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Ahmed EL-SHESHTAWY\*, Abdallah SALAH, Mostafa Abdel  
RAHMAN IBRAHIM, Dorina Nicoleta MOCUTA, Adrian TUREK  
RAHOVEANU, Ana Maria HOSSU

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## The Nitrification Capacity of Different Types of Biological Filters - An Overview

Ahmed EL-SHESHTAWY<sup>1\*</sup>, Abdallah SALAH<sup>2</sup>,  
Mostafa Abdel RAHMAN IBRAHIM<sup>3</sup>, Dorina Nicoleta MOCUTA<sup>4</sup>,  
Adrian TUREK RAHOVEANU<sup>5</sup>, Ana Maria HOSSU<sup>6</sup>

### *Abstract*

*Biological filtration is the keystone of any recirculating aquaculture system (RAS). Biological treatment process is considered the most economically feasible approach. Unfortunately, there is no ideal biofilter can be used for all different purposes. Understanding the nitrification capacity of different biological filters under actual production conditions will help the recirculating system designers in proper selection of the economically biological filters for the large scale commercial production use. In this review, we shed light on the performance, pros and cons of some of the most commonly used biofiltration systems.*

**Keywords:** *recirculating aquaculture system (RAS), biological filtration, nitrification process.*

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<sup>1</sup> Biotechnology Department, Faculty of Aquatic and Fisheries Sciences, Kafrelsheikh University, Kafr El-Sheikh City, 33516, Egypt, [Ahmed\\_Elsheshtawy@fsh.kfs.edu.eg](mailto:Ahmed_Elsheshtawy@fsh.kfs.edu.eg)

\* Corresponding author.

<sup>2</sup> Aquaculture Department, Faculty of Aquatic and Fisheries Sciences, Kafrelsheikh University, Kafr El-Sheikh City, 33516, Egypt, [Abdullahsalah91@hotmail.com](mailto:Abdullahsalah91@hotmail.com)

<sup>3</sup> Animal Production Department, Faculty of Agriculture, Kafrelsheikh University, Kafr El-Sheikh City, 33516, Egypt, [prof\\_mostafa@hotmail.com](mailto:prof_mostafa@hotmail.com)

<sup>4</sup> University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Marasti Blvd, District 1, Bucharest, Romania, [dorinamocuta@yahoo.com](mailto:dorinamocuta@yahoo.com)

<sup>5</sup> University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Marasti Blvd, District 1, Bucharest, Romania, [aditurek@yahoo.com](mailto:aditurek@yahoo.com)

<sup>6</sup> Universitatea Valahia, Bulevardul Regele Carol I 2, Târgoviște, Romania, [ana.hossu@gmail.com](mailto:ana.hossu@gmail.com)

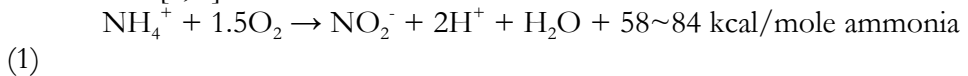


## 1. Introduction

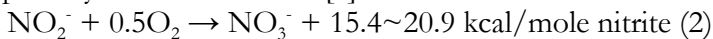
Biological filtration is a crucial determinant of the efficiency of a recirculating aquaculture system (RAS), and is vital to water treatment processes including live organisms. Ammonia is formed as the major end product of protein catabolism and is excreted by fish as unionized ammonia. Ammonia, nitrite, and nitrate are highly soluble in water. Ammonia occurs in two forms: ionized  $\text{NH}_4^+$  and un-ionized  $\text{NH}_3$ . Though unionized ammonia is highly toxic to fish, the ionized portion is relatively harmless. The proportion of each is determined primarily by the pH of the water. The higher the pH, a measure of hydrogen ion concentration, the higher is the proportion of unionized ammonia. In recirculating aquaculture systems, ammonia must be removed by a two-step process called nitrification [1].

## 2. Theoretical Background

The nitrification process is described as a two-step process, by which toxic ammonia is first oxidized into nitrite ( $\text{NO}_2^-$ ) by *Nitrosomonas* sp. and nitrite is then oxidized to the less toxic nitrate ( $\text{NO}_3^-$ ) by *Nitrobacter* sp. The two steps in the reaction are normally carried out sequentially. Equations 1 and 2 illustrate the chemical conversions occurring in the process of nitrification [2, 3]



*Nitrosomonas* is the most commonly identified genus associated with this step, even though other genera, including *Nitrosococcus*, and *Nitrosospira*. Some subgenera, *Nitrosovibrio* and *Nitrosolobus*, can as well autotrophically oxidize ammonia [4]



*Nitrobacter* is the most commonly identified genus associated with the second step, though other genera, including *Nitrococcus*, *Nitrospina*, and *Nitrospira* can as well autotrophically oxidize nitrite [4]

## 3. Argument of the paper

Biological filters consist of some solid media which serves as a surface on which bacteria can attach and live. Water containing ammonia and/or nitrite flow over this media and the bacteria attached to it. The bacteria remove the ammonia from the water and use it as an energy source to drive their life processes [5]. Nitrification is carried out in a wide variety

of biofiltration systems, which can be divided into two general types: submerged (e.g. fluidized bed filters, bead filters) fixed film filters and emerged (rotating biological contactors, trickling filters) [6-8]. Unfortunately, an ideal biofilter for all purposes does not exist but each biofilter type has their own advantages and limitations [9]. Numerous efforts have been made to put guidelines for reporting biofilter performance [10-13].

## 4. Arguments to support the thesis

### Performance of different biofiltration systems

#### 1. Emergent Filters

The emergent filters are designed to increase oxygen transfer as water cascades directly over the biofilter media. In the case of the trickling filter the cascade is achieved by water falling over the biofilter media while, rotating biological contactors produce the same effect by rotating the biofilter media in and out of the water [13-17].

##### 1.1. Rotating Biological Contactor (RBC)

The rotating biological contactor (RBC) is a robust fixed-film bioreactor representing excellent operational attributes in recirculating aquaculture systems. The efficiency of the RBC as biofilter is defined according to its mechanical and biological performance characteristics. In addition to highly efficient nitrification of ammonia under heavy feeding conditions (1.21 g/m<sup>2</sup>/day), the RBC has significant influence on control of secondary water quality and hydraulic considerations affecting the overall design and performance of the system [18]

##### 1.2. Trickling Filter

A common biofilter type is the trickling filter due to its simplicity and non-mechanical nature. The main advantages of trickling filters compared to other filter types applied in aquaculture are: high process stability due to constant high oxygen levels; CO<sub>2</sub> removal by degassing; water cooling in summertime; and simplicity of design, construction, operation and management [19]. While, the main disadvantages of trickling filters are: the relatively low volumetric removal rates (with consequently large sized biofilters); biofilm shedding; and risk of clogging when not properly designed and operated. [16]. Lyssenko and Wheaton [20] mentioned the nitrification performance of trickling filter. The study showed that the aerial ammonia removal was (0.64 g/m<sup>2</sup>/day)

#### 2. Submerged Filters

Submerged filters assume that sufficient oxygen can be transported with the water circulated through the filter. This assumption is normally assured by use of high recirculation rates, internal recycling, or through oxygen enrichment of influent waters. These filters are distinguished by the strategies used to manage their biofilm accumulations. There are three fundamental types of submerged filters [13].

### 2.1. Moving bed biofilm reactor (MBBR)

The moving bed biofilm reactor is an attached growth biological treatment process of drinking water as well as for water treatment in fish farms depending on a continuously operating, non-clogging biofilm reactor with a high specific biofilm surface area, low head loss, and no requirement for backwashing. The reactor can be operated under either aerobic conditions for nitrification or anaerobic conditions for denitrification. For nitrification, the media is maintained in constant circulation via a coarse air bubble aeration system creating aerobic conditions and for denitrification via a submerged mixer for anoxic conditions. Media usually occupies up to 70% of the reactor volume, in that at a higher percentage fill reduces mixing efficiency. The media is kept within the reactor volume by an outlet sieve or screen, which may be vertically mounted, rectangular mesh sieves, or cylindrical bar sieves, vertically or horizontally mounted. The media most often used is made of high density polyethylene (density 0.95 g/cm<sup>3</sup>) and shaped as a small cylinder with a cross on the inside of the cylinder and 'fins' on the outside [21, 22]. Suhr and Pedersen [23] compared nitrification performance in submerged fixed bed biofilters (FBB) and moving bed biofilters (MBB). The study showed that the fixed bed biofilters with high porosity and moderate specific surface area (200 m<sup>2</sup>/m<sup>3</sup>) were more robust to changes and had a superior surface specific TAN removal (0.46 g/m<sup>2</sup>/d) compared to moving bed biofilters (0.27 g/m<sup>2</sup>/d). However, calculated as a volumetric TAN removal, FBBs removed 92 g/m<sup>3</sup>/d compared to 231 g/m<sup>3</sup>/d in the moving bed biofilters (filling rate: 70%). Pedersen, Oosterveld and Pedersen [24] compared moving bed (MB) and fixed bed (FB) biofilter performance. The study revealed that TAN removal in the FB biofilters was significantly higher than the MB biofilters (0.20 vs. 0.14; g N/m<sup>2</sup>/d) at steady state.

### 2.2. Fluidized bed reactors

Fluidized-sand beds are an efficient, relatively compact, and of lower cost technology for removing dissolved wastes from RAS, especially in relatively cold water applications that require maintaining consistently low levels of ammonia and nitrite [9]. Fluidized bed reactors have the advantage

of being capable of using smaller media and provide higher specific surface areas. The high surface area media can result in lower cost nitrification systems. Fluidized bed reactors are currently being used with both floating and sinking media; fluidized sand beds have become increasingly popular in the industry today, especially for larger scale operations [25]. Westerman, Losordo and Wildhaber [26] used an up flow sand filter in combination with an RBC on a full scale tilapia culture systems. They found that TAN (Total Ammonia Nitrogen) removal rates by the RBC ranged from 5.5 to 18.5 g/hr and nitrite removal rates varied from 9.4 to 22.6 g/hr. The RBC they used had a surface area of 470 m<sup>2</sup> and a hydraulic loading rate of 0.28 L/m<sup>2</sup>-min.

### 2.3. Floating bead filters

Floating bead filters (FBFs) are expandable granular filters that have a bio clarification function similar to sand filters. They act as a mechanical filtration device (clarifier) by removing waste solids, while concurrently encouraging the growth of bacteria that remove ammonia and nitrite from the water through biofiltration processes [27]. Bead filters advantages include their compact and modular design, ease of operation, and installation. Furthermore, they can be used as a hybrid filter for both solids removal and nitrification. FBFs are resistant to biofouling and require little water for backwash. The bead filter is typically either propeller-washed or bubble-washed during its backwashing process, which expands the bed and separates trapped solids from the beads. The beads used are food-grade polyethylene with a diameter of 3–5 mm with a specific gravity of 0.91, and have a moderate specific surface area of 1150–1475 m<sup>2</sup>/m<sup>3</sup> (Malone et al. 1993).

## 5. Arguments to argue the thesis

There isn't an ideal biofilter for all purposes but each biofilter type has their own advantages and limitations.

The ideal biofilter should fulfil the following requirements;

- Have maximum media specific surface area
- With a small footprint
- Remove all of the inlet ammonia concentration
- Use low-cost media
- Produce very little amount of nitrite
- Increase oxygen transfer
- With minimal head loss
- Require very little maintenance
- Would not capture solids

Cost effective

Unfortunately, there is no one biofilter possesses these characters but each biofilter has some of these characters not all.

## 6. Conclusions

There is substantial debate as to the most suitable biological filter technology for recirculating aquaculture applications. This may be attributed to the wide variety of water quality requirements and environmental conditions showed by recirculating aquaculture systems. The ideal biofilter would have maximum media specific surface area, need a small footprint, remove all of the inlet ammonia concentration, use low-cost media, produce very little amount of nitrite, increase oxygen transfer, have minimal head loss, require very little maintenance to operate, and would not capture solids moreover, should be cost effective. Lamentably, there is no one biofilter which meets all of these standards, each biofilter, as described above, has its own strength and weaknesses and areas of best application that need to be considered during the system design phase to obtain maximum production with the lowest cost.

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