An Evaluation and Comparison of the Biofiltration Performance Characteristics of Rotating Biological Contactors (RBC’s) and Moving Bed BioReactors (MBBR’s) in Recirculating Aquaculture Systems (RAS)
Bacterial Nitrification of Ammonia

BIOFILTER

Ammonia (NH₃) → Nitrite (NO₂⁺) → Nitrate (NO₃⁻)

Nitrifying bacteria, concentrated on the biofilter media surfaces, convert ammonia to nitrite and then to relatively harmless nitrate.
Biofiltration in Recirculating Aquaculture Systems (RAS)

Categories defining Nitrifying Biofilters

**Submerged Biofilters**
- Fluidized sand filters
- Bead filters
- Structured or random packed filters
- Moving Bed BioReactors (MBBR)

**Emergent Biofilters**
- Trickling filters
- Rotating Biological Contactors (RBC)
Comparative Nitrifying Capacity

Comparative Biofilter Performance Parameters by Surface Area (Ariel Tan Removal Rates)

Submerged Filters

**Bead Filters** (Wheaton et al, 1994)  0.2-0.3 g/m²-day

**Fluidized Sand Filters** (Thomasson, 1991)  0.25-0.35 g/m²-day

**MBBR** (Rusten et al, 2006; Drennan et al, 2006)  0.46 g/m²-d

Emergent Filters

**Trickling Filters** (Wortman, 1990)  1.0 g/m²-day

**Trickling Filters** (Greiner and Timmons, 1998)  0.75–1.0 g/m²-day

**Trickling Filters** (Lyssenko and Wheaton, 2006)  0.64 g/m²-day

**RBC** (Miller and Libey, 1985)  0.63–0.78 g/m²-day

**RBC** (Van Gorder and Jug-Dujakovic, 2005)  1.2 g/m²-day

**RBC** (Marin et al, 2011)  1.4 g/m²-day

Wide deviations occur with experimental variations in temperature, hydraulic loading rate, and substrate concentration.
MOVING BED BIOREACTORS
Moving Bed BioReactors (MBBR’s)

- A “fixed-film” submerged biofilter using a buoyant plastic media as the carrier element for nitrifying bacterial growth, which is vigorously agitated via air injection.
Kaldnes MBBR Media

Requires a very distinctive surface area/specific gravity/buoyancy relationship, as well as self-scouring capability under heavy loading and turbulent operational conditions.
Moving Bed BioReactors (MBBR’s)

Center for Marine Biotechnology

AES Low-Space Bioreactor

Open-containment Bioreactors
Moving Bed BioReactors (MBBR’s)

Requires significant aeration manifolds and diffuser arrays.
Containment and Agitation of Media

The media must be screened or otherwise maintained within the containment vessel.
ROTATING BIOLOGICAL CONTACTORS
Rotating Biological Contactors

RBC’s

- A “fixed-film” bioreactor using circular plates aligned on a central axis, submerged ~50%, and rotated to alternately expose the biologically active media to the culture water and to the air.
Critical Design Qualifications

Advantages


- The RBC is self-aerating, providing oxygen to the attached biofilm,
- The RBC is a low-head device minimizing pumping energy needs,
- The RBC is non-clogging due to shearing of loose biofilm caused by the rotation, and
- once established, the RBC performance is reliable and resistant to sudden failures.
Critical Design Qualifications

Advantages


- RBC’s are “generally quite stable in operation, have a high ammonia removal efficiency compared to some other biofilters, and operate with very little head loss”.

Timmons et al (2001), *Recirculating Aquaculture Systems* ...

- RBC’s require little hydraulic head,
- have low operating costs,
- provide gas stripping, and
- maintain a consistently aerobic treatment environment.
Critical Design Qualifications

Disadvantages

• “Almost all problems with RBC’s fall into the category of mechanical failures”. (Wheaton)

• “Their primary disadvantage is that they require a power source to turn them, and mechanical breakdown can be a problem with poorly designed units.” (Hockheimer and Wheaton)

• “The main disadvantages of these systems are the mechanical nature of their operation, and the substantial load on the shaft and bearings”. (Timmons)
New Designs from Research

- Other researchers have attempted to adapt the RBC for commercial recirculating aquaculture systems.

Dr. Mike Timmons / Cornell University

Dr. Thomas Losordo / North Carolina State University

Virginia Tech
All of these designs have been abandoned due to mechanical problems associated with …

- … the drive motor, chain, and pillow blocks.
- … the weight-supporting axle.
- … the disassociation of the biofilter media from the axle.
Commercial Aquaculture Systems using Rotating Biological Contactors

- Commercial RBC’s manufactured for the sewage treatment industry are mechanically reliable, but are usually prohibited by commercial cost and operational energy demand.

Bill Martin stands in front of one of his many RBCs, commercially manufactured for the municipal sewage treatment industry, and installed at his tilapia culture facility in Virginia.
From 1985-1995, several aquaculture facilities were designed and operated using dozens of small (0.6 m diameter) floating/air-driven RBC’s, for the commercial production of finfish in closed systems.
• Larger biofilters (1.22 m diameter) were designed and built to accommodate larger-scale fish production facilities.

• Constructed with neutral buoyancy, allowing frictionless rotation of the non-weight bearing central shaft within the guiding channels of the fiberglass staging unit.
• Rotation is affected by the injection of air below, and/or water onto a centrally placed paddlewheel.

• Using spokes and rigorous attachment methods, the media is secured to the rotating shaft, and since no gear motor is required, is rotated at full 50% submergence.

Several 10,000 ft² (930 m²) RBC’s are rotated during acclimation procedures using only a small linear air compressor.
Commercial Aquaculture Systems using Rotating Biological Contactors

- For over 15 years, the larger RBC’s have been incorporated in closed recirculating production facilities for the commercial production of striped bass, hybrid striped bass, yellow perch, steelhead trout, coho salmon and tilapia.
Comparing MBBR’s and RBC’s

- TAN removal capabilities
- Mechanical characteristics
- Energy Requirements
- Footprint
- Reliability
- Pricing
## Comparative Nitrifying Capacity

### Comparative Biofilter Performance Parameters by Specific Volume (VTR)

<table>
<thead>
<tr>
<th>Biofilter Type</th>
<th>Performance Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Moving Bed BioReactors (measured as “unexpanded”)</strong></td>
<td></td>
</tr>
<tr>
<td>MBBR (Pfeiffer and Mills, 2008)</td>
<td>125 g/m³-day</td>
</tr>
<tr>
<td>MBBR (Suhr and Petersen, 2010)</td>
<td>200-230 g/m³-day</td>
</tr>
<tr>
<td>MBBR (Guerdat et al, 2010)</td>
<td>267 g/m³-day</td>
</tr>
<tr>
<td><strong>Rotating Biological Contactors (assembled)</strong></td>
<td></td>
</tr>
<tr>
<td>Rotating Biological Contactor (Van Gorder, 2005)</td>
<td>312 g/m³-day</td>
</tr>
<tr>
<td>(This VTR level was measured at an elevated substrate concentration (3 mg/l NH₃).)</td>
<td></td>
</tr>
<tr>
<td>RBC (Van Gorder and Jug-Dujakovic, 2005)</td>
<td>280 g/m³-day (ADJUSTED)</td>
</tr>
</tbody>
</table>

Wide deviations occur with experimental variations in temperature, hydraulic loading rate, and substrate concentration.
### Comparative Nitrifying Capacity

#### Spatial Characteristics

<table>
<thead>
<tr>
<th>Technology</th>
<th>Volumetric Surface Area (m²/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MBBR (k1 media - unexpanded)</td>
<td>500</td>
</tr>
<tr>
<td>MBBR (expanded – 50% fill rate)</td>
<td>250</td>
</tr>
<tr>
<td>FCS-RBC (expanded)</td>
<td>280</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Technology</th>
<th>Arial Tan Removal Rate (g/m²/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MBBR</td>
<td>0.46</td>
</tr>
<tr>
<td>RBC</td>
<td>1.0</td>
</tr>
</tbody>
</table>

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<tr>
<th>Technology</th>
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<tr>
<td>MBBR</td>
<td>267</td>
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<tr>
<td>MBBR (expanded)</td>
<td>134</td>
</tr>
<tr>
<td>RBC</td>
<td>280</td>
</tr>
</tbody>
</table>
Comparative Nitrifying Capacity

Required biofiltration capacity (at 110% designs specs) for the removal of ammonia resulting from the feeding of 30 kgs of feed/day.

**Ammonia production rate**

0.03 kgs NH₃/kg feed x 30 kg feed = 900 g NH₃

<table>
<thead>
<tr>
<th>Biofilter Characteristics</th>
<th>MBBR</th>
<th>FCS/RBC-10000</th>
</tr>
</thead>
<tbody>
<tr>
<td>VTR</td>
<td>267 g/m³-day</td>
<td>280 g/m³-day</td>
</tr>
<tr>
<td>Media required (110% -unexpanded)</td>
<td>3.7 m³</td>
<td>3.5 m³</td>
</tr>
<tr>
<td>Biofilter volume (expanded)</td>
<td>7.4 m³</td>
<td>3.5 m³</td>
</tr>
</tbody>
</table>
## Mechanical Characteristics

<table>
<thead>
<tr>
<th>MBBR</th>
<th>RBC</th>
</tr>
</thead>
<tbody>
<tr>
<td>• non-clogging biofilm reactor</td>
<td>• non-clogging biofilm reactor</td>
</tr>
<tr>
<td>• maintains <strong>adequate</strong> oxygen availability (submerged)</td>
<td>• maintains <strong>maximum</strong> oxygen availability (emergent)</td>
</tr>
<tr>
<td>• <strong>low</strong> head loss</td>
<td>• <strong>low</strong> head loss</td>
</tr>
<tr>
<td>• <strong>moderate</strong> specific biofilm surface area</td>
<td>• <strong>moderate</strong> specific biofilm surface area</td>
</tr>
<tr>
<td>• no requirement for backwashing</td>
<td>• no requirement for backwashing</td>
</tr>
<tr>
<td>• <strong>agitation</strong> within the reactor maintains the media in constant motion creating a scrubbing effect that prevents clogging and sloughs off excess biomass</td>
<td>• <strong>rotation</strong> of the reactor maintains the media in constant motion creating a sloughing effect that removes excess biomass.</td>
</tr>
<tr>
<td>• <strong>the media must be kept within the reactor volume by an inlet and outlet sieve or screen</strong></td>
<td>• <strong>no inlet or outlet sieve or screen is required.</strong></td>
</tr>
</tbody>
</table>
Operational Energy Requirements

**MBBR**

- requires injection of 0.08-0.13 m³ air/min/m³ of biofilter to maintain the agitation of the media.
- 1 hp regenerative blower will agitate 10-13 m³ of MBBR (@ 1 meter depth).

**RBC**

- FCS-RBC design requires injection of 0.02 m³ air/min/m³ for rotation of 1.22 m diameter RBC.
- 1 hp regenerative blower will provide for rotation of 100 m³ of RBC (1/8 the energy requirement).
A rectangular MBBR with 1.5 m depth requires 5.0 m² (55 ft²) of floor space.

A cylindrical MBBR with 1.5 meter depth requires a 2.5 m diameter containment, or ~6.3 m² (68 ft²) of floor space.

Footprint

Sizing an MBBR for maintaining 30 kg/day feed rates...

- VTR = 267 gms/m³-day
- 110% sizing requires 7.4 m³ biofilter volume (expanded)
Sizing an FCS-RBC for maintaining 30 kg/day feed rates ...

- VTR = 280 gms/m$^3$-day
- Requires 3.5 m$^3$ biofilter volume

With containment, the 3.5 m$^3$ RBC10000 requires 5 m$^2$ (55 ft$^2$) of floor space.
<table>
<thead>
<tr>
<th>Pro's</th>
<th>Con's</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economical to build from commercially available materials. Also provides gas stripping</td>
<td>Can have problems with media carryover on system start-up, with reports of intermittent bed motility and system crashes</td>
</tr>
<tr>
<td>Raw filter media has moderate specific surface area, which allows for conservative design and capacity for expansion or load fluctuation</td>
<td>Media density changes over time with biofilm accumulation, necessitating a bed growth management strategy</td>
</tr>
<tr>
<td>Can be field built using a variety of proven methods or purchased from vendor, opening various design and construction options</td>
<td>Can require relatively expensive plumbing to ensure that media is not back-siphoned on pump shut-down or power failure</td>
</tr>
<tr>
<td>Pro's</td>
<td>Con's</td>
</tr>
<tr>
<td>------------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------</td>
</tr>
<tr>
<td>They are self-aerating, require little hydraulic head, have low operating costs, provide gas stripping, and maintain a consistently aerobic treatment environment.</td>
<td>Can’t be field built. The unacclimated floating RBC must be buoyant to an elevated level to accommodate the anticipated settling following biofilm development.</td>
</tr>
<tr>
<td>They are self-cleaning due to the shearing of loose biofilm caused by the rotation of the media through the water.</td>
<td>Larger-scale designs will require RBCs of increased diameter, while maintaining structural integrity and low-energy operation. These are presently in development.</td>
</tr>
</tbody>
</table>
Comparative pricing of the FCS-RBC and MBBR appropriate for the application of 30 kgs of feed/day.

<table>
<thead>
<tr>
<th>BIOFILTER</th>
<th>MEDIA VOLUME</th>
<th>MEDIA PRICE/ COST</th>
<th>EXPANDED VOLUME</th>
<th>CONTAINMENT COST</th>
<th>ROTATION/AERATION ARRAY</th>
<th>TOTAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCS-RBC</td>
<td>3.5 m³ (124 ft³)</td>
<td>$35/ft², $4340</td>
<td>3.5 m³ (124 ft³)</td>
<td>* $3900</td>
<td>$100</td>
<td>$8240</td>
</tr>
<tr>
<td>MBBR</td>
<td>3.7 m³ (131 ft³)</td>
<td>$30/ft³, $3930</td>
<td>7.4 m³ (261 ft³)</td>
<td>** $3090</td>
<td>*** $1200</td>
<td>$8220</td>
</tr>
</tbody>
</table>

* FCS-RBC Fiberglass Stage & Lid
  Pumping Station & Level Control

** Red Ewald Fiberglass Raceway
  17’ x 4’ x 4’

*** Aeration Array – 0.85 m³/min (30 ft³/min)
  1 HP blower/40 diffusers/plumbing
Overall Comparison

- The FCS-RBC maintains > 2X the VTR rate over the “expanded” MBBR.
- Both biofilters operate at minimal head pressure, with no hydraulic loading limitations, however the MBBR requires screened restraints to maintain the media within the containment.
- They both maintain a similar footprint.
- The FCS-RBC operates using 1/8 the energy levels.
- The MBBR requires more maintenance for stability of media. Both biofilters are highly reliable with competent management.
- The purchase/construction costs are comparable.