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FACT SHEET

Recirculating aquaculture tank production systems – component options

Recirculating aquaculture production systems have stirred a great deal of interest in the aquaculture community in the United States and worldwide. There is little doubt that most fish grown in ponds, floating net pens, or raceways can be reared in commercial scale recirculating systems. Unfortunately, the economic viability of growing commonly cultured species in recirculating systems is not as certain. Recirculating systems have generally been expensive to build, increasing the cost of producing fish in these systems.

Due to the higher cost of producing fish in recirculating systems, operators have not fared well in the market place when in competition with producers using traditional pond aquaculture technology. Closed recirculating production systems will not be used on a wide scale until the total cost of producing fish in these systems begins to approach that for ponds and other competitive production systems. The challenge to the designers of recirculating systems is to develop systems that maximize production capacity per dollar of capital invested. To do so, components used in recirculating systems need to be designed and developed to reduce the cost of the unit while maintaining reliability.

Research and development activities in recirculating systems have been ongoing for at least two decades. Numerous alternative technologies exist for each process and operation used in recirculating systems. Selection of a particular technology depends upon the species being reared, production site infrastructure, production management expertise and numerous other factors.

Critical processes

In designing recirculating systems, the developer should keep in mind that the production system must be capable of maintaining an excellent culture environment for the aquatic crop. Maintaining good water quality is of primary importance in aquaculture. While poor water quality may not be lethal to the crop, little or no growth as well as increased incidence of disease can result from stress due to a poor environment. Critical environmental parameters include the concentrations of dissolved oxygen, un-ionized ammonia-nitrogen, nitrite-nitrogen, and carbon dioxide in the water of the production system. Nitrate concentration, pH, and alkalinity levels within the system are also important.

By-products of fish metabolism include carbon dioxide, ammonia-nitrogen, and particulate and dissolved feacal solids. In recirculating tank systems, proper water quality is maintained by pumping tank water through specialized filtration and aeration equipment. Water treatment components must be designed to eliminate the effects of each of these waste products. Additionally, each component must be designed to work in conjunction with other components of the total system.

Component selection for water treatment

Technologies commonly used in recirculating systems and some of the component options include the selections that follow.

Waste solids removal

Decomposition of fish waste and uneaten feed can exert a significant oxygen demand and produce large quantities of ammonia-nitrogen. These solids are generally classified into three categories: settleable, suspended, and fine or dissolved solids.

Settleable solids

Settleable solids are generally the easiest of the three categories to deal with and should be removed from the culture tank water as rapidly as possible. This is accomplished most easily in round culture tanks, with bottoms that gently slope to a central drain, with a circular flow pattern. Settleable solids will sink to the bottom and move toward the centre of the tank with the circular flow. The settled solids should be removed from the centre of the tank on a continuous or at least daily basis.

In rectangular raceways with plug flow (flow that moves longitudinally through a rectangular tank), solids are more difficult to remove as the velocity at the bottom of the tank is generally slower than in round tanks. If water velocity at the tank bottom can be increased to move the settled solids to the end of the tank, then solids can be removed using a sediment trap. The sediment trap (sump) should span the bottom of the raceway perpendicular to the direction of flow.

Alternatively, settleable solids can be kept in suspension with continuous agitation and removed in a separate flow-stream (also referred to as a side-stream) to a properly designed settling tank. Settling tanks (or basins) provide a quiet, non-turbulent area where the rate of water flow is slowed and solids may settle out of suspension by gravity. Settling tanks may or may not include tube or lamella sedimentation materials that are constructed with bundies of tubes or plates set at specific angles to the horizontal (usually greater than 40°C to reduce both the settling distance and circulation within the settling tank. The use of settling plates reduces the size requirements of settling basins, thus saving space within a facility. The benefits of using tank-settling basins outside of the rearing tank are simplicity of operation, low energy requirements, and generally the low cost of implementation. Disadvantages include the relatively large size of settling basins and poor removal efficiency of small or low-density particles. Additionally, if settling basins are not cleaned on a regular basis, waste solids can break down within the basin and contribute to the ammonia-nitrogen production and the oxygen demand of the system.

Another alternative, external to the culture tank, Is a centrifugal settling component commonly referred to as a hydro-cyclone or swirl separator. In this design, water and particulate solids enter the separator tangentially, creating a circular or swirling flow pattern in a conical shaped tank. The heavier solids move towards the wails and settle to the bottom where they are removed continuously. The main advantage is the relative compact size of the hydro-cyclone design. A major disadvantage of this system is the high replacement water requirement caused by a continuous stream of wastewater. An additional disadvantage is that hydro-cyclones require large pumps to maintain high flows during operation, thus increasing the system's energy requirements.

Suspended solids removal

From an aquaculture engineering viewpoint, the difference between suspended solids and settleable solids is a practical one. Suspended solids will not settle out of the water column under still (non-turbulent) conditions in one hour and would not be expected to be removed by conventional gravity settling. Suspended solids are not always dealt with adequately in recirculating systems. Most current technologies for removing suspended solids generally involve some form of mechanical filtration. Two commonly used types of mechanical filtration include screen filtration and expendable granular media filtration.

Screen filtration

Screen filters are beginning to be used more widely in closed recirculating systems. Screen filter technology utilizes some form of fine mesh material through which a stream of water passes while the suspended solids are retained on the screen. Both metal wire meshes and fine plastic meshes are used in screen filters. The features that make each screen filter different and the challenge in designing these units are the process of removing the solids from the mesh surface before they clog the filter.

One method of removing solids Involves rotating the screen surface past a scraper bar and/or high-pressure spray jets of water. The solids are carried away from the screen in a small stream of water (Figure 1). Another variety of screen filter utilizes a stationary screen and a movable water spray cleaning system. A third variation employs an inclined screen that Is frequently or continuously shaken to move the collected solids by gravity from the screen mesh and Into a small waste stream.

As with the hydrocyclone, the main advantage to using a screen filter is their small size. The main disadvantage of most currently available commercial screening devices is the high cost for units with even modest treatment capabilities. Other disadvantages Include high maintenance requirements due to the mechanical nature of the screening devices and potentially high volumes of water lost during the washing process.

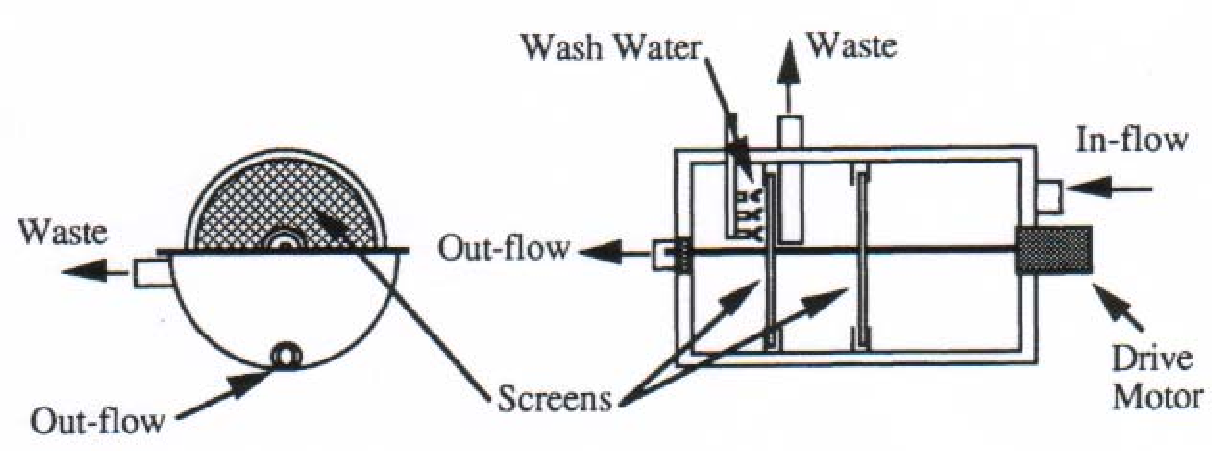

Figure 1: Disk type rotary screen filter with hydraulic cleaning.

Expandable granular media

Expandable granular media filters function by passing water laden with suspended solids through a bed of granular media (sand, plastic beads). The solids either stick to the media or are trapped within the open spaces of the filter media. Over time the filters will become clogged with solids and require cleaning, often referred to as backwashing. Backwashing an expandable media filter requires that the filter bed be agitated to release the solids trapped on or between the media.

In aquaculture, the most common filtration media used is sand. In systems with few fish or low feed rates, pressurized downflow sand filters, commonly used for swimming pools, have been widely used. While these filters are capable of removing a significant fraction of the suspended solids from production systems receiving large quantities of feed, the solids build-up would require frequent backwashing. Backwashing these filters is accomplished by reversing the flow of water through the filter media, causing the bed to expand or "boil," releasing trapped solids and causing bacterial growth to be scraped off the filter media. Bacterial growth on the sand can also create gelatinous masses within the filters that are impossible to clean with backwashing, necessitating chemical or mechanical cleaning of the filter. Additionally, from an operational viewpoint, downflow sand filters reduce or stop the flow of water when they clog. Even short-term interruptions of water flow can be disastrous to intensive recirculating systems.

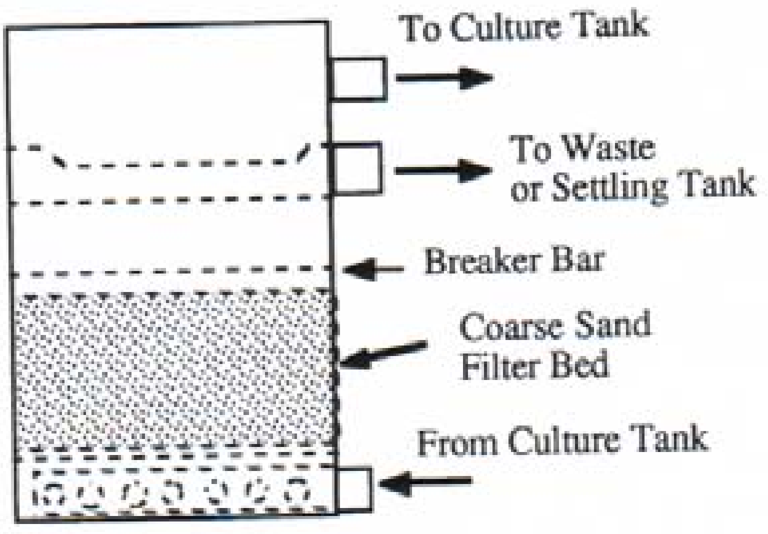

Figure 2: Typical upflow sand filter configuration.

An alternative design that has been employed successfully in the soft-shell crab shedding industry in Louisiana is that of upflow expandable bed filters (Figure 2). This technology uses a coarse sand bed to trap and filter out suspended solids from water flowing in an upward direction. Using coarse sand media produces more spaces between the sand particles, thus providing a higher solids loading capacity and reducing the required frequency of backwashing. In upflow sand filters, if the filter bed becomes clogged, the water channelizes through part of the filter bed (short-circuiting the filter bed) and is not filtered properly. Upflow sand filters are backwashes by expanding the sand bed with a flow rate that is 5 to 10 times greater than the normal filtering flowrate. A major disadvantage of this type of sand filter is the additional pumping requirement to provide more flow for backwashing.

Another disadvantage to this type of system is high water consumption for backwashing. Unless the backwashing system is automated, the process can be time and labour intensive.

Fine and dissolved solids removal

Many of the fine suspended solids and dissolved organic solids that build up within intensive recirculating systems cannot be removed with the traditional solids removal mechanisms described above.

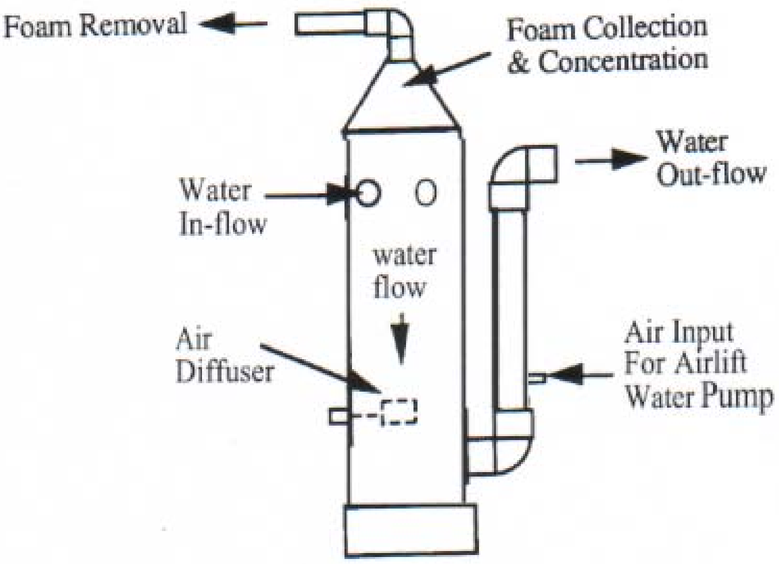

Figure 3: A typical counter-current foam fractionator design.

Foam fractionation, a process also referred to as air-stripping or protein skimming, is often employed to remove and control the build-up of these solids. Foam fractionation is a process where air is introduced into the bottom of a closed column of water, creating foam at the column's surface. The process removes surface active dissolved organic compounds (DOC) from the water column by physically adsorbing DOC on the rising bubbles. Fine particulate solids are trapped within the foam at the top of the column. Foam can be collected at the top and removed. The main factors affecting operational design characteristics of the foam fractionator are bubble size and contact time between the air bubbles and the DOC. A counter-current design (bubbles rising against a downward flow of water) is used to improve efficiency by ensuring a longer contact period between the water and the air bubbles (Figure 3). Diffusers producing smaller bubbles also increase process efficiency.

Ammonia and nitrite-nitrogen control

Controlling the concentration of un-ionized ammonia nitrogen (Nh3 in the culture tank is a primary design consideration in recirculating systems. Ammonia nitrogen must be "removed" from the culture tank at a rate equal to the rate it is produced to maintain a stable and acceptable concentration. In production systems with ammonia nitrogen treatment processes external to the culture tank, the efficiency of the ammonia nitrogen removal process will dictate the recirculating flow rate (eg. a less efficient removal system will require a higher recycle flow rate). While there are a number of technologies available for removing ammonia nitrogen from water (air stripping, ion exchange, and biological filtration), biological filtration is the most widely employed. Air stripping of ammonia nitrogen through non-flooded (no standing water in the reactor) packed columns requires that the pH of the water be adjusted to above 10 and readjusted to safe levels (7 to 8) prior to re-entry into the culture tank. Ion exchange technology is costly and requires a mechanism for "wasting" ammonia laden salt water. Salt brine is used to "regenerate" the filter by removing ammonia-nitrogen from the resins (filter media) once they become saturated with ammonia nitrogen.

The ammonia nitrogen treatment system currently receiving the most attention in research and development is biological filtration. In biological filtration (also referred to as bio-filtration), a substrate with a high specific surface area (large surface area/unit volume) is provided for nitrifying bacteria to attach and grow. Ammonia and nitrite-nitrogen in the recycled water are converted to nitrite and nitrate by Nitrosomonas and *Nitrabacter* bacteria, respectively. Commonly used bio-filter substrates include gravel, sand, and plastic beads, rings, and plates. The following is a review of the most commonly used bio-filtration technologies.

Rotating biological contactor

Rotating biological contactors (RBC) have been used in the treatment of domestic wastewater for decades and are now widely used as nitrifying filters in aquaculture applications. RBC technology is based on the rotation of a substrate attached to a shaft at approximately 3 revolutions per minute (rpm). Approximately 40 percent of the substrate is submerged in the recycle water (Figure 4). Nitrifying bacteria grow on the media and rotate with the RBC, alternately contacting the nitrogen rich water and the air. As the RBC rotates, it exchanges carbon dioxide (generated by bacteria) for oxygen from the air. Advantages of RBC technology are simplicity of operation; the ability to remove carbon dioxide and add dissolved oxygen, and a self cleaning capacity. Nitrifying bacterial floc (particles) fall off the substrate during normal operations. The loss of bacterial floc adds organic solids that must be removed by a filtering component. Poorly designed RBCs have experienced mechanical breakdowns.

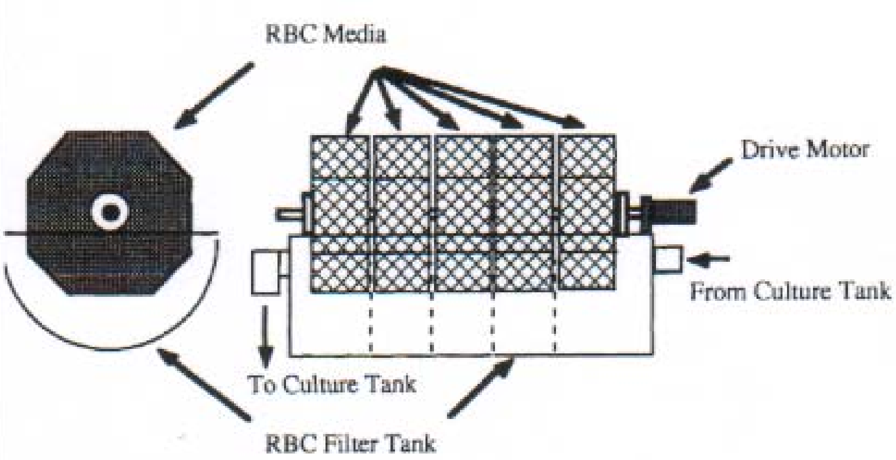

Figure 4: Typical rotating biological contactor unit.

In early aquaculture applications, RBCs were fabricated with simple discs cut from corrugated fibreglass plate. More recently, RBC technology has used media with high specific surface area such as plastic blocks or a polyethylene tubular media (resembling hair curlers). These newer plastic media provide a significant increase in ammonia and nitrite-nitrogen removal capability for relatively small RBC units. The designer should note that filter media will increase in weight as much as tenfold during operation. As such, the support structure for the media must be designed to accommodate the additional weight.

Expandable media filters

Expandable media filters, described in the previous section for removing suspended solids, are also used as biofilters in some aquaculture applications. Generally operated as upflow filters, coarse sand provides a high amount of surface area (per unit volume) for nitrifying bacteria to colonize. A major advantage of this technology is the combining of nitrification and solids removal process into one component. Major disadvantages are the large pump required for backwashing the filter and the large volume of water used during this process. Although the wastewater can be recovered in a separate settling basin, this adds expense to the overall water treatment system. Upflow sand filters do not utilize all of the surface area of the sand as substrate for bacterial colonization. In the normal operational mode, the granular media functions as a packed bed, and individual granules are in contact with one another. Upflow sand filters should only be used where the fish are fed lightly (fed 1 percent or less of the total fish weight, eg. in holding or purging tanks), in conjunction with a lightly stocked culture tank or with another type of nitrifying filter that will provide additional ammonia nitrogen removal.

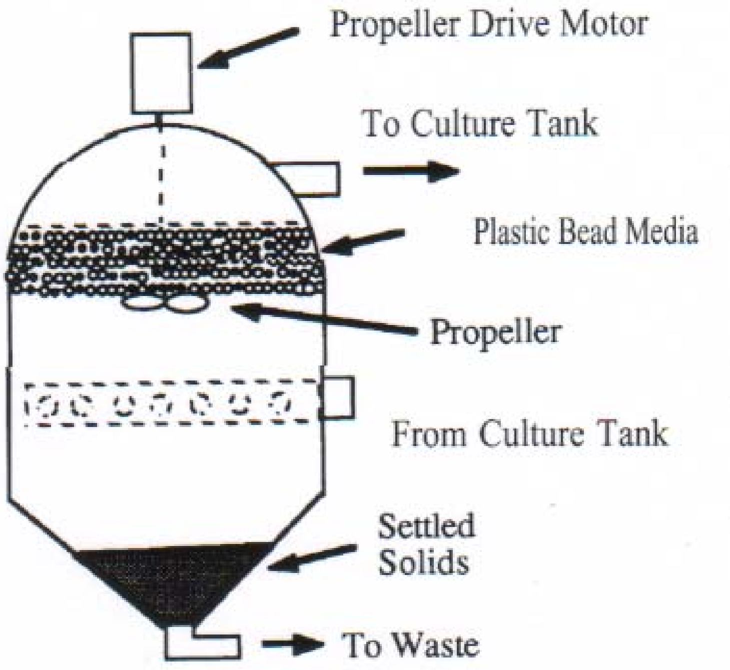

Figure 5: A prototype upflow floating plastic bead filter.

Alternatively, low-density plastic pelleted media has been used as biofilter substrate. In recent research and development efforts at Louisiana State University, a prototype "floating bead" filter has been developed for use in intensive fish production (Figure 5). The filter consists of a 12- nch (30 cm) deep bed of floating low density plastic beads (0. 12 to 0. 16 inches in diameter), used in an upflow filter configuration. The filter operates on the same principles as the upflow sand filter. Nitrification and solids removal are accomplished by passing water through the plastic bead bed. While the larger bead size has a lower specific surface area than the sand (grains) used in upflow sand filters, the unique bed "expansion" mechanism eliminates high flow rate requirements for cleaning the filter and uses substantially less water. A propeller, which is mounted within the bead bed, churns the beads when it is activated and shears off excess biological floc and waste solids. Upon completion of this bed expansion operation, given a short "resting" period (no pumping for 3 to 5 minutes), the beads refloat; waste solids settle to the cone-shaped bottom of the filter and are drained from the filter with minimal water loss. Due to low water loss during each filter backwashing, frequency maybe increased for rapid removal of oxygen demanding solids from the system. Additionally, the backwashing sequence can be automated through a timing circuit, reducing labour.

Fluidised bed filters

Fluidised bed filters are essentially upflow filters that are operated continuously in the expanded (backwash) mode. Fluidised bed filters generally use sand of smaller diameter and lesser density than upflow sand filters. Plastic beads with densities slightly greater than water have also been used successfully in fluidised bed filter applications. Theoretically, fluidised bed filters allow nitrifying bacteria to colonize the entire surface area of the filter media. The turbulent and well-oxygenated environment resulting from the high water flow rate through the filter provides superior conditions for the growth of nitrifying bacteria. The turbulent environment also provides continuous shearing of the bacteria from the media and makes the filter self-cleaning. The main advantage of fluidised bed technology is the high nitrification capacity in a relatively compact unit. Major disadvantages are no solids removal capacity (eg. they generate bacterial solids) and the high energy required to continuously fluidise the filter media.

Packed tower filters

Packed tower filters used in aquiculture systems have evolved from high rate trickling filters for sewage treatment. This type of filter consists of a water distribution system at the top of a reactor filled with media having high specific surface area and providing large spaces (Figure 6). As these filters are operated in a non-flooded configuration, they provide nitrification, aeration, and some carbon dioxide removal. The flow rate through packed towers is limited by the space available to pass water through the filter. Generally, packing media with more voids can pass a higher rate of flow per square foot of cross sectional surface area. The main disadvantage of packed tower filters is similar to that for fluidised bed and RBC technology. Solids are generated by the filters rather than being removed. Additionally, if the recycled water is not pre-filtered to remove suspended solids, packed towers will clog. As with RBC media, the weight of the biological growth on packed tower media should be considered in designing the support structure.

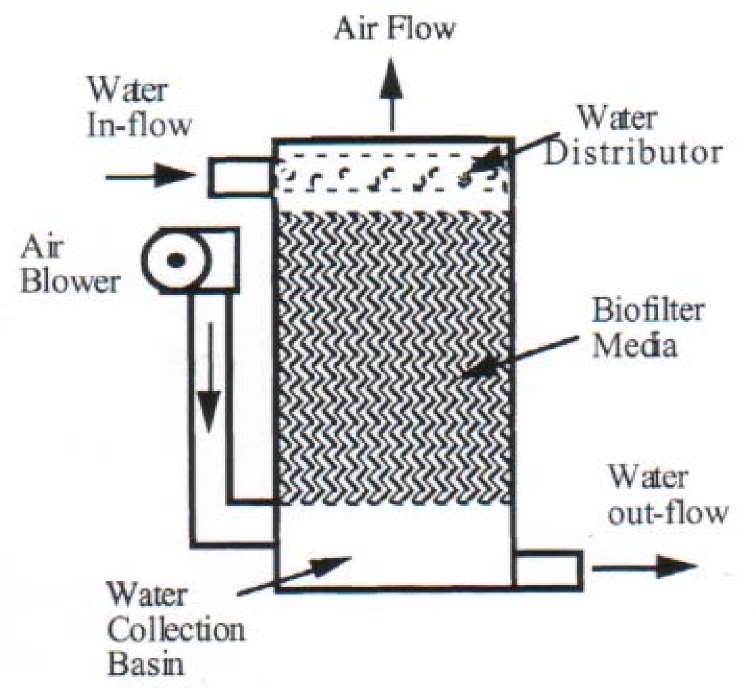

Figure 6: Packed tower nitrifying filter with forced gas exchange.

Dissolved gas control

Recirculating systems must be designed to maintain adequate dissolved oxygen (DO) levels and minimize carbon dioxide (CO_2) in the culture tank. Maintaining DO concentrations in excess of 6 mg/ L and CO_2 concentrations of less than 20 mg/L will contribute to reducing stress on most cultured species and improve growth rates. Information on some of the component options in aeration, degassing and oxygenation follows.

Aeration

The term aeration is used hereto refer to the dissolution of oxygen from the atmosphere into water as opposed to adding oxygen from a pure oxygen source. The process of pure oxygen gas transfer to water will be referred to as oxygenation.

Diffuser aeration

The diffusion of low-pressure air from "airstones" into the culture tank is not an efficient means of adding dissolved oxygen. In warm-water fish production applications with tank DO concentrations of 6 to 7 mg/L, the efficiency of air diffusers in the culture tank is poor with an effective oxygen transfer rate of 0.4 pounds O_2/hp hour (0.25 kg O_2/kw h). From a practical sense, in intensive fish culture, aeration using only diffuser airstones may create more turbulence than the cultured species can tolerate. For example, a production tank at 82^0 F (28°C) that receives 29.75 pounds (13.5 kg) of pelleted feed per day would have an oxygen demand of at least 0.31 pounds O_2/h (0.14 kg O_2/h). This tank would require a 0.33 hp (0.25 kilowatt (kw)) air blower supplying 21 cubic feet (0.60 m^3) of air per minute to 70 three-inch long (7.6 cm) airstone diffusers.

Mechanical aeration

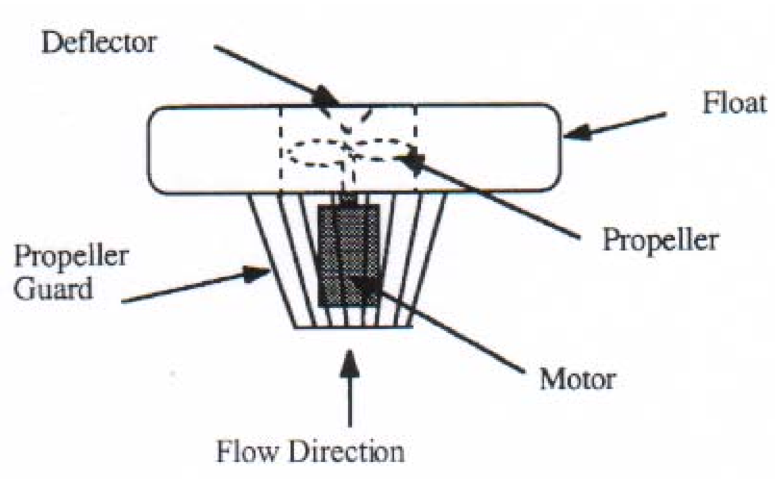

Figure 7. A typical vertical pump aerator

The principle of mechanical aeration is to move or splash water into the air to increase contact surface area between air and water. The larger contact surface area enhances the rate of oxygen transfer to the water. While the paddlewheel design is the most widely used and efficient means of mechanical aeration in ponds, their size and the excessive water velocities they create limit their use in tanks. Vertical pump aerators provide a viable alternative. A vertical pump aerator consists of a submersible motor with a propeller attached to the motor shaft (Figure 7). The motor and propeller are suspended beneath a float that has a hole in the centre and is sometimes fitted with a deflector plate. While operating, the propeller forces water through the hole In the float and Into the air. In most models, a screen to exclude fish from the intake surrounds the motor and propeller. In comparison with airstone diffusers, vertical pump aerators on average are 50 percent more efficient at transferring oxygen.

Packed column aerators

An ideal location to aerate and de-gas water (eg. remove carbon dioxide) is in the recycle flow-stream just prior to re-entry into the culture tank. In systems utilizing submerged biological filtration, the concentration of dissolved oxygen will most likely be lowest and carbon dioxide highest at the outflow of this component. Packed column aerators (PCA) are an effective and simple means of aerating water that is already in a flowstream. A packed column aerator can be identical in design to a packed tower-nitrifying filter. Water is introduced into a reactor filled with media. Proper design criteria include non-flooded operation and free air exchange through the reactor. Given a PCA influent DO concentration of 4 mg O_2/ L an effective oxygen transfer rate of 1.25 pounds O_2/hp h (0.75 kg O_2/kwh) can be attained. While this is a low transfer rate, keep in mind that the true "energy cost" for using a PCA in combination with an existing flow-stream is only the energy required to pump water 3 to 4 feet to the top of the PCA. If the PCA is to be used for carbon dioxide stripping a low pressure air blower should be used to force at least 5 times as much air (by volume) as water through the PCA media.

Oxygenation

Pure oxygen is used in recirculating systems when the intensity of production causes the rate of oxygen consumption within the system to exceed the maximum feasible rate of oxygen transfer though aeration. Sources of oxygen gas include compressed oxygen cylinders, liquid-oxygen (often referred to as LOX) and on-site oxygen generators. In most applications, the choice is between bulk liquid oxygen and an oxygen generator. The source selection will be a function of the cost of bulk liquid oxygen in your area (usually dependent on your distance from the oxygen production plant) and the reliability of the electrical service needed for generating oxygen on-site.

As in aeration, the addition of gaseous oxygen directly into the culture tank through diffusers is not the most efficient use of pure oxygen. At best, the efficiency of such systems is less than 40 percent. A number of specialized components have been developed for use in aquaculture applications. For an extensive review of component options the reader is referred to Boyd and Watten (1989). A review of the more commonly used components follows.

Downflow bubble contactor

A properly designed low pressure oxygen diffusion system is capable of effectively transferring in excess of 90 percent of the oxygen mixed through the component. One such system is a downflow bubble contact oxygenator (DFBC), also referred to as a bicone or a Speece cone. The DFBC system consists of a cone shaped reactor with water and oxygen input port at the top (Figure 8). As the water and oxygen bubbles move down the cone, the flow velocity decreases until it equals the upward velocity of the bubbles. This configuration and mode of operation provides a long contact time between the water and bubbles and nearly 100% absorption of the injected gas. The dissolved oxygen concentration of water leaving a DFBC can be as high as 25 mg/L given a system pressure of approximately 10 psi.

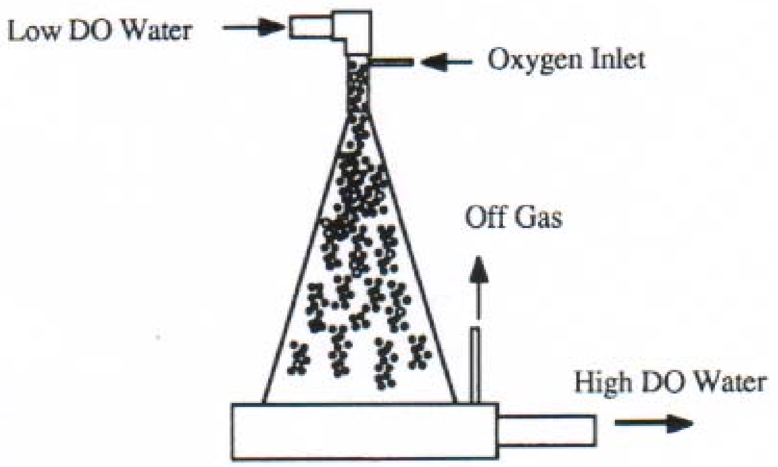

Figure 8: Downflow bubble contact aerator.

Counter current diffusion column

The counter current oxygen injection column is another simple low pressure technology for dissolving oxygen in water. This system utilizes a tall reactor column (approximately 10 feet long) oriented in a vertical direction. Low DO water flows downward from the top of the reactor while gaseous oxygen is introduced at the bottom through a diffuser. In this system the rate of rising oxygen bubbles is slowed by adjusting the downward flow velocity of the water. Then only few bubbles reach the top of the column before they are dissolved. The advantage of this component, as with the DFBC, is that it is simple, efficient, and low cost. Oxygen transfer efficiencies are less than those for DFBC systems.

U-tube diffusers

At elevated operating pressures, more oxygen can be absorbed by water and the rate of oxygen transfer is greater. A U-tube oxygen diffusion system is a common and energy efficient method of adding pressure to a flow-stream in aquaculture. A typical U-tube consists of a contact loop, usually a pipe within a pipe (Figure 9), buried in the ground to at least 33 feet in depth (the height of water required to add one atmosphere of pressure -14.7 psi). The contact loop is placed below tank level to minimize energy requirements rather than pumping water "up hill" to gain the extra hydrostatic pressure created by a column of water. Oxygen is mixed with the water at the entrance to the U-tube and travels with the current to the bottom of the water column. The additional pressure from the water column accelerates the rate of oxygen absorption Into the water. The principal advantages to this system are the low energy requirements for oxygenating large flow-streams and the resistance to clogging with particulate solids. The major disadvantage is the construction cost of drilling the shaft and installing the U-tube. Oxygen transfer efficiencies are generally below 70 percent with effluent oxygen concentrations of up to 250 percent of atmospheric saturation (15 to 20 mg/L).

Pressurized spray towers

There are numerous types of pressurized oxygen columns and spray towers. Spray towers are pressurized vessels that operate in a non-flooded mode. Influent water is sprayed as fine droplets into a reactor containing an atmosphere of enriched or pure oxygen gas. Given high enough operating pressures, this type of oxygenation system can produce oxygen concentrations in excess of 100 mg/L. Absorption efficiency Is approximately 55%, and these systems are susceptible to bio-fouling.

Pressurized packed columns

Pressurized packed columns are more commonly used than spray towers and are operated in a flooded mode (water fills the reactor). Influent water enters the top of a pressurized chamber that contains a media with a high specific surface area (much like packed towers). Oxygen gas is introduced at the bottom of the column and travels upward counter to the water flow. Oxygen transfer efficiency can range from 50 to 90% with effluent dissolved oxygen concentrations in excess of 100 mg/L. The major disadvantage of this system is one of biological growth building up on the packing media and the need for periodic cleaning.

Disinfection

Due to the high density of fish in recirculating systems, diseases can spread though the cultured population quickly. While treatment with chemicals approved for use with specific fish is possible, many of these chemicals can have a devastating impact on the nitrifying bacterial populations within the bio-filter and culture system. There are a number of alternatives to traditional chemical/antibiotic treatments used in recirculating systems. The continuous disinfections (destruction of pathogenic organisms) of the recycled water have been accomplished with ozone or ultraviolet irradiation.

Ultraviolet irradiation

When micro-organisms (including disease causing bacteria) are exposed to the proper amount of ultraviolet (UV) radiation, they are killed. The effectiveness of the UV sterilization depends upon the size of the organism, the amount of UV radiation, and the level of penetration into the water of the radiation. To be effective, micro-organisms must come in close proximity of the UV radiation source (0.2 inches or less). The presence of turbidity reduces the effectiveness even further. To assure the effectiveness of a UV radiation system, the water should be pre-filtered with some form of particulate filtration device.

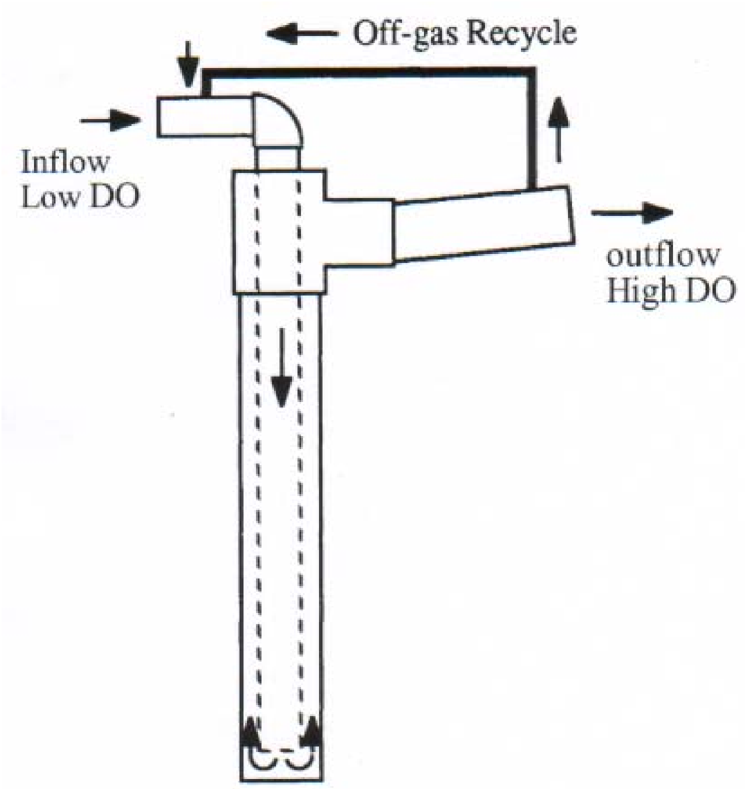

Figure 9: Typical u-tube oxygen diffusion design.

The most popular and effective type of UV "sterilization" unit is one with a submerged UV radiation source. In this type of unit, recycled water is passed by an elongated UV lamp (much like a neon light bulb). The lamp is inside a quartz glass watertight jacket and does not come in direct contact with the water. The UV lamp and quartz tube are held within a small diameter pipe through which the treated water flows. As water passes along and around the UV lamp, the microorganisms are exposed to the UV radiation. Keeping the quartz jacket clean is imperative to the proper operation of the unit. UV sterilization units are usually rated by their manufacturers according to their water flow rate capacity. Increased efficiency can be achieved by reducing the flow rate through a given unit. The main disadvantage of UV sterilization is the need for clean water with low suspended solids concentrations. Clear water is not always economically achievable in heavily fed recirculating systems. Additionally, the UV lamp output decreases with time and requires routine (costly) replacement. The main advantage of UV sterilizations is that they are safe to operate and are not harmful to the cultured species.

Ozonation

Ozone (O3) gas is a strong oxidizing agent in water. Ozone has been used for years in the disinfection of drinking water. The efficiency of the disinfecting action depends upon the contact time and residual concentration of oxygen in the water with the microorganisms. Ozone must be generated on site because it is unstable and breaks down in 10 to 20 minutes. Ozone is usually generated with either a UV light or a corona electric discharge source. There are numerous commercial ozone generation units available.

Ozone is usually diffused into the water of a recirculating system in an external contact basin or loop. The retention time of this "sidestream" process must be long enough to insure the proper microorganism kill rate and the destruction of the ozone molecule. Residual ozone entering the culture tank can be very toxic to crustaceans and fish. Ozone is also toxic to humans in low concentrations. Great care should be taken in venting excess ozone from the generation, delivery, and contact system to the outside of the building. Ozonation systems should be designed and installed by experienced personnel.

Summary

The previous discussion has outlined the major components and options used in recirculating aquaculture production systems. This is by no means a complete listing and the reader should be aware that new technologies are continually being developed.

It is important to keep In mind that one should not attempt to simply link the components outlined here and expect to have a properly operating system. Most commercially available systems are (or should be) the result of years of development so that each component is properly sized and integrated to maintain optimum system performance. When reviewing your options, always seek the assistance of a knowledgeable and experienced person, who has designed or operated an economically viable recirculating fish production system.

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