FISH FARMING

IN

RECIRCULATING AQUACULTURE SYSTEMS

(RAS)

Louis A. Helfrich and George Libey

Department of Fisheries and Wildlife Sciences

Virginia Tech

INTRODUCTION

AQUACULTURE (farming of fish under controlled conditions) is a growth industry striving to satisfy a growing market for food fish. It currently is one of the fastest growing sectors of agriculture in the United States. Farm-reared freshfish is increasing in popularity and profitability. Catfish, trout, striped bas, oysters, clams and other aquatic species are fast becoming the new "cash crops" of the 1990's.

Growing public demand for a healthy tasty and affordable food is stimulating the "boom" in this industry. The decline in wild fish populations as a result of overharvest and water pollution has promoted the culture of farm-fresh that are grown in contaminant-free waters in indoor tank systems.

RAS DEFINED

Recirculation aquaculture systems (RAS) represent a new and unique way to farm fish. Instead of the traditional method of growing fish outdoors in open ponds and raceways, this system rears fish at high densities, in indoor tanks with a "controlled" environment. Recirculating systems filter and clean the water for recycling back through fish culture tanks.

New water is added to the tanks only to make up for splash out and evaporation and for that used to flush out waste materials. In contrast, many raceway systems used to grow trout are termed "open" or "flow through" systems because all the water makes only one pass through the tank and then is discarded.

Fish grown in RAS must be supplied with all the conditions necessary to remain healthy and grow. They need a continuous supply of clean water at a temperature and dissolved oxygen content that is optimum for growth. A filtering (biofilter) system is necessary to purify the water and remove or detoxify harmful waste products and uneaten feed. The fish must be fed a nutritionally-complete feed on a daily basis to encourage fast growth and high survival.

EXPERIMENTAL SYSTEM

RAS have been in existence, in one form or another, since the mid 1950's. However, only in the past few years has their potential to grow fish on a commercial-scale been realized. New water quality technology, testing and monitoring instrumentation, and computer-enhanced system design programs, much of it developed for the waste water treatment industry, have been incorporated and have revolutionized our ability to grow fish in tank culture.

Nevertheless, despite its apparent potential, RAS should be considered a high-risk, experimental form of agriculture at this time. They can be used to culture high-densities (over a million pounds) of fish annually, but their ability to do so economically remains to be demonstrated, conclusively and repeatedly.

BENEFITS OF RAS

RAS offer fish producers a variety of important advantages over open pond culture. These include a method to maximize production on a limited supply of water and land, nearly complete environmental control to maximize fish growth year-round, the flexibility to locate production facilities near large markets, complete and convenient harvesting, and quick and effective disease control.

RAS can be of various sizes ranging from large-scale production systems (over 1 million pounds per year) to intermediate-sized systems (500,000 pounds per year), to small systems (50,000 pounds per year). They can be used as grow-out systems to produce food fish or as hatcheries to produce eggs and fingerling sport fish for stocking and ornamental fish for home aquariums.

Intensive Production:

RAS applies to the broiler house or swine barn concept, so prevalent and effectively used in modern poultry and pork production systems, to rear large numbers of fish in a relatively small space. Indoor fish farming in tanks may revolutionize fish production in the same way that confinement systems altered the pork and poultry farming industries.

This is an excellent alternative to open pond culture where low densities (extensive culture) of fish are reared free in large ponds and are subject to losses from diseases, parasites, predation, pollutants, stress, and seasonally suboptimal growing conditions.

Water and Land Conserved:

RAS conserve both water and land. They maximize production in a relatively small area of land and use a relatively small volume of water. For example, using a RAS it is possible to product over 100,000 pounds of fish in a 5,000 square-foot building, whereas 20 acres of outdoor ponds would be necessary to produce an equal amount of fish with traditional open pond culture.

Similarly, since water is reused, the water volume requirements in RAS are only about 20% of what conventional open pond culture demands. They offer a promising solution to water use conflicts, water quality, and waste disposal. These concerns will continue to intensify in the future as water demand for a variety of uses escalates.

Location Flexibility:

RAS are particularly useful in areas where land and water are expensive and not readily available. They require relatively small amounts of land and water. They are most suitable in northern areas where a cold or cool climate can slow fish growth in outdoor systems and prevent year-round production. RAS provide growers who are geographically disadvantaged because of a relatively short growing season (less than 200 days) or extremely dry (desert) conditions, a competitive, profitable, year-round fish production system.

They can be located close to large markets (urban areas) and thereby reduce hauling distances and transportation costs. RAS can use municipal water supplies (dechlorination is necessary) and discharge waste into sanitary sewer systems. Nearly all species of food fish and sport fish that are commonly reared in ponds including catfish, tout, and striped bass can readily be grown in high densities when confined in tank systems.

Species and Harvest Flexibility:

RAS are currently being used to grow catfish, striped bass, tilapia, crawfish, blue crabs, oysters, mussels, and aquarium pets. Indoor fish culture systems offer considerable flexibility to (1) grow a wide diversity of fish species, (2) rear a number of different species simultaneously in the same tank (polyculture) or different tanks (monoculture), (3) raise a variety of different sizes of one or several species to another depending on market demand and price.

RAS afford growers the opportunity to manipulate production to meet demand throughout the year and to harvest at the most profitable times during the year. This flexibility in the selection of species and harvest time allows the grower to rapidly respond to a changing marketplace in order to maximize production and profitability. RAS permit the grower to competitively respond to market price and demand fluctuations by altering harvest rates and times and the species cultured. Tank culture systems are now being used to hold and purge (depurate) contaminated of off-flavor, pond reared catfish until they are acceptable for marketing.

RAS do have some disadvantages when compared to open pond culture. They are relatively expensive systems to develop (building, tanks, plumbing, biofilters) and to operate (pumping, aerating, heating, lighting). Moreover, they are complex systems and require skilled technical assistance to manage successfully.

Constant supervision and skilled technical support are required to manage and maintain the relatively complex circulation, aeration, and biofilter systems, and to conduct water quality analysis. The danger of mechanical or electrical power failure and resulting fish loss is always a major concern when rearing fish in high densities in small water volumes.

Operating at or near maximum carrying capacity requires fail-safes in the form of emergency alarms and backup power and pump systems. The business and biological risk factors are correspondingly high. Continuous vigilance and quick reaction times (15 minutes or less) are needed to avert total mortality. However, the higher risk factor, capital investment, and operating costs can be offset by continuous production, reduced stress, improved growth, and production of a superior product in the RAS.

THE RAS DESIGN

The functional parts of a RAS include a: (1) growing tank, (2) sump of particulate removal device, (3) biofilter, (4) oxygen injection with U-tube aeration and, (5) water circulation pump. Depending on the water temperature and fish species selected, a water heating system may be necessary. Ozone and ultraviolet sterilization also may be advantageous to reduce organic and bacteria loads.

Water Supply:

A good supply of water, adequate in both quantity and quality, is essential to a successful fish farming enterprise, RAS or otherwise. Ground water obtained from deep wells or springs is the best source of water for fish culture. It generally is free of pollutants and has relatively high hardness levels, which are beneficial under some circumstances. Municipal water supplies also can be used after chlorine, floride, and other chemicals are removed.

Other sources of water, particularly surface waters from streams, rivers, ponds, and lakes, are not recommended for fish culture. Surface waters may contain fish diseases, parasites, pesticides, and other pollutants that can kill or slow the growth of fish. Testing the quantity and quality of the available water supply is one of the first steps for a prospective fish farmer to take to insure an adequate supply of high quality water.

Because RAS recycle most of their water, they consume considerable less than other types of culture and are especially well adapted to areas with limited water supplies. The required quantity of water needed to grow fish varies with the species of fish selected, size of the culture system, and investment size. As a general rule, a minimum water volume of 1-5 gallons is needed for every pound of fish reared and minimum water flows of 10-25 gallons per minute (more for trout) are needed to grow 50,000 pounds of warmwater fish per year.

Open vs. Closed Systems:

Tank culture systems are referred to as recirculating (closed) systems because they recycle or reuse water. No system is ever completely "closed," because some water must be added periodically to replace evaporative loses and that used to flush out waste materials. Some water change is necessary since no filter is 100% effective. Nevertheless, RAS can operate efficiently by occasionally adding only a relatively small amount of water on a daily or weekly schedule.

Open (flow-through) systems refer to those that simply allow water a single pass through the system before it's discarded. Flow through systems can also be used in indoor tank culture of fish if an abundant and continuous supply of high quality water is available. Trout farmers typically use open systems rather than recirculating ones, because trout require large volumes of high quality, cold water. Open systems "leak" most of the water quickly, whereas closed systems "leak" water slowly. RAS are more suitable for warmwater fish such as channel catfish, striped bass, and tilapia that can tolerate lower water quality conditions and higher temperatures than trout. They also are now being used to rear marine species such as redfish, oysters, clams, and softshell blue crabs.

The Virginia Tech RAS System:

A RAS for the intensive production of freshwater fishes was designed and constructed at the Department of Fisheries and Wildlife Aquaculture Center on the campus of Virginia Tech. Visitors to the Aquacutlure Center are welcome, but an appointment is required (call 540-951-4917).

The Virginia Tech RAS has nine production units (each is an independent system with a 3,355 gallon total capacity). Each system consist of a 2,250 gallon rectangular (20- x 5- x 3.5-feet deep) fiberglass growing tank where the fish are reared, a 520 gallon sump tank (5- x 5- x 3.5-feet deep) to collect waste materials, a semi-cylindrical, 525 gallon biofilter tank (5- x 7- feet in diameter) housing a 3-stage rotating biological contactor (RBC) to detoxify ammonia and nitrite, and a U-tube aerator (40 feet deep) used to diffuse pure oxygen injected at the top of the U-tube (figure 1).

Water flow in the system is maintained at 85-90 gpm (about one tank exchange per 30 minutes) by two ¼ hp pumps suspended near the top of the sump tank. The general flow pattern through the system is: (1) from the bottom of the culture tank, (2) through two outlet ports (3 inch pipe), (3) into and up through a multi-tube clarifier in the sump tank, (4) pumped (6 feet in height) from the top of the sump tank (5) into 3-stage elevated biological filter, (6) gravity flow down the inside pipe and up the outside pipe (40 feet each way) of the U-tube aerator and, (7) back into the fish culture tank.

Each culture tank has 5 inlet ports distributed uniformly to allow for the even redistribution of filtered, oxygenated water from the u-tube aerator. Effluents average about 100 gallons per day of wastewater (2-3 percent) per tank. Each sump tank is isolated form the system and drained and rinsed of their collected wastes once or twice per week depending on water quality conditions. Effluents are drained into a central septic tank and pumped into a septic field system.

Lighting is minimized to reduce fish stress, and is provided by six (150 watt) incandescent fixtures. A wall-mounted rheostat is used to gradually increase and decrease light intensity at dawn and dusk. Photoperiod is on a 14 h light: 10 h dark cycle.

The system was designed for demonstration-research purposes and represents a small, commercial-scale (45,000 lbs. per year production capacity) version of an aquaculture enterprise. Each of the nine identical, but independent, systems was configured to provide relatively uniform, stable, and optimum conditions for growth and survival. Collectively, they offer sufficient replication for nutritional, physiological, and genetic experiments.

Fish Culture Tanks:

Fish can be grown in tanks of nearly every shape and size. Fish tanks typically are rectangular, circular, or oval in shape. Circular or oval tanks with central drains are somewhat easier to clean and circulate water through than rectangular ones. Rectangular tanks are usually built with or set upon inclined floors to facilitate cleaning and circulation.

Rearing tanks range in size from 500 to 500,000 gallons capacity. The size of the tank depends on a variety of factors including: stocking rates, species selected, water supply, water quality, and economic considerations. The tank must be designed to correspond with the capacity of other components of the system, particularly size of the biofilter and sump so that all parts of the system are synchronized.

Tanks can be constructed of plastic, concrete, metal, wood, glass, rubber and plastic sheeting, or any other materials that will hold water, not corrode, and are not toxic to fish. Smooth surfaces on the inside of the tanks are recommended to prevent skin abrasions and infections to the fish, and to permit cleaning and sterilization.

Light weight, durable, plastic tanks can be conveniently moved and readily cleaned when necessary, but they require special support to prevent stretching when filled with water. Stainless steel also is a good tank material, but can be expensive. Marine-grade plywood tanks are inexpensive, but leak if not properly sealed and are not as durable as tanks of other materials. Concrete tanks may be the most economical to build, but they are relatively permanent and immovable structures once constructed. Non-toxic plastic or rubber liners can but used over frames made of wood, metal, concrete, or other materials.

Biofiltration:

The biological filter (biofilter) is the heart of the RAS. As the name implies, it is a living filter composed of a media (corrugated plastic sheets or beads or sand grains) upon which a film of bacteria grows. The bacteria provide the waste treatment by removing pollutants. The two primary water pollutants that need to be removed are (1) fish waste (toxic ammonia compounds) excreted into the water and (2) uneaten fish feed particles. The biofilter is the site where beneficial bacteria remove (detoxify) fish excretory products, primarily ammonia.

Ammonia and Nitrate Toxicity:

Ammonia and nitrite are toxic to fish. Ammonia in water occurs in two forms: ionized ammonium ($NH4+$) and unionized (free) ammonia ($NH3$). The latter, $NH3$, is highly toxic to fish in small concentrations and should be kept at levels below 0.05 mg/l. The total amount of $NH3$ and $NH4$ remain in proportion to one another for a given temperature and pH, and a decrease in one form will be compensated by conversion of the other. The amount of unionized ammonia in the water is directly proportional to the temperature and pH. As the temperature of pH increases, the amount of $NH3$ relative to $NH4$ also increases.

In addition to ammonia, nitrite ($NO2$) poisoning of fish also is an imminent danger in RAS. Nitrite levels should be kept below 0.5 mg/l. Brown blood disease (methemoglobinemia) occurs in cultured salmon and channel catfish when hemoglobin is oxidized by nitrite to form methemoglobin (a respiratory pigment of the blood that cannot transport oxygen). The disease can occur at nitrite concentrations of 0.5 mg/l or greater. As the name implies, the blood has a characteristic chocolate brown color. Adding salt ($NaCl$) at a rate of 1 pound per 120 gallons of water (a chloride to nitrite ratio of 16:1) will suppress this disease in soft water; a ratio of 3:1 is effective in hard water.

Calculating Ammonia Loading:

The amount of ammonia excreted into a tank depends on a number of variables including the species, sizes, and densities of fish stocked and environmental conditions (temperature, pH). Ammonia loading can be roughly estimated from the biomass (weight) of fish in the tank or it can be based on the weight of feed fed each day.

On the average about 25 mg (milligrams) of ammonia per day is produced for every 100 grams (3.5 ounces) of fish in the tank. Therefore, in a tank containing 1,000 striped bass fingerlings each weighing 75 g (75,000 g total fish weight), the daily ammonia load produced by all the fish would be 18,750 mg (18.8 g). To remedy excessively high ammonia levels, add freshwater, eliminate feeding or reduce the density of fish in the tank.

Ammonia loading also can be estimated based on the total amount of feed fed. For manufactured fish feed with standard protein levels of 30 to 40 percent, simply multiply the total weight of the feed (in grams) times 25. For example, if the fingerling stripers are fed 1 pound (454 grams) of pelleted feed per day, the amount of ammonia produced per tank would be about 11,350 mg per day.

Nitrification:

Ammonia is a poisonous waste product excreted by fish. Since fish cannot tolerate this poison, detoxifying ammonia is fundamental to good water quality, healthy fish, and high production.

Detoxification of ammonia occurs on the biofilter through the process of nitrification. Nitrification refers to the bacterial conversion of ammonia nitrogen (NH_3) to less toxic NO_2, and finally to non-toxic NO_3. The process requires a suitable surface on which the bacteria an grow (biofilter media), pumping an continuous flow of tank water through the biofilter, and maintaining normal water temperatures and good water quality.

Two groups of aerobic (oxygen requiring), nitrifying bacteria are needed for this job. Nitrosomonas bacteria convert NH_3 to NO_2 (they oxidize toxic ammonia excreted by fish to less toxic nitrite), the Nitrobacter bacteria convert NO_2 to NO_3 (they oxidize toxic nitrite to largely nontoxic nitrate).

Nitrification is an aerobic process and requires oxygen. For every 1 milligram of ammonia converted about 5 milligrams of oxygen is consumed, and additional 5 milligrams of oxygen is required to satisfy the oxygen demand of the bacteria involved with this conversion. Therefore, tanks with large numbers of fish and heavy ammonia loads will require plenty of oxygen before and after the biofiltration process.

Nitrification is an acidifying process, but is most efficient when the pH is maintained between 7 and 8 and the water temperature is about 27-28 C. Acid water (less than pH 6.5) inhibits nitrification and should be avoided. Soft, acidic waters may require the addition of carbonates (calcium carbonate, sodium bicarbonate) to buffer the water. The addition of a salt as a therapeutic in striped bass as freshwater bacteria temporarily adjust to alteration in salinity.

Biofilter Design and Materials:

A biofilter, in its simplest form, is a wheel, barrel, or box that is filled with a media that provides a large surface area on which nitrifying bacteria can grow. The biofilter container can be constructed of a variety of materials, including plastic, wood, glass, metal, concrete, or any other nontoxic substance. In small-scale systems, some growers have used plastic garbage cans or septic tanks. The size of the biofilter directly determines the carrying capacity of fish in the system. Larger biofilters have a great ammonia assimilation capacity and can support greater fish production.

A biofilter must provide sufficient surface area for the colonization (attachment) of nitrifying bacteria. It needs to provide a large surface area to support bacterial populations at densities adequate to reduce the load of waste products (ammonia) excreted by the fish population in the tank. It is essential that the water flowing through the biofilter come into direct contact with the bacteria film growing on the surface media for a time period sufficient to allow the bacteria to convert toxic NH_3 and NO_2 to less toxic NO_3. Careful calculation of the flow-through rates (turnover or contact time) and size (volume and depth of the biofilter) is fundamental.

The biofilter media can be corrugated plastic, styrofoam or glass beads, lava rock, sand, gravel, or similar material that supplies large surface area. The quality and quantity of surface area of the media provided for nitrifying bacteria are important determinants of the efficiency of the biofilter. The ideal biofilter media has (1) high surface area for dense bacterial growth, (2) sufficient pore spaces for water movement, (3) clog resistance, (4) easy cleaning and maintenance characteristics. We use and recommend plastic because it's lightweight, flexible, and easy to clean, but it can be expensive.

Biofilter Sizing:

The biofilter in any RAS design must be sized to correspond with the other system components. Important factors that must be considered in designing a biofilter are: media surface area (square feet of surface for bacteria attachment), ammonia leading (ounces of ammonia that need to be converted per day per square foot of media area), and hydraulic loading (gallons of water per day per square foot media surface).

Types of Biofilters:

Biofilters can be configured in many ways. The two general categories are (1) submerged bed filters and (2) emerged bed filters. Submerged bed filters can have fixed (immobile) media in which the water flow can be upward, downward or horizontally through the media.

The fluidized bed reactor (FBR) is a commonly used submerged bed filter. The FBR consists of fine particles (sand, dense plastic, glass beads, minerals, etc.) in a container through which upwelling water flows thereby "fluidizing" or suspending the media in the water column. FBRs offer large surface area per unit volume and theoretically greater nitrification. However, as with other submerged bed filters, all of the oxygen needed for conversion of ammonia to nitrate must be dissolved. Submerged bed filters often need supplemental aeration both before and after the water passes through the filter. If the inlet dissolved oxygen is low, the efficiency of ammonia conversion is reduced.

Emerged bed filters are of two basic types: (a) trickling filter (TF) sometimes called packed columns, and (b) rotating biological contactors (RBC). These filters have the advantage of not requiring the addition of oxygen prior to water entering the filter. In fact, these filters frequently supply al the oxygen used to support fish respiration. For this reason these types of filters are often employed in RAS.

The trickling filter is designed to have water slowly cascade down through the media column, which is suspended above the water. Water enters the column (which is filled with biofilter media) from an overhead spray pipe and trickles down through the biofilter media where nitrification occurs. The waterfall action of this filter adds oxygen to (aerates) the water.

Trickling filters can become clogged and lose efficiency. When a filter accumulates too much organic material it can experience "ponding" and "short coming." In severe instances the filter can cease functioning altogether. We use trickling filters in the Virginia Tech Aquaculture Center on some of our smaller fish culture tanks that contain only a limited number of fish.

The rotating biological contractor (RBC) has a water-wheel configuration consisting of plastic media attached to a central axle which spins slowly, moving the media through the water in the RBC containment vessel. Advantages of the RBC are that it is self-aerating and self-cleaning. Once established, it tends to be very stable and can operate for years without failure.

The Virginia Tech system uses the RBC-type biofilter. The RBC has three circular stages (6' diam x 1' thick, 1,950 ft^2 per stage, 5,850 ft^2 total) mounted to a central shaft. The shaft is rotated at 2 rpm by a ¼ hp gearmotor. The biofilter media and tank (525gallon) are divided into three partitions or stages so that filtered water passes in sequence form one to another. Staging the RBC allows greater nitrification efficiency for a given amount of media or RBC size.

Biofilter Start-up:

Efficient biofiltration depends on colonization of the biofilter media by nitrifying bacteria. Complete colonization of a biofilter is dependent on a number of environmental conditions and may take one to three months. Inoculation of a new tank with seed bacteria from a existing system can reduce start-up times and facilitate full efficiency. The addition of commercially available "specially selected strains" of bacteria has not probed to speed bifilter start-up as many advertisements claim. Cooler water temperatures, below 70 F (21 C), can reduce bacterial activity, slow the bacterial colonization, and diminish the effectiveness of the biofilter.

Recirculation Rates (turnover times):

The recirculation rate (turnover time) is the amount of water exchanged per unit of time. This can easily be determined by dividing the volume of water in the tank by the capacity of the pump (in gallons per minute). For example, the turnover rate in a 2,500 gallon tank system circulated with a water pump rated at 45 gallons per minute (63,360 gallons per day) would be 25.3 tank volumes per day (a rate of slightly more than one volume per hour).

Increasing the number of turnovers per day would provide increased biofiltration, greater nitrification (bacterial contact), and reduced ammonia levels. Most fish production recirculation systems are designed to provide at least one complete turnover per hour (24 cycles per day).

Compartmentalization:

The ability of isolate the components of the system (biofilter, fish tank, and sump) is an important design feature, particularly critical when it becomes necessary to do filter maintenance or to treat the fish with chemicals and drugs. Cleaning and declogging static biofilters can pose difficult problems, particularly if there is no provision for shutting down the system for maintenance. Some therapeutic chemicals and drugs used to treat such fish may be harmful to nitrifying bacteria on the biofilter. A sudden drop in the efficiency of the bacteria can result in toxic NH_3 concentrations and fish kills.

Other filters:

Other types of filtration (mechanical and chemical) are available and can sometimes be used to supplement the efficiency of biofilters in removing ammonia in fish production systems. Most of these measures are useful only to temporarily control ammonia and nitrite in small systems.

In chemical filtration, water is pumped through a chemical media of activated carbon, zeolite, or other substances. These chemicals have microscopic pores that trap ammonia ions and remove them from the water. The familiar activated charcoal filter, popular in aquaria, can be incorporated as an auxiliary filter to support biofiltration in fish production systems, but this form of filtration requires periodic replacement with large quantities of relatively costly activated charcoal.

Zeolite filters are frequently used to remove NH_4 (and indirectly NH_3) at an estimated rate of 1 mg NH_4 per 1 g of zeolite. The use of zeolite requires regular and constant pumping of water through the filter and regular replacement of large quantities of expensive zeolite. Zeolite can be recharged with a salt solution (10%) and reused, but salt water disposal then becomes an environmental problem, particularly in inland waters.

Sump:

A sump (clarifier tank) is used to prevent the excessive accumulation of fish excretory products and waste feed. Waste products increase the biological oxygen demand (BOD), decrease the dissolved oxygen content, lower the carrying capacity (density of fish) that can be reared, and may result in off-flavor in fish products. Accumulation and decomposition of waste material results in the production of toxic compounds such as ammonia (NH_4, NH_3, NO_2) and hydrogen sulfide (h_2S) that can be hazardous to fish health.

The clarifier tank is designed as a settling basin (large volume tank with a slow flow rate to increase sedimentation). Its purpose is to concentrate and remove suspended solids (fish feces, uneaten feed particles) before they clog the biofilter or consume valuable oxygen supplies. The clarifier should be a separate tank, isolated from the fish tank and the biofilter, so that it can be cleaned periodically (daily) as needed. To increase the efficiency of the clarifier, various filters (plastic filters, sand filters, metal screens) can be inserted into the sump tank.

In the Virginia Tech RAS, water flow in the sump tank is directed upward through a multi-tube clarifier (corrugated plastic filter) which removes large, settleable particles from the water column by gravity (particles with densities great tan water will sink). The waste material sinks, collects, and is concentrated in the bottom of the sump where it can be drained out. The sump tank should have a v-shaped bottom to concentrate waste particles and facilitate cleaning. Another technique for the removal of waste particles for suspension in the water column includes the use of a hydroclone, a cone shape tank that uses centrifugal force to increase gravitational force and enhance waste particle settling.

The size of the clairifier tank needs to by fully integrated with the sizes of the fish tank and biofilter and also with the turnover rate of the system (pump size). Volume of the sump and flow rates through the sump must be adjusted to maximize sedimentation of suspended particles. Sump column in the Virginia Tech system represents about 15% of the total and flow rates average about 90 gallons per minute.

Oxygen Management:

Successful fish production depends on good oxygen management. The addition of oxygen in a pure form or as atmospheric air (aeration) is essential to (1) the survival (respiration) of fish held in high densities, (2) the survival of aerobic, nitrifying bacteria on the biofilter and, (3) for the decomposition (oxidation) of organic waste products. Supplying sufficient oxygen to sustain healthy fish and bacterial populations and to meet the biochemical oxygen demand (BOD) for fish waste and unconsumed food is critical. Maintain oxygen levels, near saturation or even at slightly super-saturation at all times. Low oxygen levels will reduce growth, feed conversion rates, and overall fish production.

The amount of oxygen needed in RAS depends on a number of factors. Oxygen demand is directly correlated with the density of fish in the tanks, feeding rates, water temperatures, flow rates, and nitrification. It is also a function of physical conditions such as water temperature and water volumes. Increasing dissolved oxygen concentrations through oxygen injection, aeration, and increasing water flow rates (turnover times) are ways to increase the density (carrying capacity) of fish that can be held in tanks of fixed size.

Atmospheric oxygen can be added to the tanks by surface agitation with aerators or by large blowers. Surface aerators may not be cost effective or efficient in evenly distributing oxygen throughout large commercial-scale systems. Blowers can be effectively used to supply oxygen and also to mechanically rotate RBS.

Pure Oxygen:

Pure oxygen injection systems are increasingly being used in aquaculture. They are particularly useful in maintaining oxygen-saturated conditions in recirculating systems with high densities of fish. Pure oxygen can be delivered and stored in a tank as liquid oxygen or it can e produced on-site by a oxygen generator. Bottled oxygen gas also is sometimes kept as an emergency backup system for RAS, but this alternative usually is too expensive and bulky to be practical.

Liquid oxygen technology is relatively simple, efficient, and cost-effective; especially if purchased in bulk quantities and if the site is located near a reliable supplier. A liquid oxygen system consists of a storage tank for the liquid gas, vaporizers to turn liquid oxygen to gas, and supply lines to the fish tanks. It conveniently requires no external power supply and is therefore free of power failures and the consequent fish kills. Most growers rent or purchase a liquid oxygen storage tank of a size sufficient to provide two to four week supply of oxygen. The size of the tank corresponds with the fish production capacity of the system.

Oxygen generators (pressure swing adsorption systems, PSAs) are particularly advantageous at remote sites where liquid oxygen deliveries would be costly and expensive. Generators produce oxygen by using electric energy. They are expensive to purchase and operate, and they are subject to power failures. Selecting the proper size of the oxygen generator and carefully calculating the cost of electric power needed are important considerations.

Oxygen Diffusion:

Effective diffusion of pure oxygen gas into a liquid (water) can best be accomplished using a U-tube oxygenation, counter-current flow injectors, or micro-bubble devices (tubes or fine wetstones). The purpose is to dissolve much of the oxygen injected so that it is available to the fish, rather than wasted by bubbling out of solution to the atmosphere.

The U-tube in the Virginia Tech system consists of a shallow well (40 feet deep) into which tow concentric pipes (one outer 6 inch and an inner 3 inch diameter pipe) are suspended. The water, injected with oxygen at the top of the U-tube, flows down the inner pipe, up the outer pipe, and back into the fish culture tank saturated with oxygen. The U-tube increases oxygen transfer because of the longer contact time and greater atmospheric pressure (two atmospheres at the bottom of the U-tube) of the entrained oxygen gas bubbles and water. Although the U-tube aerator is not essential, oxygen enrichment (entrainment) is significantly increased by this cost-effective method.

Ozone Sterilization:

Ozone (O3) is a naturally occurring gas (upper atmosphere) that consists of three atoms of oxygen. It is a powerful oxidizing agent that can be used to break down compounds. Ozone must be used with caution since it is directly toxic to aquatic life and may form harmful biproducts (hypochlorite, hypobromite). Careful redox potential measurements and special injection equipment apparatus are needed to determine and control ozone applications.

Carbon Dioxide:

In addition to toxic ammonia, carbon dioxide tends to concentrate in intensive fish production systems. As carbon dioxide increases, the pH of the water decreases, and fish respiration is affected. Carbon dioxide levels should be maintained at levels less than 30 mg/l for good fish growth. Some carbon dioxide is beneficial since it reduces pH and mitigates ammonia toxicity. Carbon dioxide removal can be accomplished with any device (RBC, packed column) that increases air-water contact.

Emergency Systems:

Fish farmers using RAS usually have made a substantial economic commitment in the system, feed, and fingerling fish. The standing crops of fish in the tanks at any particular time represent costly inventory that become increasingly valuable as they approach marketable size.

Fish kills caused by suffocation resulting from power failures (even short-term ones) are not uncommon. The oxygen demand in tanks with high densities of large fish is high. During emergency power failures, the grower generally has a response time of 10 minutes or less to avoid a total kill. Sublethal oxygen concentrations can be equally harmful because they cause slow growth, increase the susceptibility of fish to disease and parasites, and decrease production and profitability.

Fish farming in RAS is risky business where "an ounce of prevention" is a worthy and important consideration. Fish kills from oxygen deficits as a result of power failures constantly threaten growers with financial ruin. Protection by designing alarm systems, or using backups and alternatives for emergencies is essential.

An alternative bottled oxygen gas or liquid oxygen system is suggested for growers who rely primarily on oxygen generators. The Virginia Tech RAS uses liquid oxygen, but also has a secondary, standby surface agitator system in each tank and a backup electric generator for emergencies.

An emergency water supply reservoir consisting of a large volume of high quality water (oxygenated, dechlorinated) and the proper water temperature stored in a standby tank provides a good margin for safety. Sudden declines in water quality or outbreaks of disease can be effectively controlled in certain instances by rapidly flushing growing tanks with freshwater, by quickly altering water temperatures.

PRODUCTION CONSIDERATIONS

Fish Species Selection:

RAS can be used to rear nearly any species of fish, freshwater or marine or other aquatic animal. Hybrid striped bass, channel catfish, and tilapia are the most common freshwater species grown in these intensive culture systems. Red drum (redfish) and soft shell blue crabs are the main saltwater species being reared RAS. Because RAS requires high capital investment, it is best designed to grow high-value species such as striped bass for food or stocking in private recreational angling waters or aquarium fish.

Certain fish species are easier to grow and more available than others. Two species dominate the U.S. aquaculture industry today: channel catfish and rainbow trout. Their popularity is a result of the desirable traits that they express. For example, their culture requirements are well known, the demand high, and the economics viable. Small (fingerling) fish are available for grow out nearly year-round, they tolerate crowding and stress, and disease resistant, and grow rapidly to a marketable size.

Recirculating systems generally are not suitable for rearing coldwater species such as salmon and trout. Trout and salmon require clean, cold water and generally do not thrive in warm, recycled waters. However, a wide variety of fish, particularly catfish and hybrid striped bass, and other aquatic species, including shrimp and mussels are good candidates for farming in recirculation systems.

Feeds and Feeding:

A complete feed, containing all the essential minerals and vitamins for healthy fish growth, and formulated specifically for the fish species being reared, is necessary for fish production in RAS. Do not substitute other animal feed for fish feed. Even different fish species have different nutritional requirements, particularly the quality and quantity of protein needed, that must be met to optimize growth.

We recommend feeding a commercial feed of dry, floating pellets so that the feeding activity and health of the fish can be easily observed at the water surface. The size of the pellet should correspond with the size of the fish. Feed the largest pellet that the fish will readily swallow in order to maximize consumption and minimize waste. To keep feed fresh, order only a limited supply and store it in a cool, dry area, free of insects and rodents. In case of a liability problem with contaminated feed, it's a good idea to freeze small samples of each new batch of feed purchased for subsequent analysis if necessary.

Cultured fish generally are fed 3 to 5 percent of their body weight or all the feed that they can consume in a short period of time, say five minutes. Feed remaining in the tank after five minutes is seldom eaten and overfeeding can seriously degrade water quality. A good, quick indicator of problems with water quality or disease is when fish go off feed or refuse to eat. If fish suddenly stop feeding, immediately check for high ammonia levels, low oxygen concentrations, diseases, or other problems. Reduced feeding rates occur at very high and low water temperatures.

To maximize growth, feed on a regular schedule at the same time each day. More frequent feedings several times per day) have resulted in better growth rates and feed conversion efficiencies than a single daily feeding. Distribute the feed as uniformly as possible throughout the tank to prevent uneven growth and stunting. At the Virginia Tech Aquaculture Facility, the fish are hand fed. Automatic feeders and demand feeders can be used in commercial operation to reduce labor costs.

Warm Temperature:

Water temperature strongly influences feeding and growth rates of cultured fish. The water temperature preferences of most cultured fish are well known and can be maintained year-round in RAS. In general, cultured fish species can be classified as either cold water species that prefer temperatures of 50-65 F, (trout), cool water species prefer temperatures of 65-80 F, (yellow perch), and warm water species (channel catfish) that prefer temperatures 80-90 F. Water temperature also influences the water quality processes occurring in recirculation systems. For example, the optimum water temperature for bacterial nitrification activity is 85 F, which may or may not be optimal for the fish species being cultured.

Energy conservation is one of the major advantages of recirculation aquaculture systems. Once the tank water is heated to the optimal temperature for fish growth, only a small amount of heat energy is required to maintain the temperature. However, heat loss from the building and from the water via evaporation, splash-out, or waste water must be minimized to assure economic success.

A unique thermal property of water is its high specific heat – it heats and cools slowly. Therefore, once the optimal water temperature for fish growth is reached, only a small amount of energy is necessary to maintain the best thermal condition. Heat losses through convection and conduction are minimal in a well insulated building.

Heat can be provided by heating the air in the building, or directly heating the water, and by using heat exchangers. Water temperature in the Virginia Tech system is supplied by heating the air in the building with four propane space heaters. The room temperature is generally kept 2-4 degrees above that of the water to reduce condensation in the building. The Virginia Tech system is housed in a specially constructed 110- x 50- x 16-ft high farm utility building. The interior and exterior walls and ceiling are covered with 19 gage corrugated aluminum siding and insulated with R-19 and R-30 fiberglass blanketing. At times, room temperatures and working conditions can become hot and humid, especially when growing warm water fish in the summer. High temperatures and humidity can be controlled through ventilation with an electric fan.

Directly heating the water is another alternative, but this strategy requires expensive insulated tanks with lids that maintain the heat, but inhibit feeding and observation of the fish. Alternatives such as solar heating and heat exchangers are being considered.

ADDITIONAL CONCERNS

Legal Restrictions:

Aquaculture enterprises are subject to a number of federal, state, and local regulations. This legislation restricts the type of fish and aquatic animals that can be reared and sold (fish farmers permits) international and interstate transportation of exotic fishes (i.e. Lacey Act); pollution and discharges of waste water effluents (National Pollutant Discharge Elimination System, NPDES permit); water withdrawals; altering waterways and wetlands (Clean Water Act, Section 404 permit); the use of drugs and chemicals (Federal Drug Administration, FDA); and processing and marketing fish.

In Virginia, for example, permits are required from the Virginia Department of Game and Inland Fisheries (VDGIF) and the Virginia Marine Resources Commission (VMRC) to possess and sell certain species of sportfish. The State Water Control Board (SWCB) issues permits for (1) the discharge of aquaculture effluents (pollutants) into surface waters (VPDES permit), (2) water use (ground water withdrawal), and (3) discharge, construction, dredging, or filling in surface waters or wetlands (401 and 404 permits). Discharges for ammonia, suspended solids, and other chemical parameters must be monitored and the standards met. The Virginia Department of Agriculture and Consumer Services (VDACS) regulates concerned with land-use planning, public health, and occupational safety also administer laws concerning aquaculture enterprises.

Market Opportunities:

A wide variety of freshwater fish can be farmed in RAS for a diverse number of purposes. Many species are commonly grown as food fish for marketing as live or processed products to wholesalers or retailers and directly to supermarkets and restaurants. The major food fish species reared in the U.S. are channel catfish and rainbow trout. Other species with good potential for farming as food are hybrid striped bass, red drum, tilapia, yellow perch, walleye, and shrimp.

Fish can be marketed alive, thereby reducing processing concerns, or they can be sold fresh on ice, or frozen. Value-added products such as smoke, marinated, boiled, and pickled fish may expand the demand and induce a greater price per pound.

In addition for food fish, hatcheries can be established to sell fish eggs to other growers or to market fingerling (2-6 inches) sportfish for stocking in private ponds and lakes for angling. Bait minnows, crayfish, and some aquatic insects can be marketed to bait dealers for sale to anglers. Goldfish, tropical fish, turtles, and other aquatic animals and water plants are cultured and marketed as aquarium pets and for stocking in ornamental ponds.

Financing:

Most aquaculture firms are developed and supported entirely through private credit and financing. Limited federal and state assistance is extended to fish farmers. Federal financing is sometimes made by the Farmers Home Administration (FmHA) in the form of business and industry loans to promote economic development in rural areas and small towns and other types of loans. The Small Business Administration, Farm Credit Administration, an Appalachian Regional Commission also may provide loans for aquaculture development. Limited state financing may be available from the Departments of Economic Development and Agriculture.

Horticulture and Aquaculture:

Combining the farming of fish and greenhouse vegetables has grown increasingly in popularity and profitability. Double cropping of both fish and vegetables is a new way to integrate two forms of agriculture into a single enterprise. A major advantage of rearing two high value crops such as fish and tomatoes is that waste water from the fish tank is used to irrigate and fertilize the plants. At the same time, tomato beds are used as sand biofilters to clean the water of ammonia wastes so that it can be recycled back into the fish tanks. The horticulture-aquaculture enterprise recycles waste products and doubles the crops and profits.

Retrofitting Old Industrial Plants:

Renovating obsolete waste water treatment plants, greenhouses, and other similar industrial facilities to create RAS may be possible in certain instances, but generally is not economically feasible in most situations we have encountered. Frequently it is more costly to redesign existing facilities than to build new ones.

Scams:

The high risk inherent in RAS fish farming, as in all other forms of fish culture, is compounded by the fact that a number of "questionable entrepreneurs" are marketing "paper recirculation systems" that have never been built or tested in commercial scale operations. These systems may grow fish in theory, but not in reality. Some of these systems may grow fish (biological succes), but not necessarily in an economically viable manner. We advise individuals considering investing in recirculation aquaculture to demand to visit a commercial-scale enterprise that incorporates the system being sold. Most successful aquaculture enterprises using recirculation systems are selling fish, not their system.

Outlook:

The long-term demand for aquaculture products is excellent. An increasing human population, especially for older adults who proportionally eat more fish than youth do, and an increasing public awareness of the importance of fish in the diet, and human health and fitness are driving fish consumption upwards.

Correspondingly, the prospects for RAS are good. A number of experts believe that the future trend in the aquaculture industry is toward intensive fish farming. Growing fish in indoor tank culture systems is analogous to rearing poultry, hogs, or cattle in confinement or feed lot systems. Open pasture systems have proven less efficient in the farming of most farm food animals than confinement systems, and this will likely be true for rearing fish.