Use of Ammonia and Nitrate Sensors for Activated Sludge Aeration Control

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Overview

Sensors Available
• Optical
  - Nitrate / Nitrite
• Ion Selective Electrodes (ISE)
  - Ammonium / Nitrate

ISE Theory of Operation
• Relationship of Ammonia & Ammonium
• Potassium & Chloride Compensation electrodes

Biological Nitrogen Removal basics

Control Strategy
• Ammonium to control aeration rates
• Nitrate to control recycle rates

Case Studies using Ammonia to control aeration rates
Sensors Available
Optical

Based upon principle that nitrates and nitrates absorb certain wavelengths of light – a miniature spectrophotometer

• Advantages:
  • No electrodes to replace
  • Continuous ultrasonic self cleaning

• Disadvantages
  • Cost 3x of ISE
  • No ammonia measurement
Ion Selective Electrode (ISE)

Based upon principle that electrodes generate a mV output proportional to compound of interest

• **Advantages:**
  • Low cost
  • Measure ammonium and nitrate in one package

• **Disadvantages**
  • Requires manual or air cleaning
  • Requires replacement electrodes every other year
Theory of Operation
Optical

Influent → Biological Tank → Effluent

Absorbance vs. Wavelength

200 nm → 720 nm

UV → Visible light

VUV, UVC, UVB, UVA
Continuous Ultrasonic Self Cleaning

No maintenance
Continuous cleaning
No compressed air requirement

After 1 week of installation, post trickling filter, pre aeration contact chamber
ISE Sensor Design

Four Measuring Electrodes
- NH$_4$-N
- NO$_3$
- K
- Cl

All electrodes can be exchanged individually

New electrodes are automatically recognized
Relationship of Ammonia & Ammonium

$\text{NH}_4^+ + \text{OH}^- \rightarrow \text{NH}_3 + \text{H}_2\text{O}$

- Uncompensated $\text{NH}_4^+$ detection good up to approx. pH 8.5
- pH values $>8.5$ $\text{NH}_4^+$: detection requires pH compensation
The need for Compensation Electrodes

ISE’s have known and predictable interferences:

• Ammonium’s primary interference is Potassium

• Nitrate’s primary interference is Chloride
NH₄: Interference mainly by Potassium ions

c (NH₄-N) [mg/l]
displayed by the VARiON system

<table>
<thead>
<tr>
<th>Potassium contents</th>
<th>Ammonium value increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 mg/l</td>
<td>0.7 mg/l</td>
</tr>
<tr>
<td>50 mg/l</td>
<td>3.4 mg/l</td>
</tr>
</tbody>
</table>

automatic, dynamic compensation with potassium electrode

real c (NH₄-N) [mg/l]
NO$_3$: Interference mainly by Chloride ions

c (NO3-N) [mg/l]
displayed by the VARiON System

<table>
<thead>
<tr>
<th>Chloride contents</th>
<th>Nitrate value increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 mg/l</td>
<td>0.7 mg/l</td>
</tr>
<tr>
<td>500 mg/l</td>
<td>3.6 mg/l</td>
</tr>
</tbody>
</table>

automatically, dynamic compensation with chloride electrode
Robust electrodes

Metal grid effectively protects the sensitive ISE membranes from damage due to physical cleaning.

Easily clean electrodes, even with plastic brushes.

Important: do not use detergents/soaps for cleaning, as they destroy membranes.

Use only warm water and, e.g., a toothbrush.
Biological Nitrogen Removal basics
Biological Nitrogen Removal

1) **nitrification**
   - autotrophic bacteria
   - ammonium \( \text{NH}_4 \)
   - nitrite \( \text{NO}_2 \)
   - nitrate \( \text{NO}_3 \)
   - nitrogenuous \( \text{N}_2 \)

2) **denitrification**
   - heterotrophic bacteria
   - nitrate \( \text{NO}_3 \)
   - nitrogen gaseous \( \text{N}_2 \)

No oxygen

Recirculation

Air

Nitrosomonas

Nitrobacter

Nitrospira
Ammonia control objective

1) nitrification
   (autotrophic bacteria)

2) denitrification
   (heterotrophic bacteria)

As Ammonia level rises above setpoint, increase air supply rate to further nitrification
Nitrate control objective via aeration

1) nitrification
   (autotrophic bacteria)
   - ammonium $\text{NH}_4$
   - nitrite $\text{NO}_2$
   - nitrate $\text{NO}_3$

2) denitrification
   (heterotrophic bacteria)
   - nitrogen gaseous $\text{N}_2$
   - nitrate $\text{NO}_3$

As nitrate level rises above setpoint, decrease air supply rate to further denitrification.
Nitrate control objective via recirculation

1) nitrification
   (autotrophic bacteria)

2) denitrification
   (heterotrophic bacteria)

- Nitrate $\text{NO}_3$
- Nitrogen gaseous $\text{N}_2$
- Ammonium $\text{NH}_4$
- Nitrite $\text{NO}_2$
- Nitrate $\text{NO}_3$

Use of Nitrate to control Internal Mixed Liquor flow rate

**Nitrosomonas**
**Nitrobacter**
**Nitrospira**

no oxygen

air

recirculation
Ammonia based Control Strategy

Source: Ammonia Controlled Aeration by Don Esping
Typical Aeration Basin Control Strategy - DO

DO setpoint chosen to minimize historical NH$_4$ breakthrough.
Objective of Ammonia based Aeration control

Aeration control based on ammonia measurement essentially is applied for one of two reasons:

- Limiting aeration: Aeration is limited to prevent complete nitrification. The potential benefits include energy savings, increased denitrification, and in some cases improved bio-P performance.

- Reducing effluent ammonia peaks: Aeration is manipulated to reduce the extent of effluent ammonia peaks.

Source: Myths About Ammonia Feedforward Aeration Control
Ammonia/Aeration Basin Control Strategies

Ammonia Feedback Control

Cascade setpoint control slow to adjust DO

Example

NH4 < 1.5 mg/L then DO setpoint = 0.5 mg/L
NH4 > 1.6 mg/L then DO setpoint = 2.0 mg/L
Ammonia Feed Forward – Feedback Control

Upstream NH₃. Min & Max limiting DO. Downstream NH₄.
Types of Single Sludge Nitrogen Removal

Post-denitrification

Aeration

Anoxic Removal

Pre-denitrification

Pre and Post-denitrification
Case Study: Wheaton Sanitary District

Source: Wheaton Case Study NH₄ to control DO
Aeration Basin Instrumentation
Constant Airflow Mode - upstream

NH₃ and DO are inversely proportional. DO response to NH₃ is fast.
Constant Airflow Mode – downstream

Tank 3 Operational Parameters (Airflow Control)

DO swings based upon NH₃ loading at influent
DO control mode – 2ppm setpoint

Airflow inversely proportional to DO. Note NH₃ breakthrough.
NH$_3$ Predictive Control

Airflow proportional to NH$_3$ concentration. Note lower limit on airflow for mixing.
Case Study:
U.K. 4 Stage Bardenpho

Source: Ammonia Controlled Aeration
Plant Layout and Sensor Location
DO setpoint vs Predictive NH4 Control

20% airflow savings overall
Effect of Limiting Aeration preventing Complete Nitrification

RTC Effluent ammonia setpoint of 1 mg/L
Case Study Summaries - Cons

• Need reliable and accurate sensors – test sensors for requirements

• Control can be more complex
  • Sensor outlay and maintenance
  • More monitoring
  • More maintenance (0.5 to 3 hours/week/device)
  • Cascade loops – lag times/fine tuning
  • Historical treatment or process model algorithms

• Blower turndown critical but must maintain minimum airflow for mixing

• Low D.O. bulking a concern—especially if D.O. <2.0 mg/L
Case Study Summaries - Pros

• Switching to NH$_3$ control can decrease airflow by 20%

• More stable effluent D.O. concentrations

• Allows for Limiting Aeration preventing complete nitrification to further increase savings

• Feed-forward provides greater safety w.r.t. peak loadings
  • More stable effluent ammonia in high flows

• Depending on the starting conditions, even the simplest control (e.g. 1-point D.O. control) can provide significant energy savings
  • Take advantage of the low end of the blower curve
  • Minimal cost of implementation (VFD, in-tank instrumentation, programming)
QUESTIONS

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