Thank you to our valued patron, Black & Veatch, for sponsoring this webinar and for their continued support of the Academy.

Black & Veatch is an employee-owned global engineering, procurement, consulting and construction company with a more than 100-year track record of innovation in sustainable infrastructure. Since 1915, we have helped our clients improve the lives of people around the world by addressing the resilience and reliability of our most important infrastructure assets.
Filtrate Treatment Facility Startup

Presented by: Miguel E Miranda and Shawna Martinelli Gill
Objective and Schedule

- Who is DC Water and why Annamox?
- Project timeline
- Contract Structure
- Equipment overview
- Control strategy development
- Ramp up performance
  - Pros and cons of our unique methods
- Operational Demonstration (OD) 1 and OD 2
- Lessons Learned
Flow and Service Overview

- Treats wastewater for a population of 2.1 million over a 725 mi$^2$ service area
- 384 MGD design average flow
- 555 MGD complete treatment during wet weather
- Produces Class A biosolids
Plant Flow Diagram

Head of the plant

Filtrate Treatment Facility

Filtrate

Electricity

Heat recovery steam generation

Co-Generation

Land application or other beneficial use

Belt Filter Press post-dewatering

Sodium Bisulfite

Contact tanks

Sodium Hypochlorite

Nitrification/denitrification tanks

Filter influent pumps

Multimedia filters

To POTOMAC RIVER

TO POTOMAC RIVER

Dissolved air flotation thickening

Blend tanks

Gravity sludge thickening

Primary sedimentation tanks

Secondary sedimentation tanks

Secondary reactors

Nitrification/denitrification reactors

Primary sedimentation tanks
What is Anammox and the Demon® System?

- Anammox are a group of anaerobic ammonium oxidizing bacteria that do not require oxygen or methanol to transform NO₂ to Nitrogen gas.

- The Demon® System is a process that uses ammonia oxidizing bacteria (AOB) and Anammox to efficiently remove Ammonia (NH₃/ NH₄⁺).

- Reduces operational cost of high aeration of oxygen (blowers cost) and methanol demand.
Due to Anaerobic Digestion we have an additional 30%-40% Ammonia load

During Dewatering at the Belt Filter Presses we generate a concentrated filtrate side stream (~1,600 mg/L of Ammonia)

Demon can treat Ammonia concentrations of approx. 2,000mg/L, unlike mainstream biology which treats concentration of about 100 mg/L or less
Preplanning occurred concurrently with THP and Anaerobic Digestion in 2009–2012
Detail design with B&V was 2012–2013

Bidding Process
Control strategy developed Emerson/WWW/DCW

Construction and Control Strategy FAT

Final Loop testing
Clean Water Testing for oxygen transfer efficiency
Mech. Wet Testing with PC Construction

Initial Reactor 5 seeding and ramp up
Seeding reactors 1–4

Operational Demonstration 1
Reactor 2 and 5 ramp up
Operational Demonstration 2

Operational optimization
Process Transfer to Operations
Unique Contract Structure

- “Design–Bid–Build”
  - Commissioning team involved in the development of the control strategy and contract structure
  - Focused on integrating the system controls with our existing system instead of purchasing a vendor control package
    - We were able to tailor the system to what we wanted
Feed Tanks and Feed System

- Filtrate is pumped from the Belt filter presses to FTF
  - Dilution water is added along the way

- Two tank @0.5 MG

- Feed pumps that maintain pressure in feed loop

- Actuated valves draw from loop to feed reactors
Six Basins
- Volume = ~1MG
- 30ft deep
  - Hi operational level – 27 ft
  - Low operational level – 22.5 ft

Two blowers per basin (Lead/Lag)

Four mixers per basin

One Hydrocyclone per basin
Neuros Blowers

- Has internal PI Controller but is operated via PCS

- Variable Speed blower
  - To achieve lower airflows a blow off valve is used

- Three operating mode
  - DO, Airflow, Constant speed

- Operates by trying to match operator input DO or Airflow values

*Note that these blowers are designed to Start/Stop frequently*
Invent Mixers/Aerators

- Used in tandem with Neuros blowers to create fine bubbles

- Variable speed motors to be able to adjust speed
  - Initially we were varying our mixer speeds during aerating vs mixing (operator input)

- High level protection at 27ft

- Low level protection at 5ft
Decanter SDK 450

- No in tank mechanical parts
- Pneumatic Air Cabinet provides protection from loss of MLSS
- Decant Effluent goes to Raw Waste Water Pumping Station #1
**Hydrocyclone System**

Overflow: AOB/NOB/OHO (Ordinary Heterotrophic Organisms) Recycled or Wasted

Underflow: Anammox returned to Process

- Waste Valve
- Pre-Screen
- Cyclone Pump
- Recycle Valve
**Instrumentation**

- **Sc1000 meter**
  - HACH pH/Temperature probe
    - pH range: 6.6–6.8
  - HACH Dissolved Oxygen Probe
    - DO range: 0–1 mg/L

- **Sc200 meter**
  - HACH Conductivity Sensor
    - Range: 2,000–6,000 uS
Control Strategy
# Control Strategy

<table>
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<tr>
<th>DEMON Control Modes</th>
<th>Description</th>
<th>Tabular Representation</th>
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| **Intermittent Feed Mode** | - Feeding and Aerating occurs separately  
- Aeration time is predetermined  
- Maximize denitrification by using high COD  
- Used during start-up | | |
| **Timed Mode** | - Feeding and Aerating occur at the same time  
- Aeration time is predetermined  
- Used during ramp up  
- Very hands-on (sampling) | | |
| **pH Control Mode** | - pH and DO probes to control Feeding and Aerating  
- Blower starts when pH reaches upper setpoint and stops when pH drops to the lower setpoint  
- Feed occurs when above the lower pH setpoint and stops when upper setpoint is reached | | |
FTF Start–Up Events

- First shipment of Annamox seed was delivered from Strass, Austria in Late 2017
  - They can remain dormant over long periods of time

- Seed sludge had a layover before its final destination in FTF Reactor 5!
FTF Start-Up Events

Point A

Point B
Unique Start Up Modes

- **Nitritation/Denitritation (N/dN) Mode** – develop acclimated AOBs and Heterotrophic bacteria prior to seeding.

- **Nitritation Only Mode (N)** – develop a high NO$_2$ environment prior to seeding as well as some treatment benefits.

- In both Mode NOBs were quickly out selected prior to seeding.

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**2A – Modes of Reactor Operation**

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D = operation for deammonification
N/dN = operation for nitritation and denitritation to low NO2-N
N = operation for nitritation only
CT = controls system testing (variable modes)
Unique Start Up Modes

AerAOB

NOB

AnAOB rate (mg NH₄-N/gVS/d)

Specific activity (mg N/gVS/d)

9/22/2017
9/23/2017
10/12/2017
11/11/2017
11/21/2017
12/11/2017
12/31/2017
1/20/2018
1/31/2018
2/28/2018
3/1/2018
3/31/2018
4/30/2018
5/20/2018
6/9/2018

9/22/2017
9/23/2017
10/12/2017
11/11/2017
11/21/2017
12/11/2017
12/31/2017
1/20/2018
1/31/2018
2/28/2018
3/1/2018
3/31/2018
4/30/2018
5/20/2018
6/9/2018
30 Day Operation Demonstration

Treating all incoming load

No operational changes allowed

Design Load for Rx1–5 were 0.35 to 0.4 kg/m3-day

Filtered decant Samples (and duplicate) were taken to an external lab
Process Performance: OD1

DC Water FTF OD - 1
% Removal of Ammonia per Reactor

% NH4-N Removal Rate

Rx-1  Rx-2  Rx-3  Rx-4  Rx-5

70.0% 75.0% 80.0% 85.0% 90.0% 95.0% 100.0%

When stable, biology is self-sufficient and resilient
  ◦ When troubleshooting reactors can be put offline until issues are resolved

Importance of Chemical Balance
  ◦ Low pH can lead to high NOB population

Need to waste excess biology to assist with settling
  ◦ Excessive AOB can prevent Annamox from settling
OD1 Results & Lessons Learned

- Important of chemical balance

![Graph of Reactor 5 Average pH and Effluent Concentrations](image-url)

- Diagram showing pH and concentration trends over time.

...
## OD1 Results & Lessons Learned

- **Important of chemical balance**

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OD1 Results & Lessons Learned

- Sinking and Floating Solids

Empty Feed Tank

Lamella Plate Settler
OD1 Results & Lessons Learned

- Sinking and Floating Solids: Part 2
Excess Polymer and Coating
30 Day Operation Demonstration

Two Reactors selected by DC Water to challenge with sustained peak Nitrogen loading rate of 0.6 kg NH$_3$–N/d/m$^3$

Minimum 72% ammonia removal and minimum of 65% total nitrogen removal

Filtered decant and feed tank Samples (and duplicate) sent to external lab(s) and DC Water lab and Hach used to validate results
## OD2 Results & Lessons Learned

### OD2 % Removal for Reactors 4 & 6 Combined

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<td>Maximum</td>
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### OD2 % Removal for Reactors 4 & 6 Separately

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<td>&gt;62%</td>
</tr>
<tr>
<td>Average</td>
<td>86.6%</td>
<td>81.6%</td>
<td>87.0%</td>
<td>84.9%</td>
</tr>
<tr>
<td>Minimum</td>
<td>80.5%</td>
<td>73.7%</td>
<td>83.0%</td>
<td>80.1%</td>
</tr>
<tr>
<td>Maximum</td>
<td>91.4%</td>
<td>89.5%</td>
<td>92.8%</td>
<td>91.0%</td>
</tr>
</tbody>
</table>
OD2 Results & Lessons Learned

DC Water OD2 - Loading Rate per Reactor

NH3-N Loading Rate (kg N/m3-day)

Design Load  Reactor 4 Load  Reactor 6 Load

Excessive Foaming in feed tank and reactors

Immediate impact on reactor performance and TSS when poor filtrate quality occurs due to belt operation or polymer efficiency
Decanter Failure (OD1 & 2)

- Decanter Failure in Reactor 5 originally, Reactors 2 & 3 at conclusion of OD1, and failure of Reactors 4 and 6 conclusion of OD2

This is a mixer!
Decanter Removal and short term riser modifications

Quickest solution but with big consequences
  - Biological lost
  - Limited feed
Ops Optimization

- Loss of Biology through wasting or supernatant
Ongoing feed quality issues
- Feed Tank emptying and solids removal

Installation of a Cerlic to determine baseline versus process upset

Create bypass of feed tank to flush
Long term intent: modify one reactor to continuous overflow with a baffle wall configuration.

DCW currently working with specialty firm on Computational Fluid Dynamics (CFD) model of baffle wall with invent aerator mixers.

If pending simulations are agreeable will try full scale pilot in one of the 6 reactors.

In meantime modifying 2 of the decanters to be robust enough to treat load of FTF in interim.
Process Champion
  - Requires a level of attention and understanding beyond typical continuous flow operations

CFD of unique equipment combination; contribution of blowers and invent mixer/aerators to decanter

Lack of adequate buffer or equalization before feeding
  - Ability to remove solids from reactor and feed tanks (Sinking and Floating)
  - Ability to Bypass FTF or flush feed tank

Individual sample lines for each reactor (combined overflow of reactors and feed tanks to common decanter line)
Questions?

Contact

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Shawna Martinelli – smartinelli@dcwater.com
Supplemental info
Unique Start Up Modes

Reactor 3 - Transition from N/dN to DEMON Mode

- Rx-3 N Load
- Rx-3 Eff NH4-N
- Rx-3 Eff NO2-N
- Rx-3 Percent NH4-N Removed

NH4-N Loading, kg/m3/d, Percent NH4-N Removed/100

Concentration, mg/L

Graph showing data points for different parameters over time from 3/1/2018 to 6/28/2018.
Standard Nitrification / Denitrification

Aerobic Environment (Autotrophic Bacteria)

**Nitrification**

1 mol Ammonia ($\text{NH}_3 / \text{NH}_4^+$)

O$_2$ (energy)

Alkalinity

Nitrite Oxidizing Bacteria (NOB)

1 mol Nitrite ($\text{NO}_2^-$)

Nitration

Anoxic Environment (Heterotrophic Bacteria)

**Denitrification**

1 mol Nitrite ($\text{NO}_2^-$)

O$_2$ (energy)

1 mol Nitrate ($\text{NO}_3^-$)

Carbon (BOD)

Denitrification

1 mol Nitrite ($\text{NO}_2^-$)

$\frac{1}{2}$ mol Nitrogen Gas ($\text{N}_2$)

Carbon (BOD)

Denitrification

Standard Nitrification / Denitrification

NITRIFICATION

DENITRIFICATION
**DEMOM (R) (Anammox) Process**

\[
\text{NH}_4^+ + 1.32 \text{NO}_2^- + 0.066 \text{HCO}_3^- + 0.13 \text{H}^+
\]

\[
0.26 \text{NO}_3^- + 1.02 \text{N}_2 + 0.066 \text{CH}_2\text{O}_{0.5}\text{N}_{0.15} + 2.03 \text{H}_2\text{O}
\]

**Advantages**

- 63% reduction in oxygen demand (energy)
- Nearly 100% reduction in carbon demand
- 80% reduction in biomass production
- No additional alkalinity required
Standard Effluent Performance

- 90% removal of ammonia-nitrogen

\[
NH_4 \text{ removal} = \frac{NH_4^{\text{inf}} - NH_4^{\text{eff}}}{NH_4^{\text{inf}}} \times 100
\]

- 10–15% production of nitrate-nitrogen

\[
NO_3 \text{ production} = \frac{NO_3^{\text{eff}} - NO_3^{\text{inf}}}{NH_4 \text{ inf} - NH_4 \text{ eff}} \times 100
\]

- 80% removal of total nitrogen (could increase in with influent carbon)

- Typical Guidelines:
  - Residual alkalinity 250 – 300 mg/L as CaCO₃
  - Residual NH₃–N of 100 – 300 mg/L
  - Nitrite concentration below 15 mg/L
Full Scale Operational Requirements

► Sampling
  • Steady State – 2–3 x per week analysis of influent / effluent
  • Measurements of NH3–N, NO3–N, NO2–N and TSS

► Sensors
  • pH, DO, Conductivity and optional NH3–N

► Regular Operation
  • DO range of 0.3 – 0.5 mg/L (normal COD); 1 mg/L (excess COD)
  • pH typically around 7.0
  • Hydrocyclone – 1 hr per cycle; increasing NO3–N, Inc. time
Target: <3 mg/L, > 3 to 15 mg/L ok for start up, 15 to 35 mg/L take measures to reduce, >35 mg/l put the system in OFF–LINE (manual mix overnight) to allow anammox to consume the NO2.

- **Cause:** Limited diffusion
- **Action:** Longer shearing time

- **Cause:** Over Aeration
- **Action:** Reduced Blower VFD, if severe increase mixing time
NO$_3$–N Rise

(Target: < 12 % for NO3–N/ NH$_3$–N removed)

- **Cause:** NOB proliferation
- **Action:** SRT should be 1.5 days until the NO3 concentrations are normal, if needed reduce tank volume (by lowering decanter height) to achieve this
NH₃–N Rising

Target: Target > 82% of Influent Ammonia removal ~100 to 300 mg/L (residual requirement of 100–300 mg/L)

- **Cause:** Deficient O₂
- **Action:** Increase aeration volume (Blower % VFD)

- **Cause:** AOB SRT too low
- **Action:** Reduce sludge wasting

- **Cause:** Inhibition/Toxicity
- **Action:** Troubleshoot individual possibilities
The most common in a DEMON system for AMX:

- High NO2 level (>100 ppm for >2 days)
- High level (>1.0mg/L) dissolved oxygen – for long periods of time
- High level of TSS (heavy TSS not wanted due to competition in cyclone)
- Overdosing Polymer – causes layering effect on granules which needs to be removed
Foam

- **Causes:**
  - Over dosage of polymer – minimal foaming is tolerable
  - Biomass die off – OHO/AOB/NOB
  - Toxic event

- **Actions:**
  - If a >10% reduction of Ammonia removal is seen, reduce or stop feed until problem is identified
  - Check polymer dosing and adjust if over dosage
Instrumentation

- Sc1000 meter
  - HACH pH/Temperature probe
  - HACH Dissolved Oxygen Probe
- Sc200 meter
  - HACH Conductivity Sensor
- DO Blaster

Operating range:
- Temperature: 20 to 38 °C (ideal 30 °C), 68 to 100 °F (ideal 86 °F)
- DO: 0.3 – 0.5 mg/L, 0.5 – 1.0 mg/L (excess COD)
- pH: 6.5 to 7.5
- Conductivity: 2,500 to 4,500 mg/l
Instrument float probe identification

- The Instrument float seats on top of the water surface
- Wipe build up with a disposable wipe and rinse probes with DI water
Control Strategies’ Operational phases

Aeration/Fill (A / X) or Aeration phase (A / X / E)

Equipment status
- Blowers – ON
- Feed pump/valve – ON/Open (Aeration/Fill only)
- Mixers – ON
- Decant Valve – Close
- Hydrocyclones – ON or OFF
Control Strategies’ Operational phases

- Blowers - OFF
- Feed pump/valve – ON/Open (Mix/Fill only)
- Mixers – ON
- Decant Valve – Close
- Hydrocyclones – ON or OFF

Mix/Fill (A / X) or Mix (A / X / E)
Control Strategies’ Operational phases

Settling phase

Equipment status
- Blowlers – OFF
- Mixers – OFF
- Feed pump/valve – Off/Close
- Decant Valve – Close
- Hydrocyclones – OFF
Control Strategies’ Operational phases

Decant phase

Equipment status
- Blowers – OFF
- Mixers – OFF
- Feed pump/valve – Off/Close
- Decant Valve – Open
- Hydrocyclones – OFF
Control Strategies’ Operational phases

Pause

Equipment status
- Blowers – OFF
- Mixers – ON
- Feed pump/valve – Off/Close
- Decant Valve – Close
- Hydrocyclones – OFF
Operational Phases

Aeration/Fill (A / X)

Aeration (A / X / E)

Mix/Fill (A / X)

Mix (A / X / E)
Operational Phases

- **Phase X’s Final Mixing**
- **Settling Phase**
- **Decant Phase**
- **Pause**
Operational Modes

- **In Service** – allows PCS to run system after pressing “Start.” Is only available when all appropriate equipment is in AUTO.
- **Pause** – can be initiated when running the process, will freeze the active timer while continuing the elapse timer. All components shall stop, mixers will run at “Mixer” speed. After 60 minutes and alarm shall activate. Intended for short periods of time
  - **Resume** – Return you from pause to whatever phase you were at
  - **Extend** – Add another 60 minutes to the allowable time
- **Suspend** – similar to Pause but for a few days, will occasionally feed and aerate
- **Off-line** – stop the sequence, turns off all equipment besides the mixers, removes the reactor from the queue, and mixers are in “Mixer” speed.
- **OOS** – used when you want to stop mid-sequence, also when the reactor needs to be drained for larger maintenance
DEMON® Operational Philosophy as an SBR

Phase A Phase X Phase E

Fill
Aeration
Mixing

Single Repetition
Continue repetition until tank is full

Sedimentation
Decant

Tank
Level

pH_{min}

Low pH setpoint For Phase E

(Typically 5-15 repetitions)