WELCOME
TO THE MAY EDITION
OF THE 2019
M&R SEMINAR SERIES
BEFORE WE BEGIN

• SAFETY PRECAUTIONS
  – PLEASE FOLLOW EXIT SIGN IN CASE OF EMERGENCY EVACUATION
  – AUTOMATED EXTERNAL DEFIBRILLATOR (AED) LOCATED OUTSIDE

• PLEASE SILENCE CELL PHONES OR SMART PHONES

• QUESTION AND ANSWER SESSION WILL FOLLOW PRESENTATION

• PLEASE FILL EVALUATION FORM

• SEMINAR SLIDES WILL BE POSTED ON MWRD WEBSITE (www.MWRD.org: Home Page ⇒ Reports ⇒ M&R Data and Reports ⇒ M&R Seminar Series ⇒ 2019 Seminar Series)

• STREAM VIDEO WILL BE AVAILABLE ON MWRD WEBSITE (www.MWRD.org: Home Page ⇒ MWRDGC RSS Feeds)
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Wendy is currently a Senior Engineer at Metro Wastewater Reclamation District in Denver advising the Operations Director and Superintendent on wastewater process unit operations at a 140 MGD wastewater treatment plant. Wendy oversees a 6 MW combined heat and power generation facility and is a project manager of energy-related projects.

Wendy is a Class A Wastewater Operator in Colorado and a Certified Energy Manager.
Taking Ammonia-Based Aeration Control to the Next Level
Real World Experience and Lessons Learned

Robert W. Hite Facility
Denver, Colorado
Agenda

1) MWRD - Denver
2) Ammonia-based aeration control at MWRD-Denver
3) Feedback control system testing
4) Comparison of feed-forward versus feedback controls
5) Control system selection
6) Relate this to Stickney’s ABAC system?
Robert W. Hite Treatment Facility
Two Secondary Treatment Areas

South Secondary

North Secondary
Why ammonia-based aeration control (ABAC)?

- Reducing energy consumption
Pilot-testing two feedback systems
1) Direct ABAC
2) Cascade ABAC

Later:

Full-scale use of two aeration control systems:
1) Cascade (feedback) ABAC
2) Feed-forward ABAC
What’s the difference between feed-forward and feedback ammonia-based aeration control?
Feed-forward ABAC (BIOS™) – North Secondary

**Effluent NH₄⁺ set point**
Operator-entered

Dissolved oxygen controller
Airflow setpoint

Feed-forward Controller
Based on ASM1 + Optimized Algorithm

DO set point

probes
NH₄⁺
DO
Temp
TSS

Airflow controller
Valve position
Airflow meter
Airflow control valve

**Anoxic zone**

**Aeration basin**

Secondary Clarifier
Effluent

Air header

*Bioprocess Intelligent Optimization System (BIOS™), BioChem Technology, Incorporated, King of Prussia, PA*
**Feed-forward ABAC (ASM1) – North Secondary**

### Drawbacks
1. Complicated (?)
2. Proprietary
3. Needs lots of analyzers/probes

Ammonia removal rate,

\[
\left( \frac{mg_{NH_3}}{L/hr*g_{MLSS}} \right) =
\]

\[
- \left( f_{NH} + \frac{1}{Y_A} \right) \mu_A \cdot \frac{S_{NH}}{K_{NH} + S_{NH}} \cdot \frac{S_{DO}}{K_{DOA} + S_{DO}} \cdot X_A + k_a \cdot S_{ND} \cdot X_H - f_{NH} \cdot \mu_H \cdot \frac{S_S}{K_S + S_S} \cdot \frac{S_{DO}}{K_{DOH} + S_{DO}} \cdot X_H
\]

- Autotrophic Uptake
- Nitrification
- Ammonification
- Heterotrophic Uptake

Insignificant

Modified to use measurable variables

Incorporated into measured NH₄ adjustment

Specific Ammonia Removal Rate

\( mg_{NH_4} \) removed per g of TSS

Mixed Liquor Suspended Solids

\( g \) of TSS
Feedback ABAC (PID) — South Secondary

Drawbacks
1) Complicated (?)
2) Reactive/time lag
3) Oscillations
4) Seasonal adjustments
MWRD Denver - Ammonia Loading Profile

Influent ammonium

Effluent Ammonium
Pilot-testing two feedback systems

1) Direct ABAC
2) Cascade ABAC
Goals for PID ABAC Demonstration Test

• Implementable by District staff
• No reduction in nitrogen removal efficiency (at as good as DO control)
• Reduce power consumption
Feedback (Direct) ABAC

**Features:**
- Simple – control airflow directly from ammonia measurement
- Has been applied successfully at a number of facilities.
- Limits on DO and airflow can be applied in the logic.
- Improved energy efficiency over DO control

*Proportional integral derivative*
Direct ABAC Instrumentation

South Secondary

6 Parallel Basins – Modified Ludzack Ettinger process

Two duplicate basins in parallel, one test basin and one control
Results from Direct Control

- Testing period – 3 months
- Average 10% decrease in airflow compared with DO control
- Too much oscillation/instability – DO would vary too rapidly
  - Rise and fall to undesirable levels
  - Control valves moving frequently
  - Preferred to have slower ammonia control manipulate the set point of the faster DO control (cascade control)
    - Simplifies control system tuning
  - No fail safe condition if the controller or analyzer fails – difficult to establish
Cascade ABAC Instrumentation

South Secondary

6 Parallel Basins – Modified Ludzack Ettinger process

Two duplicate basins in parallel, one test basin and one control
Findings - Feedback Cascade ABAC

SSEC Controller Performance
Basin 6, Zone 7
Sunday, Feb 17 & Monday, Feb. 18, 2019
50:50 flow split between NSEC & SSEC

Effluent ammonia from Zone 8 is now below the effluent ammonia target, but aeration continues for 3.75 hours in Zone 7.

DO setpoint increases even though effluent ammonia drops below effluent ammonia target.

Lag between when effluent ammonia drops below target and when DO and airflow setpoint begins to drop in Zone 6.

Oscillation in influent ammonia.

Lag between when effluent ammonia drops below target and when DO and airflow setpoint begins to drop in Zone 6.

Lag between when ammonia loading begins and when the controller responds to the load.

Beginning of basin ammonia loading.

Effluent ammonia target.

Dissolved oxygen.
SCADA Control Panel
Compare: Direct versus Cascade Feedback Control

**OK**

- Direct Control - too much oscillation/instability – DO would vary rapidly
  - Rise and fall to undesirable levels; control valves moving frequently

**Better**

- Cascade control – NH3 concentration dictates DO set point, keeping DO concentration from varying rapidly
  - This simplifies PID control system tuning
- DO controller is the fail safe for an cascade feedback failure;
  - Fail safe system for a direct controller is more difficult to develop.
Effective use of the feedback cascade controller

• Need more steady-state conditions for PID controller
• Need to activate extra aerated volume (i.e. swing zone) when peak load is anticipated
  • Might use additional ammonia probe or program swing zone activation for a specific time of the day
• Tuning to minimize windup and oscillation
• ISE probe can be unstable at low NH3 concentrations
  • Colorimetric NH3 analyzer may not sample frequently enough
• Periodic adjustment of tuning constants (every four months?)
  • Not a “smart” controller; requires intensive and frequent(?) tuning
Feed-forward ABAC (BIOS™) – North Secondary

Feed-forward Controller
Based on ASM1 + Optimized Algorithm

Effluent NH₄⁺ set point
Operator-entered

DO set point

Dissolved oxygen controller
Airflow setpoint
Airflow controller
Airflow meter
Valve position
Airflow control valve

Probes:
NH₄⁺, DO, Temp, TSS

Anoxic zone
Aeration basin

Secondary Clarifier
Effluent

Air header
Feed-forward ABAC Instrumentation

North Secondary
12 Serpentine Basins – Modified Ludzack Ettinger process
Virtual Zone Control – DO Profiles

- Influent & RAS Flow, $Q_{I,RAS}$
- IMLR Flow, $Q_{IMLR}$

Total Flow
$Q_{\text{Total}} = Q_{I,RAS} + Q_{IMLR}$

NH4 Loading
$Q_{\text{Total}} \times NH_4^+$

Dissolved Oxygen

CSTR 1
Volume: 386.9 m$^3$

CSTR 2
Volume: 384.9 m$^3$

CSTR 3
Volume: 413.8 m$^3$

CSTR 4
Volume: 626.6 m$^3$

CSTR 5
Volume: 626.6 m$^3$

CSTR 6
Volume: 626.6 m$^3$

CSTR 7
Volume: 626.6 m$^3$

CSTR 8
Volume: 626.6 m$^3$

CSTR 9
Volume: 626.6 m$^3$

CSTR 10
Volume: 626.6 m$^3$

CSTR 11
Volume: 626.6 m$^3$

NH4 Loading
$Q_{\text{Total}} \times S_{NH_4^+}$

Total Flow

Ammonium, $NH_4^+$
Feed-Forward Control

NSEC Controller Performance
Basin 10, Pass B
Sunday, Feb. 17, & Tuesday, Feb. 19, 2019

Influent ammonium
Effluent ammonia
Effluent ammonia set point
Dissolved oxygen set point
Effluent ammonia target

Aeration increases within a half hour of ammonia load increases.

Influent NH4 mg/L
Effluent NH4 mg/L
B-Pass DO Setpoint
Operator Entered NH3 Effluent Setpoint
Features: Feed-forward Auto Tuning

• The BIOS software includes the ability to automatically update the specific ammonia removal rate – every 24 hours.
• BIOS compares the predicted effluent NH3 to the measured
  • The specific ammonia removal rate is adjusted to align these values (10%).

Ammonia removal rate, \( \frac{mg_{NH_3}}{L \cdot hr \cdot g_{MLSS}} \) =

\[ SARR \cdot \frac{S_{NH}}{K_{NH} + S_{NH}} \cdot \frac{S_{DO}}{K_{DOA} + S_{DO}} \cdot X_{MLSS} \]

Specific Ammonia Removal Rate (mg NH4 removed per g of TSS)
Mixed Liquor Suspended Solids (g of TSS)
Features: Analyzer Fault Detection

- 3σ (99.85 Percentile)
- 1σ (68.2% Percentile)
- 1.5σ (95.45% Percentile)
- −3σ (0.15 Percentile)

Average (50 Percentile)

68.2% of the data is between 1σ and 1.5σ.
99.7% of the data is between 3σ and −3σ.

Ammonia loading (lbs/day)
TIME
## Final Controller Comparison

<table>
<thead>
<tr>
<th>Feature</th>
<th>Feedback</th>
<th>Feed-forward</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport lag</td>
<td>Can be significant</td>
<td>Minimal</td>
</tr>
<tr>
<td>Oscillation</td>
<td>Can be significant</td>
<td>Acceptable level</td>
</tr>
<tr>
<td>Proprietary software</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Instrumentation</td>
<td>Two analyzers</td>
<td>Five analyzers</td>
</tr>
<tr>
<td>Tuning</td>
<td>Recommended periodically</td>
<td>Self-tuning</td>
</tr>
<tr>
<td>Failsafe</td>
<td>DO controller</td>
<td>Archived NH3 load data</td>
</tr>
<tr>
<td>DO prediction accuracy</td>
<td>Acceptable</td>
<td>Acceptable</td>
</tr>
</tbody>
</table>
Aeration Control at MWRD – Going Forward

- Both systems are saving money (10% - 20% over DO control alone)
- Ammonia control not always superior to DO control
- Future upgrade – which controller will we settle on?
  - MWRD diurnal peaks are probably too large for PID control;
    - Too much lag time
    - Instability (oscillation) equals system inefficiency
  - Feed-forward: no lag, no oscillation, self-tuning capability
    - No of required analyzers for feed-forward was not a drawback
- Future Upgrades the NSEC
  - Probably standardize on the feed-forward system
  - Maybe look at integrated package that include blower controls
  - Design whole aeration system in conjunction with the control system
Thank you

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Direct-Drive Turbo Blower Demonstration

• Blower manufactured by APG-Neuros
• Largest direct-drive turbo blower available on the market
  • 1 MW (1,340 HP), 23,000 scfm
• First full-scale demonstration of this blower
• Frictionless shaft rotation with magnetic bearing system

1MW permanent magnet synchronous motor

1MW VFD and power panel assembly
Typical Aeration Tank at Stickney