before fish health is affected. Excessive humidity can be a problem, however, because it causes deterioration of building structural components, electronic monitoring equipment, stored feed and other corrosion sensitive materials. Humidity is best handled through a multi-tiered approach:

1. Keep moisture sensitive materials out of a fish culture room. Store feed in a separate room. Store electronic monitors in an office or "clean" room. Use lights and other structural components which can tolerate high moisture conditions. Plywood, for example, should be exterior quality at minimum. CDX plywood is suitable for use in a fish culture building if the "C" grade veneer faces inside the room. "D" grade veneers cannot tolerate high moisture conditions even through the plywood contains exterior grade glue. A better choice for interior sheathing is to use "white board" - plywood coated with fiberglass or plastic. This material is commonly used as sheathing in hog farrowing houses and is readily available from farm supply construction centers. Avoid use of water-borne preservatives in the construction materials used inside a fish production building since preservatives may leach out of the wood and cause fish health problems. Oil-borne preservative such as pentachlorophenol will not leach into water as easily.

2. Construct the room so that moisture does not move into the walls. If moist air moves into a wall the air will eventually cool to its dewpoint and condense inside the wall leading to matted and ineffective fiberglass insulation, rotting of wall structural members, shorting of electrical components, and paint blistering. A vapor barrier is of obvious premier importance in any fish culture building when temperatures and ventilation rates will be controlled. Vapor barriers placed on the warm side of walls prevent moisture movement into the wall. Warm air holds greater amounts of water vapor than does cold air.

   Four to six-mil polyethylene is the most common vapor barrier. If whiteboard is used as wall sheathing, the seams of the sheathing should be sealed with silicone to provide a vapor barrier. Ceilings must also be moisture-proofed.

3. Install air heat exchangers. A heat exchanger will allow the venting of high-humidity air and replace it low-humidity, outside air. The purpose of the heat exchanger is to transfer heat from the exhaust air to the incoming air. Heat exchangers are sized to keep interior moisture levels at 50-80% relative humidity. Higher humidities may lead to condensation problems and lower levels lead to dust problems. Some studies have demonstrated that air held at 50 - 80% R.H. is detrimental to air-borne bacteria. A heat exchanger transfers approximately half of the exhaust heat to incoming air. A small disadvantage to the

use of heat exchangers in a fish production building is the slight loss of heat energy associated with the moisture content of the vented air. While the temperature of the vented air may be lower, the latent heat content of the exhaust air is still high due to the vapor still present in the air. Dry air in a fish culture building can easily absorb heat energy without an accompanying increase in temperature. As the relative humidity of air increase, the air is less likely to absorb heat without also changing temperature.

4. Vent the cold side of the wall. Regardless of the quality of the vapor barrier, a small amount of water vapor will find its way into a wall in a fish culture building. All building cavities should be vented to allow the escape of this moisture. Roof ridge vents may be installed to vent attic spaces. In some cases, it may be necessary to vent walls by drilling 5/8" holes through the top plate. Three holes are recommended for every stud in the wall. Vent holes may be drilled into the top and bottoms of exterior sheathing. Small louvers should be placed into these vent holes to prevent the entrance of

Monitor, Provide Automatic Control

An alarm and monitor system is strongly recommended for commercial- scale fish culture systems. Monitor and control devices should be planned into the building design during remodeling. The system should monitor oxygen level, high and low water level, temperature, water flow, and electrical flow. Systems currently on the market will measure these parameters and call 4 telephone numbers with an alarm message if the parameters are outside of specified ranges. In addition, a monitor system can automatically adjust electrical component to control water quality. According to manufacturers data, temperature, oxygen levels, water flow rates and water level can all be manipulated automatically by a system costing approximately $6,000.

Historic Preservation

Many older barns are remodeled for aesthetic reasons. If an agricultural building is more than 50 years old and has notoriety for its architecture or association with important persons or events, the building may be registered on the National Register of Historic Places. The registration of a building does not limit the use or even destruction of the structure but it does give its owner eligibility for remodeling tax credits and perhaps property tax freezes. To qualify for a 20% tax credit, a building must meet these criteria:

1. the building is listed on the National Register of Historic Places. (A 10% tax credit is available for nonregistered buildings built before 1936.)

2. the building is used for income-producing purposes,

3. rehabilitation costs are greater than $5,000, and

4. at least 75% of the existing internal structural framework is retained.

To discuss the potential for tax credits as you remodel your old barn into a fish culture facility, contact the National Trust for Historic Preservation, 53 West Jackson Blvd., Suite 1135, Chicago, Illinois 60604, (312-939-5547).

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APPENDIX A

(from Midwest Plan Service Structures and Environment Handbook 1)

Calculating Heat Loss

The rate of heat loss through each building component is proportional to its area and the difference between the inside and outside temperatures. The rate of heat flow is also determined by the R_T value of the building component; the higher the R_T value, the lower the rate of heat flow. The rate of heat loss from each building component, q, is given by:

Eq 631-1.

$$q = (A/R_T) \times (t_i - t_o)$$

- q = rate of heat loss from the building component, Btu/hr
- A = area of the building component, ft^2
- R_T = total resistance to heat flow of the component, F-ft^2-hr/Btu
- t_i = inside temperature, F
- t_o = outside temperature, F

The floor perimeter is a special case and the R_T value in Table 631-3 is given per foot of length. In this case the area, A, is replaced by the length of the exterior wall.

To obtain the total heat loss from a building, the losses through each building component are simply added together. The following sample problem illustrates the procedure.

Sample Problem

Find the amount of heat loss that will occur in a 24' x 36' building constructed as illustrated in Fig 631-18. The inside design temperature is 60 F and the outside design temperature is -10 F. The building has two 3' x 7' doors, insulated with 1", 1 pcf of molded polystyrene.

Step I

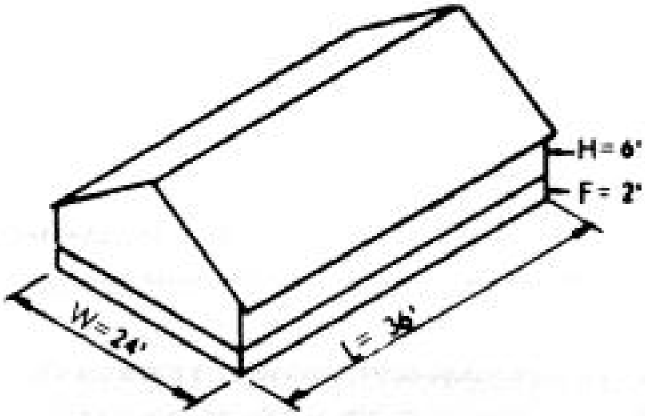
List the length, width, wall height, and foundation height. Calculate the perimeter, frame wall area (excluding windows and doors), concrete wall area, ceiling area, window area, and door area. The resistance of the frame wall is 12.47 from Table 631-2. The R_T for a 6" concrete wall with 2" polystyrene insulation is 11.58 from Table 631-2. The $R_T$for the ceiling is 13.47 and for the doors is 7.99 from Table 631-3.

Step II

The heat losses, q, for the ceiling, walls, and perimeter are found by placing the appropriate values from Step I into the heat loss equation.

The R_T value of 2.22 in the perimeter equation assumes 2" x 24" polystyrene perimeter insulation, Table 631-3.

The total heat loss, q_b, from the building is the sum of the ceiling, wall, perimeter window, and door losses.



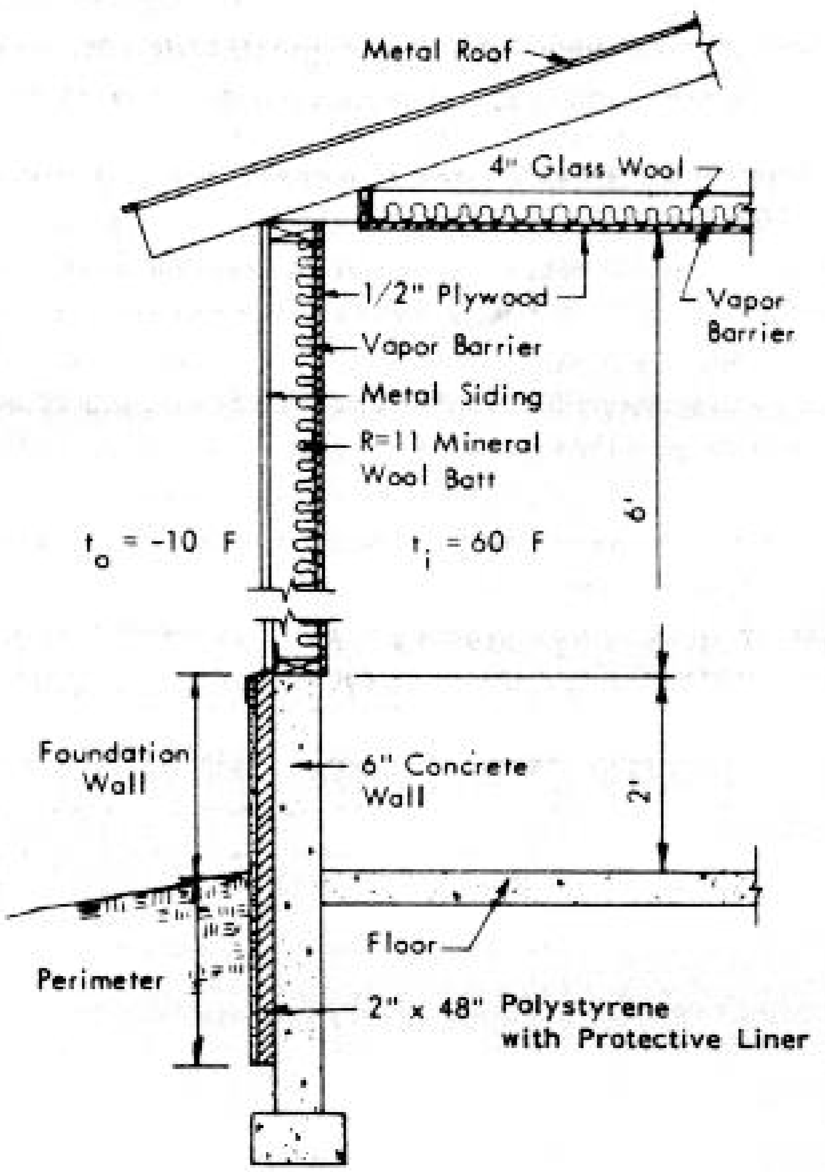


Fig 631-18. Sample problem building wall.

WORKSHEET-HEAT LOSS

Step I

Building dimensions	(ft)	Surface area	(ft^2)	R_T values	
Length (L)	36	Ceiling area	864	ceiling	13.47
Width (W)	24	Window area	0	Window	
Frame wall height (H)	6	Door area	42	Door	7.99
Concrete wall height (F)	2	Frame wall area less window & door area	678	Frame wall	12.47
Perimeter	120			Concrete wall	11.58
		Concrete wall area	240	Perimeter	2.22

Design temperatures (F)

t_o (outside temp) = -10 t_i (inside temp) = 60

$Delta_t$ = 70

Step II

Heat loss from building, q_b

Ceiling $$q_c = \frac{Delta_t \times \text{ceiling area}}{\text{ceiling } R_T} \qquad q_c = \frac{70 \times 864}{13.47} = 4490 \text{ Btu/hr}$$

Windows $$q_{wi} = \frac{Delta_t \times \text{window area}}{\text{window } R_T} \qquad q_{wi} = 0$$

Doors $$q_d = \frac{Delta_t \times \text{door area}}{\text{door } R_T} \qquad q_d = \frac{70 \times 42}{7.99} = 368 \text{ Btu/hr}$$

Frame walls $$q_w = \frac{Delta_t \times \text{frame wall area}}{\text{frame wall } R_T} \qquad q_w = \frac{70 \times 678}{12.47} = \ = 3806 \text{ Btu/hr}$$

concrete walls $$q_f = \frac{Delta_t \times \text{concrete wall area}}{\text{concrete wall } R_T} \qquad q_f = \frac{70 \times 240}{11.58} = 1451 \text{ Btu/hr}$$

Perimeter $q_p = \dfrac{Delta_t \times perimeter}{perimeter\ R_T}$ $\qquad q_p = \dfrac{70 \times 120}{2.22} = 3784$ Btu/hr

$q_b = q_c + q_{wi} + q_d + q_w + q_f + q_p = 13{,}899$ Btu/hr

Or:

Building heat loss, q_b can be expressed in terms of the inside-outside temperature difference, At:

$q_b = A/R \times Delta_t$ Eq 631-2.

A/R =sum of all (area/resistance) ratios of the building

Using the above sample problem:

Building (A/R) = ceiling (A/R) + frame wall (A/R) + concrete (A/R) + perimeter (A/R) + window (A/R) + door (A/R)

= 864/13.47 + 678/12.47 + 240/11.58 + 120/2.22 + 0 + 42/7.99

= 64.14 + 54.37 + 20.73 + 54.05 + 5.26

= 198.55 Btu/hr-F

Therefore, the heat loss from the building is:

q_b =198.55 x $Delta_t$
= 198.55 x 70
= 13,899 Btu/hr

Effects of Changing Insulation Values

Note three important items in the example that can affect the quantity of heat loss:

1.Use enough insulation.

Suppose the insulation in the frame walls is decreased from R =11 batt insulation to 25/32" insulating sheathing (see Table 631-2). This is a decrease in R_T value from 12.47 to 4.43. Recalculating the heat loss from the frame walls and building yields:

Frame wall:
q_b = $Delta_t$ x frame wall area e frame wall R_T
= 70 x 678 + 4.43
= 10,713 Btu/hr

Therefore, the new building heat loss is:
q_b =20,806 Btu/hr

This represents an increase in heat loss through the frame wall of 180%. The total building heat loss increases 50%.

2.Insulate all areas.

The use of insulation on concrete walls and around the building perimeter often went unnoticed until recent years. The illustrate the effectiveness of insulating the concrete wall and perimeter, assume the 2" x 48" insulation covering the concrete wall and perimeter in Fig 631-18 is neglected. Recalculation of the heat loss from the concrete wall, perimeter, and building yields:

Concrete wall:
R_T = 1.33 (Table 631-1)
Perimeter:
R_T = 1.23 (Table 631-3)
Concrete wall:
q_f = $Delta_t$ x concrete wall area
÷ concrete wall R_T
= 70 x 240 ÷ 1.33
= 12,632 Btu/hr
Perimeter:
= $Delta_t$ x perimeter ÷ perimeter R_T
= 70 x 120 ÷ 1.23
= 6,829 Btu/hr
Therefore, the new building heat loss is:
= 28,125 Btu/hr

The heat loss through the concrete wall increases 771%; and the perimeter, 80%. Not insulating the concrete wall and perimeter causes the total heat loss of the building to almost double.

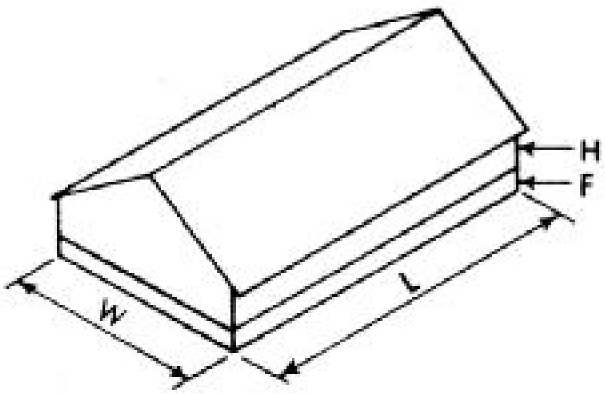
3.Install windows only when necessary.

Single pane glass is poor insulation. If windows are required, use thermopane or windows with storms to cut heat loss. Th illustrate heat loss through windows, assume there are eight in this building. The windows are single thickness having an area of 8.75 ft^2 (2'-6" x 3'-6"). Recalculating the building heat loss yields:

Windows:
q_{wi} = $Delta_t$ x window area ÷ window R_T
= 70 x (8.75 x 8) ÷ 0.91
= 5385 Btu/hr
Frame walls:
= $Delta_t$ x (frame wall area - window area)
÷ frame wall R_T
= 70 x (678 - 70) ÷ 12.47
= 3413 Btu/hr
Therefore, the new building heat loss is:
q_b = 18,891 Btu/hr

The heat loss through the eight windows is over 1 1/2 times the heat loss of the four frame walls. The total building heat loss increases 36%.

WORKSHEET-HEAT LOSS



Step I

Building dimensions *(ft)*
Length (L) _________
Width (W) _________
Frame wall height (H) _________
concrete wall height (F) _________
Perimeter _________

R_T values
Ceiling _________
Window _________
Door _________
Frame wall _________
concrete wall _________
Perimeter _________

Surface area *(ft^2)*
Ceiling area _________
Window area _________
Door area _________
Frame wall area
less window & door area _________
Concrete wall area _________

Design temperatures, F

t_o (outside temp) = _________ , t_i (inside temp) = _________
$Delta_t$ = _______

Step II

Building heat loss, q_b

Ceiling $q_c = \dfrac{Delta_t \times \text{ceiling area}}{\text{ceiling } R_T}$ $q_c = \dfrac{(\quad) \times (\quad)}{(\quad)}$ = ______ Btu/hr

Windows $$q_{wi} = \frac{\text{Delta}_t \times \text{window area}}{\text{window } R_T} \qquad q_{wi} = \frac{(\quad) \times (\quad)}{(\quad)} = \underline{\qquad\quad} \text{ Btu/hr}$$

Doors $$q_d = \frac{\text{Delta}_t \times \text{door area}}{\text{door }_T} \qquad q_d = \frac{(\quad) \times (\quad)}{(\quad)} = \underline{\qquad\quad} \text{ Btu/hr}$$

Frame walls $$q_w = \frac{\text{Delta}_t \times \text{door area}}{\text{frame wall }_T} \qquad q_w = \frac{(\quad) \times (\quad)}{(\quad)} = \underline{\qquad\quad} \text{ Btu/hr}$$

Concrete walls $$q_f = \frac{\text{Delta}_t \times \text{door area}}{\text{concrete wall }_T} \qquad q_f = \frac{(\quad) \times (\quad)}{(\quad)} = \underline{\qquad\quad} \text{ Btu/hr}$$

Perimeter $$q_p = \frac{\text{Delta}_t \times \text{door area}}{\text{perimeter }_T} \qquad q_p = \frac{(\quad) \times (\quad)}{(\quad)} = \underline{\qquad\quad} \text{ Btu/hr}$$

$$q_b + q_c + q_{wi} + q_d + q_w + q_f + q_p = \underline{\qquad\quad} \text{ Btu/hr}$$

APPENDIX B

Heating Fuel Cost Comparison

Choosing a Fuel

You can run electricity through your heat pump, burn corn cobs in your biomass furnace, stoke up the wood stove--there are numerous ways to keep your home warm in the winter.

What you pay for that warmth depends largely on what fuel you use and the efficiency of your furnace. Unfortunately, finding out which fuel is cheapest for you is about as easy as comparing corn cobs to kilowatts. That's because fuels are sold in a variety of units, ranging from the ton, to the gallon, to the cord.

The worksheet on the back of this page helps you compare costs of different types of fuels. It takes into account both fuel costs in your area and the efficiency of your particular furnace or stove. After doing the computations, you'll know approximately what it will cost you to put one million Btu's (British thermal units) into your house, using a particular type of fuel and furnace. During the heating season, it takes about 100 to 150 million Btu's to heat the average Iowa home.

Using the Worksheet

To use the worksheet, do the following computations for each fuel you want to price:

Get local fuel prices. Write them in column 2. Make sure the figures correspond to the units listed in column 2. For example, LP gas is priced by the gallon, electricity by the kilowatt-hour, wood by the cord.

Find out the annual efficiency of your heating system (or the heating system you're considering). If you have an older heating system, you may not know its efficiency In that case use the typical efficiency figure already listed in column 3. Efficiencies are available for most new furnaces and stoves. If you know the system's efficiency, cross out the given figure in column 3 and put the actual efficiency In the blank. (The actual efficiency of heating systems varies. Your heating system efficiency might be much higher or lower than the typical efficiencies given.)

Multiply column 1 by column 2.

Divide the result by column 3. Put this figure in column 4.

Column 4 shows the cost of putting 1 million Btu's of heat into your house, using a specific fuel.

Other Considerations

Fuel cost isn't the only factor to consider when choosing a heating system. Other factors to consider include the cost of buying the system, the convenience and availability of the fuel, storage space needed, reliability of the system, maintenance expenses, and safety and environmental concerns.

Prepared by Tom Greiner, extension agricultural engineer, and Diana Pounds, communications specialist at Iowa State University.

Fuel	(1) Quantity for one million Btu's		(2) Fuel price		(3) Annual efficiency		(4) Fuel cost per million Btu's
Natural gas	10.0 Ccf	X	$______ per Ccf	÷:	(0.67 or ______)	=	$ ______
LP gas	11.11 gal.	X	$______ per gal.	÷:	(0.67 or ______)	=	$ ______
Fuel oil	7.14 gal.	X	$______ per gal.	÷:	(0.55 or ______)	=	$ ______
Electricity (resistance)	293 kWh	X	$______ per kWh	÷:	(1.00 or ______)	=	$ ______
Electricity (heat pump)	293 kWh	X	$______ per kWh	÷:	(1.50 or ______)	=	$ ______
Hard coal	0.0417 ton	X	$______ per ton	÷:	(0.50 or ______)	=	$ ______
Hard wood	0.0357 cord	X	$______ per cord	÷:	(0.50 or ______)	=	$ ______
Medium wood	0.0476 cord	X	$______ per cord	÷:	(0.50 or ______)	=	$ ______
Soft wood	0.0714 cord	X	$______ per cord	÷:	(0.50 or ______)	=	$ ______
Kerosene -	7.41 gal.	X	$______ per gal.	÷:	(0.99 or ______)	=	$ ______
Biomass							

(garbage, $_______
pulp, etc.) 143 lbs. X per lb. ÷: (0.50 or ______) = $ ______

Three examples

Following are three examples. In the first, heating fuel cost is computed, using a 67 percent-efficient furnace and natural gas price of 51 cents. The second example shows the fuel cost when natural gas remains at 51 cents per Ccf, but the furnace efficiency is 92 percent. In the third example, heating fuel cost is figured for a 100 percent-efficient resistance electric furnace and an electricity cost of 7.04 cents per kWh.

$.51
Natural --------
gas 10.0 Ccf X per Ccf ÷ (0.67 or X) = $ 7.61

$.51
Natural --------
gas 10.0 Ccf X per Ccf ÷ (X or .92) = $ 5.54

$.0704
Electricity ---------
(resistance) 293 kWh X per kWh ÷ (1.00 or X) = $20.63

Solar energy

To compare solar costs, the cost of installing solar equipment must be considered. See extension publication *Active Solar Collectors-Are They a Good Investment?* (Pm-1034).

*This figure represents the efficiency of the heat pump It's the heat output of the unit divided by the electricity used, usually called the coefficient of performance (COP).

Units

Ccf = 100 cubic feet of as
therm = about 1 Ccf
kWh = 1 kilowatt-hour
cord = a 4 x 4 x 8 foot stack of wood

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APPENDIX C - Calculating R-Values (from MWPS Structures and Environment Handbook 1)

Table 631-1. Insulation values.

From 1981 ASHRAE Handbook of Fundamentals. Values do not include surface conditions unless noted otherwise. All values are approximate.

Material	R-value Per inch (approximate) 1/k	R-value for thickness listed 1/C
Batt and blanket insulation		
Glass or mineral wool, fiberglass	3.00-3.80*	
Fill-type insulation		
Cellulose	3.13-3.70	
Glass or mineral wool	2.50-3.00	
Vermiculite	2.20	
Shavings or sawdust	2.22	
Hay or straw, 20"		30+
Rigid insulation		
Exp. polystyrene,		
extruded, plain	5.00	
molded beads, 1 pcf	5.00	
molded beads, over 1 pcf	4.20	
Expanded rubber	4.55	
Expanded polyurethane, aged	6.25	
Glass fiber	4.00	
Wood or cane fiberboard	2.50	
Polyisocyanurate	7.04	
Foamed-in-place insulation		
Polyurethane	6.00	
Building materials		
Concrete, solid	0.08	
Concrete block, 3 hole, 8"		1.11
lightweight aggregate, 8"		2.00
lightweight, cores insulated		5.03
Brick, common	0.20	
Metal siding	0.00	
hollow-backed		0.61
insulated-backed, 3/8"		1.82
Softwoods, fir and pine	1.25	
Hardwoods, maple and oak	0.91	
Plywood, 3/8"	1.25	0.47
Plywood, 1/2"	1.25	0.62
Particleboard, medium density	1.06	
Hardboard, tempered, 1/4"	1.00	0.25
Insulating sheathing, 25/32"		2.06
Gypsum or plasterboard, 1/2"		0.45
Wood siding, lapped, 1/2" x 8"		0.81
Asphalt shingles		0.44
Wood shingles		0.94
Windows (includes surface conditions)		
Single glazed		0.91

with storm windows	2.00
Insulating glass, 1/4" air space	
double pane	1.69
triple pane	2.56
Doors (exterior, includes surface conditions)	
Wood, solid core, 1 3/4"	3.03
Metal, urethane core, 1 3/4"	2.50
Metal, polystyrene core, 1 3/4"	2.13
Air space (3/4" to 4")	0.90
Surface conditions	
Inside surface	0.68
Outside surface	0.17

*The insulation value of fiberglass varies with ban thickness.
Check package label.

Ways of expressing the value of insulation are:

R = thermal resistance, hr-ft^2-F/Btu.

It is the resistance to heat flow of 1 ft^2 of material when the temperature difference between the two sides is 1 F.

R is an additive quantity; 2" of a material has twice the R-value of 1". Also the individual R- values for all materials in a given section of a structure can be added together to obtain a total R-value.

R_T = total thermal resistance.

It is the total resistance of an entire wall, ceiling, etc. section, including the air film coefficients.

U = overall coefficient of heat transmission, Btu/hr-ft^2-F = 1/R_T

It is the heat in Btu/hr that passes through an entire wall, ceiling, etc. section of 1 ft^2, in one hour per 1 F temperature difference between the air on the warm side and the air on the cold side.

k = thermal conductivity, Btu-in./ft^2-F-hr.

It is the heat in Btu/hr that passes through a piece of material 1" thick and 1 ft^2, when the temperature difference between the two sides is 1F.

C = thermal conductance, Btu/ft^2-F-hr.

C is like k, except it is given for the total thickness: k for glass wool = 0.29; C for 3" glass wool = 0.10. By convention, C does not usually include the effects of boundary layer resistances.

In the following discussion, R is used because the insulation value of a wall is easier to calculate, and many insulations are marked with their R-value.

Example 1:

Given the wall in Fig 631-7, find the total R-value. From Table 631-1 find the R-values for each material.

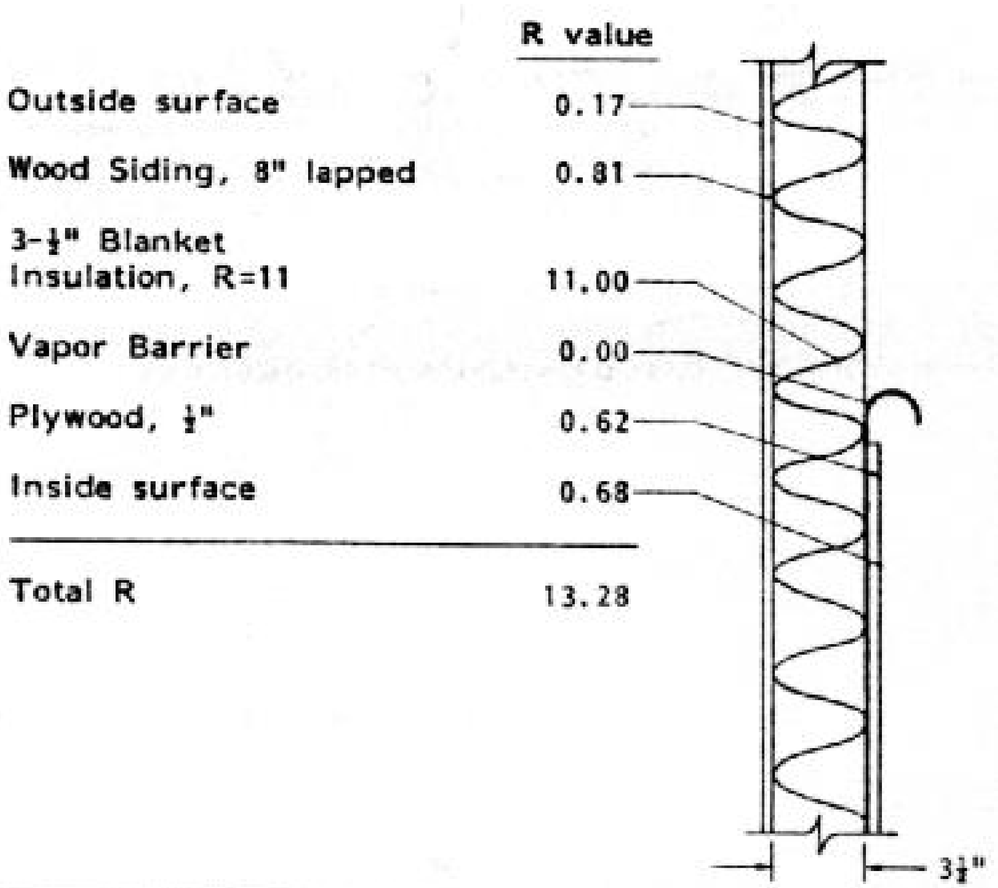
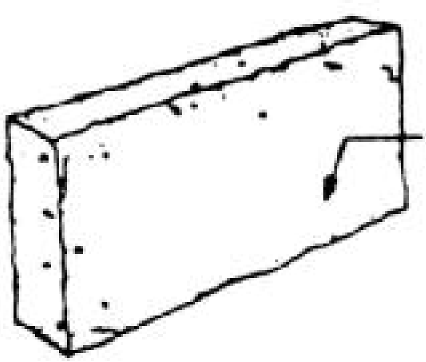


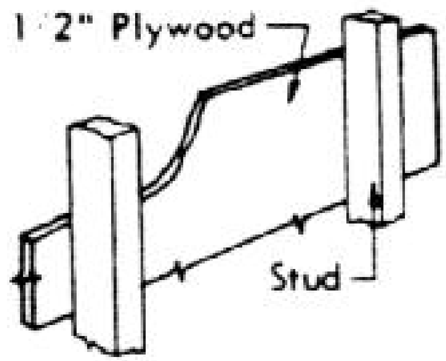
Fig 631-7. R-value of a wall section.

By adding the individual R-values, we find the wall has a total R-value of 13.28. Note that the blanket insulation provides more than 80% of the total R. Example calculations for other wall constructions are shown in Table 631-2.



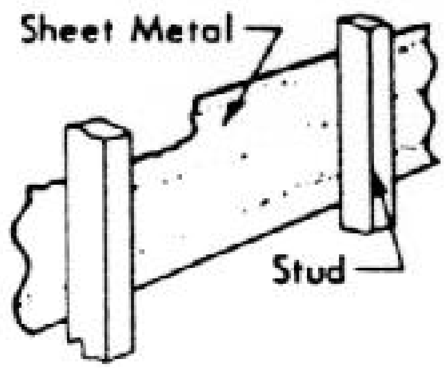
Outside surface (15 mph wind)	0.17
Concrete (6")	0.48
Inside surface (still air)	0.68

Total resistance, R_T	1.33



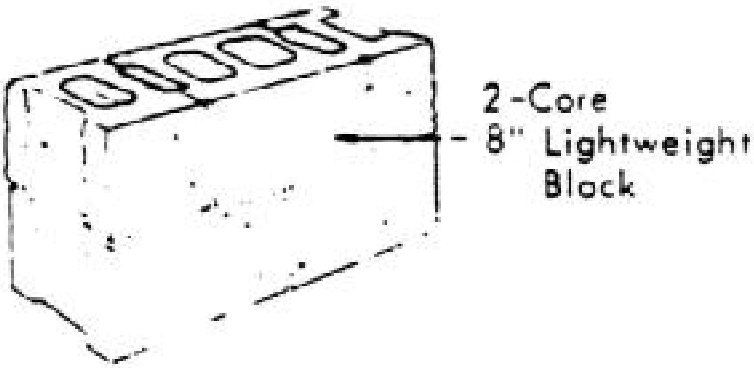
Outside surface (15 mph wind)	0.17
Plywood (1/2")	0.62
Inside surface (still air)	0.68

Total resistance, R_T	1.47



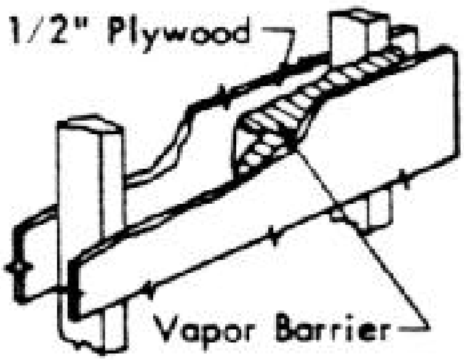
Outside surface (15 mph wind)	0.17
Sheet metal	0.00
Inside surface (still air)	0.68

Total resistance, R_T	0.85



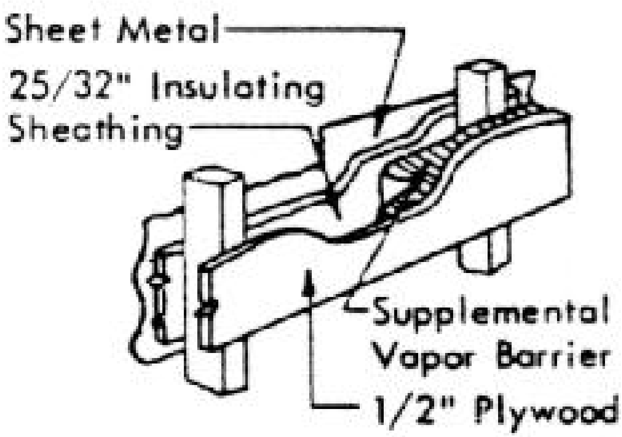
Outside surface (15 mph wind)	0.17
8' lightweight concrete block	2.00
Inside surface (still air)	0.68

Total resistance, R_T 2.85



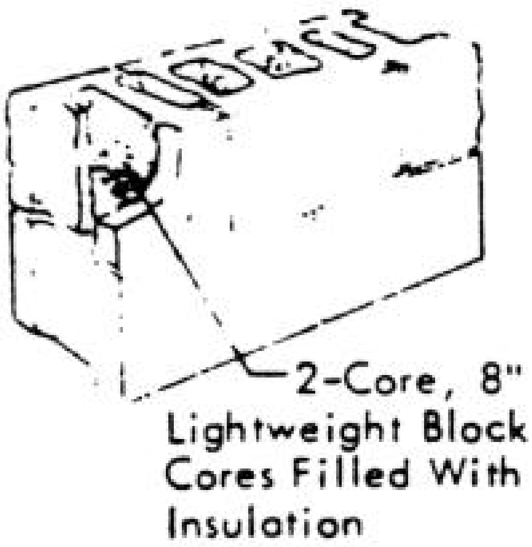
Outside surface (15 mph wind)	0.17
Plywood (1/2")	0.62
Air space	0.90
Supplemental vapor barrier	0.00
Plywood (1/2")	0.62
Inside surface (still air)	0.68

Total resistance, R_T	2.99



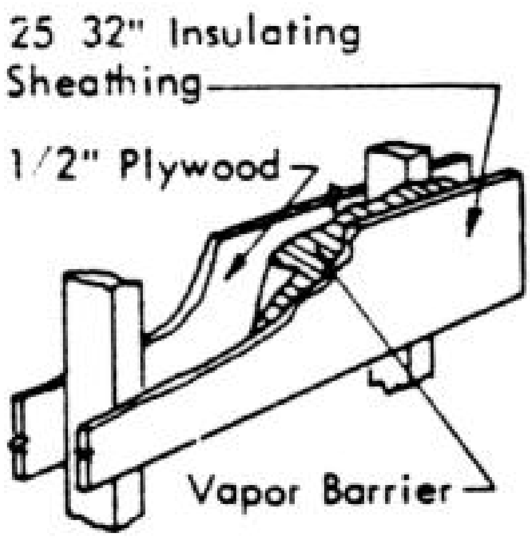
Outside surface (15 mph wind)	0.17
Sheet metal	0.00
Fiber board insulating sheathing, (25/22")	2.06
Air space	0.90
Supplemental vapor barrier	0.00
Plywood (1/2")	0.62
Inside surface (still air)	0.68

Total resistance, R_T	4.43



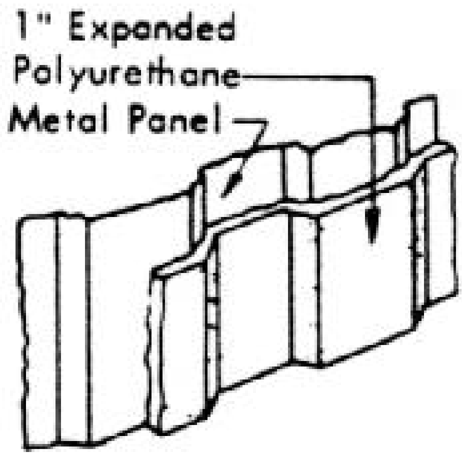
Outside surface (15 mph wind) 0.17
8" lightweight concrete block,
cores filled with vermiculite 5.03
Inside surface (still air) 0.68

Total resistance, R_T 5.88



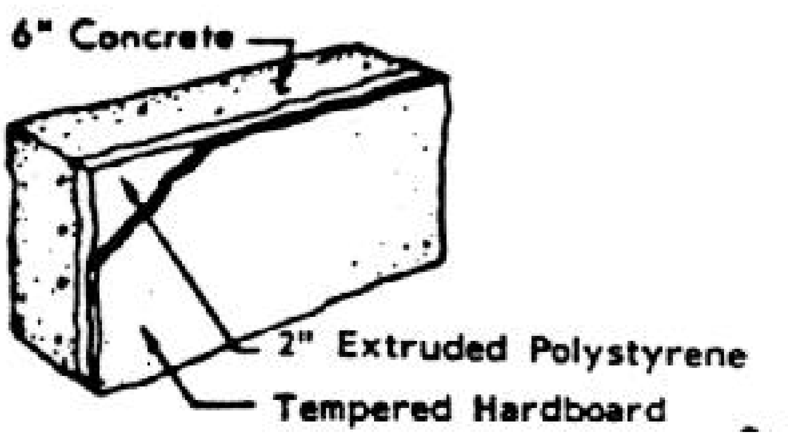
Outside surface (15 mph wind) 0.17
Plywood (1/2") 0.62
Air space 0.90
Supplemental vapor barrier 0.00
25/32" insulating sheathing 2.06
Inside surface (still air) 0.68

Total resistance, R_T 4.43



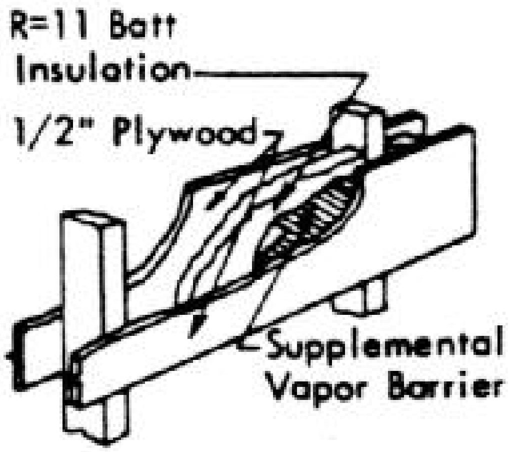
Outside surface (15 mph wind)	0.17
Sheet metal	0.00
Expanded polyurethane (aged)	6.25
Inside surface (still air)	0.68

Total resistance, R_T	7.10



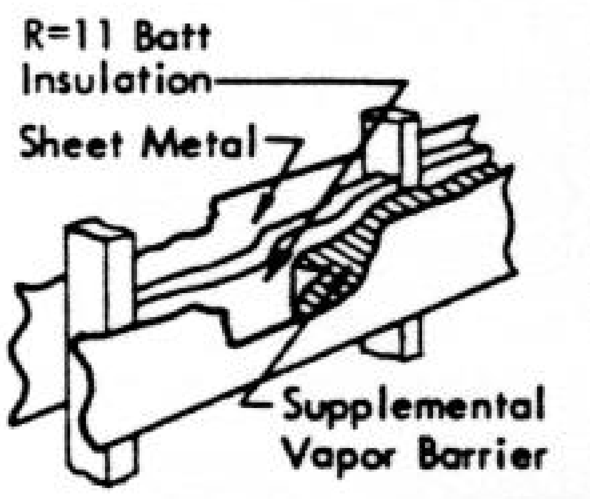
Outside surface (15 mph wind)	0.17
Concrete (6")	0.48
Extruded polystyrene (2")	10.00
Hardboard, tempered	0.25
Inside surface (still air)	0.68

Total resistance, R_T	11.58



Outside surface (15 mph wind)	0.17
Plywood (1/2")	0.62
Batt insulation, R=11	11.00
Supplemental vapor barrier	0.00
Plywood (1/2")	0.62
Inside surface (still air)	0.68

Total resistance, R_T	13.09



Outside surface (15 mph wind)	0.17
Sheet metal	0.00
Ban insulation	11.00
Supplemental vapor barrier	0.00
Plywood (1/2")	0.62
inside surface (still air)	0.68

Total resistance, R_T	12.47

Computer Monitoring of Recirculation Systems "An Alarming Thought"

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Introduction

"Aquaculture is agriculture", and like modern agriculture, aquaculture is progressing towards intensive, controlled environment production units (i.e. intensive recirculation systems). Through this technology comes an increase in production potential, but with a corresponding increase in risk of catastrophic loss. In pond aquaculture, response times are often measured in terms of hours and even days. In intensive systems, response time can be measured in heart beats. This leads to a need by a manager for accurate, real-time information on systems status and performance, and reliable backup for critical systems.

As a preface to this discussion, even an engineer has to confess that the most sophisticated monitoring and alarm system is an attentive human operator. An experienced manager can detect the moment he or she steps into a facility whether something is amiss, often just from a change in background noise. But most facilities are not staffed continuously, or are complex and spread out over several buildings. (Based on my own experience, most system failures occur either late Sunday, or ten minutes after the last person has left the facility.) Thus, the need for some form of continuous monitoring of critical water quality parameters and of selected systems.

Factors that affect the design of any monitoring/alarm systems, include:

1) *type and size of facility*: whether it is a hatchery, production and growout system, or just broodstock maintenance; cold water or warm water facility; freshwater or saltwater; the source of water from wells or gravity fed; single building or multiple buildings.

2) *type and number of tanks*: circular rearing tanks, raceways, or small ponds; individual rearing tanks or large production tanks; aeration with air or oxygen injection; recirculation or flow through systems.

3) *number and value of fish*: semi-intensive, intensive or super "just keep them wet " intensive systems; baitfish, trout, catfish, or prize Koi.

4) *location and operating procedures*: remote location or next door; on-site staff, full or part-time operators.

5) *budget*: just one bell or microcomputer controlled back-up response.

What follows is a brief discussion of technology that is currently available for monitoring an intensive recirculation system and provide for adequate back-up in case of system failures. Various types of sensor, probes, and monitoring equipment will be described, as well as integrated systems. Both high-tech and low tech solutions will be presented. But what must be emphasized again is that the best monitoring/alarm systems is still an attentive operator and second that any system is only as good as the care that is taken in its design, installation and maintenance.

Monitoring

Priorities "A Question of Timing"

Table 1 presents a short list of some of the potential "emergencies" in the life of any intensive system. In addition to these, always keep in mind Murphy's Law: "If anything can go wrong, it will!". There is no question that intensive systems need some form of continuous monitoring and alarm system to avoid catastrophic loss of product. In fact, considering the odds, its surprising that any fish survive. In designing a system, it is important not to go overboard in terms of technological complexity and in the shear number of alarms and monitors. Sophisticated alarm systems are of little use, if the hired help continually disarms them due to unreliability, or too many sleepless nights answering false alarms.

When designing a system, always keep in mind what the critical water quality requirements are and some sense of their relative importance and required response times. Basically, all a fish needs to survive is water (excluding Chinese catfish and tilapia!). But the water must have sufficient oxygen, be at a proper temperature and not contain too high a concentration of waste products (i.e. ammonia). At high densities, the most important parameter to monitor (besides water) is the dissolved oxygen level. If the water flow or aeration is cut off for any number of reasons, low oxygen and the resulting increased stress levels can lead to disease problems and/or mass mortality within minutes. Thus in designing the oxygen monitoring system, a simple bell may not be adequate, especially if you live 20 minutes away. Some form of backup aeration must be provided for and automatically engaged to insure survival, for the fish and yourself. After dissolved oxygen, other important parameters to monitor are temperature and ammonia levels. But unlike oxygen, temperature changes and ammonia can take several hours to days to reach dangerous levels. Thus there should be time to analyze the problem and take the necessary steps to correct it, in a more relaxed manner.

Where to Monitor - "A Question of Importance"

Table 2 lists some of the important systems and parameters that need to be monitored in intensive recirculation systems (Huguenen and Colt, 1989). The actual number of functions that are monitored, depend on the specifics of the system and the operating conditions. In some cases, only a few monitoring points may be necessary. In any case, it is important to be sure that your monitoring the "critical" parameter. It helps little to monitor water flow into a tank, if the standpipe has fallen, and water is draining out faster than its coming in! The critical parameter here is water level in the tank. Similarly, there is no advantage in knowing that power is supplied to a pump motor, if the pump is jammed or the motor overloaded and shutdown. What one needs to monitor is whether or not water is being pumped and at an adequate volume for system needs.

What To Monitor

Water Level

Probably the easiest parameter to measure, water levels are commonly monitored for both high and low levels in production tanks. Other locations to monitor include the intake side of pumps in wells or sumps and should include automatic shutdown of pumps to prevent their damage in the case of low levels. Supple reservoirs or headtanks should be monitored for both high and low levels. High levels can indicate unusual change in normal water demands, due to clogged pipes or valves accidentally turned off. Low levels can be caused by pump or water supply failure. If immersion heaters are used, low level monitoring should be designed to turn them off, to prevent damage. Individual tanks can be monitored to detect plugged drain lines, fallen standpipes or large leaks. Sensors in production tanks need to be located so that passing fish don't accidentally trigger them. Alarm levels should be set so that normal operating transients do not activate an alarm. This can be accomplished either by setting the levels optimistically or allowing some time delay before activating an alarm after a sensor is triggered. In addition, any storage tanks of chemicals (i.e. sodium thiosulfate injection systems) should be monitored to give warning of depletion and also prevent injector pump damage.

Temperature

In any controlled environmental system, continuous and precise monitoring of temperature in rearing tanks is critical in order to optimize production, reduce stress and minimize risk of disease. Usually systems are monitored for both excessive high and low temperature, but it is important to remember that the two are not necessarily of equal importance. While low temperature may reduce growth, excessive high temperature may yield a new career. Since most temperature controllers are cyclic in nature (either on or off), temperature alarm limits should not be set too tight, to prevent unnecessary alarms due to short term transients. If immersion heaters are used, it is a good idea to use several low watt units rather than one single high wattage unit. Then if one unit breaks down, the impact is limited to a single unit and the overall effect is minimized.

Pressure

The aeration system is one of the most critical components in any intensive system. Response time to failure is very short. Thus if anything is to be monitored and have backup capability, this is it. Air/oxygen pressure is relatively easy to monitor and set up alarms for. Excessive high pressure can indicate blocked supply lines, valves turned off, or clogged diffusers. Excessive low pressure might mean a ruptured airline, open or jammed pressure relief valve, disconnected diffusers or blower failure. Pressure sensors can also be used to monitor the suction and discharge side of pumps. Although it should be noted, that a pressure or suction can exist without necessarily an adequate flow of water to systems.

Water Flow

In some cases, the actual measurement of flow rates is important, such as well performance monitoring or chemical injection systems. Normally though, monitoring simply that water which is flowing with an "on-off" device is adequate to insure water supply to critical systems. One such system is in-line heaters. That require a water flow to prevent overheating and potential meltdown. Another is submerged filters, where anaerobic condition can be fatal.

Electric Power

Power failure is probably the most common emergency situation and the one most easily monitored. This is especially important when systems (i.e. pumps, filters, etc.) are located some distance from the main building. With three phase electric power, it is quite possible to lose power only in some systems, but not all. This can occur when only one phase is down. Some single phase equipment, dependent upon wiring, can continue to operate.

Physical Plant Security

Readily available, intrusion alarms, smoke and high temperature (i.e. fire) sensors are commonly used to protect against fire, theft and vandalism. Often existing systems can be connected directly to proposed monitoring systems.

Water Quality Monitoring

Currently mature technologies exist for on-line monitoring of pH, dissolved oxygen and conductivity. These instruments usually consist of a sensor in the sample flow stream and an electronics/display package. Many models include an integrated alarm circuitry for low or high readings, that can easily be connected to a monitor/alarm system. Other parameters such as ammonia are relatively difficult to monitor on-line, but simple techniques exist for routine grab sample monitoring.

How To Monitor

What follows is a short review of various sensors that can be utilized to monitor system status and performance. Several variations on each are available from multiple sources, most notably the wastewater treatment industry and the chemical and petroleum industry. In most cases, the sophistication and corresponding expense of these types of sensors is not necessarily required in aquaculture facilities. But, until specific equipment becomes available for aquaculture and for high valued products, the added cost can be easily justified. One should keep in mind that in any system, the overall reliability is determined by the most unreliable part (i.e. weakest link). Some idea of relative costs are presented in Table 3.

Water Level

Float Switches. The basic float switch is designed to monitor a single, discrete, preset liquid level. These usually consist of a small permanent magnet encapsulated within a float. The float moves with the water surface, and actuates a hermetically sealed reed switch within the stem or body of the switch. The rugged construction of this design provides for long, trouble free service with minimum maintenance required. Several designs are available for mounting either vertically (top or bottom) or horizontally (side walls) in tanks or sumps. In addition, combining two float switches with a latching relay, allows for differential level control for pump-up or pump-down applications. These are also available as a single rod with floats that ride up and down the rod actuating reed switches inside the rod. Other variations include a single float which is tethered by it electrical cable. A relay inside the float switch is activated depending whether the bulb is floating upward on the surface or hangs down at the bottom. Float switches are simple, foolproof and relatively inexpensive, but they can be easily tripped by a mischievous fish.

Optical Liquid-Sensing Sensors These probes detect liquid levels using an internal infra-red circuit. If the probe tip is immersed, light is refracted out into the liquid. If the probe is dry, light is reflected back into a phototransister sensor. Combined with a control module, high or low levels can be monitored and fill or drain operations performed. These are very sophisticated sensor, and somewhat expensive.

Non-Contact Ultrasonic Level Sensors. These sensors operate by measuring the exact time required for an ultrasonic pulse to travel to the water surface and return. They are capable of measuring distance (levels) from 0.5 to 30 feet with an accuracy of up to 1% in open air. A variety of outputs are available ranging from alarm relays at preset levels to continuous level data. Expensive, but very flexible in their application.

Conductivity Level Switches. These operate on a simple conductivity principle, whereby a small electric current is passed through the conductive liquid when the level reaches the bottom of the electrode sensor. The current can be completed between a single electrode and a grounded metal tank, or between two electrodes. A very simple concept, but somewhat expensive to implement and subject to fouling.

Pressure Sensing Level Systems. The measurement of water level is accomplished by mounting a pressure transducer on the discharge side of an air supply, and then measuring the pressure required to bubble air through an immersed pipe in the water column. The pressure required to force the air bubbles out is directly proportional to the depth. These systems are excellent where fouling of float switches could be a problem. Their only drawback is the expense of both the pressure transducers and the signal conversion hardware.

Temperature

The four most common temperature transducers are thermocouples, the RTD, the thermistor, and the integrated circuit sensor. Each is based on some change in the physical property caused by a change in temperature. A thermocouple consists of two dissimilar metal wires jointed together. When heated or cooled, a small electric voltage is generated, that is linearly proportional to the junction temperature. Thermocouples are probably the most versatile temperature transducers available today. Hardware is readily available the performs all the necessary tasks of measuring the voltage and performing the voltage to a temperature conversion. Thus temperature measurements become as easy as twisting two wires together and connecting them to the monitoring hardware. The RTD (resistance temperature detector) takes advantage of the change in resistance of certain metals (platinum, nickel and nickel alloys) as a function of temperature. RTD's are extremely stable and accurate, but also expensive. Like the RTD, the thermistor is also a temperature sensitive resister, composed of semiconductor material. The thermistor is extremely sensitive and able to detect minute changes in temperature, but they tend to be somewhat fragile. The integrated circuit transducer is relatively new. They supply an output (current or voltage) that is linearly proportional to their absolute temperature, and are relatively stable, linear and accurate.

Of the four, thermocouples are the easiest to use, but do require the most expensive hardware for signal conversion and compensation. Thermistors are the most precise, over limited temperature ranges, and are most often used in temperature controllers. RTD's have very limited use, because of their high costs.

Pressure

Pressure measurements can be used to either maintain pressure at some set-point value (air compressor for control values) or sense that the pressure is moving out of some safe range (high/low alarm). Pressure is defined as a "force per unit area" and this force produces a deflection, distortion or some other physical change. This change can be measured directly using a pressure transducer, and excitation power supply and a signal processor. A pressure control switch employs this proportional deflection to trip an electrical switch at a preset pressure setting.

The use of pressure sensors to monitor water depth has already been mentioned. Pressure sensors are not commonly used to measure flow rates, due to the pressure fluctuations created by opening and closing valves in aquaculture systems. The most important system to monitor for pressure is of course the aeration system. Low pressure switches are available in a wide variety of configurations and price scales. It is important to remember, when specifying pressure switches that 1 psig equals 27.68 inches of water. Thus for typical aquaculture systems, the pressure in an aeration system will usually be below 5 psi or 140 inches of water (12 feet). Some pressure switches are rated high enough in load switching capacity, that they can be used directly to activate backup aeration blowers. Others will require some intermediate stage, such as an audible alarm with manual start-up or solid-state or mechanical relays.

Flow Rates

Rotameters. The rotameter operates on the variable area principle, where the fluid flow raises a float in a tapered tube, increasing the area for passage of the fluid. The greater the flow, the higher the float is raised, which is directly proportional to the flow rate. The float reaches a stable position, when the upward force exerted by the flowing fluid equals the downward force exerted by the weight of the float. It is important to note that because of this manner of operation, the rotameter must be vertically orientated.

The rotameter has numerous advantages, including:

- linear scale
- long measurement range (10 to 1 flow rate)
- low pressure drop
- operates over a wide range of pressures and temperatures
- inherently self-cleaning
- can be installed directly after fittings
- simplicity of design.

Rota meters can be used to measure almost all fluids, over a range of flows from 0.0002 cc/min to 60 GPM. In addition, adjustable proximity switches can be externally mounted on the flow meters, which are tripped at predetermined flow rate. These in turn can activate warning lights, pumps or other equipment.

Drag Discs/Paddle/Vane Flow Switches. All of these devices are designed to monitor for flow/no-flow or low flow conditions. Each operates on the drag force of the moving water against a small disk/paddle or vane in its path. They are available in a wide range of flow rates and pipe sizes and often can be externally adjusted for switch point. Normally the drag discs and paddles are installed using a "Tee" fitting, while the vane type is installed in-line. Simple, elegant, inexpensive, but the subject to fouling.

Turbine and Paddle wheel Flow Meters. Turbine flowmeters are one of the most widely used technology for accurately monitoring flow rates. Within the turbine flowmeter, the moving water engages a vaned rotor, which rotates at a speed proportional to the flow rate. As the turbine rotates, it can either mechanically indicate flow rate or total flow or electronically generate a pulse that can be sent to other hardware. In a paddlewheel flowmeter, the rotor and blades are perpendicular to the flow, usually mounted in a "Tee" fitting. Paddlewheel flowmeters are very tolerant of particles in the system and a very low cost substitute, where high accuracy of the turbine flowmeter is not required. Where only total flow is required rather than flow rate (GPM), then the turbine meter turns out to be an excellent, low cost solution.

Water Quality

Dissolved Oxygen. There are now a number of dissolved oxygen probes and analyzers available, that are specifically designed for the aquaculture industry. Several newer models are microprocessor-based instruments capable of measuring levels of dissolved oxygen up to 100 ppm (important for monitoring oxygen injection systems). Standard recorder outputs are now provided for both temperature and D.O. that include 4-20 mA and 0-1 VDC, as well as RS- 232 or RS-485 serial output for direct interfacing with microcomputers. Almost all of the newer models include high/low setpoint control relays for controlling external aeration devices, pumps, valves or other equipment (phone dialers). Although the initial investment in this equipment can be high, it must be weighed in terms of the potential loss and poor growth due to low dissolved oxygen levels.

pH and Ammonia. Both of these parameters have relatively long response times when compared to dissolved oxygen and other monitored parameters. pH is easily measured with a vast assortment of readily available meters and test kits. On-line ammonia monitoring is feasible, but very expensive and difficult in practice. There is equipment available that can analyze a continuous side stream sample using wet-chemistry and a colorimetric analysis technique. But these techniques are expensive and require frequent standardization and maintenance (Gibbs, 1991).

Bringing It All Together

Now that one can theoretically monitor the recirculation system for many of its potential problems (excluding "Mother Nature's"), the next step is bringing them to the attention of the manager, especially when he's at home asleep. Two systems will be presented, ranging from the simplest (inexpensive) to the more complex (expensive). The choice of system and design is extremely dependent on site specific variables, previously reviewed.

Automatic Dialers

A very inexpensive, simple and versatile monitoring system can be built around several readily available automatic phone dialers/alarm systems. These units originally were designed for home and business security monitoring, but work quite well as a central control unit. One such unit (Sensaphone, Phonetics, Inc., Aston, PA) has been used by several hatchery and recirculation systems with excellent results (Hamilton and Faerber, 1990, Losordo, 1991). The Sensaphone unit automatically monitors the following conditions (Sensaphone, 1990):

- AC electric power -- checks for power failure
- temperature - monitors temperature between 0 Deg. F and 128 Deg. F., checks to see if it exceeds or falls below user-programmed high and low limits, reports actual temperature.
- high sound level - fire/smoke alarm, intruder alarm
- battery - condition of its battery back-up
- four additional digital alert inputs or 3 digital and 1 temperature

All monitoring is a continuous process. When a problem arises, the unit will announce the alarm condition locally for 30 seconds. If no response is given, it will then sequentially dial up to four user-programmed telephone numbers with an alarm message. It will state, in English, the existing problem, disconnect, and wait for an acknowledging telephone call. It will continue dialing-out until its message is properly acknowledged. One can also call in and receive a status report on the monitored conditions and listen to the background sounds through a built in microphone.

For a small operation, such a system might easily manage to monitor adequately all the key operating parameters, for example: air/oxygen pressure, critical water levels and flows, water temperature and dissolved oxygen level. This could be accomplished by wiring several monitoring sensors (normally closed) in series, such that if any one of them is tripped, an alarm is generated. In addition, high sound levels from a fire/smoke alarm would also trigger an alarm.

Computer Based Monitoring/Alarm Systems

At the other end of the spectrum are systems built around sophisticated, dedicated computer based monitoring and data logging systems. (Ebeling, 1991). Over the past few years, several such systems have become available and surely more will follow. One such program is the "Hatchery Management System" (Rutledge Aqua Control, Inc., Snohomish, WA). This program is a computerized system which provides "continuous monitoring, alarm, control, automatic data gathering and analysis and chronology of hatchery event". One important advantage of these types of systems, is that in addition to sounding an alarm, they can also explain to the operator what to do about it. Especially with complex and interconnected systems, this becomes important, to take the guess work and the hunt out of responding to an alarm. Also these systems have the ability to store data over time. Thus giving the hatchery managers the ability to analyze the cause-and-effect relationships between control or adjustment decisions and actual results, allowing fine tuning of future control decisions and increased hatchery efficiency. All of these systems are standard input sensors, such as dry contact binary sensors and low voltage analog sensors and normally 24 VDC output for operating control relays.

Keeping It Working

Just a few final words on overall system design and maintenance. Most of these are taken from Shepherd and Morris (1987) review of practical emergency procedures for fish culturists.

System Design

- choose sensors carefully to avoid false alarms (fish love to rub against float level sensors)

- remember that aquaculture tends to be rather liquid in nature, so protect all electrical connections and equipment from moisture

- mount sensors where they are visible and easily accessible for service and adjustment

- clearly label the sensor's armed and unarmed modes, preferably with LED's at each station to show sensor status

- use the fewest possible sensors

- include expansion capability in all components of the system

- remember water and electricity make for a fatal combination, use low single voltages (5 VDC, 1 2 VDC or 24 VAC) to protect both the fish and you.

Maintenance

- have a well prepared maintenance manual

- weekly/monthly/yearly maintenance scheduling system and files of major service records

- daily/weekly/monthly instrument check sheets

- regular system checks, including:
triggering each sensor
checking status lights and signal strength
checking operation of the automatic dialer system

- staff training to handle routine alarms

- staff familiarization with complete operating system, including water supply, aeration and emergency back-up systems

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Hugenin, J. E. and J. Colt. 1989. Design and operating guide for aquaculture seawater systems. Elsevier, N.Y.

Losordo, T. 1991. Personal communication.

Shepherd. B. G. and J. G. Morris. 1987. A review of practical emergency procedures for fish culturists. Aquacultural Engineering, 6:155-169.

Table 1: "Short List" of Potential Problems

Category	Area	Specifics
External (Outside your control)	"Mother Nature"	floods, tornados, wind, snow ice, drought
	"Man	electrical outages,brown-outs, contamination, vandalism /theft
Internal	"Staff"	operator error maintenance overlooked, causing -failure of back-up systems -failure of system components automatic controls turned off alarms deactivated
Water Supply	Flow	value shut or opened too far pipe or value plugged pump failure/loss of suction head intake screen plugged
	Level	drain value open

		standpipe fallen or removed
		leak
		overflowing tank
		water demand exceeding supply
	Quality	low dissolved oxygen, high CO_2
		supersaturated
		high/low temperature or pH
		ammonia/nitrite/nitrate
		other minerals/chemicals/organics
Filters	Sand Filters	low inflow dissolved oxygen
		channeling/caking
		excessive head loss
	RBC	stopped rotating
		physically damaged
	Trickling Filters	physically plugged by organics
		channeling
Aeration	Blowers	motor overheated
		drive belt broken
	System	diffusers plugged/disconnected
Physical Plant	Electrical	GRIC circuit breakers tripped

Table 2: Typical Alarm System Monitoring Points

Water Level	supply sumps to pumps (high/low)
	drain sumps (high)
	headtanks/ reservoirs (high/low)
	chemical storage tanks (low)
	culture tanks (high/low)
	filters (high/low)
Water Flow	supply line pumps
	submerged filters (low)
	in-line heaters (low)
Temperature	heating/cooling systems (high/low)
	heat exchangers
	culture tanks (high/low)
Pressure	air pressure in aeration system
	suction & discharge side of pumps
	intake & discharge side of filters
	pressure actuated control values
Dissolved Oxygen	culture tanks (low)
	inflow to submerged filters (low)
	water supply (supersaturated)

Physical Plant Security	high temperature/smoke sensors
	intruder alarms
Others	ozone injection systems
	automatic filter backwash systems

Table 3: Costs of Monitoring Sensors/Transducers/Hardware

(These are estimates based on current catalog prices)

Flow Rate	Rotameters (acrylic)	$40-250
	Turbine Meters	$1000-1500
	paddlewheel sensors	$200-400
	Indicator Meters	$400-1000
	Totalizing Turbine Meters	$50-200
Flow Switches	Drag diskcs (Tee mounted)	$100
	Paddle (Tee mounted)	$45
	Vane (in-line)	$40
Level Indicators	Float Switches	$10-50
	latching relays	$50-100
	Rod high/low controller	$200-350
	Ultrasonic level	$300-1000
	Optical probes	$100
	Controllers	$150
	Conductivity level switches	$120-300
	Pressure sensing	$500-750
Temperature (Sensors)	Thermocouples	$10-50
	RTD's	$100
	Thermistors	$40-100
	Integrated Circuit Transducers	$5-20
(Hardware)	Thermocouples/monitored point	$50-150
	RTD's	$250
	Thermistors	$250
	Integrated Circuit Transducers	$100
Pressure	control switches	$8-100
	measurement hardware	$300-500
Water Quality	dissolved oxygen probes	$150-500
	meters	$500-1500
	pH probes	$30-500
	meters	$200-1000
Automatic phone Dialer		$300-3200
Computer Controller		Call for Quote

Sources of Equipment

(No endorsement of products by Ohio State University or the author is intended, nor is criticism implied of other manufacturers of similar products which are not included.)

Agriculture Magazine Buyer's Guide
P.O. Box 2329
Asheville, NC 28802
(704) 254-7334

Canadian Aquaculture Buyer's Guide
4611 William Head Road
Victoria, BC V8X 3W9
(604)478-9209

OMEGA Engineering, Inc.
P.O. Box 2284
Samford, CT 06906
(800) 826-6342
(monitoring & control equipment)

Cole-Parmer Instrument Co.
7425 North Oak Park Avenue
Chicago, IL 60648
(800) 323-4340
(instrumentation & control equipment)

Keithley Metrabyte
440 Myles Standish Blvd.
Taunton, MA 02780
(508) 880-3000
(data acquisition & control plug~in boards)

Royce Instrument Corp.
13555 Gentilly Rd.
New Orleans, LA 70129
(800) 347-3505
(water quality monitoring equipment,automatic phone dialers, computer control systems)

Raco Manufacturing & Engineering Co.
1400-62nd St.
Emeryville, CA 94608
(415) 658-6713
(automatic phone dialers)

Aquatic Eco-Systems, Inc.
2056 Apopka Blvd.
Apopka, FL 32703
(407) 886-3939
(automatic phone dialers, pressure switches)

Capital Control Co.,Inc.
P.O. Box 211
Colmar, PA 18915
(800) 523-2553
(water quality monitoring equipment)

Hach Co.
P.O. Box 608
Loveland, CO 80539
(800) 227-4224
(instruments & test kits)

Island Science
P.O. Box 564
Novato, CA
(41 5) 898-1422
(computer software)

Ryan Heco Products, Co.
P.O. Box 588
Burbank, CA 91503
(818) 841-1141
(control & monitoring equipment)

YSI Inc.
Yellow Springs, OH 45387
(513) 767-7241
(water quality monitoring equipment)

Zeigler Bros.,Inc.
P.O. Box 95
Gardners, PA 17324
(717) 677-6181
(monitoring equipment & computer monitoring)
systems)

Rutledge Aqua Control Systems, Inc.
P.O. Box 967
Snohomish, WA 98290

(206) 568-2044
(computer software)

"Real Life Experiences" with Recirculating Systems

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Introduction

World per capita seafood consumption is projected to jump from 27.3 pounds/year to 34 pounds/year by the year 2000. With the current projected rate of increase in population this corresponds to an increase of 31 million pounds annually (Lee, 1991). According to Lee Weddig, President of the National Fisheries Institute1 this increase is occurring at a time when catches from the ocean are nearing their peak. The majority of increased consumption is expected to fall to aquaculture production (Egan, 1990).

From the period 1985-1988 aquaculture production grew by 20% compounded annually. According to one aquaculture Analyst's projections, the industry should have topped $30 billion in 1990 and he expects a continued increase of 10-15% compounded annually through out the rest of the century (Davlin, 1990).

Closer to home, the U.S. per capita consumption of seafood products has increased by 25% since 1980. The National Fisheries Institute claims that last year only about 15% of the U.S. seafood consumption came from farm raised products. However, it is expected to climb to 25% by the year 2000 (Egan, 1990).

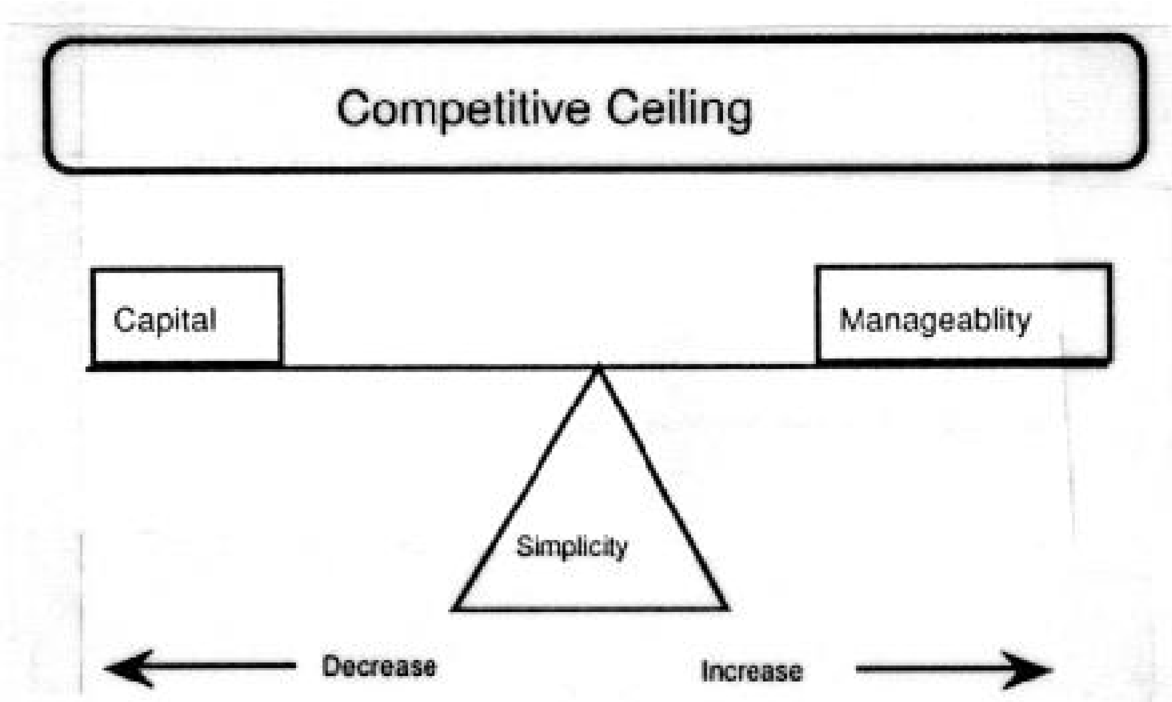
In 1989 the United States had a net deficit in seafood imports of $3.2 billion. Among commodity products this deficit ranked second, only behind petroleum. Estimates say that unless aquaculture continues to grow at the present rate the U.S. will have to import as much as 80% of it's seafood consumption by 2000 (Egan, 1990).

In view of the good news and predictions for aquaculture, why are the media and industry rife with stories of failing aquaculture ventures? Despite what many industry representatives and enthusiasts claim, there is much that is unknown about aquaculture technology and the fish themselves.

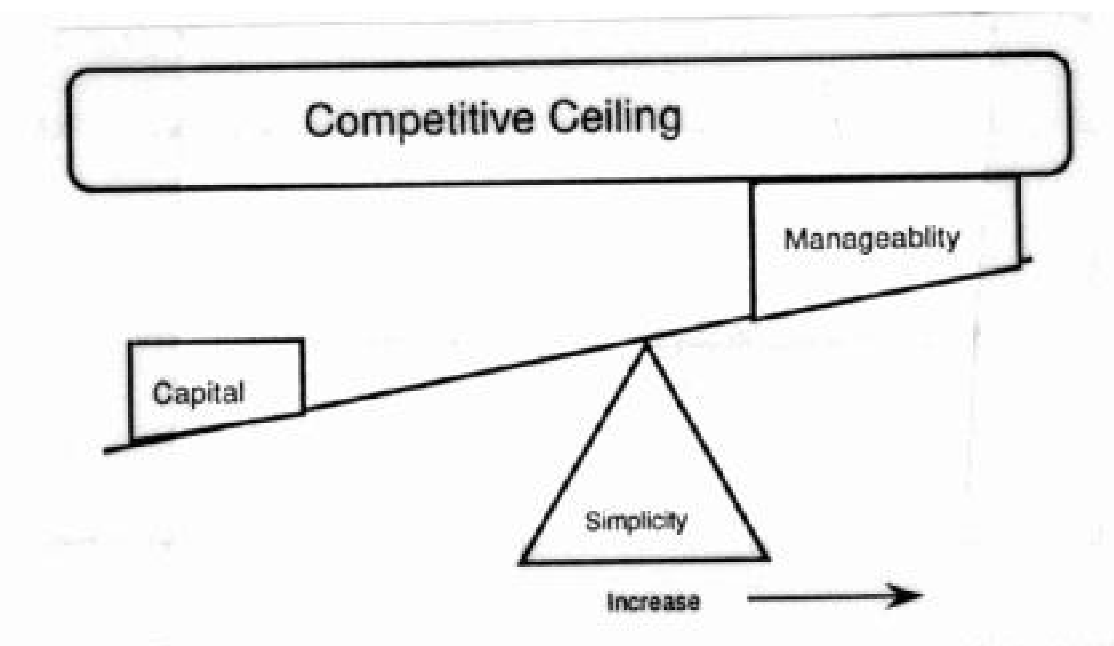
There is a serious need for research to gain a better understanding of current technologies and methods of biofiltration, aeration, genetic enhancement, and water sterilization. There is much to learn about fish nutrition, water quality, and their concomitant interactions with disease. There is also room for improvement in processing, market analysis, management strategies and system design. Although aquaculture as an industry is still in it's infancy and much is still unknown, enough information exists to develop successful operations if one proceeds cautiously.

Many of the intensive, recirculating systems that have succumbed to failure have not done so because of the unknowns still facing the industry, but because of a failure to adhere to what I consider three fundamental concepts.

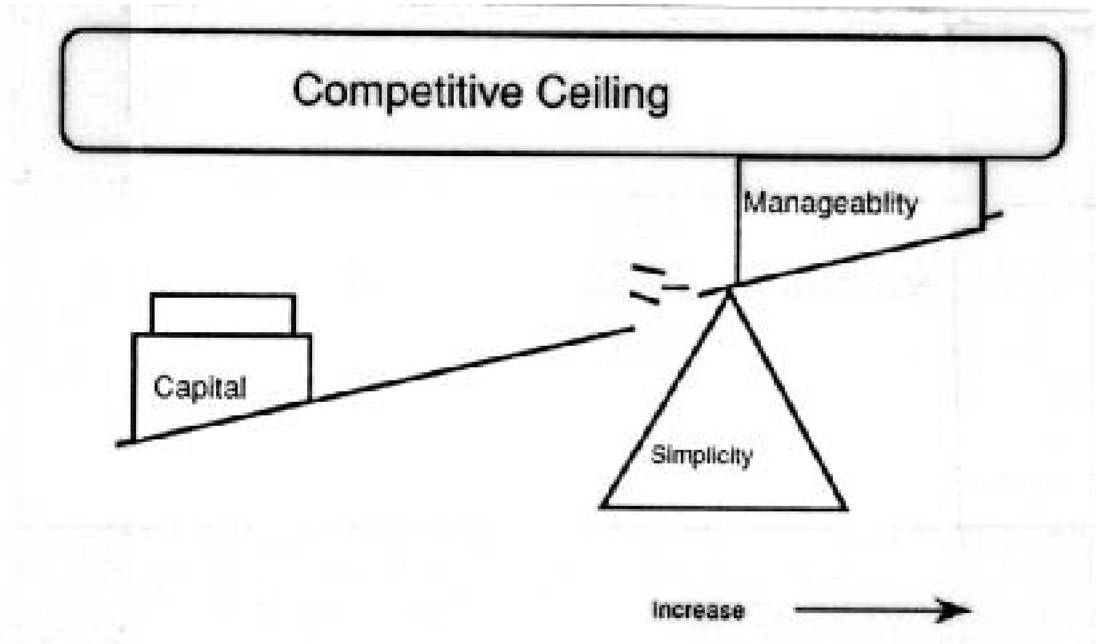
These three concepts are sufficient capital, simplicity, and manageability of the system. None of the concepts should be viewed as independent or mutually exclusive of each other. The relationship between the three may best be exemplified by the following models.



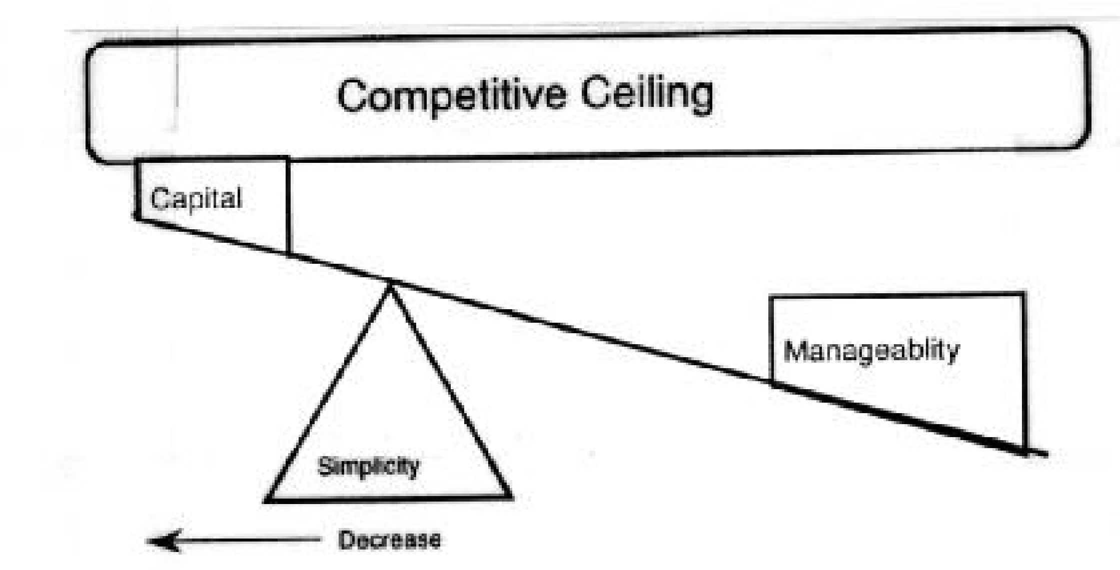
In a well designed system, simplicity can be viewed as the fulcrum upon which the capital expenditures and the manageability are balanced. For the venture to be successful the system must be maintained below a competitive ceiling. An increase in any member of the system which attempts to rise above this ceiling makes the system uncompetitive in the market and breaks the system.



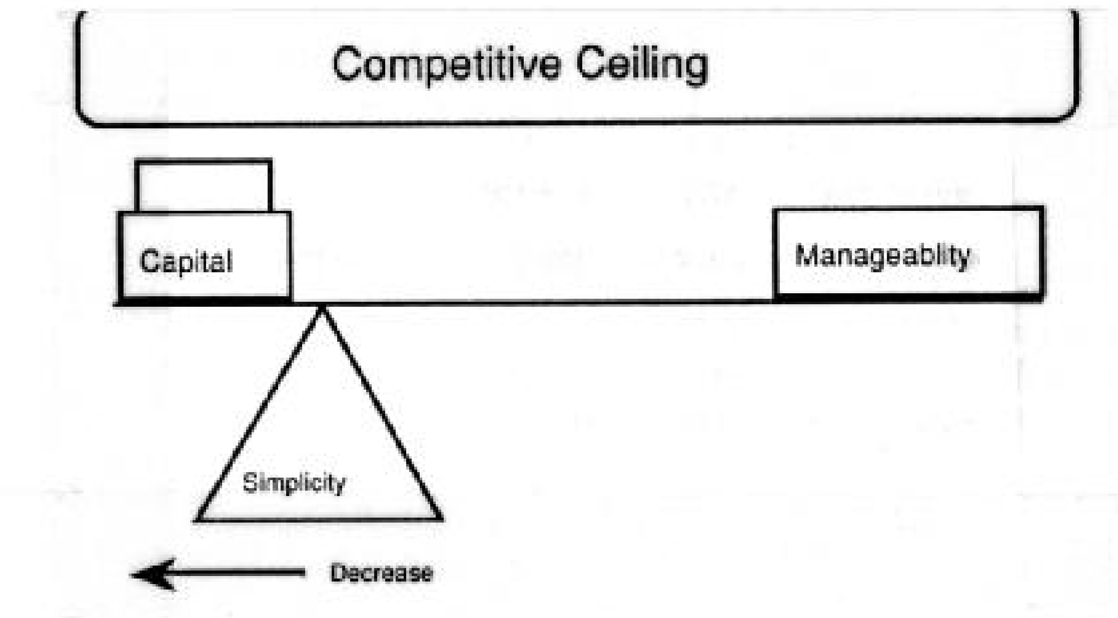
If the simplicity is increased there is a concomitant increase in the manageability of the system for the same level of capital input.



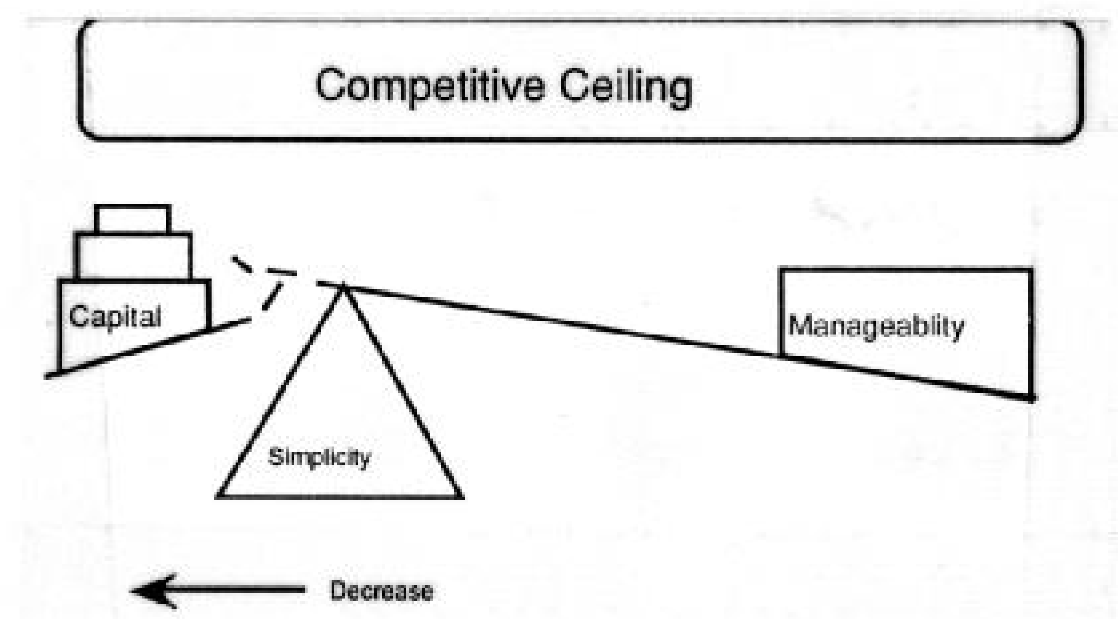
A level is quickly reached at which attempting to make the system more manageable pushes it past the competitive ceiling and the system breaks. This may occur by making the system overly simple, as might happen if an essential component, such as supplemental oxygen, was left out. Or the system may be broken if additional capital expenditures increased cost of production past the competitive ceiling.



If the simplicity is decreased (complexity increased) there is a concomitant decrease in the manageability for the same level of capital inputs.



The more complex system may run at a lower level of manageability, which will eventually translate into lower profits. Or an increased initial capital expenditure is required to attain the original level of manageability to again balance the system. As is indicated it requires a large input of capital to effect a small change in manageability of a complex system.



A point is quickly reached in a complex system where the system is broken by the shear weight of the capital invested to make the system more manageable. This is an example of an overcapitalized system.

Simplicity

Almost by definition, an intensive recirculating system defies the term simplicity. Although it should be recognized that there is an inherent complexity in such a system, a conscious effort should be made to minimize this complexity. Certain steps can be taken to keep the complexity to a minimum.

The first step is to realistically and critically evaluate your goals and resources. This may sound overly simplistic, almost to the point of condescension, but it is the most critical step in developing a successful aquaculture venture. An amazing number of systems fail because a realistic stock wasn't taken of one's expectations or resources. The most important thing to remember about this step is to be absolutely honest and realistic. Being unrealistic will only serve to harm your investment.

It is fine to have a personal goal of having the most advanced recirculating system in the world or to raise 20 million pounds/year. But this is unrealistic if your resources include 100 gpm and a capital investment of $500,000. Conversely it is fine to raise fish with resources of 100 gpm and a capital investment of $500,000 unless you are dishonest with yourself about your goals and push the system to attain 20 million pounds/year.

Once you have evaluated your goals and resources you can begin to design your system to match these goals and resources. If your goals are high you may opt for a larger more complex system. But it should be kept in mind that the greater the complexity, the more room there is for error. In addition, the problems that develop will also be more complex.

The next step should be to develop a general model to assist you in determining your needs as defined by your goals and resources. The model should assist you in determining those methods and technologies which will provide the simplest design possible. It should include, but not necessarily be limited to, the parameters outlined in the appendix.

As a fish culturist there are two things that you can count on. The first, no matter how prepared or careful you are, you will experience problems with your system. The second, no matter how careful you are, you will lose fish; which is probably the basis for the cliche, "you are not a fish farmer until you have killed a million fish". However, what separates a fish farmer from a successful fish culturist is that the latter minimizes the occurrence of problems and loses.

The best way to minimize losses is through good management practices; the most important of which is to learn to recognize signs of impending trouble. A good manager must learn to recognize these signs and be prepared ahead of time to respond quickly and appropriately. Another proven way to minimize problems in a system is to limit the number of variables that can go wrong (ie. keep the system as simple as possible).

There is a tendency in intensive recirculating systems to rely on an overabundance of technology to defend against problems and losses. Often, managers will feel that they have anticipated every need as a result of investing great sums of capital in state of the art technology. This can lead to a false sense of security. The result usually being that the manager is caught unprepared if he/she suffers a system failure or large losses of fish.

A few rules to keep the system as simple as possible are as follows:

1. Do not use equipment or machinery for something that can be done as quickly or efficiently by hand.

This is the easiest rule to violate. It is tempting to purchase a piece of equipment, or state of the art system that is designed to save time and labor. Even though it may not be apparent at first, that piece of equipment might not be as beneficial or benevolent as it appears. Buying a piece of equipment you can do without will likely confront you with one or more of the following:

a) increased cost of production.

b) mechanical failures are usually beyond the capacity of the laborer or manager to repair.

c) reliance on a piece of equipment experiencing a failure will lead to down time.

d) mechanical equipment can generally perform one function in one way. Working by hand allows you added flexibility.

e) A training period is required before a laborer or manager becomes proficient with the equipment. With experience, a laborer may perform a function nearly as fast without the equipment.

f) in many cases it requires a laborer to operate the equipment. If the laborer is not comfortable with the equipment or feels it is inefficient he/she may not use the equipment even though it is available.

2. When possible monitor your system frequently and manually.

There are three good reasons for opting to monitor your system manually. The first, and most significant of the three, is that in general a computer monitoring system puts distance between the manager and the fish. A computer can only react once a problem exists and can not warn you that a problem is developing. More often than not, a good fish culturist will catch a problem long before a computer can detect one. Utilizing a computer monitoring system creates that false sense of security that allows a manager to lose touch with how his/her system is changing.

The second reason is that computer monitoring systems are expensive. This will increase the cost of your finished product significantly, particularly for small ventures.

The third reason is that computer monitoring systems are not infallible.

They are subject to the following problems:

a) power failures

b) operator errors

c) software deficiencies

d) monitoring probes are subject to fouling giving erroneous readings

3. Approach equipment or technology that has not been proven with caution.

This statement is not meant to imply that new and developing technology is not viable. However, weigh the cost/benefit ratio carefully. Ask yourself if this new technology is something you absolutely require, or if there isn't a proven technology that might work nearly as well. You should never invest in a technology until you have talked to someone who has actually raised fish in such a system.

Manageability

The bottom line in the manageability of a system is the size of that system and how efficiently it can be worked. How big should the system be? Again the size of the system will depend on your goals and resources. However, a good rule of thumb is that the system should be large enough to conserve the economy of scale, but not so large that it can't be worked efficiently. This will depend a great deal on your site selection, species selection, capital, cost and availability of supplies, and proximity to suppliers and your targeted market.

If the evaluation of your goals and resources indicate that your system should remain small, you may not be eligible for the discounted rates on inputs that larger producers receive. In this case you may wish to start or join an existing co-operative.

Co-operatives often enable it's members to receive discounts by buying in bulk and passing the savings on to it's members. Some purchases that might be made by a co-operative include feed, oxygen, electricity, fingerlings, and other supplies. Some co-operatives have been known to share labor pools as well as processing and shipping resources.

Manageability refers not only to the entire system but to individual system components as well. A major misconception in intensive systems is that bigger is better. This may be true to some degree, but like everything else, too much of a good thing is problematic.

For example, increasing the volume of a rearing tank to increase the production in that tank could be beneficial. However, there is a point at which the tank becomes too large or too deep and hinders the efficiency of cleaning, harvesting, and sampling the tank.

Another example is the storage of feed in a bulk bin. You may be able to double your storage area for a few dollars more and save 15% on your feed purchases by buying a larger quantity, but it defeats the purpose if you can't utilize the extra feed before the feed quality deteriorates. Allowing feed quality to deteriorate may decrease growth rate, kill your fish, or at best lead to throwing out the bad feed. Therefore, any savings achieved has been offset by decreasing the manageability of your feed system.

Your system should be designed so that once it is up and running you minimize the perturbations to the system while maximizing the efficiency of your labor force. The easier the system is to work the happier the fish and laborers will be. These features will be reflected in your profit margin.

A final word on large systems. In general, the larger the system is, the greater the buffering capacity of that system. The increased buffering capacity allows the system to absorb greater changes. However, it should be remembered that this ability to absorb changes also makes it more difficult to affect changes when correcting a problem. Lag times are generated. It takes longer for problems to show up and conversely longer to clear up.

Capital

Having a strong capital investment is the cornerstone of any successful venture; however, it will not ensure success. Using it wisely is what makes or breaks the success of the venture. Although economics is beyond the scope of this paper, and will be covered by Dr. O'Rourke, I would like to allude to three recurring themes regarding capital investment that are prevalent in unsuccessful recirculating systems.

1. A general failure to anticipate needs.

This occurs in two ways. The first is a failure to maintain a sufficient cash flow to carry the venture through a system failure. The second is a failure to maintain a sufficient cash flow and provide for periods of extended culture cycles.

More often than not, in intensive systems, culture cycles are extended beyond their predicted harvest date. Rarely do the fish perform up to the idealistic expectations of the managers. Therefore a sufficient cash flow should be maintained to allow for the possibility of such an occurrence.

2. A tendency to overcapitalize the project.

State of the art technology and equipment has a tendency to be expensive and rarely holds it's value. Since the aquaculture industry is still in it's infancy, the associated technology is also still developing. Therefore, caution should be taken that you do not overspend for the benefits you will attain. When investing you should keep the following points in mind.

a) the technology is new, therefore the equipment is susceptible to problems.

b) much of the high technology equipment requires time to learn to operate efficiently.

c) the equipment loses it's value quickly.

d) depreciation can be a heavy burden.

e) newly developed technology in a developing industry becomes

outdated quickly.

3. A tendency to expand too quickly.

It is generally agreed to be of benefit to start small and expand at a later date. It is easier to approach a venture capitalist to expand a small successful operation than to find investors to keep a larger troubled project afloat. Starting small enables you to get a good feel for your site, your system, and potential for success before investing large sums.

It takes time for a system to reach an equilibrium. Therefore, enough time should be allowed to determine if the system is truly in balance before serious consideration is given to expansion. Expanding before a system has reached an equilibrium can mask problems that are already inherent in your design and will only amplify the problem. A manager that expands a system too quickly is often faced with a cash flow problem because of hidden system problems that arise.

A final word on expansion. It is important in scaling up from a small pilot project to a larger scale facility to realize that the parameters do not necessarily behave in a linear fashion. This is particularly true in examining the hydraulics of the system. It is then equally important to realize how the altered hydraulics will effect the other system components.

In summary, the future for aquaculture looks bright. According to projections, world consumption is rising at a time when the oceans are reaching their maximum sustainable yield. The increased consumption is expected to be filled by aquaculture production.

Although some intensive recirculating systems to date have failed, it is generally due to the inability to balance a sufficient working capital with a well designed, simple, and manageable system. If one begins with a realistic evaluation of their goals and available resources the likelihood for success will be enhanced. Any intensive recirculating system has the potential for success if it is designed to be simple and manageable without being overcapitalized.

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Egan, Jack. 1990. The fish story of the decade: as the ocean's bounty declines, the booming aquaculture business hooks corporate investors. U.S. News & World Report. Nov. 26, 1990. pp.52-56.

Lee, Wayne. 1991. Fish by design. Seafood Leader. 11(1):70-82.

Appendix

Some parameters that should be included in a working model to assist in determining needs for system components. This list is not all inclusive nor definitive and should only be viewed as a general outline.

Total water volume	Number feedings/day
Tank size	Amount feed/tank/day (max)
Tank volume	Amount feed/tank/day (avg)
Nominal flow rate	Total feed/day
Residence time	Total feed/week
Percentage recirculated	Total feed/month
Percentage makeup water	Feed protein (%)
Wellhead maximum output	Protein Source
Wellhead avg output	Nitrogen input/day
Wellhead maximum temperature	Nitrogen input/week
Wellhead minimum temperature	Nitrogen input/month
Wellhead average temperature	Nitrogen removal
Recycle water temperature	-fish
	-dilution/discharge
Loading density (maximum)	Nitrogen uptake biofilter
Loading density (average)	Estimated BOD (max)
Stocking weight	Estimated BOD (avg)
Harvest weight	Estimated BOD/day

Growth rate
Increase fish wt/day
Increase fish wt/month
Growout period (maximum)
Growout period (average)
Biomass/tank (initial)
Biomass/tank (ending)
Feed required

BOD oxygen (g/day)
Pounds oxygen/pound BOD

Electricity Cost
Electricity/day
Electricity/month
Oxygen cost/100 cu ft

Oxygen metabolism
Oxygen transfer efficiency
Oxygen uptake efficiency
Oxygen use/tank
Oxygen use/day
Oxygen use/month
Oxygen pounds/pound fish
Oxygen pounds/pound feed
Oxygen input rate

Mortalities (%)
Mortalities/day
Mortalities/month
Mortalities/tank/cycle
Acceptable mortality level

pH
alkalinity
hardness
total dissolved solids
total suspended solids
well chemistry

Allowable discharge levels
- Ammonia
- Nitrates
- Nitrites
- Total Nitrogen
- Total Phosphorus
- BOD/COD
- Total dissolved solids
- Total suspended solids
- pH
- Temperature

(CO_2 production and removal should not be overlooked)

Conclusions

LaDon Swann
Illinois-Indiana Sea Grant Program
Patrick O'Rourke
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The sponsors of this workshop hope that you have enjoyed the time spent during this workshop. There were some very informative presentations given during the past two days. After listening to the presentations, we hope that two themes are clear. First, no workshop (this one included) can possibly cover every aspect of recirculating systems in enough depth that a prospective producer can "walk away" from the workshop with enough information in hand that a profitable system can be constructed. At best, information from this workshop can be used as a base or added to other information sources. The learning process should be continual and the key to success in any business is knowing as much as possible before starting. Someone entering into a new business, must be an "expert" in many fields. The analogy of a chain being only as strong as its weakest link is very appropriate.

Commercial aquaculture in recirculating systems is no exception. Aquaculture is a high risk business, and of all the production methods used recirculating systems are generally considered as being the riskiest of all methods. For example, three major companies which have farmed either Tilapia or channel catfish have closed their operations because of loss of investment. This is not uncommon for a production method still on the proving grounds.

From an academic viewpoint, instead of giving up on recirculating systems like a large number of people have done recently, we feel that there is now even a greater need for cooperative inter-regional research to develop improved recirculating system components and test their economic feasibility.

Interested producers should also realize that with a good understanding of recirculating systems, an excellent marketing plan and a realistic business plan profitability may be possible in recirculating systems. Anticipated marginally higher production costs in recirculating systems may be offset if the product is properly marketed.

Acknowledgments

Without the hard work of many people involved in planning and organizing, this workshop would not have been possible. Appreciation is expressed to the speakers who were willing to develop a manuscript of their presentation prior to the workshop. By doing so we feel that we have a quality proceedings for those who have attended and as a reference for others in the future. Our sponsors need to be recognized (see list of sponsors in proceedings) for their willingness to donate money to help reduce the cost of the registration. Susan Parrent and her staff in Professional Development at Illinois State University were invaluable in planning the logistics portion of the workshop. Finally, Marlena Thomas spent many long days preparing this proceedings.

Sponsors

A special thanks is extended to the following sponsors who have contributed funding for this workshop.

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Contacts For Aquaculture Permits In Illinois and Indiana

Illinois	***Indiana***
Aquaculture Facilities Permit	**Fish Importation and Fish Haulers and Suppliers Permits**
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Aquaculture Coordinator	Indiana Dept. of Natural Resources
Jake Wolf Memorial Fish Hatchery	
Box 560	607 State Office Building
Manito, IL 61546	Indianapolis, IN 46204

309/968-7531

Restricted Species Transportation Permit

Illinois Dept. of Conservation

Division of Fisheries

600 N. Grand Ave. West, Ste. 3

Springfield, IL 62701-1787

217/782-6424

National Pollution Discharge Elimination System (NPDES) Permit

Illinois Environmental Protection Agency

Div. of Water Pollution Control, Permit Section

2200 Churchill Road

Box 19276

Springfield, IL 62794-9276

217/782-0610

317/232-4080

National Pollution Discharge Elimination System (NPDES) Permit

Dept. of Environmental Mgt.

Permit Section

P. 0. Box 6015

Indianapolis, IN 46206-6015

317/232-8736

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Indiana Dept. of Natural Resources

Division of Water

2475 Directors Row

Indianapolis, IN 46241

317/232-4167

Information on Fish Processing

Div. Food Animal Affairs

Indiana State Board of Health

1330W. Michigan Ave

Indianapolis, IN 46206-1964

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Both Indiana and Illinois have a very active Aquaculture Association which organize many activities that can benefit Aquaculture directly or indirectly. Their addresses and membership fees are listed below.

Indiana Aquaculture Association

Dr. Gary Miller, Treasurer
Indiana Aquaculture Association
P. 0. Box 426
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219-457-5802

Full member... $30.00 per year
Student member...$10.00 per year

Sustaining member...$100.00 per year

Illinois Aquaculture Industry Association

I.A.I.A.
c/o Dan Selock
Fisheries Research Lab
Southern Illinois University-Carbondale
Carbondale, Illinois
618-453-6025

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North Central Regional Aquaculture Center

The North Central Regional Aquaculture Center (NCRAC) was formed in February, 1988. It is one of five regional aquaculture centers administered by the U.S. Department of Agriculture. The purpose of these centers is to work together within the broader, integrated aquaculture program of USDA to promote a well developed and sustainable aquaculture industry in the U.S.A. Programs of NCRAC are jointly administered by Michigan State University and Iowa State University. The Office of the Director is located on the MSU campus in East Lansing, Michigan.

NCRAC is an administrative unit that serves 12 states in the heartland of America. It relies on leaders in the aquaculture industry for direction in its programs. An Industry Advisory Council (IAC) sets priorities. A Technical Committee works with the IAC to formulate programs on priorities. Regional programs are meshed with activities of other centers to avoid duplication. Teams of research and extension aquaculture specialists from Midwest universities and public agencies develop and execute work plans to solve priority problems. A Board of Directors oversees administration and management of NCRAC's programs

---

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Aquaculture Books

Aquaculture: Principles and Practices. Pillay, T. 1990. 576 pp. $139.00

Aquaculture Engineering. Wheaton, F. 1977. Robert E. Krieger Publishing Co., Malabar, FL 708 pp. $72.00

Aquaculture: The Farming and Husbandry of Freshwater and Marine Organisms. Bardach, J., Ryther, J., and McLarney, W. 1972. Wiley- Interscience, Box 092 Somerset, NJ 08873, 868, pp. $49.00.

Channel Catfish Farming Handbook. Tucker, C. and Robinson, E. 1990. 464 pp $59.00.

Culture and Propagation of Striped Bass and Its Hybrids. Edited by R. Harrel, Kerby, J. and Minton, R. 1990. 79 pp. $50.00

Engineering Aspects of Intensive Aquaculture 1991 Proceedings from the Aquaculture Symposium Cornell University, Ithaca, NY 352 pp.

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Intensive Aquaculture Regional Workshop on Commercial Fish Culture Using Water Resuse Systems. Swann, D. L. 1990. Illinois/Indiana Sea Grant Program 3-90-7. 61 pp. $5.00

Principles and Practices of Pond Aquaculture. Edited by: Lannan, J. Smiterman, R. and Tchobanoglous, G. 1986. Oregon State Univ. Press, Corvallis, OR 252 pp. $45.00

Principles of Warmwater Aquaculture. Stickney, R. 1979. John Wiley and Sons, Inc. 375 pp. $59.00

The Freshwater Aquaculture Book: A Handbook for Small Scale Fish Culture. McLarney, W. 1984. Harley and Marks, Inc. 583 pp. $37.00

"Third report to the Fish Farmers-status of Warm water Fish Farming and Progress in Fish Farming Research." Dupree, H. K. and J. V. Hunter, ed. 1984. U. S. Government Printing Office; Superintendent of Documents; Washington, D. C. 20402, U. S. Fish and Wildlife Service. Stock #024- 010-00654-4 Price $8.00.

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