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Recirculating Aquaculture Tank Production Systems

Management of Recirculating Systems

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Recirculating systems for holding and growing fish have been used by fisheries researchers for more than three decades. Attempts to advance these systems to commercial scale food fish production have increased dramatically in the last decade. The renewed interest in recirculating systems is due to their perceived advantages, including: greatly reduced land and water requirements; a high degree of environmental control allowing year-round growth at optimum rates; and the feasibility of locating in close proximity to prime markets.

Unfortunately, many commercial systems, to date, have failed because of poor design, inferior management, or flawed economics. This publication will address the problems of managing a recirculating aquaculture system so that those contemplating investment can make informed decisions. For information on theory and design of recirculating systems refer to SRAC Publication No. 451, *Recirculating Aquaculture Tank Production Systems: An Overview of Critical Considerations,* and SRAC Publication No. 453, *Recirculating Aquaculture Tank Production Systems: Component Options.*

Recirculating systems are mechanically sophisticated and biologically complex. Component failures, poor water quality, stress, diseases, and off-flavor are common problems in poorly managed recirculating systems. Management of these systems takes education, expertise and dedication.

Recirculating systems are biologically intense. Fish are usually reared intensively (0.5 pound / gallon or greater) for recirculating systems to be cost effective. As an analogy, a 20-gallon home aquarium, which is a miniature recirculating system, would have to maintain at least 10 pounds of fish to reach this same level of intensity. This should be a sobering thought to anyone contemplating the management of an intensive recirculating system.

System operation

To provide a suitable environment for intensive fish production, recirculating systems must maintain uniform flow rates (water and air / oxygen), fixed water levels, and uninterrupted operation.

The main cause of flow reduction is the constriction of pipes and air diffusers by the growth of fungi, bacteria and algae, which proliferate in response to high levels of nutrients and organic matter. This can cause increases or decreases in tank water levels, reduce aeration efficiency, and reduce biofilter efficiency. Flow rate reduction can be avoided or mitigated by using oversized pipe diameters and configuring system components to shorten piping distances. The fouling of pipes leaving tanks (by gravity flow) is easily observed because of the accompanying rise in tank water level. If flow rates gradually decline, then pipes must be cleaned. A sponge, cleaning pad or brush attached to a plumber's snake works well for scouring pipes. Air diffusers should be cleaned periodically by soaking them in muriatic acid (available at plumbing suppliers).

Flow blockage and water level fluctuations also can result from the clogging of screens used to retain fish in the rearing tanks. Screen mesh should be the largest size that will retain the fish (usually 3/4 to 1 inch). The screened area around pipes should be much larger than the pipe diameter, because a few dead fish can easily block a pipe. Screens can be made into long cylinders or boxes that attach to pipes and have a large surface area to prevent blockage. Screens should be tight-

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ly secured to the pipe so that they cannot be dislodged during feeding, cleaning and harvesting operations.

An essential component of recirculating systems is a backup power source (see SRAC Publication No. 453). Electrical power failures may not be common, but it only takes a brief power failure to cause a catastrophic fish loss. For example, if a power failure occurred in a warmwater system (84º F) at saturated oxygen concentrations containing 1/2-pound fish at a density of 1/4 pound of fish per gallon of water, it will take only 16 minutes for the oxygen concentration to decrease to 3 ppm, a stressful level for fish. The same system containing 1-pound fish at a density of 1 pound of fish per gallon would plunge to this stressful oxygen concentration in less than 6 minutes. These scenarios should give the prospective manager a sobering feeling for how important backup power is to the integrity of a recirculating system.

Certain components of backup systems need to be automatic. An automatic transfer switch should start the backup generator in case personnel are not present. Automatic phone alarm systems are inexpensive and are essential in alerting key personnel to power failures or water level fluctuations. Some phone alarm systems allow in-dialing so that managers can phone in and check on the status of the system. Other component failures can also lead to disastrous results in a very short time. Therefore, systems should be designed with essential backup components that come on automatically or can be turned on quickly with just a flip of a switch. Finally, one of the simplest backups is a tank of pure oxygen connected with a solenoid valve that opens automatically during power failures. This oxygen-solenoid system can provide sufficient dissolved oxygen to keep the fish alive during power failures.

Biological filters (biofilters) can fail because of senescence, chemical treatment (e. g., disease treatment), or anoxia. It takes weeks to months to establish or colonize a biofilter. The bacteria that colonize a biofilter grow, age and die. These bacteria are susceptible to changes in water quality (low dissolved oxygen [DO], low alkalinity, low or high pH, high CO_2, etc.), chemical treatments, and oxygen depletions. Biological filters do not take rapid change well!

Particulates

Particulate removal is one of the most complicated problems in recirculating systems. Particulates come from uneaten feed and from undigested wastes. It has been estimated that more than 60 percent of feed placed into the system ends up as particulates. Quick and efficient removal of particulates can significantly reduce the biological demand placed on the biofilter, improve biofilter efficiency, reduce the overall size of the biofilter required, and lower the oxygen demand on the system. Particulate filters should be cleaned frequently and maintained at peak efficiency. Many particulates are too small to be removed by conventional particulate filters and cause or complicate many other system problems.

Water quality management

In recirculating systems, good water quality must be maintained for maximum fish growth and for optimum effectiveness of bacteria in the biofilter (Fig. 1). Water quality factors that must be monitored and / or controlled include temperature, dissolved oxygen, carbon dioxide, pH, ammonia, nitrite and solids. Other water quality factors that should be considered are alkalinity, nitrate and chloride.

Temperature

Temperature must be maintained within the range for optimum growth of the cultured species. At optimum temperatures fish grow quickly, convert feed efficiently, and are relatively resistant to many diseases. Biofilter efficiency also is affected by temperature but is not generally a problem in warmwater systems. Temperature can be regulated with electrical immersion heaters, gas or electric heating units, heat exchangers, chillers, or heat pumps. Tempera-

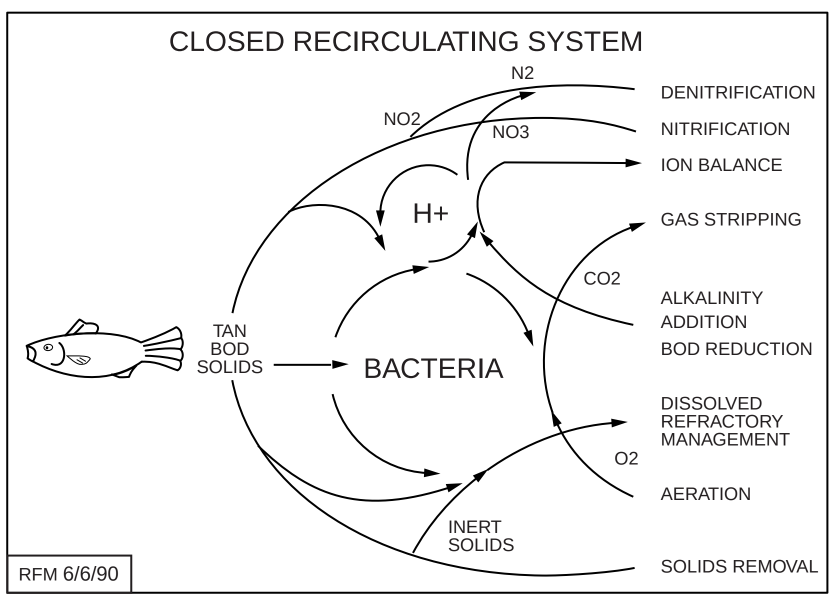


Figure 1. Diagram of fish wastes and their effects on bacterial and chemical interactions in a recirculating system.

Courtesy of Ronald F. Malone, Department of Civil Engineering, Louisiana State University, from Louisiana Aquaculture 1992, "Design of Recirculating Systems for Intensive Tilapia Culture," Douglas G. Drennan and Ronald F. Malone.

ture can be manipulated to reduce stress during handling and to control certain diseases (e.g., Ich and ESC).

Dissolved oxygen

Continuously supplying adequate amounts of dissolved oxygen to fish and the bacteria / biofilter in the recirculating system is essential to its proper operation. Dissolved oxygen (DO) concentrations should be maintained above 60 percent of saturation or above 5 ppm for optimum fish growth in most warmwater systems. It is also important to maintain DO concentrations in the biofilter for maximum ammonia and nitrite removal. Nitrifying bacteria become inefficient at DO concentrations below 2 ppm.

Aeration systems must operate continuously to support the high demand for oxygen by the fish and microorganisms in the system. As fish approach harvest size and feeding rates (pounds / system) are near their maximum levels, oxygen demand may exceed the capacity of the aeration system to maintain DO concentrations above 5 ppm. Fish show signs of oxygen stress by gathering at the surface and swimming into the current produced by the aeration device (e. g., agitator, air lift, etc.) where DO concentrations are higher. If this occurs, a supplemental aeration system should be used or the feeding rate must be reduced.

Periods of heavy feeding may be sustained by multiple or continuous feedings of the daily ration over a 15- to 20-hour period rather than in two or three discrete meals. As fish digest food, their respiration rate increases dramatically, causing a rapid decrease in DO concentrations. Feeding small amounts continuously with automatic or demand feeders allows DO to decline gradually without reaching critical levels. During periods of heavy feeding, DO should be monitored closely, particularly before and after feedings. Recirculating systems require constant monitoring to ensure they are functioning properly.

Water said to be “saturated” with oxygen contains the maximum amount of oxygen that will dissolve in it at a given temperature, salinity and pressure (Table 1). Pure oxygen systems can be incorporated into recirculating systems. These inject oxygen into a confined stream of water, creating supersaturated conditions (see SRAC Publication No. 453).

Supersaturated water, with DO concentrations several times higher than saturation, is mixed into the rearing tank water to maintain DO concentrations near saturation. The supersaturated water should be introduced into the rearing tank near the bottom and be rapidly mixed throughout the tank by currents generated from the water pumping equipment. Proper mixing of the supersaturated water into the tank is critical. Dissolved oxygen will escape into the air if the supersaturated water is agitated too vigorously. If the water is mixed too slowly, zones of supersaturation can cause gas bubble disease. In gas bubble disease, gases come out of solution inside the fish and form bubbles in the blood. These bubbles can result in death. Fry are particularly sensitive to supersaturation.

Carbon dioxide

Carbon dioxide is produced by respiration of fish and bacteria in the system. Fish begin to stress at carbon dioxide concentrations above 20 ppm because it interferes with oxygen uptake. Like oxygen stress, fish under CO_2 stress come to the surface and congregate around aeration devices (if present). Lethargic behavior and a sharply reduced appetite are common symptoms of carbon dioxide stress.

Carbon dioxide can accumulate in recirculating systems unless it is physically or chemically removed. Carbon dioxide usually is removed from the water by packed column aerators or other aeration devices (see SRAC Publication No. 453).

pH

Fish generally can tolerate a pH range from 6 to 9.5, although a rapid pH change of two units or more is harmful, especially to fry. Biofilter bacteria which are important in decomposing waste products are not efficient over a wide pH range. The optimum pH range for biofilter bacteria is 7 to 8.

The pH tends to decline in recirculating systems as bacterial nitrification produces acids and consumes alkalinity, and as carbon dioxide is generated by the fish and microorganisms. Carbon dioxide reacts with water to form carbonic acid, which drives the pH downward. Below a pH of 6, the nitrifying bacteria are inhibited and do not remove toxic nitrogen wastes.

Optimum pH range generally is maintained in recirculating systems by adding alkaline buffers. The most commonly used buffers are sodium bicarbonate and calcium carbonate, but calcium hydroxide, calcium oxide, and sodium hydroxide have been used. Calcium carbonate may dissolve too slowly to neutralize a rapid accumulation of acid.

Table 1. Oxygen saturation levels in fresh water at sea level atmospheric pressure.

Temperature		DO	Temperature		DO
ºC	ºF	mg/L (ppm)	ºC	ºF	mg/L (ppm)
10	50.0	10.92	24	75.2	8.25
12	53.6	10.43	26	78.8	7.99
14	57.2	9.98	28	82.4	7.75
16	60.8	9.56	30	86.0	7.53
18	64.4	9.18	32	89.6	7.32
20	68.0	8.84	34	93.2	7.13
22	71.6	8.53	36	96.8	6.95

Calcium hydroxide, calcium oxide and sodium hydroxide dissolve quickly but are very caustic; these compounds should not be added to the rearing tank because they may harm the fish by creating zones of very high pH. The pH of the system should be monitored daily and adjusted as necessary to maintain optimum levels. Usually, the addition of sodium bicarbonate at a rate of 17 to 20 percent of the daily feeding rate is sufficient to maintain pH and alkalinity within the desired range (Fig. 2). For example, if a tank is being fed 10 pounds of feed per day then approximately 2 pounds of bicarbonate would be added daily to adjust pH and alkalinity levels.

Alkalinity, the acid neutralizing capacity of the water, should be maintained at 50 to 100 mg as calcium carbonate/L or higher, as should hardness. Generally, the addition of alkaline buffers used to adjust pH will provide adequate alkalinity, and if the buffers also contain calcium, they add to hardness. For a more detailed discussion of alkalinity and hardness consult a water quality text.

Table 2. Percentage of total ammonia in the un-ionized form at differing pH values and temperatures.

pH	Temperature (ºC) 16	18	20	22	24	26	28	30	32
7.0	0.30	0.34	0.40	0.46	0.52	0.60	0.70	0.81	0.95
7.2	0.47	0.54	0.63	0.72	0.82	0.95	1.10	1.27	1.50
7.4	0.74	0.86	0.99	1.14	1.30	1.50	1.73	2.00	2.36
7.6	1.17	1.35	1.56	1.79	2.05	2.35	2.72	3.13	3.69
7.8	1.84	2.12	2.45	2.80	3.21	3.68	4.24	4.88	5.72
8.0	2.88	3.32	3.83	4.37	4.99	5.71	6.55	7.52	8.77
8.2	4.49	5.16	5.94	6.76	7.68	8.75	10.00	11.41	13.22
8.4	6.93	7.94	9.09	10.30	11.65	13.20	14.98	16.96	19.46
8.6	10.56	12.03	13.68	15.40	17.28	19.42	21.83	24.45	27.68
8.8	15.76	17.82	20.08	22.38	24.88	27.64	30.68	33.90	37.76
9.0	22.87	25.57	28.47	31.37	34.42	37.71	41.23	44.84	49.02
9.2	31.97	35.25	38.69	42.01	45.41	48.96	52.65	56.30	60.38
9.4	42.68	46.32	50.00	53.45	56.86	60.33	63.79	67.12	70.72
9.6	54.14	57.77	61.31	64.54	67.63	70.67	73.63	76.39	79.29
9.8	65.17	68.43	71.53	74.25	76.81	79.25	81.57	83.68	85.85
10.0	74.78	77.46	79.92	82.05	84.00	85.82	87.52	89.05	90.58
10.2	82.45	84.48	86.32	87.87	89.27	90.56	91.75	92.80	93.84

Nitrogen wastes

Ammonia is the principal nitrogenous waste released by fish and is mainly excreted across the gills as ammonia gas. Ammonia is a byproduct from the digestion of protein. An estimated 2.2 pounds of ammonia nitrogen are produced from each 100 pounds of feed fed. Bacteria in the biofilter convert ammonia to nitrite and nitrite to nitrate, a process called nitrification. Both ammonia and nitrite are toxic to fish and are, therefore, major management problems in recirculating systems (Fig. 2).

Ammonia in water exists as two compounds: ionized (NH_4^+) and un-ionized (NH_3) ammonia. Un-ionized ammonia is extremely toxic to fish. The amount of un-ionized ammonia present depends on pH and temperature of the water (Table 2). Un-ionized ammonia nitrogen concentrations as low as 0.02-0.07 ppm have been shown to slow growth and cause tissue damage in several species of warmwater fish. However, tilapia tolerate high un-ionized ammonia concentrations and seldom display toxic effects in well-buffered recirculating systems. Ammonia should be monitored daily. If total ammonia concentrations start to increase, the biofilter may not be working properly or the feeding rate/ammonia nitrogen production is higher than the design capacity of the biofilter.

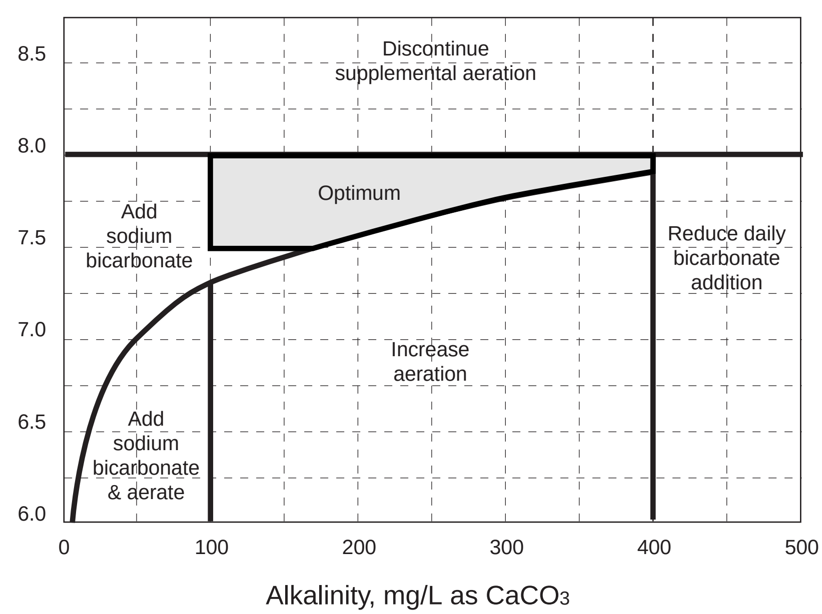


Figure 2. The pH management diagram, a graphical solution of the ionization constant equation for carbonic acid at 25ºC.

Courtesy of Ronald F. Malone, Department of Civil Engineering, Louisiana State University, from Master's Thesis of Peter A. Allain, 1988, "Ion Shifts and pH Management in High Density Shedding Systems for Blue Crabs (Callinectes sapidus) and Red Swamp Crawfish (Procambarus clarkii)," Louisiana State University.

Table 3. Nutrient solution for pre-activation of biofilter.

Nutrient	Concentration (ppm)
Dibasic ammonium phosphate, $(NH_4)_2HPO_4$	40
Dibasic sodium phosphate, Na_2HPO_4	40
Sea salts "solids"	40
Sea salts "liquids"	0.5
Calcium carbonate, $CaCO_3$	250

Biofilters consist of actively growing bacteria attached to some surface(s). Biofilters can fail if the bacteria die or are inhibited by natural aging, toxicity from chemicals (e. g., disease treatment), lack of oxygen, low pH, or other factors. Biofilters are designed so that aging cells slough off to create space for active new bacterial growth. However, there can be situations (e. g., cleaning too vigorously) where all the bacteria are removed. If chemical additions cause biofilter failure, the water in the system should be exchanged. The biofilter would then have to be re-activated (taking 3 or 4 weeks) and the pH adjusted to optimum levels.

During disruptions in biofilter performance, the feeding rate should be reduced considerably or feeding should be stopped. Feeding, even after a complete water exchange, can cause ammonia nitrogen or nitrite nitrogen concentrations (Fig. 3) to rise to stressful levels in a matter of hours if the biofilter is not functioning properly. Subdividing or compartmentalizing biofilters reduces the likelihood of a complete failure and gives the manager the option of "seeding" active biofilter sludge from one tank or system to another.

Activating a new biofilter (i. e., developing a healthy population of nitrifying bacteria capable of removing the ammonia and nitrite produced at normal feeding rates) requires a least 1 month. During this activation period, the normal stocking and feeding rates should be greatly reduced. Prior to stocking it is advantageous, but not absolutely necessary, to pre-activate the biofilters. Pre-activation is accomplished by seeding the filter(s) with nitrifying bacteria (available commercially) and providing a synthetic growth medium for a period of 2 weeks. The growth medium contains a source of ammonia nitrogen (10 to 20 mg/l), trace elements and a buffer (Table 3). The buffer (sodium bicarbonate) should be added to maintain a pH of 7.5. After the activation period the nutrient solution is discarded.

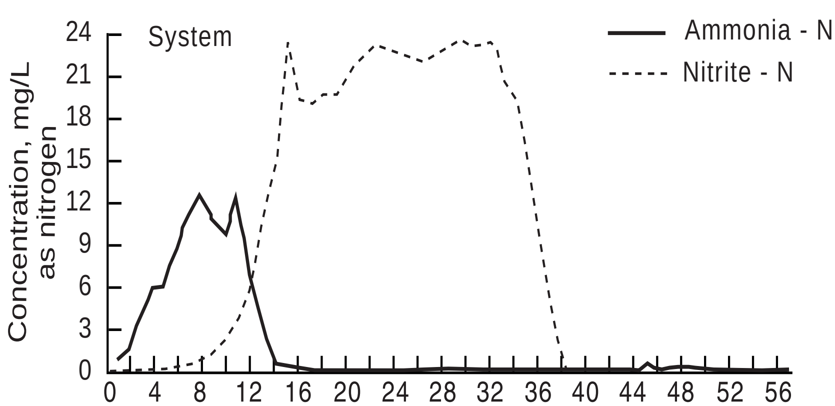


Figure 3. **Typical ammonia and nitrite curves showing time delays in establishing bacteria in biofilters.**

Courtesy of Ronald F. Malone, Department of Civil Engineering, Louisiana State University, from Master's Thesis of Don P. Manthe, 1982, "Water Quality of Submerged Biological Rock Filters for Closed Recirculating Blue Crab Shedding Systems," Louisiana State University.

Many fish can die during this period of biofilter activation. Managers have a tendency to overfeed, which leads to the generation of more ammonia than the biofilter can initially handle. At first, ammonia concentrations increase sharply and fish stop feeding and are seen swimming into the current produced by the aeration device. Deaths will soon occur unless immediate action is taken. At the first sign of high ammonia, feeding should be stopped. If pH is near 7 the fish may not show signs of stress because little of the ammonia is in the un-ionized form.

As nitrifying bacteria, known as *Nitrosomonas*, become established in the biofilter, they quickly convert the ammonia into nitrite. This conversion takes place about 2 weeks into the activation period and will proceed even if feeding has stopped. Once again, fish will seek relief near aeration and mortalities will occur soon unless steps are taken. Nitrite concentrations decline when a second group of nitrifying bacteria, known as *Nitrobacter*, become established. These problems can be avoided if time is taken to activate the biofilters slowly.

Nitrite concentrations also should be checked daily. The degree of toxicity to nitrite varies with species. Scaled species of fish are generally more tolerant of high nitrite concentrations than species such as catfish, which are very sensitive to nitrite. Nitrite nitrogen as low as 0.5 ppm is stressful to catfish, while concentrations of less than 5 ppm appear to cause little stress to tilapia. Nitrite toxicity causes a disease called "brown blood," which describes the blood color that results when normal blood hemoglobin comes in contact with nitrite and forms a compound called methemoglobin. Methemoglobin does not transport oxygen properly, and fish react as if they are under oxygen stress. Fish suffering nitrite toxicity come to the surface as in oxygen stress, sharply reduce their feeding, and are lethargic. Nitrite toxicity can be reduced or blocked by chloride ions. Usually 6 to 10 parts of chloride protect fish from 1 part nitrite nitrogen. Increasing concentrations of nitrite are a sign that the biofilter is not working properly or the biofilter is not large enough to handle the amount of waste being produced. As with ammonia buildup, check pH, alkalinity and dissolved oxygen in the biofilter. Reduce feeding and be prepared to flush the system with fresh water or add salt (NaCl) if toxic concentrations develop.

Nitrate, the end product of nitrification, is relatively nontoxic except at very high concentrations (over 300 ppm). Usually nitrate does not build up to these concentrations if some daily exchange (5 to 10 percent) with fresh water is part of the management routine. Also, in many recirculating systems some denitrification seems to occur within the system that keeps nitrate concentrations below toxic levels. Denitrification is the bacteria-mediated transformation of nitrate to nitrogen gas, which escapes into the atmosphere.

Solids

Solid waste, or particulate matter, consists mainly of feces and uneaten feed. It is extremely important to remove solids from the system as quickly as possible. If solids are allowed to remain in the system, their decomposition will consume oxygen and produce additional ammonia and other toxic gases (e. g., hydrogen sulfide). Solids are removed by filtration or settling (SRAC Publication No. 453). A considerable amount of highly malodorous sludge is produced by recirculating systems, and it must be disposed of in an environmentally sound manner (e. g., applied to agricultural land or composted).

Very small (colloidal) solids remain suspended in the water. Although the decay of this material consumes oxygen and produces some additional ammonia, it also serves as attachment sites for nitrifying bacteria. Therefore, a low level of suspended solids may serve a beneficial role within the system as long as they do not irritate the fishes' gills.

If organic solids build up to high levels in the system, they will stimulate the growth of microorganisms that produce off-flavor compounds. The concentration of solids at which off-flavor compounds develop is not known, but the system water should never be allowed to develop a foul or fecal smell. If offensive odors develop, increase the water exchange rate, reduce feeding, increase solids removal, and/or enlarge biofilters.

Chloride

Adding salt (NaCl) to the system is beneficial not only for the chloride ions, which block nitrite toxicity, but also because sodium and chloride ions relieve osmotic stress. Osmotic stress is caused by the loss of ions from the fishes' body fluids (usually through the gills). Osmotic stress accompanies handling and other forms of stress (e. g., poor water quality). A salt concentration of 0.02 to 0.2 percent will relieve osmotic stress. This concentration of salt is beneficial to most species of fish and invertebrates. It should be noted that rapidly adding salt to a recirculating system can decrease biofilter efficiency. The biofilter will slowly adjust to the addition of salt but this adjustment can take 3 to 4 weeks. Table 4 summarizes general water quality requirements of recirculating systems.

Water exchange

Most recirculating systems are designed to replace 5 to 10 percent of the system volume each day with new water. This amount of exchange prevents the build-up of nitrates and soluble organic matter that would eventually cause problems. In some situations, sufficient water may not be available for these high exchange rates. A complete water exchange should be done after each production cycle to reduce the build-up of nitrate and dissolved organics.

For emergency situations it is recommended that the system have an auxiliary water reservoir equal to one complete water exchange (flush). The reservoir should be maintained at the proper temperature and water quality.

Fish production management

Stocking

Fish management starts before the fish are introduced into the recirculating system. Fingerlings should be purchased from a reputable producer who practices genetic selection, knows how to carefully handle and transport fish, and does not have a history

Table 4. Recommended water quality requirements of recirculating systems.

Component	Recommended value or range
Temperature	optimum range for species cultured - less than 5º F as a rapid change
Dissolved oxygen	60% or more of saturation, usually 5 ppm or more for warmwater fish and greater than 2 ppm in biofilter effluent
Carbon dioxide	less than 20 ppm
pH	7.0 to 8.0
Total alkalinity	50 to 100 ppm or more as $CaCO_3$
Total hardness	50 to 100 ppm or more as $CaCO_3$
Un-ionized ammonia-N	less than 0.05 ppm
Nitrite-N	less than 0.5 ppm
Salt	0.02 to 0.2 %

of disease problems in his/her hatchery. Starting with poor quality or diseased fingerlings almost ensures failure.

Fish should be checked for parasites and diseases before being introduced into the system. New fish may need to be quarantined from fish already in the system so that diseases will not be introduced. A few fish should be checked for parasites and diseases by a certified fish diagnostician. Once diseases are introduced into a recirculating system they are generally hard to control, and treatment may disrupt the biofilter.

Fish are usually hauled in cool water. As they come into the system they usually have to be tempered or gradually acclimated to the system temperature and pH. Fish can generally take a 5º F change without much problem. Temperature changes of more than 5º F should be done at about 1º F every 20 to 30 minutes. Stress can be reduced if the system is cooled to the temperature of the hauling water and then slowly increased over a period of several hours to days.

Recirculating systems must operate near maximum production (i. e., maximum risk) capacity at all times to be economical. It is not cost effective to operate pumps and aeration devices when the system is stocked with fingerlings at only one-tenth of the system's carrying capacity. Therefore, fingerlings should be stocked at very high rates, in the range of 30 fish per cubic foot. Feeding rates should be optimum for rapid growth and near the system maximum—the highest feeding rates at which acceptable water quality conditions can be maintained. When more feed is required, fish stocks should be split and moved to new tanks. This would gradually reduce the stocking rate over the production cycle.

Another approach is to divide the rearing tank(s) into compartments with different size groups of fish in each compartment. In this approach, the optimum feeding rate for all the compartments is consistently near the biofilter's maximum performance. As one group of fish is harvested, fingerlings are immediately stocked into the vacant compartment or tank. Compartment size within a tank may be adjusted as fish grow, by using movable screens.

Feeding

Knowing how much to feed fish without overfeeding is a problem in any type of fish production. Feeding rates are usually based on fish size. Small fish consume a higher percent of their body weight per day than do larger fish (Table 5). Most fish being grown for food will be stocked as fingerlings. Fingerlings consume 3 to 4 percent of their body weight per day until they reach 1/4 to 1/2 pound, then consume 2 to 3 percent of their body weight until being harvested at 1 to 2 pounds. A rule-of-thumb for pond culture is to feed all the fish will consume in 5 to 10 minutes. Unfortunately, this method can easily lead to overfeeding. Overfeeding wastes feed, degrades water quality, and can overload the biofilter.

Table 5. Estimated food consumption by size of a typical warmwater fish.

Average weight per fish (lbs.)	(g)	Body weight consumed (%)
0.02	9	5.0
0.04	18	4.0
0.06	27	3.3
0.25	113	3.0
0.50	227	2.75
0.75	340	2.5
1.0	454	2.2
1.5	681	1.8

Table 6 approximates a feeding schedule for a warmwater fish (e.g., tilapia) stocked into an 84º F recirculating system as fry and harvested at a weight of 1 pound after 250 feeding days. Feed conversion is estimated at 1.5: 1, or 1.5 pounds of feed to obtain 1 pound of gain.

Tables 5 and 6 are estimates and should be used only as guidelines which can change with differing species and temperatures.

Growth and feed conversion are estimated by weighing a sample of fish from each tank and then calculating the feed conversion ratios and new feeding rates from this sample. For example, 1,000 fish in a tank have been consuming 10 pounds of feed a day for the last 10 days (100 pounds total). The fish were sampled 10 days earlier and weighed an average of 0.33 pounds or an estimated total of 330 pounds.

Table 6. Recommended stocking and feeding rates for different size groups of tilapia in tanks, and estimated growth rates.

Stocking rate (number/ft3)	Weight (g) Initial	Final	Growth rate (g/day)	Growth period (days)	Feeding rate (%)
225	0.02	0.5-1	-	30	20 - 15
90	0.5-1	5	-	30	15 - 10
45	5	20	0.5	30	10 - 7
28	20	50	1.0	30	7 - 4
14	50	100	1.5	30	4 - 3.5
5.5	100	250	2.5	30	3.5 - 1.5
3	250	450	3.0	70	1.5 - 1.0

A new sample of 25 fish is collected from the tank and weighed. The 25 fish weigh 10 pounds or an average of 0.4 pounds per fish. If this is a representative sample, then 1,000 fish should weigh 400 pounds. Therefore, the change in total fish weight for this tank is 400 minus 330, or 70 pounds. The fish were fed 100 pounds of feed in the last 10 days and gained 70 pounds in weight. Feed conversion then is equal to 1.43 to 1 (i.e., 100 ÷ 70). In other words, the fish gained 1 pound of weight for each 1.43 pounds of feed fed. The daily feeding rate should now be increased to adjust for growth of the fish.

To calculate the new feeding rate, multiply the estimated total fish weight (400 pounds) by the estimated percent body weight of feed consumption for a 0.4-pound fish (from Table 5). Table 5 suggests that the percent body weight consumed per day should be between 2.75 and 3 percent. If 3 percent is used, then 400 times 0.03 is 12.0. Thus, the new feeding rate should be 12 pounds of feed per day for the next 10 days, for a total of 120 pounds. Using this sampling technique the manager can accurately track growth and feed conversion, and base other management decisions on these factors.

Feeding skills

Feeding is the best opportunity to observe overall vitality of the fish. A poor feeding response should be an immediate alarm to the manager. Check all aspects of the system, particularly water quality, and diagnose for diseases if feeding behavior suddenly diminishes.

Fish can be fed once or several times a day. Multiple feedings spread out the waste load on the biofilter and help prevent sudden decreases in DO. Research has shown that small fish will grow faster if fed several times a day. Feeding several times a day seems to reduce problems of feeding dominance in some species of fish. Many recirculating system managers feed as often as every 30 minutes. Multiple feedings at the same location in a tank can increase dominance because a few fish jealously guard the area and do not let other fish feed. In this situation, use feeders that distribute feed widely across the tank. Fish can be fed by hand, with demand feeders, or by automatic feeders, but stationary demand and belt type feeders tend to encourage dominance. Whichever method is used, be careful to evenly distribute feed and **not to overfeed**.

Always purchase high quality feed from a reputable company. Keep feed fresh by storing it in a cool, dry place. Never use feed that is past 60 days of the manufacture date. Never feed moldy, discolored or clumped feed. Molds on feed may produce aflatoxins, which can stress or kill fish. Feed quality deteriorates with time, particularly when stored in warm, damp conditions. A disease known as “no blood” is associated with feed that is deficient in certain vitamins. In a case of “no blood,” the fish appear pale with white gills and blood appears clear, not red. Another nutritional disease known as “broken back syndrome” is caused by a vitamin C deficiency. The only management practice for “no blood” disease and “broken back syndrome” is to discard the feed being used and purchase a different batch or brand of feed.

Fines, crumbled feed particles, are not generally consumed by the fish but add to the waste load of the system, increasing the burden on particulate and biological filters. Therefore, it is recommended that feed pellets be sifted or screened to remove fines before feeding.

Off-flavor

Off-flavor in recirculating systems is a common and persistent problem. Many times fish have to be moved into a clean system, one with clear, uncontaminated water, where they can be purged of off-flavor before being marketed. Purging fish of off-flavor can take from a few days to many weeks (depending on the type and severity of off-flavor). If fish remain in the purging tanks for an extended period, their feeding rate may need to be reduced, or off-flavor may develop within the purging system.

See SRAC Publication No. 431, *Testing Flavor Quality of Preharvest Channel Catfish*, for detailed information on off-flavor.

Stress and disease control

The key to fish management is stress management. Fish can be stressed by changes in temperature and water quality, by handling (including seining and hauling), by nutritional deficiencies, and by exposure to parasites and diseases. Stress increases the susceptibility of fish to disease, which can lead to catastrophic fish losses if not detected and treated quickly. To reduce stress fish must be handled gently, kept under proper water quality conditions, and protected from exposure to poor water quality and diseases. Even sound and light can stress fish. Unexpected sounds or sudden flashes of light often trigger an escape response in fish. In a tank, this escape response may send fish into the side of the tank, causing injury. Fish are generally sensitive to light exposure, particularly if it is sudden or intense. For this reason many recirculating systems have minimal lighting around the fish tanks.

Diseases

There are more than 100 known fish diseases, most of which do not seem to discriminate between species. Other diseases are very host specific. Organisms known to cause diseases and/or parasitize fish include viruses, bacteria, fungi, protozoa, crustaceans, flatworms, roundworms and segmented worms. There are also non-infectious diseases such as brown blood, no blood and broken back syndrome. Any of these diseases can become a problem in a recirculating system. Diseases can be introduced into the system from the water, the fish, and the system’s equipment.

Diseases are likely to enter the system from hauling water, on the fish themselves, or on nets, baskets, gloves, etc., that are moved from tank to tank. Hauling water should never be introduced into the system. Fish should be quarantined, checked for diseases, and treated as necessary. Equipment should be sterilized (e. g., chlorine dip) before moving it between tanks. If possible, provide separate nets and baskets for each tank so they will not contaminate other tanks. Disease can spread rapidly from one tank to another if equipment is freely moved between tanks or if all the water within the system is mixed together as in a common sump, particulate filter or biofilter.

A manager needs to be familiar with the signs of stress and disease which include:

- Excitability
- Flashing or whirling
- Skin or fin sores or discolorations
- Staying at the surface
- Erratic swimming
- Reduction in feeding rate
- Gulping at the surface
- Cessation of feeding
- Mortalities

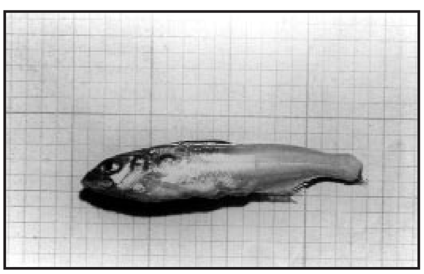
Whenever any of these symptoms appear the manager should check water quality and have a few fish with symptoms diagnosed by a qualified fish disease specialist.

The most common diseases in recirculating systems are caused by bacteria and protozoans. Some diseases that have been particularly problematic in recirculating systems include the protozoal diseases Ich (*Ichthyophthirius*) and *Trichodina*, and the bacterial diseases columnaris, *Aeromonas, Streptococcus* and *Mycobacterium*. It appears that *Trichodina* and *Streptococcus* diseases are problematic in recirculating systems with tilapia, while *Mycobacterium* has been found in hybrid striped bass in intensive recirculating systems.

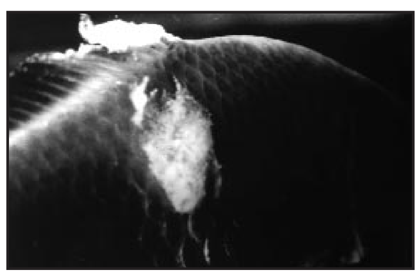
It may be possible to treat diseases with chemicals approved for fish (see SRAC Publication No. 410, *Calculating Treatments for Ponds and Tanks*), although few therapeutants are approved for use on food fish species other than catfish and rainbow trout. Treatment always has its problems. In the case of recirculating systems, chemical treatments can severely disrupt the biofilter. Biofilter bacteria are inhibited to some degree by formalin, copper sulfate, potassium permanganate, and certain antibiotics. Even sudden changes in salt concentration will decrease biofilter efficiency. If the system is designed properly, it may be possible to isolate the biofilter from the rest of the system, treat and flush the fish tanks, and then reconnect the biofilter without exposing it to chemical treatment. However, there is a danger that the biofilter will reintroduce the disease organism. Whenever a chemical treatment is applied, be prepared to exchange the system water and monitor the DO concentration and other water quality factors closely. Fish usually reduce their feed consumption after a chemical treatment; therefore, feeding rates need to be monitored carefully.

Tables 7 and 8 give possible causes and management options based on the observation of the fish or water quality tests.

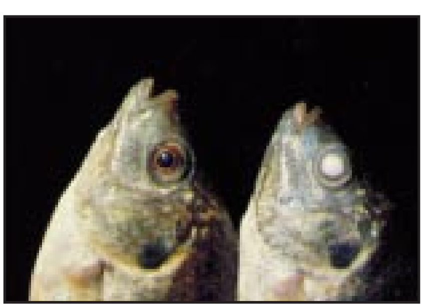
Examples of fish diseases



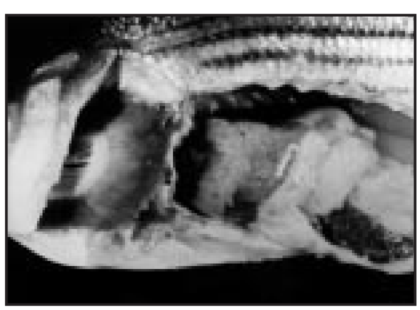
A–Columnaris



B–*Aeromonas*



C–*Streptococcus*
(cataract and pop-eye)



D–*Mycobacterium*
(granular liver and spleen)

Conclusions

Recirculating systems have developed to the point that they are being used for research, for ornamental / tropical fish culture, for maturing and staging brood fish, for producing advanced fry / fingerlings, and for producing food fish for high dollar niche markets. They continue to be expensive ventures which are as much art as science, particularly when it comes to management. Do your homework before deciding to invest in a recirculating system. Investigate the efficiency, compatibility and maintenance requirements of the components. Estimate the costs of building and operating the system and of marketing the fish without any return on investment for at least 2 years. Know the species you intend to grow, their environmental requirements, diseases most common in their culture, and how those diseases are treated. Know your potential markets and how the fish need to be prepared for that market. Be realistic about the

Table 7. Possible options in managing a recirculating tank system based on observations of the fish.

Observation	Possible cause	Possible management
Fish:		
Excitable/darting/erratic swimming	■ excess or intense sounds/lights	reduce sound level/pad sides of tank/reduce light intensity
	■ parasite	examine* fish with symptoms
	■ high ammonia	check ammonia concentration
Flashing/whirling	■ parasite	examine fish with symptoms
Discolorations/sores	■ parasite/bacteria	examine fish with symptoms
Bloated/eyes bulging out	■ virus or bacteria	examine fish with symptoms
	■ gas bubble disease	check for supersaturation and examine fish with symptoms
Lying at surface/not swimming off	■ parasite	examine fish with symptoms
	■ low oxygen	check dissolved oxygen in tank
	■ high ammonia or nitrite	check ammonia and nitrite concentrations
	■ bad feed	check feed for discoloration/clumping and check blood of fish
	■ high carbon dioxide	check carbon dioxide level
Crowding around water inflow/aerators	■ low oxygen	check dissolved oxygen in tank
	■ parasite/disease	examine fish with symptoms
	■ high ammonia or nitrite	check ammonia and nitrite concentrations
	■ bad feed	check feed for discoloration/clumping and check blood of fish
Gulping at surface	■ low oxygen	check dissolved oxygen in tank
	■ parasite/disease	examine fish with symptoms
	■ high ammonia or nitrite	check ammonia and nitrite concentrations
	■ high carbon dioxide	check carbon dioxide level
	■ bad feed	check feed for discoloration/clumping and check blood of fish
Reducing feeding	■ low oxygen	check dissolved oxygen in tank
	■ parasite/disease	examine fish with symptoms
	■ high ammonia or nitrite	check ammonia and nitrite concentrations
	■ bad feed	check feed for discoloration/clumping and check blood of fish
Stopping feeding	■ low oxygen	check dissolved oxygen in tank
	■ parasite/disease	examine fish with symptoms
	■ high ammonia or nitrite	check ammonia and nitrite concentrations
Discolored blood – Brown	■ high nitrite	examine fish with symptom; add 5 to 6 ppm chloride for each 1 ppm nitrite; purchase new feed and discard old feed
Clear (no blood)	■ vitamin deficiency	examine fish with symptom; check feed for discoloration/clumping; purchase new feed and discard old feed
Broken back or “S” shaped backbone	■ vitamin deficiency	examine fish with symptom; purchase new feed and discard old feed

*Have fish examined by a qualified fish diagnostician.

money, time and effort you are willing to invest while you are in the learning curve of managing a recirculating system.

Finally, design the system with an emergency aeration system, back-up power sources, and backup system components. Monitor water quality daily and maintain it within optimum ranges.

Exclude diseases at stocking. Perform routine diagnostic checks and be prepared to treat diseases. Reduce stress whenever and however possible. STAY ALERT!

Table 8. Possible management options based on water quality and feed observations.

Observation	Possible management
Low dissolved oxygen (less than 5 ppm)	■ increase aeration ■ stop feeding until corrected ■ watch for symptoms of new parasite/disease
High carbon dioxide (above 20 ppm)	■ add air stripping column ■ increase aeration ■ watch for symptoms of new paraside/disease
Low pH (less than 6.8)	■ add alkaline buffers (sodium bicarbonate, etc.) ■ reduce feeding rate ■ check ammonia and nitrite concentarations
High ammonia (above 0.05 ppm as un-ionized)	■ exchange system water ■ reduce feeding rate ■ check biofilter, pH, alkalinity, hardness, and dissolved oxygen in the biofilter ■ watch for symptoms of new parasite/disease
High nitrite (above 0.5 ppm)	■ exchange system water ■ reduce feeding rate ■ add 5 to 6 ppm chloride per 1 ppm nitrite ■ check biofilter, pH, alkalinity, hardness, and dissolved oxygen in the biofilter ■ watch for symptoms of new parasite/disease
Low alkalinity	■ add alkaline buffers
Low hardness	■ add calcium carbonate or calcium chloride
Discolored/clumped feed	■ purchase new feed and discard old feed ■ watch for symptoms of new parasite/disease

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