FUNDAMENTALS OF GRANULAR MEDIA FILTRATION

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OVERVIEW

- Filtration basics
- Filtration theory
- Filter media selection and design
- Monitoring and Troubleshooting
FILTRATION BASICS AND THEORY
WHAT IS FILTRATION?

- **Definition**: any process that removes suspended particles through a porous medium

- **Types of Filters**
  - Granular media filters (GMF)
    - Slow sand filters
    - **Rapid depth filters**
  - Membrane filters (MF/UF/NF/RO)
### Typical Filtration Pre-Treatment

<table>
<thead>
<tr>
<th>Filtration Type</th>
<th>Coagulation</th>
<th>Flocculation</th>
<th>Sedimentation</th>
<th>Filtration</th>
<th>NTU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>![Coagulation Icon]</td>
<td>![Flocculation Icon]</td>
<td>![Sedimentation Icon]</td>
<td>![Filtration Icon]</td>
<td>Any</td>
</tr>
<tr>
<td>Direct</td>
<td>![Coagulation Icon]</td>
<td>![Flocculation Icon]</td>
<td>![Sedimentation Icon]</td>
<td>![Filtration Icon]</td>
<td>&lt;15 NTU</td>
</tr>
<tr>
<td>Contact</td>
<td>![Coagulation Icon]</td>
<td>![Flocculation Icon]</td>
<td>![Sedimentation Icon]</td>
<td>![Filtration Icon]</td>
<td>&lt;10 NTU</td>
</tr>
</tbody>
</table>
A TYPICAL GRAVITY DEPTH GMF

Components

- Flow control
- Media
- Underdrain and support
- Backwash system

*Picture from MWH (2005) Water Treatment Principles and Design*
GRANULAR MEDIA TYPES

Configuration
- Mono media
- Dual media
- Multimedia

Types
- Silica sand
- Anthracite coal
- GAC
- Other (e.g. garnet)
FILTER UNDERDRAINS AND SUPPORT
UNDERSTANDING A FILTER RUN

- **Turbidity (NTU)**
  - Ripening
  - Operating Turbidity
  - Breakthrough

- **Head Loss (ft)**
  - Terminal head loss
  - Clean bed head loss
  - Time to breakthrough

**Filter run time (hours)**

0 20 40 60 80 100

0 3 6 9 12

0 100

0 0.1 0.2 0.3
### Surface vs. Recycled Water Filtration

<table>
<thead>
<tr>
<th>Typical</th>
<th>Surface Water</th>
<th>Recycled Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drivers</td>
<td>sediment, pathogens, organic solids</td>
<td>pathogens, organic solids</td>
</tr>
<tr>
<td>Pretreatment</td>
<td>Any</td>
<td>direct/contact</td>
</tr>
<tr>
<td>Source Water</td>
<td>1 to 100 NTU</td>
<td>1 to 10 NTU</td>
</tr>
<tr>
<td>Turbidity Req’d</td>
<td>0.3 NTU/0.1 NTU</td>
<td>2 NTU</td>
</tr>
<tr>
<td>Filtration Rate (gal/ft²-min)</td>
<td>3/6 (mono/dual)</td>
<td>5 (up to 7.5)</td>
</tr>
</tbody>
</table>
**Filtration Theory**

- Modeled as 2-step process
  1. Particle transport
  2. Particle attachment

- Particle transport mechanisms
  - Sedimentation
  - Interception
  - Brownian motion (diffusion)

- Straining *not* desirable

- Overall removal is sum of all mechanisms

*Picture from Lawler and Benjamin 2006*
PARTICLE TRANSPORT EFFICIENCY

Transport efficiency driven by:
- Filtration rate
- Media design
- Particle size
- Temperature
- Density (sed. only)

Graph from Lawler and Benjamin 2006
Actual data matches up with theory!
WHY IS CHEMISTRY SO IMPORTANT?

- Chemistry needs to be right for particles to “stick”
- Both particles and media are naturally negatively charged and thus *repelled* by each other
- For excellent filtration, the surface chemistry of target particles must be modified – coagulation!
PARTICLE ATTACHMENT EFFICIENCY

- Attachment is driven by chemistry
- Attraction/repulsive forces
  - London-van der Waals force
  - Electrical double-layer interaction
  - Born repulsive force
  - Hydration force

From V. Jegatheesan and S. Vigneswaran (2005)
Filtration Media Selection and Design
# How does theory affect design?

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>Head Loss</th>
<th>Effluent Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time</td>
<td>Cumulative Volume</td>
</tr>
<tr>
<td>Depth</td>
<td>↑</td>
<td>↓^a</td>
</tr>
<tr>
<td>Media Size</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>Velocity</td>
<td>↑</td>
<td>↓</td>
</tr>
<tr>
<td>Influent Conc.</td>
<td>↑</td>
<td>↓</td>
</tr>
</tbody>
</table>

- **Increased media depth**
- **Increased media size**

from Lawler and Benjamin 2006
HEADLESS ACROSS FILTER BED

Filter Clogging ($\Delta h/\Delta h_0 - 1$)

Media Depth (inches)

Anthracite

Sand

5.0 gal/ft^2-min

7.5
WHAT MAKES DESIGN GMF COMPLICATED?

Two competing goals:

1. Particle removal (i.e., effluent quality)
2. Filter run length (i.e., head loss accumulation)
HOW DO WE BALANCE COMPETING VARIABLES?

Modifying three basic design parameters

- Media selection
- Depth of media
- Filtration rate (flow velocity)

In terms of cost

- Biggest cost driver will be filtration rate
  - Filter area is function of filtration rate
APPROACH TO MEDIA SELECTION

Begin with good understanding of treatment goals and water quality

Approaches to Design
- Follow industry design standards
- Modeling approach
- Filter piloting
SPECIFYING GMF MEDIA

- Effective grain size ($d_{10}$)
- Uniformity coefficient (UC)
  - $UC = d_{60}/d_{10}$
  - Smaller the better
  - Typically <1.5
- Media depth (L)
  - $L/d_{10} > 1000$
- Trends over time
  - Deeper and coarser
  - Higher filtration rates
DEFINE FILTER MEDIA GOALS

What does better performance mean?
- Reduce head loss accumulation
- Improve effluent water quality
- Reduce risk of breakthrough
- Manage a combination of goals for multiple source waters
MODELING APPROACH TO MEDIA SELECTION

Model Calibration (historical data)
- Water quality
- Chemical use
- Breakthrough
- Head loss changes

Performance Modeling (under various conditions)
- Feed water qualities
- Media sizes and depths

Media Selection
- Particle removal
- Time to breakthrough
- Time to Max. head loss
- Optimal balance
EXAMPLE OF MODELING RESULTS

![Bar Chart](chart.png)

**Time to Headloss (h)**

**Filter Loading Rate (gpm/ft²)**

- **Existing Filters**
- **Alternative**

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*Note: The chart illustrates the comparison of time to headloss between existing filters and an alternative for different filter loading rates.*
FILTER OPERATIONS
CLEAN-BED REMOVAL AND RIPENING

- Surface chemistry is improved through chemical conditioning (coagulants and polymers)
- Particle-particle attachment is more efficient than particle-media attachment
- Ripening needed for excellent removal
- Typical practice to have a filter-to-waste step
FILTER PERFORMANCE MONITORING

- Turbidity standard performance metric
  - NTU = Nephelometric Turbidity Unit
  - Based on light *scattering*
- Particle counters – based on light *blockage*
- Surrogate parameter for treatment performance
- Regulatory limits of 0.3 or 0.1 NTU

*Old school turbidity by Jackson candle (JTU)*
Filter Performance Data: Douglas et al, 2015, City of Ottawa

Cryptosporidium, microsphere, & PRD1 log-removal vs. filter turbidity relationship
Britannia Pilot Plant - 2014 trials

- Crypto Log-removal
- 4.5 M/S log removal
- PRD1 (phage) log removal
- Power (Crypto Log-removal)
- Power (4.5 M/S log removal)
- Power (PRD1 (phage) log removal)

log removal (filtration only)

filter effluent turbidity (NTU)

- \( y = 1.1622x^{-0.58} \)
- \( y = 0.7141x^{-0.738} \)
- \( y = 0.5895x^{-0.821} \)
GMF Filter O&M Troubleshooting

- Excellent influent water quality = ease of operation
- Balance turbidity and head loss using chemical dose
- Backwash management
- When issues arise - filter surveillance!
  - Visual observation
  - UFRV
  - Filter coring – media changes/mudballs
  - Watch head loss – air binding
  - Backwash profile – improved sequence
QUESTIONS?

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From Williams 2009
UNDERSTANDING THE EXISTING MEDIA

Filter Coring of Existing Media

Sieve Analysis

33