Biofloc and RAS Only from The Standpoint of Ammonia Elimination

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How to cite this article:

Ajith, P., Subash, P. M., & Ulaganathan, M. (2026). Biofloc and RAS only from the standpoint of ammonia elimination. Agrolife Frontiers, 1(6), 101-106.

Abstract

Ammonia accumulation is a critical issue in aquaculture systems due to its toxic effects on aquatic organisms, including reduced growth, increased oxygen demand, and elevated mortality. Approximately 78% of nitrogen in aquaculture systems originates from protein-rich feed, with only 25% contributing to animal growth and the remainder excreted as waste, ultimately forming inorganic ammonia. This article explores three primary ammonia transformation pathways: assimilation by photoautotrophic algae, oxidation by autotrophic nitrobacteria, and assimilation by heterotrophic bacteria. Among these, heterotrophic assimilation forms the basis of Biofloc Technology (BFT), an innovative approach that uses added carbon sources to stimulate microbial biomass growth, which efficiently uptakes ammonia while improving water quality. In contrast, Recirculating Aquaculture Systems (RAS) primarily rely on autotrophic nitrification for ammonia control, requiring precise management of oxygen, pH, and alkalinity. While RAS offers enhanced biosecurity and reduced water use, challenges remain in nitrate accumulation and system complexity. This review highlights the advantages and limitations of BFT and RAS, offering insight into sustainable ammonia management strategies for high-density aquaculture operations.

Keywords: Ammonia management, Biofloc Technology (BFT), Recirculating Aquaculture Systems (RAS), Nitrification, Aquaculture sustainability

Introduction

Ammonia accumulation remains one of the most critical challenges in aquaculture systems, particularly in the culture of high-protein feed-dependent species such as finfish and shrimp. As aquaculture practices intensify to meet global seafood demand, innovative strategies are essential to maintain water quality, ensure animal welfare, and support sustainable production. Among various nitrogen management approaches, Biofloc Technology (BFT) has emerged as a promising and environmentally sound method, especially for species like white-leg shrimp that require high dietary protein inputs. By harnessing the metabolic potential of heterotrophic bacteria to convert toxic inorganic nitrogen into microbial biomass, BFT offers both improved ammonia removal and enhanced nutrient recycling. This article explores the biochemical pathways of nitrogen transformation in aquaculture systems, with a particular focus on the mechanisms and advantages of BFT compared to traditional autotrophic nitrification and photoautotrophic uptake, and also examines its application alongside Recirculating Aquaculture Systems (RAS) to create integrated, low-waste production environments.

Ammonia Removal in Biofloc Technology Systems

Ammonia is a very poisonous inorganic nitrogen molecule used in aquaculture that damages fish and shrimp by lowering growth, increasing oxygen consumption, degrading water quality, and perhaps increasing mortality. About 78% of nitrogen in aquaculture water originates from feed, which is high in protein—25–30% for finfish and up to 40–45% for shrimp like white-leg shrimp. But feed use is inefficient: just 25% of nitrogen from protein helps animals grow, and about 75% of it ends up in the water as excrement, metabolic waste, or dissolved organic molecules, which microbes then break down into inorganic ammonia. The main routes for ammonia transformation in aquaculture. There are three routes for ammonia removal or transformation in aquaculture system: intake by photoautotrophic algae, nitrification and nitration of autotrophic nitrobacteria, and assimilation of heterotrophic bacteria.

Route 1: Photoautotrophic intake by algae or phytoplankton

Actually, the intake route of ammonia by photoautotrophic algae is the process of well-known photosynthesis as follows:

$$16\ NH_4^+ + 92\ CO_2 + 92\ H_2O + 14\ HCO_3^- + HPO_4^{2-} \rightarrow C_{10}6H_263O110N16P + 106\ O_2$$

Where, C106H263O110N16P represents the stoichiometric formula for algae.

In this procedure, the ionic ammonia of NH_4+ Is the first-order employed inorganic Nitrogen for synthesis of organic molecules. However, a carbon to nitrogen to phosphorus ratio (C:N:P) of roughly 106:16:1 is also required, meaning that exogenous additions of inorganic carbon and phosphorus sources are required to promote ammonia assimilation. This makes it generally difficult to control the growth of algae, particularly blue green algae or cyanobacteria, and can easily lead to cyanobacteria blooming, a major decline in water quality, and a catastrophe for human daily life.

Route 2: Autotrophic oxidation by nitrobacteria

Autotrophic nitrobacteria, the chemical autotrophic bacteria, can oxidize ammonia by using inorganic carbon sources without the need of phosphorus:

$NH_4^+ + 1.83\ O_2 + 1.97\ HCO_3^- \rightarrow 0.0244\ C_5H_7O_2N + 0.976\ NO_3^- + 2.9\ H_2O + 1.86\ CO_2$

Microbial biomass is represented by the chemical formula $C_5H_7O_2N$. The rate of nitrification is limited by the slower growth of nitrobacteria, which are in charge of ammonia oxidation, in comparison to heterotrophic bacteria. There are no efficient additives that hasten this organic process. Despite having enough dissolved oxygen, the production of a hazardous intermediate called nitrite (NO_2) oxidizes haemoglobin's Fe^{2+} to Fe^{3+}, obstructing oxygen transport and resulting in asphyxiation in aquatic animals. Additionally, nitrification causes nitrate (NO_3) to build up, which encourages algal blooms. It also reduces carbonate alkalinity (HCO_3^-), which lowers water pH and has an impact on water quality in general.

Route 3: Assimilation by heterotrophic bacteria

Ammonia also could be assimilated by heterotrophic bacteria through a process Different from those of photoautotrophic algae (route 1) and autotrophic Nitrobacteria (route 2)

$NH_4^+ + 1.18\ C_6H_{12}O_6 + HCO_3^- + 2.06\ O_2 \rightarrow C_5H_7O_2N + 6.06\ H_2O + 3.07\ CO_2$

Where the chemical formula for microbial biomass, such as route 2 or Eq. (5), is represented by $C_5H_7O_2N$. Although roughly half of the HCO3 will be used up, more dissolved oxygen is required for the bio-reaction of Eq. (6) processing than with route 2. In contrast, Eq. (6) of method 3 requires the production of carbohydrate ($C_6H_{12}O_6$) and produces roughly 40 times the amount of microbial biomass.

Biofloc Technology (BFT) is a novel approach to ammonia removal and reuse in aquaculture that is based on route 3. Although ammonia buildup is a significant problem in aquaculture, methods 1 and 2 are not appropriate for removing it. Using algae or phytoplankton in Route 1 may result in overgrowth, quick decomposition, and the release of toxins. The intricate procedures used in Route 2, which was created for sewage treatment, are inappropriate for aquaculture. However, biofloc technology (BFT), an efficient and environmentally responsible technique for ammonia transformation in aquaculture, was developed as a result of route 3.

Ammonia Removal in Recirculating Aquaculture Systems

By efficiently controlling ammonia levels and minimizing water exchange, Recirculating Aquaculture Systems (RAS) enable improved environmental management and increased fish stocking density. Autotrophic nitrification, a two-step process in which ammonia is transformed to nitrite by ammonia-oxidizing bacteria and subsequently to nitrate by nitrite-oxidizing bacteria, is responsible for maintaining ammonia levels below 1 mg L^{-1}. A low C/N ratio (0–1) is necessary for this process, which employs carbon dioxide as a carbon source and oxygen for bacterial growth. A C/N ratio of 2 can diminish nitrification efficiency by 70% (Zhu & Chen, 2001).

A sump, fish tanks, solids removal tanks, and bio-filtration (nitrification) tanks are commonly seen in RAS. The majority of the solids are trapped in solids removal machines, which receive water from fish tanks that are rich in both organic and inorganic waste. Water that has been clarified but still contains a lot of ammonia goes into the bio-filtration tanks to be nitrified. For additional treatments like UV, ozone, pH, and temperature control, purified water with minimal ammonia and solids travels to the sump. To facilitate nitrification, DO levels are kept between 5 and 6 mg L^{-1} (Colt, 2006). Bicarbonate is added to maintain a pH of about 7 after nitrification consumes alkalinity and causes pH reductions (Martins et al., 2009; 2010). To eliminate trapped particles and lower nitrate, the byproduct of nitrification, periodic water exchange is required (Ramli et al., 2017). In order to eliminate the requirement for water exchange, current research focuses on integrating denitrification units that employ solid wastes to lower nitrate levels (Fontenot et al., 2007; Ramli et al., 2008; Yogev et al., 2017). Turbidity < 1000 mg L^{-1} as an indirect indicator of the C/N ratio (Ramli et al., 2008), pH at 7, and DO $>$ 5 mg L^{-1} for fish and nitrification are the three main metrics to keep an eye on in RAS. Probes can measure DO and turbidity, but laboratory tests are necessary for C and N levels (Ebeling et al., 2006; Martins et al., 2010; Mota et al., 2015).

Conclusion

Ammonia management is a critical component of sustainable and intensive aquaculture practices. While traditional methods such as photoautotrophic assimilation and autotrophic nitrification provide avenues for ammonia removal, they present limitations including unstable algal growth and accumulation of harmful intermediates like nitrite and nitrate. In contrast, Biofloc Technology (BFT), which utilizes heterotrophic bacteria for ammonia assimilation, offers a more efficient and eco-friendlier alternative by converting waste nutrients into microbial biomass that can be reused within the system. Similarly, Recirculating Aquaculture

Systems (RAS) enable effective ammonia control through nitrification and advanced filtration processes, though they require precise management of water quality parameters such as dissolved oxygen, pH, and C/N ratio. Together, BFT and RAS represent modern, complementary strategies that can enhance water quality, reduce environmental impact, and support the intensification of aquaculture operations. Continued innovation and integration of these systems, including advances in denitrification and nutrient recycling, will be essential for meeting the growing demand for sustainable aquaculture production.

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