Low Dissolved Oxygen Biological Nutrient Removal

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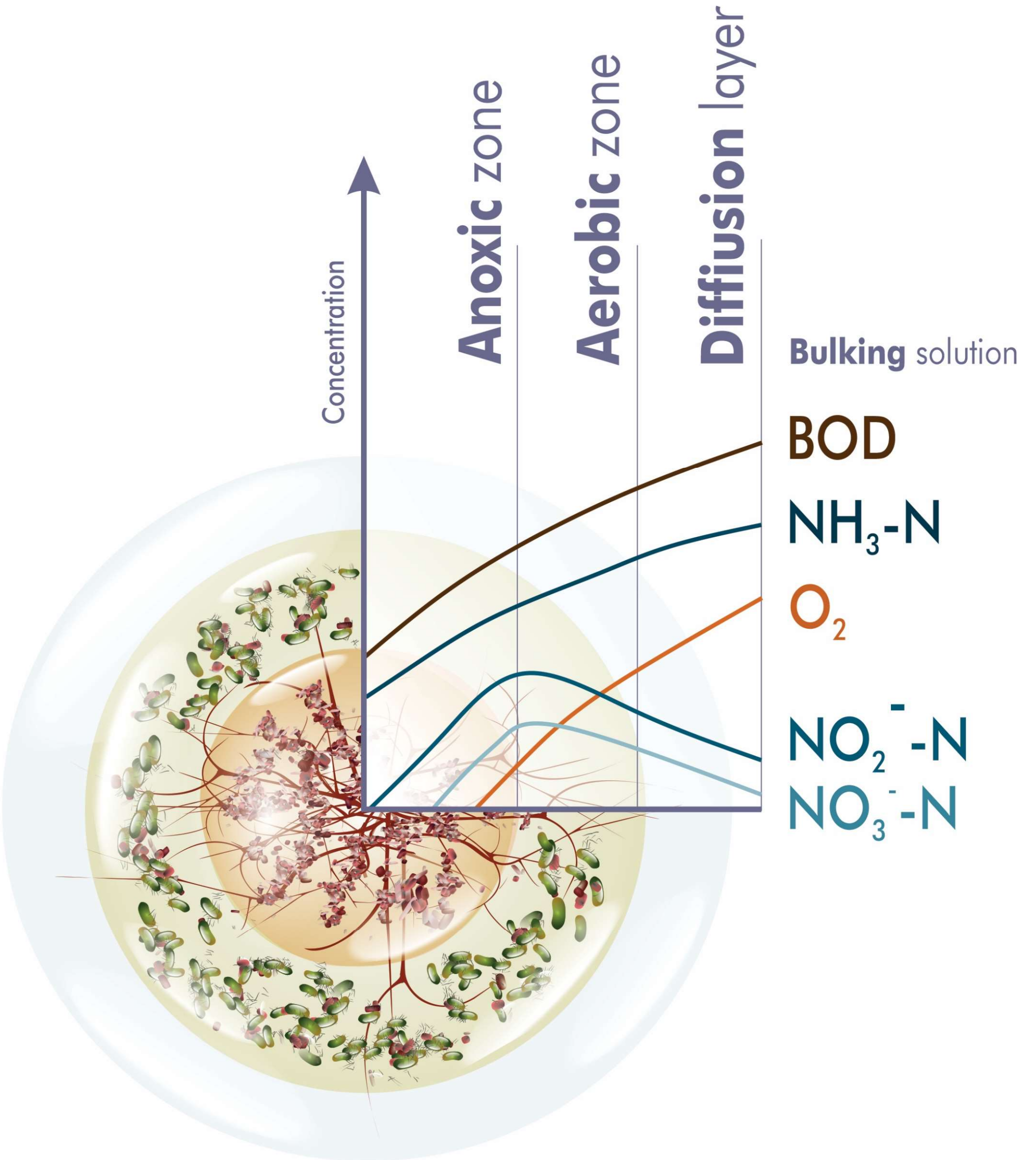
LNRA/NRCA 2026 Wastewater Treatment Plant Operators Training Workshop

Agenda

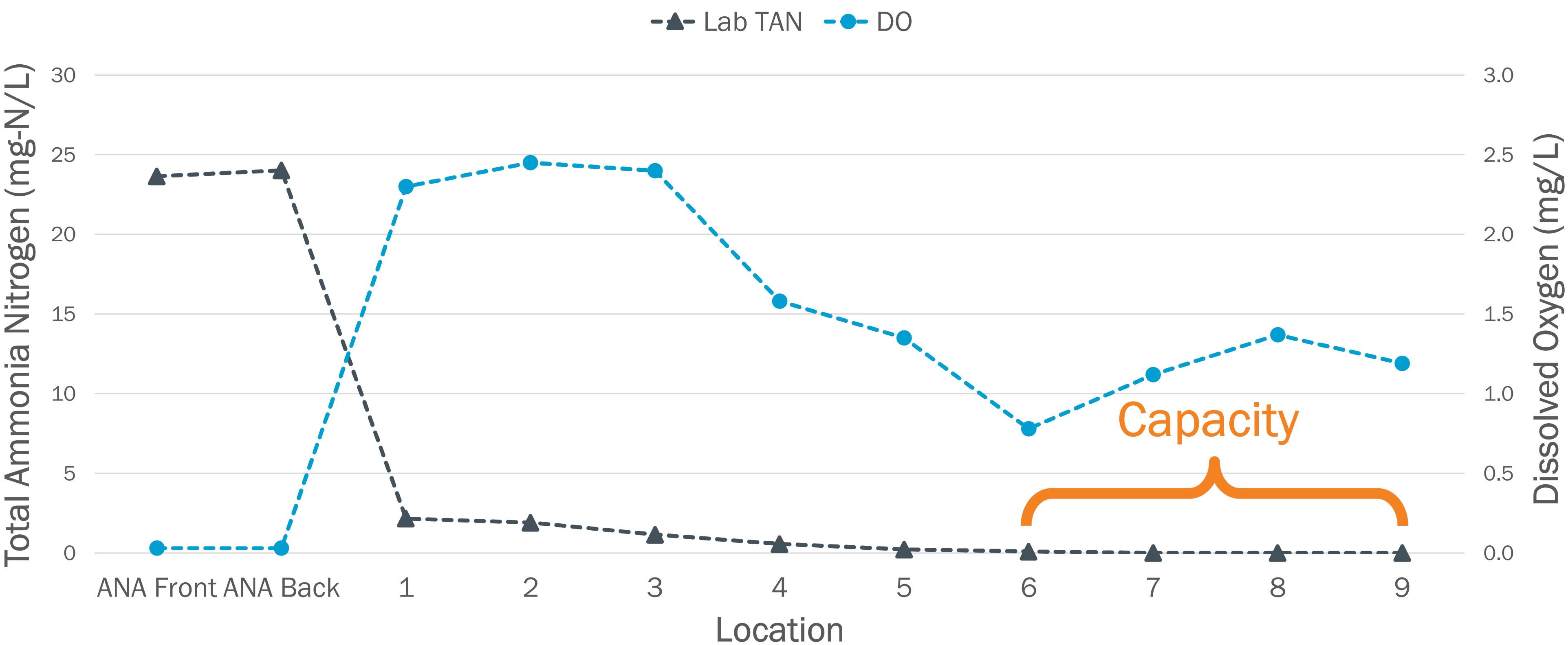
- Background
- Aeration System Design
- Low DO Considerations
- Case Studies
- Key Takeaways

Motivation for Low DO Activated Sludge Processes

– Reduced aeration energy (10-40%)
– Simultaneous nitrogen removal (including shortcut SND)
– Simultaneous nitrogen and phosphorus removal
– Less recycle requirements
– Less carbon and alkalinity required
– Easy to implement with existing infrastructure

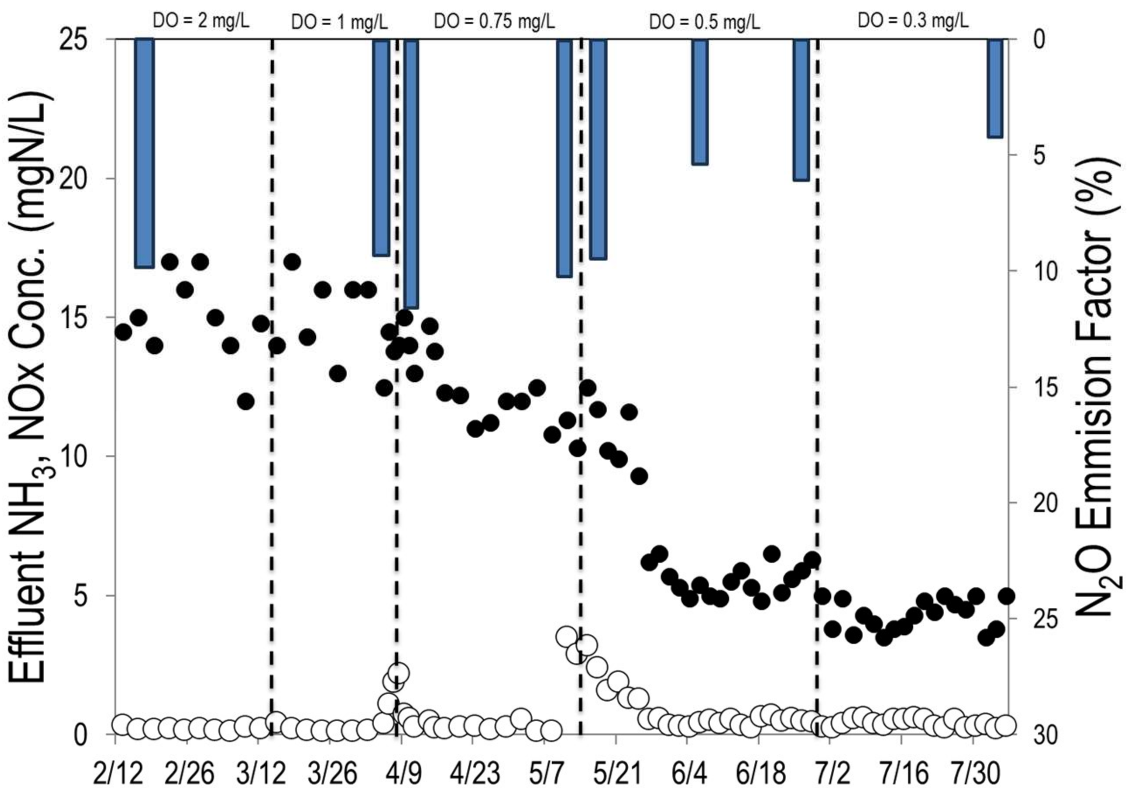


Example DO and Ammonia Profile



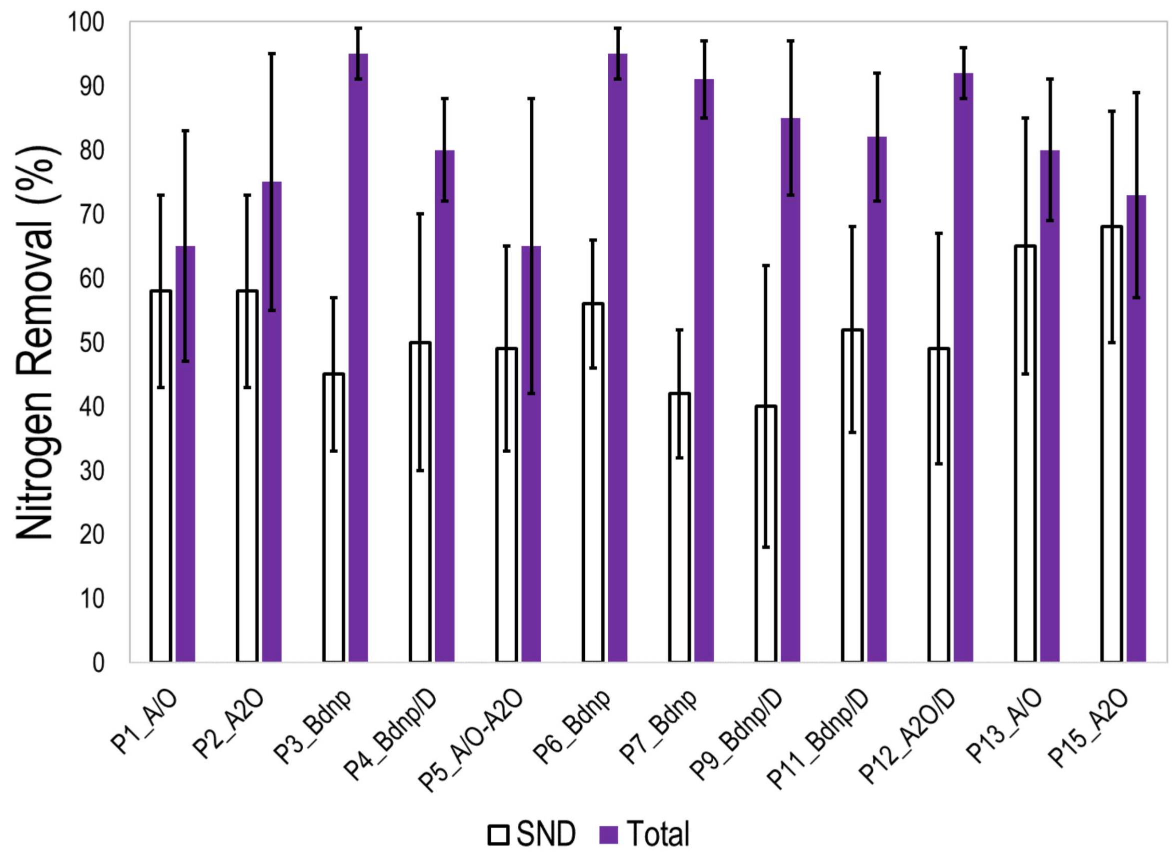
Impact of DO Concentration on Effluent TIN

[A/O Process at 6–8-day SRT]

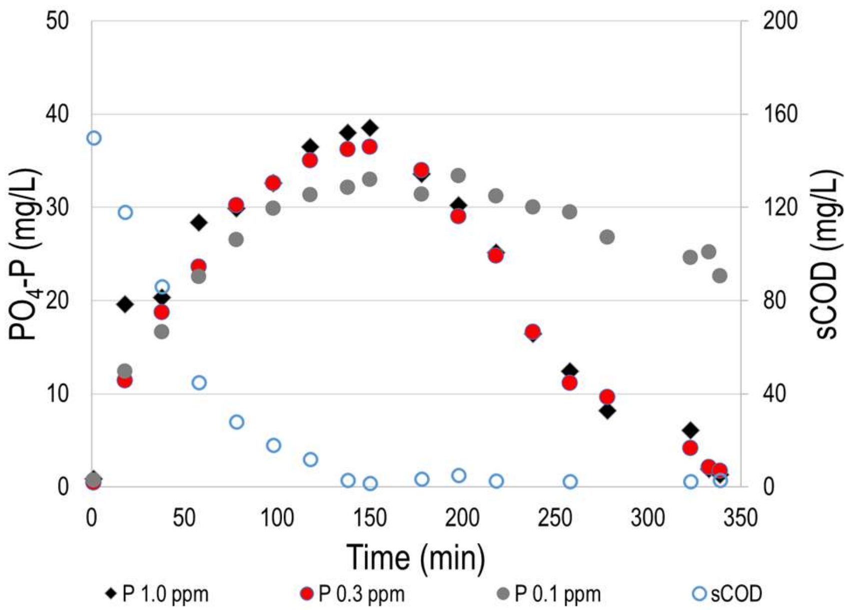


SND can contribute to more than half of TIN removal

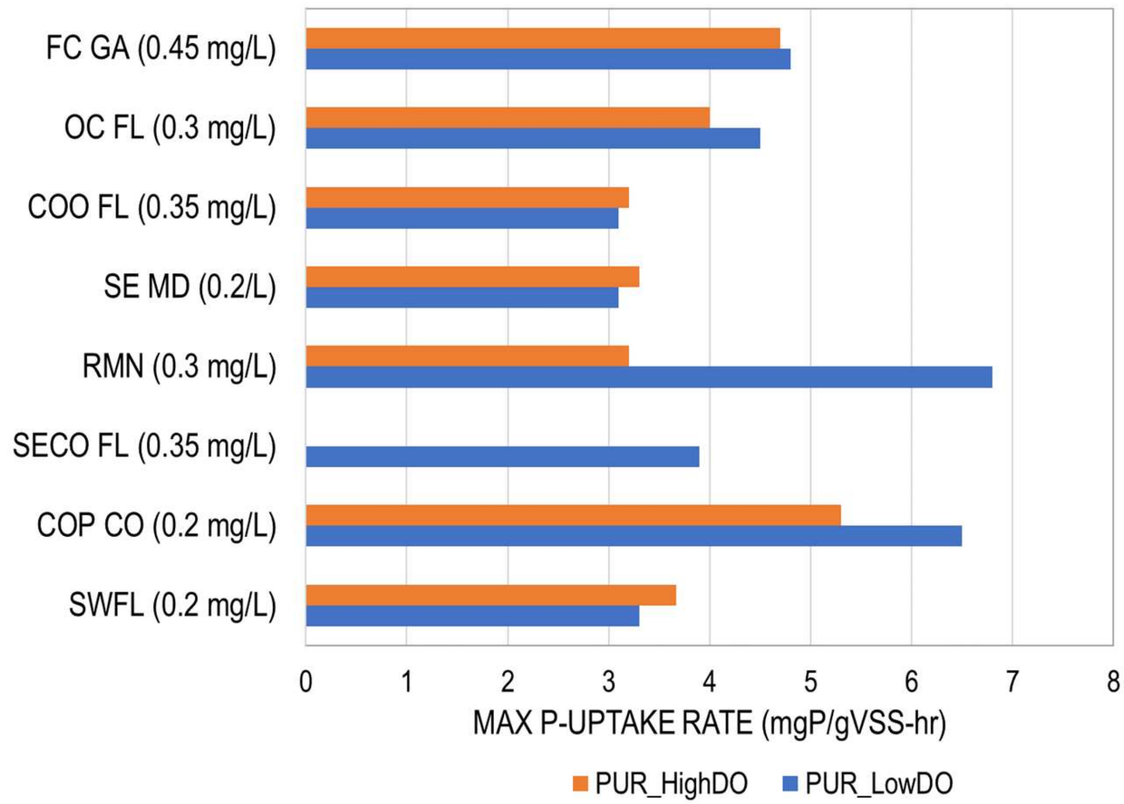
Data from full-scale facilities



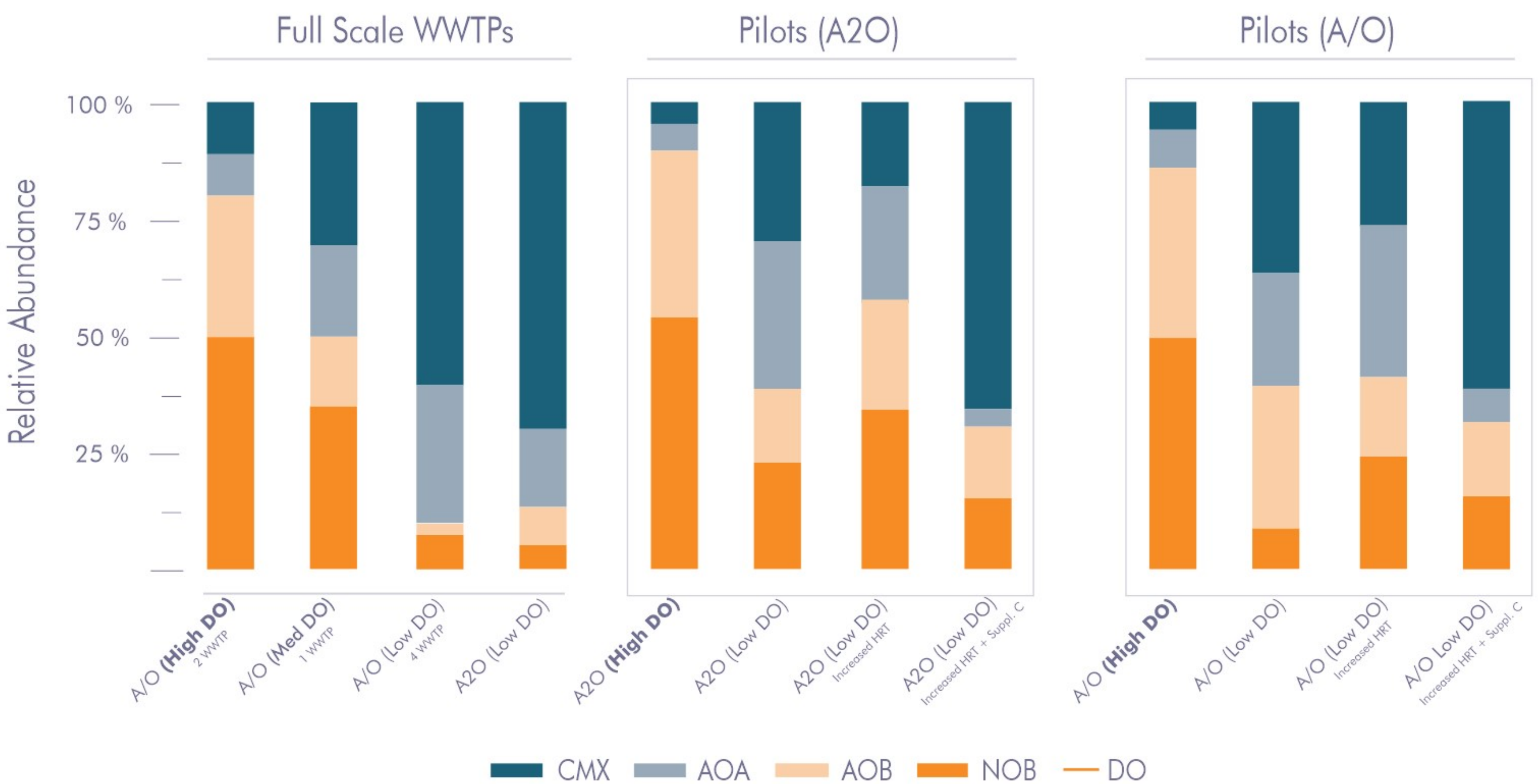
Higher P Uptake Rates Observed in Low DO Plants



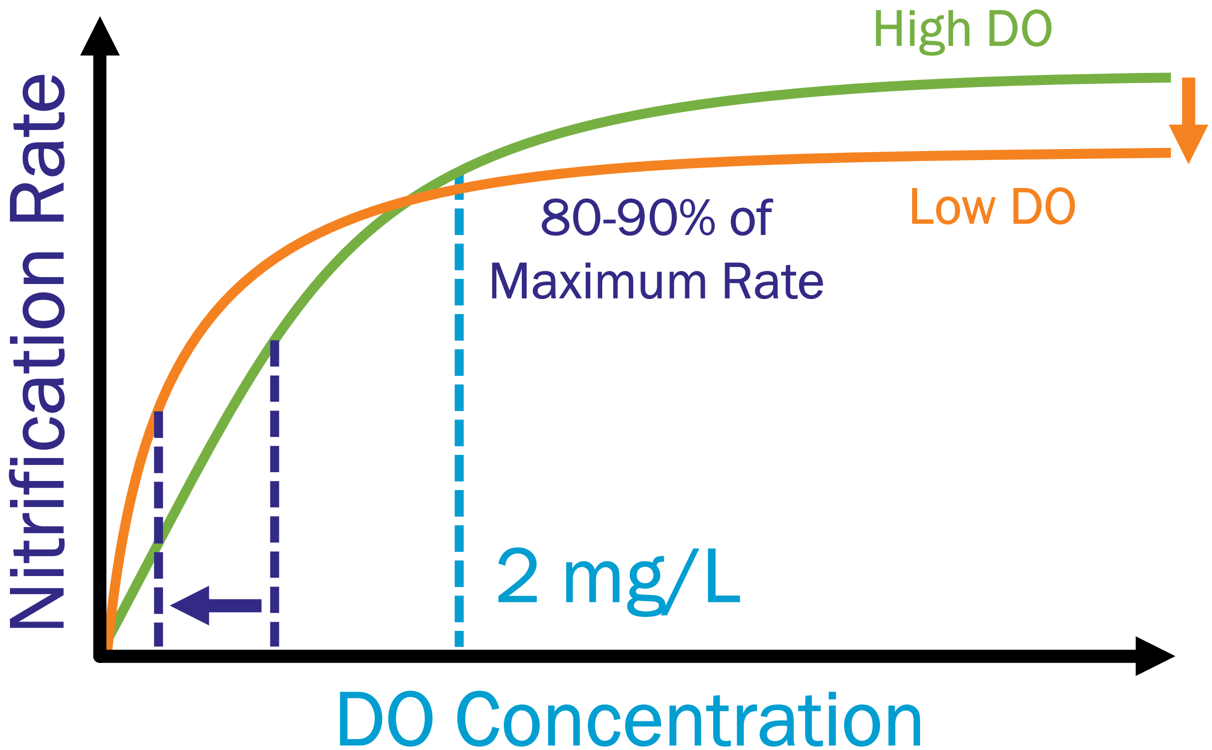
Rate (mgP/gVSS/hr)	High DO	Low DO
Max P Release	13.23 ± 1.92	14.16 ± 1.61
Max P Uptake	5.53 ± 1.85	6.52 ± 1.92
P:VFA	0.41 ± 0.05	0.56 ± 0.04



Nitrifier Community Shift at Low DO



Nitrification Kinetics



- Maximum nitrification rate is reduced by 10-20%
- Affinity for oxygen increases
- Requires biomass adaptation and acclimation
- Lower turndown of aeration system required

Aeration System Design

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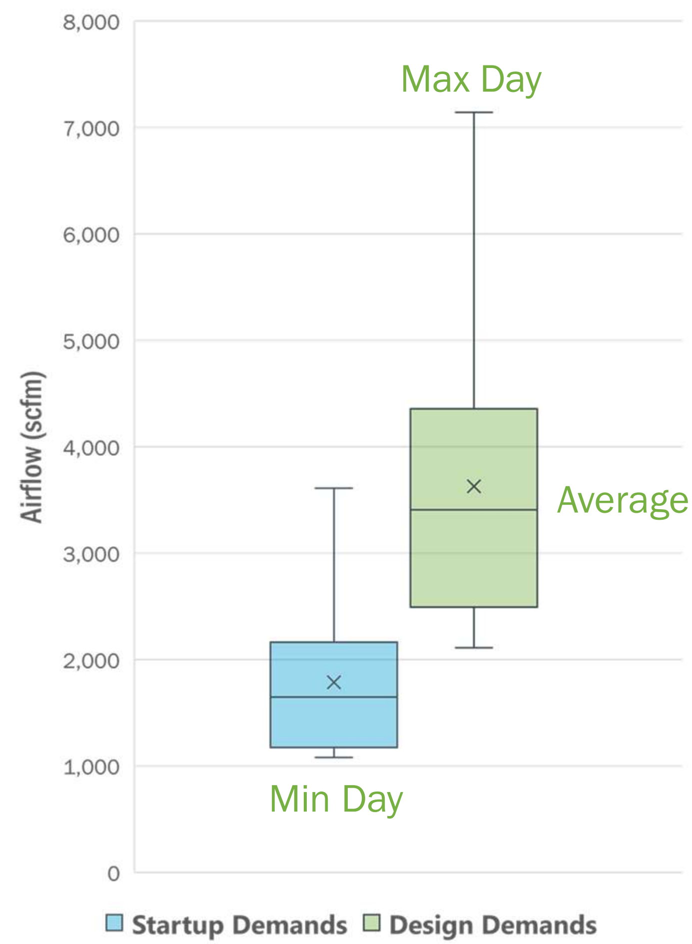
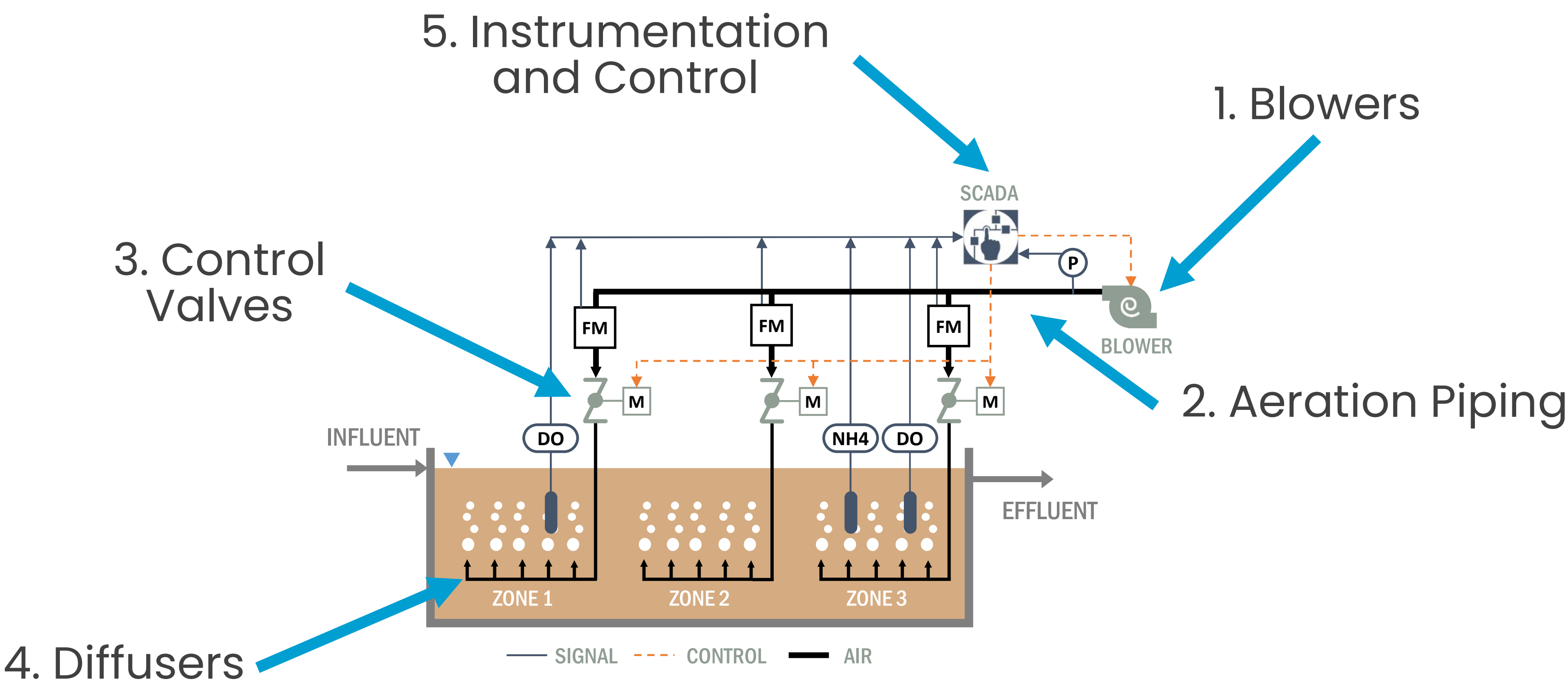
Aeration System Design

- Starts with determining aeration demand
  - Rules of thumb
  - Textbook calculations
  - Wastewater process simulators
- Often designed with wide range of operating conditions
  - Min/max process temperatures
  - Min/max flows and loads
  - Startup/current and future conditions



Low DO Implementation Considerations



Blowers

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Blower Types

- Centrifugal
  - Single Stage
    - Geared
    - Direct Drive
      - Magnetic Bearing
      - Air Bearing
  - Multistage
- Positive Displacement
  - Rotary Lobe
  - Screw

Blower Controls

- Local and/or Master Control Panel
  - Startup and shutdown procedures
  - Cycling duty/standby blower(s)
  - Motor speed control
  - Inlet/outlet vane control
  - Discharge valve control
- Header pressure control
- Airflow control
- Most-Open-Valve control (MOV)

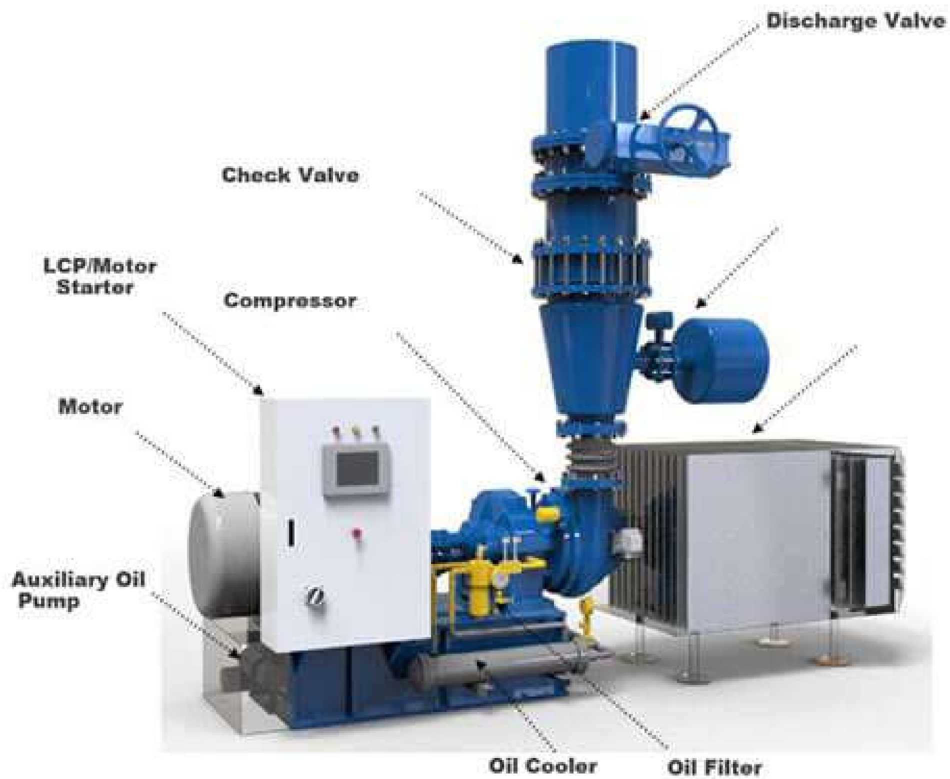
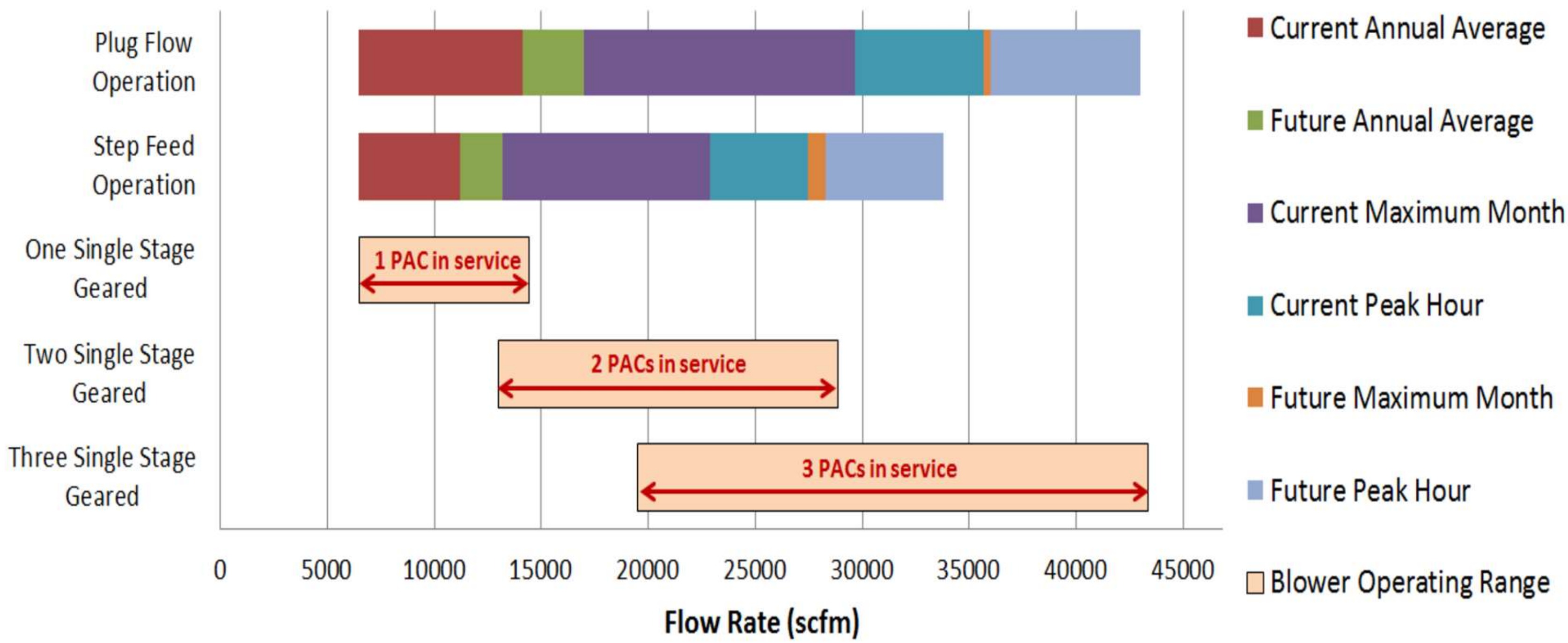


Photo Courtesy of Gasho

Blower Control

Variable Frequency Drives (VFD)	Inlet Throttling	Inlet and Outlet Guide Vanes
• Positive Displacement • Single Stage, Direct Drive • Multistage Centrifugal	• Multistage Centrifugal	• Single Stage, Integrally Geared

Blower Operating Range



Excess Airflow?

- Blowoff valves
- Discharge to offline tanks
- Aerated channels
- Condensate purge valves
- Install smaller “trim” blower

Aeration Piping

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Aeration Piping

Pipe Diameter (inches)	Velocity (fpm)
4 – 6	2,000 – 3,000
8 – 12	2,500 – 4,000
14 – 18	3,000 – 4,500
20 – 30	3,500 – 5,000
>30	4,000 – 7,000

- Cover required airflow range
- Keep build-out velocities within range
- Provide isolation valves for maintenance
- Avoid buried pipe
- Include condensate drains at low points
- Balance number of controlled zones with desired level of control
  - Too few in a plug-flow system can lead to significant DO gradients
  - Too many can be costly and result in controllers “fighting” one another

Control Valves

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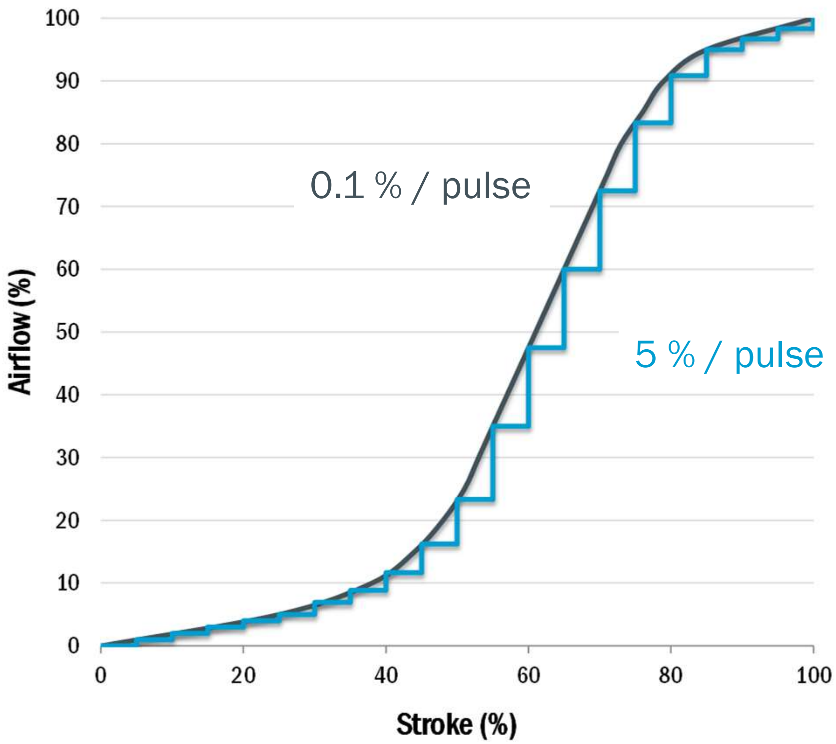
Control Valve Considerations

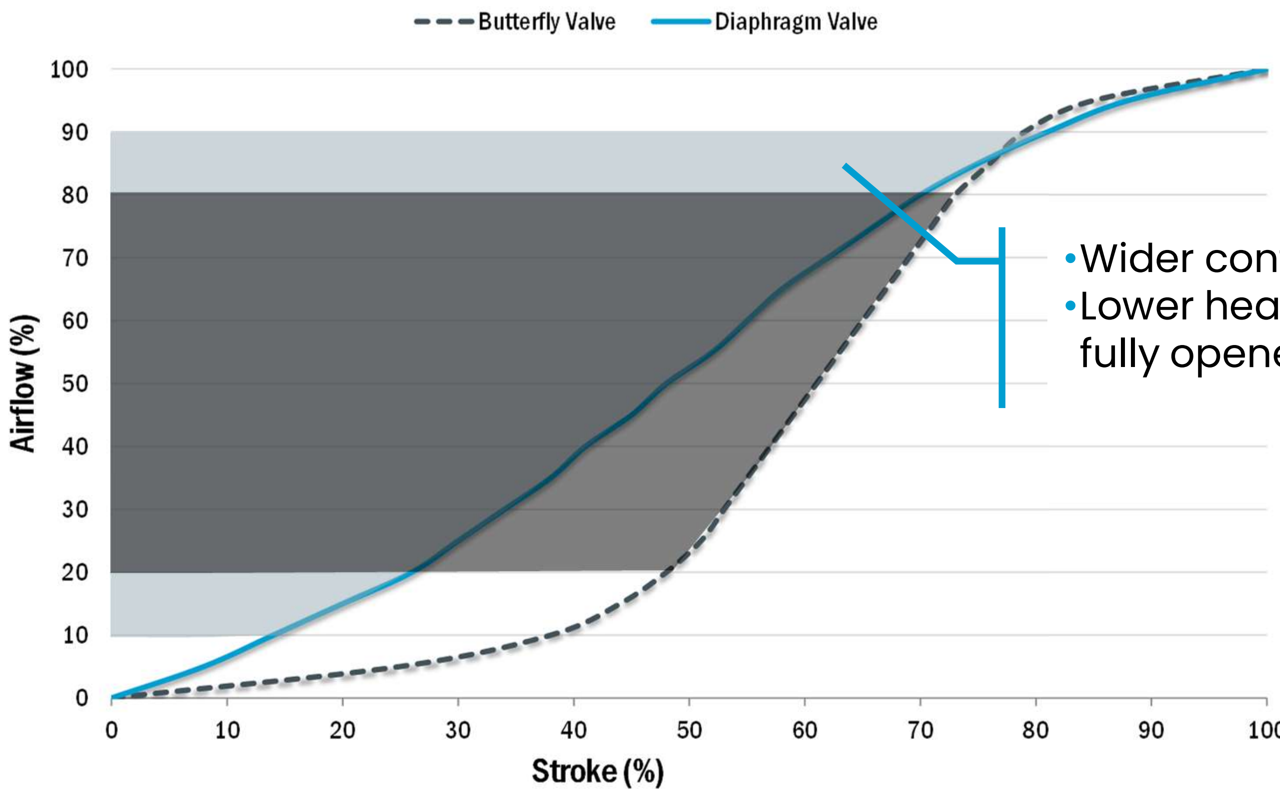
- Controls airflow by inducing head loss
- Typically coupled with airflow control and/or DO control
- Sized for required airflow range
- Head loss when fully open is important when utilizing most open valve (MOV) control
- OPEX savings or stringent treatment objectives should justify more complex control systems

Actuator Considerations

- Actuators should be rated for continuous duty
- Sufficiently long time to open/close (>90s)
  - Too fast can result in overshooting and reduce valve position accuracy and repeatability
  - Too slow never tracks with setpoint
- Valve position control loops should avoid hunting

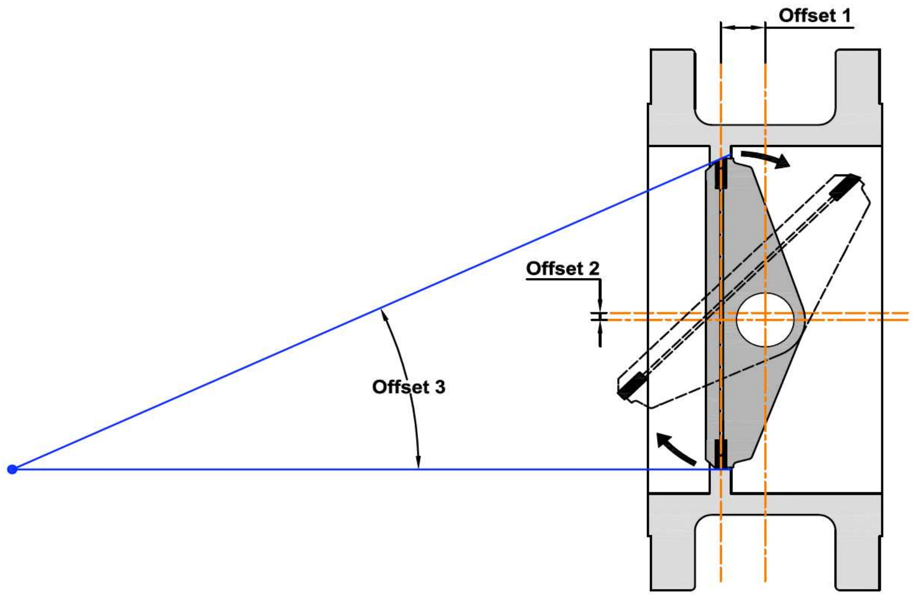


Valve Control Range



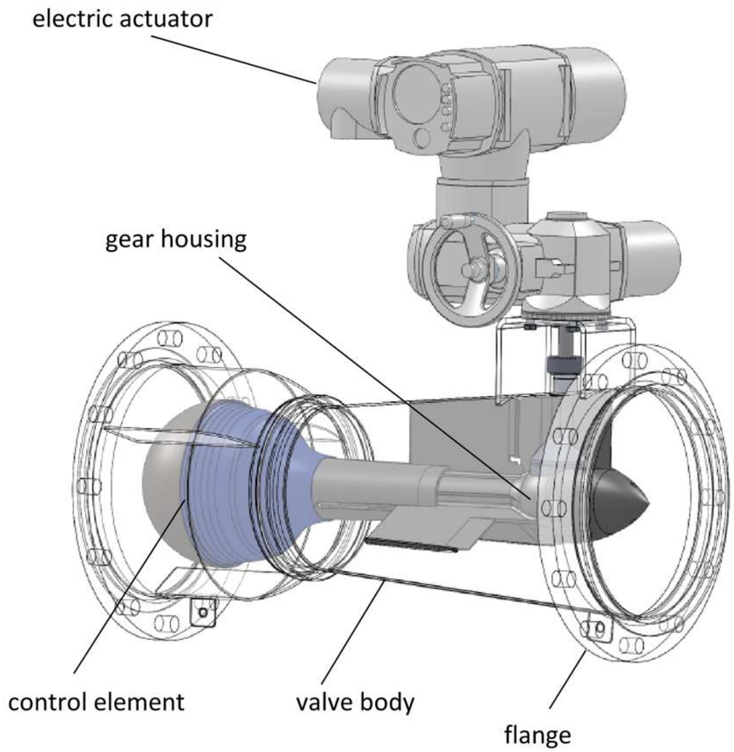
- Wider control range
- Lower head loss when fully opened

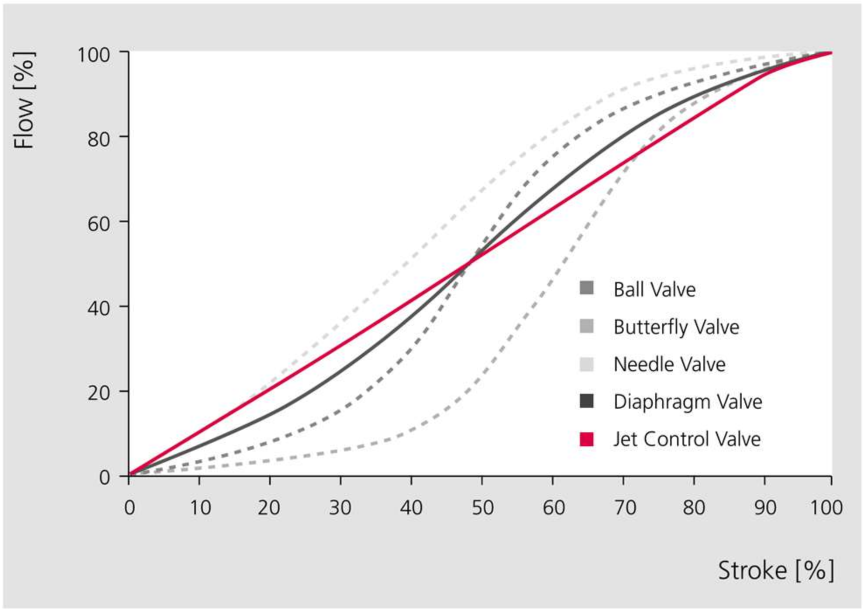
Triple Offset Butterfly Valves



- e.g., DeZurik High Performance Butterfly Valve

Binder Jet Control Valve





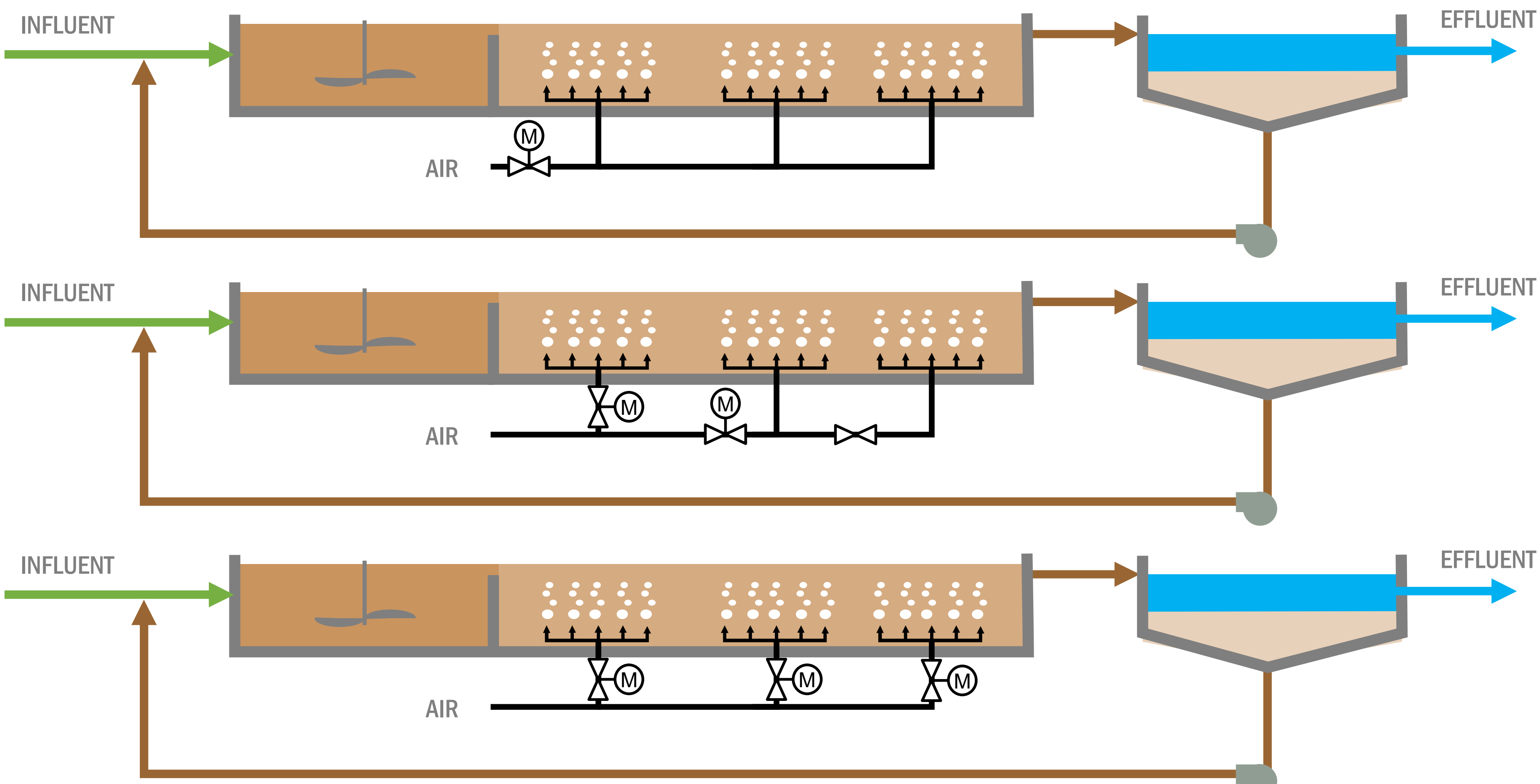
Comparison VACOMASS® jet control valve with conventional valves

Orifice Valves

Binder Diaphragm Valves (Knife Gates)

Egger IRIS Valve

Aeration Control Valve Layouts



Diffusers

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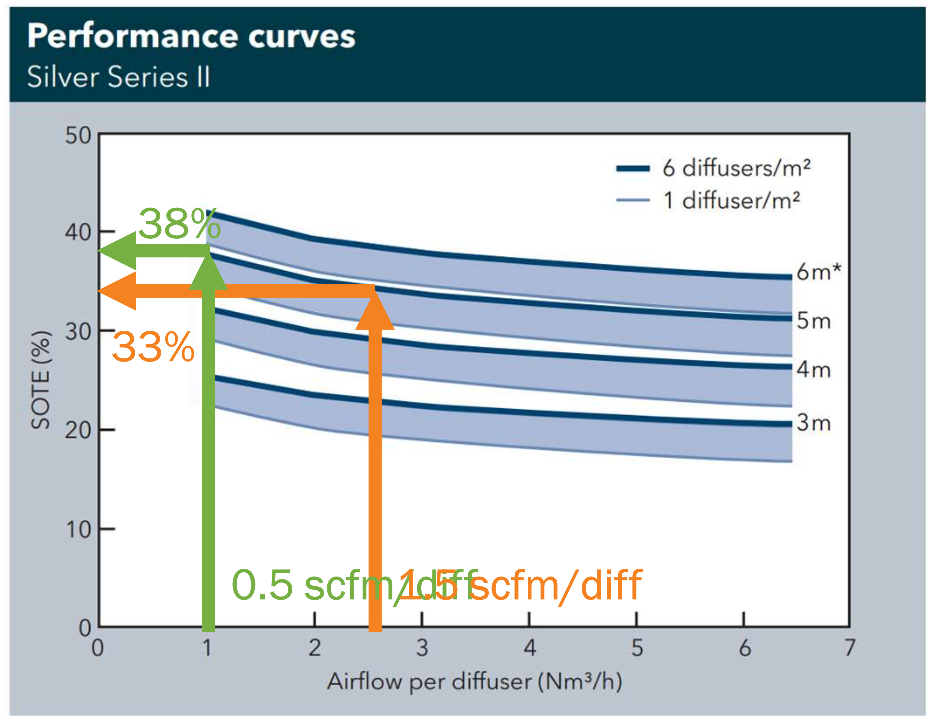
Mechanical Benefits of Low DO Operation

- Lower head losses in distribution piping and valving
- Allows operating at lower blower discharge pressures
- Higher driving force to dissolve oxygen into water
- Minimum air flux for even air distribution
- Minimum airflow for mixing
- Consider supplemental mixing in last zones (e.g., mixer/aerator or large bubble mixing)
- When designing for low DO, tapering can be reduced



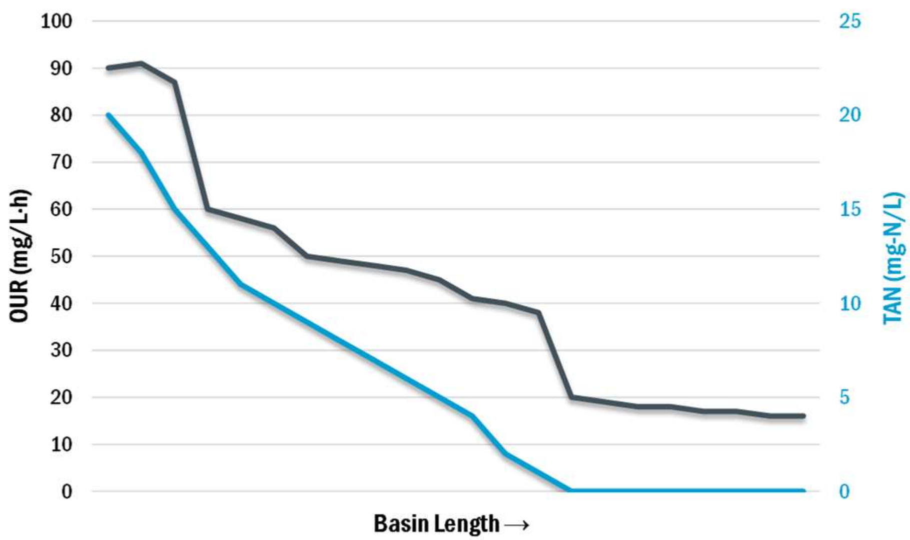
Xylem Aeration Products – Sanitaire Silver Series II Diffusers

*Submergence

Diffuser Tapering Considerations

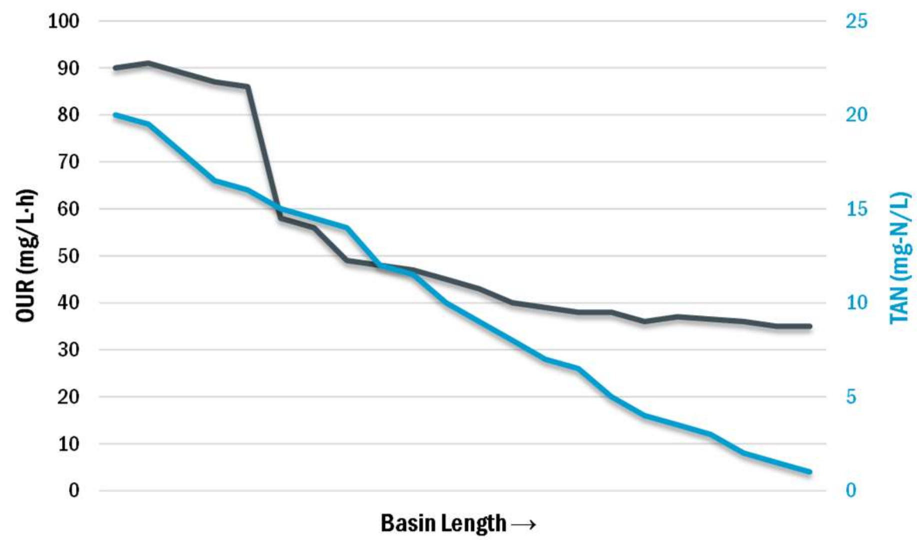
Diffuser Tapering Considerations

Conventional DO Control



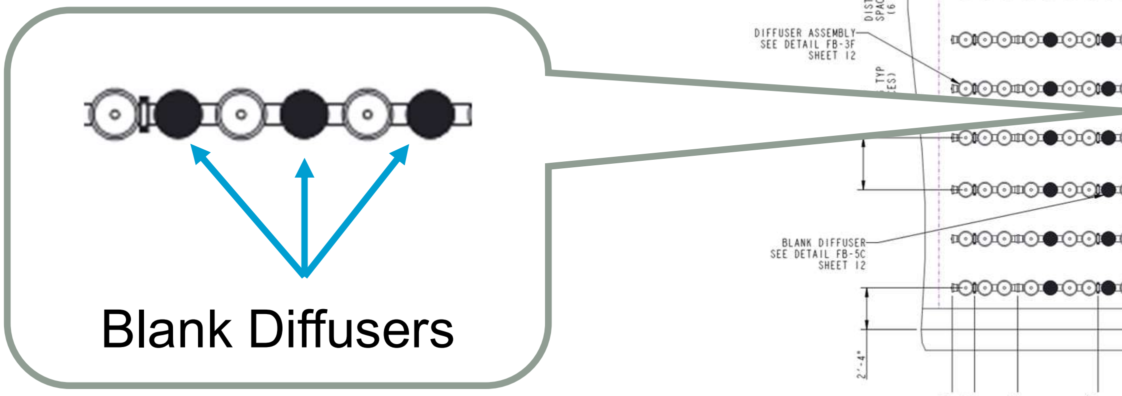
2 mg/L DO setpoint
Variable Airflow

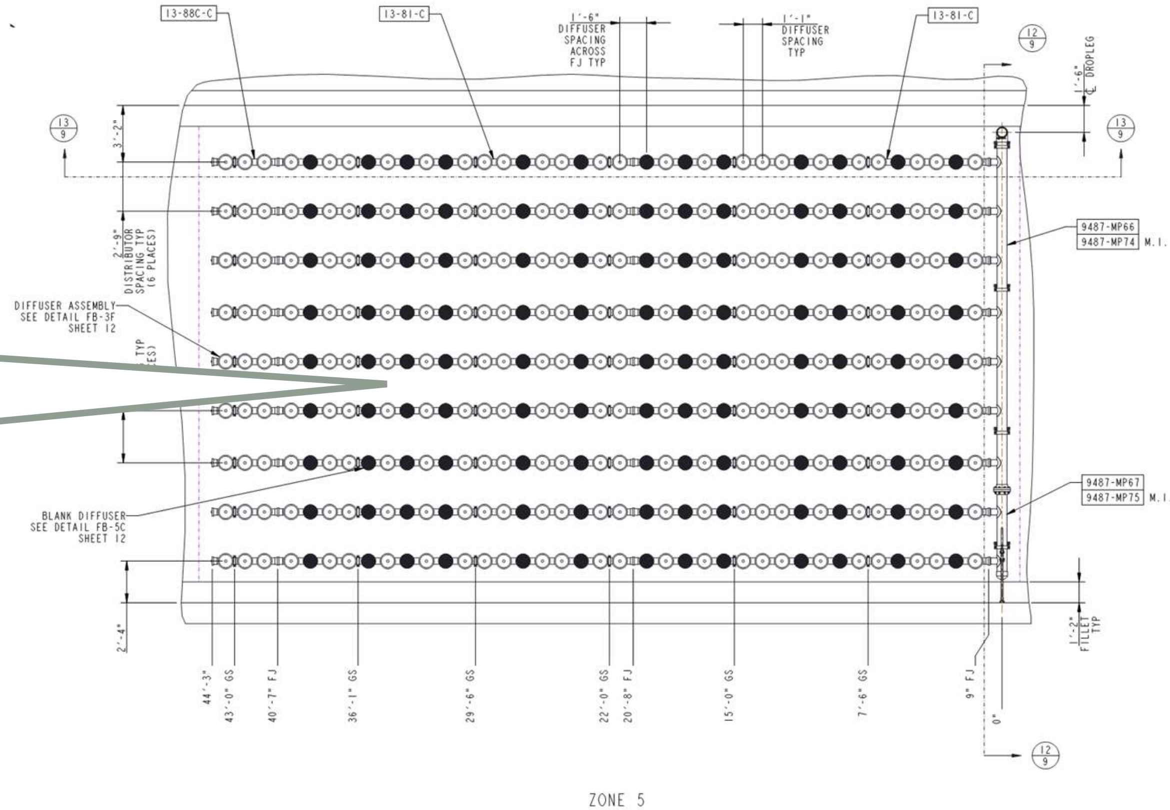
Low DO Control

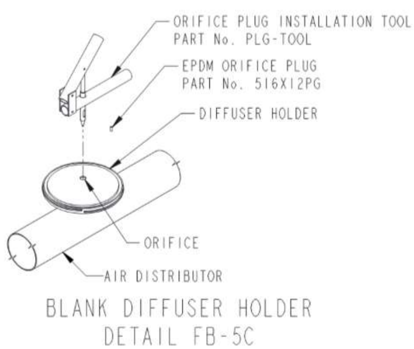


1 mg/L TAN setpoint
Variable DO and Airflow

Diffuser Blanks







- Change diffuser density without modifications
- Install only what is needed for next 10 years

Instrumentation and Process Control

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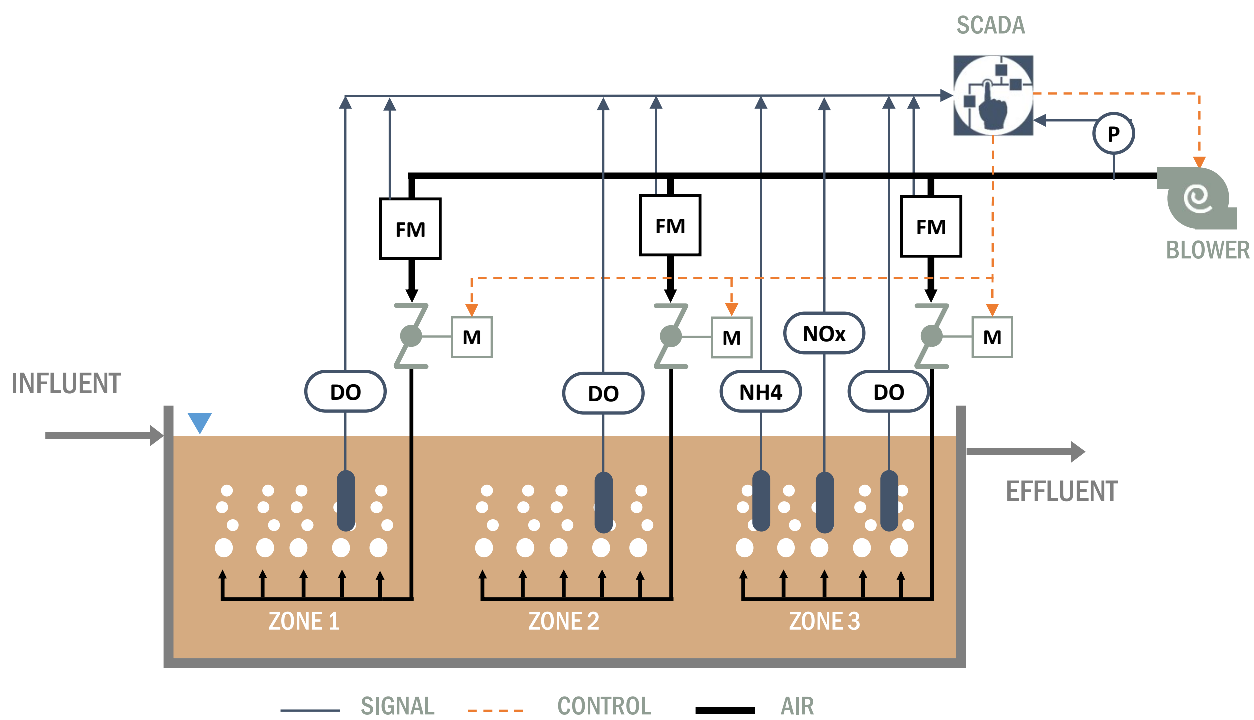
Diffused Aeration Control

- DO control with manual DO setpoints
- Ammonia based aeration control (ABAC)
- Ammonia versus NOx-N (AvN) control

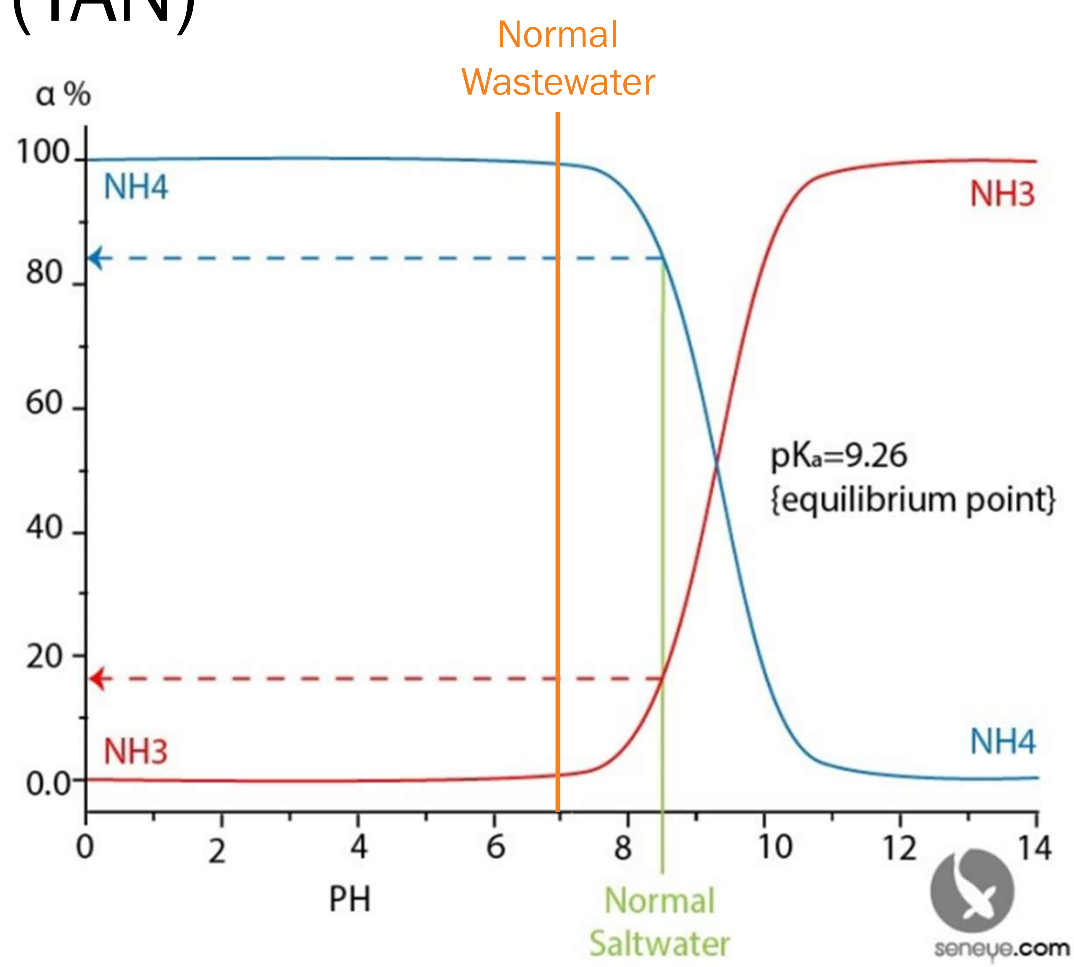


Total Ammonia Nitrogen (TAN)

- Free ammonia (NH_3) plus ammonium (NH_4^+)
- TAN expressed as nitrogen (N)
- Also expressed as NHx (as N)
- Common mistakes:

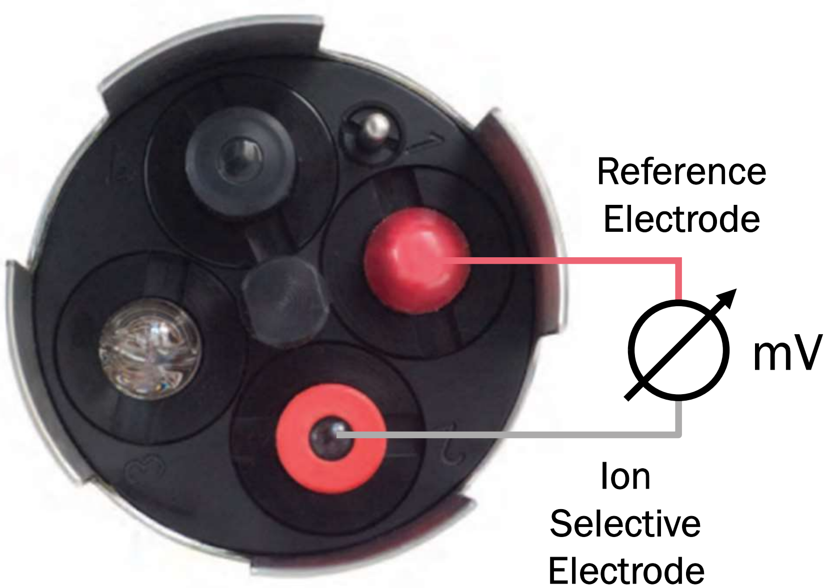
  10 mg/L NH_4^+ = 7.8 mg/L NH_4-N

  10 mg/L NO_3^- = 2.2 mg/L NO_3-N

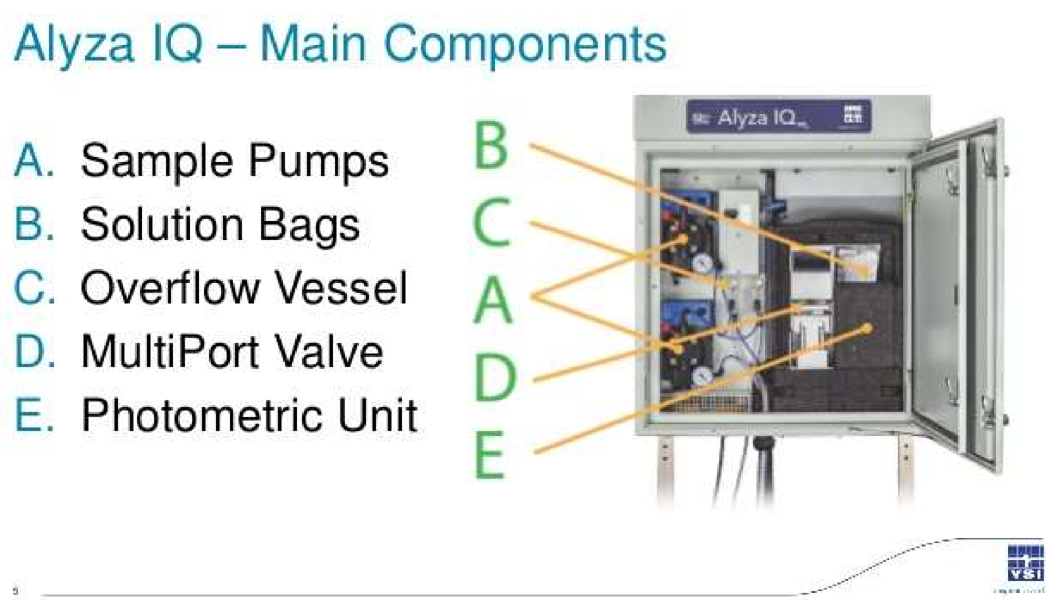


How do we measure ammonia/ammonium?

Ammonium ISE Sensors



Ammonia Analyzers



Comparison of Sensors and Analyzers

Ammonium ISE Sensors

- Fast response time (e.g., T90 <1 minute)
- Measurement range: 1 – 1,000 mg/L NH_4-N
- Background ammonium 1-2 mg/L required
- Requires routine cleaning and calibration checks (e.g., weekly)
- Lower initial investment
- High O&M cost

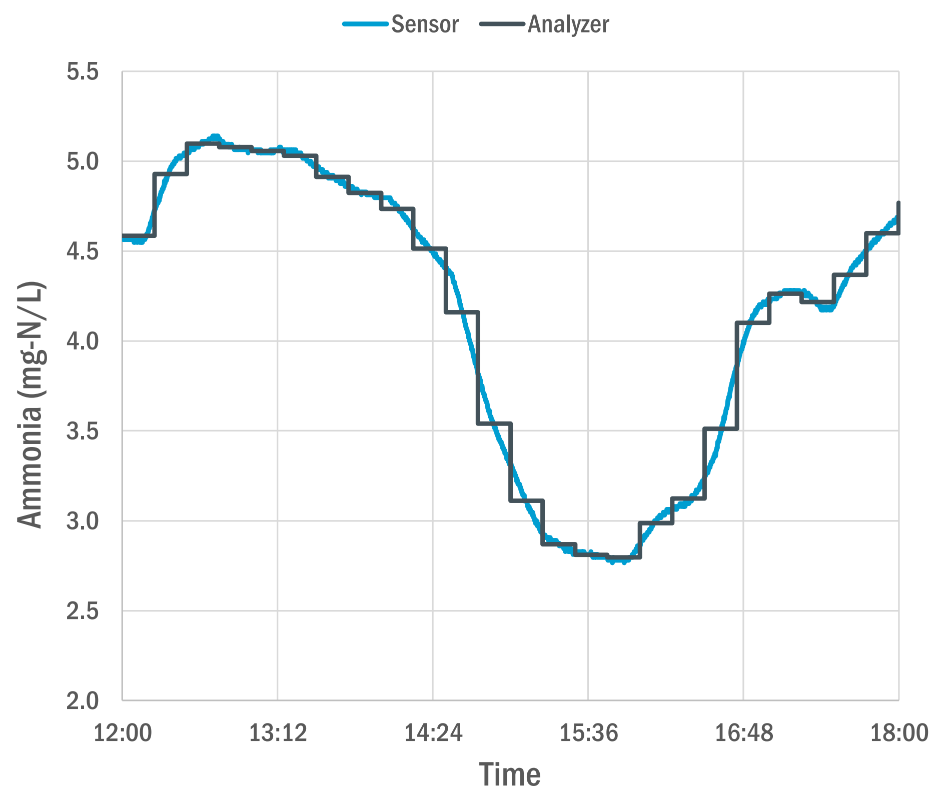
Ammonia Analyzers

- Slow response time (e.g., 1 sample every 15 minutes)
- Narrow measurement range (e.g., 0.05 – 20 mg/L NH_4-N)
- High accuracy
- Sample filtration required
- Self cleaning/calibration
- Higher initial investment
- Low to moderate O&M cost

Instrumentation Considerations

- Airflow meters
  - Aeration header
  - Estimated based on blower output
  - Individual drop legs

- Pressure transmitters
  - Aeration header
  - Blower inlet/discharge



Airflow Control

- Airflow control loop is ‘fast’
- Airflow meter should be accurate over controllable airflow range
- Valve Position Bounds
  - Minimum opening required for mixing or airflow per diffuser
  - Maximum opening based on system limits or design
  - Controllable range of aeration control valve

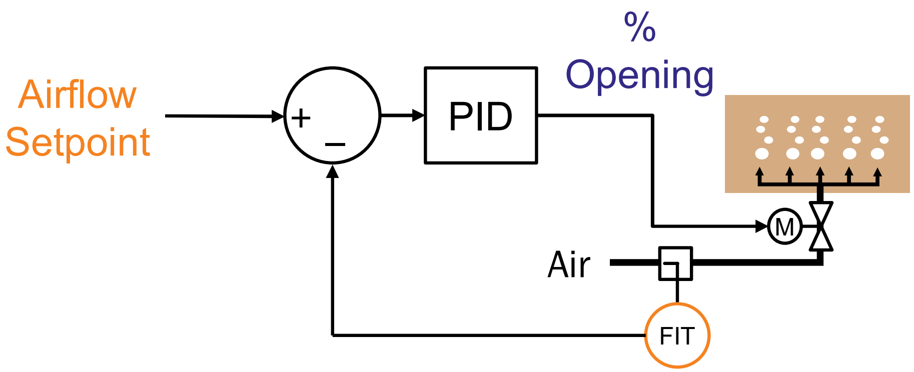


Photo Courtesy of ABB

DO Control

- Direct control of valve position
- Cascading control of airflow setpoint
- Airflow Setpoint Bounds
  - Minimum airflow required for mixing or airflow per diffuser
  - Maximum airflow based on system limits or design
  - Accuracy range of airflow meter
  - Blower capacity and turndown

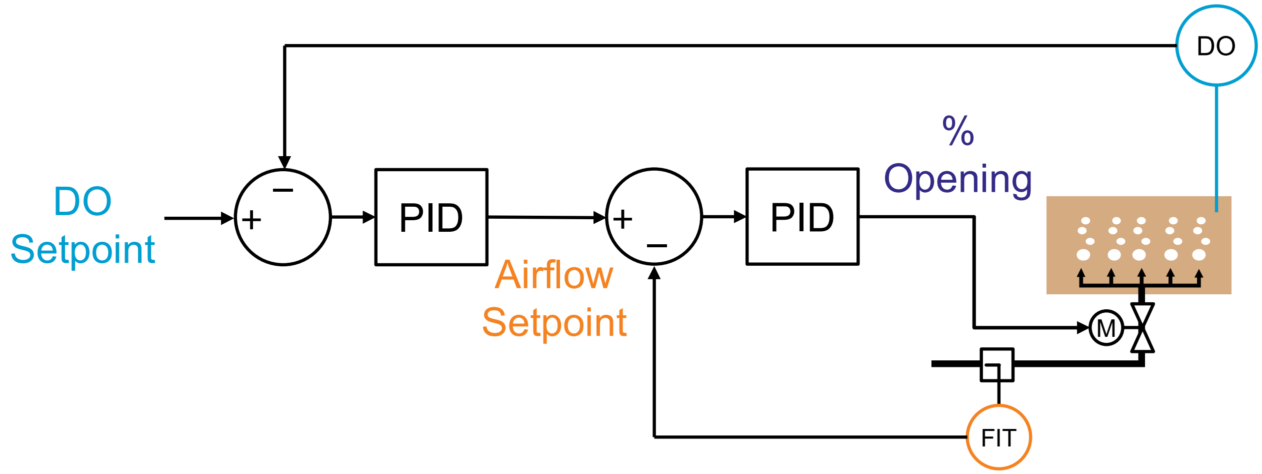
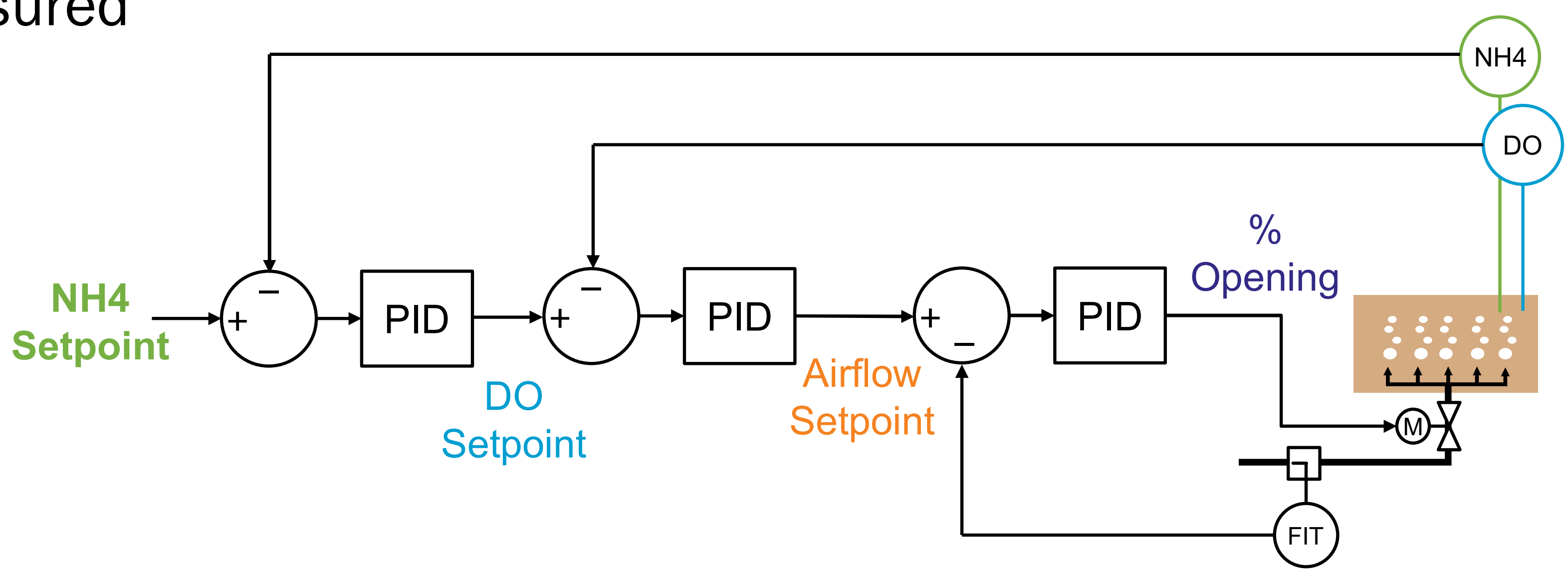


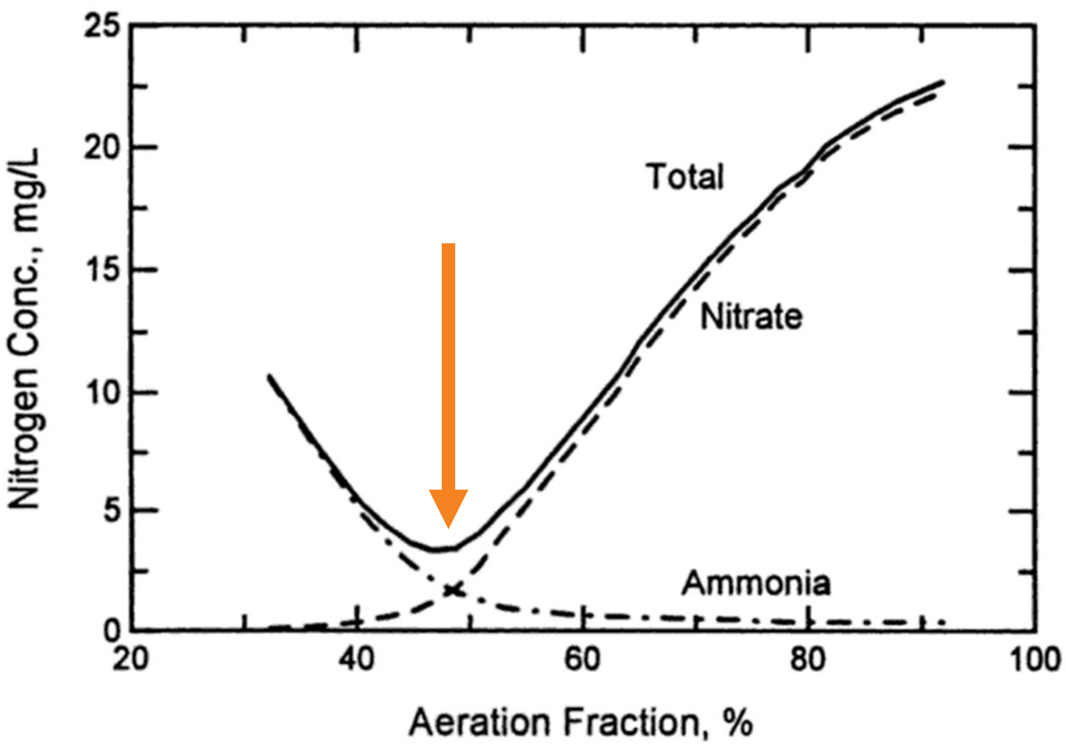
Photo Courtesy of InsiteIG

Feedback Ammonia-Based Aeration Control (ABAC)

- Additional layer of control on top of DO control (can be used to directly control valve position but not recommended)
- 'Very slow' control loop because DO concentration has to change followed by nitrification rates and then ammonium concentration that is measured



Ammonia versus NOx-N Control

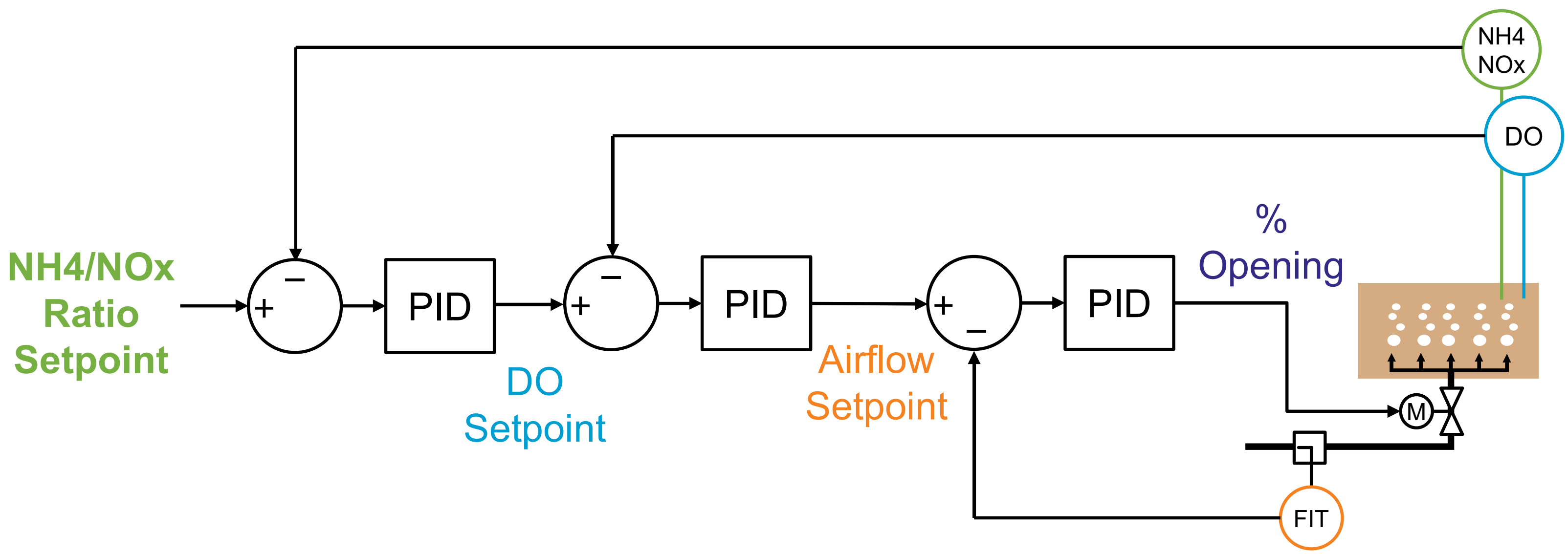


Batchelor, B (1983). Simulation of single-sludge nitrogen removal. Journal of Environmental Engineering

- Target effluent ammonia to NOx-N ratio of 1 to maximize nitrogen removal
- Intermittent aeration with high DO and variable aerobic fraction (difficult to implement full-scale)
- Continuous aeration with variable DO setpoint

Ammonia versus NOx (AvN) Aeration Control

- Adjusts DO setpoint or aerobic fraction to maintain ammonia vs. NOx (NO_3 + NO_2) ratio setpoint
- Setpoint of 1 (i.e., NH_4-N = NOx-N) results in lowest total nitrogen by optimizing anoxic/aerobic fraction



Mechanical Aeration

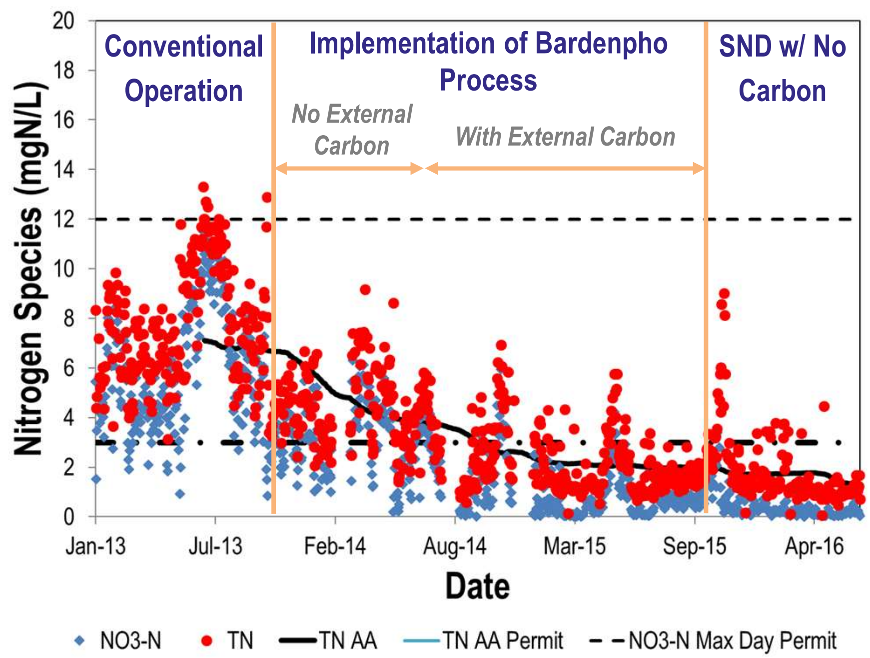
Mechanic Aerators

- Variable water surface elevation
  - Adjustable effluent weir
  - Adjustable aerator depth/position
- Variable speed
  - VFD
  - High/low speed
- Variable operating time
- Supplemental mixing

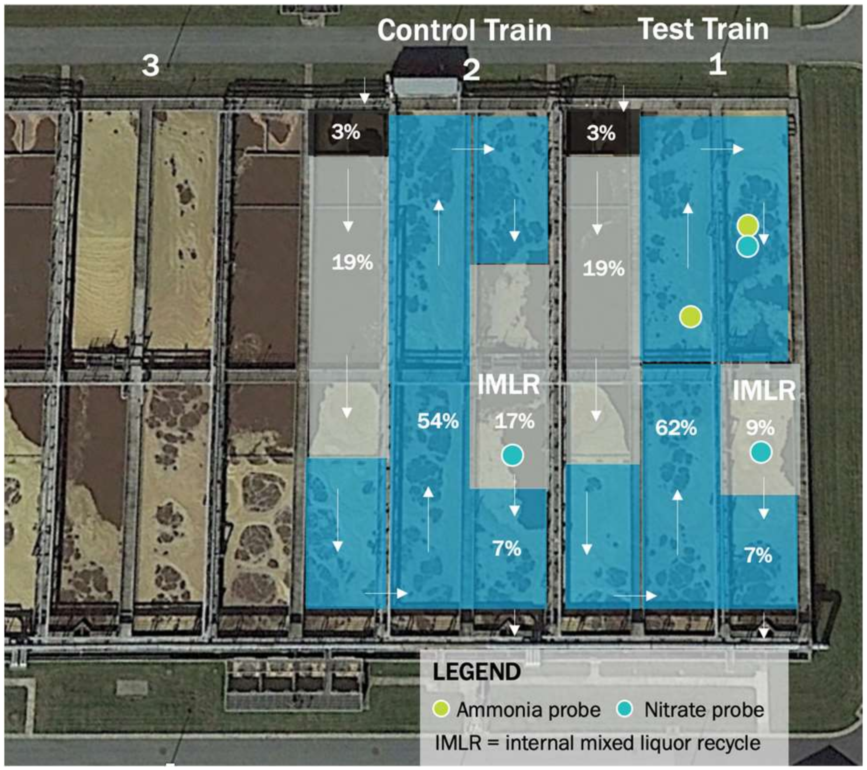
Case Studies

Orange County Utilities, FL

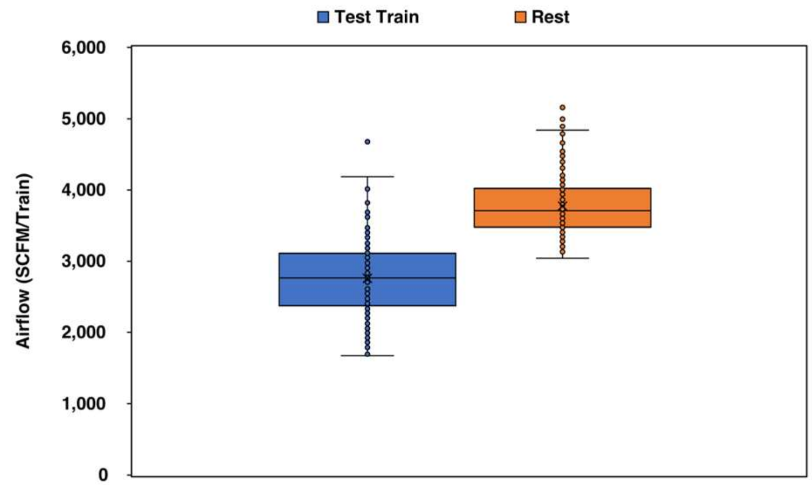
Northwest WRF

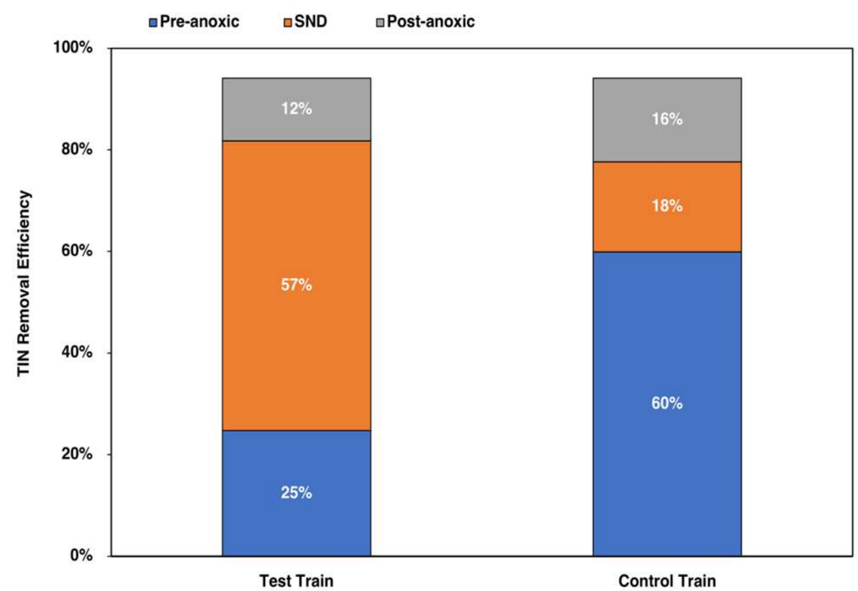


WSSC Water, MD



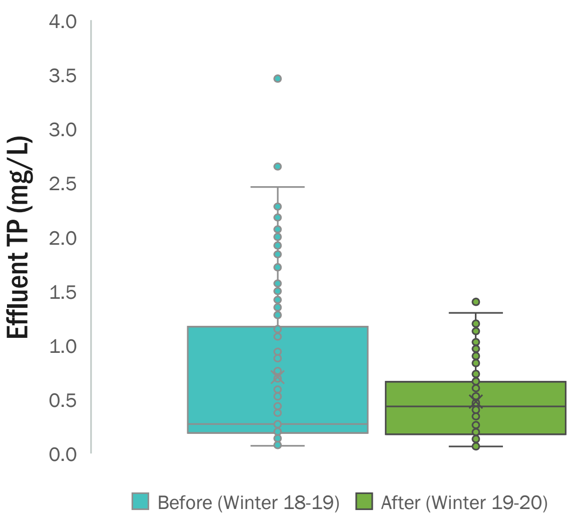
Seneca WRRF





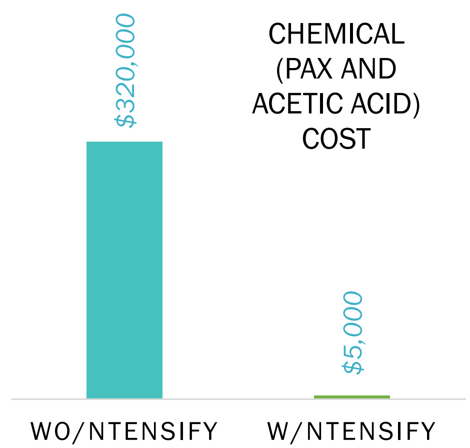
James R. DiIorio WRF

Effluent TP Reduction



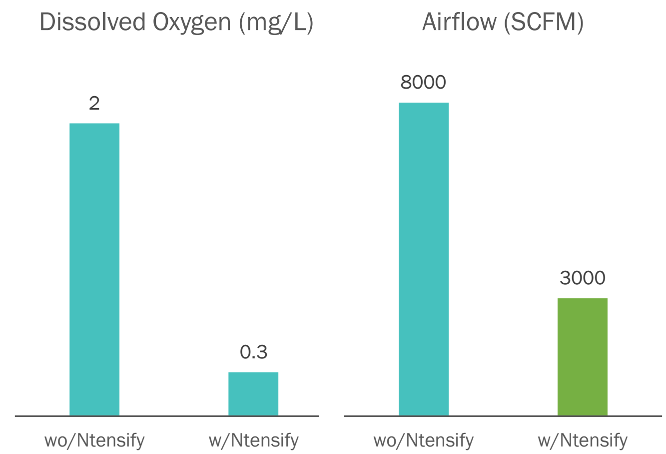
Improved EBPR reliability

Chemical Savings



>$300k/yr cost savings on chemical usage

Aeration Savings



>$150k/yr cost savings on aeration energy

Key Takeaways

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Key Takeaways

- SND generally occurs in systems when oxygen input is controlled and restricted.
- Aeration control strategies:
  - Automatic DO setpoint control with manual low DO setpoint
  - Ammonia-based aeration control (ABAC)
  - Ammonia vs. NOx (AvN) control
- Sufficient DO is provided so that nitrification can occur but is restricted so that the nitrite and/or nitrate formed must be used.
- Low DO operation can result in significant energy savings (10-40%), reduce chemical requirements, and improve N and P removal.
- Selection of microorganisms with high oxygen affinities and adaptation period required.

Thank you.

- Questions?