Biofilm Reactors:
OPERATIONAL OVERVIEW AND APPLICATIONS FOR NUTRIENT REMOVAL

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Acknowledgements

• Water Environment Federation (WEF) Manual of Practice (MOP) No. 29
  – Operation of Nutrient Removal Facilities
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Outline

• What is a biofilm?
• Why is this important?
• Biofilm reactor controls
• Current applications
• Future direction
What is a biofilm?

• “cells immobilized at a substratum and frequently embedded in an organic polymer matrix [EPS] of microbial origin” - Characklis and Marshall 1990

• Why biofilm and not fixed film???
  – Biofilm is scientifically accepted term
  – Better describes what the film is (i.e. biological film)
What is a biofilm?

- Cell residence time independent of hydraulic residence time
- Increased volumetric activity
- Increased operational stability
- Increased resistance to toxic/inhibitory shock loads
- Different bioconversion processes in the same reactor
Why is this important?
Why is this important?

• What makes a biofilm different?
  – Not all cells see the same thing
  – Mass transfer constraints
• What controls a biofilm?
  – Rate of transfer into the biofilm
  – Thickness of biofilm
  – Activity in the biofilm
Why is this important?

• Biofilm Research
  – Confirmed stratification of biofilm
    • Heterotrophs outside
    • AOB and NOB inside
  – Measured DO, ammonium, nitrite, and nitrate in a biofilm
Biofilm Operation

- How does stuff get into a biofilm?
Biofilm Operation

• Controlling nitrification
  – Gets stuff into the biofilm “faster”
    • Decrease “smooth” flow layer thickness
    • Increase liquid dissolved oxygen concentration
  – Prevent excess biofilm thickness and sloughing
    • Consistent, gentle scouring of biofilm
    • Not too thick, not too thin, but just right
Biofilm Operation

• What are our “knobs” to turn?
  – Liquid velocity
    • Aeration (MBBR, IFAS)
    • Mechanical mixing (MBBR)
    • Backwashing (BAF)
    • Flushing water (Trickling Filter)
    • Rotation speed (RBC)
  – Increase DO concentration
    • Increases with liquid velocity increase
Biofilm Operation

• Solids settleability
  – Small particle size = poor bioflocculation
  – Options:
    • Downstream flocculation (biological or chemical)
    • Downstream filtration

Odegaard et al WEF/IWA Biofilm Reactor Technologies 2010
Manitowoc WWTP
Technologies

• Oldest applications in wastewater treatment
  – Trickling filter (1890s)
  – Attachment to walls observed to increase removal in activated sludge (1960s)

• Aerobic processes

• Low-tech, easy to operate
Technologies

A. TRICKLING FILTER

B. MOVING BED BIOFILM REACTOR (MBBR)

C. INTEGRATED FIXED FILM ACTIVATED SLUDGE (IFAS)

D. ROTATING BIOLOGICAL CONTACTOR (RBC)

E. BIOLOGICALLY ACTIVE FILTER (BAF)
Technologies – Trickling Filter

• Biofilm support
  – Rocks
  – Cross flow media

• Main Controls
  – Recirculation flow rate
    • Increase recirculation flow increases liquid velocity and oxygen concentration
  – Forced ventilation
    • Oxygen supply
    • Temperature control
Key Components

• **Spülkraft (SK) Value**
  – Measure of the *intensity* of water application
  – More intense application → higher SK value → thinner film and fewer flies
  – More intense flow → less frequent application

• **Wetting efficiency**
  – Frequency of water application
  – Too frequent → odor issues
  – Not frequent enough → fly issues
  – Provide sufficient recovery time for biofilm without drying out

• **How can these parameters be controlled?**
  – Number of arms
  – Rotational speed
  – Recirculation pumping rate
Spülkraft (SK) Value

• SK value
  – $\text{SK} = \frac{\text{THL}}{N_a \cdot \omega_d}$
  – $\text{THL} =$ Total Hydraulic Load (influent plus recirculation)
  – $N_a =$ Number of arms
  – $\omega_d =$ Rotational speed

• Increased SK $\rightarrow$ More Intense Application $\rightarrow$ Healthier biofilm

Lower SK $\rightarrow$ Less Healthy Biofilm

Higher SK $\rightarrow$ Healthier Biofilm
Number of Arms

Two Arms
- Increased application intensity
- Requires faster rotation speed
- More time between application

Four Arms
- Decreased application intensity
- Requires slower rotation speed
- Less time between application
Example

- Trickling filter operation
- $Q_{in} = 3.3$ MGD
- $Q_r/Q_{in} = 3$
- Rotational speed = 4 min/rev.

2 ARMS

4 ARMS
Where are we Operating?

<table>
<thead>
<tr>
<th>PROJECT NAME: DWU Trickling Filters Design and Operation</th>
<th>DATE: December 2010</th>
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</thead>
</table>

### Dallas Plant Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Flow</td>
<td>40 MGd</td>
<td>Total influent flow</td>
</tr>
<tr>
<td>Primary Effluent BOD</td>
<td>85 mg/L</td>
<td>Dallas Plant primary effluent</td>
</tr>
<tr>
<td>Number of Trickling Filters</td>
<td>12</td>
<td>Number of trickling filters following decommissioning</td>
</tr>
<tr>
<td>Number of Arms per Filter</td>
<td>4</td>
<td>Number of distributor arms per trickling filter</td>
</tr>
</tbody>
</table>

### Operational Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recirculation rate</td>
<td>4 [-]</td>
<td>Ratio of recirculation flow to influent flow, ( Q_r/Q_i )</td>
</tr>
<tr>
<td>Rotational speed</td>
<td>8 min/rev</td>
<td>Rotational speed of distributor arms</td>
</tr>
</tbody>
</table>

### Process Performance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Removal Efficiency</td>
<td>70.2%</td>
<td>BOD removal in Dallas Plant trickling filters</td>
</tr>
<tr>
<td>Effluent BOD</td>
<td>25.3 mg/L</td>
<td>Effluent BOD from Dallas Plant trickling filters</td>
</tr>
<tr>
<td>SK Value</td>
<td>0.800 m/in/pass</td>
<td>Spulkrat number; measure of operating dosing rate intensity</td>
</tr>
<tr>
<td>SK Ideal Range</td>
<td>1 to 9 m/in/pass</td>
<td></td>
</tr>
<tr>
<td>Organic Loading Rate</td>
<td>12.2 lbs/1,000 cf-day</td>
<td>BOD loading to Dallas Plant trickling filters</td>
</tr>
<tr>
<td>Organic Loading Range</td>
<td>25 to 75 lbs/1,000 cf-day</td>
<td></td>
</tr>
</tbody>
</table>

[Graph showing the relationship between Recirculation Rate and Rotational Speed with lines for different SK values and an Operating Point marker.]
Key to Success with Trickling Filters

• Find the Right Balance
  – Process and hydraulic performance
    • Loading rates
    • Recirculation rate
  – Biofilm thickness and health
    • Rotational speed
    • Recirculation rate
    • Number of distributor arms
  – Odor and fly control
    • Rotational speed
    • Number of distributor arms
Technologies - MBBR

- Moving Bed Biofilm Reactor
- Floating media in reactor
- **NO** suspended growth recycle
- Compact process
- Multi-stage process
  - L:W close to 1:1
  - Later stages: low concentrations
  - Select for “bugs” that thrive under a set of conditions
- Main controls
  - Aeration supply rate
Technologies - MBBR

- Media retention is key
- Retention Sieves
  - Effluent cylinders
  - Drains
  - Overflows
  - Everywhere...
- Influent screening is critical
  - With primary clarifiers: 6 mm
  - Without primary clarifiers: 3 mm
Technologies - MBBR

• What can we control?
  – Biomass concentration
    • Biofilm thickness: self regulating
    • Media volume: typically set during design
  – Not a lot of control
  – DO concentration
    • Medium bubble aeration
    • Operate at higher DO 4-6 mg/L)
Technologies - IFAS

- IFAS
  - First application – 1943
  - Gained momentum in late 1990s
  - Main driver: increased nitrification in same tank volume
Technologies - IFAS

- **Floating media**
  - Same control as MBBR for the biofilm
  - Same control as AS for suspended growth

- **Fixed media**
  - “Clumping” risk
  - One big mass of biomass
  - No diffusion to center
  - Periodic sparging is key
    - Fine bubble aeration
    - Coarse bubble scouring

- **What can we control?**
  - Aeration supply rate!
Biofilm and Future Nutrient Limits

• What role can biofilms play?
  – Lower P limit leads to larger chemical demand
  – Maximize biological phosphorus removal
    • More existing basin available for selector volume
    • Incorporate selector volume for bio-p and denitrification
    • No new tankage
• What role can biofilms play?
  – Clarifier limitation
    • Increase biomass without increasing MLSS
    • Higher biological activity, same solids loading to clarifier
  – Wet weather
    • High peak flows can “washout” suspended growth
    • Biofilms are “stuck”
    • High peak facilities may benefit from biofilm process
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