Aquacultural Engineering Society News

AES News, Summer 1998, Vol. 1, No. 2

'98 Recirculating Aquaculture Conference a Huge Success

Virginia Tech and the AES (among others) hosted the *Second International Conference on Recirculating Aquaculture*, July 16-19 at the Hotel Roanoke Conference Center in Roanoke, Virginia, USA. This '98 Conference was a huge success, and might well have been the best meeting yet to focus on recirculating aquaculture. The Conference featured presentations by national and international experts in all aspects of recirculating aquaculture, a strong trade show of 34 vendors, and a healthy mix of aquaculture producers, industrial suppliers, and academics. Attendance reached 500. More than 100 attendees traveled to Roanoke from outside of the U.S., representing 22 countries.

On Friday and Saturday, the Conference featured a trade show and three concurrent sessions of invited speakers, reviewing:

- Isolation and Quarantine
- Small Scale Systems
- Feeds for Recirculating Systems
- Automation
- Waste Management
- Biofiltration
- Business Management
- International Recirculating Systems
- Coldwater Aquaculture
- Aquatic Animal Health
- Denitrification

The AES also held a one-day session of contributed engineering papers on Saturday.

Papers of invited presentations and abstracts of contributed AES presentations are available in a 409 page proceedings. The Proceedings are available on CD-ROM ($10 or $15 for US or international orders, respectively) and as a paperback hardcopy ($47.95 or $52.95 for US or international orders, respectively). To order a copy of the '98 Conference Proceedings, please contact Ms. Terry Rakestraw at 540-231-6805 (ph) 540-231-9293 (fax), or rakestra@vt.edu (e-mail).

As during the First Conference on Recirculating Aquaculture (held in 1996), the 1998 conference organizers and the Hotel Roanoke provided an unsurpassed combination of fine food, lodging, and hospitality. The '98 Conference was largely organized and facilitated by Dr. George Libey (AES Member), Dr. George Flick, and other faculty and staff at Virginia Tech; their efforts are appreciated.

Inside:

Letter From Your President

The Aquacultural Engineering Society sessions continue to draw crowds as demonstrated by the attendance during the technical presentations at the *Second International Conference on Recirculating Aquaculture*. At that meeting, past AES president Dr. Fred Wheaton delivered the opening plenary address and the AES organized two half-day sessions on advances in biofiltration and feeds for recirculating systems.

AES past president Dr. Raul Piedrahita is currently coordinating our involvement in the upcoming *Aquaculture Europe '98* conference to be held in Bordeaux, France, October 7-10, 1998.

Our next U.S. meeting involvement will come January 27-30, 1999 at the World Aquaculture Society's *Aquaculture America '99* conference in Tampa, Florida. At that meeting, AES president-elect Dr. Tom Losordo will begin his one year term.

Have a good summer and fall. If I don't see you in France, I will catch up with you in Tampa.

Dave Brune,
AES President

Elsevier's Journal Aquacultural Engineering

We have begun shipping the 1998 *Aquacultural Engineering* journals to our journal receiving members as they arrive. Aquacultural Engineering volume 18, nos. 1 - 3, have already been shipped. The AES will mail the remaining 1998 journals to our journal receiving members as they arrive. Thank you for being patient.

Recirculating Aquaculture Production Systems: The Status And Future, Part II

By Thomas M. Losordo • North Carolina State University

THE STATUS OF TANK-BASED PRODUCTION TECHNOLOGY

In Part 1 of this three-part series, I endeavored to highlight important considerations and clarify some common misconceptions about recirculating aquaculture production systems technology. In Part II of this series, I will try to describe the status of recirculating systems technology in North America and Europe. Where possible, I will provide some examples of these technologies that are currently producing aquacultured products in a commercial setting. Keep in mind, many of the commercial systems being used today are considered as proprietary designs by their owners and in many cases we were not able to get permission to include detailed information about these systems.

Recirculating systems being used today fall into two general broad categories: 1) Industrial scale systems, usually housed in warehouse structures and 2) smaller agricultural barn or greenhouse type systems. There are however, crossovers between these two categories. That is, there are numerous examples of greenhouse-based systems that are industrial scale.

INDUSTRIAL SCALE SYSTEMS

In recent years a number of very large scale operations have come into existence. In most cases these production units are housed in large, open warehouse type structures. These systems are usually owned by corporations that are seeking to become a major force in the (fish) market-place with large quantities of product available on a year-round basis. These industrial scale facilities have also sought to reduce capital costs and the cost of producing fish by taking advantage of the "economy of scale." Examples of industrial scale facilities in the United States include projects by AquaFuture in Massachusetts (Hybrid Striped Bass & Tilapia), BioSheter in Massachusetts (Tilapia), AquaMar Industries in Maryland (Tilapia), Integrated Foods Technologies in Pennsylvania (Hybrid Striped Bass & Tilapia), Blue Ridge Fisheries in Virginia (Tilapia), MinnAqua in Minnesota (Tilapia), Fish-N-Dakota in North Dakota (Tilapia), Archer Daniels Midland in Iowa (Tilapia), Sierra AquaFarms in California (Sturgeon), and Solar AquaFarms in California (Tilapia). In the past 5 years, the two industrial scale facilities that have ceased operation include Natures Catch in Kentucky (Hybrid Striped Bass) and J.R. Simplot in Idaho (Tilapia). On a similar scale, but in the out-of-doors, Kent SeaFarms (J. Carlberg, pers. comm.) of California operates a tank based system as the largest producer (> 3 million pounds in 1997) of hybrid striped bass in the United States. While Kent SeaFarms began operation as a flow-through system with water recirculation only for oxygen addition, technological innovations now recycle and treat the water so that only 25% of the total farm volume is replaced per day. With a recycle flow rate of 25,000 gpm, Kent SeaFarms water treatment includes tilapia culture for solids reduction, large scale nitrifying reactors, and constructed wetlands for polishing.

AquaMar Industries provides a good example of industrial scale recirculating systems in the USA.

AquaMar Industries, Inc.

AquaMar Industries of Pocomoke City, Maryland began operations in 1987 as a startup aquaculture company and is a good example of "growing a business" based on in-house R & D while minimizing debt. Jerry Redden, General Manager provided the following description of their operation (J. Redden, pers. comm.). The AquaMar growout units are housed in a 188' x 120' steel warehouse type of structure. The growout system consists of eighteen 30,000 gallon raceway tanks with an individual water treatment system for each tank. Mr. Redden considers details of the treatment system as AquaMars proprietary design. Aeration to the culture system is provided by both low pressure air and diffusers and pure oxygen gas. While the AquaMar growout system has over 540,000 gallons of fish culture volume, the system discharges only 3,000 gallons of wastewater per day. The AquaMar system requires three full time individuals (120 person-hours per week) to operate the facility. In addition, Mr. Redden serves as full time Managing Partner and AquaMar employs a full time secretary. With a production rate of 25,000 - 35,000 pounds per month of 1.25 to 1.5 pound tilapia, total production cost including debt service is estimated at $1.10 per pound. All of the product is sold live from their Delmarva Peninsula location into the northeastern markets of the United States. AquaMar has plans to add another production building which is expected to boost production by 60,000 pounds per month. Mr. Redden expects production costs for the combined facilities to drop to approximately $0.85 per pound.

European Industrial Scale Systems

Examples of industrial scale recirculating systems in Europe include carp culture in Germany, eel culture in Denmark and the Netherlands, sea bass fingerling culture in Italy, Greece, France and Spain, and salmon fingerling culture in Scotland and Norway. In Europe, the salmon industry is upgrading flow through salmon fingerling production facilities with recirculating technology to conserve heat and increase growth rates, intensifying production systems, conserve fresh water supplies, and meet tightening environmental discharge restrictions. A good example of this can be found in Scotland where Finfish Limited (S. Edwards, pers. comm.; I. Schei, pers. comm.) has recently installed a new indoor tank system to rear fingerlings up to 10 grams. The Finfish Limited system recycles water only to add supplemental oxygen to reduce new water flow requirements and increase stocking capacity. A heat pump is used to extract waste heat from the systems outflow. The system hold up to 375,000 fingerlings at densities of 1/2 pound per gallon of tank volume (62,000 lbs total) in eight 9,000 gallon tanks that have integral particle traps and sludge collectors to capture fish waste and uneaten food. The particle traps clean the effluent before being discharged to the environment and reduces the ammonia buildup in the tanks which reduces the flow-through requirements of the system.

In the European aquaculture industry, eels have been produced in recirculating systems for decades. A typical configuration of equipment that has gained favor with Northern European eel growers is shown in Figure 1. Water leaving the culture tanks flows by gravity through a drum screen filter. The screen cleaned water is then pumped from a sump though a non-pressurized biological filter and collected in another sump. This water is adjusted for pH and alkalinity then pumped through a high pressure oxygen contact cone. In one popular configuration, the water from the drum screen filter passes up through a submerged fixed media filter and overflows to a traditional non-submerged trickling filter adjacent to it (Figure 1). In some cases a side-stream flow is pumped through a denitrification reactor to convert nitrate-nitrogen to nitrogen gas that is then liberated from the water with aeration or agitation.

It is important to point out that when reading international trade journals and other publications, the terminology used to describe recirculating systems is often quite different between the United States and Europe. In the U.S., a 90% recycle system refers to a system where 90% of the water is retained on a daily volumetric basis and only 10% of the system volume is replaced per day. In Europe, however, a 90% recycle system refers to a recycle flow rate of 90% with 10% of the total flow rate being new. With this terminology, a system with 100,000 gallon of culture tank water volume and a total flow rate entering the culture tanks of 1,666 gallons per minute (a 60 minute exchange rate for the tanks) the new water entering the system (ie. makeup water) would be 166 gpm and the recycled water would be 1,500 gpm. With this new water flow rate, the total volume of the system would be replaced 2.4 times per day (240,000 gallons rather than 10,000 gallons per day with the U.S. terminology).

AGRICULTURAL SCALE SYSTEMS

Across the United States and in Europe, there are hundreds of agricultural scale aquaculture production units based on recirculating technology. These systems are usually operated as small or family based businesses. Production capacity is usually less than 250,000 pounds per year and rarely are any two technologies similar. The intensity of production varies widely from less than two tenths of a pound of fish per gallon of water for some hydroponic based systems to one pound per gallon for systems utilizing pure oxygen gas for aeration. In North America, a few examples of these production systems include: Northern Tilapia of Ontario Canada, AquaMana of Indiana, Dakota Fish-N-Fillet in North Dakota, Til-Tech Aquafarm, Inc. in Louisiana, and Maryland Pride Farms of Maryland. Northern Tilapia and Dakota Fish-N-Fillet are good examples of this scale of production.

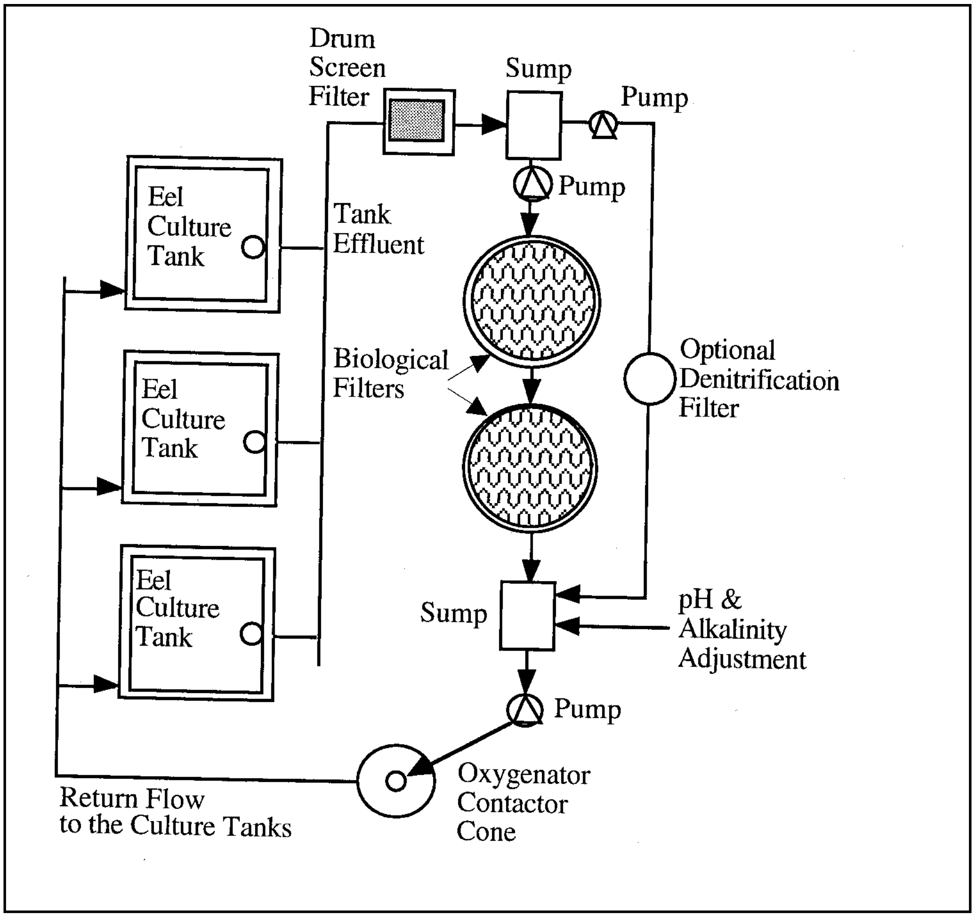

Figure 1. Plan view of a popular eel culture system layout used in Europe.

Northern Tilapia, Inc.

Northern Tilapia, a "small business" owned by Gary Chapman (G. Chapman, pers. comm.) in Lindsay Ontario, operates a tilapia hatchery and growout system. The growout system is located in a greenhouse and consist of four 10,000 gallon circular fish culture tanks. The recirculating system design is based on a prototype developed at Cornell University. The fish culture tanks are fitted with simple double drains that allow for the collection of settleable solids within the culture tanks. These solids leave each culture tank in a flow that equals approximately 25% of the total flow leaving the tank and are removed (collectively) by a single drum screen filter (Figure 2). The clarified water is pumped to downflow bubble contact reactors for oxygenation with pure oxygen gas before returning to the culture tanks. Water from the upper standpipe entrance in each culture tank is pumped to packed column aerators to remove carbon dioxide from the water. This water falls onto the top of two 4 foot diameter downflow polystyrene floating bead biological filters. These "micro-bead" filters are located adjacent to each culture tank and overflow directly back into the fish culture tanks.

Northern Tilapia stocks the growout tanks with advanced fingerlings (approximately 1/4 pound, 100 grams) and harvests between 5,000 and 7,000 pounds of market sized (1.3 - 1.5 pound fish) tilapia from one of the four tanks every

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Recirculating Aquaculture Production Systems: The Status And Future, Part II

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month. In its first year of operation Northern Tilapia harvested over 60,000 pounds of fish in 9 harvests. Annual harvests from these four tanks are expected to reach 85,000 pounds in 1998. Northern Tilapia markets live fish to distributors in Canada.

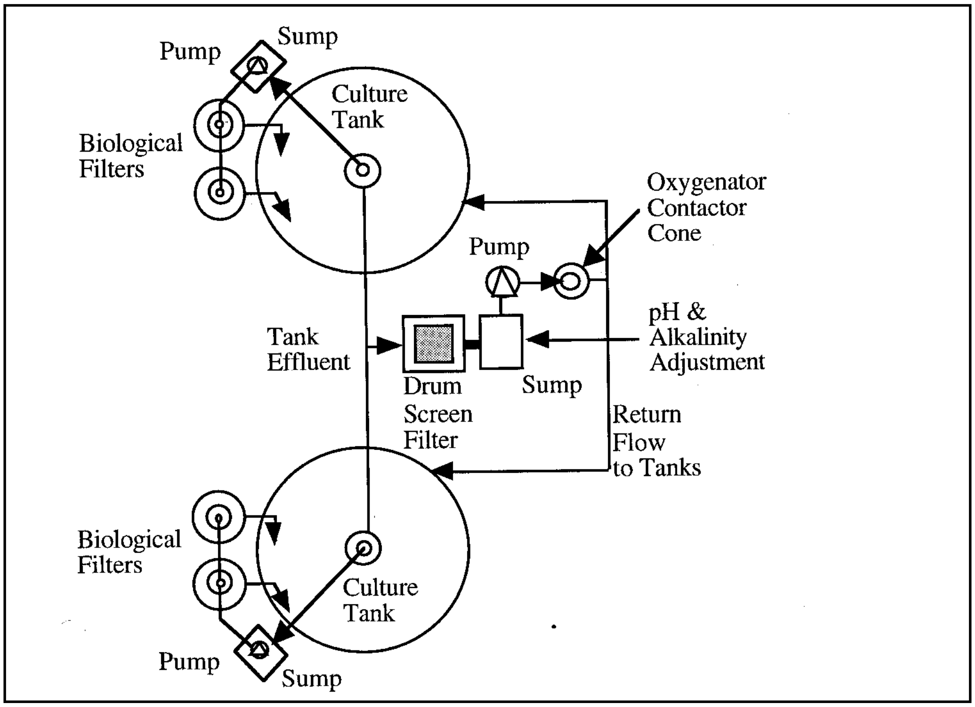

Figure 2. Plan view of a recirculating system design used by Northern Tilapia and developed at Cornell University.

Dakota Fish-N-Fillet

Dakota Fish-N-Fillet was started in 1991 by Mark and Nicki Willows (M. Willows, pers. comm.) in Binford North Dakota. The tank system, water treatment system, unique coal-fired heating system and office are housed in a rebuilt lumber yard building measuring 148' x 56'. Being a newcomer to the industry in 1991, Mark relied on the design services of a consultant for the development of his system. The Dakota Fish-N-Fillet system consists of two 6,500 gallon tanks and eight 10,000 gallon circular galvanized steel tanks with plastic liners. The smaller tanks are used as nursery and harvest / holding tanks and the larger tanks are for growout. All of the water from the culture tanks flows to one common water treatment system. Solid wastes are first removed by a large "tube-type" settling basin. Water is pumped by two 7.5 hp centrifugal pumps with the flow split between a closed circuit loop to three large trickling filter towers and a downflow bubble contactor oxygenation reactor. The water from the oxygen contact unit returns to the fish culture tanks. Additionally, a mixture of air and ozone are added to the culture tanks directly with air diffuser stones. The design production capacity of the system was 100,000 pounds annually. In actual operation, monthly harvests have ranged from 5,000 to 10,000 pounds with the highest annual production to-date reaching 80,000 pounds live weight. Dakota Fish-N-Fillet estimates that their cost of producing tilapia has ranged from $0.73 to $1.10 per pound depending on feed and fingerling costs and the associated growth rate of the fish. This cost of production includes interest payments on loans but does not include loan principal payments or a salary for management. The Willowses operate the facility as a family business with outside help from two high school students for monthly harvesting activities. Mark Willows has found that not all fingerlings or feed are created equal, noting that his success in producing fish quickly and economically varies with the varying quality and cost of each. Dakota Fish-N-Fillet markets their fish live through the North American Fish Farmers Cooperative in which Mark is the marketing manager. The price to the farmer, FOB farm-gate, has ranged seasonally from $1.25 to $1.80 per pound.

RECIRCULATING TECHNOLOGIES AND LAYOUTS

There are many technological commonalities between the recirculating production systems being used today. As described in Part I of this series, a number of processes must be addressed in water treatment in order to grow fish in recirculating systems (see Figure 1 of Part I in AES News, Vol. 1, No. 1). Configuration of the components, materials used for construction, feed or fingerlings used, and the skills of the operator is what causes each system to be unique. Common to all cost-effective systems is either reasonable capital investment with respect to productive capacity or low operating costs while maintaining consistent productivity, or both.

Production systems utilize round, semi-square, or rectangular tanks. Tank materials include concrete or concrete block, fiberglass, glass-coated steel, galvanized steel, or plastic liners supported by a wooden or steel frame. Waste solids removal is usually accomplished with some form of gravity settler (settling basin, or swirl separator), a drum screen filter, or a granular media filter. Ammonia is almost always "removed" (converted to nitrate) with a biological filter. Some agricultural scale greenhouse systems use plants to remove ammonia, nitrite and nitrate-nitrogen. In larger scale systems using plants as filters, a biofilter is used in combination. To date, no systems have proven commercially viable with ammonia removal provided by ion exchange.

Biofilter configuration and the type of biofiltration media used has a major impact on the capital cost, energy utilization, and operational characteristics of recirculating systems. Trickling filters tend to be expensive to build due to the high cost of rigid fixed media and the relatively large volume of media needed due to the low specific surface area of the filter media. Trickling filters, however, are very stable and dependable biological filters. Fluidized bed filters, utilizing sand as a biofiltration media, usually require less capital investment and less space, but require more energy to run and can lose sand media if not properly designed or operated. Rotating biological contactors (RBCs), while biologically very stable, are even more expensive than trickling filters and have been prone to mechanical failures if not properly designed. In the late 1990's a new "breed" of biofilters began to appear in aquacultural uses. These filters are often referred to as “mixed bed reactors.” All of these filters have the common feature of a moving bed of particles used as biofilter media. These filters differ in their size, shape and density of the media and how the bed is mixed. Mixed bed filters are different from the typical fluidized bed reactor because the media (not being sand) usually requires less energy to be kept in motion and can be mixed mechanically, hydraulically, or with air.

Aeration in systems with fish culture densities less than 1/3 pound per gallon of culture volume is usually accomplished with atmospheric oxygen (air). In systems with fish culture densities in excess of 1/2 pound per gallon of water, pure oxygen is used. Aeration is usually accomplished with blown air and air diffusers in the culture tank when air is used. Pure oxygen gas is most often added to the flow stream returning to the tank with some form of contact unit (u-tube, downflow bubble contactor, packed column, low head oxygenator) with 70+% efficiencies being achieved (oxygen dissolved / oxygen used). In shallow, less than 7 foot deep water columns, oxygen can not be dissolved efficiently in water with even expensive fine pore diffusers placed at the bottom of the culture tank.

COMMON PROBLEMS IN THE INDUSTRY

Biosecurity

An increasingly more common problem facing the recirculating tank-based aquaculture industry today is one of disease control. In current recirculating production systems, it is common for several tanks to be run off of one water treatment unit. Notable financial losses have resulted from entire facilities using a common treatment system with no way to contain disease outbreaks. In many systems where there are individual water treatment units, often there is little physical separation of the tanks within the fish culture area. In this type of layout, it is imperative that some form of quarantine unit be used in conjunction with the growout system. The quarantine unit should not have any connection with the main production facility such that liquid or aerosol cross contamination can occur. Intensive live stock agricultural production systems routinely utilize strict biosecurity procedures. Separate hatchery and nursery facilities and restricted access to growout units with “shower in / shower out” protocols have provided a level of disease control not routinely seen in the fish production business. As production culture intensities increase in the future, and more diseases begin to appear, biosecurity will become a essential part of intensive production systems.

Production Cost vs. Market Price

Over the past 10 years, millions of dollars have been lost on indoor fish farming. In the worst cases, individuals have lost their entire “life savings.” Even though a production systems may be technologically sound and properly operated, excessive capital investment and / or cost of operations did not allow them to be profitable in today’s marketplace. Keep in mind, as the aquaculture industry grows, prices tend to fall not rise in the long term. Before investing in recirculating systems technology, a sound business plan that reflects realistic pricing for the crop you want to grow is essential. Data used in this plan should come from a system that has growout units of similar or larger scale of those being proposed. Several times a month, this author is approached by people who share the vision that recirculating systems will play a major part in aquculture’s future. Often they are considering buying a “turn-key” system. My advice is generally the same. Learn all you can about the aquaculture business and the system you are planning to use / buy. Visit as many operating sites as you can, but most especially the site of the person or company offering you their system. At best, you will see a business plan with actual capital and operating expenses. At the very least, you should ask to see records or invoices of feed purchases and fish sales for a period of not less than one year. As a minimum, this data will tell you the productive capacity of the system and allow you to calculate the feed conversion ratio attained. If these data are not made available, you should ask why not.

A VIEW OF THE FUTURE

Aquaculture based on recirculating systems is still going through “growing pains.” Despite the warnings sounded in this article, the author remains optimistic about the future of aquaculture based on water reuse technology. There is not a single best way to raise aquatic crops in tank based production systems. However, there are successful production operations ongoing in the United States and Europe. As we learn more about each unit process required to renovate the water being recycled (ie: solids removal, ammonia removal, denitrification, oxygenation, CO_2 removal, disinfection), the efficiency of each process should increase. Increased efficiency should lead to reductions in component sizing and associated reductions in water flow (pumping energy) for each process. Continuous development and improvements in technologies are making recirculating systems more reliable. With a larger domestic market, local manufacturing should reduce the cost and increase the variety of the components and supplies available for the creation of cost effective production systems.

With the ability to maintain optimum water quality and temperatures year-round, improved feeds and genetic stock will lead to significant reductions in the time and costs required to grow aquacultured products.

REFERENCES

James Carlberg, Executive Vice President, Kent SeaFarms Corporation, 11125 Flintkote Ave., Suite J, San Diego, CA 92121, USA, Personal Communication.

Jerry Redden, General Manager, AquaMar Industries, Inc., 1945 Pocomoke Beltway, Pocomoke City, MD 21851, USA, Personal Communication.

Stuart Edwards, Manager, Fishfish Limited, Inverpolly, Ullapool, Ross-shire, 1V26 2YB, Scotland, UK, Personal Communication.

Idar Schei, Managing Director, AquaOptima AS, Pir-Senteret, 7005 Trondheim, Norway, Personal Communication.

Gary Chapman, Owner, Northern Tilapia, Box 37, Bond Head, Ontario L0G 1B0, Canada, Personal communication.

Mark Willows, Owner, Dakota Fish-N-Fillet, RR 1 Box 14BB, Binford, ND 58416, USA, Personal communication.

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RECIRCULATION IN PHOTOSYNTHETIC AQUACULTURE SYSTEMS

By David E. Brune and Jaw-Kai Wang

AQUACULTURE POND CAPABILITY

Within the last thirty years, U.S. aquaculture production has grown from a farmgate value of around $100 million to a value approaching 1 billion dollars (USDA, 1997). Pond production continues to dominate aquaculture production. Pond-reared catfish account for nearly half of the total U.S. aquaculture production, with the majority of this production emerging from four states — Mississippi, Alabama, Arkansas, and Louisiana.

Within these same three decades pond culture practices have undergone major change. The industry's demand for water has been the driving and shaping force for pond aquaculture. Mississippi dominates pond fish culture because of the availability of large volumes of shallow groundwater in the Mississippi Delta region. However, even in Mississippi, the availability of water and land suitable for pond aquaculture continues to diminish. As a result, the farmers have been under continuous pressure to intensify production.

In the early days production was limited to the biomass that wind-driven re-aeration could support, calculated to be approximately 1300 lbs/acre (Drapcho and Brune, 1989, 1993). In the late 50s, Auburn University was recommending catfish farms target harvests at around 1300 lbs/acre (Stickney 1996). In 1969, industry-wide catfish production averaged 1100 lbs/acre with a total production of 44 million lbs with the best managers routinely achieving 1500 lbs/acre. The 1997 production was recently projected at 520 million lbs on 164,000 acres of ponds for an average farm production of 3200 lbs/acre (USDA, 1997). Well-managed farms are estimated to be producing 4000-5000 lbs/acre (Tucker, et al., 1991).

To achieve these increased carrying capacities, producers first added emergency aeration, then routine nightly aeration, and in some cases of very high carrying capacities (in particular, shrimp culture systems) 24-hr aeration. One to two hp per acre aeration is now standard practice in the industry. Occasionally, farmers will report 7000-8000 lbs/acre of production, with researchers sometimes achieving as high as 12,000 lbs/acre (Avault, 1980). However, pond production in excess of 5000 lbs/acre, which corresponds to peak feed applications of 80-100 lbs/acre, is not routinely successful. Even if oxygen needs are met at these levels, total ammonia concentrations often reach limiting or toxic levels.

Algal "bloom and crashes" are often observed at these high carrying capacities. This situation tends to lead to a succession of algal species, in particular dominance by blue green algae. This can result in a undesirable "off flavor" produced by an unwanted algal population dominating the pond, causing the flesh of the fish to have an unacceptable taste and odor.

POND LIMITATIONS AND RECIRCULATION

Can pond fish production be increased beyond what has been achieved without requiring additional water resources or producing additional environmental impact? This question can best be addressed by understanding the fundamental limitation of the aquaculture pond. In a raceway the fish carrying capacity is ultimately limited by the accumulation of toxic metabolites, such as NH_3 and CO_2, distributed into the water flow. If the water is to be used for additional fish culture, then specific waste treatment processes must be added to the flow path to remove the limiting metabolites. In contrast, in pond culture, the pond is both the waste treatment process and culture containment.

The basic treatment process of the pond is algal photosynthesis. While some effort has been made to eliminate algal growth to encourage other treatment processes, such as nitrification or NH_3 volatilization, most successful pond culture practices continue to be tied to management of highly eutrophic "green water" systems. The algal growth observed in ponds receiving the typical maximum feed application rate of 80-100 lbs/acre/day rarely exceeds sustained fixation levels 1-3 gm C/m^2/day (Brune 1995). In contrast, high rate algal production ponds are routinely operated at sustained levels of 6-12 gm C/m^2/day. Algal production systems are designed to maintain uniform water velocities throughout the culture volume. This ensures that no horizontal or vertical stratification occurs. Therefore, 100% of the water column is utilized. In addition, the algal cell population is maintained at a young cell age (1-2 days), either through direct harvesting of the algal biomass or by control of system hydraulic detention time.

These observations suggest that the pond treatment capacity, and therefore fish carrying capacity, can likely be increased three- to four-fold by reconfiguring the pond to maintain a uniform velocity and mixing profile throughout the entire pond. Creating a velocity profile in the pond allows the different processes occurring in the pond – fish culture, solid waste removal, algal harvest, and gas exchange – to be compartmentalized into a series of processes subject to more control by the operator, with enhanced reliability and predictabilty.

To-date, the development of pond aquaculture has paralleled developments in other fields of agriculture, a trend resulting in the need for increasing productivity, less labor, more automation, and more process control with a higher degree of reliability and consistency of production. The social and market forces driving these changes are likely to intensify. We can expect future pond aquaculture to move from "farming" the waters to true production systems in which manipulated "ecosystems" (the fish pond) are redesigned into a series of more controllable fish production and waste treatment processes. The major counter-balancing force will be the need to constrain costs.

One of the simplest and least expensive techniques to increase aquaculture production efficiency is to crowd the aquatic animals into a confined space, column, tank or raceway, while connecting this raceway to the bulk pond with a low head, high-volume, controllable water mover establishing a uniform pond water velocity. The entire pond/fish culture process when flow stabilized is subject to computer control and adjustment. By controlling the water velocity across the fish, a more uniform water quality can be maintained for all fish. With the fish confined to raceways, fish predation can be eliminated, and fish feeding efficiency is improved since feed is not lost to the pond. Furthermore, the operator can better observe the feeding behavior of the fish, and if necessary, chemical treatment of confined fish in a smaller volume of water is easier and more economical. Labor requirements for harvesting, sorting and inventory of fish are significantly reduced.

By maintaining a uniform slow velocity in the pond, the photosynthetic capacity and therefore waste treatment capacity can be vastly improved. Water movement ensures that 100% of the pond volume, surface area and depth are utilized.

Recent work has demonstrated that under tropical conditions, where year round algae and animal production can be maintained, the bulk photosynthesis of the pond can be achieved in marine shrimp/algal tanks, and the fish component can be replaced by fluidized oyster columns (Wang and Jakob, 1991). In this system, the shrimp tank is also the algae culture tank. The waste management takes place in the shrimp/algae tank, while circular water movement in a tank with a center drain allows settleable waste to be removed. The algae remove the dissolved waste, while the oysters remove the algae.

In a fluidized packed oyster column, the oysters are suspended individually in a stream of high-velocity water pumped from the shrimp pond. An integrated oyster/shrimp production system utilizes the fluidized bed technology to produce bivalves, such as oysters and clams. The bivalve production is combined with shrimp production to form an integrated shrimp/algae/oyster process that uses shrimp pond water to produce marine diatoms, which in turn, are used to feed the oysters, thereby, eliminating food costs for oysters while simultaneously reducing the shrimp pond effluent management problem.

THE CLEMSON PAS: FIELD EXPERIENCE WITH POND RECIRCULATION

Researchers at Clemson University have demonstrated that current industry pond fish production of 5000 lbs/acre can be increased to 14,000 lbs/acre through the use of a new technique known as the Partitioned Aquaculture System (PAS) (Brune et al., 1997). The PAS concept has been studied and developed at Clemson University since 1988. The basic premise of the system is physical separation of the fish culture unit from the wastewater treatment unit to facilitate better management of both fish production and waste removal and treatment (Figures 1 and 2). In the PAS design, the ponds are configured into a long, narrow channel to allow for the maintenance of a uniform and controlled water velocity throughout the pond. This configuration has been used by sanitary engineers for wastewater treatment in a system referred to as an algal oxidation ditch. It also has been used for the high-rate production of algal biomass. This system couples high density raceway culture of fish with paddle-wheel driven high-rate algal growth basins for treatment of ammonia and organic wastes, allowing 100% reuse of culture water in self-contained, self-oxygenating culture units (Drapcho, 1993). The water flow through the raceway and algal oxidation ditches is maintained with a low head paddle-wheel circulation device operating at 1.5 to 3 rpm. In addition, a settling basin is located at the outlet of the raceways to capture and concentrate fish waste for removal from the system.

The PAS technology builds upon the largest and least expensive production technology in the U.S. – earthen pond production – most typically used for channel catfish production. It incorporates and maximizes the best features of earthern ponds, while simultaneously reducing some of the problems of typical pond systems.

Since algal growth cannot be excluded from a fish pond, the PAS has been designed to optimize and control the algal growth. The action of the driving paddle wheel results in slow and constant mixing of the pond water, which ensures better distribution of nutrients and light in the water column. The primary advantage of this configuration is that the uniform mixing allows for efficient growth of algae in the pond. It also reduces the swings between algal blooms and crashes resulting from the algal population exceeding levels that can be supported by nutrient inputs from the fish feeding. Research to-date suggests that an additional

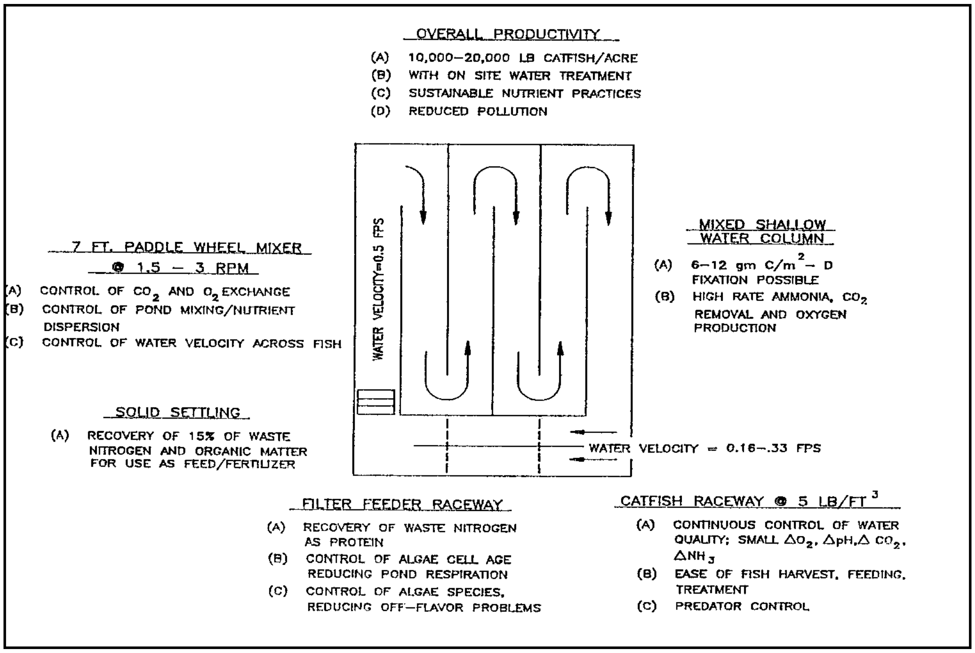

Figure 1. Schematic representation of the Clemson partitioned aquaculture system.

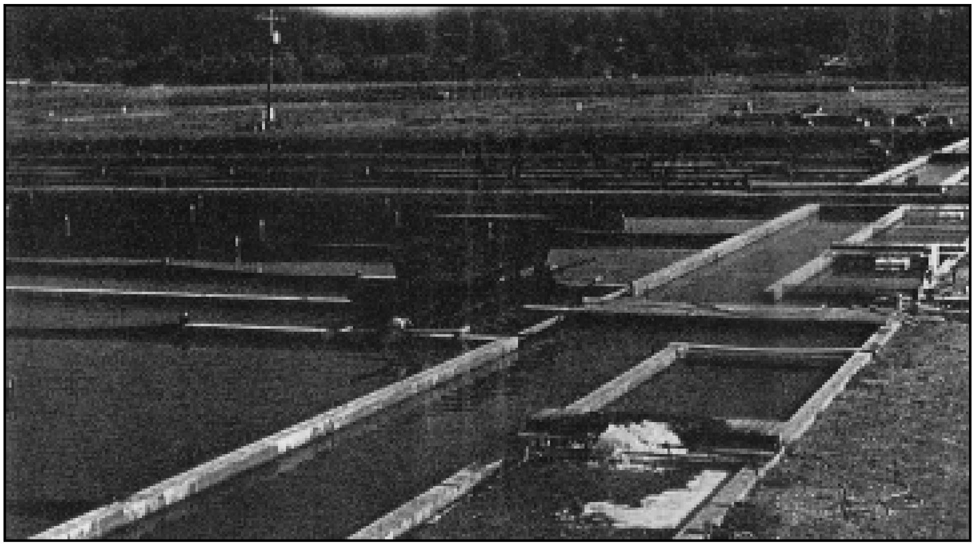

Figure 2. Fish raceways and paddlewheels in the Clemson partitioned aquaculture system.

increase of production to 20,000 lbs/acre may be possible by coupling the fish/algal system to co-culture of filter-feeding organisms such as tilapia (*Oreochromis niloticus)* and utilizing multiple stocking/ harvestings per year.

The PAS concept offers several advantages over the existing culture technologies with regard to algal management. Since the filter feeding fish which consume the algae are held separately from the bulk pond water, there can be more control of the growth rate and productivity of the algal biomass. During the 1997 season, algal photosynthesis was stabilized at levels of 50 mg O_2/liter/day net light bottle using tilapia co-culture, resulting in constant chlorophyta algal densities of 15-20 cm secchi disk. Blue green algae were excluded from the units as a result of the high algal grow rate and short algal cell age.

A second major advantage of controlling water velocity in the pond is its allowance for control of the gas exchange rates in the pond. By decreasing the water velocity during the day and increasing the water velocity at night, it is possible to minimize oxygen loss from super-saturated levels as a result of algal photosynthesis during the daylight hours. At the same time maximizing reaeration of the water column at night, which is necessary to compensate for algal respiration that occurs in darkness. One of the most important aspects of the PAS operation is that water velocities are computer controlled. The water quality is continuously monitored by electronic sensors. This information is, in turn, inputted to a series of computer algorithms, which send commands to the paddlewheel to change water speeds as required to optimize pond oxygen levels. Such fine management is not possible by human control. Furthermore, settleable solid wastes are collected in a sump, rather than being deposited in the pond. The collected solids become a concentrated source of phosphorus and nitrogen-rich fertilizer for land crops requiring only small water removal from the system. Therefore, the recirculating PAS does not require significant amounts of makeup water beyond the normal volumes needed to meet evaporation and seepage losses, and produces no discharge to surface water.

Additional advantages are derived from confinement of the fish in a more manageable area: the culturist can control the environment; accelerate growth rates; supplement oxygen levels; manage water quality; maximize feeding and improve feed conversion; treat disease and control parasites; eliminate predation by birds; and easily manage fish size with grading, transfer, and harvest operations.

In typical pond aquaculture, only about 25% of the protein nitrogen in the feed ultimately become fish biomass. The remaining 75% of the nitrogen in fish feed is lost through denitrification, seepage to groundwater, ammonia volatilization, or is discharged from the facility and becomes a pollutant in local surface or ground waters. Most aquaculture facilities are already facing limits on water use and discharge. The PAS approach offers the potential to significantly reduce these problems, provide increased yields, and increase nitrogen recovery through recycling of nutrients.

THE UNIVERSITY OF HAWAII INTEGRATED OYSTER/ALGAE/ SHRIMP RECIRCULATING PRODUCTION SYSTEM

Integrating two distinctively different aquaculture production components is not a simple matter. There are fundamental discrepancies among the environments required for the production of oysters, shrimp, or algae. In an integrated oyster/ shrimp recirculating production system, it is essential that the demand for resources by both oysters and shrimp remain constant. Additionally, the effluent discharge from the fish tanks must equal that which can be handled by the oysters in the system, and that the nutrients added by the shrimp feed must equal the nutrient demand by algae/oyster growth.

It is therefore important for the components in an integrated production system to be operated as close to steady-state, as possible; that is to say, the demand for resources and the discharge of waste must remain balanced. This steady-state concept is fundamental to the design of an integrated production system. It implies that if oysters and shrimp are to be produced by an integrated system, then the biomass of both the shrimp and oysters within that system must remain constant.

For example, if shrimp require 120 days to grow to market size, and a culture system contains 120 shrimp tanks, and there is one shrimp in each tank, and one shrimp is harvested and re-stocked every day, the shrimp bio-mass in the production system will be nearly constant. This can also be done with the oyster production. In their early stages of growth, each organism requires less resources. By dividing the production into multiple stages, the space utilization efficiency of the production system can be greatly increased.

In 1997, the Kona Bay Oyster & Shrimp Company (KBOS) constructed an integrated system at the Natural Energy Laboratory of Hawaii Authority (NELHA) site in Kailua-Kona, Hawaii (Hering, 1997). The system was based on research done at the former Agricultural Engineering Department (now Biosystems Engineering) of the University of Hawaii at Manoa using funds provided by the United States Department of Agriculture (USDA). Subsequent USDA Small Business Innovative Reasearch (SBIR) Grants supported the development of a pilot production system (U.S. Patent Disclosure, 1996; U.S. Patent, 1997). A year-long monthly examination of the oyster meat and the system water quality by the Department of Health, State of Hawaii, under the supervision of the FDA, found no contamination (zero tolerance) of Salmonella, Vibrio cholerae, Vibrio vulnificus, or Vibrio parahaemolyticus, and acceptable levels of fecal coliforms. A certificate (# HI 25 SS) for the Handling and Sale of Shellfish was issued on 24 September 1993, to Aquaculture Technology, Inc., the company that operated the pilot facility funded by the USDA-SBIR grants.

The current KBOS system is designed to efficiently remove waste products from the animal growing area. The return water entering the algal/shrimp tanks is used to cause a circular flow in the tank. This causes the solid waste products to concentrate in the bottom center of the tank (Goldsmith et al., 1994). Each algal/shrimp tank and oyster column base is equipped with a bottom center drain. When this drain is opened, the solid waste products concentrated over the drain are removed. The KBOS system has been operating with water re-use of 80 to 95%.

The production facility has six production modules. Each module consists of eight algal/shrimp tanks, 4 six-inch diameter oyster columns (Figures 3 and 4), 2 twelve-inch diameter oyster columns, 6 eighteen-inch diameter columns, one 5-hp pump and associated PVC plumbing to recirculate the water between tanks. The water returning from the oyster columns is introduced into the shrimp tanks from a height of approximately one and a half feet. This serves as an aerator for each algal/ shrimp tank. In traditional intensive shrimp culture ponds electrical paddle-wheel aerators are run twenty-four hours a day. In the KBOS oyster/shrimp production system the amount of electricity used to run the 5-hp pump is approximately equal to the amount of electricity/unit biomass required to power the paddle wheels used in intensive shrimp ponds.

In the KBOS system, the shrimp tank is used to produce algae. By controlling the nutrient input to the tank, and by making sure there are oysters to remove algae continuously, the dominate algal species, Chaetoceros spp., can be maintained. This is one of the few successful attempts to control the dominant algal species and maintain it in an open commercial size operation. The ability to control the algal species is important to the success of the system, since the dominant algal species must be the right food for the oysters.

Oyster production tanks are constructed with polyurethane resin and PVC. The resin-coated interior of the tanks produces a waterproof interior and is easily cleaned. All materials that come into contact with the oysters or feed water meet the specification for food contact surfaces. There are a total of forty-eight shrimp/algae tanks, 27 feet in diameter and 48 inches in height. Tanks are above ground to eliminate the possibility of runoff water contaminating the production system.

KBOS expects full production of Penaeus stylirostris and C. virginica in late 1998 or early 1999. The lack of reliable year-round shrimp post larva and oyster spat has forced the Kona Bay Oyster & Shrimp Company to develop its own hatcheries with increased project development time and cost. However, the high-quality of shrimp produced from this operation has resulted in a farm gate price $7 to $10 per pound (heads on), and is expected to reach $11 per pound in 1998.

Detailed design information of the KBOS system is proprietary, but an outline of design procedure can be found in Wang and Jakob (1991).

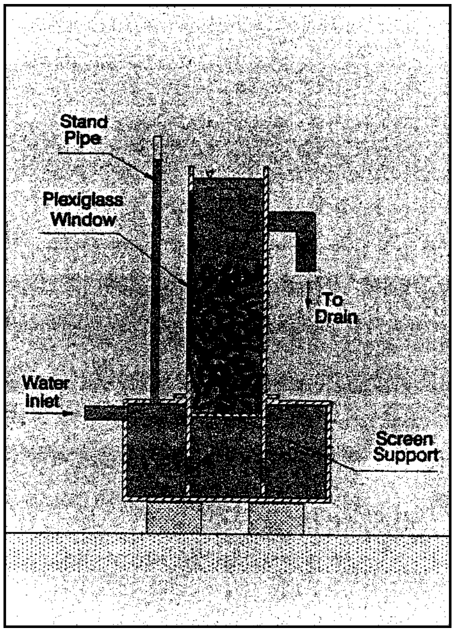

Figure 3. Cross section of KBOS fluidized-bed oyster grow out column.

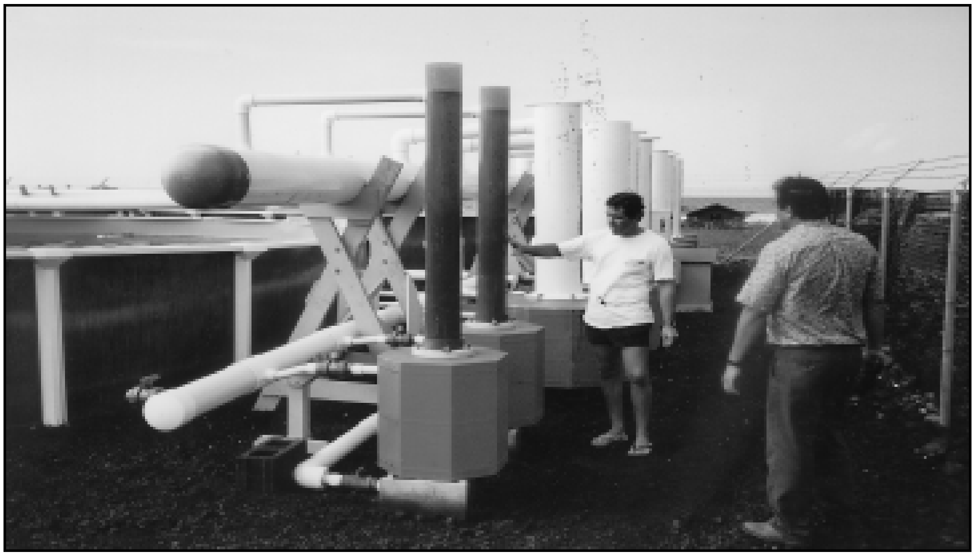

Figure 4. KBOS fluidized-bed oyster grow out columns.

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UPCOMING MEETINGS

Aquaculture America '99

The AES will be holding our Annual Meeting at *Aquaculture America '99*, which is the US Chapter of the World Aquaculture Society's Annual Meeting in the Tampa (Florida) Convention Center, January 27-30, 1999. The AES will be sponsoring a 1-day technical session of contributed engineering papers and two 1/2-day workshops — one on fundamentals and the other an advanced focus on aeration and gas exchange.

Morning: Fundamentals (Intended for the novice)

8:30 am *Basic Water Quality and Cycles in Aquatic Systems,*
Dr. K.A. Rusch, Louisiana State University
9:15 am *An Overview of Pond Rearing Techniques & Issues*
Mr. Harry Daniels, North Carolina State University
10:00 am Break
10:30 am *Recirculating Rearing Techniques & Issues,*
Dr. Steven Summerfelt, Freshwater Institute
11:15 am *The Hydroponic Approach to Raising Fish,*
Dr. Jim Rakocy, University of the Virgin islands
12:00 pm Lunch

Afternoon: Advanced Engineering Focus Session: Aeration & Gas Exchange

1:30 pm *Gas Transfer Kinetics, a Refresher,*
Dr. Michael Timmons, Cornell University
2:00 pm *Dynamics and Management of Oxygen and Carbon Dioxide in Photoosynthetic Aquaculture Systems,*
Dr. David Brune, Clemson University
2:30 pm *Oxygen Transfer into High Density Tanks and Raceways,*
Dr. John Colt, National Marine Fisheries Service
3:00 pm Break
3:30 pm *Carbon Dioxide Stripping Opinions and Advantages,*
Dr. Raul Piedrahita, University of California
4:00 pm *Avoiding Nitrogen Supersaturation In Ponds, Tanks, and Raceways,*
Dr. Barnaby Watten, U. S. Geologic Survey

For more information contact:

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Aquaculture Europe '98

The next international conference organized by the European Aquaculture Society (EAS) will take place in Bordeaux, France, October 7-10, 1998. The key topic will be "Aquaculture and Water: Fish Culture, Shellfish Culture, and Water Usage." The 3-day conference will consist of oral and poster papers, selected and case study papers, poster sessions, and technical excursions. Workshops are also being offered on recirculation technology, larval rearing in fish and shellfish, and co-management of production basins in fish and shellfish culture.

The AES is co-sponsoring the special one day workshop on recirculation systems that will be run complementary to the Conference's scientific session addressing this topic. The Conference session "Developments in Recirculation Systems" is scheduled for all day October 7.

Developments in Recirculation Systems

10:00-10:30 Losordo, T. (USA)
Recirculating aquaculture technology for finfish production: considerations and components for solids, removal and biological nitrification and oxygenation.
10:30-11:00 Eding E. and A. Klapwijk (The Netherlands)
Amonia removal in recirculation systems.
11:00-11:30 Blancheton J. P. (France)
Developments in recirculation systems for Mediterranean fish species.
11:30-12:00 van Rijn J. (Israel)
Denitrification and phosphore removal in recirculation systems.
12:00-12:20 Boley A., W. R. Miller, A. B. Fink, and G. Haider (Germany)
Denitrification in aquaculture recirculating systems with different biodegradable polymers.
14:00-14:30 Cripps, S. J. and A. Bergheim (The Netherlands)
Advances in solids management for intensive aquaculture systems.
14:30-14:50 Malone, R., A.A. De Los Reyes, and L. E. Beecher (USA)
Use of bioclarifiers to simplify recirculating system design and operation.
14:50-15:20 Summerfelt, S. and R. Piedrahita (USA)
Oxygenation and carbon dioxide control.
15:20-15.40 Helgason S., M. Smaradottir, and J.P. Blancheton (Iceland)
The effects of environmental CO_2 *on acid-base balance: a study in catheterized halibut and sea bass.*
16:00-16:20 Lorenzen K. (United Kingdom)
Ammonic transformations in intensive pond culture: implications for the design of integrated recirculation systems.
16:20-16:40 Avnimelch, Y. (Israel)
Activated suspension ponds, a new concept of recirculating ponds.
16:40-17:00 Lefebvre S. and J. Hussenot (France)
Modelling the nitrogen flux in water of an intensive earth pond marine fish-farm (Dicentrarchus labrax.)

The "Recirculating System Workshop" on October 8, will include presentations and discussions on various aspects of recirculating aquaculture by international experts, producers, and designers of commercial recirculation systems. The workshop organizers have invited commercial system suppliers to participate and present their system philosophy and design. To date, the following suppliers have confirmed their participation:

- Hesy, The Netherlands (eel and catfish)
- Idee, France (seabass and turbot)
- Sunfish, Norway
- Aqua-Optima, Norway (salmon)
- Fisch-Technik, Germany
- Other suppliers are yet to be confirmed.

All participating suppliers have systems in operation at commercial farms, and are representative for a given area and farm type. All supplier presentations will be standardized to a hypothetical reference farm operation, which will be fixed at a yearly production capacity of 100 MT. The suppliers will present information on their selected system, tank, and production outline. The discussion will focus on the removal of suspended solids and other waste material, the effluent discharges, economic consequences, etc. Raul Piedrahita (rhpiedrahita@ucdavis.edu) is coordinating the AES involvement in the conference session and workshop.

Aquaculture Europe '98 is also holding a session on "Feeding Techniques and Water Quality Management," October 9, which will deal with new feeding strategies, demand and satiation feeders, and interactions between water quality, feed intake capacity, and waste per unit biomass. Besides a number of contributed presentations, several invited presentations have been confirmed, which include:

- *Feed optimization in fish culture using integrated "feedback" systems*, by S. Kadri (UK)
- *Demand feeding systems in aquaculture ....*, by M. Paspatis (Greece)
- *New ways of calculating the optimal food ration*, by A. Alänärä (Sweden)

For more information on *Aquaculture Europe '98*, contact:
European Aquaculture Society, EAS Secretariat, Slijkensesteenweg 4, B-8400 Oostende, Belgium; +32-59-32 38 59 (ph); 32-59-32 10 05 (fax); or eas@unicall.be (email).

World Aquaculture '99

The Aquacultural Engineering Society will sponsor two days of technical sessions and workshops at the Annual Meeting of the World Aquaculture Society in Sydney Australia scheduled for April 26 - May 2, 1999. The first day will include a President's Session that will feature 4 invited speakers from around the globe highlighting advancements in aquaculture engineering in Europe, Latin America, Australia, and Asia. Also on the first day will be a producer oriented 1/2 day workshop focusing on water reuse technology in pond and tank systems. During the second day, the AES will sponsor a technical session to include between 12 and 16 contributed scientific paper presentations. The prelimnary workshop programs follow:

Advances in Aquaculture Engineering Around the Globe (President's Session)

8:30 *Aquacultural Engineering in Australia*
Dr. John Patterson, James Cook University, Australia
9:10 *Advances in Aquaculture Engineering in Europe*
Dr. James Muir, University of Sterling, Scotland
9:50 Questions and Discussion
10:00 Break
10:30 *Aquacultural Engineering in Latin America*
Mr. Germán Merino, Universidad Católica del Norte, Chile
11:10 *Aquacultural Engineering in Southeast Asia*
Dr. Rolando Platon, Southeast Asian Fisheries Development Center, Philippines
11:50 Questions and Discussion
12:00 Lunch break

Advances in Water Reuse Technology in North America

1:30 *Water Reuse Technology in Freshwater Ponds*
Dr. David Brune, Clemson University, USA
3:00 Break
3:30 *Water Reuse Technology in Tank Systems*
Dr. Thomas Losordo, North Carolina State University, USA
5:00 Session ends

AQUACULTURE AMERICA '99
Tampa Convention Center, Tampa, Florida USA
January 27-30, 1999

AQUACULTURE ON THE RISE

The **Aquacultural Engineering Society** was founded in 1993 to provide a forum for addressing engineering problems related to aquaculture. Its membership is open to engineers and non-engineers engaged in the culture, processing, and/or distribution of aquatic organisms or their by-products. The AES serves as an authoritative source of engineering information and support to the aquaculture industry. Working with other aquacultural groups and societies, the AES brings people together to discuss new ideas and technologies of benefit to the aquacultural community as a whole.

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