A Novel Approach for Recirculating Aquaculture Systems (RAS)

Igal Magen

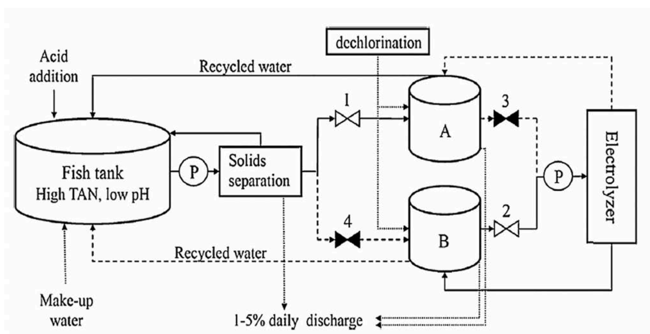

FIGURE 1. *Schematic description of the suggested TAN operation approach. A and B are intermediate tanks, operating alternately as electrolysis or water receiving tanks (Ben Asher 2016).*

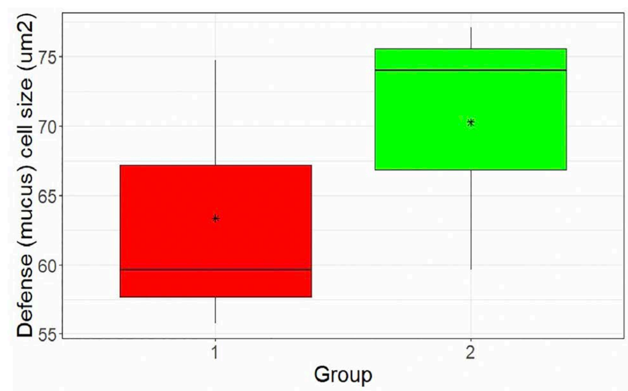

FIGURE 2. *Defense mucous cell size. Group 1: BioFishency ELXTM and Group 2: Reference biofilter solution.*

A typical modern RAS is comprised of nine water treatment units: solids separation, CO_2 degasification, nitrification reactor (biofilter) and an oxygen enrichment system, with additional water treatment steps commonly required to reduce water consumption up to "zero discharge": foam fractionator, denitrification reactor, dosing pump to add chemicals for alkalinity compensation, disinfection unit and a sludge thickener. These components, each with its own operational requirements and specifications, ideally should be synchronized with the others to achieve the required water quality at a reasonable cost.

To date, available RAS technologies suffer from several limiting factors restricting their wide application. Biological nitrogen removal is often identified as the weakest chain link in the RAS water treatment process. This is evident in operation of nitrification and denitrification bioreactors, which often tends to be unpredictable or unstable, thereby raising uncertainties over performance reliability over time (Graham *et al*. 2007).

In addition, nitrification reactors are the main source of off-flavor agents, which lead to one of the major challenges faced by near-zero-discharge RAS (Lindholm-Lehto and Vielma 2019). Further, nitrification biofilters have a high oxygen demand, require long start-up times, especially in cold water, and are a potential source for the proliferation of pathogenic bacteria. High capital costs are particularly apparent in RAS focused on coldwater fish, which requires large biofilter surface areas. Consequently, robust, environmentally friendly and economically feasible alternatives for biological reactors are crucially sought for zero-discharge RAS (Ben-Asher and Lahav 2016).

Ammonia Electrooxidation

Electrooxidation of dissolved ammonia has been documented since the early 1960s. Marinčić and Leitz (1978) were the first to propose this process in the context of wastewater treatment. RAS technologies that rely on electrochemical water treatment for transforming ammonia excreted by fish into innocuous nitrogen gas have been suggested (Gendel and Lahav 2012) and shown to generally provide good water quality, satisfactory growth rate and cost competitiveness. The main incentive to apply electrooxidation processes in aquaculture is the one-step ammonia oxidation directly to $N_{2(g)}$.

The process in saline-water RAS (Fig. 1) is based on maintaining relatively high NH_4^+ concentration in the rearing water, along with neutral pH, calculated to maintain NH_3 below the chronic toxicity threshold, commonly 0.05 mg N/L for fish. Water flowing out of the fish tank is collected in two treatment tanks (Figs. 1A and 1B). When a treatment tank is full, it is disconnected from the fish tanks and undergoes batch-mode electrolysis in which total ammonia-nitrogen (TAN) is oxidized completely by the $Cl_{2(aq)}$ species formed on the anode due to chloride (Cl^-) electrooxidation. Chloride is the major anion present in any saline water. During the electrolysis period in the first treatment tank, the flow from the fish tank is directed to the second treatment tank. Once the electrolysis step is finished in the first treatment tank, the TAN-devoid and disinfected water undergoes a dechlorination step to ensure that no residual chlorine or chloramine are sent to the fish tanks.

The electrolysis step is operated to remove the exact daily mass of TAN released by the fish, thereby maintaining a constant TAN concentration in the fish tank. The process necessitates an efficient solids separation step to ensure that the solids retention time in the fish tanks would result in minimum growth of autotrophic (i.e., nitrifying) bacteria in the fish tank water.

The process concept is based on a mechanism called indirect ammonia electrooxidation, or in simple terms, a direct oxidation of NH_4^+ into $N_{2(g)}$ via its reaction with electrochemically generated active chlorine (Eq. 1), which renders nitrification and denitrification unnecessary. Upon its reaction with NH_4^+ (Eq. 2), active chlorine

TABLE 1. Comparison of Atlantic salmon production in a BioFishency system compared to conventional RAS.

	Stocking number	Harvest number	Initial weight (g)	Final weight (g)	Initial biomass (kg)	Final biomass (kg)	FCR
Biofilter	150	144	190	383	29	55	0.90
Bio-Fishency ELX	163	163	190	371	31	60	0.81

TABLE 2. Comparison of gilthead sea bream production in a BioFishency system compared to a flow-through system.

Criteria	BioFishency ELX™	Flow-through
Survival (%)	95.3	98
FCR	1.04	1.09
Growth rate (g/d)	0.30	0.27
Fish health	NPS**	NPS**
Water consumption (m3)	2.97	540

is reduced to chloride ions that can be oxidized again into active chlorine at the anode of the electrochemical reactor, so the overall reaction (Eq. 3) does not include the chloride ion. A beneficial byproduct of Eq. 1 is that the generated chlorine, apart from oxidizing ammonia, acts to disinfect the water, and is also capable of oxidizing organic compounds that cause off-flavor, such as geosmin and MIB.

Eq. 1: Chlorine generation $2Cl^- + 2H^+ \rightarrow Cl_2 + H_{2(g)}$
Eq. 2: Ammonia oxidation $3Cl_2 + 2NH_4^+ \rightarrow N_{2(g)} + 6Cl^- + 8H^+$
Eq. 3: Overall reaction $2NH_4^+ \rightarrow N_{2(g)} + 3H_{2(g)} + 2H^+$

Advantages of Electrooxidation

Many advantages can be listed for operating RAS with no biofilters. The main incentive to apply electrooxidation in aquaculture is the single-step oxidation of TAN directly into $N_{2(g)}$. However, application of an electrochemical reactor as a water treatment component in RAS has further benefits. From a general engineering or operational standpoint, a single component that serves a multi-purpose solution — ammonia removal, disinfection and off-flavor prevention — is often advantageous over an application of several consecutive treatment steps of nitrification, denitrification and disinfection. The system is also characterized by temperature independence, ease of operation, no startup period, the ability to turn the system on and off at will and lower facility footprint compared to biofilters.

BioFishency ELX™ – Performance and Capabilities

An advanced electrochemical water treatment system for cost-efficient ammonia removal and water disinfection, BioFishency ELX™ compares favorably with biological RAS, all in a fully controlled environment, while eliminating off-flavor agents, to deliver a reliable and high-quality product year-round. Suitable for both coldwater and warmwater species. Disinfection is part of a multi-stage solution is built into a single operation, BioFishency ELX™ directly transforms ammonia to nitrogen gas. The system supports a small carbon footprint, requires considerably less space and energy and operates immediately upon electrical supply.

Several proof-of-concept and pilot studies were conducted using BioFishency ELX™ technology with several species and systems, as presented below, from fingerlings to grow-out, and as a purging unit under a regular feeding regime and water discharge typical of RAS.

Atlantic Salmon

A proof-of-concept study was conducted by the RASLab team, Bergen, Norway, using Atlantic salmon *Salmo salar* smolt stocked at 190 g for 54 days. The objectives were to demonstrate a RAS operation based solely on the BioFishency ELX™ system and compare fish growth rate and health and welfare parameters. Fish growth, survival, production and feed conversion were similar between the BioFishency ELX system and a conventional RAS (Table 1).

Fish health was evaluated using a methodology developed by Quantidoc (Quantidoc - Hjem | Quantidoc) that analyzes mucous cell size, density and distribution to assess whether cells are in a defensive or healthy state. Once mucous cells are in a defensive state, environmental conditions and the effect of external stressors are not optimal due to causes such as handling, pharmaceuticals and other factors such as water chemistry. Fish sampled after termination of the experiment indicated that the fish in the BioFishency ELX™ system were in better health. Mucous cell size and density was smaller than in the biofilter system, indicating a

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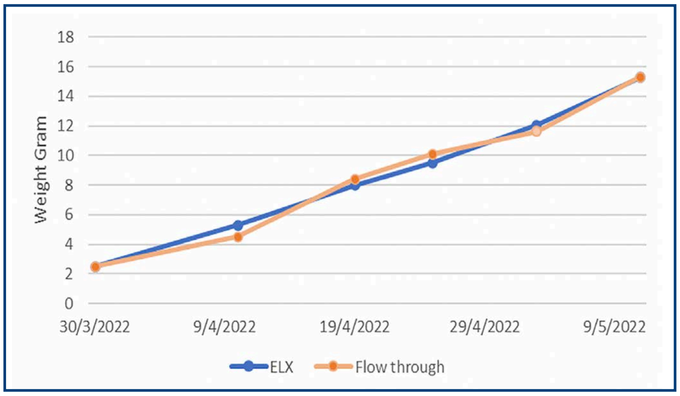

FIGURE 3. *Growth rate of gilthead sea bream grown in a BioFishency ELXTM system compared to a flow-through system.*

lower defense activity, and more optimal environmental conditions for fish. Further, Quantidoc has developed a formula to calculate "defense activity" and the results from this formula clearly indicate the same results (Fig. 2).

Gilthead Seabream

Testing was conducted by ArDag Ltd. at Eilat, Israel, using gilthead seabream *Sparus aurata* starting at 2 g for 45 days. The objective was to compare BioFishency ELX™ water treatment vs. a water flow-through system by comparing the fish growth rate and health and welfare parameters. Growth, survival and feed conversion were similar between the two systems (Table 2, Fig. 3).

Rainbow Trout

Testing was conducted at the BioFishency's R&D facility (Acre, Israel) using rainbow trout *Oncorhynchus mykiss* starting at 475 g for 50 days. The objectives were to demonstrate grow-out of rainbow trout in saline water and to evaluate the effect on product quality using a sensory panel. Rainbow trout (475 g) were stocked at 95 kg/m^3 in a Biofishency ELX system. The final weight was 724 g, with a growth rate of 0.84 percent/d or 5.0 g/d. The objectives were to quantify the purging effect on water and fish tissue.

Secondary metabolites of several microorganisms, which lead to unsavory off-flavor and odor of the fish, result in severe economic losses and negative reputation to the RAS industry. As a mitigation strategy for the off-favor problem, RAS operators typically perform a purging (flushing) step prior to marketing. The purging process aims at eliminating the off-flavor agents that accumulate in fish tissues during grow-out. Performed in separate purging tanks, fish are held under a flow-through regime. The purging process is based on maintaining negligible concentrations of the off-flavor agents in the water, thereby promoting diffusion of chemicals from fish tissues to the water.

In contrast to the grow-out period, purging is performed under starvation and requires vast quantities of water for exchange. During purging, which normally requires 7-14 days, the fish lose ~5 percent of their weight, thereby decreasing farmers' revenue. Purging has become a bottleneck for the development of the RAS industry in general, and specifically for growing fish species (e.g., Atlantic salmon) away from their native climate and natural water sources. This is especially relevant in coldwater species, where the diffusion of the off-flavor compounds from fish flesh to clean water is relatively slow.

During the trial, fish were exposed to water spiked with 750 ng/L of MIB and geosmin, after which the BioFishency ELX™ system was introduced during the purging, while continuing to feed fish. Within five days, all MIB in the water had been removed, while in seven days, the system efficiently oxidized geosmin. High uptake by the fish muscle of both MIB and geosmin was measured after the spiking (670 and 750 ng/kg, respectively). In just seven days, MIB was not detected in the fish flesh, and within ten days, geosmin was fully removed from skin and muscles.

The results of this study indicated that MIB and geosmin can be fully eliminated with BioFishency ELX™ in less than ten days, while fish can continue growing regularly during the depuration period and no extra water discharge is required. In practice, by using the Biofishency ELX a given RAS facility may shorten the time to market, prevent fish biomass loss and increase annual revenue by at least 5 percent.

Notes

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