THE EFFICIENCY OF ROTATING BIOLOGICAL CONTACTORS IN A CLOSED RECIRCULATING FISH CULTURE SYSTEM

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EFIKASNOST ROTACIONIH BIOLOŠKIH KONTAKTORA U ZATVORENOM RECIRKULACIJSKOM SUSTAVU ZA UZGOJ RIBE

Abstrakt

Recirkulacijska akvakultura predstavlja jednu od opcija okolišno održive i ekonomski isplative akvakulturne proizvodnje čije su beneficije jasno prepoznate. Pravilnom upotrebom različitih komponenti i tehnologija recikliranja vode, sustav omogućava kontrolu kvalitete vode u intenzivnim hranidbenim režimima. Biološka filtracija kao redukcija toksičnih dušičnih spojeva nastalih probavom proiteina jedan je od krtitičnih procesa koji određuje efikasnost cijelog proizvodnog sustava. Brojni tipovi biofiltera upotrebljavanih u različitim proizvodnim i istraživačkim pogonima razlikuju se po vrsti organizama, dizajnu, materijalu, cijeni i sl. Pri dizajniranju biofiltera trebaju biti uzeti u obzir svi kriteriji održavanja optimalne kvalitete uzgojne vode, kao i potrebni prostor te ekonomska isplativost. Rotirajući biološki kontaktor, od kojih je najčešći biodisk filter, sastoji se od okruglih ploča fiksiranih na centralnu osovinu. Diskovi se polako okreću da bi naizmjenice izložili aktivni biološki medij vodi koja sadrži otopljeni dušični otpad, i zraku kao izvoru kisika. Ovaj rad opisuje karakteristike rotirajućih bioloških kontaktora u komercijalnom recirkulacijskom sustavu i koristeći rezultate drugih autora daje usoredbu sa ostalim tipovima biofiltera. Rotirajući biološki kontaktor sa stopom nitrifikacije od 1,21 g/m^2/day pokazao se kao jedan od najefikasnijih biofiltera za upotrebu u akvakulturi.

Ključne riječi: *akvakultura, recirkulacija, biofilter, nitrifikacija.*

INTRODUCTION

Biological filtration is a critical determinant of the efficiency of a recirculating aquaculture system, and is essential to water treatment processes involving live organisms. Ammonia is the principal nitrogenous waste of fish, and results from the digestion of protein. Ammonia dissolved in the water exists as two compounds in equilibrium: ionized ammonium (NH_4^-) and unionized ammonia (NH_3). While unionized ammonia is extremely 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 (H^+) concentration, the higher is the proportion of unionized ammonia. Without significant dilution, as in recirculating aquaculture systems, ammonia must be removed by a two-step process called nitrification. Nitrifying bacteria, concentrated on the biofilter media surfaces, convert ammonia to nitrite and then to relatively harmless nitrate. Nitrate is allowed to accumulate to levels determined by the amount of dilution (defining the % recirculation rate of the recycle system). Since both ammonia and nitrite are toxic to fish, their levels must be managed through the efficient design of biofiltration systems. Biological filters must provide adequate surface area for the growth of nitrifying bacteria. *Nitrosomonas* and *Nitrosospira* convert ammonia to nitrite, and *Nitrobacter* and *Nitrospira* convert nitrite to nitrate. The water containing the dissolved waste must be brought in contact with the surface area supporting these populations of bacteria. During operation, the filter cannot be permitted to clog with fish wastes or the sloughing bacterial biomass. The filter media must therefore be self-cleaning, or involve manual or automated management technologies to remain unclogged.

Nitrite (NO_2) is the intermediate product of nitrification and the biofiltration process. Under normal operating conditions, biofiltration should maintain a balance of nitrifying bacterial populations which will control both ammonia and nitrite levels.

Biofilter design must take into account all of the stated water quality management criteria, as well as considerations of space and cost efficiency. A rotating biological contactor or biodisc filter is a fixed film bioreactor composed of circular plates aligned on a central axle. The discs are rotated slowly, to alternately expose the biologically active media to the water carrying the nutrients (the nitrogenous wastes of the fish), and to the air, providing an unlimiting source of oxygen to the bacteria.

Various mechanical designs of this biofilter configuration have been considered for recirculating aquaculture systems for decades (Lewis and Buynak, 1976). The RBC has been shown to outperform many other fixed film configurations applied to fish culture systems (Van Gorder and Fritch, 1980; Miller and Libey, 1984, 1985; Rogers and Klemetson, 1985). Wheaton *et al.* (1994) defines the inherent advantages of RBCs for aquaculture as: they are self-aerating, providing oxygen to the attached biofilm; they are a low-head device, minimizing pumping energy needs; they are a non-clogging device due to shearing of loose biofilm caused by the rotation.

The aim of this study is to describe the performance of rotating biological contactors as an integral part of a commercial closed recirculating fish production system. This paper also provides a practical comparison of RBC design and performance considerations with other biofilter options.

MATERIALS AND METHODS

The present recirculation system design includes side-by-side "cross-flow" concrete tanks, each tank measuring 30 meters long x 1.2 meters wide, with a volume of 57,000 liters. The two tanks share a central wall with a total volume of 114 m^3 of water, and are integrated with a filtration/pumping/oxygenation/ozonation system. The cross-flow tanks have influent and effluent pipe manifolds at floor level running their entire length. Perpendicular influent jets distribute water flow uniformly across a u-shaped tank floor, providing the appropriate cross-flow pattern and velocity, effecting the movement of solids to adjacent effluent ports. Each tank is divided by partitions into four increasingly large sections, each thereby receiving a proportionally increased volume of oxygenated water (Van Gorder and Jug-Dujaković, 1996). Water quality is maintained by integrated skid-mounted unit processes for the recirculation of the tank volume. Water returning from the tanks is mechanically filtered through a microscreen drum clarifier (60 micron). The flow then enters rotating biological contactors providing the required biofiltration (Van Gorder and Jug-Dujaković, 2005). A pump distributes the water to a carbon dioxide sparging chamber, and under pressure to an oxygen/ozone saturator, from which supersaturated levels of dissolved oxygen and ozone are distributed to the culture tanks. A chemical feed pump maintains pH, using NaOH dosing.

Computer telemetry systems monitor electrical status, flow rates, and temperature, while controlling feeding, clarifier function, emergency oxygen activation, pH, and oxygen and ozone flow. Computer control functions also include emergency response and notification for disruption or variance in flow rate, dissolved oxygen levels, pH and temperature. For this study, eight separate grow-out systems, using 16 RBCs, were studied, each system employing the RBC model described above in the table1.

Table 1. Description of the characteristics and dimensions of RBCs used in the study.

Tank Design	System Volume (liters)	Total Surface Area (m^2)	Biofilter Specifications: Total Specific Surface Area (m^2/m^3)	Total Flow Rate (liters/min)
Cross-Flow Raceways (8 systems)	115,000 (2 tanks/system)	1860 (2 RBC's)	258 (2 RBC's)	1900

For the culture systems observed in this study, the flow rates through the system components permit the tank water volumes to be circulated through the biofilters in an average of 55 minutes. The system was fed the same feed (40% protein, 16% fat) which was automatically administered several times daily over a sixteen hour light cycle. A theoretical level of TAN production is estimated as a function of the feeding levels. Biofilter efficiency is measured as a function of the removal of that ammonia, thus establishing a steady state TAN concentration within the culture tanks. The daily replacement of 5% of the water as a function of the recirculation % of the system, was also considered in the removal of ammonia.

Over a five-week period, the average level of feed per day was determined for each of eight production systems. This level of feeding was mathematically converted to levels of ammonia produced. Using Wheaton *et al* (1994), an ammonia production rate of 0.03 kg TAN/kg feed is assigned, and represents the mass of ammonia that must be removed by biofiltration and dilution, in order to maintain equilibrium.

RESULTS AND DISCUSSION

Table 2 lists the average feed levels administered to eight separate culture systems over a 5-week period, and the average levels of TAN produced by the fish. With a steady-state situation, the levels of TAN produced, less than 5% removed through water exchange, is assumed to indicate the levels of TAN removed by biofiltration.

Table 2. Average feed amount administered to eight separate systems and the average TAN removal rate for each system

	Average feed amount/tank/day kg	Average TAN removed/m^2/day kg
Tank		
1	33,60	1,19
2	31,16	1,15
3	35,04	1,27
4	38,80	1,17
5	29,60	1,08
6	30,92	1,14
7	35,42	1,29
8	30,62	1,12
Weekly average TAN removal rate (g/m^2/day)		1,21

A comparison of RBC design and performance considerations with other biofilter options was accomplished using data available from different authors (table 3).

Table 3. Comparative nitrification capacity for various types of biofilters:

Source	Ammonia removal rate
Submerged Filters (Wheaton *et al.,* 1994)	0.3-0.6 gms/m^2-day
Bead Filters (Wheaton *et al.,* 1994)	0.20-0.25 gms/m^2-day
Fluidized Sand Filters (Thomasson, 1991)	0.25-0.35 gms/m^2-day
Rotating Biological Contactor (this study)	1.21 gms/m^2-day

For fine media biofilters such as fluidized sand or bead filters, volumetric comparisons of nitrification efficiency are often used. By volume, this RBC, with 258 m^2/m^3, demonstrates a nitrification rate of 312 gms/m^3-day. Tsukuda *et al.* (1997) estimate nitrification rates for cold water fluidized sand filters at 150-410 gms/m^3-day. *Malone et al* (1993), citing data from Thomasson (1991) and Monaghan *et al.* (1996), reported ammonia removal rates of 630-800 gms/m^3-day in water.

Rotating Biological Contactors have been demonstrated to be one of the most efficient and robust biofilters available for nitrification of aquaculture wastes. They demonstrate extremely high nitrification rates, while providing additional qualifications for self-aeration, off-gassing, and low-head operation. An ammonia removal rate of 1.2 g/m^2-day surpasses all other biofilter configurations cited. With a volumetric nitrification rate of 312 g/m^3-day, comparisons to fluidized sand filters demonstrate a nearly equal volumetric nitrification rate and significant superiority in energy efficiency, ease of management, and reliability. Considering this, in addition to the positive considerations that have always been attributed to this biofilter, the RBC provides a reliable and effective alternative for consideration in commercial recirculating aquaculture systems.

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