Exploring Recirculating Aquaculture Systems

Grade Level:	**Subject Area**:	**Time**:
5-12	Computer Science, Aquaculture, Biology	*Preparation:* 30-60 minutes *Activity:* 40-50 minute class *Clean-up:* 0-5 minutes

Student Performance Standards (Sunshine State Standards):

03.06 Interpret, analyze, and report data (SC.912.L.16.1; SC.912.N.1.1, 2, 3, 4, 6, 7; SC.912.N.2.2, 5; SC.912.N.3.1; SC.912.N.4.1; MA.912.S.3.1, 2; MA.912.S.4.2; MA.912.S.5.1, 2, 3, 4, 5).
09.05 Demonstrate the ability to work cooperatively (MA.912.A.1.4, 5; MA.912.F.5.1, 2, 7).
11.11 Identify aquaculture/mariculture species of commercial importance in your area (SC.812.L.17.16).
13.01 Identify and describe the qualities water should possess for use in aquaculture (LA.910.1.6.1, 2, 3, 4, 5; SC.912.L.17.In.a).
13.02 Explain how changes in water affect aquatic life (LA.910.1.6.1, 2, 3, 4, 5; SC.912.L.17.2, 3, 7, 10).
13.07 Identify/explain environmentally safe methods of aquaculture wastewater disposal (SC.912.L.17.2, 6, 8, 11, 14, 15, 16, 17, 18, 20; SC.912.N.1.1, 2, 4, 5. 6; MA.912.A.1.6).
21.01 Identify and use basic computer programs (LA.7.6.1, LA.1112.6.4.1, SC.4.N.3.1).

Objectives:

1. Students will be able to identify each component of an RAS.
2. Students will be able to explain how to piece together components of an RAS.
3. Students will be able to manipulate variables and make observations in a digital model RAS.

Abstract:

Recirculating Aquaculture Systems are becoming prevalent in the US aquaculture industry, and there are numerous advantages and disadvantages (from environmental, economical, and marketing perspectives) for using these systems. In order to be efficient, careful planning goes into the design engineering to achieve satisfactory and sustainable production levels. In this lesson, students will explore

an RAS computer tutorial and navigate to examine content summarizing RAS components and descriptions. There is a digital self-test within the RAS computer tutorial to assess understanding of system components and their functions. Students will be able to launch the RAS digital model and explore by manipulating variables (e.g., stocking densities, filtration efficiencies, feeding rates, temperature, etc.) and observing model simulation results. Through the use of this model, students will become knowledgeable about the utility of recirculating aquaculture systems (RAS) for aquaculture production, their advantages and disadvantages relative to cost, production efficiency and yield, and level of complexity. Students will be able to identify system components, their function within the integrated system, and their appropriate installation and maintenance.

Interest Approach:

Ask the students to identify the word *recirculating* as they think it is used in reference to aquaculture production. What kind of filtration would a RAS need? Is their aquarium (or classroom system) a RAS? Tell them a RAS should recirculate (re-use) 90% of its water each day.

Student Materials:

1. Personal computer (Mac or Win) with CD-Rom drive and internet connection

Teacher Materials:

Material	*Store*	*Estimated Cost*
Software (provided at no cost and teachers are free to make copies for student use)	Contact Amber Garr agarr1@hboi.fau.edu	Free

Student Instructions:

1. Review the *RAS Components* handout as homework and be familiar with the terminology.
2. Launch the RAS computer tutorial and navigate to examine content summarizing RAS components and descriptions.
3. Take digital self-test within the RAS computer tutorial to assess understanding of system components and their functions
4. Launch RAS digital model and explore by manipulating variables (e.g., stocking densities, filtration efficiencies, feeding rates, temperature, etc.) and observing model simulation results.

Teacher Instructions:

Preparations:

1. Confirm software is installed on computer workstations and running properly.
2. Teacher should also be familiar with RAS components and their functions prior to the lesson.
3. Assign *RAS Components* handout reading as homework.

Activity:

1. Circulate and facilitate student exploration of the software.

Post work/Clean-up:

1. No clean up other than regular computer workstation management.

Anticipated Results:

1. Students will manipulate variables in a digital model RAS to correctly identify each component of an RAS.
2. Students will know how to piece together components of an RAS.
3. Students will gain basic knowledge about system components and their functions.

Support Materials:

1. *Types of Systems* presentation
2. *Site Selection and Appropriate Systems* presentation
3. *Recirculating Systems* presentation
4. *Recirculating Aquaculture Systems Components* handout
5. IFAS Publication (SRAC 451): "Recirculating Aquaculture Tank Production Systems: An Overview of Critical Considerations" http://tal.ifas.ufl.edu/publications.htm
6. IFAS Publication (SRAC 452): "Recirculating Aquaculture Tank Production Systems: Management of Recirculating Systems" http://tal.ifas.ufl.edu/publications.htm
7. IFAS Publication (SRAC 453): "Recirculating Aquaculture Tank Production Systems: Component Options" http://tal.ifas.ufl.edu/publications.htm
8. IFAS Publication (SRAC 454): "Recirculating Aquaculture Tank Production Systems: Integrating Fish and Plant Culture" http://tal.ifas.ufl.edu/publications.htm
9. Colt, J. and B. Watten. 1988. Application of pure oxygen in fish culture. *Aquaculture Engineering* 7:397-441.

10. Creswell, R.L. 1990. *Aquaculture Desk Reference*. Van Nostrand Reinhold. New York, New York. 234 pp.
11. Landau, M. 1992. Introduction to Aquaculture. John Wiley and Sons, New York. 440 pp.
12. Losordo, T.M., M.P. Masser, and J.E. Rakocy. 1999. Recirculating Aquaculture Tank Production Systems: A Review of Component Options. SRAC Publication Number 453. USDA, Washington, D.C. USA.
13. Losordo, T.M. 1997. Tilapia Culture in intensive recirculating systems. Pages 185-208 in: B. Costa-Pierce and J. Rakocy (eds.) *Tilapia Aquaculture in the Americas, Volume 1.* World Aquaculture Society, Baton Rouge, Louisiana.
14. Spotte, S. 1979. *Fish and Invertebrate Culture: Water Management in Closed Systems*. John Wiley & Sons., New York, New York.

Explanation of Concepts:

Purpose and function of various RAS components
Application of concepts via manipulation of the RAS digital model

Support Materials

Recirculating Aquaculture Systems Components
Handout

Traditional aquaculture production requires large quantities of water — approximately one million gallons of water is needed to fill a one-acre pond. In contrast, Recirculating Aquaculture Systems (RAS), through water treatment and reuse utilize less than 10% of the water required by ponds to produce comparable yields. RAS are designed to provide excellent culture conditions, supporting high densities of the species being cultured, providing adequate feed, and maintaining good water quality. Poor water quality, while not necessarily lethal to the crop, and result in reduced growth and stress related diseases. Critical water characteristics include concentrations of dissolved oxygen, un-ionized ammonia-nitrogen, nitrite/nitrate-nitrogen, carbon dioxide, pH, alkalinity, and chloride levels. The by-products of metabolisms include carbon dioxide, ammonia-nitrogen, particulate and dissolved fecal solids, and uneaten food. Therefore, RAS must effectively: 1) remove solids (settleable and suspended), 2) control ammonia and nitrite-nitrogen concentrations, and 3) dissolved gasses. Effective RAS design is based upon components that address each of these water quality issues (Figure 1).

WASTE SOLIDS REMOVAL: MECHANICAL FILTRATION

Decomposition of solid wastes and uneaten or indigestible feed produce large quantities of ammonia-nitrogen and consume significant amounts of dissolved oxygen as they decompose (BOD – Biological Oxygen Demand). There are three categories of waste solids: 1) settleable, 2) suspended, and 3) fine or dissolved solids. Each requires a different RAS component to eliminate or minimize impact on water quality.

1) Settleable solids —probably the easiest to remove, and should be removed from the system as quickly and frequently as possible. Properly placed bottom drains in circular, or hex/octagonal, tanks with circular flow patterns, and minimal agitation will accumulate at the bottom and removed (in a separate flow stream of water or the flow leaving the tank). Depending on the flow rate in the tank, some solids can be removed from the surface, while slower flows may result in accumulation at the bottom of the tank (Figure 2). Another method of removal of settleable solids is to keep them in suspension (high flow or aeration/agitation) with an exterior settling tank/basin.

An advanced design for removal of solids, termed the ECO-TRAP™, utilizes a plate spaced just above the bottom of the tank where a small portion of the flow (5%) and settled solids leave via a separate flow stream, while 95% of the water discharges through a large strainer mounted at the top of the particle trap (Figure 3A). Outside of the tank, the solids flow from the sediment trap enters a sludge collector (Figure 3B); the waste particles settle and are retained, while the clarified water exits the top of the collector. The advantage of using an external settling basin is simplicity of operation, low cost of construction, low energy requirements; their disadvantage are space requirements (they are usually fairly large, cleaning requirements (if they are not cleaned regularly the solids will contribute to ammonia-nitrogen production), and water requirements for cleaning.

2) Suspended solids — Suspended solids are nothing more that settleable solids if they were in static water. However, due to their smaller particle size these solids remain suspended in the water column under most aquaculture conditions (e.g. current flow, aeration). Therefore, a different strategy is required to remove them (because they contribute to the ammonia-nitrogen concentrations as much as their larger counterparts. Suspended solids are usually removed through mechanical filtration utilizing fine-mesh screens or granular media.

Screen filtration — for suspended solids comes in a variety of configurations (Figure 4). What they all have in common is that the effluent water with solids passes through a fine-mesh stainless steel or polyester screen, particles impinge on the screen, and as it becomes clogged, a high pressure backwash flow removes the particles from the flow-stream and exits as wastewater (4A). The most common screen filter is the drum filter (4B) because it can be adjusted to solids loading, it has a larger surface area than standard disk filters, and it not likely to collapse under high loading rates of solids. A more detailed description of the design and operation of a drum filter is found in Figure 5. The main advantage of screen filter technology, over settling basins and other forms of swirl (centrifugal) separators is their small size and relatively low water loss during backwash. Inclined belt screen filters (5C) collect suspended solids in the water and then as a conveyor they are lifted out of the water and removed by a high pressure backwash sprayer.

Granular media filtration — removes suspended solids by passing wastewater through a bed of granular media, such as sand or plastic beads, where the solids either adhere to the media or become trapped in the interstices between media. As the media becomes clogged, solids are removed by a “backwashing” process at which the media is subjected to high-pressure, reverse flow causing the bed to expand and “boil”, thus releasing the solids through a waste flow-stream. The common sand filter, used in swimming pool filtration, has been adapted for higher solid loads with the use of floating plastic beads

(Figure 6). Solids are removed as the wastewater passes upward through the beads, and are later collected by stopping flow and using a propeller to expand the media bed to release the solids that settle to the bottom. Another bead filter design (called the "bubble washed" bead filter) resembles an "hour glass" with two chambers connected by a narrow passage (Figure 7). The bubble bead filter performs similarly to the propeller bead filters, but backwashing and removal of solids occurs when the water is lowered, the beads fall through the "washing throat". When the filter is refilled, the beads return to the top filter chamber while the solids remain in the lower sludge settling chamber.

Foam Fractionation — Some of the "super" fine particles and dissolved organic compounds are not easily eliminated from the culture system through mechanical filtration. A highly effective process for this purpose is called "foam fractionation" (also air-stripping or protein skimmers). Simply, air is bubbled up through a closed column resulting in foam at the surface. Dissolved organic compounds (DOC) are physically absorbed by the bubbles, and fine solid particles become trapped in the surface foam and can be removed (Figure 8).

AMMONIA AND NITRITE-NITROGEN CONTROL: BIOLOGICAL FILTRATION

Ammonia and nitrite-nitrogen are byproducts of the metabolism of protein in feeds (fecal material and decomposition of uneaten feed). If un-ionized ammonia (NH_3), and to a lesser extent nitrite, are allowed to concentrate in the culture system, they will become toxic to the animals in culture. In RAS, ammonia and nitrite-nitrogen must be removed at the same rate that it is produced in order to maintain a stable culture environment. Biological filtration (biofiltration) is the most commonly used method to control ammonia. It is based on the oxidation of ammonia to nitrite, and finally the less toxic nitrate, Two groups of bacteria are responsible for this conversion — *Nitrosomonas* (ammonia) and *Nitrobacter* (nitrite to nitrate). A substrate that has a high specific surface area (large surface area per unit volume) provides an attachment site for the bacteria. Some common substrates include sand or gravel, plastic beads, plastic rings, or plates.

Rotating Biological Contactor — Rotating biological contactors (RBCs) have been used in municipal wastewater treatment systems for decades, but recently was adapted for aquaculture systems. RBC technology is based on the rotation of filter media attached to a shaft partially submerged in water (@ 40% submerged) (Figure 9). The nitrifying bacteria (described above) coat the surfaces of the filter media, and as the cylinder rotates, it will spend 40% of the time submerged and 60% exposed to air. This is an important aspect of all biological filtration. The oxidation of ammonia/nitrite-nitrogen requires a great deal of oxygen (known as BOD or "Biological Oxygen Demand"), and without abundant availability of oxygen the biofiltration is compromised. Therefore, the alternate submergence in nutrient rich water, followed by exposure to the atmosphere, makes the RBC a very efficient biofiltration system. The tangential velocity of the outer edge of the rotation unit should be about 35 – 40 feet/minute, so for a 4-foot diameter contactor should rotate at 3 – 4 revolutions per minute (rpm). RBCs can be rotated by a motorized, gear-driven engine attached to a shaft, of they can be designed to be turned by water, similar to a water wheel, provided using an air-lift pump.

The advantages of RBCs are simplicity of operation, oxygenation and degassing CO_2, and self-cleaning capacity. Disadvantages include high capital costs and a tendency for mechanical problems (associated with the increased weight of the contactor, which may increase 10-fold over time). These systems, as a nitrifying filter, will have a design criteria of 3.6 kilograms of feed/day/m^3 of medium (0.189 pounds/day/ft^3) or 76grams of TAN/ day/m^3 of medium, assuming that 2.5% of food becomes TAN (total ammonia nitrogen).

Trickling Filters — Trickling filters are also an offspring of municipal wastewater treatment systems (Figure 10). This type of filter is comprised of media with a low specific surface area (less than 330m^2/m^3 or 100ft^2/ft^3), allowing for large voids (air spaces) within the media. Wastewater is delivered at the top of the filter, usually with a rotating distribution bar, and gravity feeds through the media. Since the filter media in trickling systems are not submerged, they not only provide biological filtration (nitrification) but also aeration and removal (or degassing) of excess carbon dioxide (CO_2). Trickling filters have a slightly higher efficiency 90 grams TAN/day/m^3 of medium, but they are relatively large and expensive, given the high cost of most filter media.

Fluidized Bed Filters — are essential mechanical sand filters operated continuously in the expanded (backwashing) mode so that the sand media becomes fluidized. An upflow of pressurized water to keep the sand grains in motion, and not in continuous contact with one another, providing an excellent substrate for nitrifying bacteria that allows the entire surface for colonization. In most cases, fluidized beds use a fine-grained sand (finer than typical mechanical sand filters), and in some cases plastic beads have been used. Usually, fluidized sand filters are tall columns, which minimize their footprint in the facility. Other advantages include the low cost of sand as a filter media, compared to plastic beads, rings, etc., and its high efficiency of removing TAN. Depending on the temperature, nutrient concentration, and size of the unit (and assuming 2.5% of feed converts to TAN), a fluidized bed filter should have a design criterion of 20 – 40 kg of feed/day/m^3 of medium or 1.25-2.5/lb/ft^3.

DISSOLVED GASSES

The adequate supply of oxygen (O_2) and the timely removal of carbon dioxide (CO_2) are critically important in maintaining healthy animals in aquaculture systems. Typical concentrations for a healthy environment for most fish is a dissolved oxygen (DO) level of at least 6 mg/L and a (CO_2) concentration below 25 mg/L. There are two terms commonly used to refer to oxygen delivery to the system: 1) aeration is used for the normal dissolution of oxygen from the atmosphere into the water (a typical air pump), while 2) oxygenation refers to the transfer of pure oxygen into the culture water.

Aeration — Aerating the water as it flows into a culture tank usually is insufficient to maintain a sustaining DO, and aeration within the tank is required. Paddlewheels, airlifts, propeller-aspirators all move the water into contact with the atmosphere and are quite efficient at transferring oxygen into the water. Air diffusers (airstones or a porous material) create small bubbles created under low air pressure from a "regenerative" type of blower. A rule of thumb for the transfer rate of diffused aeration is around.0.45 kg O_2/kW-h (0.75 lbs./hp-hr), and typical oxygen consumption rate of a well-designed RAS (one in which settleable solids are quickly and efficiently removed) can be estimated at 50% (or 0.5 kg O_2/kg of feed fed). So if 4.5 kg (10 pounds) of feed is applied over an 18-hour period, the estimated oxygen consumption rate would be 0.125 kg O_2/hour (0.28 lbs/hour). With an oxygen transfer rate of 0.455 kg O_2/kW-h (0.75 pounds/hp-hour), a diffused aeration system would require a blower of 0.275 kw (1/3 hp).

Packed Column Aerators — most effectively transfer oxygen and remove CO_2 (degassing) from the system flow stream after biofiltration and just prior to returning to the culture tank. Biological oxygen demand (BOD) is highest in biofilters, resulting in the lowest O_2 and highest CO_2 in the system at its outflow. Packed column aerators (PCA) are essentially identical in design to the trickling biological filter (Figure 10). Water is introduced at the top, and trickles over stacked media, while air is introduced at the bottom. A good rule of thumb (particularly for degassing) is to force at least five times as much air as water (by volume) up through the PCA media.

Oxygenation — Intensive rearing systems (high density of culture animals) may consume DO at a greater rate than can be reasonably provided through conventional aeration. In such cases, pure oxygen is transferred, usually from compressed oxygen cylinders, liquid oxygen (LOX) or on-site oxygen generators, the later two being the most common source. Adding pure oxygen to water through conventional diffusers is only about 40% efficient, and therefore costly. As such, several specialized components have been developed to increase oxygen transfer efficiency to over 90%.

Down-flow Bubble Contactor — also referred to as a bicone or Speece cone, introduces both water and oxygen at the top of the cone (Figure 11). As the water moves down, the velocity is reduced until it is essentially equal to the upward velocity of the bubbles, resulting in longer contact time and almost 100% oxygen transfer.

U-tube Diffusers — Increasing pressure in a flow stream is a cost effective way to increase transfer efficiency, and u-tube diffusers accomplish this by burying a pipe vertically in the ground to a depth of at least 10 meters (33 feet), the height of water required to add one atmosphere of pressure (14.7 pounds/in.^{2}). The contact loop is comprised of a pipe within a pipe, and the oxygen is introduced at the top of the loop. The top of the contact loop is below tank level, and buried to 33 feet, to minimize costs, compared to pumping water 33 feet high to achieve the same pressure (Figure 12). Therefore, u-tube diffusers are relatively inexpensive to operate (ideal for large flow rates), but have the disadvantage of construction costs for drilling and installation.

Low Head Oxygenation — is required where the source water is only slight above the culture tank; it is often used in raceways placed in series where the outflow of one raceway is just a few feed from the intake of the next. It is made up of a perforated, horizontal distribution plate and multiple, vertical contact chambers (Figure 13). Oxygen is introduced through to top of one contact chamber and exits into the adjacent one. The efficiency of this component is dependent upon the length of water fall, flow rates of both water and oxygen, the DO of the influent water, and the number of contact chambers. Packing the contact chambers with medium also will increase transfer efficiency.

DISINFECTION

An inherent disadvantage of RAS, as opposed to flow-through aquaculture systems, is the threat of disease spreading throughout every tank in the system. Use of chemical or antibiotic treatments can decimate the nitrifying bacteria living within the biofilter and the culture system. An alternative to chemical treatments and a common disease preventative is continuous disinfection of the recycled water using ultraviolet irradiation or ozonation.

Ultraviolet Irradiation — Bacteria and other microorganisms are killed when exposed to a sufficient amount of ultraviolet (UV) radiation. Therefore, the organisms living in water that passes in close proximity to UV will die and the water sterilized. Typically, a UV bulb (similar in design as a florescent light bulb) is housed in a quartz cylinder, which is then placed inside the flow stream pipe (the bulb does not come into direct contact with the water). The efficiency of UV irradiation is determined by: 1) the size of the organism, 2) proximity to the UV source (should be around 0.5 cm), 3) level of penetration of the radiation through the water (influenced by turbidity), 4) exposure time (flow rate relative to the length of the UV tube. The advantages of UV disinfection is that it is safe and is not harmful to the cultured species, nor does it affect the health of the bacteria within the biofilter. The main disadvantages are the requirement for clear water with low suspended solids, the cost of the UV bulbs, and the need for periodic replacement.

Ozonation — Ozone (O_3) gas is a strong oxidizing agent that has been used to treat municipal water supplies for years. In aquaculture systems with high levels of dissolved and suspended organic materials, the efficacy of ozonation may be limited. The efficiency of ozone to disinfect is dependent upon contact time with the microorganisms and the residual concentration of ozone in the water (after oxidizing all of those dissolved and suspended organics). Ozone is supplied by an on-site ozone generator (due to its short life span – 10 to 20 minutes), and usually through an external contact basin or loop. There, the exposure time can be adjusted to ensure sterilization and any residual ozone is destroyed. Residual ozone entering the culture tanks is highly toxic to crustaceans and fish; ozone in the air also is toxic to humans in low concentrations. Therefore, great care should be taken to vent excess ozone outside the building and generating systems properly installed.

PUMPS AND MEASUREMENT OF FLOW

Consistent flow of water through recirculating aquaculture systems, and the ability to alter its speed, pressure, and direction are critical to virtually all of the functions of the components. In some cases, the flow stream may need to be pressurized (for mechanical filtration). In other cases water retention time in culture tanks may be different than in side stream disinfection components. In almost all cases, moving water through gravitational means is the most cost effective, although the water still has to be pumped to some elevation to begin its journey through the system.

There are a variety of pump designs, each with certain engineering criteria for a specific function. These include reciprocating or piston pumps (like the old hand pumps at wells), rotary pumps with screws and gears, peristaltic pumps (accurate delivery, but at small volumes), centrifugal pumps (with impeller blades in a housing), and airlift pumps. Although each of these varieties may have a specialized use, centrifugal pumps are by far the most common for RAS use.

Air-lift Pumps — are not mechanical pumps, and they are most commonly associated with undergravel filters in small saltwater aquariums. Air-lift pumps consist of a tube that is upright and partially submerged in water with a bend (or elbow) parallel to the water's surface. Air is pumped into the bottom of the tube, usually through a diffuser (airstone), and the air-water mixture becomes lighter (less dense) than water in the tube, causing it to float or rise to the surface. As the mixture rises in the tube more water is drawn into the bottom of the tube as replacement for the outflow at the top of the tube.

Air-lift pumps can move moderate amounts of water, but very little head is generated. They are often used within culture tanks to create a current, either to modify the behavior of the culture organisms (swimming into currents) or to facilitate the collection of settleable solids. When rearing larvae in hatcheries, air-lifts may be used to keep planktonic larvae, and their food, evenly distributed in the tank.

The efficacy (or flow rate) of air-lifts to transfer water is dependent upon: 1) the volume of air being provided, 2) the diameter of the air bubbles (the smaller the bubbles, the greater the flow), 3) the diameter of the pipe (greater the pipe diameter the more flow), and 4) the degree of submergence of the pipe (the higher the percentage of submergence, the greater the flow rate).

The effective performance of recirculating aquaculture systems requires that each component within the system successfully functions in its role to deliver treated, high quality water back to the crop in the culture tanks. Although the design and construction of these components is important, it is no more important than their placement within the flow stream of the RAS. A generalized schematic of the major processes was provided in Figure 1, although there are several variations (and disinfection is not included). A generic sequence of components, starting at the culture tank, would be:

Settleable Solids Removal — The first line of defense before settleable solids breakdown into less manageable suspended solids or dissolved organics, and then ammonia. They are removed at the base of the culture tank or in a settling tank (sump) immediately after water leaves the tank. Water is gravity fed to the sump because any pumping would further breakdown particles to suspended solids.

Suspended Solids Removal — The next step in the water treatment process is the final removal of the remaining solids in the flow stream. This includes various types of screen filters, or granular media filters (Figures 4 – 7). In most cases, a pump is installed between component 1 and 2 to provide pressure to move water through fine screens and media and to provide head for elevation to the next component. Foam fractionation also occurs at this point, but it is usually not in this sequence of components (Figure 8). Typically, foam fractionators are either located as a separate side stream loop or placed directly inside the culture tank.

Ammonia and Nitrite-nitrogen Removal — After most of the solids have been removed, the clear water is transferred to the biofiltration component, either a rotating biological contactor (RBC, Figure 9), trickle filter (requires head Figure 10), or fluidized bed filter (pressurized). At this stage, *Nitrosomonas* and *Nitrobacter* bacteria attached to the filter medium oxidize ammonia (both ionized and un-ionized) and nitrite, reducing the concentration of these toxic compounds before the treated water is returned to the culture tank. The bacteria create a significant biological oxygen demand (BOD), and the effluent from biofilters has the lowest dissolved oxygen (DO) and highest CO_2 within the recirculating system.

Aeration and Degassing — Dissolved oxygen concentration usually needs to be increased to adequate levels (> 6 mg/L) before returning the treated water to the culture tank. Some systems will aerate the water as part of the flow stream, or aeration and carbon dioxide removal may take place as a separate contact loop (similar to a foam fractionation loop). These may include packed column aerators, down-flow bubble contactors, u-tube diffusers, or low-head oxygentation (Figures 11 – 14).

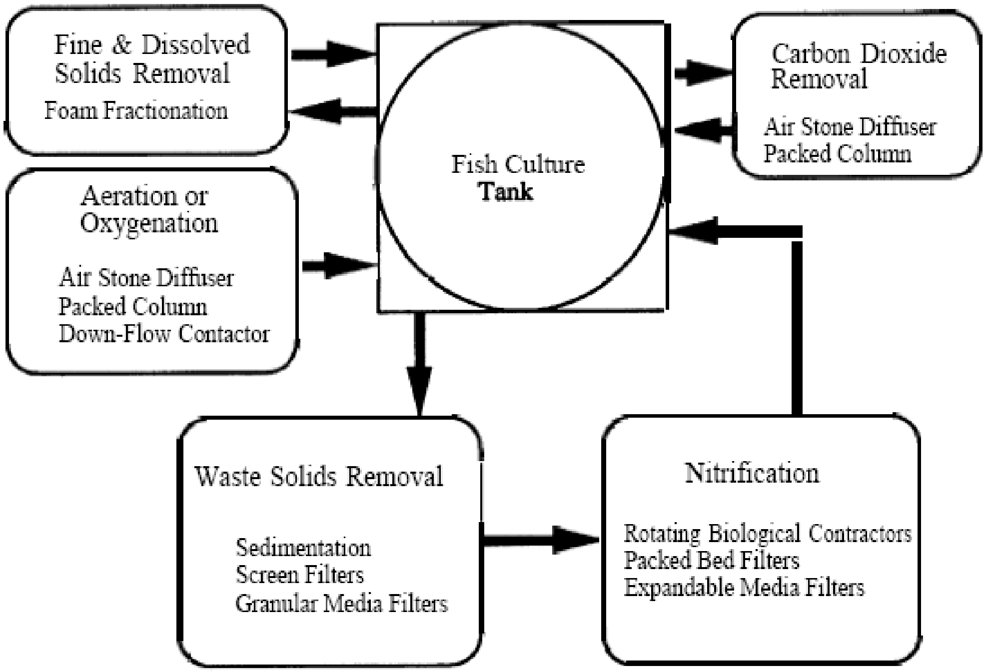

Figure 1. Required unit processes and typical components used in recirculating aquaculture production systems (SRAC).

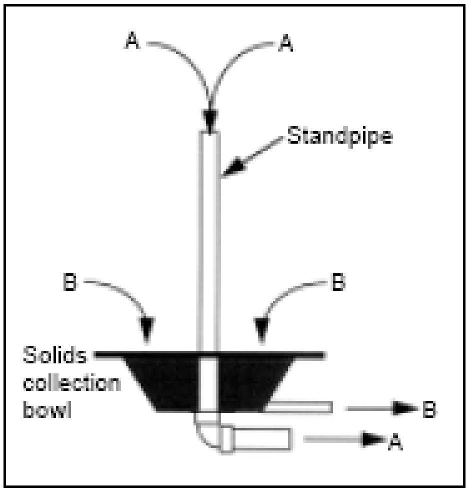

Figure 2. Double drain for removing settleable solids from a culture tank: A) suspended solids flow stream; B) settleable solids flow stream (after Losordo 1997).

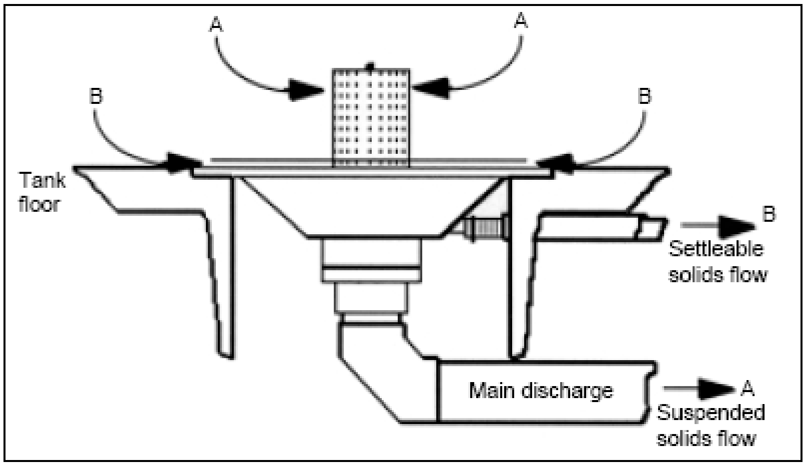

Figure 3A. ECOTRAP™ particle trap is a double-drain that concentrates much of the settleable solids in only 5% of the water flow.

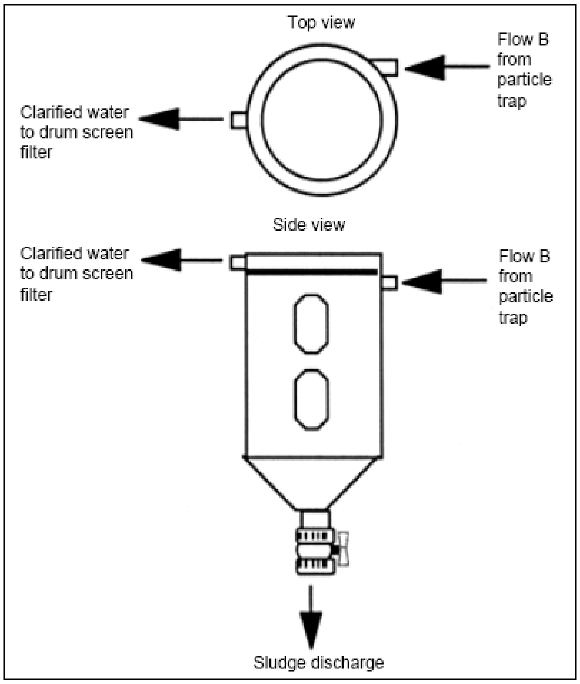

Figure 3B. The sludge collector that works in conjunction with ECOTRAP™ remove settleable solids from the flow stream (B).

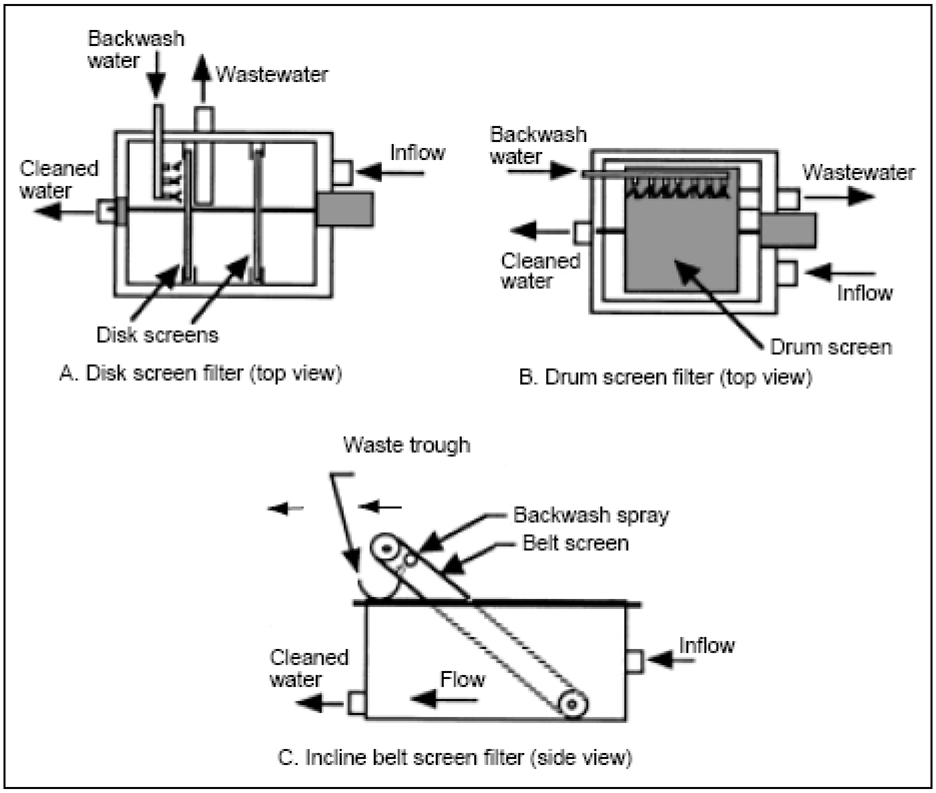

Figure 4. Three different screen configurations used to capture and remove suspended solids in recirculating aquaculture systems (RAS).

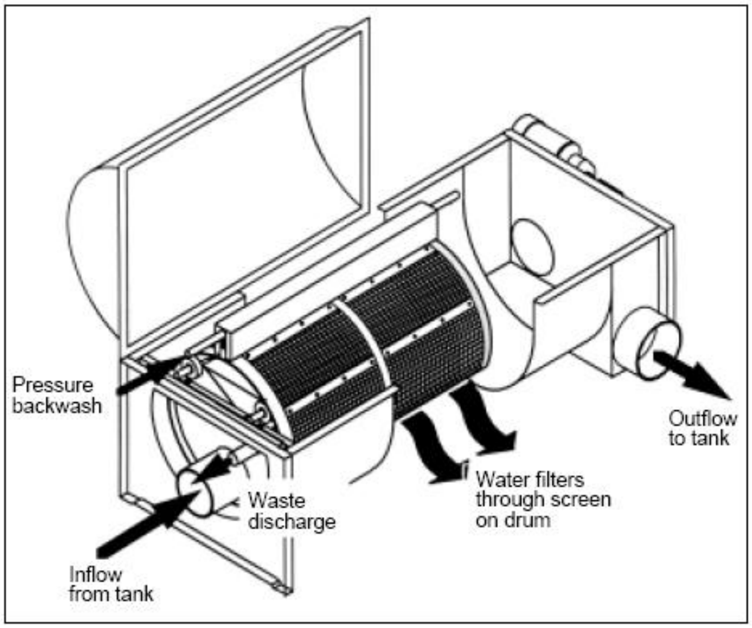

Figure 5. A cut-away and expanded mid-section of a drum filter to remove waste solids from an RAS.

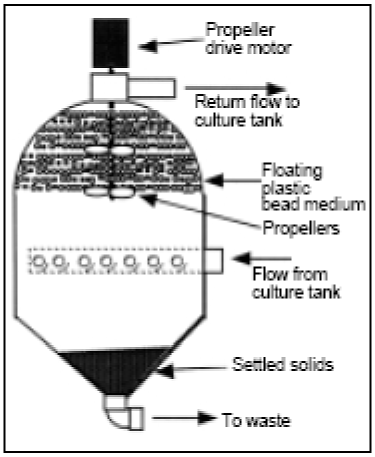

Figure 6. Solids entering this bead filter flow upward and are captured in the spaces within the floating media. A propeller is used to expand the media bed during backwashing, and the settled solids are removed from the drain at the bottom of the filter unit.

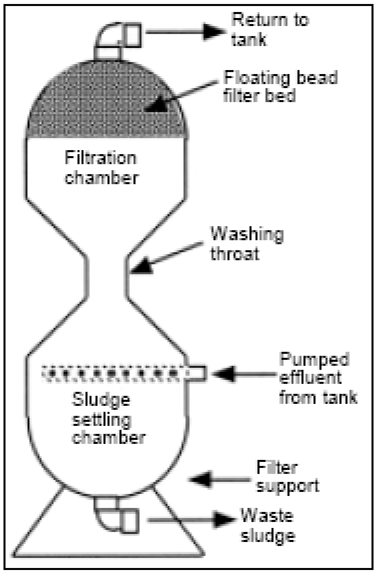

Figure 7. The bubble bead filter performs similarly to the propeller bead filters, but backwashing and removal of solids occurs when the water is lowered, the beads fall through the "washing throat". When the filter is refilled, the beads return to the top filter chamber while the solids remain in the lower sludge-settling chamber.

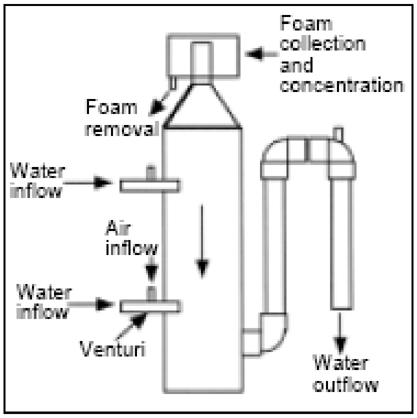

Figure 8. A pump driven, venture foam fractionator design. (after Losordo, 1997)

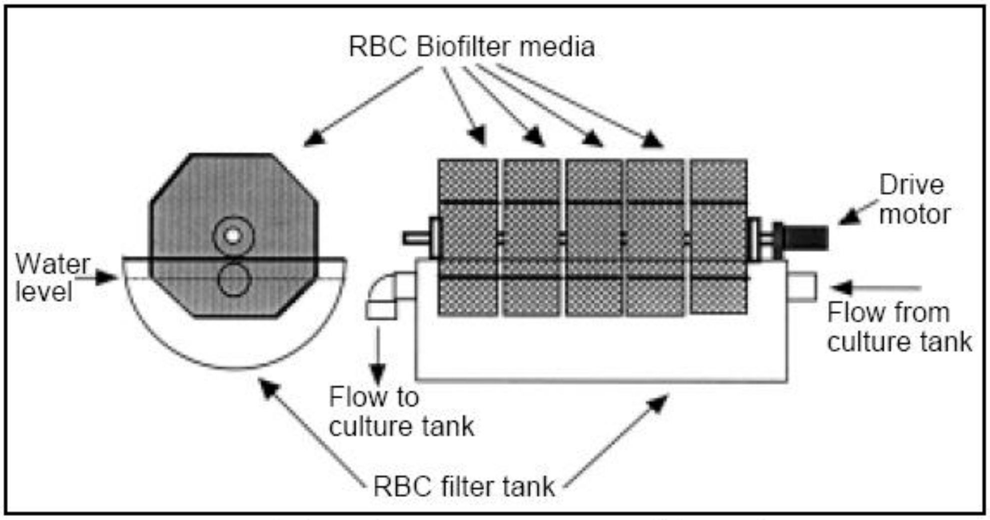

Figure 9. A rotating biological contactor (RBC) unit powered by an electrical motor.

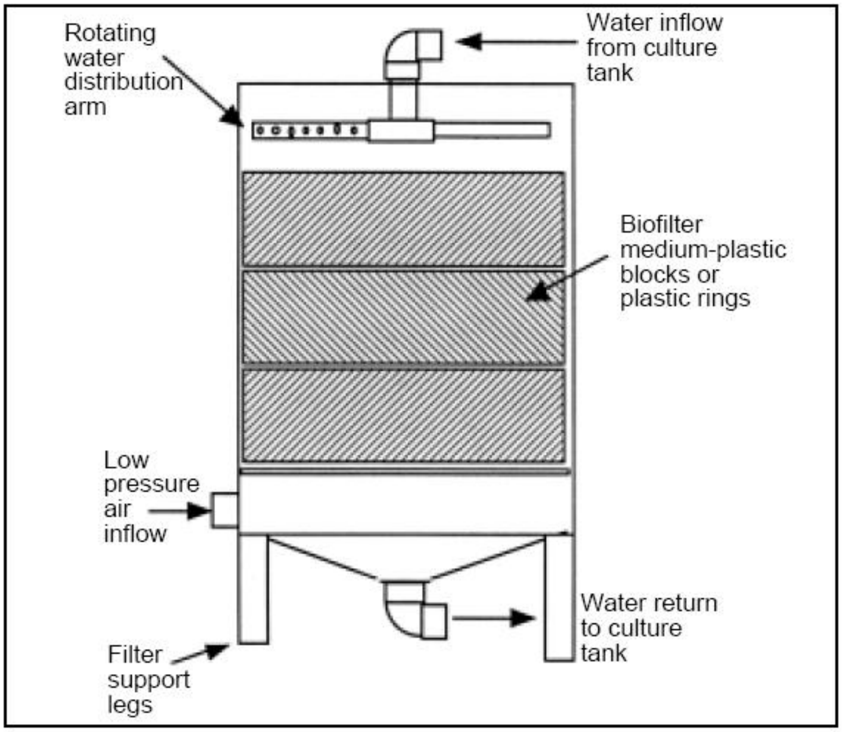

Figure 10. A trickling biological filter utilizes non-submerged filter media that receives wastewater evenly distributed through a rotating distribution bar.

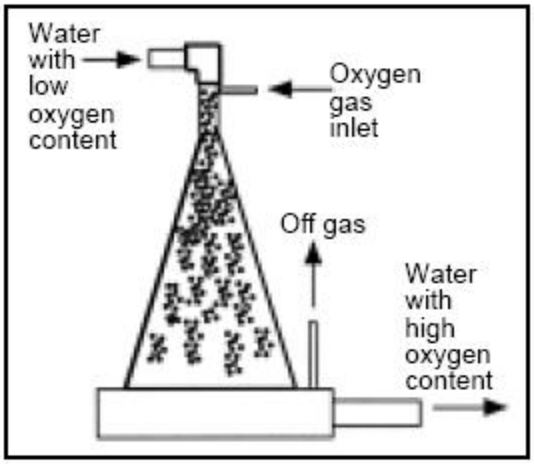

Figure 11. A down-flow bubble contact aerator (after Colt and Witten 1988).

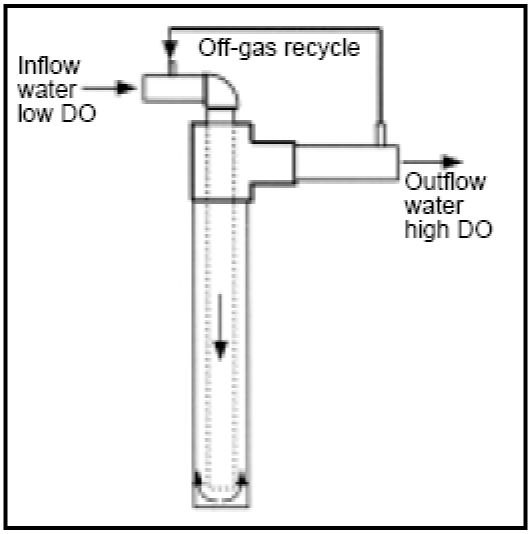

Figure 12. A typical U-tube oxygen diffuser design (SRAC 1999)

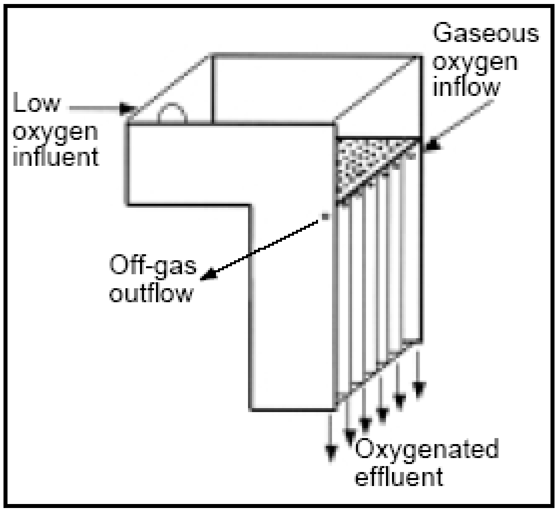

Figure 13. Multi-staged low head oxygenator with front plate removed to show internal compartments (after Losordo 1997)

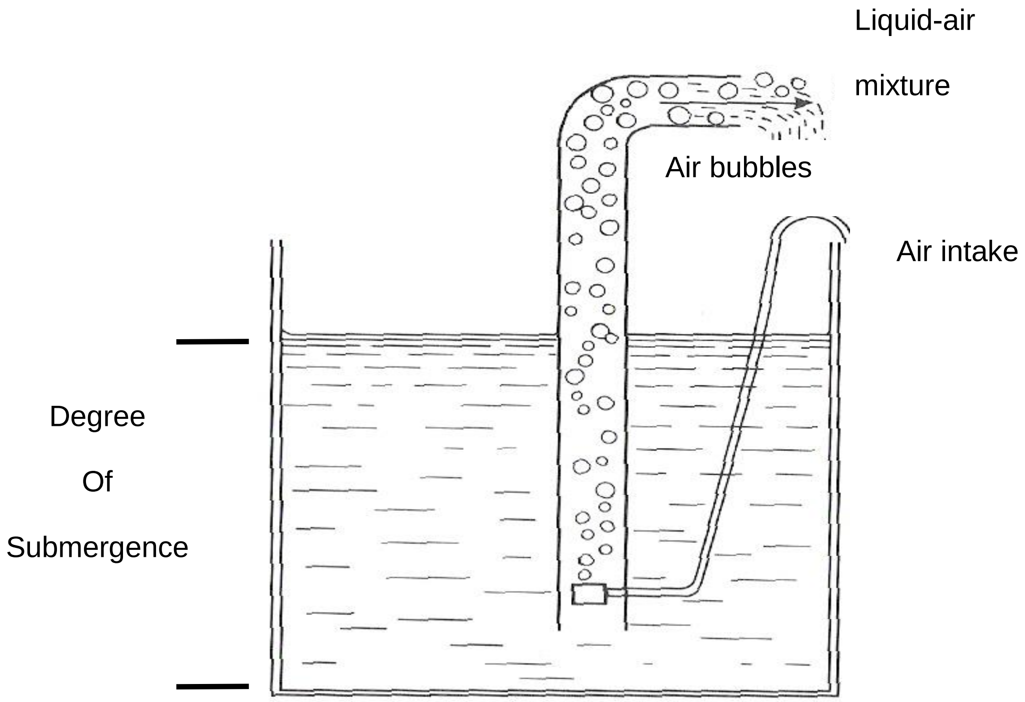

Figure 14. An air-lift pump. Flow rate is a function of pipe diameter, air flow, bubble size, and degree of pipe submergence.