Wastewater treatment technology in aquaculture

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The aquaculture industry has become an axis for criticism from environmental groups because of an apparent negative effect on the environment from the release of wastewater (Doupe *et al*. 1999). The fish farming industries that are releasing wastewater into the environment of Canada must obtain a certificate of approval to comply with the Water Resource Act for resource protection and sustainable development (Moccia *et al*. 1997). An aquaculture industrial management plan has been developed for the treatment and disposal of wastewater in recent years (Fernandes *et al*. 2001). Aquaculture not only requires the supply of clean water, but also, the release of clean water into the environment is important for the protection of the aquatic environment and reuse of water sources. Enormous pressure is exerted from environmental control institutions worldwide for wastewater treatment in aquaculture before water is released into the environment (Bunting 2001). Volumes of literature exist on the prospective environmental effects on marine and freshwater systems from aquaculture industrial operations based on the rapid growth of the industry in the world (Boyd 2001). Hyper-nutrification and eutrophication with resultant algal blooms, oxygen depletion and deprivation of benthic habitat in the surrounding area of open cage operations with no waste collection system and limited flushing are the principle wastewater issues (Boyd 2001). Thus, the aquaculture industry has recognized that, in addition to the requirement of a continuous supply of clean water, they also must develop technology for the treatment of wastewater. The development of wastewater treatment technology in the aquaculture industry will minimize ecological and social problems and provide greater long-term economic safety for operation of the industry (Doupe *et al*. 1999).

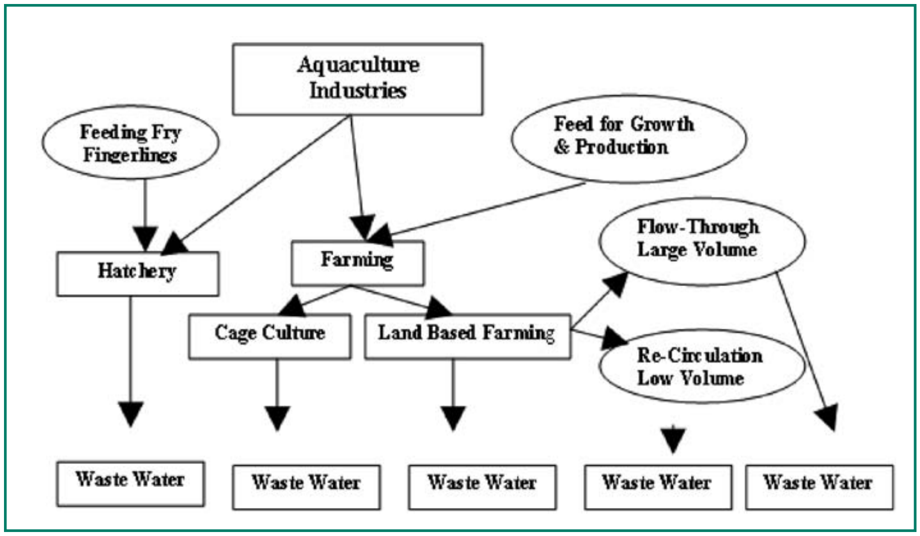

Fig. 1. Production of wastewater from aquaculture industries.

Aquaculture Wastewater

Wastewater generation in aquaculture is a result of its operation from hatcheries and farming systems. As shown in Figure 1, generally there are three operating systems for aquaculture. The quantity and quality of wastewater from aquaculture operations vary according to the type and location of the aquaculture system (Dochoda *et al*. 1999). The wastewater from a hatchery is different from that of a production farm in terms of quality and quantity of waste (Oberdorff and Porcher 1994). Pond or tank systems, such as those characteristically used to raise catfish and tilapia, also need better technology for control of wastewater (Rebecca and Triplett 1997). The cage and pen systems, used for the production of salmon and other species, are comparatively open to natural water and, therefore, can release wastewater into the environment, entirely untreated (Rebecca and Triplett 1997).

In intensive commercial aquaculture operations, the sources of wastewater are primarily from uneaten food and fish feces, which is 30 percent unconsumed dry feed and 30 percent consumed food egested as feces (Axler *et al*. 1996). The production of aquaculture waste in water can be estimated on the basis of several factors: growth, nutrients, energy gains, energy nutrient needs and excretory feed waste output by the systems in operation (Cho and Bureau 1997). Bioenergetic models and the Fish-PrFEQ software have been developed for the estimation of production, feeding ration and waste output in aquaculture (Cho and Bureau 1998). The waste in water from the aquaculture industry can be classified in two categories, soluble and solid waste.

Aquaculture Wastewater Composition

Aquaculture wastewater composition is directly related to the nature and quantity of feed fed to the species being reared and also, to the type system in operation. The major sources of waste from aquaculture consist of untreated water with excreta, fecal matter and uneaten feed from fish. However, it has been estimated that total organic output from a salmon farm may be close to 2.5 tons wet weight per ton live weight fish (Ackefors and Enell 1994). There are two major elements in aquaculture wastewater, nitrogen and phosphorus (Axler *et al*. 1996). The production of 20 kg N/ton and 3-4 kg P/ton of fish production has been seen in Atlantic salmon farms (Einen *et al*. 1995). The food and fecal waste constitute the majority of the suspended solids. Thus, aquaculture waste depends on the feed composition and feeding technology. If the concentration of suspended solids (SS), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), total nitrogen and total phosphorus in the outlet from the aquaculture facility are lower than in the inlet, it means that wastes produced are retained within the system. Thus, wastewater treatment technology in aquaculture is not only dependant on the system of culture but, also on the composition of wastewater produced by the particular fish production facility.

Wastewater Treatment Technology for Cage Culture

Cage aquaculture systems differ from traditional land-based aquaculture facilities. The wastewater production from cage aquaculture can be classified into two main sources: soluble waste and transport or dispersal waste from cages (Tlusty *et al*. 2001). Organic molecules may diffuse into the water making them subject to subsequent dilution after release from the cage (Schnoor 1996). The second waste is a voluminous group that is made up of dispersal particles larger than those considered to be soluble (Tlusty *et al*. 2001). Various apparatus designed to collect the waste from cages have been developed. However, many of them restrict water flow and are difficult to maintain, particularly in uncovered marine sites (Pillay 1992). Thus, a well-flushed location of cages in the marine environment reduces wastewater production by allowing time for diffusion of nutrients (Pillay 1992). Aquaculture Waste Transport Simulator (AWATS) is a model that has been developed for the estimation of dispersal of waste in coastal waters from cages and net pens (Robert *et al*. 2000). Applications of this model provide a complete picture of flow-field, which is required for cage culture site selection. The installation of cages in the marine environment is one of the main factors in controlling wastewater.

Recently, one aquaculture facility began using polyvinyl chloride bags as replacements for net cages (Stephen 2000). They created a system of impermeable enclosures. In this technology water pumped into the bag through a single opening created a steady counterclockwise current. A swirl separator system used centrifugal force to collect feces and waste feed which sank to the bottom of the bag and were collected by waste traps before being sent to a clarifier. From the large floating clarifier, wastes were pumped to shore. Nutrient-rich water from the clarifier was pumped to a lagoon before it was returned to the pit. A solution of *Nitrosomas* and *Nitrobacteria* was added to the inflow pipe that filled the bag, thus maintaining constant ammonia levels in the wastewater. Similarly, another company, Future SEA, developed waste capture technology in the treatment of wastewater for the aquaculture industry. The technology can be applied to freshwater and marine systems. The experimental technology for wastewater treatment to be used for growout production of Atlantic salmon began with the installation of the equipment in the spring of 2001.

Wastewater Treatment Technology for Land Based Aquaculture Industry

Wastewater treatment technology for land based aquaculture is adapted largely from municipal wastewater treatment. Sedimentation is one of the simplest methods to reduce the waste from the aquaculture industry. The basic principle in this system is to allow solid particles, mainly uneaten feed and feces, to settle out of the waste prior to release of effluent water into the environment. In this system, settleable substances can sink and floatable particles can collect on the water surface (Czysz *et al*. 1989). The separated wastes are removed from surface and bottom of the aquaculture chambers and may undergo further treatment before disposal.

Many technologies have been applied to the treatment of aquaculture wastewater during the growth of the industry (Daniel and Trudell 1990). Sedimentation is widely applicable in commercial fish farming, as it requires no energy input and no specialized operation skills (Daniel and Trudell 1990). The disadvantage of sedimentation systems is that they typically require large areas of land (Pilay 1992). The degree of waste removal by sedimentation in aquaculture depends on system design, type of construction and operation. The diameter and the density of the suspended particles determine the sinking velocity (Czysz *et al*. 1989). Also, sedimentation is not very effective at removing extremely small particles or dissolved waste in water.

Mechanical filtration can remove waste from aquaculture effluents. A device called a low-head-swirl concentrator can remove suspended solids in water using centrifugal force (Pillay 1992). Traditionally, recirculating systems were designed to filter the entire tank of water one to two times per hour.

Recently, one experiment demonstrated that appropriate management in pond draining and fish harvesting would reduce the effects of wastewater on the environment (Line *et al*. 2001). In that experiment, teaseed cake was used to anesthetize tilapia and allowed effective harvest by seining, without draining the ponds.

The wastewater management technology of land-based systems depends on design criteria. For example, sound waste management in conjunction with a fish hatchery at the Oneida Fish Culture Station in the USA controls the phosphorus discharge to nearshore areas of Lake Oneida (Kristen *et al*. 1998).

Bioengineering Technology for Wastewater Treatment

Advances in bioengineering have tendered most methods of wastewater treatment technology effective in the aquaculture industry. Bioengineering also offers one strategy to reduce the waste production in water through the process of oxygen injection, automated feeding, on site re-pelleting technology and recirculation technology (Mayer *et al*. 1995).

The principal treatments of wastewater involve solids removal, ammonia oxidation, aeration and disinfection. Recently, one technology has been proposed that would use solid waste from aquaculture for the production of biogas. The results of the experiment showed that production of biogas and methane increased as feeding rates and volumetric loads increased in fish farms (Lanari and Franci 1997). The experiment was conducted to evaluate the potential for use of waste removed from the water of fish farms to produce biogas in lock systems where water was partially recirculated for rainbow trout culture. The system components were two 1.4 m^3 fish tanks with sloping bottoms, each connected to a sedimentation column and containing 50 kg trout biomass. Biogas production was 158 l/day with methane content higher than 80 percent. Specific load on the digester was 0.45 kg COD/m^3 with a gas yield of 0.96m^3 /kg COD and specific gas production of 0.41m^3/m^3 of digester. This was an integrated approach for the use wastewater in the production of energy within the aquaculture industry, particularly for earthen pond management systems.

Biological Treatment of Wastewater

Biofiltration is another technology recently being applied in aquaculture for the treatment of wastewater. The basic principle of this technology is the formation of a filter bed through the attachment and growth of beneficial bacteria that extract dissolved chemicals from the water and convert them to particulate biomass or harmless dissolved compounds (Geoffrey 2000). The two major bacterial genera involved in the processes of waste removal are Nitrosomonas *and* Nitrobacter. Nitrosomonas *is responsible for nitrifying ammonia to nitrite, while* Nitrobacter *converts nitrite to nitrate* (Geoffrey 2000). Given a proper environment, the bacteria grow in a thin film covering the surface filter beads. Each cubic foot of packed media contains approximately 600,000 beads that provide a large amount of surface area for the propagation of bacterial films (Geoffrey 2000). Management of biofiltration is critical at the high loadings typical of recirculating aquaculture systems used for the production of food and/or ornamental fish.

Conclusions

A worldwide comprehensive development plan is required for wastewater treatment technology in the aquaculture industry. Only a few countries have developed wastewater management plans for aquaculture for the protection of the environment and its natural resources.

- Technology for the treatment of wastewater in aquaculture is not only essential for the growth of the industry but, also, important for environmental sustainability.
- A land use plan must be developed for the allocation of areas suitable for aquaculture, with thought given to installation and effective operation of wastewater treatment plants.
- In aquaculture industrial technology, suitable measures must be considered from the initial stage of site selection and farm design to the operational stage of wastewater treatment.
- In designing cage aquaculture operations with bag systems, collection of dissolved waste must maintain the natural quality of the marine water.

Notes

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Book Review

L. Kanduri, and R.A. Eckhardt. 2002. **Food Safety in Shrimp Processing—A Handbook for Shrimp Processors, Importers, Exporters and Retailers**. Iowa State Press—A Blackwell Publishing Company, Ames, Iowa USA. 174 pp. Hardcover. US$129.99

When asked to review this book I was at first curious as to how the authors managed to produce a 192-page book on a subject as narrowly focused as safety in shrimp (not seafood) processing. They did so by developing an excellent reference book, covering not only the recent evolution of Hazard Analysis Critical Control Point (HACCP) to its present status as the primary food safety inspection system in the US, but also by including valuable information related to shrimp quality, processing technology and microbiological testing.

The introductory chapter provides an excellent chronology of HACCP as applied to seafood products as well as a description of other seafood inspection programs offered by the Department of Commerce's National Marine Fisheries Service (NMFS) and the International Organization for Standardization (ISO) series of standards for quality and environmental management as adopted by most European countries. The authors point out the difference between the HACCP and ISO systems by noting that "HACCP is a tool for ensuring food safety whereas ISO is a tool for quality normalization." Unfortunately, subsequent chapters tend to blur this distinction between quality and safety.

The introductory chapter also makes note of the fact that since 41 percent of the total marine and freshwater shrimp production in 1998 was from aquaculture, so particular attention should be paid to hazards associated with shrimp farming - namely, "residues of agrochemicals, veterinary drugs and heavy metal organic or inorganic contamination." Following an excellent chapter describing the implementation of a sanitation program as a prerequisite to HACCP, the authors wisely use chemicals/drugs as an example in establishing critical control points (CCP) and subsequent HACCP Plan requirements, namely establishing critical limits, monitoring procedures, corrective actions, verification and record keeping. Chapter four provides an excellent overview of value-added shrimp processing procedures.

It was at about that point in the book where I became somewhat confused.

Table 4.4 "Hazard Analysis for Raw Shrimp" for example, under the receiving step (considered a process) notes that this is **not** a critical process. Normally it would not be — unless the product was

(Continued on page 59)