Filter Operations
April 23rd & 24th, 2013

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Overview

• Learning objectives
  – Filtration Background
  – Filter Design Considerations
  – Why should operators optimize filtration?
  – How to measure the progress of optimization?
  – What are the important parameters?
  – What tools and techniques are needed?

• Necessary skills to assess filter efficiency

• Parameters used for comparison
History of Rapid Gravity Filters

- First used at the turn of 20th century
- Used as “roughing” filters as pre-treatment for slow sand filters e.g. London, England
- Used after sedimentation before floc formation and settling was well understood e.g. Cincinnati and Detroit in the US, and Zurich, Switzerland

1905 Richard Miller WTP, Cincinnati, OH
Filtration – Where is it?

- **Purpose**: remove particulate material from water

**Conventional Treatment**

1. **Rapid Mix**
2. **Floc/Sed**
3. **Dual-Media Filter**
4. **Storage**
5. **Distribution**

**Direct Filtration**

1. **Rapid Mix**
2. **Floc**
3. **Dual-Media Filter**
4. **Storage**
5. **Distribution**
Filtration – What does it look like?

What's missing???
History of Water Filtration
Filtered Water Turbidity Standards

Turbidity (NTU)

Prior to 1962: 10.0
1962 to 1976: 5.0
1976 to 1993: 1.0
1993 to 2003: 0.5
2003 to Present: 0.3
AWWA/Partnership Goal: 0.1

NTU = Nephelometric Turbidity Unit
IESWTR Performance Standards

• Turbidity Performance Requirements
  – Combined FE Turbidity must be < 0.3 NTU in 95% of measurements, and never > 1 NTU

• Individual Filter Requirements
  – Continuous monitoring required for each filter, and exceptions reported
Filter Backwash Recycle Rule

- FBRR applies to surface water and GWUDI utilities that:
  - Recycle thickener supernatant
  - Recycle spent filter backwash water
  - Recycle dewatering system liquid streams
- There is no size limitation for plants
- Rule requires that these streams be returned to a location prior to all conventional processes
What Else Do Filters Do??

• We ask filters to do MORE than filter….
  – GAC – taste & odor control
  – Mn treatment
  – Biological treatment
    • Especially for preozone
Filters and Particle Size

(After Stumm, ES&T, Vol. 11, p. 1066, 1977)
To address size & shape of particles desired to be removed

• Create environment in filter media for removal
  – Physical, but mostly
  – CHEMICAL

• Chemical influences
  – Source water quality
  – Pretreatment
  – Softening
  – Recarbonation
  – Prefilter chemicals
The Prediction of Filtration Performance

- Particle Removal and Filter Effluent Quality; Head loss increase; A Complex Function of:

**Site Specific & Uncontrolled**
- Ionic composition
- Temperature
- Influent Particle sizes, surface properties, shape and concentration
- Deposit morphology/porosity
- Detachment

**Designer Controlled**
- Filtration Rate
- Media: size, depth, material, surface characteristics, porosity
- Coagulants/flocculants
What does this all mean?

• Filter media
  – Provides pore spaces to collect particles

• Collected particles
  – Accumulate
  – Need to be removed
  – Taken away and dealt with

• Performance depends on
  – Particle conditions – shape and chemistry
  – Media / underdrain conditions
  – Operational techniques
Hydraulic Considerations

- Example Filter Cross Section Layout
- Design Velocity Guidelines
- Inlet Velocities to Prevent Floc Damage
- Inlet Velocities to Prevent Media Scouring
- Distribution of Backwash Water
- Distribution of Air Scour
To prevent media scouring ensure inlet gate is not opposite a trough
Design Velocity Guidelines

Inlet Channel ~3 ft/s excluding gate width

Inlet Gate or Valve ~2 ft/s

Backwash Distributers ~4 ft/s – several needed

Waste Channel free discharge to tank – velocity can be high

Backwash Header ~6 ft/s
Keep flooded to prevent air ingress

Air Scour Header, valve and drop pipe ~80 ft/s

Filter Outlet Channel ~4 ft/s

Filtered Water Outlet ~6 ft/s, Filter to Waste 8 ft/s

Discharge Weir above floor

Filter Outlet Channel ~4 ft/s

>10 ft
Air Scour 3.0 scfm/sq ft

Water surface 6 inches above media at start, but increases during low rate backwash - affects blower back pressure

Note: SCFM not ACFM

Air Scour Distributer Header – design varies to suit underdrain type

Underdrain to give +/- 5% air distribution
Backwash 6 to 25 gpm/sq ft

- Allow > 1 ft under trough during backwash
- Media expansion 15 to 30%, 20% normal
- Free discharge from troughs and gullet
- Underdrain to give better than +/- 5% distribution during backwash
- Backwash distribution directed to floor – note closed end
Multi- and Mono-Media Filters

- Dual-Media - Anthracite and Sand (> 3 ft) most common
- Multi-Media – Lower layer of garnet or ilmenite ($\text{FeTiO}_3$) usually not beneficial – mixes with sand layer
- Dual-Media - Sand with GAC cap for taste and odor removal not organics removal
- Mono-Medium Coarse Sand – Used for tertiary filtration and some overseas water applications for simplicity
- Mono-Medium Coarse Anthracite (5 to 6 ft) – not recommended for potable water, especially if high rate
- Mono-Medium GAC – Can be up to 10 ft deep for high EBCT for organics removal - 12 inches sand underneath to prevent biomass sloughing into filtrate
Media Recommendations

- Use AWWA B100-01 Granular Filter Media as basis for specifications - Read and apply it!!!
- Enforce full QA/QC procedures from suppliers premises to after backwashing and skimming
- Do NOT use bulk tanker delivery – severe media attrition will result plus possible contamination
- Use semi-bulk containers / bags of woven material
- Protect bags from weather – sun (UV), rain and freezing
- Do not stack bulk bags – they will burst
- Avoid hydraulic placement if possible – attrition can be severe leading to more backwashes to remove fines
Filter Media – Key Issues

• Filters are the most important part of water treatment process
• Media must be sourced from experienced vendors (e.g. Unifilt and F.B. Leopold)
• Tight QA/QC must be maintained
• Media is heavy (4,000 lb) – check structural floor loads, including fork lift trucks and hoppers
• Anthracite is particularly vulnerable to attrition and incorrect supply (SG, ES, UC etc.)
• Effective backwash procedures are crucial for good media performance
Filter Backwashing

• Filters get cleaned by
  – Using correct amount of wash water
  – At the correct flow rate
  – For the correct amount of time

• Most common problems
  – Not following procedures
  – Inconsistent schedules
  – Poorly designed filters
  – Poorly designed support facilities
  – Backwashing based on run time and not adjusting for water quality
Constant Rate Control - Recommended

Mode of Operation
Inlet water channel level provides flow set point. Valve position controlled by flow signal. As flow to inlet channel increases, water level increases, allowing more flow through all filters. Flow feedback loop maintains constant flow though individual filter. As headloss builds up, the flow drops, causing valve to open to maintain constant flow rate. All filters operate at same flow rate. Avoid control loop “hunting” as this leads to turbidity breakthrough.
Controlled Declining Rate – Avoid in US

Mode of Operation
Water level in the filter controls valve position directly. As flow to inlet channel increases, water level increases, allowing more flow through all filters. The flow meter is passive and monitors flow only. As headloss builds up, the level increases in the filter, causing valve to open to maintain the same water level for all filters. Filters operate at higher flows when clean and lower flows as the headloss builds up. Filters are usually backwashed on a regular time schedule.

If weir gate is used then constant rate possible. Weirs split flow equally to all filters.
Underdrains and Backwashing Techniques

• Large variety of underdrain designs – lateral and plenum are two main groups

• Backwashing Techniques
  – Separate air scour + high rate backwash (good)
  – Combined air scour + low rate backwash, followed by high rate backwash (best)
  – High rate backwash with surface sweeps (adequate)

• Waste backwash water removal:
  – Troughs in USA,
  – Weirs in Europe

• Backwashing fluidizes the media
Effect of Water Temperature and Viscosity, on Backwash Rate

- Effect of Temperature on the Viscosity of Water and Wash Rate for Equivalent Expansion.
Media Selection and Fluidization

Sand
SG 2.6 to 2.70
ES 0.45 to 0.55 mm
UC <1.4
UC <1.4 (critical)

Sand (Average)
SG 2.65 ES 0.50 mm
ES x UC = 0.70 →
Backwash = 16.5 gpm/ft²

Anthracite
SG 1.55
→ 14.0 gpm/ft²

Anthracite
UC 1.7 →
19.2 gpm/ft²

Anthracite
SG 1.6 to 1.7 (critical)
ES 0.8 to 0.9
UC < 1.4 (critical)

Anthracite (Average)
SG 1.65 ES 0.85
ES x UC = 1.19 →
Backwash = 15.8 gpm/ft²

European anthracite
has low SG of 1.4
Media Expansion, Backwash and Temperature Effects

At low temperature and high backwash the result is too high expansion of 50% → media loss.

Aim for 20% to 30% expansion for sand/anthracite.
Troughs – Stainless Steel

- Trough support up and down thrust restraint - adjustable
- Lateral brace to prevent vibration
- Trough stiffener to prevent vibration
- Trough side stiffener (retro)
Media Loss – Common Causes

- Uncontrolled air
  - Most common
- Poor air water distribution
  - Possible, watch for spouts
- Too high backwash rate
  - Possible, watch for churning
- Gas bubbles on media
  - Unlikely, but dry-bed causes severe foaming
  - Biogrowth leading to bubbles on grains

Foam after dry bed

How Air Causes Media Loss

- Air Scour Only Limit
- Anthracite
- Sand
- Anthracite
- Sand
- Air Scour and Rising Wash Limit
- No Media Loss
- Media Loss
Filter Underdrains - Lateral and Plenum

- Lateral (Orifice Based with and without diffusion caps)
  - F B Leopold (Shown)
  - AWI
  - Johnson
  - Roberts
  - Severn Trent
- Plenum Concrete Monolithic Floor with Nozzles
  - Eimco (Shown)
  - IDI
  - Orthos
Lateral vs. Plenum Floor

Pros
- Quicker to install
- Easier to retro-fit
- Pressure contained in “pipe” lateral – leaks less likely
- Factory built – tends to be more consistent

Be careful applying the “capped” versions of lateral underdrains, especially for bio-filters, due to blockage risks

Cons
- Requires skilled installation
- Deep flume disrupts base slab, makes deeper excavation
- Distribution efficiency depends on lateral length
- No access to clean underdrain if blocked
- Plastic laterals less successful than SS
Filter Aid (Polymer)

- Lowers effluent turbidity
- Proper dose
  - Reduce ripening time
  - Stabilize turbidity
  - Stabilize rate of headloss
- Overdose…
  - May increases rate of headloss development
  - Take longer to clean
Why Optimize Filters?

• Major barrier against pathogen passage
• Maximize production efficiency
• Minimize spent filter backwash water
  – Duration
  – Frequency
• Increasing reliance on other WQ goals
  – T&O control
  – Mn control
  – Bacteriological stability
How is Progress Measured?

- DATA / TRENDS
- Individual filter turbidity
- Filter run times
- Amount of filter backwash water required
- Production efficiency
  - What comes in vs. what goes out
- Uniform filter run volume (UFRV)
Filters Provide Flexibility, but....

• More Filters - greater chance that:
  – Bad filter goes unnoticed
  – Other processes can control filter ops

• Less Filters – greater chance that:
  – Other filters stressed when one is out of service
  – Operations less flexible
  – Plants may operate only part of day
Operator Perspective of Filter Theory

• Filter is particle storage device – not just particle removal device
  – During storage phase – gentle handling needed
  – During removal phase – vigorous handling needed

• Filters often designed as dual-media units
  – Provides deeper bed filtration
  – Longer runs

• Good filtration depends on good pretreatment
  – Remember multiple barriers
  – Short run times = poor efficiency, lots of spent backwash
Key to Good Filter Operational Techniques

• **Continuous operation**

• **At startup**
  – Bring filter rate up slowly
  – Don’t start a dirty filter

• **During filter run**
  – Ensure filter applied water is stable
  – Avoid or minimize hydraulic shock
  – Monitor headloss, NTU, run time
  – Use filter aid if appropriate for conditions

• **After backwash**
  – Rest the filter before returning to service, or
  – Filter to waste
Key to Good Filter Backwash Techniques

• Prior to backwash
  – Record filter run information
  – Verify backwash program parameters

• During backwash
  – Choose a temperature dependent high flow wash rate
  – Avoid washes that are too short or long
  – Hose down the side walls and pipes/gutters
  – OBSERVE THE BACKWASH

• Observations at each backwash
  – Surface or air wash effectiveness
  – View surface for boils or “hot spots”
  – Look for uneven wash areas or uneven troughs
Backwash Program

• Drain
  – Make sure level is low enough to maximize energy and minimize media loss
• Surface wash or air wash
  – 3 to 4 minutes is usually sufficient
• Low rate – initiates expansion
• High rate – expands media, temp dependent
• Low rate - restratification
Key to Good Filter Maintenance Techniques

• Once per quarter (per season)
  – Adjust high flow rate for temperature
  – Check media expansion – make adjustments
  – Review unit filter run volume data
  – Check media depth
  – Review all filter profiles

• Once per year
  – Core the filter – solids retention
  – Send media to lab for sieve analysis
  – Add media if necessary
  – BUT – know why it’s being lost
Probing Media Depth to the Gravel Layer
What Parameters are Important?

• Parameters to examine
  – Media depth and percent expansion
  – $L/d_e$ ratio
  – Unit Filter Run Volume (UFRV)
  – Solids retention of media
  – Backwash use / turbidity / temperature
  – Filter profile
  – Sieve analyses – ES & UC, loss of mass

• What do these parameters tell us?
  – Filter health
  – Process modifications
  – Backwash procedure modifications
Filter Inspection Techniques

- Visual observation of filter surface and components
- Probing media
- Solids retention analyses
- Core sampling
- Sieve analyses / media assessments
Tools and Techniques for Inspection

• HEALTH & SAFETY REQUIREMENTS
• Review AWWA Standard B100
• Measurement Tools
  – Shovel, level, 3/8 inch steel rod, tape measure
• Coring Tool
  – 1 1/2 inch electrical conduit, 5 foot length, baggies
• Expansion Tool
  – One-inch interval tubes or cups
• Laboratory Instruments and Tests
  – Turbidimeter, glassware, balance, sample bottles, baggies
• COMMUNICATIONS
Filter Inspection Tools
Media Assessment – L/D ratio

- Bed Depth Measurement (Drained Bed)
  - Know original specs
    - Effective size - Uniformity Coefficient - Depth - L/D ratio
  - Use a 3/8 inch steel rod to poke into media, or dig into it to measure depth
    - If filter is dual or mixed bed, note depth of each strata, and depth of mixed interface
  - Check to see if troughs are level, then measure distance from trough to bed - check for mounding
  - Calculate L/D ratio - should be >1100 for low NTU production
Example – L/D

- Dual Media - originally 36 inches 1 mm anthracite and 6 inches 0.5 mm sand
- Measurement shows 32 inches of anthracite, 6 inches of mixed layer, and 3 inches of sand = 41 total inches
- Rough L/D calculation (send media for analysis)
  - \((32\text{in} \times 25.4)/1\text{mm} \approx 813\)
  - \((6\text{in} \times 25.4)/0.75 \text{ mm} \approx 203\)
  - \((3\text{in} \times 25.4)/0.5\text{mm} \approx 152\)
  - Therefore L/D = 1168
Core Sampling for Solids Retention

- Solids retention analysis best way to determine backwash effectiveness
- Use core sampling tool and baggies to obtain depth samples
  - Take samples at 0-2 inches, 2-6, 6-12, 12-18, 18-24, etc., until all bed strata are sampled
  - Sample before and after backwash
  - Wash 50 grams of each sample with 5 successive 100 mL washes of lab water
  - Measure turbidity of each X 2- plot on graph as NTU/100 grams media
Inserting Core Sampling Tubes

Sample Tubes

Backwash Troughs
Examining Media Core Samples
Lab Setup for Core Samples

• Turbidimeter
• Pan balance
• Baggies – before and after
• Glassware
• Lab water
• Weigh boats or other plastic cups
Guidelines – After Backwash

• < 30 NTU
  – Bed is too clean - examine wash rate and length - this bed will not ripen quickly

• 30 - 60 NTU
  – Well cleaned and ripened bed - no need for action

• 60 - 120 NTU
  – Slightly dirty bed - reschedule retention analysis soon

• > 120 NTU
  – Dirty bed - evaluate filter wash system and procedures

• > 300 NTU
  – Mudball problem - rehab bed
Solids Retention

- Measures the effectiveness of backwash
- Can show too little or too much backwash
- Change in historical solids retention is cause for concern
- Graph results for database
Spent Backwash Turbidity Analyses

• Too little / too much washing is a common problem
• After the first coring, and before the bed expansion measurement and second coring, the washwater turbidity should be measured for duration of wash
• Sample at 1 minute intervals and analyze
• Graph results as NTU vs. time
• Record all data
  – Volume of backwash, rates,
  – Ramping intervals, operator habits
Washwater Turbidity Plot

• Turbidity vs. Time
• Helps prevent Excessive washing
  – Wastes washwater
  – Strips ripening
• AWWA goal of 10 NTU
• This filter washed too long
Operators Sampling Backwash Water
Bed Expansion Measurement with Expansion Tool

- Check high flow wash rate (seasonally adjusted)
- Desire 20 – 30% expansion
- Position and tie down the expansion tool so that it rests on top of the bed
- Wash bed under normal conditions and observe amount of expansion
Use of Expansion Tool
## Backwash Rate Temp Correction

- **Bed Expansion Measurement Rate Requirement**
  - Temp (Deg C) | Multiply 25 Deg value by
  - 30 | 1.09
  - 25 | 1.00
  - 20 | 0.91
  - 15 | 0.83
  - 10 | 0.75
  - 5 | 0.68
Example – Bed Expansion

- Bed Expansion Measurement with Expansion Tool (Example for 30 inch bed)
  - dual media bed - need for a ramping rate, and a final rate
  - initial ramp might be 5 to 10 percent, or about 2-3 inches
  - observe expansion tool and adjust

- Bed depth measured at 30 inches
- Bed expansion tool captured 9 inches
- Bed Expansion Measurement calculations
  - 9 inches divided by 30 inches = 30% approx
Calculation of ES & UC from sieve analysis

- Sieve pans used for media size analysis
- ES = $D_{10}$
  - 90% larger, 10% smaller
- UC = $D_{60} / D_{10}$
- Example sieve analysis for anthracite
  - ES = 1.2
  - UC = 1.2
  - 1.2 better than 1.4
Unit Filter Run Volume

- **UFRV** - amount of water that is filtered during the filter run time
  - should be determined for every filter run
  - Goal - UFRV of 5,000 gallons per square foot per run
    - Same at low rate or high rate
  - Excessive UFRVs are risky
  - Change in historical UFRV cause for concern
- Example:
  - 600,000 gals per run / 120 square feet = 5,000 UFRV
Sometimes, you can just tell....
Thank you!
Questions?