Biological Nutrient Removal Operations

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Outline

* Nutrient Removal Overview
* Process Considerations
* Process Monitoring
* Problems & Troubleshooting
* Questions

Nutrient Removal Overview

Wastewater Characteristics Important in BNR Process Design/Operation

* Design Flow
* Quantity and Type of Influent BOD/COD
* Influent Nitrogen
* Influent Phosphorus
* Temperature Range
* Diurnal TKN Peaking Factors
* Alkalinity
* Dissolved Oxygen
* BOD/TKN Ratio
* BOD/P Ratio

Wastewater Characteristics

* Strong Sewage Better Than Weak Sewage
* Readily Biodegradable BOD is Important
* Seasonal, Wet Weather, and Weekend/Holiday Variations in Strength Can Affect Performance
* Weak Sewage Can Result In:
    * Inadequate COD to Achieve Usual Degree of Denitrification
    * Inability to Achieve/Maintain Anaerobic/Anoxic Conditions
* High Flows Lead To:
    * Reduced Hydraulic Retention Time
    * Increased Clarifier Solids Loading

Removal of Phosphate from Wastewater

General

* Get It Into A "Solid" and Then Remove The "Solid"
* When Treating the Solid, Don't Allow P
* Release and Recycle Back To Sewage
* Types of "Solids"
  * Biological (Microorganisms)
  * Chemical (Precipitates)

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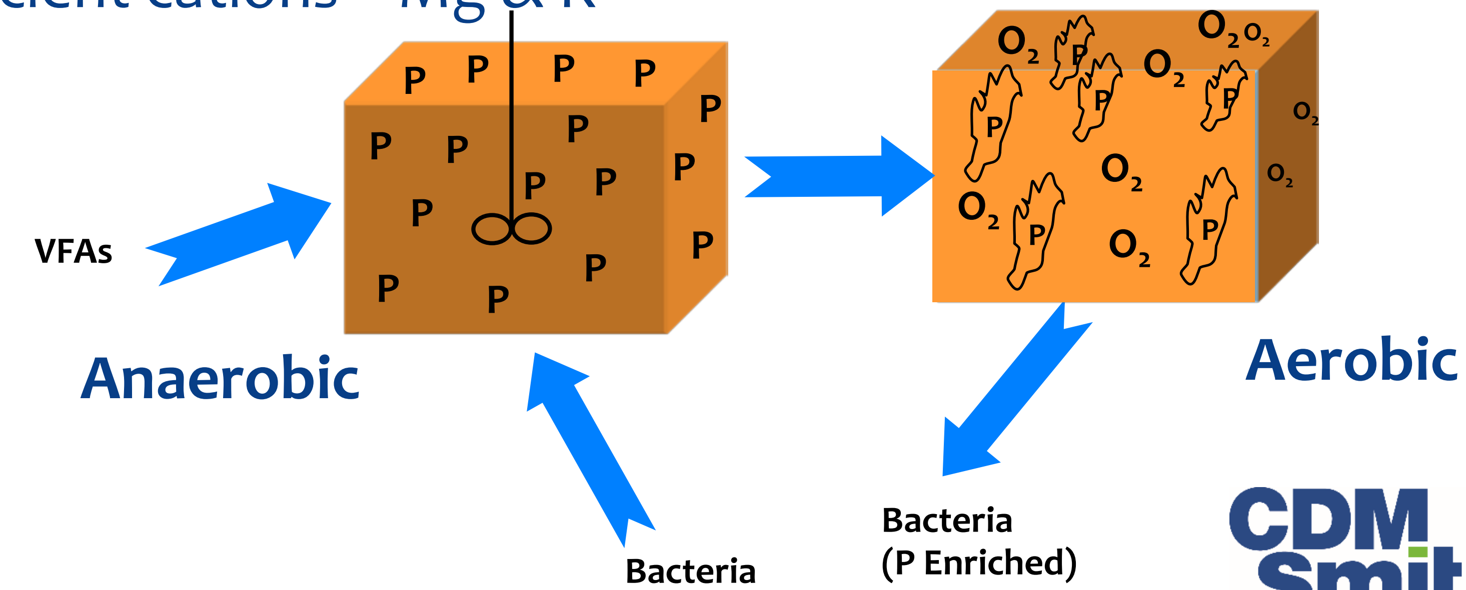
Requirements for Enhanced Biological Phosphorus Removal (EBPR)

* Readily biodegradable BOD / COD (VFAs) — **Volatile Fatty Acids**
* Relatively high BOD / TP Ratio (>20:1)
* Anaerobic Conditions (No D.O. & No Nitrates)
* No Toxics
* Sufficient cations - Mg & K



Origins of Nitrogen in Wastewater

Domestic Sources

* Urea   Fecal Matter (Protein)

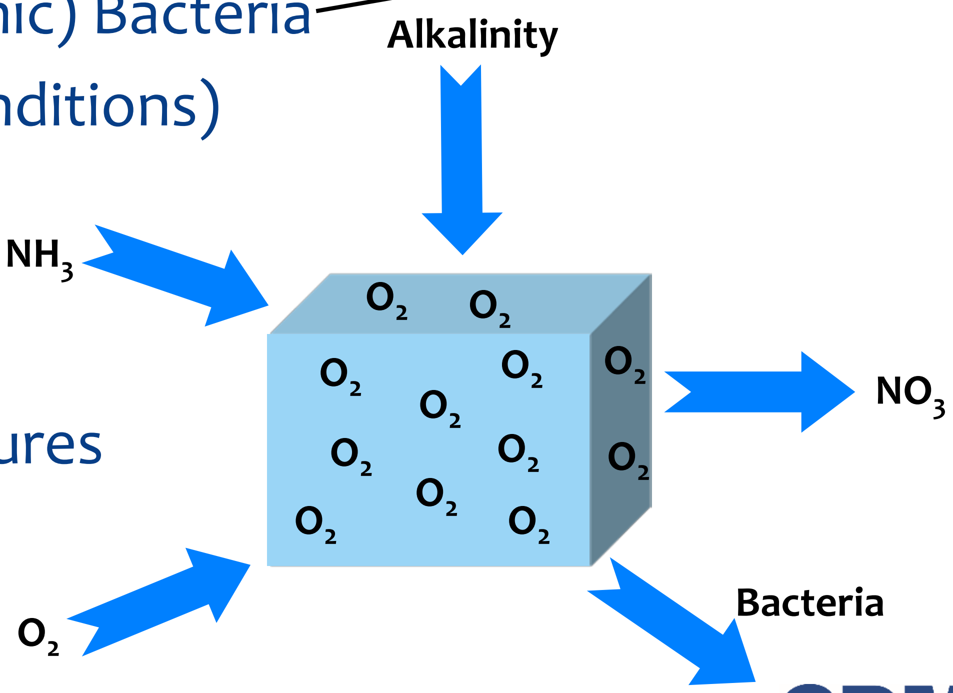
Industrial Sources

* Meat & Milk Processing
* Petroleum Refineries
* Ice Plants
* Fertilizer Manufactures
* Synthetic Fiber Plants
* Cleaners

Environmental Conditions for Biological Nitrification

Can synthesize all the compounds required for growth from simple inorganic salts

- Nitrifying (Autotrophic) Bacteria
- Oxygen (Aerobic Conditions)
- pH, Alkalinity
- Sufficient Mean Cell Residence Time for Operating Temperatures
- No Toxics



Results of Nitrification

- TKN $\longrightarrow$ $NO^{\overline{3}}$
- O_2 Demand = 4.57 mg O_2 /mg NH_3 -N
- Alkalinity Demand = 7.14 mg $CaCO_3$ /mg NH_3 -N
- Nitrifier Yield = 0.1-0.15 mg VSS/mg NH_3 -N

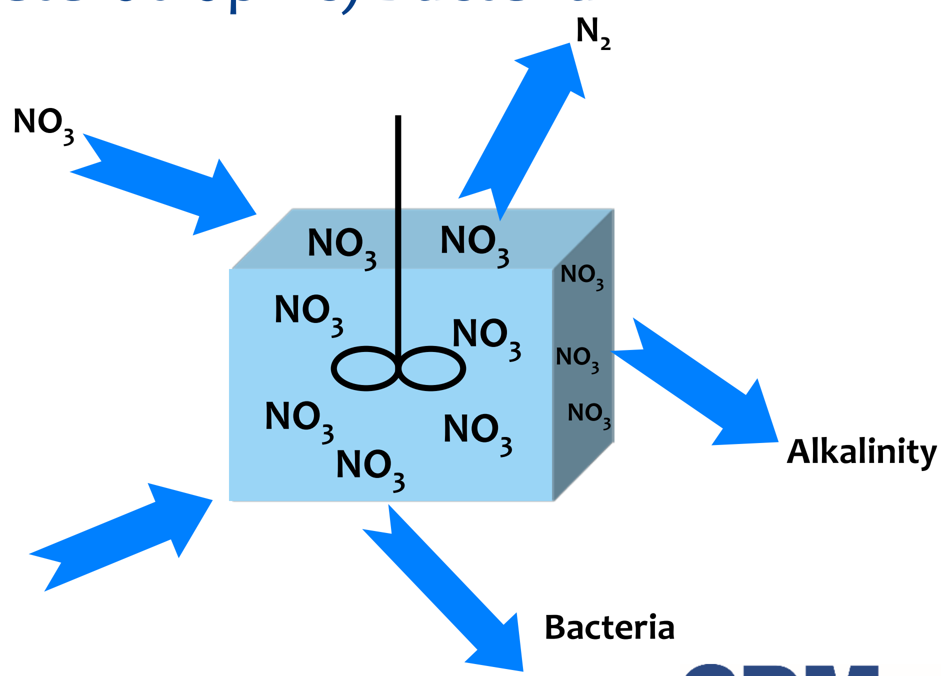
Environmental Conditions for Denitrification

Can thrive in alternating oxic, anoxic and anaerobic environments

Must be supplied with complex organic compounds for their metabolism and growth

* Denitrifying (Facultative Heterotrophic) Bacteria
* Food (BOD or Methanol)
* Nitrate
* No Oxygen

Anoxic Condition



Results of Denitrification

Nitrate ➡ Nitrogen Gas, N_2

* Oxygen Recovery ≅ $\dfrac{2.86 \text{ mg } O_2}{1.0 \text{ mg } NO_3 \text{ reduced}}$

* Alkalinity Demand ≅ $\dfrac{3.0 \text{ mg } CaCO_3}{1.0 \text{ mg } NO_3 \text{ reduced}}$

* Solids Yield ≅ 0.4 mg VSS/mg COD removed

Process Considerations

* General Monitoring Requirements
* Anaerobic (Fermentation)
* Pre-Anoxic
* Aeration
* Post-Anoxic
* Rearation
* Side streams
* Problem Solving

General Operational Considerations

* Requires More Knowledgeable Operator
* Proper Operator Training
* Adequate Onsite Laboratory Facilities With Trained, Experienced Staff
* Basic Principles Similar For All BNR Processes
* Diurnal, Seasonal, and Wet Weather Variations in Strength Can Affect Performance
* Raw Sewage Characteristics Directly Affect Performance

Anaerobic (Fermentation) Zone

* Receives Influent Flows and Recycle Sludge
* Induces the Release of Phosphates Stored In the Sludge and Sets the Stage for the Uptake of More Phosphates
* Presence of Readily Degradable Organics, Zero Dissolved Oxygen and Zero Nitrates Stimulate the Release of Phosphates. Higher Influent Organic Loading Helps Improve the Release of Phosphates
* Presence of Dissolved Oxygen, and Nitrates Inhibit the Release of Phosphates. Low Organic Concentrations Reduce the Amount of Phosphates Released
* Good Operation Requires Low Dissolved Oxygen and Minimal Amount of Nitrates in the Recycle and Higher BOD in the Influent
* Need to Monitor for D.O., Nitrates, Soluble BOD, and Orthophosphates

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First Anoxic Zone

* Receives Flow From the Anaerobic Zone and Internal Recycled Mixed Liquor From the Aeration Zone
* Uses Carbon in the Influent and Nitrates From the Aeration Zone and Reduces Nitrates to Nitrogen Gas through Denitrification. Denitrification Rates are Much Higher Compared to the Second Anoxic Zone Due to the Influent Organic Loading
* Presence of Dissolved Oxygen Can Inhibit Denitrification
* Nitrate Loading is Proportional to the Internal Recycle Rate From the Aeration Zone
* Need To Monitor For D.O; Nitrates, Orthophosphates, Internal Recycle Flows

Aeration Zone

* Removes Carbon That is Not Removed During Denitrification. Removes Phosphates Entering the System. Converts Ammonia Nitrogen to Nitrate Nitrogen
* Low Dissolved Oxygen Can Cause Insufficient Nitrification. Phosphate Removal Efficiency May Be Reduced. Denitrification of Nitrates is a Possibility
* High Dissolved Oxygen May Reduce the Denitrification Capacity in the First Anoxic Zone
* Need to Monitor for Dissolved Oxygen, Orthophosphate, Nitrates, and Ammonia

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Second Anoxic Zone

* Receives Nitrified Mixed Liquor From the Aeration Zone
* Ideal Conditions are Low Dissolved Oxygen and Adequate Detention Time
* Denitrification Capacity is Limited Due to Limited Substrate Availability. Denitrification Rates are Much Lower than the First Anoxic Tank
* High Dissolved Oxygen in Mixed Liquor May Inhibit Denitrification
* Higher Level of Nitrification in the Aeration Zone and Insufficient Nitrogen Removals in the Preceding Anoxic and Aerobic Stages Can Overwhelm the Second Anoxic Tank and Cause Nitrates to Leak into the Effluent and Assure the Presence of Nitrates in the Recycle Sludge and Eventually in the Fermentation Tank
* Need to Monitor for Nitrates, Ammonia, Orthophosphates and for Dissolved Oxygen

Reaeration Zone

* Receives Mixed Liquor From the Second Anoxic Tank
* Air Increases D.O. in the Bulk Liquid
* Improves Settleability of the Sludge
* May Prevent Release of Phosphates in Final Clarifiers
* Useful for Mixing Chemicals for Further Removal of Phosphates
* Nitrifies any Ammonia Nitrogen that is Not Nitrified in the Aeration Zone

Final Clarifier

* Receives Mixed Liquor From the Reaeration Tank
* Separates Sludge From Bulk Liquid (MLSS)
* Dissolved Oxygen in the Recycle May Be Regulated Through the Sludge Blanket Depth
* High Sludge Blanket Depth May Create Anaerobic Conditions and Cause Release of Phosphates

Anaerobic Tank

Monitoring Parameters
* Orthophosphorus
* Nitrate
* Dissolved Oxygen
* Return Sludge Flow Ratio

Controls
* Return Sludge Flow Rate
  * Nitrate Return

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Anaerobic Tank

* Hydraulic Retention Time
  * RAS Flow Rate
  * Water Depth
* Mixing Intensity
  * Solids Deposition
  * Oxygen Input
* Oxygen Input
  * Hydraulic Turbulence
  * Mixing
* Zone Switching
  * Anoxic/Anaerobic

Pre-Aeration Anoxic Tanks

Monitoring Parameters

* Dissolved Oxygen
* Nitrates
* Internal Recycle Flow Ratio

Controls

* Internal Recycle Flow Rate
* Zone Switching
* Solids Residence Time

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Pre-Aeration Anoxic Tanks

Controls

* Primary Sedimentation By-Pass
* Aeration Zone Effluent Dissolved Oxygen

Aeration Tank

Monitoring Parameters

- Dissolved Oxygen
- Mixed Liquor Suspended Solids
- Ammonia/Nitrates/Alkalinity

Controls

- Solids Residence Time
- Oxygen Input
- Zone Switching

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Second Anoxic Zones

Monitoring Parameters

* Dissolved Oxygen
* Nitrates
* Ammonia

Controls

* Aeration Tank Effluent Dissolved Oxygen
* Solids Residence Time
* Chemical Supplement - Methanol

Process Monitoring

* Toxicity
* Metals
* pH and Alkalinity
* Temperature
* ORP

Toxicity

* Compounds that are toxic include solvent organic chemicals, amines, proteins, tannins, phenolic compounds, alcohols, cyanates, ethers, carbamates and benzene.
* Because of the numerous compounds In some cases, it may be difficult to pinpoint the source and extensive sampling of the collection system may be required
* Vigilant with respect to septage receiving
* Industrial Pretreatment Program (IPP)

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Nitrification Inhibition by Metals

Metal	Inhibitory Concentrations (mg/l)	Current Sludge Concentration (mg/kg)
Ammonium	436-1000	
Cadmium	1.0-14.3	1.8
Chromium	0.25-20.0	115
Copper	0.005-20.0	515
Lead	0.50-20.0	
Nickel	0.1-12.0	33
Zinc	0.08-11.0	934
Aluminum	? (15-26)[a]	76710
Silver	? (5)	96
Mercury	1.0-5.0	
Calcium	? (2500)[a]	38660

(a) Inhibitory to Heterotrophs

pH and Alkalinity

* The pH of mixed liquor has a significant effect on the growth rate of the nitrifying bacteria. The optimum pH range for the highest growth rate is between 7.5 and 8.6. On either side of this range, the growth rate drops off rapidly.
* In the aerobic zones of the Process Trains, the nitrifying bacteria consume oxygen and bicarbonate alkalinity (HCO_3-) and produce carbonic acid (H_2CO_3).

pH and Alkalinity

* Alkalinity is measured in terms of calcium carbonate or $CaCO_3$, and it is generally accepted that 7.14 lbs of alkalinity is needed for every 1.00 lb of ammonia oxidized.
* The denitrification process, taking place in the anoxic zones of the process tanks, will actually add some alkalinity back into the wastewater to aid in the nitrification process taking place in the aerobic cells. The amount of alkalinity recovered, approximately 50% of the alkalinity lost during nitrification, will not be needed in order to satisfy the nitrification demand.

pH and Alkalinity

* Rather than measuring the alkalinity of the wastewater entering the biological process, it is more efficient to measure the alkalinity in the effluent, prior to discharge. At this location the sample will represent the residual alkalinity in the MLSS. If the alkalinity level is at a level of 50 to 70 mg/l, the operator can be sure that sufficient alkalinity is available, plus the alkalinity recovered by the denitrification process, to satisfy the requirements of the nitrification process

Temperature

* The temperature of the mixed liquor significantly affects the growth rate of the nitrifiers. Nitrifiers can grow within a wide temperature range, 4°C to 50°C (39°F to 122 ° F); however, the optimum temperature range is 30°C to 36°C (86°F to 97 ° F).
* At temperatures below 10°C (50 °F) if nitrification has been established in a system, it can be maintained. However, at temperatures below 10°C., it is virtually impossible to grow enough nitrifiers in a system to achieve nitrification.

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Temperature Effect on SRT

Temperature, °C/°F	Washout SRT	Operating SRT
24/75.2	2.7	5.4
23/73.4	2.7	5.4
22/71.6	2.7	5.4
21/69.8	2.7	5.4
20/68.0	2.8	5.6
19/66.2	3.0	6.0
18/64.4	3.1	6.2
17/62.6	3.3.	6.6
16/60.8	3.5	7.0
15/59.0	3.7	7.4
14/57.2	4.0	8.0
13/55.4	4.3	8.6
12/53.6	4.6	9.2
11/51.8	4.9	9.8
10/50.0	5.3	10.6
9/48.2	5.7	11.4
8/46.4	6.2	12.4
7/44.6	6.7	13.4
6/42.8	7.3	14.6
5/41.0	7.9	15.8
4/39.2	8.6	17.2

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Temperature

* The table illustrates the impact that temperature has on the success of the nitrification process.
* With the range of wastewater temperatures normally experienced in the Southeast, temperature will not be a factor in re-establishing nitrification.
* It should be clearly understood that **over-wasting** will have a detrimental effect on nitrification and will require some time to recover.

Oxidation Reduction Potential (ORP)

* The oxidation reduction potential (ORP) is the measure of the tendency of a chemical species to acquire electrons and thereby be reduced. It is measured in millivolts (mV).
* The presence of an oxidizing agent like oxygen increases the ORP value.
* The presence of a reducing agent like CBOD5 decreases the ORP value.
* ORP can be used to set process timing

Oxidation Reduction Potential (ORP)

* During nitrification the oxidation of ionized ammonia (NH_4+) to nitrate (NO^{3}-) is performed by nitrifying bacteria when the ORP of the wastewater is +100 to +350 mV.
* During denitrification the reduction of nitrate (NO^{3}-) to molecular nitrogen (N_2) is performed by denitrifying bacteria when the ORP of the wastewater is +10 to -50 mV.
* With this information, swing zone operational times can be adjusted based on ORP trending to maximize the additional denitrification time based on ORP rather than DO readings alone.

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Problems & Troubleshooting

Common Problems

- Poor Settling
- Low DO
- Foaming
- Nutrient Deficiencies
- Odors
- Toxicity

Handling of Sidestreams

* Keep Bio-P Sludges Fresh - Aerobic
* DAF Thickening Offers Better Alternative Than Gravity Thickening
* Digestion is Capable of Resolubilizing Large Concentrations of N and P
* Recycle Streams High in N or P Should be Treated, or Not Recycled
* Rapid Methods of Sludge Dewatering are Best

Possible Remedial Measures To Improve Feed/Stop BNR Process Upsets

* Supplement BOD:
  * Primary Sludge/Overload Primaries
  * Anaerobic Digester Supernatant
  * Acid Fermenter
  * Brewery/Food Industry Wastes

* Chemical Additions:
  * Alum
  * Methanol
  * Acetates

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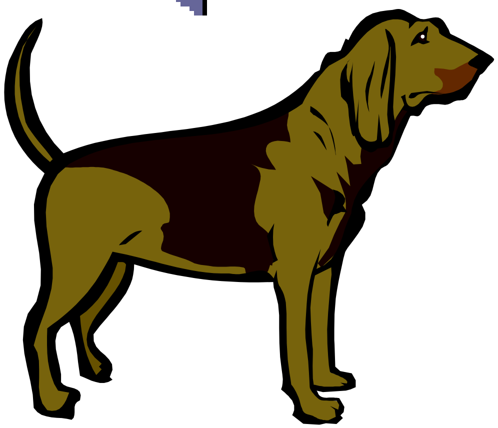
Possible Remedial Measures To Improve Feed/Stop BNR Process Upsets

* Bypass Storm Flows To:
  * Holding Tanks
  * Equalization Tanks
  * Clarifiers
  * Last Biological Zone

Review Operation



* What is the problem? – high BOD, TSS, N, or P, turbidity, high or low pH, odors, etc.
* Don’t overlook the obvious – look for in-plant operational, electrical or mechanical issues
* Check operations log and laboratory data – look at history
* What recently occurred at the WWTP?
* What recently happened upstream in the facility?
* Maintain a clear, concise operations log, wastewater checklist, dry erase board - communication

Addressing the Problem

* Identify the cause, again it may be something obvious like a power outage, pump or blower failure, air leak, spill or a slug load
* Sometimes it is best to ride out the situation and allow the process to recover on its own
* Do not make changes unnecessarily
* Do not press buttons or resets without or thinking out the problem – breakers trip as a protective

Addressing the Problem

* When making changes do them gradually – allow the system to acclimatize
* Observation, communication and documentation are key!
* Maintain a clear, concise operations log – document the resolution, for future reference, use photos and video if necessary

Questions/Discussion

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