Biofiltration in Aquaculture Systems

Romisa Gull[1], Mansoor Ahmad Rather[2]* and Rizwana Malik[2]

[1]Govt. Degree College Bemina, KVK Bandipora*, SKUAST-K, Srinagar, J & K, India
[2]Faculty of Fisheries, SKUAST-K, Srinagar, J & K, India
***Corresponding Author: mansooraqua@gmail.com**

Abstract
Like all living organisms, fish require a clean environment for optimal growth and survival. As fish respire and metabolize feed, toxic metabolites are released into the water column. Metabolite accumulation increasingly degrades system water quality. If inorganic or organic toxins within the water surpass biologically critical levels, fish growth may become inhibited and mortality increased. To maintain a clean environment in recirculating systems, a combination of mechanical and biological filtration techniques must be employed. Although nitrification can occur throughout the culture system (e.g., in biofilms on pipe and tank walls), the majority of biochemical reactions pertaining to heterotrophic and autotrophic bacteria occur within biofilters. Biofilters are specifically designed for concentrated bacterial attachment and nitrification.
Keywords: Fish, toxic metabolites, biofiltration, heterotrophic and autotrophic bacteria

Introduction

Biological filtration involves the growth and containment of specific microorganisms working as a consortium to maintain a natural and balanced aquatic environment. These organisms consume unwanted contaminants, such as ammonia, nitrite, nitrate and dissolved organics as their food source, breaking them down into water, CO_2 and nitrogen gas. Over the last two decades, aquaculture has gone through major changes, growing from small-scale homestead-level activities to large-scale commercial farming, exceeding landings from capture fisheries in many areas (National Research Council, 1992; Subasinghe *et al.,* 2000; Wing and Malone, 2005). Fish consumption per capita increased 24% from 1970 to 1998, legumes increased 13% as egg and meat consumption had a net decrease (Frazo, 1999). The need to increase aquacultural production is driving the industry toward more intensive practices. In recent years, there has been a growing concern over the impacts of aquaculture operations (Buschmann *et al.,* 1996; Harache, 2002; Naylor et al., 2000; Cranford *et al.,* 2003; Johnson *et al.,* 2004). It is estimated that 85% of phosphorus, 80–88% of carbon, 52–95% of nitrogen (Wu, 1995) and 60% of mass feed input in aquaculture will end up as particulate matter, dissolved chemicals, or gases (Masser *et al.,* 1999). Increasing regulatory pressure focusing on discharges to natural water bodies will force producers to adopt methods that are environmentally friendlier (White et al., 2004). RAS technology can reduce the effluent waste stream by a factor of 500–1000 (Chen *et al.,*1997; Timmons *et al.,* 2001). Thus, recirculating technologies may allow existing operations to upgrade and expand and comply with future regulations. This paper reviews the implications of the changing use of recirculating systems on biofiltration technologies for freshwater and marine systems with the intention of assisting researchers and biotechnologists in selection of research topics.

Materials and Methods

In biological filtration (or biofiltration), there are substrates with a high specific surface area on which nitrifying bacteria can attach and grow. Biofilters break down highly toxic (un-ionized) ammonia- based waste products from fish and fish feed. A biofilter can be constructed of any material (substrate) that has a large surface area that can support bacterial growth, is non-toxic to filter bacteria and fish, permits free flow of water through the biofilter.

Depending on design and application, biofilters have the ability to accomplish the following functions. . The first three functions are performed by biological means and the last four are done by physical processes that do not depend on living organisms.

- Remove ammonia
- Remove nitrites
- Remove dissolved organic solids
- Add oxygen
- Remove carbon dioxide
- Remove excess nitrogen and other dissolved gasses
- Remove suspended solids

Ammonia and nitrite-nitrogen in the recycled water are oxidized (converted) to nitrite and nitrate by *Nitrosomonas* and *Nitrobacter* bacteria, respectively. *Nitrosomonas* bacteria use ammonia-nitrogen (in both the bacteria use nitrite-nitrogen as an energy source and produce nitrate-nitrogen as a by-product (Tetzlaff and Heidinger, 1990):

$$\text{Ammonia to Nitrite ---- } 2NH_4 + 3O_2 \Longrightarrow 2NO_2 + 2H_2O + 4H$$

$$\text{Nitrite to Nitrate ---- } 2NO_2 + O_2 \Longrightarrow 2NO_3$$

Denitrification is the dissimilative reduction of nitrate (NO_3^-) to nitrogen gas (N_2), through the production of nitrite (NO_2^-) and gaseous nitric oxide (NO) and nitrous oxide (N_2O) intermediates.

$$NO_3^- \Longrightarrow NO_2 \Longrightarrow NO(g) \Longrightarrow N_2O(g) \Longrightarrow N_{2(g)}$$

This process is performed by heterotrophic bacteria under anoxic conditions and uses nitrate as a terminal electron acceptor in the presence of a carbon and energy source. An electron donor is required as a carbon and energy source to fuel the denitrification process.

Since the nitrifying bacteria are aerobic, adequate oxygen must be added (5-8 mg/l is optimal in most systems) to the biofilter. A ratio of 6:1 of oxygen to ammonia produced in the culture tank must be provided in the biofilter for effective removal of the ammonia by the biofilter bacteria. It takes about 4 to 6 weeks for these bacteria to become well established in the biofilter (Tetzlaff and Heidinger, 1990). At this time bacterial populations stabilize at levels that consume and convert most ammonia and nitrite into harmless nitrate.

Denitrifying bacteria

Many different species are capable of denitrification. Especially the genera *Pseudomonas, Alcaligenes, Paracoccus* and *Bacillus* comprise many denitrifiers (Knowles, 1982). In the natural environment, a complex interaction of physical, chemical and biological conditions governs the predominance of a particular denitrifying species. In view of the large diversity of denitrifiers, denitrification takes place at a wide range of environmental conditions (temperature, salinity, etc.). Unlike nitrification, where the species diversity is narrow, single environmental determinants do not have a measurable effect on denitrification (Greiner and Timmons, 1998; Zhu and Chen, 1999).

Characteristics of the ideal biofilter

Small footprint: The biofilter should occupy as little space as possible. Space allocated for biofilters takes away area that could be used for culture tanks.

Inert materials of construction: All materials used in the biofilters should be non-corrodible, UV resistant, resistant to rot or decay and generally impervious to chemical attack.

Low capital cost: The biofilter must be inexpensive to purchase or build and cheap to transport to the farm location.

Good mechanical strength: The biofilter and its components must be tough enough to withstand the normal wear and tear of a industrial/agricultural environment.

Low energy consumption: The energy cost (usually electricity) to operate the biofilters should be as low as possible.

Low maintenance requirements: The biofilters should be self cleaning with little or no care required for the normal life of the crop.

Portability: The biofilters should be easily movable to facilitate changes in operation of the facility.

Reliability: Ideally the biofilters should have no moving parts that could fail at an inopportune time.

Controllability: It should be easy to change operating variables to assure optimum performance.

Turndown ratio: The biofilters should be able to work under a wide range of water flow rates and nutrient loading levels.

Safety: The biofilters should not have any inherent dangers to either the crop or the owner/operator.

Utility: The biofilters should accomplish all of the goals set forth in beginning of this paper i.e. removal of ammonia, carbon dioxide, BOD, suspended solids etc.

Scalable: A small system should work the same way as a large system. The performance per unit volume should be constant regardless of the size of the system.

Different biofilter systems

Aquatic Plant Systems: Plants are not normally used for the primary biofilter in aquaculture systems. They do however provide a very good sink for the nitrates produced by a well functioning biofiltration system. Some commercially valuable plants grown in hydroponics systems, aquatic plants such as hydrilla, cattails, water hyacinths and duck weed can be used to absorb nitrates and phosphorus from waste water.

Fluidized bed sand filters: Regular sand filters such as the type used for swimming pool filters or potable water filters are virtually worthless as biofilters for aquaculture. The biofilm quickly fills the spaces between the grains and the pressure drop across the filter rises rapidly. Frequent back flushing is required and the active biological film is removed each time. In contrast, fluidized bed filters have been successfully used for aquaculture applications.

Bead filters: They consist of a closed vessel partially filled with small beads of plastic. Usually the vessel is filled with water and the beads float at the top of the vessel. Water flows up through the bed of beads.

RBC (Rotating Biological Contactors): A typical design consists of plates or disks that are attached to a horizontal shaft. The shaft is located at the surface of the water and it is turned at a very slow speed (1-5 rpm). The disks are half submerged in the water at all times. As they rotate, the biofilm attached to the surface of the disk is alternately exposed to air and then submerged in the water (DeLosReyes and Lawson, 1996)

Trickling Filters

Trickling filters typically consist of a packing or media contained in a vessel (Figure 1). The water to be treated is sprayed over the top of the media and collected in a sump underneath the media. The surface of the media or packing provides the substrate for the growth of a biofilm (Kamstra *et al.,* 1998).

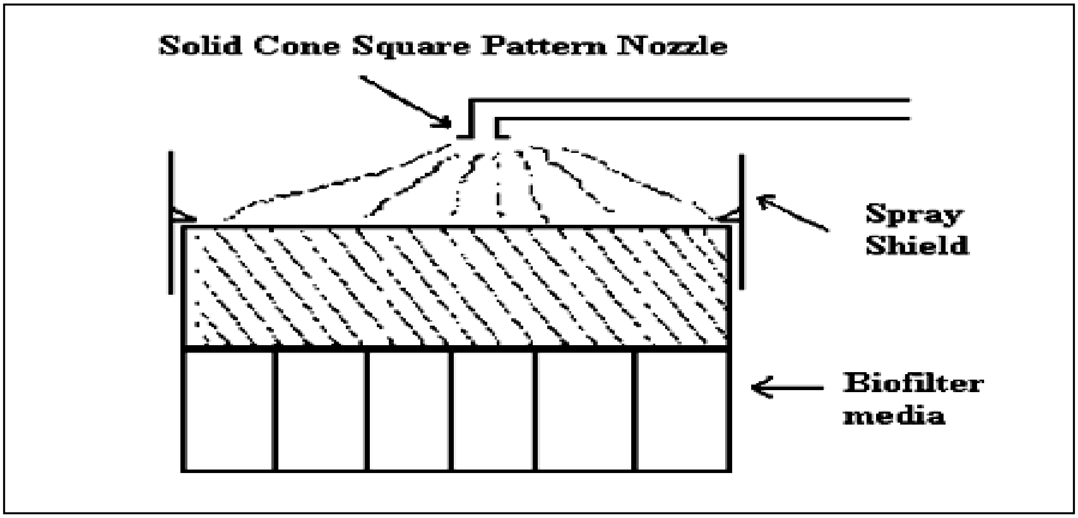

Figure 1: Trickling filter with pressure nozzle distribution system.

Submerged Bed Filters: These filters can be operated in up flow, down flow or cross (horizontal) flow.

Submerged Filters: Submerged filters are excellent choices for small systems because they are very versatile. Ideally the flow path through a submerged filter should be as long as possible. This type of biofilter is known as a long path, plug flow submerged filter. The goal should always be to provide sufficient velocity through the media to insure a fresh supply of oxygen and nutrients to the organisms on the surface of the media (Manthe *et al.*, 1988).

Conclusion

Biofilters are an attached growth process in which a biofilm is generated from the propagation of microorganisms on an inert surface. Biofilters maintain a higher active fraction of biomass, as compared to suspended growth environments, which enables the use of a smaller reactor. The efficient operation and compact size makes biofilters an attractive treatment device for the aquaculture industry, as is illustrated by their wide scale use in the performance of nitrification. Complete nitrogen removal can be achieved in recirculating aquaculture systems through the implementation of a coupled biofiltration treatment scheme employing nitrification and denitrification (Timmons, and JEbeling. Reduction of environmental pollution by using biofilter-recirculating technology is considered an important advantage over other fish culture technologies (Masser, *et al.*, 1999).

References

Buschmann, A.H., Lopez, D.A., Medina, A., 1996. A review of the environmental effects and alternative production strategies of a marine aquaculture in Chile. ***Aquacult. Eng.*** **15:** 397–421.

Chen, S., Coffin, D.E., Malone, R.F., 1997. Sludge production and management for recirculating aquacultural systems. ***J. World Aquacult. Soc*****. 28:** 303–315.

Cranford, P., Dowd, M., Grant, J., Hargrave, B., McGladdery, S., 2003. Ecosystem level effects of marine bivalve aquaculture. In: A scientific review of the potential environmental effects of aquaculture in aquatic ecosystems. vol. I. Fisheries and Oceans Canada. Can. Tech. Rep. Fish. ***Aquat. Sci.*** **2450 (1):** 12–20.

DeLosReyes Jr., A. A., Lawson, T. B., 1996. Combination of a bead filter and rotating biological contactor in a recirculating fish culture system. ***Aquacult. Eng***. **15:** 27–39.

Frazo, E. 1999. ***America's Eating Habits: Changes and Consequences***. Agriculture Information Bulletin No. 750. U.S. Department of Agriculture (USDA), Economic Research Service (ERS), Food and Rural Economics Division, Washington, DC. 494 pp.

Greiner, A. D., Timmons, N. B., 1998. Evaluation of the nitrification rates of microbead and trickling filters in an intensive recirculating tilapia production facility. ***Aquacultural Engineering***. **18:** 189 - 200

Harache, Y., 2002. Responsible aquaculture in the next century: an evolutionary perspective. p. 1–27. In: ***Perspectives on Responsible Aquaculture for the New Millennium. (***R. L. Creswell, R. Flos. eds.), World Aquaculture Society, Baton Rouge, LA, USA/ The European Aquaculture Society, Oostende, Belgium.

Johnson, S. C., Treasurer, J. W., Bravo, S., Nagasawa, K., Kabata, Z., 2004. A review of the impact of parasitic copepods on marine aquaculture. ***Zool. Stud.*** **43 (2):** 229–243.

Kamstra, A., Van der Heul, J.W., Nijhof, M., 1998. Performance and optimization of trickling filters on eel farms. ***Aquacultural Engineering*****. 17(3):** 175-192.

Knowles R. 1982. Denitrification. ***Microbiological Reviews***. **46 (1):** 43-70.

Manthe, D. P., Malone, R.F., Kumar, S., 1988. Submerged rock filter evaluation using an oxygen consumption criterion for closed recirculating system. ***Aquac. Eng*****. 7:** 97–111.

Maria Teresa Gutierrez-Wing, Ronald F. Malone. 2006. Biological filters in aquaculture: Trends and research directions for freshwater and marine applications. ***Aquac. Eng***.. **34:** 163–171.

Masser, M. P., Rakocy, J., Losordo, T. M., 1999. ***Recirculating Aquaculture Tank Production Systems. Management of Recirculating System***s. SRAC Publication No. 452 USDA.

National Research Council, 1992. ***Marine Aquaculture Opportunities for Growth***. National Academy Press, Washington, DC, 452 pp.

Naylor, R. L., Goldburg, R. J., Primavera, J. H., Kautsky, N., Beveridge, M. C. M., Clay, J., Folke, C., Lubchenco, J., Mooney, H., Troell, M., 2000. Effect of aquaculture on world fish supplies**.** ***Natur****e*. **405:** 1017–1024.

Subasinghe, R. P., Bueno, P., Phillips, M. J., Hough, C., McGladdery, S. E. and Arthur, J. E. 2000. ***Aquaculture in the Third Millennium: Technical Proceedings of the Conference on Aquaculture in the Third Millennium, Bangkok, Thailand*****.** 20-25 February 2000. NACA, Bangkok and FAO, Rome. 471 pp.

Tetzlaff, B. L. and Heidinger, R. C., 1990. ***Basic Principles of Biofiltration and System Design***. Bulletin no. 9A SIUC Fisheries and Illinois Aquaculture Center. 18 pp.

Timmons, M. B. and Ebeling, J. M. 2007. ***Recirculating Aquaculture.*** Ithaca, New York, Cayuga. AquaVentures.

Timmons, M. B. and Losordo, T. M., 1994. ***Aquaculture Water Reuse Systems: Engineering, Design and Management.*** Elsevier, Amsterdam, The Netherlands. 333 pp.

White, K., O'Neill, B. N., Tzankova, Z., 2004. ***At a crossroads: Will aquaculture fulfill the promise of the blue revolution?*** Report. Sea Web Aquaculture Clearing House, Washington, DC.

Wu, R. S. S. 1995. The environmental impact of marine fish culture: towards a sustainable future. ***Mar. Pollut. Bull.*** **31 (4–12):** 159–166.

Zhu, S. and Chen, S. 1999. An experimental study on nitrification biofilm performances using a series reactor system. ***Aquacult. Eng***. **20:** 245 – 259.