

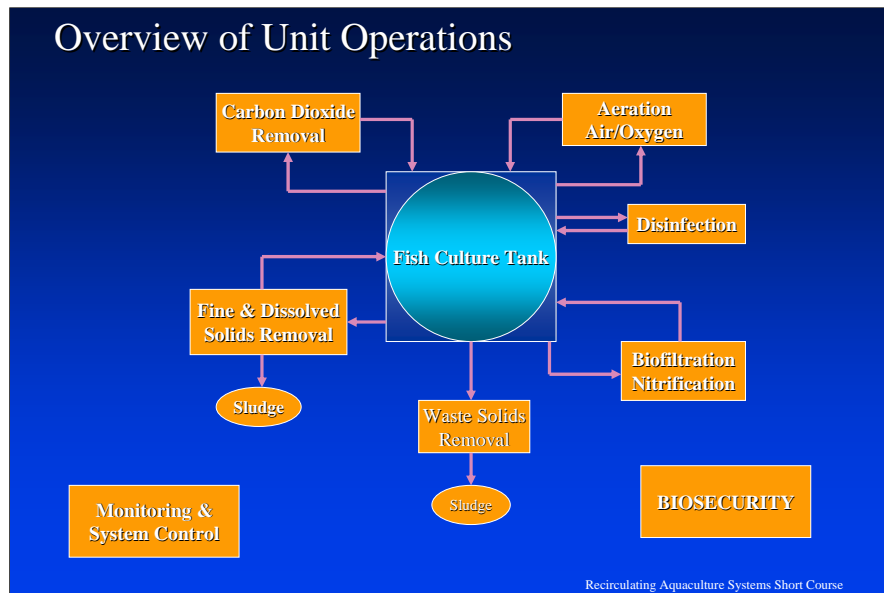
Overview of Systems Engineering

James M. Ebeling, Ph.D.

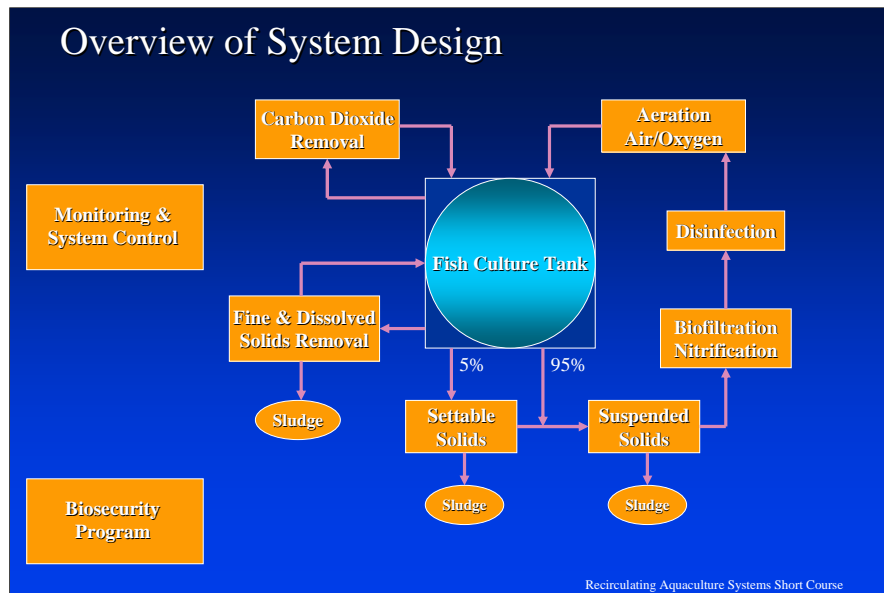
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Recirculating Aquaculture Systems Short Course

The purpose of this presentation is to provide you with an overview and “road map” that you can use to guide yourself through the various system components required for a successful recirculating aquaculture system design. Pay attention to all the small individual components and note how they are interconnected and dependent upon each other, and keep in mind that the total is always more than the just the sum of the parts. Also remember that there are numerous solutions to each ‘unit operation’ and although there are more efficient and more cost effective solutions, there is no right or wrong technology. Some work better in large scale applications, some in small scale, but it usually is the case that all work to some extent. What you use it your choice, based on sound engineering analysis of the options available for your system design and in your region of the world. Always remember the KISS concept: Keep it Simple! More fish are lost to overly complicated and sophisticated designs, so if you can’t figure out what its doing, the fish probably can’t either.



Engineers like to divide complicated systems into small parts, called unit processes, that correspond to a specific treatment process. The above figure shows how a recirculation system can be subdivided into about seven individual unit processes, that may correspond to separate systems or be linked together in a process stream. From the central fish culture tank, the effluent water moves through systems that remove the settleable and suspended waste solids, fine and dissolved solids, convert the ammonia to nitrate, remove carbon dioxide and add oxygen, and finally when required, disinfect the flow. The monitoring and control systems oversee all of these processes and control the set points for water quality and sound an alarm if they move outside of acceptable ranges. Finally, a biosecurity program and process must be maintained to prevent losses due to disease introduction from the outside.



In a real world system, the individual unit processes are usually linked together as the water flows through each process (circulation). Usually 5-10% of the discharge from the culture tank is removed from the center drain and because of a ‘tea cup’ effect has a high solids loading. Some form of settable solids removal device (swirl separator, settling basin, etc) pretreats this flow stream, which is then combined with the remaining 90-95% of the discharge from a side outlet. The remaining suspended solids are then removed usually by a rotating microscreen filter. The water then flows to some form of biofiltration, such as a trickling tower, bead filter, fluidized sand filter, moving-bed bioreactor etc, where the ammonia is converted to nitrate by bacteria. At high loading densities, a carbon dioxide stripping column is then used to remove excess CO₂ and aerate the water to saturation. Finally an oxygenation device is employed to supersaturate the flow to provide sufficient oxygen for the high levels of stocking used in commercial systems. In some cases, a UV or Ozone system is added to disinfect the returning water stream as part of a biosecurity program.

Why Reuse Water?

- Minimize water use
 - ✓ conserve heat
 - Note, heat gain can be problem in some coldwater systems.
 - ✓ decrease water demand
 - ✓ decrease wastewater discharge volume
 - ✓ reduce TMDL discharged

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Open reuse systems:

Clarifier backwash flow at FI

contained 97% of TSS produced daily

System overflow

contained 3% of TSS produced, about 4 mg/L TSS

$R = 0.94$ (6% of recycled flow is make-up water)

system volume exchanged twice per day (200% exch. rate)

Single-pass systems:

may only capture 40 to 70% of TSS produced

Why Reuse Water?

- Increase biosecurity
 - ✓ locate on smaller “pathogen-free” ground water resources
 - ✓ smaller inlet flows are cheaper to disinfect
 - ✓ smaller discharge flows are easier to screen and prevent escapement
 - ✓ locate farm away from regions with known pathogen problems

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optimize temperature for growth

increase farm yield per unit water resource input

more intensive technologies

economies of scale

increase biosecurity

locate on smaller ground water resources

increase flexibility in farm location

concentrate wastes into smaller flows

these flows are easier to treat

dramatically reduced TMDL

Why Reuse Water?

➤ Cold-water reuse systems:

✓ in Canada

- reuse water to increase 4-8°C ground water to 10 to 15°C
- increased growth rates off-sets higher capital cost

✓ in northern USA

- ground water already 11 to 13°C (near ideal temperature)
- reuse water to increase production on a given water resource
 - increased production must offset higher capital costs
- reuse water to decrease waste discharge

Culture Tank

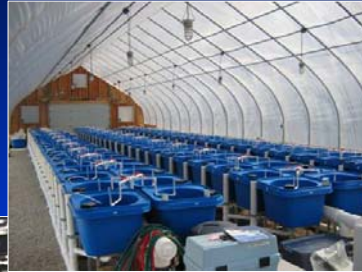


“Anything that holds water”

Recirculating Aquaculture Systems Short Course

Over the years, I have seen almost anything that holds water used in aquaculture, from swimming pools to concrete coffin liners.

Polyethylene Tanks



Recirculating Aquaculture Systems Short Course

Simple, low cost polyethylene tanks are used by many high school programs and have gained in popularity due to their low cost and long life expectancy. The smooth surface makes for easy cleaning and their light weight allows for quick set-up and relocation. They work well for the most part, but because they are very soft and malleable, they need to be well support on the bottom. Another problem is the difficulty in making water tight connections through the side walls and bottom. Uniseals[®] work well with polyethylene and are available in sizes from ½ inch to 6 inches. They are rated up to 40 psi and are warranted for 25 years.

Fiberglass Tanks



Recirculating Aquaculture Systems Short Course

One of the chief advantages of fiberglass tanks is the variety of materials, the number of different shapes they can have, sizes from small to very large and the flexibility of the material. The tank on the right is just flat sheets of fiberglass attached to one another with a large sheet for the bottom. The clear sides make for a great display, but when they fail, it's catastrophic! The tank on the right is a more traditional fiberglass tank mounted on a solid, secure concrete base and used for holding fish outdoors.

Fiberglass Tanks



Recirculating Aquaculture Systems Short Course

Fiberglass tanks can be manufactured in almost any shape and size. Fiberglass is an incredibly flexible construction material, that is easy to cut, drill and make connections too. Repairs are relative easily and modifications are simple. If the tank is too tall, cut out a section and fiberglass the too halves together and make it any height you need.

Fiberglass Tanks



Recirculating Aquaculture Systems Short Course

Large fiberglass tanks come in easily transported modules that are field assembled to almost any diameter. These tanks are buried several feet in the ground and contain several million dollars (yes, that's million!) worth of sturgeon.

Plywood/Wood Tanks



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A simple and inexpensive tank that I used in Hawaii were made of plywood panels formed into a circle and the lined with either a swimming pool liner (light blue) or a more expensive industrial liner (black). The bottom of the tank was lined with several inches of sand in which a central drainline was buried with an outside standpipe.

Steel Tanks



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For more permanent tanks, galvanized or epoxy coated steel modules can be bolted together to form extremely large (105 ft) and deep tanks (14 ft). The bottoms are usually poured concrete drain and heating coils into which the panels are embedded. Tanks can be partially buried to conserve heat and make fish observations easier.

Corrugated Panels with Liner



Steel



Aluminum

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A variation of this is corrugated steel or aluminum panels with a liner.

Plywood/Wood Raceways



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This is a very simple way to construct long, shallow raceways using plywood panels buried in the ground and a liner. These tanks are about 16 feet across and 60 feet long and are used to raise tilapia in a greenhouse. Construction is extremely simple and inexpensive. The other raceway is constructed of 4x8 plywood panels made of 2x6 frames and bolted together. The top picture is simply 2x10 secured with 2 inch galvanized pipe driven into the ground.

Concrete Tanks/ Raceways



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Concrete raceways have been used for years to raise sports fish and for holding tanks. They work great, just be sure you plan on using them for generations, because once you build them, there is no going back. I have seen hundreds of abandon raceways, because there is insufficient water available to operate them. There are some alternatives available, such as cross-flow and mixed-cell raceway designs that do make these systems workable

Aquarium Systems

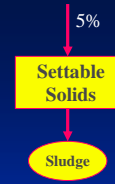


Recirculating Aquaculture Systems Short Course

In planning an aquaculture facility, don't forget the tried and true methods such as simple glass aquarium tanks. Catfish farmers get 60 cents a pound for their fish, tropical fish growers get 60 cents or more per fish!!

Settable Solids Removal

- Bottom-drawing center drain
- Settling basins
- Swirl separators/ Hydrocyclones



Rule of Thumb:
1 lb of feed \Rightarrow 0.30 lbs of solids

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It is critical to remove the solids from the recirculating systems as quickly as possible and with minimum disturbance. Solids that are allowed to remaining in the system will quickly breakdown and be both more difficult to remove and cause poor overall water quality. The dual-drain systems uses the tank as a swirl separator ('tea cup effect') and removes most of the settable solids from a small discharge from the center drain. As you will see later, this system is remarkable effective in removing the majority of large, quickly settable solids such as uneaten feed and fecal mater. This waste stream can then be further concentrated using either settling basins or additional swirl separators. Remember the point is to create a small, concentrated flow that is easily treated, rather than a large, diluted flow of waste.

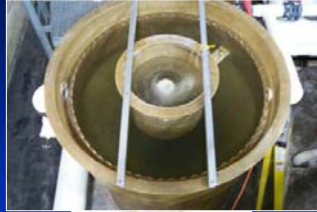
Center Dual-Drain System



Recirculating Aquaculture Systems Short Course

The dual drain system uses a center drain that removes from 5 to 20 percent of the flow and a higher sidewall drain. The bottom drain shown on the left consists of a flat plate with a small opening around its perimeter that sucks the solids off of the floor of the tank. The perforated center drain in the middle then removes the remaining flow of relative clean water. Another way is to use a drain located high up on the sidewall. This is screen to prevent fish from entering it and a standpipe is used to control the flow of water.

Settling Basin



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Over the years, settling basins have gotten a bad rap, mostly because they have been improperly designed and managed. Water flows directly from the drain in the tanks to a small diameter ring suspended in the center at the top of the settling cone. . It then flows down this ring, turns the corner and very slowly moves upward over a discharge weir and pit/. The slow velocity of the water, allows the solids to settle out quickly. The system is easy to clean by flushing the solids and starting up again.

Swirl Separator

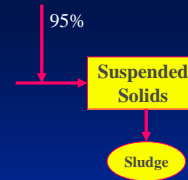


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Swirl separators take advantage of the ‘tea cup’ effect, where the solids are forced to the outside when water is too spin in a tank. These are very effective in removing large, easily settable solids and can be manufactured in almost any size or flow range. The glass swirl separators on the right have the additional advantage that during feeding when uneaten feed particles start appearing you know the fish are satiated.

Suspended Solids Removal

- Screen filtration
 - rotating microscreens
 - horizontal screen
 - vertical screen
- Pressurized bead filters
- Pressurized sand filters



Recirculating Aquaculture Systems Short Course

Suspended solids are by definition anything that won't settle out in a reasonable amount of time (say 30 to 60 minutes). They are more difficult to remove and usually some form of mechanical mechanism is used. The most common method is a screen filter, next a pressurized bead filter and if really clean water is required a pressurized sand filter.

Rotating Microscreen Filter



Recirculating Aquaculture Systems Short Course

Rotating microscreen filters are available in a variety of sizes and flow rate capacities. They have numerous advantages, the primary one being that they are easy to install and operate.

Almost all microscreen filters work on the principle of interception of the particles on a screen and their removal by means of a spray of water. The flow may be from the inside out or the outside in, but most look like the picture above. The screens are interchangeable and mesh size is usually determined by the characteristics of the water to be treated, the required discharge water quality and the trade offs of size, cost and waste discharge volumes.

Horizontal Screen Filter



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Another variation is to use a flat screen and a moving spray bar. Typically found in the food processing industry.

Inclined Screen Filter



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A finally option is to use an inclined screen filter. As solids collect on the screen, the flow of water flushes them into a collection trough on the bottom. Again, popular in the food processing industry.

Pressurized Bead Filters



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A popular option is to use a pressurized bead filter for both solids removal and biofiltration.

Pressurized Sand Filters



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If extremely high quality water is required, pressured sand filters are often employed such as these for a salt water Clown fish facility in Florida. Their chief disadvantage is the large quantities of backwash water and the high pressure drops across the filters.

Fine & Dissolved Solids

- Foam Fractionation
- Protein Skimmers



Recirculating Aquaculture Systems Short Course

Extremely fine solids and organic residues are very hard to remove by entrapment in a microscreen filter or sand filter. Foam fractionation or protein skimmers take advantage of the electrical properties of fine solids and small bubbles. I call it the 'bath tub ring effect'. After you take a bubble bath, there is a ring around the tube consisting of small fines, fats, oils and greases. The same technique is used in a foam fractionator.

Small bubbles are allowed to flow up through a column and are collected at the top. Trapped particles and organics are then drained off. Sometimes instead of air, ozone is used to create the bubbles improving efficiency and providing for some disinfection.

Solids Disposal

- GeoBags
- land application
- composting
- lagoons



↓
Sludge

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Now what do you do with all this “Waste”.

GeoTextile Bags



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One of the newest techniques for containing sludge is to use geotextile bags. The porous bags will hold the solids and allow them to drain off excess water. In many cases, a polymer or flocculation agent is added to improve solids/liquid separation. Alum can also be added as a coagulation aid, which also helps to sequester dissolved phosphorus.

Vacuum Honey Wagon



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The simplest method is to land apply the waste as a fertilizer. The problem is that this can only be done when the ground is not covered with snow and dry enough for heavy equipment. Thus some form of storage of the waste is needed and this can range from almost nothing to 9 months of production.

Waste Lagoon



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Anaerobic and aerobic waste lagoons can be used, but should have more engineering design input and maintenance than the one above!

Compost Bin



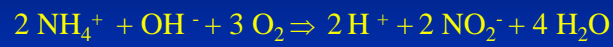
Recirculating Aquaculture Systems Short Course

Composting is an excellent alternative and creates a viable product that can be used locally or sold.

Biofiltration / Nitrification



Ammonia Oxidizing Bacteria



Ammonia → Nitrite

Nitrite Oxidizing Bacteria



Nitrite → Nitrate

Recirculating Aquaculture Systems Short Course

Biofiltration is a two step process where the potentially harmful ammonia is converted by beneficial bacteria to relatively harmless nitrate.

Biofiltration / Nitrification



1 g of ammonia yields:

4.42 g nitrate NO_3^-

5.93 g carbon dioxide

consumes:

4.34 g oxygen

7.14 g alkalinity

Rule of Thumb:

1 kg feed \Rightarrow about 0.03 kg ammonia

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As a rule of thumb, for each kilogram of feed consumed about 0.03 kg of ammonia is produced. This results in a lot of nitrate, which is normally not a major problem. But it also results in a significant quantity of carbon dioxide that can be a problem. In addition, the biofilters will consume almost 4.34 g or more of oxygen and 7.14 g of alkalinity. Both will have to be provided to maintain the systems equilibrium.

Biofiltration / Nitrification



- Submerged Biofilters
- Trickling Biofilters
- Rotating Biological Contactors (RBC)

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There are as many types and designs of biofilters as there are aquaculturists! The bottom line is all you need is surface area for the bacteria to grow on. The bacteria don't care what this is (for the most part!), so almost anything works and has been tried.

Gravel Biofilter



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This was the first biofilter media used, and was modeled after early wastewater treatment plants. They don't work, or least not for very long, because of the bacterial slime that builds up and the fact that they are impossible to clean. Anyone who has ever constructed or deconstructed one of these knows the hard work that is required.

Submerged/Trickling Biofilter



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One solution used by some diehards was to use a lighter media, such as plastic beads. Although this made construction easier, it doesn't solve the primary problem of clogging and cleaning difficulties. Also a submerged filter will quickly go anaerobic when the flow stops and all the oxygen required by the bacteria (both good and bad) must be supplied by the incoming water.

Submerged Foam Filter



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Possibly the worst designed filter was the submerged foam filter, that was a scaled up aquarium tank filter. They clogged easily, were difficult to clean and each of the foam modules weighed “tons” when fully loaded with bacteria and solids.

Classic Trickling Tower



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The trickling tower is a classical biofilter, combining both biofiltration, aeration and degassing into one unit process. Water cascades over some media on which bacteria grow, oxygen diffuses into the water and nitrogen and carbon dioxide diffuses out. They can be constructed as small as 1 inch in diameter and as large as desired.

Trickling Tower & Spray Bar



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Trickling towers don't even have to be towers, the above system is buried in a culvert below grade is often referred to as a trickling sump! Notice the even distribution of water over the surface, critical for good operation.

Smaller Version



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Smaller versions constructed of polyethylene barrels. Notice the nice light brown color of the media from the beneficial bacteria growing on it.

Rotating Biological Contactors



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Rotating Biological Contactors (RBC's) move the media through the water and then back into the air. Like the trickling towers these have the advantage of limited aeration and degassing. The above RBC's actually float in the water and are rotated by either air or a small flow of water.

RBC Drive Shaft



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The problem with RBC's has always been the shafts and the drive mechanisms. It is easy to underestimate incredible weight of bacteria and slime, and the effect of aquacultures hostile environment on motors and gear boxes. One common solution to this is to design the RBC so that it floats in the water eliminating the drive shafts completely.

Biofiltration / Nitrification



- Pressurized bead biofilters
- Fluidized sand biofilters
- Fluidized bead biofilters
- Moving bed BioReactors

Propeller Washed Bead Filter



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The floating bead filter uses floating beads! The beads act as a surface area for bacteria and also will trap solids, thus doing two jobs for the price of one filter. Backwashing of the filter is accomplished either mechanically with a motor/propeller (above) or with air bubbles.

Bubble Washed Bead Filter



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The bubbled washed bead filter uses bubbles to wash the beads! As the water flows out of the bead filter during backwashing, air is sucked in at the base and agitates the beads as they pass through the narrow middle. The bead filter in the upper right, uses air bubbles injected at the base to agitate the beads, allowing the trapped solids to settle in the bottom cone.

Drop Filters (PolyGeysers)



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Bead filters can be sized for Koi Ponds to large scale production.

Fluidized Bed Biofilters



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Usually used in large scale applications, fluidized sand beds provide large surface area for bacteria, in a small footprint. They get their name because as the water flows up through the sand bed, the sand becomes suspended in the flow or fluidized. Numerous designs have been investigated to inject the water below the sand bed and two that are most commonly used are the shown above and in the next slide. The water is injected below the bed through a series of injector tubes that run from above down to the bottom.

The Cyclo-bio uses an annular ring at the base of the sand bed to inject the water, significantly reducing the required water pressure.

Downflow micro-bead biofilter



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Relatively new, the downflow micro-bead biofilter uses very small plastic beads that float in the biofilter as the water flows down through them. The high specific surface area, low head loss, and small foot print makes them a strong competitor with the fluidized sand bed biofilter.

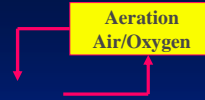
Moving Bed Biofilter



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Also relatively new is the moving bed biofilter. The media remains in suspension as the water flows through the biofilter, which is actively aerated. The high turbulence and aeration provides good mixing and contact with the media.

Aeration / Oxygenation



Oxygen Requirements

- Metabolism/respiration: 0.25 lbs O₂ / lb feed
- Nitrifying bacteria: 0.40 lbs O₂ / lb feed

Total: 0.65 to 1.00 lbs of O₂ / lb feed

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The oxygen requirements of the fish can be as high as 0.25 lbs oxygen per lb of feed or higher. The requirement of the biofilter can be as high as 0.40 lbs oxygen per pound of feed or higher if the biofilter has a lot of heterotrophic bacteria. For submerged filters (fluidized beds for examples), this all has to be provided by the incoming water to the biofilter. Overall the total can easily range from 0.65 to 1 pound of oxygen per pound of feed.

Sources of Air - Blowers



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The most common source of air for aeration is the regenerative blower. They are relatively quiet and foolproof to operate.

Aeration / Oxygenation



Aeration (less than 1/3 lb of fish / gal of water)

- Diffusers (air stones)
- Mechanical agitators
- Packed column aeration

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As a rule of thumb: for stocking densities of less than 1/3 lb per gallon of water, some form of diffusers, mechanical agitators or packed column aeration is usually adequate.

Air Lifts - Mechanical Aeration



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I have always used air lifts in tanks to provide for both aeration and water movement. In large tanks, mechanical aerators can be used.

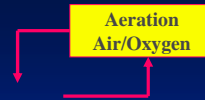
Aeration Tower



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Aeration towers are very similar to trickling biofilters. The idea is to provide surface area over which the water flows in a thin sheet, allowing gases to exchange with the atmosphere: oxygen in, carbon dioxide and nitrogen out.

Aeration / Oxygenation



Oxygenation

sources: compressed oxygen cylinders
liquid oxygen (LOX)
on-site oxygen generation

- Downflow Bubble Contactor
- Counter Current Diffusion Column
- Multi-stage Low Head Oxygenation (LHO)

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At higher stocking densities, pure oxygen needs to be used to provide sufficient dissolved oxygen for both the fish and the biofilter. There are several sources of oxygen and which one is most appropriate depends on the quantities required and in some cases where you live. Several different systems have been used to diffuse the oxygen into the water, including contactors and Low Head Oxygenators.

Oxygen Sources

on-site oxygen generators



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For remote sites and where only small flow rates are needed, on-site oxygen generators are viable sources of an enriched oxygen flow stream. Numerous commercial systems are available for both high and low oxygen demands.

LOX



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Liquid oxygen is an excellent source if you live where a reliable and economic source is available.

Emergency Supply



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Compressed gas cylinders are a good emergency backup, if all else fails. This system was designed with normally open solenoids, that are closed when powered (good) and then open to allow oxygen to flow to diffusers in the tanks if the power goes off.

Downflow Bubble Contactor



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One simple way to add oxygen is with downflow bubble contactors. The flow of water is down, oxygen is injected at the base and the bubbles tend to float up. At some downward velocity of the water is just equal to the upward velocity of the bubbles, and they stop and diffuse into the water. The difference in pipe diameter determines the velocity of the water. These are also called Speece cones.

Full Scale Speece Cone



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Speece cones can be very efficient in diffusing the oxygen into the water.

Carbon Dioxide Removal

- Packed column degassing units



Carbon Dioxide Removal

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As production levels increased and stocking densities approached 1 pound of fish per gallon of water by using oxygen, carbon dioxide levels in some systems began to build up to the point where the fish were either asleep or dead. Carbon dioxide is very difficult to remove from water, even though it is very soluble. Packed columns with very high gas to liquid ratios have been developed that effectively remove dissolved carbon dioxide.

Disinfection

Disinfection

- Ultraviolet radiation
- Ozone



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If required, two methods of disinfection are using ultraviolet radiation or ozone gas.

Monitoring & System Control

Monitoring &
System Control

Continuous

- DO
- Level
- Flow
- Temperature
- Air pressure

Phone Dialer

Periodically

- pH
- NH₃
- NO₂
- NO₃
- CO₂
- Alkalinity

It takes only one mistake to KILL
EVERYTHING IN YOUR FACILITY!!!!

Recirculating Aquaculture Systems Short Course

Usually the last system to install and the system that receives the least maintenance, the monitoring and control system will determine success or failure in aquaculture. It takes only one mistake to KILL EVERYTHING IN YOUR FACILITY!!!! I recommend that you continuously monitor such basic parameters as water level and flow, temperature and pressure in the aeration system. If you can afford oxygen, you can afford to monitor its use! Other water quality parameters are important, but do not change rapidly and can be monitored periodically (Biweekly, weekly). All the alarms should report to a phone dialer to notify staff if there is a problem after hours.

Continuous Monitoring



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Monitoring systems don't have to be complex. The commercially available system above monitors oxygen levels at four locations, has eight or more switch inputs and will automatically switch on backup systems and dial out in emergency situations.

Water Quality Lab



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Regular monitoring of other parameters such as ammonia, nitrite, nitrate, etc. requires a well equipped and maintained water quality lab. It doesn't have to be as fancy as the above picture, but it needs to be a dedicated location with all the support equipment for good laboratory practices.

BioSecurity



Recirculating Aquaculture Systems Short Course

Regular monitoring of other parameters such as ammonia, nitrite, nitrate, etc. requires a well equipped and maintained water quality lab. It doesn't have to be as fancy as the above picture, but it needs to be a dedicated location with all the support equipment for good laboratory practices.

Support Components

- Water Quality Lab
- Storage - Feed, Chemicals, Product
- Equipment Storage
- Staff Support
- Back-up Generator
- Quarantine Area
- Waste Disposal

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This is just a short list of all the other things that you need to be successful in aquaculture.

SAFETY

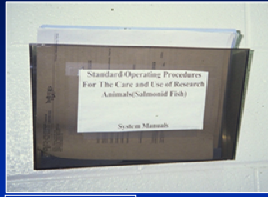
Water and electricity do not mix!

- Have Back-up Plans and Use Them!
- Train staff in emergency preparedness!
- Think!!!

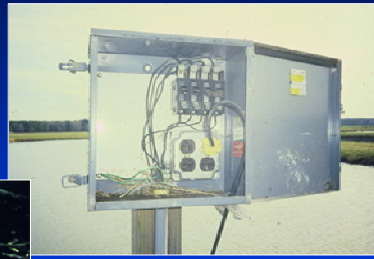
Recirculating Aquaculture Systems Short Course

Agriculture is one of the most hazardous of professions!! Always think SAFETY, or your loved ones will never forgive you!

SAFETY



The Good!



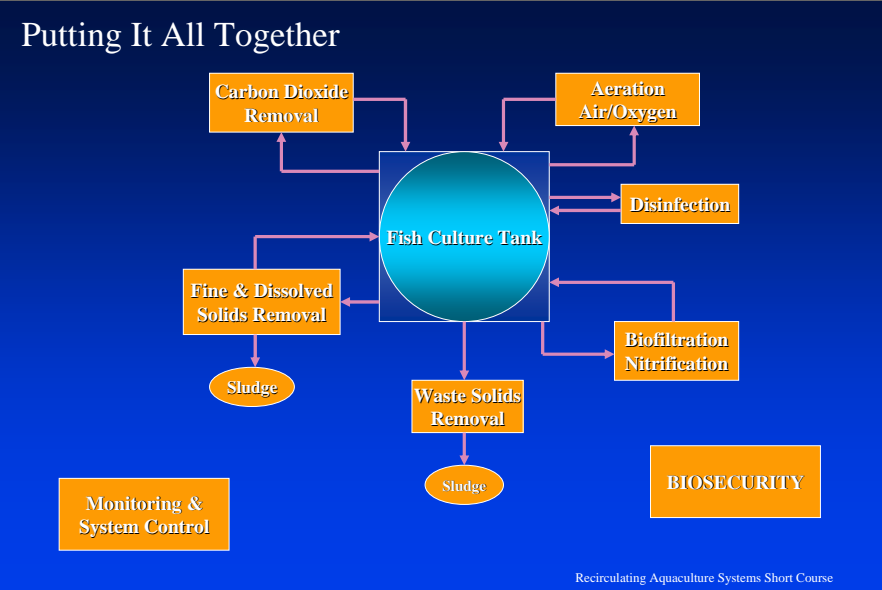
The Ugly!!



The Bad!

Recirculating Aquaculture Systems Short Course

Have emergency and standard operating procedures spelled out, so that everyone knows what to do when the worst happens, and it will!



Keep this overview in the back of your mind as you go through this course. As you visit facilities, try and identify each of these unit operations and note how they are connected to and interact with other unit operations. Remember there are a lot of options for each and no **RIGHT OR WRONG** choice, just variations that may or may not be appropriate for your size of operation or species.

Questions?

