Fifth International Conference on Recirculating Aquaculture

Roanoke, Virgina July 22-25, 2004

You are invited to participate in the Fifth International Conference on Recirculating Aquaculture, to be held at The Hotel Roanoke and Conference Center in Roanoke, Virginia, on July 22-25, 2004.

Our biennial conference and trade show is the premier forum for sharing ideas, the latest research, opportunities and technologies in recirculating aquaculture systems. It is designed for entrepreneurs, researchers, operators, managers, fishery biologists, veterinarians, engineers, food technologists, teachers, government regulators and administrators, financial managers and lenders, advisory and extension personnel. The conference features symposia on nutrition, waste management, genetics and physiology, recirculatory pond systems, species and endangered species, aquaria, fish health, bait fish, ornamentals, business management, economics and financing, international operations, education and outreach. Our popular trade show will feature exhibits from businesses, government and educational organizations that provide equipment and services to producers and supporting businesses in the aquaculture industry. Also included again this year will be guided tours of selected recirculating aquaculture research facilities.

We are looking for organizations to exhibit in the trade show, a very popular feature at our past conferences. Producers, equipment manufacturers and salespersons, service providers, investors, universities and state extension services, and government agencies are all invited to exhibit.

We plan to open the trade show on Thursday evening with a welcoming reception, and close it on Saturday afternoon. To give maximum exposure to your exhibit, booths will once again be set up around the inside perimeter of the hotel's ballroom, where the meals and refreshment breaks will be held (refer to the tentative floor plan). In addition to the trade show , the conference plenary session and symposia will feature leading experts in recirculating aquaculture and plenty of opportunities for discussion and networking. We expect between 300 and 400 participants.

Exhibitor registration is now open. To register for a booth, please see Exhibitor Registration. Indicate your preferred booth location from the floor plan, and we will do our best to accommodate your preference. First choice will go to our sponsors, and after that it will be on a first-come, first-served basis.

Would you consider becoming a sponsor, too? If you need more information, please email us at aqua@vt.edu or call 540-231-6805

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AES Information

For donations, the AES will be inserting a one-page product literature sheet in one of the newsletter mailings, and list the vendor as an AES supporter in four consecutive newsletters. Please contact one of the AES News Co-Editors if you would like to be a sponsor.

The AES News is printed quarterly by the Aquacultural Engineering Society. You can receive the AES News by joining the Aquacultural Engineering Society. If you would like to discuss the contents of the AES News , or, if you would like to contribute information to the AES News , please contact the editor:

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"Aquaculture, not the internet, represents the most promising investment opportunity of the 21st Century."

Dear Members:

The New Year has arrived and with it, I hope you bring enthusiasm and great expectations for success. We can only achieve what we hope to achieve. First we must dream, then conceptualize, then build plans, and then implement. You will be successful in 2004. More folks than me are saying this. For example, Peter Drucker, a Nobel Laureate and noted economist, says the following:

"Aquaculture, not the internet, represents the most promising investment opportunity of the 21st Century."

Wow! That should just knock your socks off! Why would he say such a thing? Simple demographics come into play that will drive demand for seafood to 183 million tonnes by 2003, but the projected supply is only expected to be 150 to 160 million metric tonnes with only 80-100 million tonnes being provided from the global capture fisheries. Thus, there is a lack of supply for the anticipated demand of nearly 50 million metric tonnes given that current aquaculture production is about 35 million metric tonnes. This is an amazing market opportunity. Simply put, every aquaculture operation will have to more than double to meet the demands that will accumulate over the next 25 years. Demand could be even higher, depending upon economic productivity of the world, with increased economic productivity translating into increased demand for higher value proteins such as fish.

What are some of our new challenges? The recent article in Science (Global Assessment of Organic Contaminants in Farmed Salmon, by R.A. Hites, J.A. Foran, D.O. Carpenter, M.C. Hamilton, B.A. Knuth, & S.J. Schwager, Vol. 303 pp. 226-229, Science January 9, 2004) highlighted issues of higher contaminants in farmed salmon than wild caught salmon (funded by the Pew Foundation). Even though the measured levels of PCB's and phenols were as much as 1000 fold less than US-FDA stated levels for safe exposure, we cannot deny the mathematical fact that the farmed salmon was typically several fold higher than the wild salmon (you can argue that you are comparing different levels of nothing, but that is not the point). We aquaculture folks have the ability to control what farmed fish eat and in that we essentially completely control the contaminant levels in the fish flesh. So, let's be proactive in this area. We should start to demand that the fishmeals we are purchasing have available contaminant level concentrations of different carcinogenic compounds. Let the price of product control how we make our purchases. We can control the agenda here.

In other news, let me also take this opportunity to bring to your attention the recent award winners recognized at the AES Issues Conference held November 3-5, 2003 in Seattle, Washington. The Issues Conference was attended by close to one hundred members from throughout North America, with seven federal, state, and private Corporate Sponsors.

The first award was the AES Award of Excellence given to Dr. John Colt in recognition of his outstanding science and technical contributions to the field of aquacultural engineering. This award, given for the first time, is generated by nominations to the Executive Board of AES for careful review of scientific contribution, leadership, and service before a choice is made. Dr. Colt is with the NMFS in Seattle and has an M.S. and Ph.D. in Civil Engineering from the University of California at Davis. He has published widely in the areas of dissolved gas monitoring,

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Message from the President continued

ammonia toxicity, oxygen supplementation, and aeration and is currently working on the development of rearing systems to improve the physiological and behavioral fitness of salmon. He is the long-time editor of Aquacultural Engineering for the Americas and is one of the founding directors of AES.

The second award was a $500 scholarship to attend the Issues Conference given to Rodrigo Labatut (Universidad Catolica del Norte, Coquimbo, Chile). Rodrigo presented a paper entitled "Culture of turbot (*scophthalmus maximus*) juveniles in a recirculating aquaculture systems using shallow raceway tanks." The co-author was Dr. J. Olivares.

This is my last letter to you for my term as President. Boy did this year go fast! It was an honor and a privilege to say the least. The major goal for this year was member recruitment. As President, I asked every member to recruit at least one new member. I hope each of you did your part. If not, it is not too late. Your other task will be to elect your incoming 2nd Vice President that will automatically progress to President in two years. We will be sending voting information to you after the Board determines the slate of candidates for the 2nd VP position; this is different than previous years when the voting occurred at the AES-WAS meeting. We hope the new procedure will be more inclusive and participatory. Members may also suggest candidates to be selected by the Board (voted on by the Board at the Annual Meeting).

Our next major gathering will be at WAS 2004 in Hawaii March 1-5, which also serves as our official Annual Meeting. I will pass the President's gavel on to Kelly Rusch, who will be assuming the Presidency. Please be as supportive of her as you were of me. Thanks to each of my fellow board members and especially our executive board who carried out their responsibilities with diligence. Thanks especially to Brian Vinci, AES Secretary Treasurer, and Brenda Marchewka, my program assistant, who did the million odd things to keep AES moving forward smoothly. We had a good year.
Happy Fishing.
Sincerely,
Mike Timmons

Integrated Design of Recirculating Aquaculture Systems

By Ron Malone

Photo courtesy of Mike Massingill, Kent SeaTech Corporation

Commonly, inland aquaculture production systems can be grouped into four categories based upon the manner in which they handle water: (1) Flow-through, (2) Open-recirculating, (3) Closed-recirculating, or (4) Pond systems. Additionally, "in-situ" production strategies, such as net pens or ranching, can be used in large systems, typically marine, where the body of water is large enough to prevent use conflicts and concerns about pollution. For a variety of socioeconomic reasons, the historical trend in the US is toward inland production strategies as opposed to "in-situ" strategies that have dominated notable aquaculture production centers such as Norway and Japan.

Historically, US aquaculture production was based largely on intensive flow-through technologies. Flow-through systems are generally associated with an abundant source of water, typically a stream or groundwater. In the classical format, water is passed through a raceway and out of the facility, flushing waste products to a receiving body of surface water. Fish in the raceway are held at high densities, often exceeding one pound of fish per gallon of tank volume. Many modern flow-through systems are configured to permit serial reuse of water, thus increasing the poundage of fish that can be supported by the water source. Tanks or raceways are simply connected end to end until the TAN (total ammonia nitrogen) concentrations rise to an unacceptable level. Flow-through systems are generally well aerated since oxygen is more rapidly depleted as TAN levels rise. In some areas, clarification (solids removal) of effluent waters is required. Flow-through production still dominates in the US trout and salmon industries. However, the limited number of suitable sites and growing environmental pressures are severely impacting the suitability of this approach.

Pond culture represents perhaps the most common method for culturing fish. Fish are stocked into an outdoor pond where natural foods are supplemented by artificial feeds. Little, if any, water needs to be flushed through the pond aside from that generated by rainfall. Although aeration is sometimes used, stocking densities are very low and natural purification cycles are relied upon to recondition the water. Water replacement is intermittent. Commonly, ponds are only drained once a year or every other year. The warm water catfish industry in Mississippi, the crawfish industry of Louisiana, the new shrimp industry of Texas, the tropical fish industry of Florida, and the emerging striped bass industry in Maryland and South Carolina are all based on pond culture. Although confronted by a series of issues including bad weather, disease, predation by migrating birds, and off-flavor, cost-effective pond culture will likely be an integral component of many near-future aquacultural production strategies.

The term "recirculating" applies to many high density aquaculture systems which wholly or partially reuse water. In its simplest form, a recirculating system consists of a culture unit, a recirculating pump, and a series of treatment units. The interest being shown in recirculating technology stems from a variety of fundamental concerns ranging from water availability to the introduction of exotic species that have confronted the more traditional pond or raceway formats (Table 1). Reuse of water implies reconditioning; so recirculating systems include a filtration package. The sophistication of the water treatment system is determined by the length

configuration is also unique among the systems presented because it is operated at a very low pH, frequently below 6. Low pH is required for breeding of tropical fish from the Amazon of South America. The system is also being adopted for use in the breeding of shrimp and marine species of fish where its ability to consistently maintain excellent water quality is highly valued.

The final system illustrated was developed in Louisiana to support the establishment of a Tilapia industry. The tilapia is an exotic species from Northern Africa and state regulations prohibited its placement in ponds, where its escape to the wild could cause severe ecological damage to native species. The fish can only be raised indoors and all water leaving the facility must be captured and treated to assure no eggs or fry escape into the wild. Central to the system is the floating bead filter which is used to provide both solids capture and biofiltration. Air is blown through air stones to provide for the simultaneous transfer of oxygen and stripping of oxygen. A foam fractionator is used in heavily loaded situations to control foam buildups that can become a nuisance. Heavy loadings and extended water use that occur in these tilapia systems dictate periodic sodium bicarbonate additions. These additions neutralize the acid production from the nitrifying bacteria. This system configuration has also been used in the production of ornamental fish and some brackish water species such as redfish and striped bass.

Summary

Recognition of the need to address the five fundamental reconditioning topics is the first step in the generation of a reliable recirculating design. Each of the treatment components in the water treatment series must be properly designed to carry the maximum load the system will experience. If one component is undersized, it will induce failure of the system as a whole when its capacity is reached.

Integration of components into a treatment train provides opportunities for cost reduction through recognition of the secondary contributions that can be made by some technologies. For example, success of early rotating biological filter systems may be attributed, in part, to the ability of cascading systems to promote gas exchange. Their ability to strip carbon dioxide created a favorable pH regime for nitrification well before this need was widely recognized by the industry. More modern designs should take advantage of these secondary contributions to reduce overall system costs.

Additionally, it must be recognized that the success of a recirculating system is determined ultimately by economics. Selection of reliable but efficient treatment processes are dictated for commercial operations. The systems must maintain suitable water quality and a disease free environment consistently, through most growout cycles, for economic benefits to be realized. As the systems presented here illustrate, there are many integrated configurations that can meet the technical requirements for reconditioning of recirculated waters. Designs should focus on the issues of cost effectiveness once reliability demands are assured.

Ron Malone, Past AES President,
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ISTA 6 Announcement and Call for Papers

Manila, Philippines

The Sixth International Symposium on Tilapia in Aquaculture will be held at the Philippines International Convention Center and the Westin Philippine Plaza in Manila. The ISTA's are held every four years and are the only international conference devoted to this rapidly growing industry. Past symposia have highlighted the advances in various regions of the world and now after 16 years it will return to Asia.

ISTA 6 will be hosted by the Bureau of Fisheries and Aquatic Resources of the Philippines Department of Agriculture. Other major sponsors include; Aquaculture CRSP, American Tilapia Association, World Aquaculture Society, The World Fish Center, Philippines Fisheries Association, PCMARD, CIRAD, Schering-Plough Aquaculture, Global Aquaculture Alliance, GIFT Foundation, and FYD International. Central Luzon State University, the Tilapia Science Center and the University of Arizona will assist with planning and organization.

The focus of the meeting will be the expanding trade in tilapia products and the role of Asia, especially the Philippines, as a center of advancement in technology as well as production for the international markets. The conference will include technical presentations, producer workshops, an industry trade show and farm tours. Social events will include a welcome reception at the Westin Plaza with its spectacular location on Manila Bay across the street from the Convention Center. It will also include a dinner at Intramuros, the magnificently restored old city with its forts, museums, galleries and restaurants.

Submission Info

The Proceedings of the ISTA's have been one of the most important sources of information on tilapia aquaculture and the advances in the science and industry over the last 20 years. Prospective authors are invited to submit manuscripts to:

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Please submit manuscripts in electronic file form. MS word for PC is the preferred format. Additional conference details, registration, and author instructions are available at
http://ag.arizona.edu/azaqua/ista/announce2.htm

The first system illustrated is a high density trout production system developed to reduce the water consumption rate and pollution level associated with flow-through trout facilities. These facilities have traditionally diverted water from an adjacent stream, passed the water through the raceway filled with trout, and laden with solids and ammonia, returned to the stream. The recirculating design reduces the water use of the facility by a hundredfold. Most wastes produced by the fish are captured and processed within the recirculating systems or captured in a concentrated sludge stream. The core of the treatment train is a micro-screen and fluidized-bed combination. These units are complimented by a sophisticated pure oxygen delivery system and a packed column which assures stripping of the carbon dioxide produced. No ion balance or foam production problems occur because the water is typically only held for 12 to 24 hours. The high rate of water turnover contributes to the robustness of this system but limits the scope of its application because it requires a lot of water at the proper temperature to operate successfully.

The Virginia Striped bass system was developed originally to support the production of striped bass. A favored food and sports fish, striped bass were once abundant along the East Coast. Fishing pressure plus habitat deterioration reduced the fisheries level to the point that it could not keep up with the market demand. An industry based primarily on pond culture of the fish sprung up and remains economically viable at this time. The illustrated recirculating system was used successfully to raise large numbers of striped bass but did not prove economically viable for that species. Similar configurations have been used successfully for the commercial production of channel catfish and tilapia, although the economic viability of the former has not been proven. This system illustrates the use of two classic technologies: a tube settler, which is a variation of a settling tank for solids capture and the rotating biological contactor, which is widely recognized as an effective biofilter. The research prototype and a notable million pound commercial version were driven by airlift pumps rather than water pumps. Even the large rotating biological contactors were turned by air rather than motors providing an elegant demonstration of this technology. This system employed pure oxygen injected through a "U-tube" system buried deep in the ground for aeration. Carbon dioxide stripping occurred in the cascading rotating biological contactor and the airlift pumps.


Photo courtesy of Mike Massingill, Kent SeaTech Corporation

The third system evolved on the West Coast in the highly urbanized environment of Los Angeles, California where space, water costs, and environmental regulations prohibit most aquaculture undertakings. The high price associated with ornamental fish allowed the development of cost-effective, computer-controlled systems capable of supporting millions of small fish. The core of the system is a large oversized fine sand-fluidized bed. It is operated to encourage the development of rich ecology of organisms encompassing not only bacteria but also protozoans, worms, and sometimes even snails. Solids capture is accomplished by a floating bead filter which is favored because its fine solids capture and stingy water loss during backwashing. A computer controls the injection of pure oxygen through an enclosed-packed column as feedback from probes placed both in the tanks and the biofilters indicate the need. A second packed column provides for stripping of carbon dioxide. The system represents an excellent example of effective use of process control. This

Table 4

Critical Process	Technology Employed			
	W. Virginia Trout System	Virginia Striped Bass System	California Tropical Fish System	Louisiana Tilapia System
Solids Capture	Microscreen	Tube settling basin	Floating bead filter	Floating bead filter
Biofiltration	Fine sand fluidized bed	Rotating biological contactors	Fine sand fluidized bed	
Aeration	Pure oxygen in a low head oxygenator	Pure oxygen with U-tubes	Pure oxygen in packed columns	Blown air through air stones
Degasification	Packed column and with air blown through air stones	Blown air in airlift pumps and cascading in the rotating biological contactor	Packed column	
Ion Balance	Turnover once a day	Turnover once a week	Turnover once a month Calcium chloride Sodium chloride	Turnover once a month Sodium bicarbonate Calcium chloride

of time the water is reused. Open recirculating systems are essentially modified flow-through systems equipped with solids capture and/or biofilters to minimize water or heating demands for a given production level. Closed recirculating systems reuse water for extended periods and thus, must extend the treatment train. Land-locked marine aquaria forced to reuse water for years must even address more subtle aspects of water reuse such as changes in ion balances.

Once considered an art, the design and operation of recirculating aquaculture systems are rapidly solidifying into a hard science. Recent scientific advances have led to a series of commercial ventures that have demonstrated the technological feasibility and sometimes economic viability of several reconditioning configurations. Whereas the issue a little over a decade ago was "if it could be done," debates now center on reducing costs of production and enhancing markets. Research efforts have clearly defined water treatments required for extended water reuse. Although this document will focus on fish production systems, the technologies described have application to the culture of many aquatic organisms. Commercial production of crustaceans (shrimp, crabs, lobsters), mollusks (oysters, clams, conch, abalone), reptiles (alligators, turtles) and amphibians (frogs) occurs. However, the wide variety of marine and freshwater fish cultured often dominates our thinking and writings. Here, the word "fish" implies consideration of a family of cultured organisms that falls outside the normal morphological bounds associated with the term.

System Design

The first step in developing a recirculating design is selection of the system's capacity. The system's capacity defines the maximum amount of fish that the system will hold, usually in pounds. This capacity defines the sizing of all the components in the system. The oxygen consumption rate and the waste production rates are driven by the poundage of fish. These rates can also be influenced by the rate of feed application since a heavily fed fish excretes more waste. Feed rates in commercial systems are usually proportional to the poundage of fish. A dry feed application rate of 1 to 2 percent of the fish body weight is widely assumed for food fish (catfish, tilapia, striped bass, redfish) at harvest size. Thus, the system capacity can be alternatively defined as pounds of feed applied per day. The two means of expressing system capacity are convertible through consideration of the feed percentage.

Design of a recirculating system is dependent on the integration of several units including the culture tanks, a recirculating pump, and a series of treatment components that are capable of operating together to recondition water in support of the designated fish load. The following sections highlight critical aspects of the sizing and design of these units. Additionally, four system configurations are described to illustrate the variety of approaches that can be successfully used provided due consideration is given to all the critical processes.

Culture Tanks

The most critical aspect of the culture tank design is the tank volume. The volume of water in combination with the amount of fish determines the system's stability. The design term used to size tanks is the density defined as the ratio of the weight of fish held in the tank to the system's water volume. The water volume used should include water held in the treatment components. Density values used for commercial applications range from 0.25 to 1.0 pounds of fish per gallon of water (lb/gal). Systems designed for fish densities at or below 0.5 lb/gal are generally considered stable. That is the operator has an hour or two to respond to a loss of aeration and about a day to respond to a biofilter failure before the fish are endangered. The response time for an aeration failure is controlled by how much oxygen is held in the systems' water and the rate at which the oxygen is being consumed by the fish. The latter is driven by the poundage of fish and the former by water volume in the system. Similarly, the accumulation of toxic compounds, such as

Table 1

Issue	Comment
Water Availability	Recirculating systems eliminate the need for huge quantities of water.
Regulatory Pressure (Environmental)	Recirculating systems can avoid or reduce permit requirements controlling solid, organic, and nutrient loads to sensitive receiving streams, lakes, or estuaries.
Quality Control	Recirculating systems facilitate quality control programs to address issues of off-flavor, size, product appearance
Climate	Heating costs are minimized with recirculating systems, expanding regions of participation and extending growing seasons.
Land	Recirculating systems dramatically reduce space requirements, reducing competition for land in sensitive wetland areas.
Disease	Disease isolation and treatment is enhanced with recirculating technologies.
Bird Predation	Severe economic losses due to predation by protected bird species can be avoided in a recirculating system.
Exotic Species	Recirculating systems provide an excellent format for the containment of regulated exotic species that can cause ecological damage if they escape

Photo courtesy of Mike Massingill, Kent SeaTech Corporation

ammonia, is driven by the rate of TAN production (pounds of fish) and the dilution potential (the water volume). Unstable systems, those approaching 1 lb/gal, have response times for oxygen measured in minutes. These systems must be monitored continuously and are normally equipped with computerized control systems. The assumed fish density is a critical factor, and its importance in the design process should not be underestimated.

Discussions of the advantages of different tank shapes are endless. It is widely recognized that tanks should be designed to assure good circulation, avoiding slack areas that will encourage in-tank settling of solids. Round tanks can be used with a circular water movement to move solids to the center of the tank, where they can be easily removed. Round tanks with a cone-shaped bottom function even better in this mode. However, round tanks make poor use of floor space. Some systems employ rectangular shaped tanks, using strategically placed airlift pumps or injection nozzles to assure solids movement. Others have advocated elongated raceways with rounded ends to assure good circulation. Virtually, any shaped tank can be made to work if the fundamental need for good circulation is addressed.

Recirculating Pumps

The first step in pump selection is the determination of the system's flow requirements. Recirculation rates are determined by the need to remove TAN from the culture tank or by the need to deliver oxygen to the biofilter. These flow requirements are nearly the same, ranging theoretically from 0.05 to 0.1 gpm/lb. In practice, commercial operators are sometimes able to run at rates as low as 0.025 gpm/lb. If the minimum flow rate needs of the system are not met, the system performance can be seriously impaired. For example, low flow rates can cause chronically high TAN levels in the culture tank while the biofilter is displaying complete TAN removal of the recirculating stream. High recirculation rates generally improve system performance, although the benefits diminish rapidly once the minimum flowrate requirements are met.

Low head centrifugal pumps are most often used in aquaculture applications. These pumps are designed to deliver large volumes of water at moderately low lifts. The lift of a pump is a measurement of the back pressure on the pump outlet during operation. It is measured as the height of water (feet) that would create an equivalent back pressure or directly in units of pressure (psi). Ideally, recirculating systems should be designed so that back pressure on the pumps is low, minimizing energy requirements. Centrifugal pumps capable of delivering flows at pressures of 20-30 feet of water (8-13 psi) are most frequently selected for large-scale recirculating applications.

Another approach to water circulation is the airlift pump. These simple pumps take advantage of the density difference induced when air is injected into a submerged vertical pipe to move water. Practical only at low lift heights (0-5 ft), airlift pumps are cost effective. Airlift pumps can move large amounts of water particularly at low lifts (0-2 ft). Their principal advantage stems from the fact that they contribute to the aeration and degasification capacity of the system. Additionally, airlift pumps are simple to maintain, containing no metal or moving parts, an important consideration in a wet environment. Because of their limited lift, airlift pumps are normally employed as part of an integrated design where all the components are designed to minimize head loss.

Table 2

Treatment Operation	Objective	Dominant Technologies
Solids Capture	To remove feces, uneaten food particles, and bacterial biomass	Settling Tanks
		Microscreens
		Granular Filters
Biofiltration	To removed dissolved organics and toxic nitrogen compounds	Rotating Bio-Contactors
		Fluidized Beds
		Granular Beds
Aeration	To replenish dissolved oxygen consumed by fish and bacteria	Air Stones
		Packed Columns
		U-Tubes
Degasification	To remove carbon dioxide produced by the respiration activities of the fish and bacteria	Packed Columns
		Air Stones
Ion Balance	To correct for changes in the chemical composition of the water which have an adverse impact	Flushing
		Chemical Addition
		Denitrification

Treatment Components

The major processes required to recondition water in recirculating systems have been identified (Table 2). The five major treatment processes: solids capture, biofiltration, aeration, degasification, and maintenance of critical ions must be addressed for a recirculating design to be successful. Recirculating system performance can be enhanced, or the length of time the water is reused extended, by addition of one or more of the optional processes (Table 3) which address specialized problems. Larger systems are also normally equipped with a backup generator or pure oxygen delivery system to support the fishes' oxygen demands during power failures. A computer is often utilized to automate and monitor some system operations.

The sophistication of the treatment block is largely controlled by water reuse. The term "turnover rate" is the most widely accepted measure of water reuse and is defined as the length of time required for the cumulative source water introductions to match the system's total water volume. Water introductions used intentionally to flush the system, to replace leaked waters, correct for spillage, or those dictated by system operation (losses due to backwashing or wash down) are considered in this calculation. Evaporative replacements are not considered since the critical ions and residual wastes are not removed by the evaporative process, and thus no net gain in water quality occurs.

As the water reuse intensifies with a declining water replacement rate, the complexity of the treatment train increases. The cost of treatment also rises, counterbalancing the benefits. Culture systems found in the US range in complexity from simple flow-through raceways where only aeration is provided, to virtually no discharge marine aquaria where even subtle shifts in trace elements are monitored. The balance between cost and benefits will most frequently dictate the turnover rate associated with "closed" recirculating systems. Generally, these systems address major waste fluxes while avoiding the long-term issues by allowing a slow water release at a rate of 2 to 10 percent daily (turnover rates of 5-10 days).

Successful Configurations

Table 4 summarizes the configuration of four successful recirculating systems employed in the US in recent years. All these systems are technologically successful. That is to say, they have been used to raise fish at high densities for extended periods. The cost effectiveness of the systems depends on value of the fish produced and the sophistication of the associated marketing effort. Examination of these systems reveals that each has addressed the need for solids capture, biofiltration, aeration, and degasification with an identifiable technology. All have employed water turnover to control the ion balance problem, and in some cases, as a means of reducing the cost of the water reconditioning technologies. Comments on each configuration are presented in the following paragraphs.

Table 3

Optional Technology	Description	Function
Foam fractionation	A tube containing air stones releases fine bubbles, which attract materials to their air/water interface, capture them, and float them to the surface where they form foam that can be readily removed.	Used to remove organic materials which are not easily attacked by bacteria which can form surfactants which cause foam build-ups. Also contributes to the control of fine solids (<10 microns) which are incidentally removed.
Ozonation	Ozone (O_3), a powerful chemical oxidant is generated by an electrical arc which passes through an oxygen enriched atmosphere. The unstable ozone molecules are introduced into the water through an air stone or venturi, where they rapidly react.	Primarily used for disinfection or color control. An effective oxidant, ozone will directly breakdown most organic material in the water, particularly the non-biodegradable organics which contribute to yellowing of the water. Also a very effective bactericide, but which can be toxic to humans and fish if not properly used.
UV Lights	Water is passed by a specially designed light bulb which produces light enriched in the dangerous UV wavelengths. This light destroys proteins in cells, scrambling RNA and DNA, thus killing bacteria, algae, protozoans, and some viruses.	Used for disinfection of recirculating waters to control disease outbreaks and algae.
Denitrification	A specialized class of bacteria operates under anaerobic conditions to convert nitrate to inert nitrogen gas usually in a submerged packed column or fluidized bed.	Used to remove nitrate accumulations also neutralizes the acidification effects of the nitrification process replenishing depleted alkalinity.