Waste Management in Closed Recirculating Aquaculture Systems

By Steven D. Van Gorder
Aquamarine Fish Farms, Inc.

Aquaculture, as with any form of animal agriculture, produces waste products. But unlike with terrestrial animals, the wastes are in a dilute liquid form. These wastes are generated in proportion to the scale of production, specifically the amount and quality of the feed provided to the fish, and to the efficiency of the methods which are used for growing the fish. The management of aquaculture wastes has become a topic of intense regulatory scrutiny, as the Environmental Protection Agency develops new waste management regulations for the entire industry. The resulting legislation will have an increasing impact on the economics of raising fish in the future.

In the United States, “traditional” forms of aquaculture have included catfish farming in ponds, trout farming in flow-through raceways, and salmon farming in cages. Most of the finfish cultured here are still produced by these methods. Each of these techniques results in a direct environmental impact, mostly in the form of the release of organic nutrients as solid wastes (fish feces), and dissolved wastes (nitrogen and phosphorus). And each uses either public or private waters to provide for the dilution and discharge of the wastes. However, increasing competition for water use, and the responsibility of government agencies to predict and regulate environmental impact, is resulting in more restrictive limits being set on water use and wastewater effluents.

All methods of aquaculture will have to adjust their management techniques to meet these regulations. The traditional aquaculture systems, due to the inherent qualifications of their design, will have significant difficulties doing so. These methods rely heavily on dilution to provide acceptable water quality for fish production. The subsequent dilution of the waste products makes its concentration and removal proportionately difficult and expensive. And while new methodologies are available which can provide for a more concentrated waste effluent, the costs of renovation and retrofitting of these aquaculture systems may be prohibitive.

Alternative methods for culturing fish have now been developed using recirculating technologies to recycle the culture water, thus reducing the volume of water required to produce a specific biomass of fish. Using these alternative methods of aquaculture have reduced the demand for the tremendous volumes of high quality water previously necessary for the production of commercial quantities of fish, and have resulted in increased options for managing and treating the levels of wastes produced.

In order to compare their water resource requirements, it is important to define the terms used in describing recirculating aquaculture systems. For instance, recirculation can refer to the reuse of water in flow-through systems, in which no water control technologies are employed except water exchange. A number designating percent recirculation in these instances denotes the amount of water that is reused after a single pass via pumping, thereby increasing the volume of water available per pass. Semi-closed systems employ various water treatment technologies, but may still require the exchange of one or more tank volumes daily. A “closed” recirculating system describes a system which exchanges less than 10% of the total system volume daily.

For the purposes of comparison of flow-through, semi-closed and closed systems, and the impact on waste management requirements, consider the following. A single trout raceway with a volume of 20,000 gallons of water and receiving 500 gallons per minute will use 720,000
gallons of water each day to maintain water quality. A semi-closed recirculating system of the same volume and capacity may be provided with appropriate tank design, biofiltration, clarification and aeration/oxygenation technologies to reduce the necessary influent volumes to a level replacing the tank water only once per day (14 gpm). A closed aquaculture system of the same volume, which recirculates 95% of its water, will use a total volume of only 1000 gallons per day, and require a influent flow rate of only 0.7 gpm.

These comparative effluent volumes are extremely important, as they relate to the waste management considerations. For the flow-through system, all of the wastes generated by the fish are eliminated from the culture tank in a very dilute form. Since these suspended solids must be concentrated from the total effluent volume of water, the methods used will require significant engineering adaptation to capture the waste solids, and will therefore be extremely expensive.

The recirculating technologies used by the semi-closed and closed systems result in the accumulation of the solid wastes in a concentrated form. The techniques which are then available to remove these solids are simplified and much less expensive. However, for dissolved wastes the treatment methods available to semi-closed and closed aquaculture systems are less comparable, considering the volumes of dilute effluent discharged. Closed systems produce a concentrated solid waste as well as a concentrated dissolved waste, both of which can be successfully and economically treated. Semi-closed systems produce a significant volume of dilute effluents that may be more difficult to treat.

The recirculating technologies, which are used in closed systems, when coupled with good management practices, also reduce the actual levels of waste generated. As with all aquaculture systems, it is essential to use good quality feeds, eliminate excessive fines in the feed, and optimize the nutritional aspects of the feed for each species cultured. Beyond this, the use of controlled-environment systems allow for more effective feed management strategies which control the number of feedings per day, eliminate uneaten feed and under-feeding, and maintain optimal water quality and feed conversion, which will result in more efficient growth, and a reduction in wastes.

However, the concentrated wastes in the effluents from closed systems represent as much danger to the environment as the dilute wastes from flow-through systems, if released. It is the concentration of these wastes through the operation of the internal water treatment systems of closed systems that provide for a number of alternative waste management strategies.

The reduction of the volume of water replaced each day from a system, and the subsequent concentration of the solids within the effluents, defines the potential for waste management in aquaculture systems. The more “closed” a system is, the easier will be the management of the wastes. However, there is a significant difference in the sophistication, and the level and cost of technologies required to maintain water quality in recirculating systems using more or less water. The dilution required by semi-closed systems significantly reduces the water quality control requirements of the recirculation technologies. Even within closed systems, the design and management requirements of a 90% recirculating system are greatly reduced from those of a 95-100% closed design. The increased costs of a recirculating system design which recycles a higher percentage of its water daily, must be balanced against the advantage of reduces water use, increased energy conservation, and the ability to deliver a more concentrated effluent stream.

Discharge to Municipal Sewer Systems
Closed recirculating systems, which are constructed in urban or suburban locations, should be eligible to release their wastes directly to the municipal sewer. The level and type of waste produced is seldom a restrictive consideration, as long as the municipality has the capacity to receive the volumes produced. The costs involved with this method of waste management must be considered, and will vary significantly from place to place.

Larger scale systems may consider the construction of their own self-contained waste treatment facility. The use of an on-site Sequencing Batch Reactor (SBR) can provide economical treatment of aquaculture wastes through both aerobic and anaerobic processes. This results in the control of the solid wastes (BOD and COD) and dissolved wastes (nitrates and phosphates) required for the direct elimination of the entire water volume into adjacent waterways.

**Land Application**

Rural aquaculture systems can discharge their wastes onto agricultural lands at an irrigation rate specified by the USDA, EPA and/or State Department of Natural Resources. With irrigation capabilities, systems adjacent to agricultural sites should have no problem discharging their wastes during temperate months. However, this is a seasonal approach, since the waste cannot be applied during winter months. It may be necessary to provide for the accumulation of the effluents during the off-season, for application to farmlands in the spring. Again the concentration of the waste will greatly affect the volume of the holding facilities involved.

In some cases, it may be possible to continually apply aquaculture wastes to such ground cover as is available on sod or tree farms. It will be necessary to work with the local agriculture extension agency to determine the potential for land application of fish culture wastes.

**Discharge to Waterways**

There are a number of options available to prepare the aquaculture effluents to be released to ponds, streams, lakes, rivers or other bodies of water. Release of effluents to surface waters requires an NPDES (National Pollution Discharge Elimination System) permit. This permit will require the reduction of the BOD, nitrogen and phosphorus within the effluents to specified levels. A combination of techniques including further solids concentration (dewatering), aerobic stabilization, hydroponics, and the use of submerged or constructed wetlands may be necessary to produce effluents of sufficient quality that they can be discharged to the environment.

The following example demonstrates the preparation of the wastewater effluents from a closed, recirculating aquaculture system for discharge.

**Solids Concentration**

A closed system employs various techniques within its water treatment design to concentrate the solid wastes of the fish. A self-cleaning tank employing the proper flow design must deliver the entire tank volume for clarification at a rate of more than once every hour. The clarifier must remove the solids from the water flow continuously, and then eliminate this collected waste from the system in a concentrated stream. For example, a microscreen clarifier with a 60 micron sieve will deliver an effluent stream with 100% of the waste suspended solids produced by the fish daily, within 5-10% of the system water volume.
The concentration of the effluent stream can be further increased using various methods, including inclined plate separators, swirl separators or settling basins. These methods are more or less effective depending on the effectiveness of the system in concentrating the wastes in a minimum effluent volume.

Once the solids are separated from the effluent stream, the supernatant must also be considered for treatment. The levels of nitrate and phosphate will determine whether this portion of the waste stream must be further treated before release. Treatment options available include anaerobic digestion and hydroponic removal.

**Aerobic Stabilization**

For most waste treatment applications, after concentration of the waste solids, the resultant slurry of concentrated wastes must be further treated. To prepare the wastes for land application, if significant odors are a concern, the slurry must be vigorously aerated as it is accumulated. This "stabilizes" the waste and results in the reduction of any odors during surface application. This process is also necessary when considering application to a constructed wetland or reed bed treatment system.

The concentrated wastewater from the aquaculture systems can be accumulated within large reservoirs, and aerated via compressed air pumps. One reservoir is filled, then continually aerated for 30-40 days, while a second reservoir begins the accumulation process. Once fully stabilized the first reservoir can be applied to the reed bed, and is available again to accumulate the continually developing aquaculture wastes.

**Reed Beds**

Perhaps the most promising alternative method of aquaculture waste management is the use of constructed wetlands. The "reed bed" has been used as an economical approach to the handling, dewatering and disposal of municipal wastewaters for many years, and seems ideally suited to the management of aquaculture wastes. The reed bed uses conventional sludge drying beds planted with a common reed. Liquid sludge is applied periodically for up to 10 years, with the end product, dried solids finally disposed of as agricultural fertilizer or landfill.

The reed system is composed of common reeds (Phragmites communis) planted in conventional sludge drying beds. The root system grows through the dried and stored sludge, and through an upper sand layer. The plants supply oxygen to the root systems, which harbor a rich bacterial environment, which feeds on the organic matter and promotes vigorous plant growth. The root system keeps channels open to the sand and lower gravel layers of the reed bed allowing gravity drainage of the beds.

The sludge is further dewatered through evaporation and the transpiration of water through the reed leaf systems. The waste solids layer becomes completely dry between applications, resulting in a crusty surface devoid of odors, and allowing for years of accumulation within the concrete confines of the reed bed.

The concentrated and aerobically stabilized wastes are applied about every 30 days. This "dosing" of the beds provides the necessary time for the drying of the sludge between applications. There are no odors involved because the sludge has been thoroughly stabilized through the aeration process during accumulation.
Most of these processes can be mechanized, and reed beds can significantly reduce the man-hours and costs required to dewater and treat sludge. Actual operation includes application of the liquid sludge and harvesting of the dormant plant material after the growing season. The plants are cut off approximately 20 cm above the sludge surface, gathered, and then removed. This plant material is removed so that new shoots can emerge from the root system in the next season. The beds will continue to operate throughout the winter, with oxygen supplied to the lower layers of the bed through the cut stems of the reeds.

Sludge can be accumulated in the beds until it reaches a depth of approximately 1 m. This may take 8 to 10 years. The sludge can then be removed using mechanical means such as a backhoe, and applied as landfill, or as fertilizer.

**Hydroponics**

Besides resulting in the accumulation of concentrated solid wastes, aquaculture in closed systems also produces concentrated dissolved wastes, specifically nitrates from the biofiltration process. Phosphates are also accumulated in sufficient levels to support the production of vegetation. The hydroponic recovery of these nutrients derived from aquaculture processes, through the integrated culture of aquatic or terrestrial vegetables, is called “aquaponics”.

The use of aquaponics as a waste management alternative involves the removal of the dissolved nutrients from the aquaculture effluents, following the removal of the solids. Some closed systems exclusively use hydroponic techniques as the biofiltration component of the design, with the plant roots directly removing ammonia from the culture water. However, the balance of fish culture to hydroponic vegetable production in this case is strongly skewed towards the production of vegetables. A very limited level of fish production results in sufficient dissolved nutrients for acres of aquaponic vegetable production.

There are much more appropriate plants for the treatment of aquaculture wastes than those terrestrial vegetables grown hydroponically as secondary crops, such as lettuce, tomatoes or cucumbers. Wastewater treatment using aquatic plants such as water hyacinth and watercress demonstrates significant potential towards polishing water for subsequent reuse or discharge. Water hyacinth especially is extremely efficient at absorbing dissolved nutrients and transforming it into plant biomass. Solids must first be efficiently removed from the wastewater, or the roots of the aquatic plants will be quickly fouled. But after sufficient contact with the roots of the plants, the wastewater stream can be transformed into an extremely clear effluent, sufficiently treated for discharge.

Of course, plants like water hyacinth simply transform the wastes from a dissolved form into plant biomass. The resultant quantities of plant material must be continually harvested and disposed of, usually as compost, and subsequently land applied.

It is tempting to further reuse the effluents flows derived after hydroponic treatment within the aquaculture systems. The water appears pristine and free of any pollutants (assuming organic hydroponic methods were employed). However, if the reuse of hydroponically treated effluents precludes the addition of adequate makeup water to the aquaculture systems, there may be deficiencies in various micronutrients necessary both to the fish, and to the bacteria within the biofilters. Under extremely high levels of recirculation, approaching 100%, many species of fish will demonstrate various problems, presumably due to the presence of a concentration of dissolved metabolites, or to the lack of some trace elements. In closed aquaculture systems, the
addition of a relatively small percentage of make-up water may be the least expensive treatment process available.

SUMMARY

Recirculating aquaculture systems are often considered too expensive or too impractical to serve the aquaculture industry at an influential level. Despite the many advantages afforded them, including water conservation, complete environmental control, the production of a quality-controlled product, with increased marketing advantages of the product, the increased cost and complexity of such systems have delayed their incorporation into the aquacultural mainstream.

However, as commercial aquaculture facilities are required to more effectively treat their effluents before discharge, the advantages afforded to closed, recirculating aquaculture systems for effective waste management alternatives, are becoming increasingly apparent and important. Before long it may become obligatory to apply recirculating technologies to all land-based methods of fish farming. And as the true cost of raising fish using traditional methods increases accordingly, the cost of using recirculating technologies will be considered much more reasonable. This process will transform what has often been considered an impractical method of aquaculture, into the most environmentally, and even economically, acceptable culture method available.