

# Biological Treatment in Recirculating Aquaculture Systems<sup>1</sup>

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We share common surroundings with most of our commercially-raised animals, so we naturally appreciate their environmental needs. However, fish are raised in a foreign environment where they are directly exposed to their own wastes, which can quickly become toxic to them. Biological treatment is the use of bacteria to convert those dissolved wastes to cell mass and other stable end products. This paper will discuss several key issues in biological treatment: (1) how wastes, bacteria, and feed are related; (2) why fixed film is the predominant biological treatment method in recirculating systems; (3) how biofilter design guidelines are derived from the needs of bacteria; and (4) how biofilter reliability is affected by the strategy employed to fulfill the design requirements.

**Wastes and Bacteria** have a complementary relationship. Dissolved wastes generated by the fish belong to one of two major categories, organic carbon and ammonia, which are used as energy and food by bacteria (figure 1). Organic carbon is both energy and food for a group of bacteria known as heterotrophs, which use oxygen for respiration. The amount of oxygen that the heterotrophs use to convert the organic waste to cell material is referred to as biochemical oxygen demand (BOD). If the organic wastes are not removed by a filter, the BOD can cause the oxygen concentration in the fish tank to decline rapidly, which can kill the fish. Ammonia is an energy source for autotrophic bacteria which use alkalinity to build cell material. Ammonia is first converted to nitrite by one group of bacteria and then to nitrate by yet another bacterial group. Nitrate is a stable end product with low toxicity and does not harm the fish in the concentrations typically present, but ammonia and nitrite are both highly toxic at low concentrations.

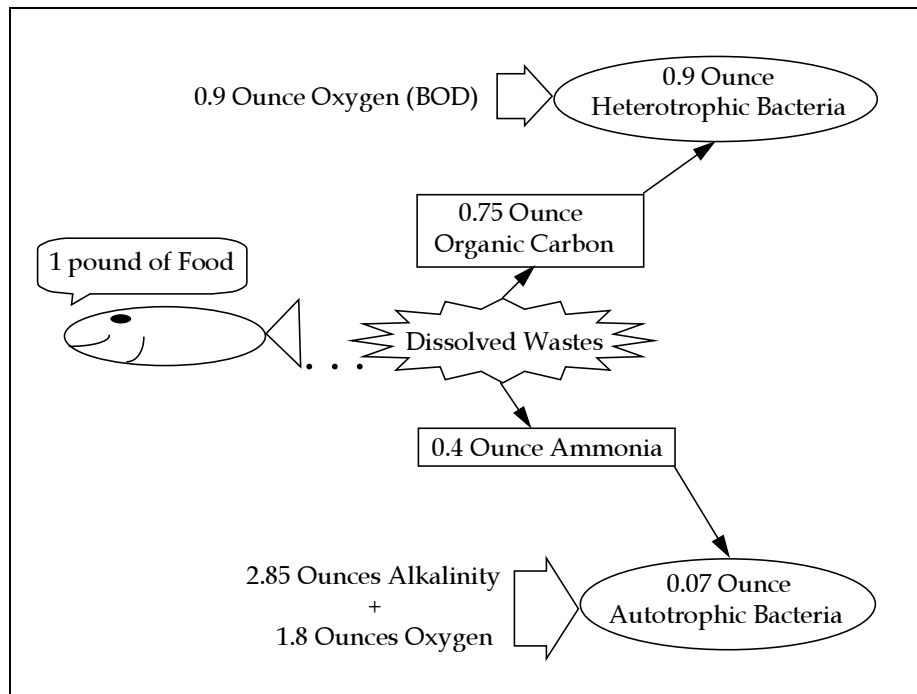
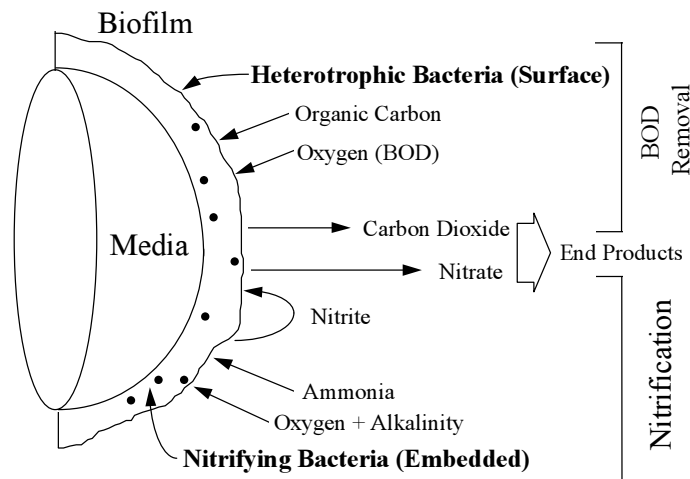


Figure 1. Fish excrete dissolved wastes, which bacteria convert to cell tissue.

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Heterotrophs grow very efficiently, doubling in population about every 8 hours. As figure 1 shows, as much as 9/10 of an ounce of heterotrophic bacteria is produced by 3/4 of an ounce of dissolved carbon, the amount the fish excrete per pound of feed. Aeration must be sufficient to supply the heterotrophs with 9/10 of an ounce of oxygen, the BOD per pound of feed. Comparatively, the nitrifiers are much less efficient, and typically require 24 hours to double in population. As a result of the one-pound feeding illustrated in figure 1, the fish excrete about 4/10 ounces of ammonia, which yields only 7/100 of an ounce of nitrifying bacteria. To perform the conversion of ammonia to nitrate, the nitrifiers require nearly 3 ounces of alkalinity and 2 ounces of oxygen per pound of feed. When water quality is sufficient to meet their environmental needs and they are given enough time to reproduce, the nitrifying bacteria will flourish, producing nitrate as their final end product (figure 2). However, if the water quality is allowed to decline or the ammonia loading is suddenly increased, ammonia and nitrite levels can increase rapidly. In summary, because the nitrifiers water quality demands are more strict and their growth is less efficient than heterotrophs, selecting biological treatment on the basis of nitrification will ensure that organic carbon is also removed.

**Biological Treatment Processes** are classified as either suspended growth or fixed film. In suspended-growth processes, the waste is added to a large aerated tank where it is converted to cellular material by suspended bacteria. These suspended bacteria must be removed by a solids separation device before the recirculating water can be returned to the culture tank. To give the autotrophic bacteria time to reproduce, a portion of the separated solids must be continually recycled to the aeration tank, and the amount of solids that are recycled must be continually monitored. Because the operational requirements of suspended growth make it a large-scale process that is management intensive, it is infrequently employed in aquacultural systems. In contrast, fixed-film processes require much less management or maintenance, and bacterial attachment (figure 2) provides sufficient time for the slow-growing nitrifiers to reproduce. Because of its advantages, biofilm nitrification has become the standard treatment method for recirculating aquaculture systems.



**Figure 2.** Heterotrophs exist on the surface because of their higher growth rates while the slower growing nitrifiers become embedded in the biofilm.

**Biofilter Design Guidelines** can be reduced to three main criterion, all of which are related to supporting a healthy nitrifying biofilm: (1) surface area; (2) substrate transport; and (3) biofilm management. A biofilter's nitrification capacity depends first upon the amount of surface area available to the nitrifiers. This is reflected by the fact that most filters convert 25 milligrams of ammonia per square

foot of media surface each day. A filter with more media surface will naturally support more nitrifiers, which will convert more ammonia, provided proper substrate transport is maintained. Substrate transport simply means maintaining a flow rate which is sufficient to deliver ammonia, oxygen, and alkalinity to the nitrifying bacteria, typically 1/40-1/10 gpm/lb-fish. To maintain a healthy flow rate, biofilm thickness must be managed. The need to manage biofilm stems from the high heterotrophic growth rates which, if left unchecked, can lead to clogging, decreased flow rates, and arrested substrate transport. It is thus important to maintain an unrestricted flow, or filter performance will suffer with ammonia and nitrite concentrations increasing suddenly.

**Biofilters** employ different strategies to fulfill their design guidelines for nitrification. There are essentially five different types of filters used in recirculating systems. Rotating biological contactors (RBCs) and trickling filters, are the least dependent on flow rate for substrate transport, because they provide oxygen to the biofilm by exposure to the air. They rely on passive bacterial shedding to manage the biofilm.

*Rotating biological contactors (RBCs)* are circular plastic cylinders with transverse blades which rotate slowly in a basin of wastewater. They use plastic media with high porosity and a correspondingly low specific surface area (e.g., 50 ft<sup>2</sup>/ft<sup>3</sup>). The high porosity is necessary because RBCs depend upon bacterial shedding to manage biofilm thickness. On average, they convert about 1,250 mg of ammonia per cubic foot of media per day. Since RBCs are exposed to air part of the time, oxygen is abundant, but a potential problem with these filters is that there is no provision for actively manage the biofilm. Clogging can result in reduced substrate transport and, in the most extreme cases, even breakage of the shaft that supports the filter.

*Trickling filters* consist of a cylindrical tank in which the wastewater is cascaded over plastic media. Like RBCs, the media is never completely submerged so bacteria can get oxygen from both exposure to air and extraction from the water. Like RBCs, trickling filters also rely on passive biofilm shedding, so they can become clogged with excess heterotrophic growth, which can reduce substrate transport and depress nitrification. Because of their similarities, RBCs and trickling filters have very similar nitrification rates, as shown in the table.

The three remaining filter types which we will discuss are fixed packed beds, fluidized beds, and expandable packed beds. All of these last three are submerged filters, where the biofilm must extract all of its substrate from the water, and the biofilm thickness must be actively managed to maintain flow.

*Fixed packed beds* are the simplest of the submerged filters, and a good example of this primitive design is the submerged rock filter, where water is circulated through an excavated pit or an artificial container filled with rocks. There are only two ways to manage biofilm thickness: (1) adjust the organic loading rate, by removing fish from the system or (2) periodically dig the rocks out, wash them down, and manually return them to the filter.

*Fluidized-sand filters* exemplify an expanded-bed filter. A medium-sized sand has a surface area to volume ratio of 700 ft<sup>2</sup>/ft<sup>3</sup> and will typically convert 17,500 milligrams of nitrogen per cubic foot of media per day, 14 times higher than a RBC or trickling filter. The sand filter has two operational modes, filtration and washing. In the filtration mode, the flow rate is controlled so that the bed is expanded by about 50%. Flow must be provided at a high enough rate to prevent clogging yet not so high that it causes continual scouring of the media. Over time, when bacterial growth begins to clog the filter, a washing mode is initiated by increasing the flow rate to scour the sand.

*Expandable granular biofilters (EGBs)* are fixed expandable beds which utilize floating polyethylene beads that have a specific surface area of 350 ft<sup>2</sup>/ft<sup>3</sup>, and convert about 8,750 milligrams of nitrogen per cubic foot of media per day. When the filter is used for both biological treatment and solids capture, in the filtration mode, water flows up through the media where solids, soluble, carbon, and ammonia are removed.

The backwash frequency must be carefully monitored to ensure that decaying solids are removed before a critical oxygen limitation develops. Backwashing is accomplished using a propeller or hydraulic washing mechanism to expand the bed which allows excess solids to drop out and scours the beads. The wash is usually executed for less than 60 seconds, to prevent excessive removal of the attached biofilm, because if too many nitrifying bacteria are removed, ammonia and nitrite levels can rise precipitously. Following the backwash, solids are allowed to settle to the bottom of the filter where they are removed.

Biofilter Type	Processes Performed	Biofilm Management	*Vol. Nitrif. Rate (mg N/ft <sup>3</sup> /day)	Operational Issues
RBC	Biofiltration	Passive	1,250	Clogging
Trickling Filter	Biofiltration	Passive	1,250	Clogging
Fluidized-Sand	Biofiltration	Active-Backwash	17,500	Flow Rate
EGB	Biofiltration & Solids Capture	Active-Backwash	8,750	Backwash Regime

\* Note: The volumetric nitrification rate is based upon the specific surface area of an average-sized media.

**Table.** Biofilter properties.

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<sup>2</sup>Each paper in this bibliography is available free of charge as a full-text PDF file from the National Sea Grant Library at <http://nsgl.gso.uri.edu/searchguide.html> (Field 1: "Golz"; Term 1: "Author") or from the author's web page at <http://mysite.verizon.net/res6m3ph/id2.html>.