

BIOLOGICAL NUTRIENT REMOVAL

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OBJECTIVES

- Familiarize yourself with the different biological and chemical methods to remove nutrients
- Understand key operational parameters
- Learn the impact of side streams
- Apply what you've learned – both here, and back at your plant!

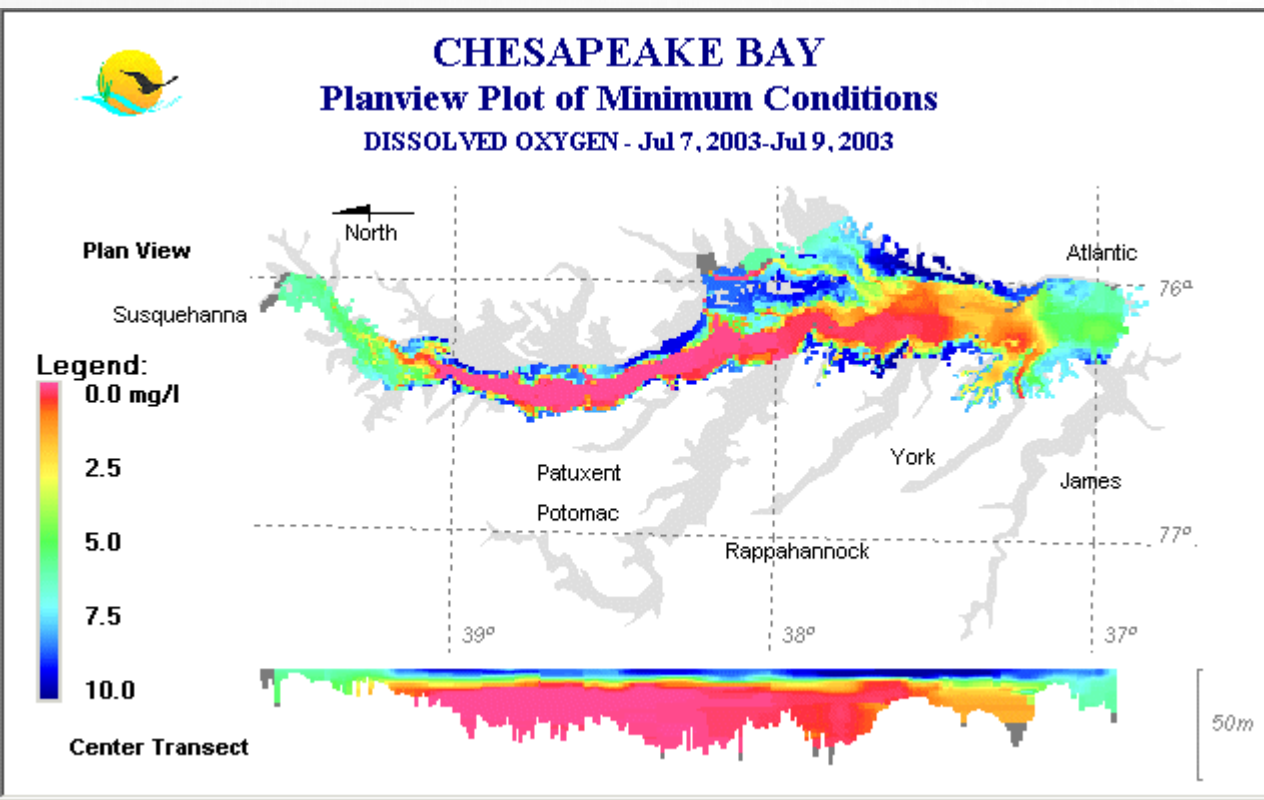
WHY DO WWTPS TREAT & MONITOR FOR NITROGEN & PHOSPHORUS?

- We have to...NPDES requirements
- Nitrogen & Phosphorus serve to limit growth of aquatic organisms in most aquatic environments
 - Three nutrient-related environments
 - Oligotrophic – nutrient poor
 - Mesotrophic – nutrient limited
 - Eutrophic – nutrient rich
- Can lead to Eutrophication in the environment...which leads to poor water quality
 - Excessive algal growth
 - Depleted DO

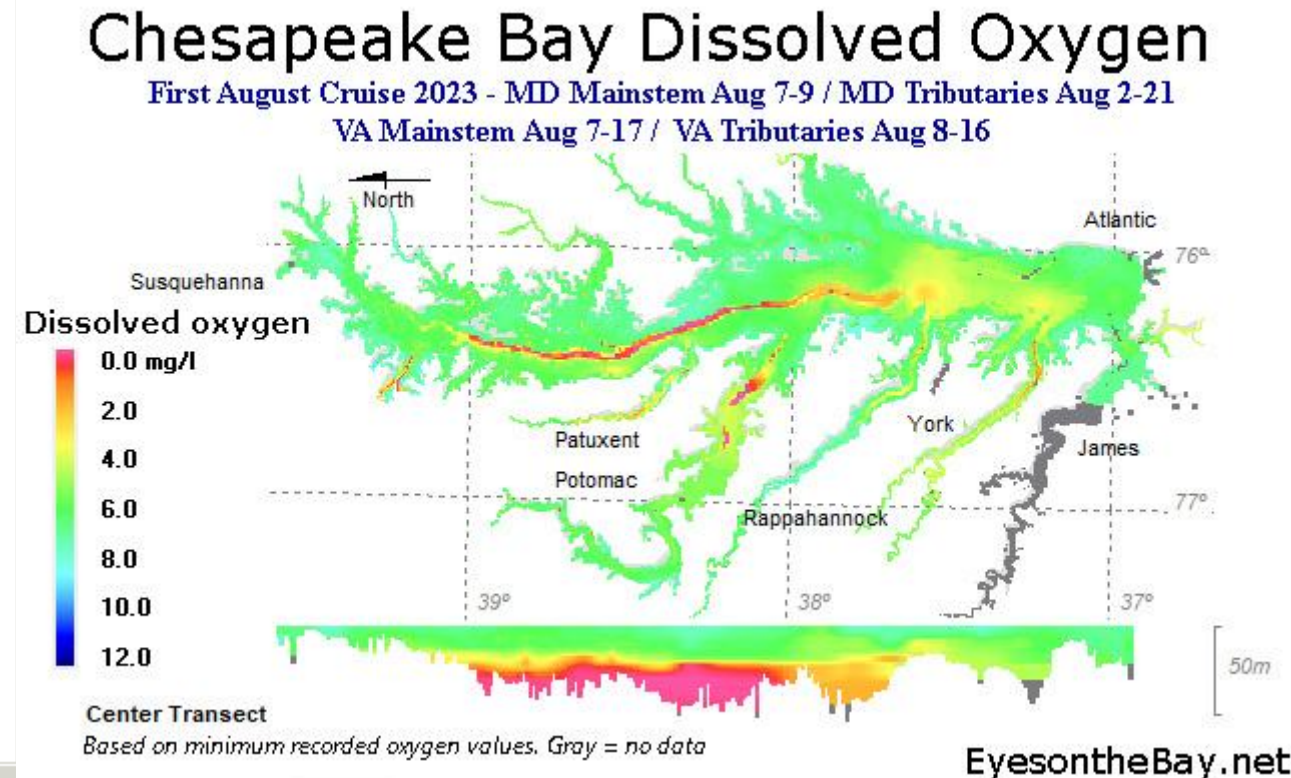


EFFECTS OF NUTRIENTS

BEFORE Nutrient Removal



AFTER 20+ years Nutrient Removal



TERMS

Term	Abbr.	Meaning – In today's Context
Mixed Liquor Recycle or Internal Recycle	MLR or IR	Aeration basin contents recycled to the anoxic zone
Return Activated Sludge	RAS	Water & settled solids drawn from the bottom of the secondary clarifier
Anoxic	Ax	Presence of nitrate and absence of free or dissolved oxygen
Oxic or Aerobic	Ox	Containing free or dissolved oxygen
Anaerobic	An	Containing no dissolved oxygen or Nitrate

TERMS

Term	Meaning – in today's context
Diurnal	The daily fluctuations seen in the influent flow & load
Carbon	BOD, sBOD, Volatile Fatty Acids (VFAs), chemicals added (methanol, acetic acid, etc)
Side Stream	Wastewater from a unit process • Thickening filtrate/centrate • Dewatering filtrate/centrate • Digester supernatant or overflow • Drying or solids storage drainage
P Uptake	Phosphorus drawn in by biomass
P Release	Phosphorus let go by biomass

DISSOLVED OXYGEN ZONES

Wastewater nutrient removal is very simple: all systems use anaerobic, anoxic, and aerobic zones

- **Aerobic Zones- Aeration Present**

- Dissolved Oxygen > 1.0 ppm
- BOD removal
- Conversion of Ammonia (NH_3) through nitrification.
- Organisms take up to ten times their body weight in Phosphorus in a process called “Luxury Uptake”.

- **Anoxic Zones- Oxygen depletion/except chemically bound**

- Dissolved Oxygen < 0.5 ppm
- Denitrification
- Heterotrophic Facultative Bacteria respire using the oxygen attached to Nitrate
- Nitrate present – bugs at work!

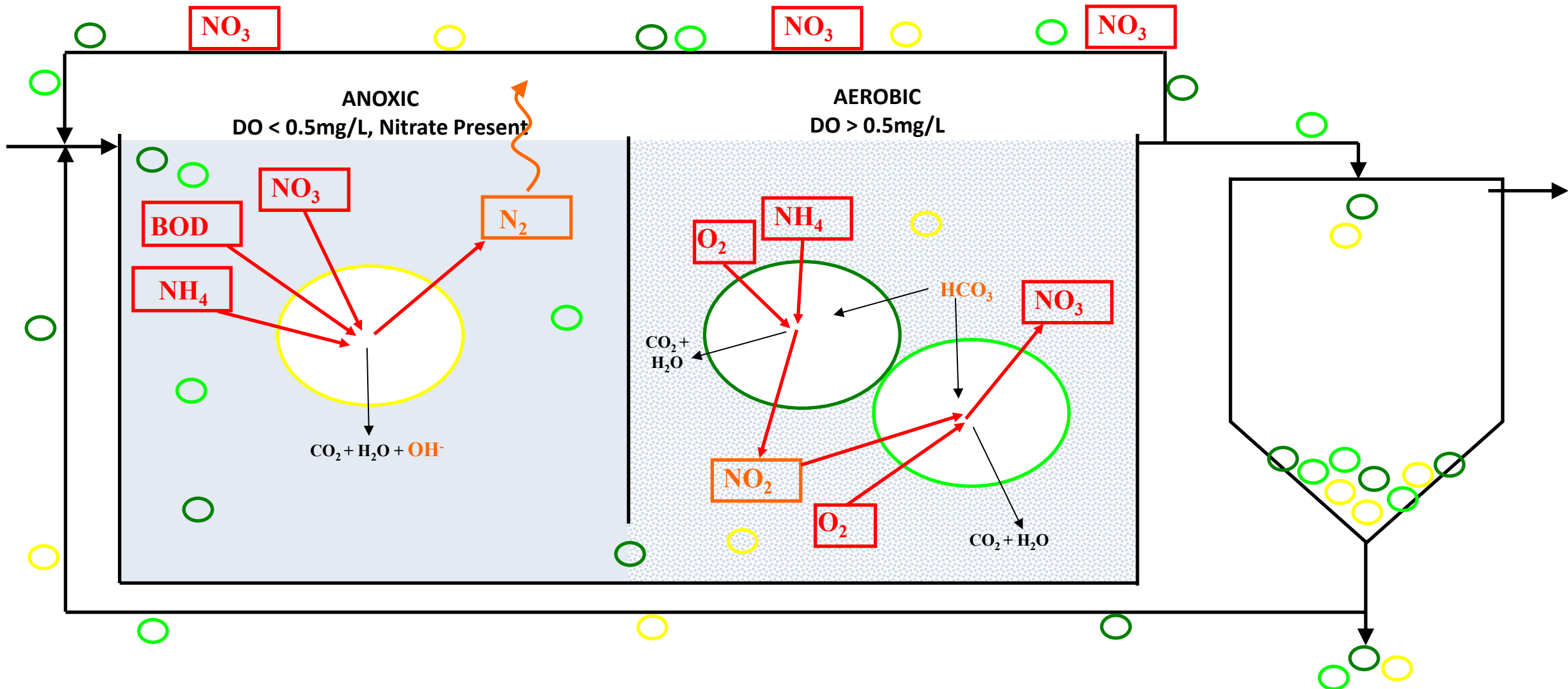
- **Anaerobic Zones- Atmospheric/ Dissolved oxygen not present**

- NO Dissolved Oxygen
- No Nitrate present
- PO_4 release

NITROGEN

BIOLOGICAL N REMOVAL

You can't control bacteria
You can only control their *environment*



SOURCES OF NITROGEN

- Municipal

- Urine
- Fecal Material
- Non-Fecal Organics
 - Meat scraps
 - Vegetable matter

- Industrial

- Animal products
- Plant products
- Chemical Processes
 - Amines
 - Pharmaceuticals

TOTAL NITROGEN REMOVAL INCLUDES TKN AND NITRATE

Total Nitrogen				
		Total Soluble Nitrogen		
		Soluble Kjeldahl Nitrogen		
Organic Nitrogen		Inorganic Nitrogen		
Particulate Organic – N	Soluble Organic - N	Ammonia – N (NH ₃ -N)	Nitrite – N (NO ₂ -N)	Nitrate – N (NO ₃ -N)
Total Kjeldahl Nitrogen			NO _x - N	

NH_4^+ VS $\text{NH}_4\text{-N}$

Sample Results

1.00 mg/L

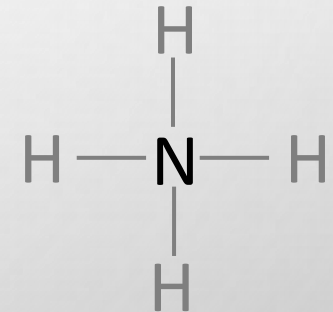
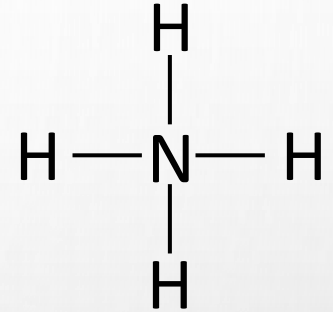
NH_4^+ = "Ammonium"

$$\text{MW} = (1 \times 4) + 14 = 18$$

0.78 mg/L

$\text{NH}_4\text{-N}$ = "Ammonium as Nitrogen"

$$\text{MW} = 14 \quad 14/18 = 0.777$$



NO_3^- VS $\text{NO}_3\text{-N}$

Sample Results

1.00 mg/L

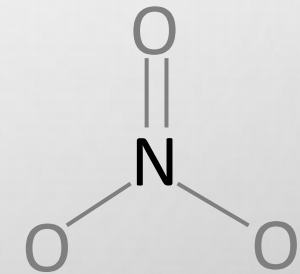
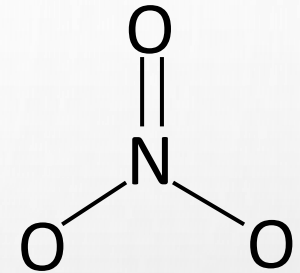
NO_3^- = "Nitrate"

$$\text{MW} = (16 \times 3) + 14 = 62$$

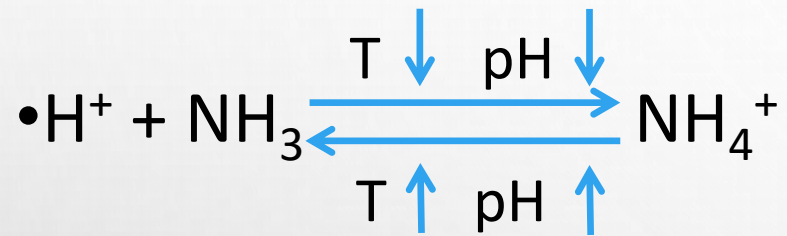
0.23 mg/L

$\text{NO}_3\text{-N}$ = "Nitrate as Nitrogen"

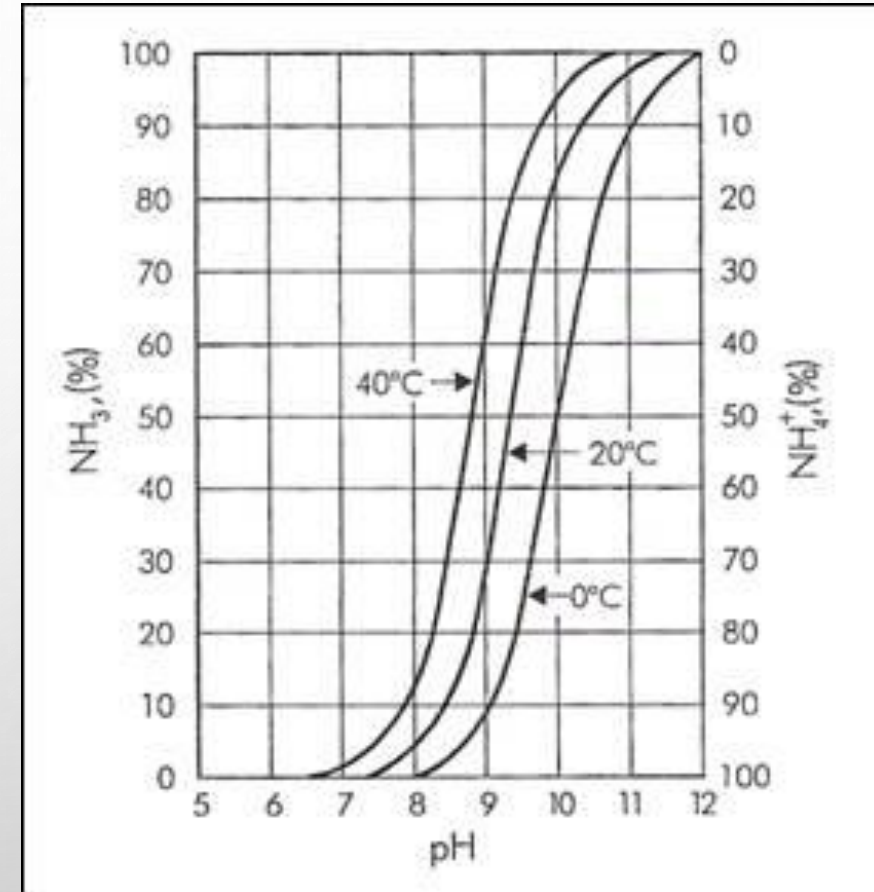
$$\text{MW} = 14 \quad 14/62 = 0.225$$



AMMONIA IONIZATION



- Higher pH produces higher NH_3
- Higher temperature produces higher NH_3
- At 20° C & pH 9.25 = 50% NH_3 & 50% NH_4^+



N CONCENTRATIONS IN WASTES

Raw Municipal Wastewater Nitrogen

Type of Nitrogen in Raw WW	Concentration, mg/L as N
Total	20-85
Organic	8-35
Ammonia	12-50
Oxidized	0-1

• Industrial Wastes

- Refining: 20-60 mg/L NH_3
- Poultry Processing: TKN >100 mg/L
- Other Food Processing: >200 mg/L
- Chemical
 - Very High
 - Very Low
- It depends on the Industry!!

NITROGEN REMOVAL

Nitrification: 2-step process

- Bacteria (*Ammonia oxidizing bacteria* - AOB) convert **ammonia** to **nitrite** with oxygen
- Bacteria (*Nitrite Oxidizing Bacteria* - NOB) convert **nitrite** to **nitrate** with oxygen

Step 1.



Step 2.



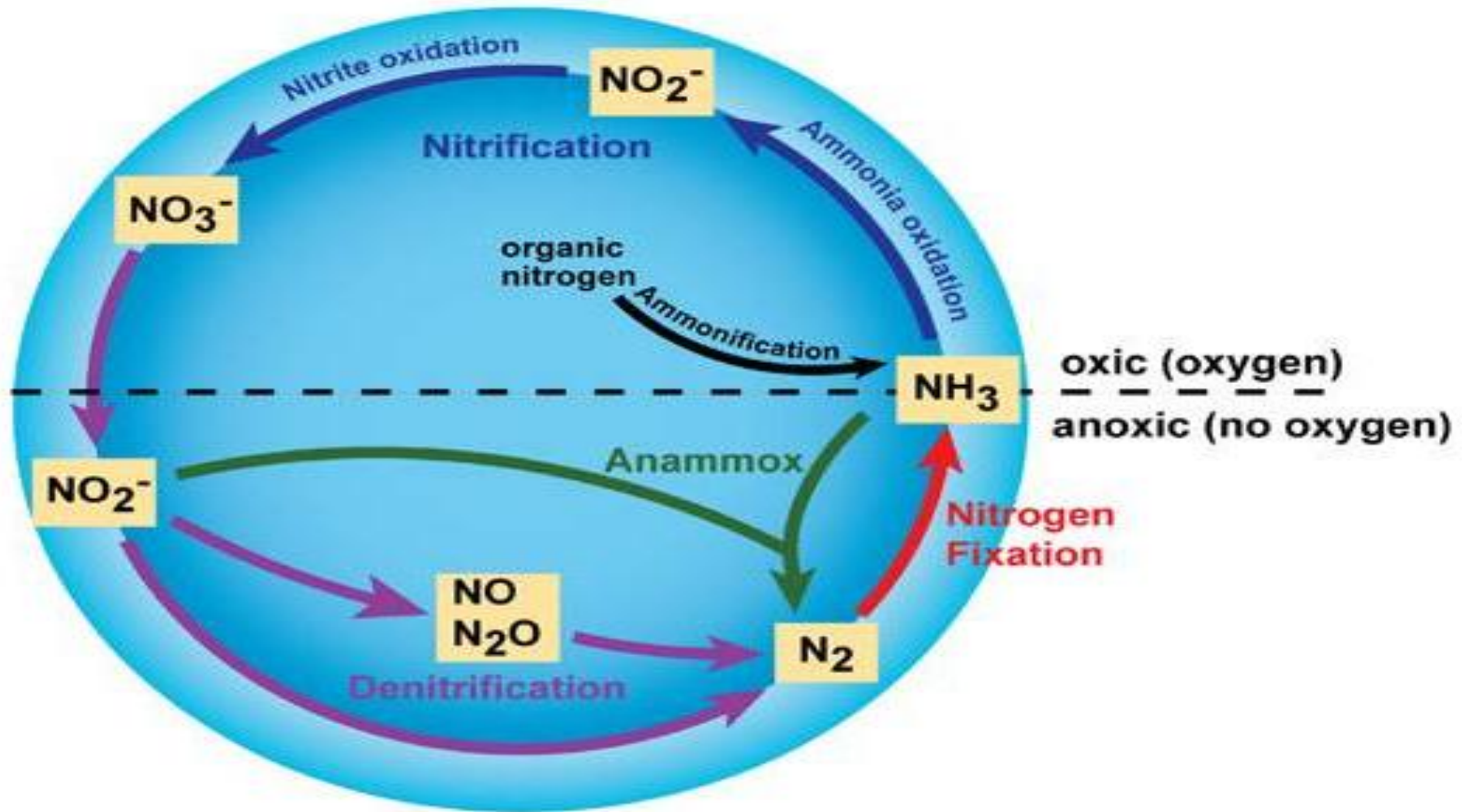
NITROGEN REMOVAL

Denitrification – Under anoxic conditions nitrate is converted to nitrite, and ultimately to nitrogen gas

- Sometimes ends at Nitrous Oxide which is a greenhouse gas



NITROGEN REMOVAL



BIOLOGICAL REMOVAL – NITRIFICATION & DENITRIFICATION

NITRIFICATION

- Chemoautotrophic Bacteria feeding on $\text{NH}_4\text{-N}$ and using O_2 as electron acceptor
- Consumes 4.57 pounds of O_2 & 7.07 pounds of alkalinity per pound of $\text{NH}_3\text{-N}$ oxidized
- Forms 0.15 pounds of new cells per pound of $\text{NH}_3\text{-N}$ oxidized
- Consumes 0.08 pounds of Inorganic carbon per pound of $\text{NH}_3\text{-N}$ oxidized

DENITRIFICATION

- Facultative Heterotrophic Bacteria feeding on carbon and using NO_3 as electron acceptor
- Creates 2.86 pounds of O_2 & 3.57 pounds of alkalinity per pound of $\text{NO}_3\text{-N}$ removed
- Forms 0.30 pounds of new cells per pound of COD consumed
- Requires roughly 4 pounds of BOD per pound of nitrate removed

DISSOLVED OXYGEN IN THE BNR PROCESS

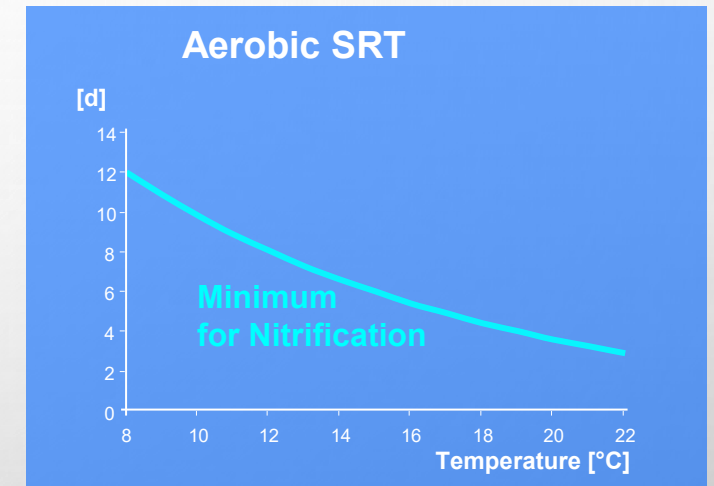
- Nitrification (Aerobic Zone)
 - For every pound of Ammonia oxidized to Nitrate, 4.6 pounds of O_2 are consumed
 - BOD requires ~ 1.2 pound O_2
 - If there isn't enough biomass (solids inventory) in the aeration basin, adding more DO will NOT remove more ammonia
- Nitrification Oxygen Example
 - BOD = 200 mg/L, $NH_3 = 25$ mg/L
 - O_2 for BOD: $200 \times 1.2 = 240$ mg/L
 - O_2 for NH_3 : $25 \times 4.6 = 115$ mg/L
 - Total O_2 required per L: $240 + 115 = 355$ mg/L
 - Total O_2 for Nitrification: $115/355 = 32\%$
 - Increase from Nitrification: $(355/240) - 100\% = 48\%$

DISSOLVED OXYGEN IN THE BNR PROCESS

- Nitrification is an aerobic process & dissolved O_2 is required
- Nitrifiers do not compete as well for oxygen as heterotrophic bacteria
- If not enough oxygen is present, or large COD loads, the heterotrophs may get most of it first
- COD/TKN Ratio above 10 have been shown to inhibit nitrification

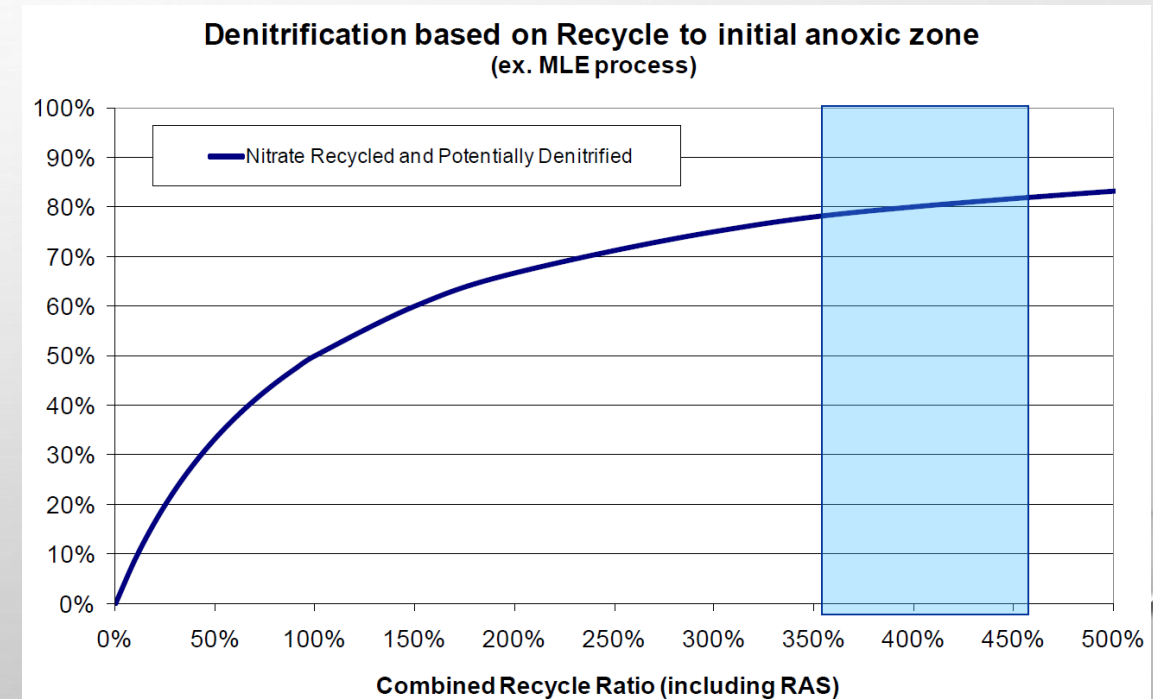
PROCESS CHARACTERISTICS THAT CAN IMPACT NITRIFICATION

- MCRT (sludge Age)
 - Generally an MCRT of >5 days is needed for stable nitrification
- Temperature: Warmer is better
 - Optimal 77-86° F
 - No activity < 39° F
 - For every 10° C decrease, you need 2x as many bugs
- pH: 7.5 – 8.0 (optimal)
 - If less than 6.5 nitrification ceases – or does it???
- Alkalinity: 50 mg/L needs to be maintained
 - To remove 1g of $\text{NH}_4\text{-N}$, need 7.07g Alkalinity
- D.O. levels are specific to the plant, load, and season
- Inhibitory Substances
 - Heavy metals
 - Quaternary Ammonium Compounds (e.g. excess polymer)
 - Solvents
 - Root Killer
 - ...

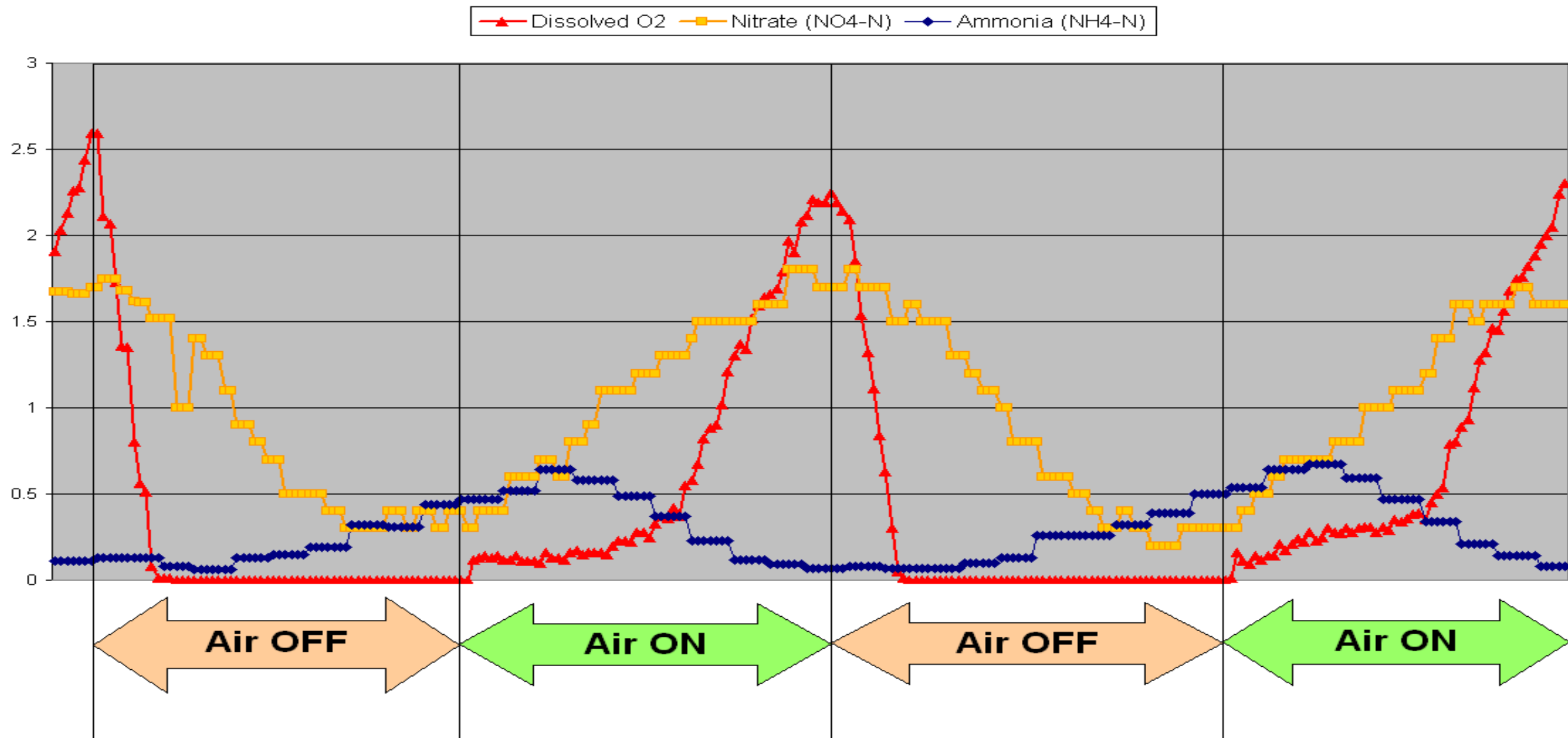


PROCESS CHARACTERISTICS THAT CAN IMPACT DENITRIFICATION

- DO
 - Oxygen in the recycle or RAS can inhibit denitrification
 - Bacteria would prefer to use O_2 – we force them to use NO_3
- Readily Biodegradable COD (rbCOD)
 - Food source – can be limiting in cold weather or low load situations
 - Supplemental Carbon sources:
 - Methanol
 - Brewery Waste
 - Glycerol
 - MicroC
 - Bug Fuel
- Internal Recirculation Flow Rate for preanoxic
 - Typically between 2-4Q
- Temperature: Warmer is better
 - Optimal 77-86° F
 - For every 10° C decrease, you need 2x as many bugs
- pH: 7.5 – 8.0 (optimal)
- Inhibitory Substances



DO, Ammonia & Nitrate in an "On-Off" Aeration Basin



BOD (OR COD) IN THE BNR PROCESS

- DENITRIFICATION REQUIRES ENOUGH CARBON

Efficiency	BOD : NH ₃	BOD : TKN
Low	>4	<2.5
Moderate	4-6	2.5-3.5
High	>8	>5

- PHOSPHORUS RELEASE REQUIRES CARBON

Efficiency	BOD : P	COD : P
Low	15-20	26-34
Moderate	20-25	34-43
High	> 25	> 43

ALKALINITY IN THE BNR PROCESS

- Nitrification:
 - For every pound of Ammonia oxidized to Nitrate, ~7.1 pounds (as CaCO_3) is consumed
- Denitrification
 - ~3.0 – 3.6 pounds (as CaCO_3) is produced per pound of Nitrate is converted
- Chemical P removal
 - Up to 1.0 pound (as CaCO_3) is consumed per 1 pound of metal salt added

Complete BNR consumes at least
60% of Alkalinity

Effluent value > 80 mg/L desired
Loss of buffering impacts pH

ALKALINITY IN THE BNR PROCESS

- pH vs Alkalinity
 - pH is a measure of the hydrogen ion concentration
 - Alkalinity is a measure of a water's ability to neutralize acid
 - Water with high alkalinity will always have elevated pH, but water with elevated pH does not always have a high alkalinity
 - BOTH measurements are needed!!!

ALKALINITY IN THE BNR PROCESS

- Why low Alkalinity affects Nitrifiers
 - pH
 - Alkalinity neutralizes acids
 - Inadequate alkalinity results in low pH
 - Carbon Source
 - Nitrifiers can't use organic compounds for synthesis & growth (autotrophs)
 - Bicarbonate/carbonate alkalinity may satisfy their need for an inorganic carbon source

OXIDATION REDUCTION POTENTIAL (ORP) IN THE BIOLOGICAL NUTRIENT PROCESS

Why not DO?

- What does a DO probe read in an Anoxic or Anaerobic zone?
- DO cannot measure the RATE of Nitrification, Denitrification, Bio-P, etc.

Measured in positive or negative millivolts

- Electron donors have a more negative redox potential
- Electron acceptors have a more positive redox potential

Can be affected by conditions other than microbial metabolism:

- pH changes
- High ionic strength wastes

Why is oxidation reduction potential important to BNR?

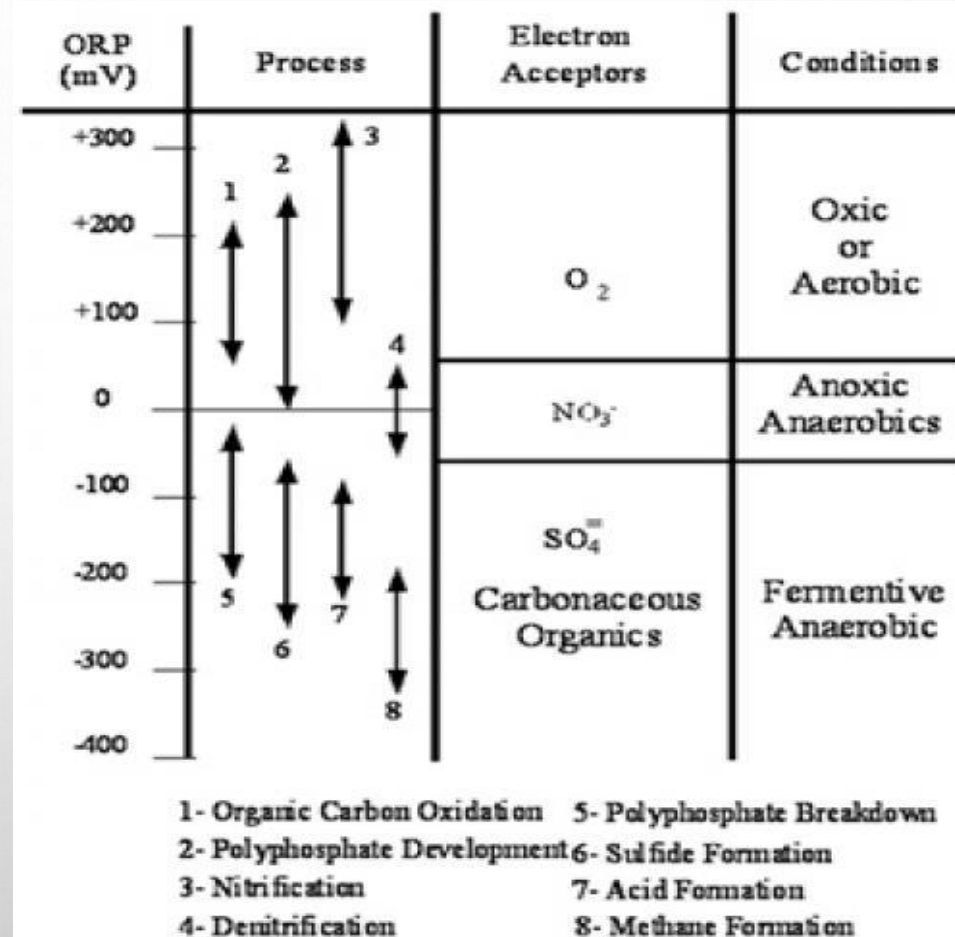
- ORP is a crystal ball: allowing operators to see what is happening in the system
- BNR microorganisms require certain environmental conditions that are best measured through ORP
- ORP is not an exact science – “Close Enough” is good enough
- ORP can be correlated to other parameters

ORP RANGES IN OPERATIONS

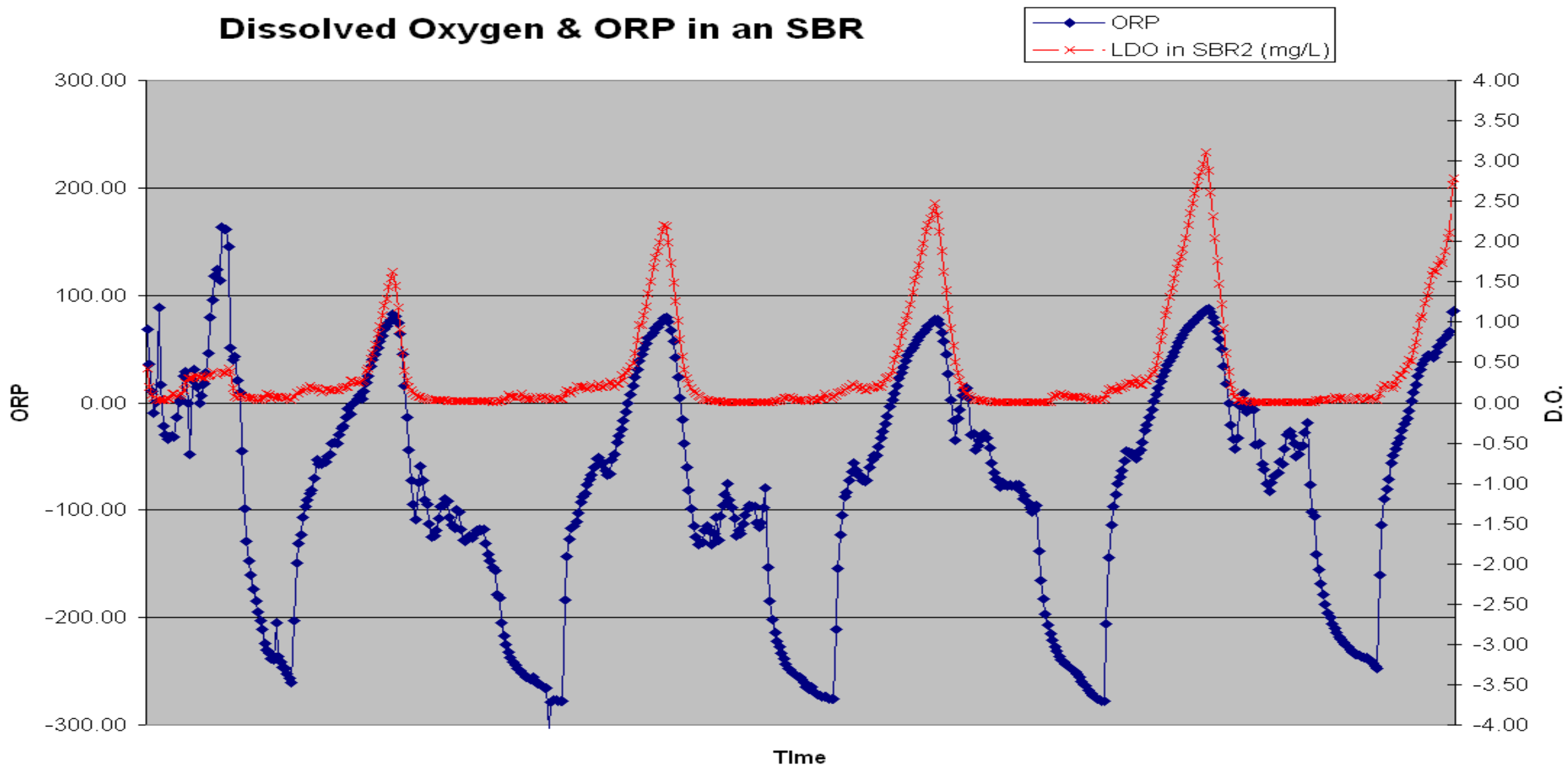
<u>Bioactivity</u>	<u>Range (mV)</u>
cBOD Oxidation	+50 to +200
Nitrification	+100 to +350*
Denitrification	-100 to +100*
Biological P release	-100 to -225*
Sulfide Formation	-50 to -250
Acid Formation	-40 to -200

* WEF MOP 21, 2013

Goronszy ORP scale



Dissolved Oxygen & ORP in an SBR

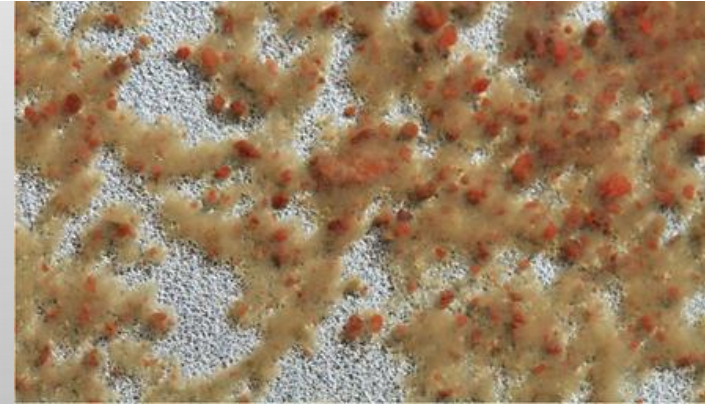
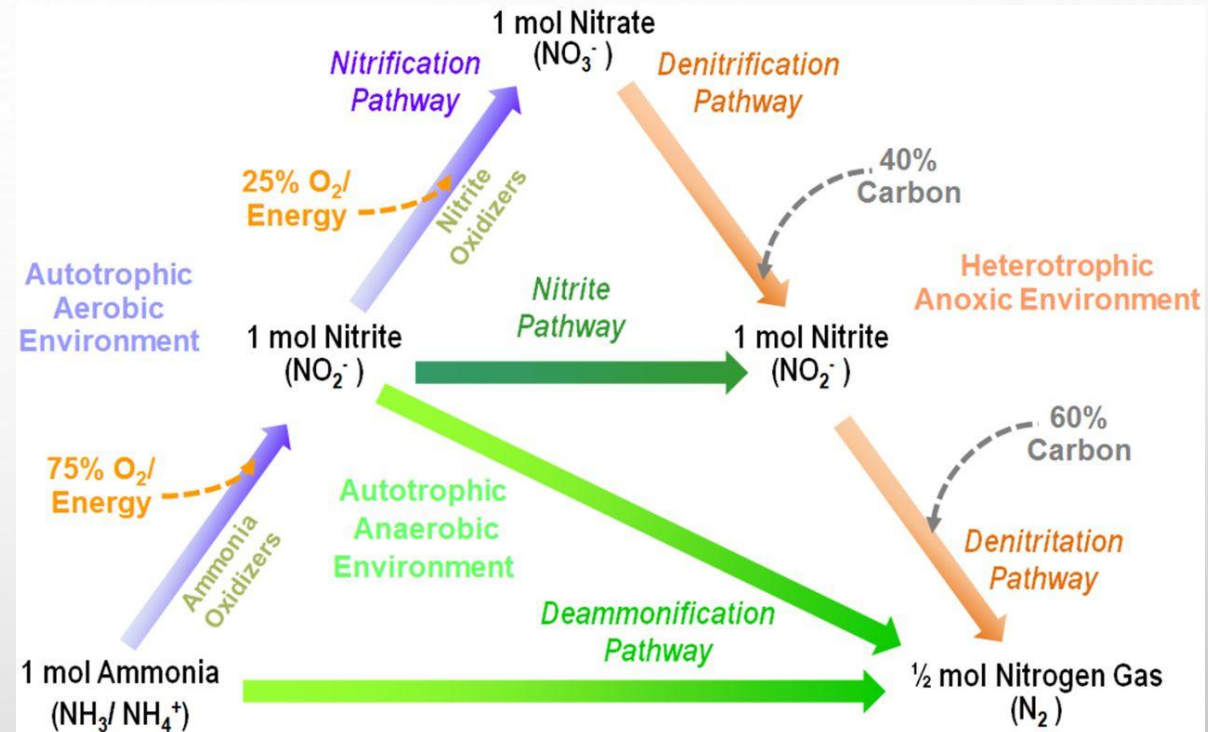


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- The diagram illustrates a wastewater treatment process. At the top, a grey arrow labeled "Air" points down into a vertical pipe that leads to a rectangular aeration tank. Inside this tank, a blue arrow labeled NH_4 points up, and a yellow arrow labeled NO_3 points down. The tank is divided into two horizontal zones: a top blue zone labeled "aerobic" and a bottom yellow zone labeled "anoxic". A dashed line connects the two zones. Below the aeration tank is a large, horizontal, orange-colored oval representing a clarifier. Three colored circles (blue, brown, and red) are positioned above the clarifier, labeled O_2 , $\text{NO}_3\text{-N}$, and $\text{NH}_4\text{-N}$ respectively. Arrows indicate the flow of these substances into the clarifier. The clarifier has a central horizontal line with arrows pointing in both directions, and two sets of horizontal bars (one on the left and one on the right) representing sludge collection. A grey pipe with two valves leads from the clarifier back up to the aeration tank. On the far left, a red circle and a blue circle are shown. On the far right, a grey arrow points out of the clarifier.

DEAMMONIFICATION

ANAEROBIC AMMONIA OXIDATION

- Method of treating high strength side streams
 - In development for mainstream
- Anammox bacteria are slow growing granules
- Can be suspended or attached growth
- On/Off aeration process required to create a little nitrite for the anammox bacteria
- 40% oxygen savings compared to traditional nitrification



ONLINE INSTRUMENT TOOLBOX



Ammonia Analyzer



Ammonium Probe



DO Probe



pH or ORP Probe



Nitrate Probe



TSS Probe

TAKE HOME MESSAGES

- Nitrification is sensitive – Aerobic SRT, DO, alkalinity, toxins can all cause problems
- If lost, nitrification can take several days to recover
- Denitrification requires “candy carbon” and an anoxic environment – keep the DO out!
- Avoid nitrite lock at all costs
- Control the environment, and you control the Microbes
- Make sure the environment is monitored!!

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