Solving the Nitrogen Problem

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Our Presenter

David Lepre

David Lepre, P.E., is a Sales Engineer at Orenco Systems® Inc., a wastewater equipment manufacturing firm based in Sutherlin, Oregon. In this role, he provides engineering assistance to commercial and municipal designers and engineers throughout his region. David came to Orenco in 2007 with a strong background as a consulting engineer. He previously designed wastewater and stormwater systems for Otak, a multidisciplinary engineering firm. Since joining Orenco, he has specialized in assisting in the design of liquid only sewers and treatment systems requiring nutrient reduction.

David has a Bachelor of Science degree in civil engineering from the Oregon Institute of Technology and is licensed as a Professional Engineer in Oregon. In his spare time, he enjoys spending time with his family and coaching his sons in sports.

Overview

- Why is nitrogen a problem?
- Why use a packed bed filter for nitrogen removal in wastewater?
- How does the nitrogen cycle work?
- What factors effect nitrogen treatment?
- How do I set up a packed bed filter to effectively treat nitrogen?

Nitrogen

- Nitrogen (N_2) is a colorless, tasteless, and generally inert gas
- Air, by volume, is composed of about 78.08% nitrogen
- Nitrogen is assimilated from the air in living things

Nitrogen Regulations

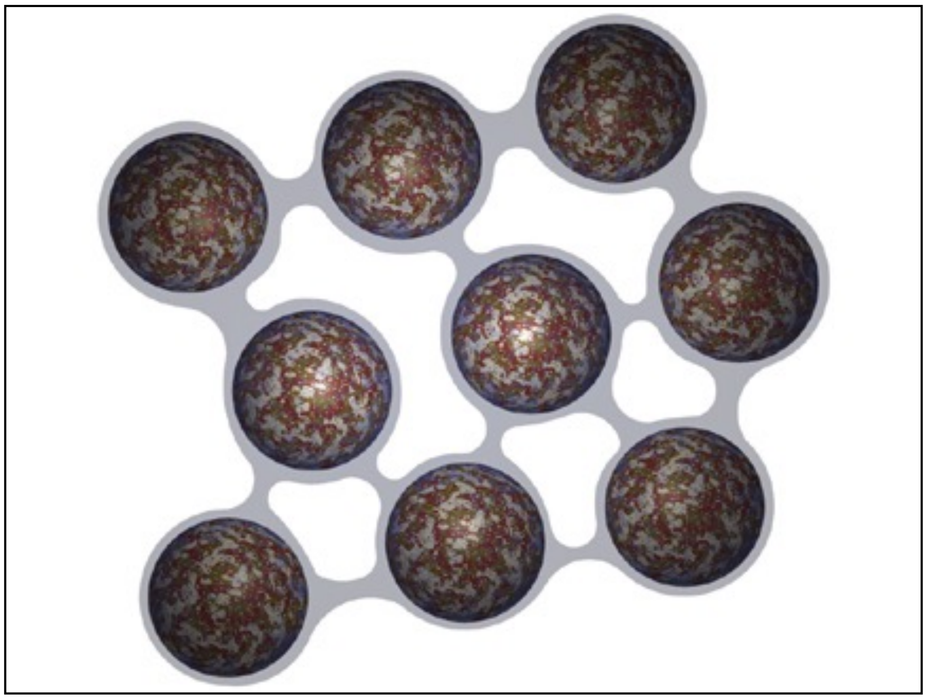
- Toxicity
- Eutrophication
- Drinking Water Standards

Introduction to the Packed Bed Filter (PBF)

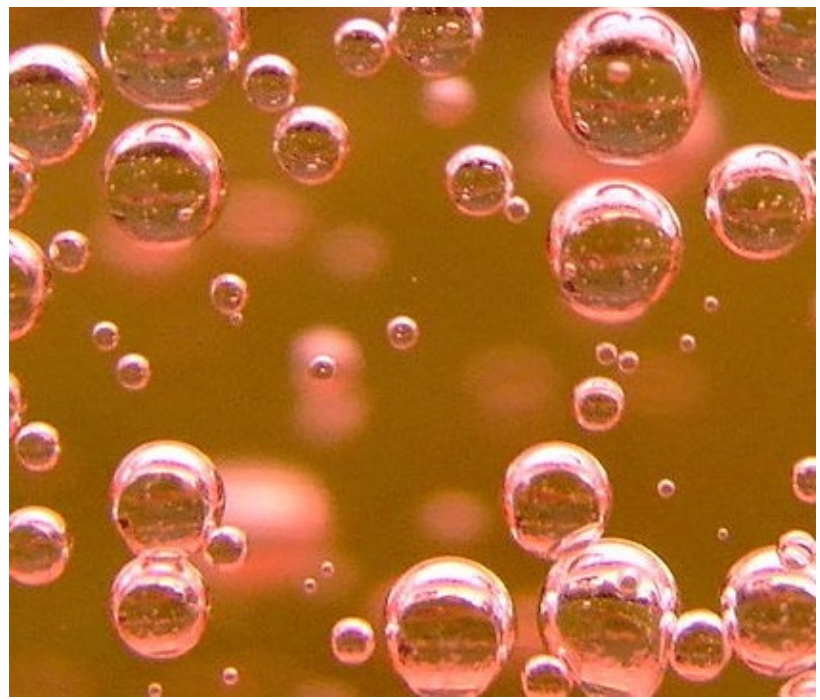
PBF designs have been used for decades to reduce nitrogen in wastewater systems from individual homes to large commercial systems

Two General Types of Treatment:
Suspended and Attached Growth

Attached growth



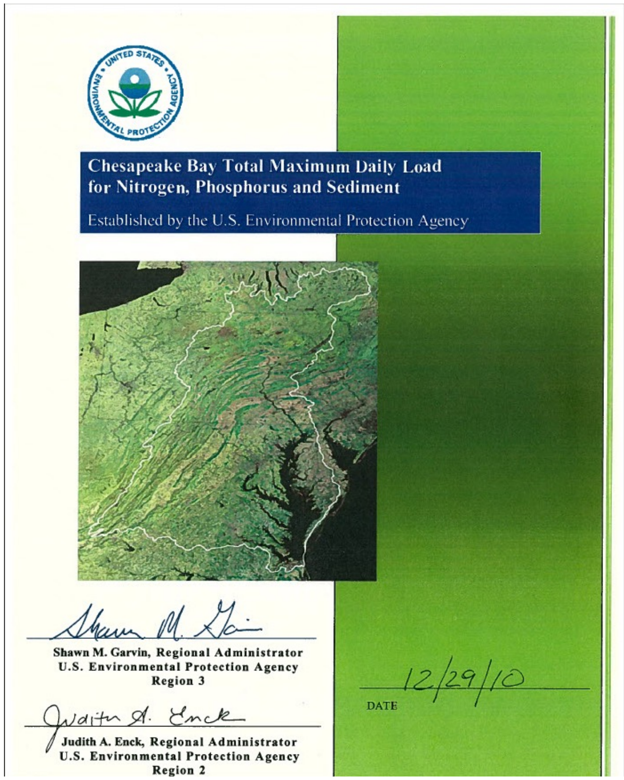
Suspended growth



Maryland Bay Restoration Fund Study

- In 2009 President Obama issued an executive order to clean up the Chesapeake Bay

- Each state (7 total) contributing to the eutrophication of Chesapeake Bay, with the help of the EPA, put together Watershed Implementation Plans (WIPs)



- Maryland, which collects a tax to publicly fund decentralized treatment systems, put together a testing program for various wastewater systems

Maryland Bay Restoration Fund Study

- Maryland's third-party "Best Available Technology" field-testing requirement for nitrogen: https://mde.maryland.gov/programs/water/BayRestorationFund/OnsiteDisposalSystems/Documents/BAT%20Ranking%20Document.pdf
- Matrix shows cost/pound of TN removed, electrical consumption, etc…
- PBFs were consistently ranked as the most cost effective technology

Comparing Treatment Performance (2021)

Vendor In Descending Order	Mean % Reduction TN (Using 60 mg/L Influent)	Mean Effluent Concentration (mg/L)
Fuji Clean CEN 5	77%	14.1
Fuji Clean CEN 7	77%	14.1
AdvanTex AX20RT	76%	14
AdvanTex AX20	71%	17
SeptiTech M40D	67%	20
Hoot BNR	64%	21
RetroFast	57%	25
Singulair TNT	55%	27
Singulair Green	55%	27

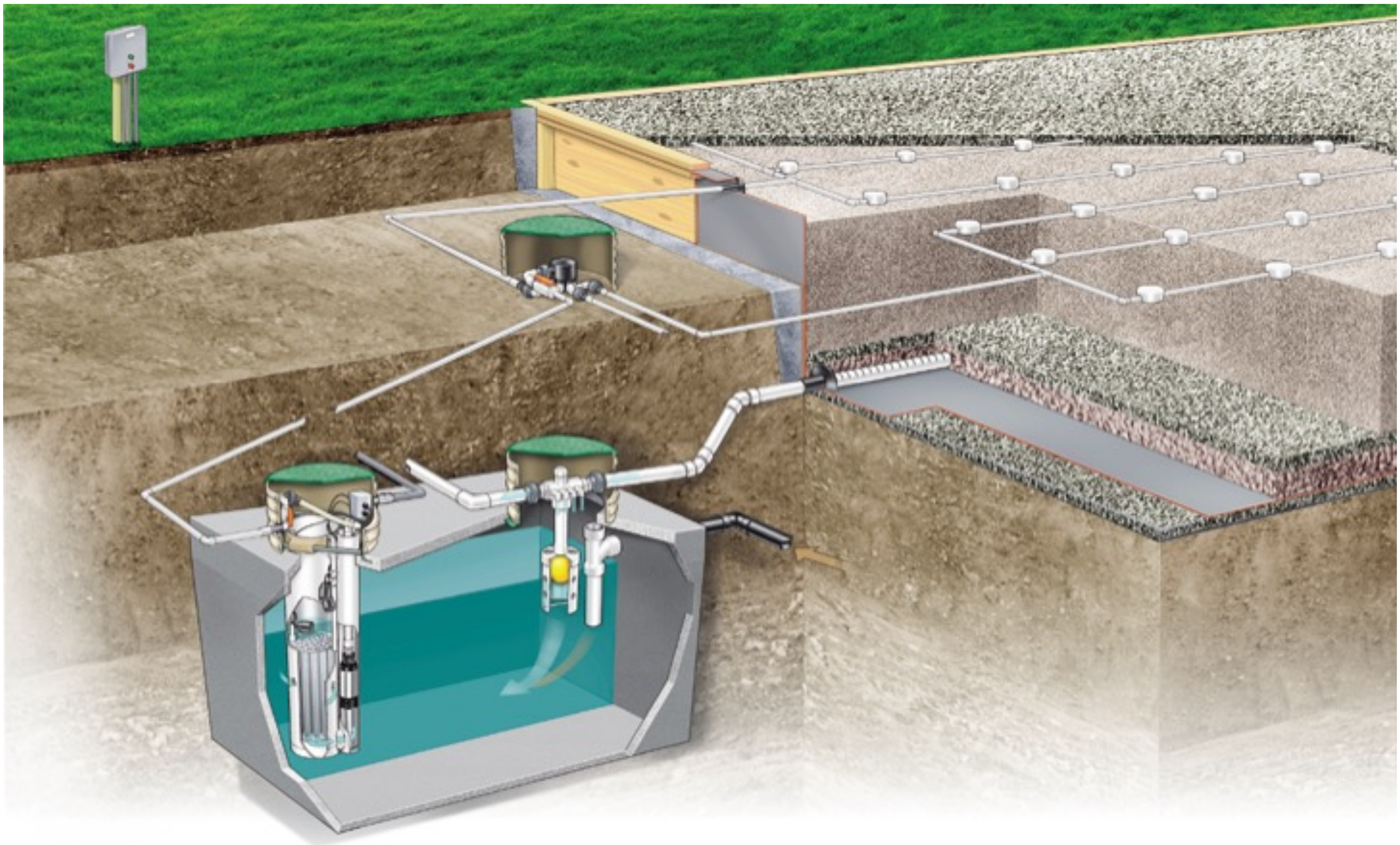
Comparing Treatment Performance (2021)

Vendor In Ascending Order	Price Per Pound of N Reduced
Fuji Clean CEN 5	$79.41
Fuji Clean CEN 7	$91.03
AdvanTex AX20	$109.19
Singulair TNT	$110.31
Singulair Green	$111.49
RetroFast	$113.94
AdvanTex AX20RT	$115.91
SeptiTech M40D	$124.16

Comparing Treatment Performance (2021)

Vendor In Ascending Order	1 Year Electrical Consumption (represented as kWh/ year)	Increased Electrical Costs Per Year Assuming $0.14 Per kWh
AdvanTex AX20RT	210.2	$29.43
AdvanTex AX20	210.2	$29.43
Fuji Clean CEN 5	446.7	$41.82
Fuji Clean CEN 7	648.2	90.75
Hoot BNR	765.77	$107.21
Singulair TNT	979.66	$137.15
Singulair Green	979.66	$137.15
RetroFast	1401.6	$196.22
SeptiTech M400D	1741.05	$243.75

Typical PBF Recirculation Configuration

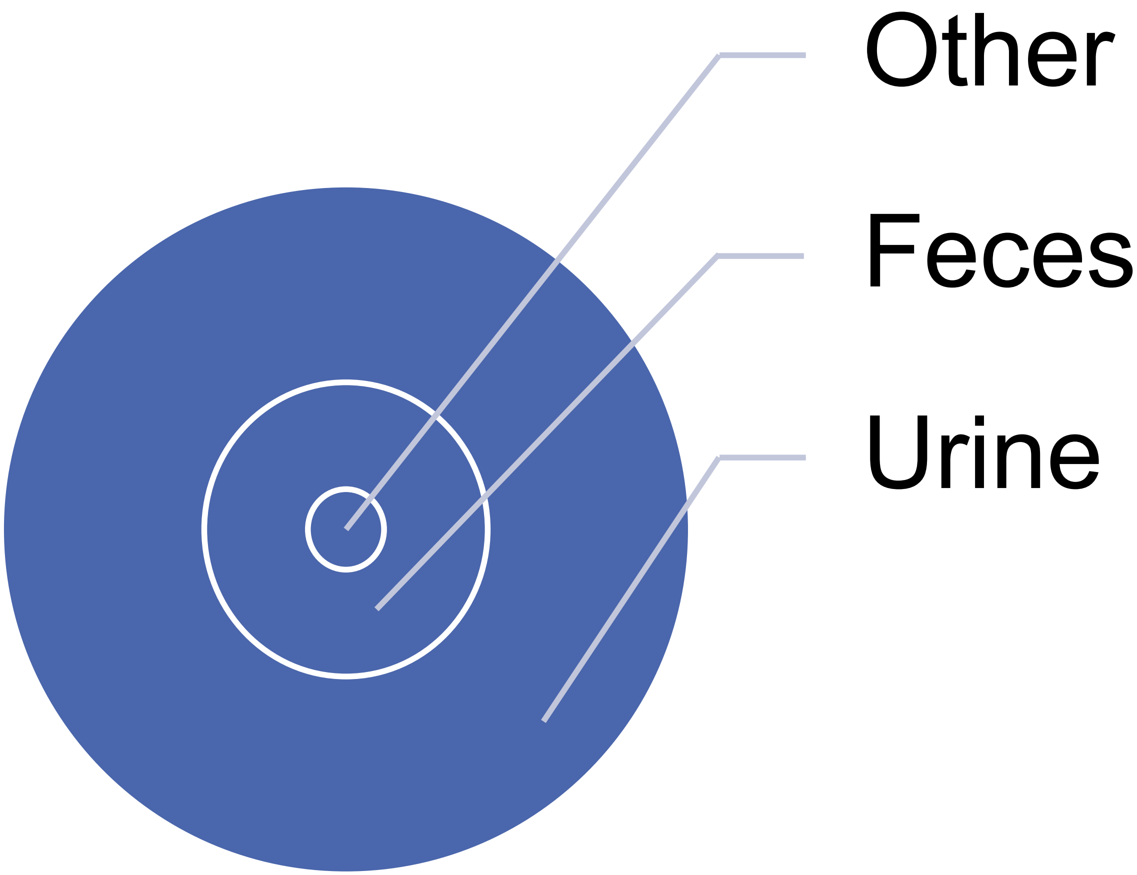


Effective Design of the PBF

Nitrogen in Wastewater

Contribution percentages for domestic waste

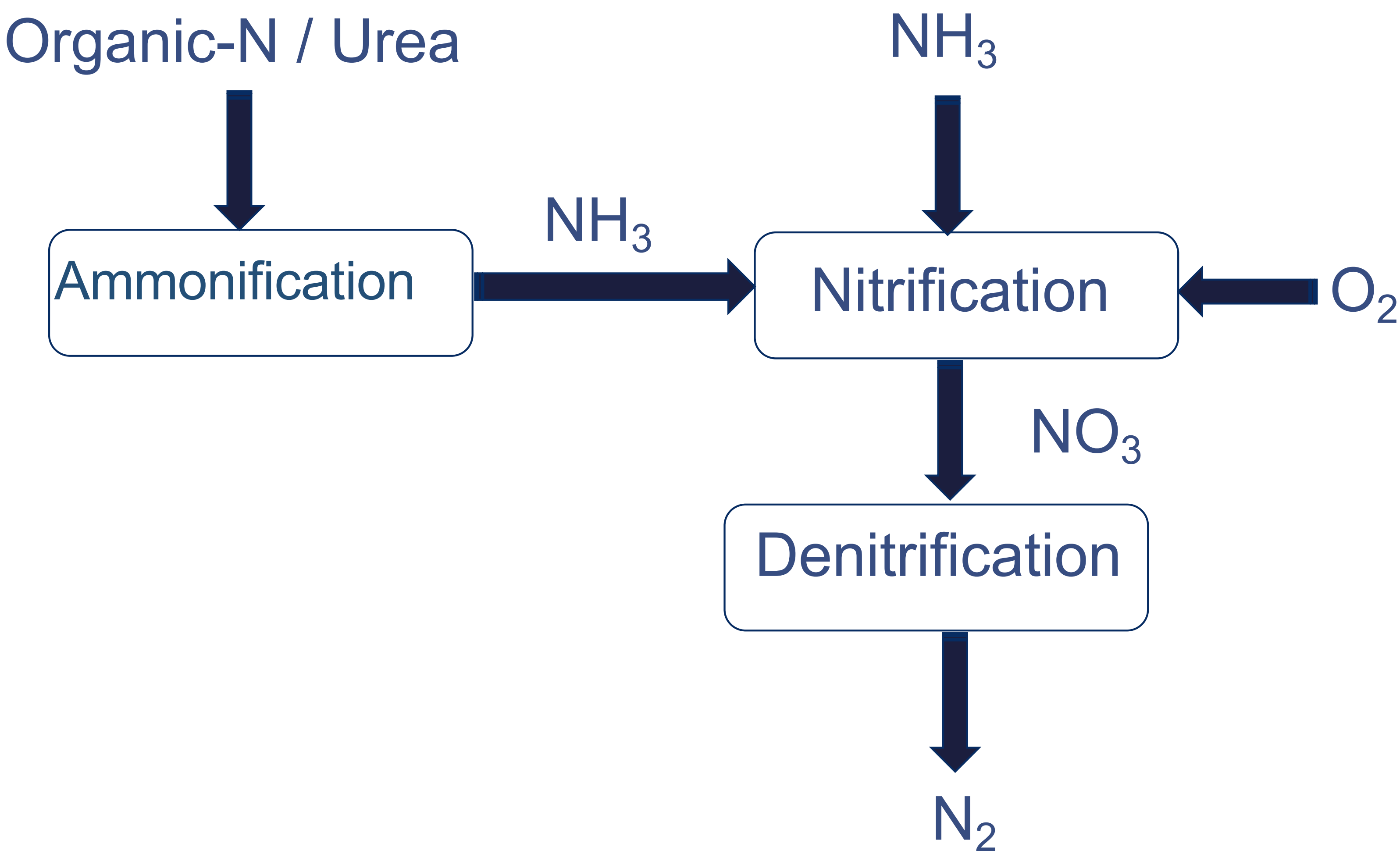
- 75% from urine
- 20% from feces
- 5% from other agents



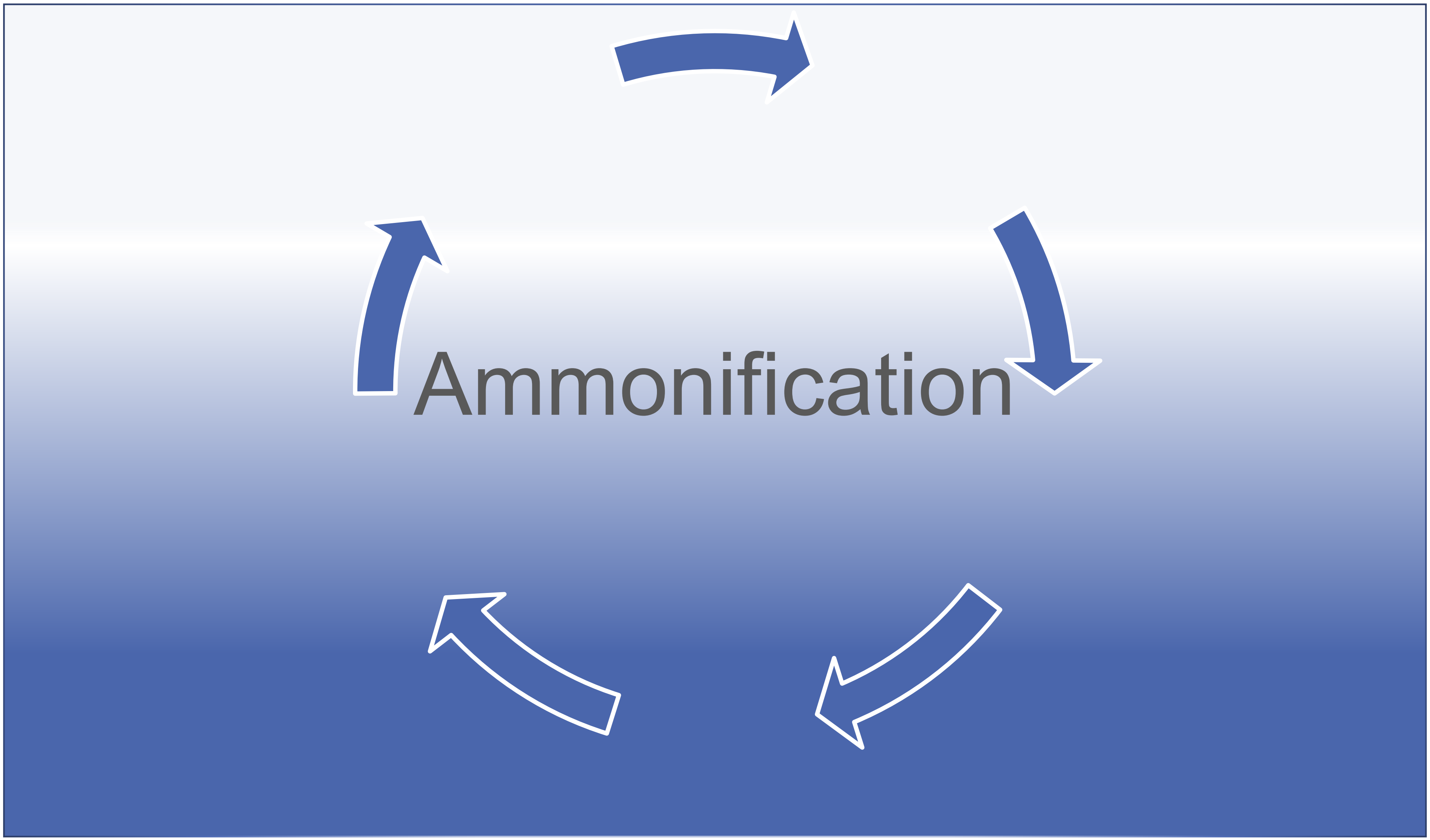
Nitrogen in Wastewater

- Organic nitrogen … Organic-N
- Ammonium nitrogen … NH_4-N
- Ammonia nitrogen … NH_3-N (un-ionized)
- Nitrite nitrogen … NO_2-N
- Nitrate nitrogen … NO_3-N

Ideal Nitrogen Treatment Process



Ammonification



Nitrification

Ammonium → Nitrite → Nitrate

Step 1

Step 2

Nitrification

In the first phase, ammonium oxidizing autotrophic bacteria known as nitrosomonas convert ammonium to nitrite

$$2NH_4^+ + 30_2 \xrightarrow{\text{nitrosomonas}} 2NO_2^- + 4H^+ + 2H_2O.$$

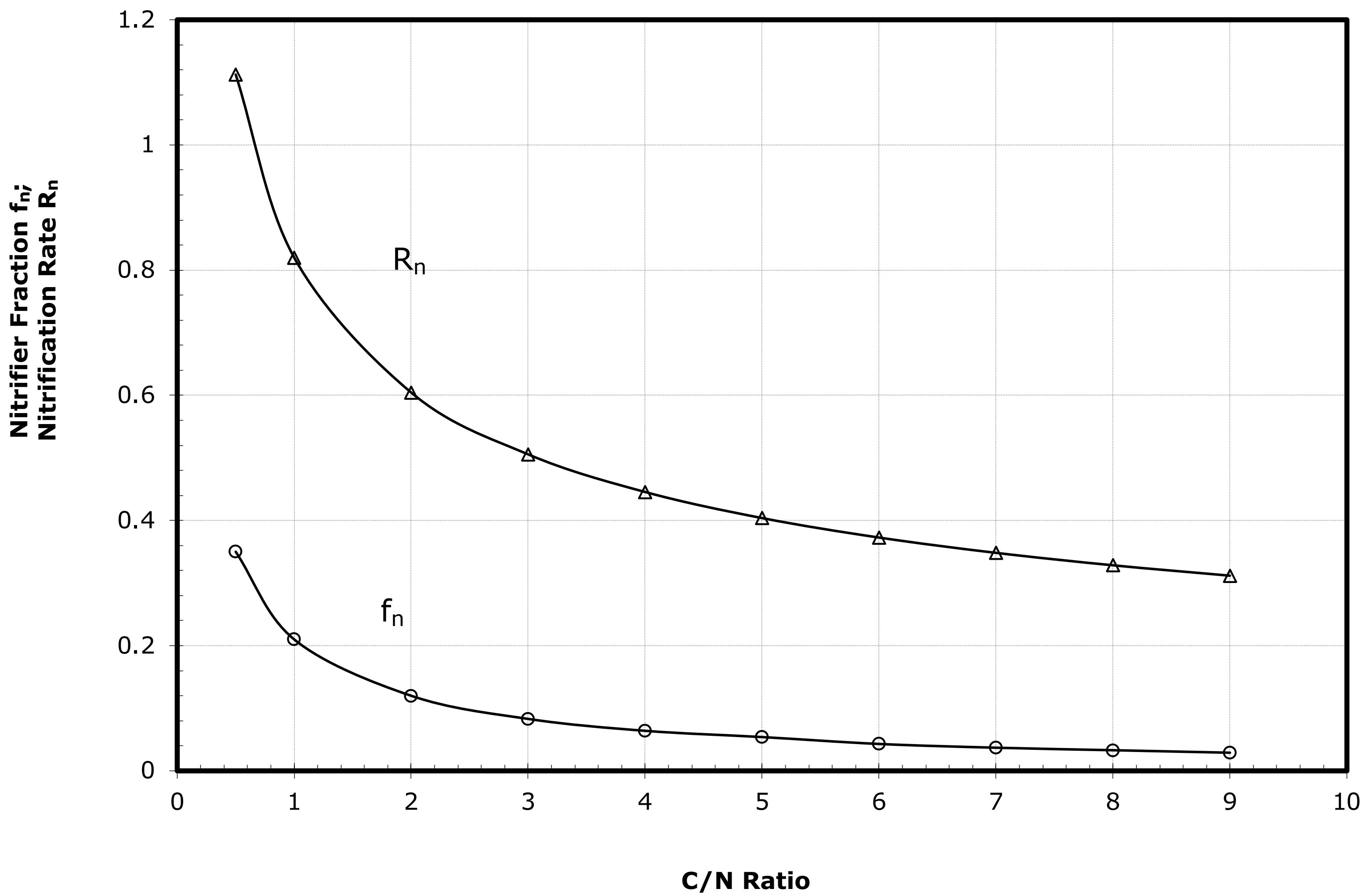
In the second phase of nitrification, a nitrite-oxidizing bacteria known as nitrobactor converts nitrite to nitrate

$$2NO_2^- + 0_2 \xrightarrow{\text{nitrobactor}} 2NO_3^-$$

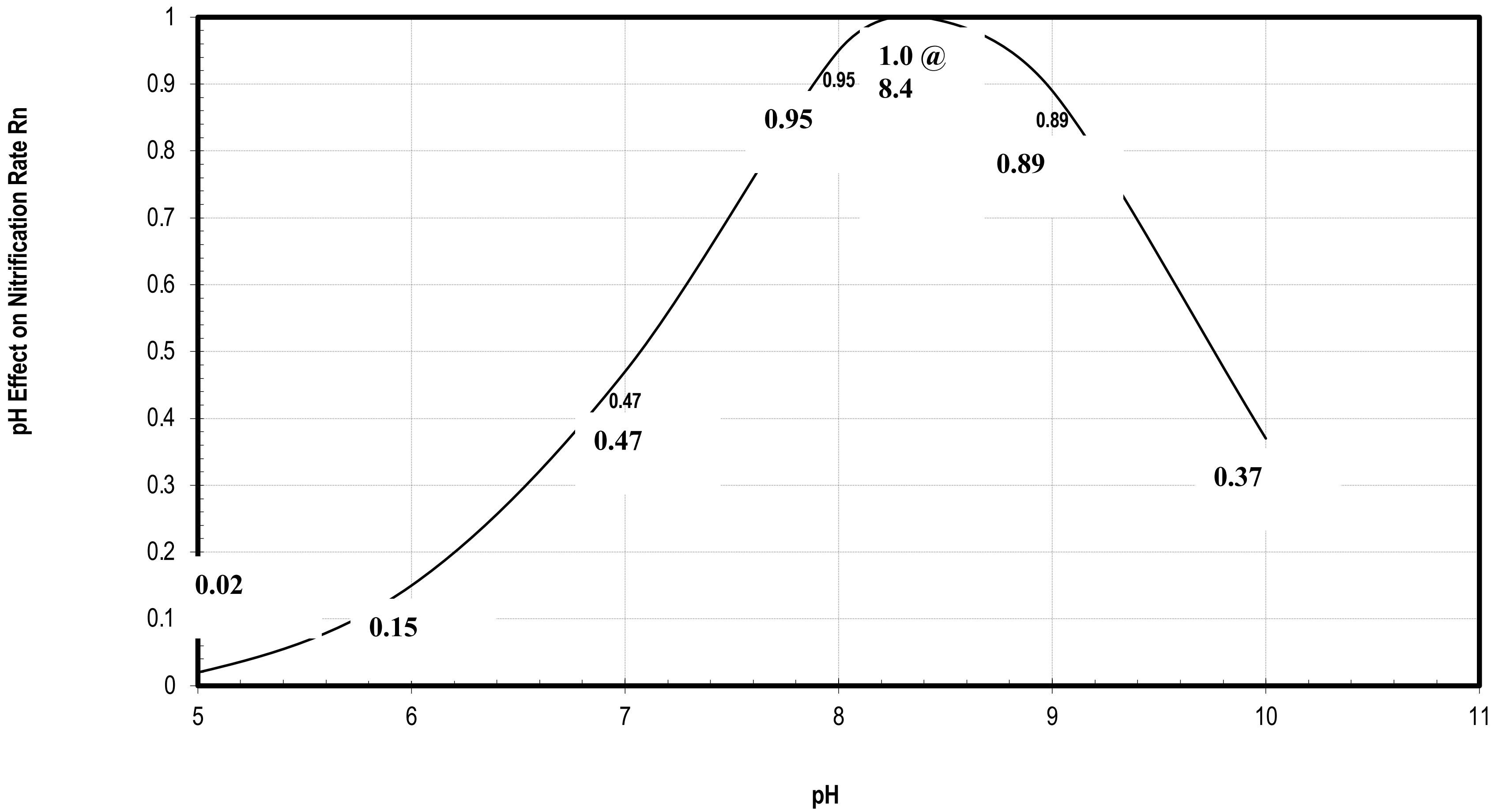
Nitrification … What’ s Needed

- Adequate aeration volume
- Sufficient aeration capacity
- Sufficient alkalinity/pH,
- No significant toxicity
- Temperature

Nitrification Reaction Rate vs BOD/TKN



pH Effect on Nitrification



Alkalinity Demand & Need

Used to determine how much supplemental alkalinity is needed

Equation B3

$$\text{Alkalinity Demand} = \text{TKN}_i \text{ mg/L x } \frac{5 \text{ mg/L Alkalinity}}{1 \text{ mg/L TKN}}$$

Equation B4

$$\text{Alkalinity Need} = \text{Alk Demand} + \text{Target Residual Alk} - \text{Influent Alk}$$

Example

PTE values of 80 mg/L TKN and 160 mg/L Alkalinity in waste stream
Target residual of 100 mg/L alkalinity
Determine the amount of alkalinity required to buffer the treatment process

Solving for Equation B3:

$$Alkalinity\ Demand = 80\ mg/L\ x\ \frac{5\ mg/L\ Alkalinity}{1\ mg/L\ TKN} = 400\ mg/L\ Alkalinity$$

Now solving for Equation B4:

$$Alkalinity\ Need = 400\ mg/L + 100\ mg/L - 160\ mg/L = 340\ mg/L$$

Therefore the system will require supplemental alkalinity addition to buffer the treatment process.

Nitrogen Considerations

- Typical forms of alkalinity
  - ~ Soda ash (sodium carbonate)
  - ~ Magnesium hydroxide
  - ~ Quicklime

Denitrification

- Denitrification is the microbial utilization of nitrate under anoxic conditions. (DO < 0.3 mg/L is preferred)

- Denitrification is a multi-stage process where nitrate (NO_3^-) is reduced to nitrogen gas (N_2), which is liberated back into the atmosphere after rising to the liquid surface in tiny bubbles.

Denitrification

Anoxic denitrification conversion in wastewater can be expressed by the following reaction:

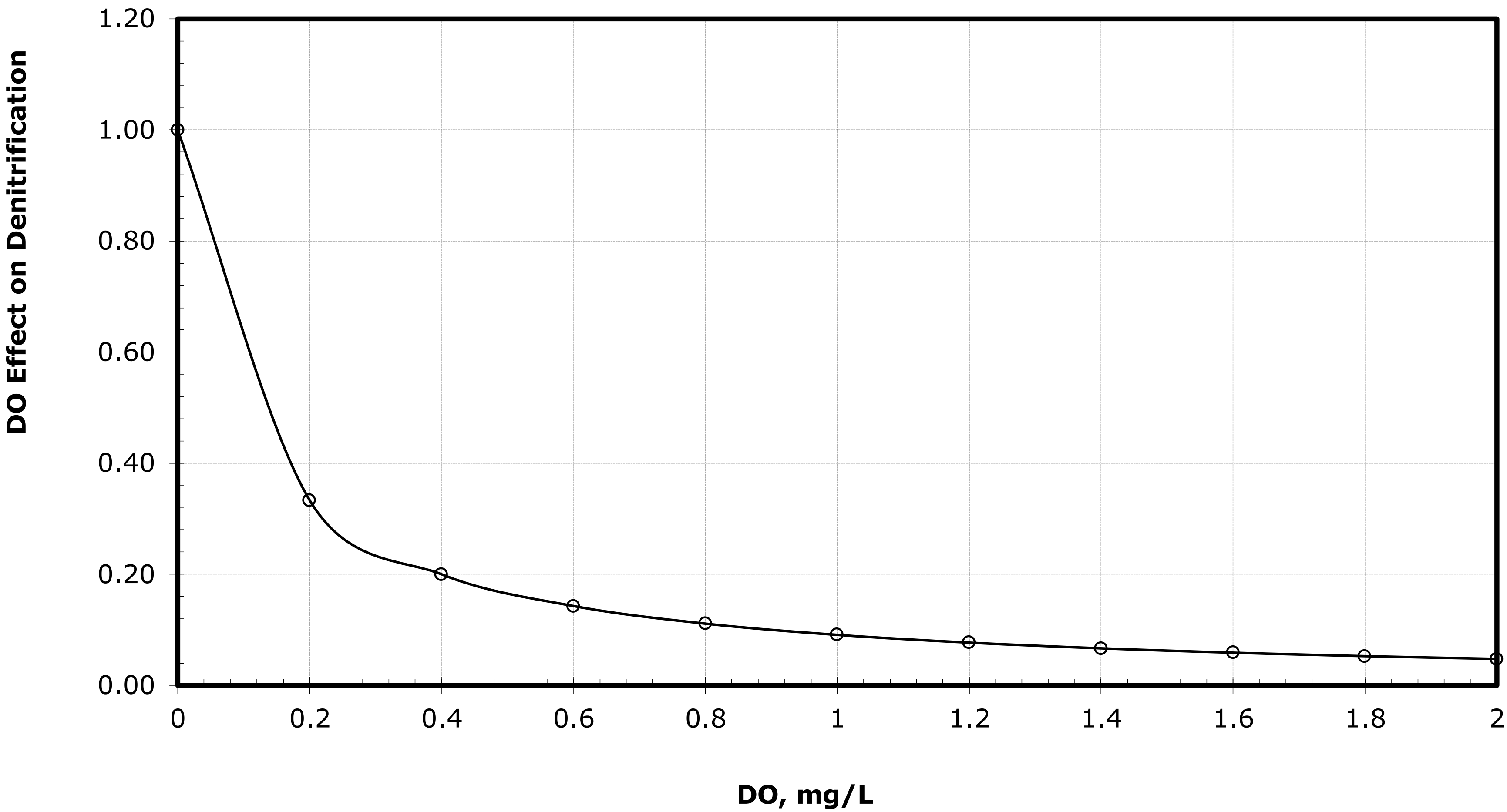
$$C_{10}H_{19}O_3N + 10NO_3^- \xrightarrow{\text{pseudomonas}} 5N_2^- + 3H_2O + 10CO_2 + 10OH^- + NH_3$$

Microbial denitrification consumes 4 mg carbon for each mg nitrate utilized

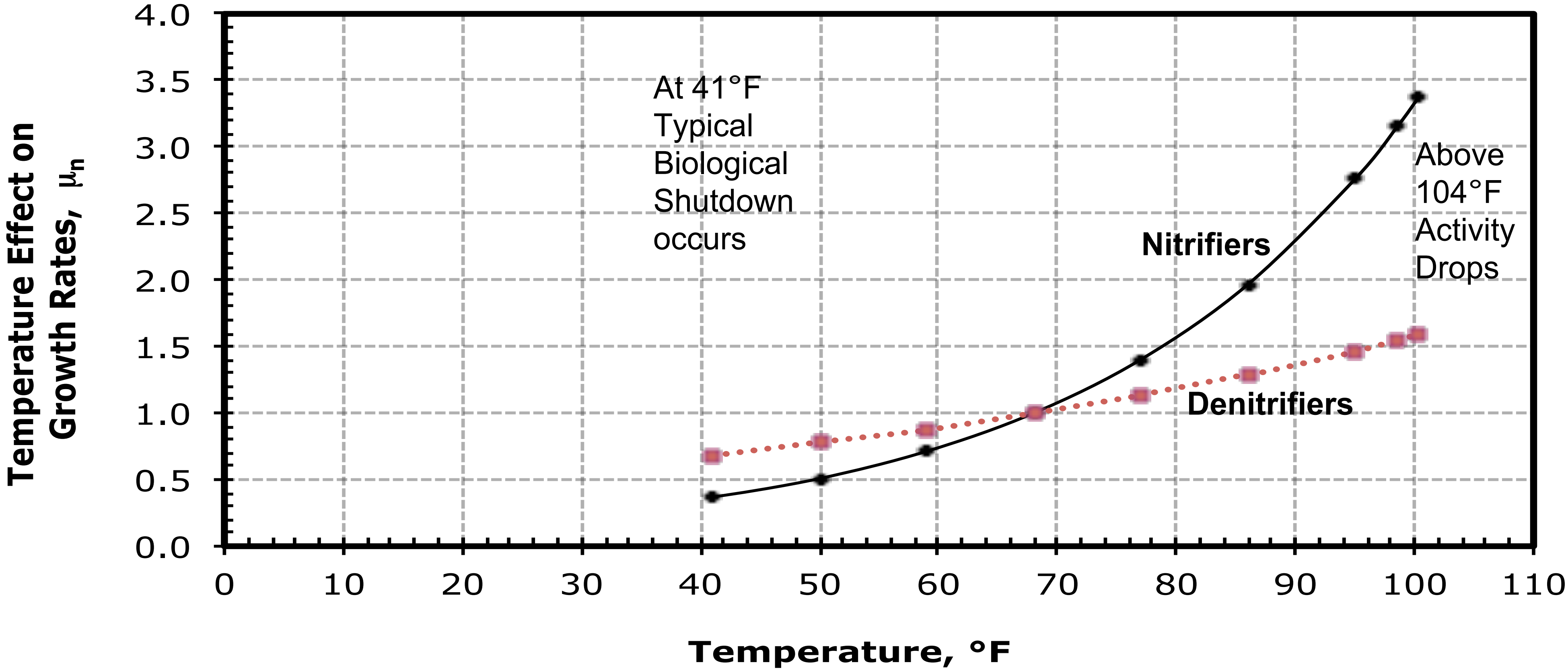
The rule-of-thumb in wastewater applications though, is to use a BOD/NO_3^- range between 4:1 and 8:1.

Also, denitrification recovers 3.57 mg alkalinity ($CaCO_3$).

Effect of DO on Denitrification



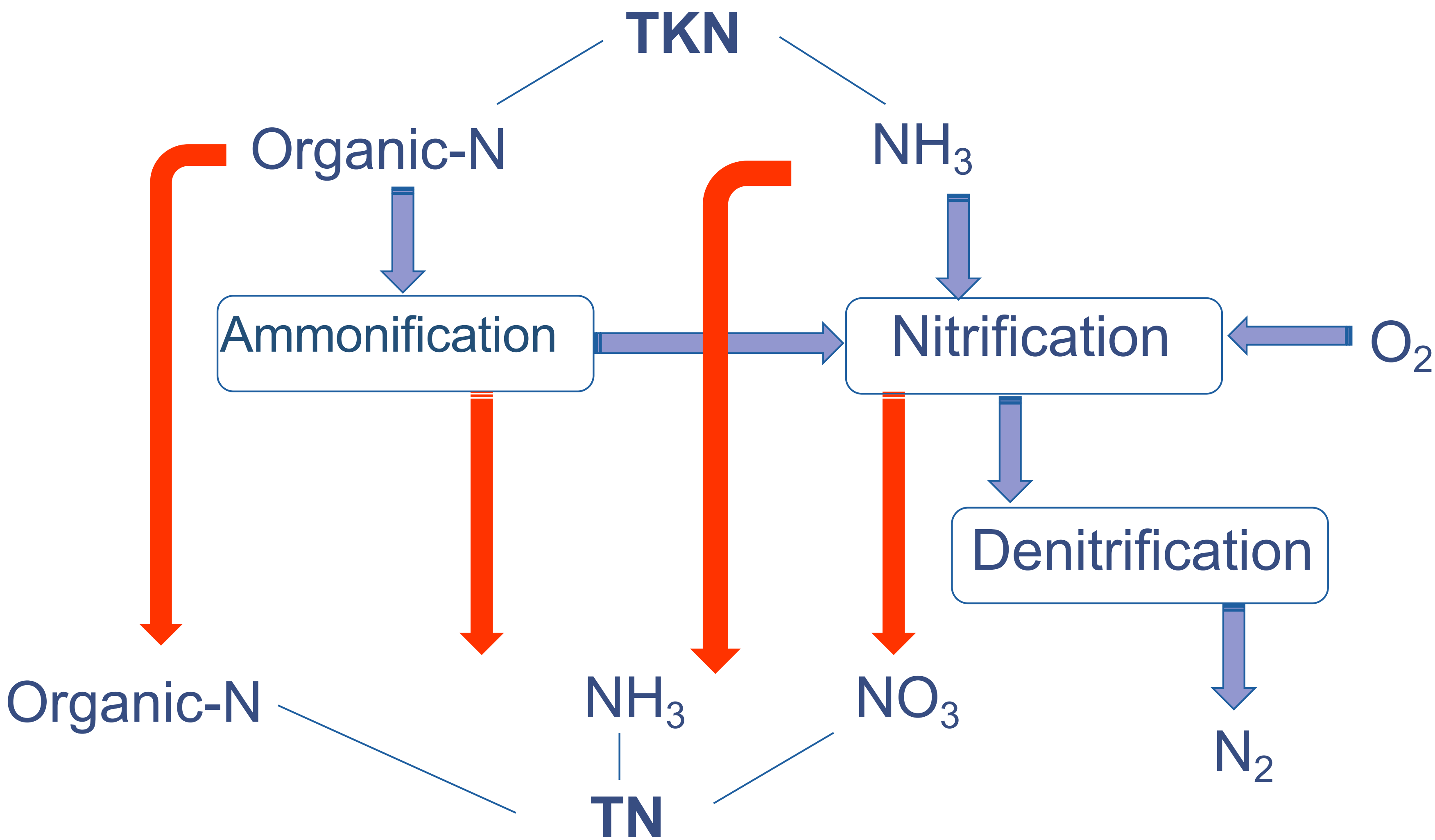
Temperature Effect on Nitrogen Processes



Nitrogen Considerations

- Toxins must be eliminated
  - ~ Water softeners
  - ~ Commercial applications with heavy cleaners
  - ~ Other sources

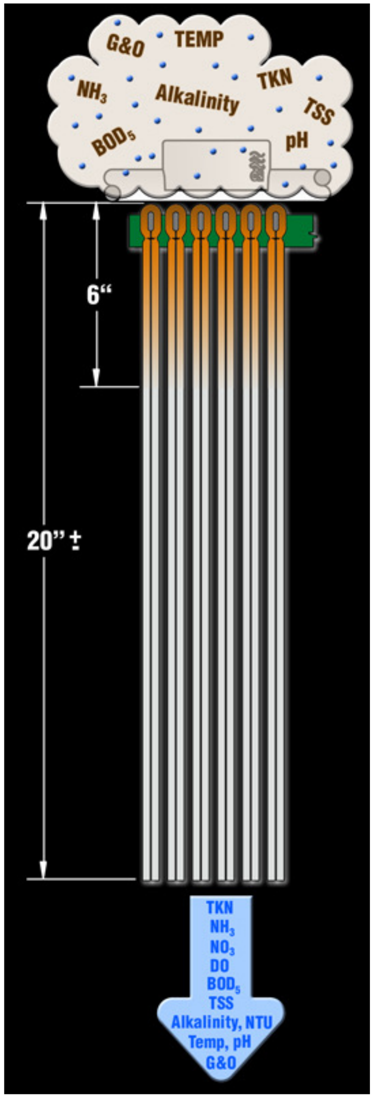
Realistic Nitrogen Treatment Process



Oxygen Availability in Air

Packed Bed Filter Biofilms

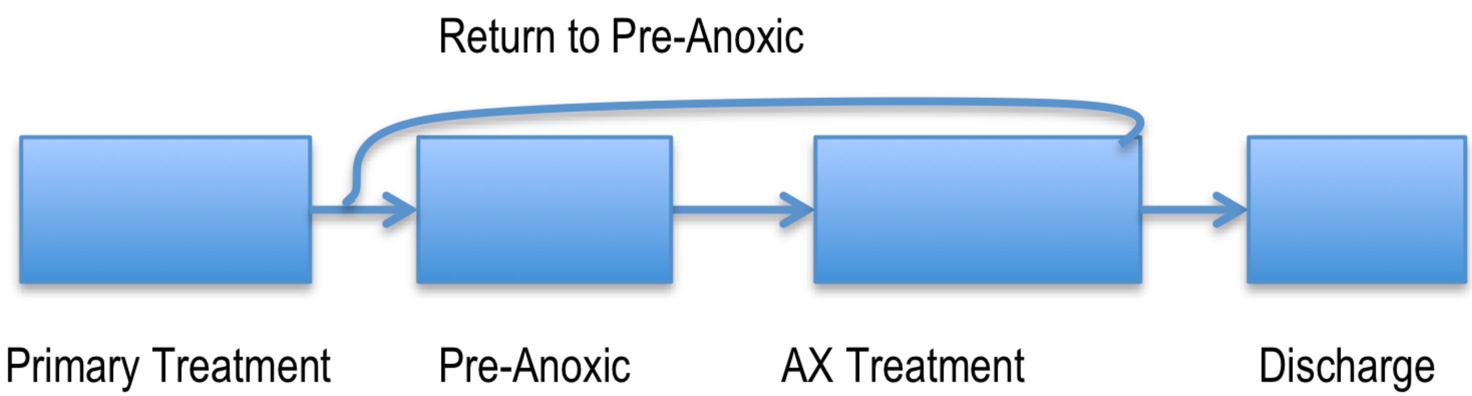
- Oxygen is diffused from the air
- CBOD is met in the upper levels of the media
- Ammonification happens in the lower regions



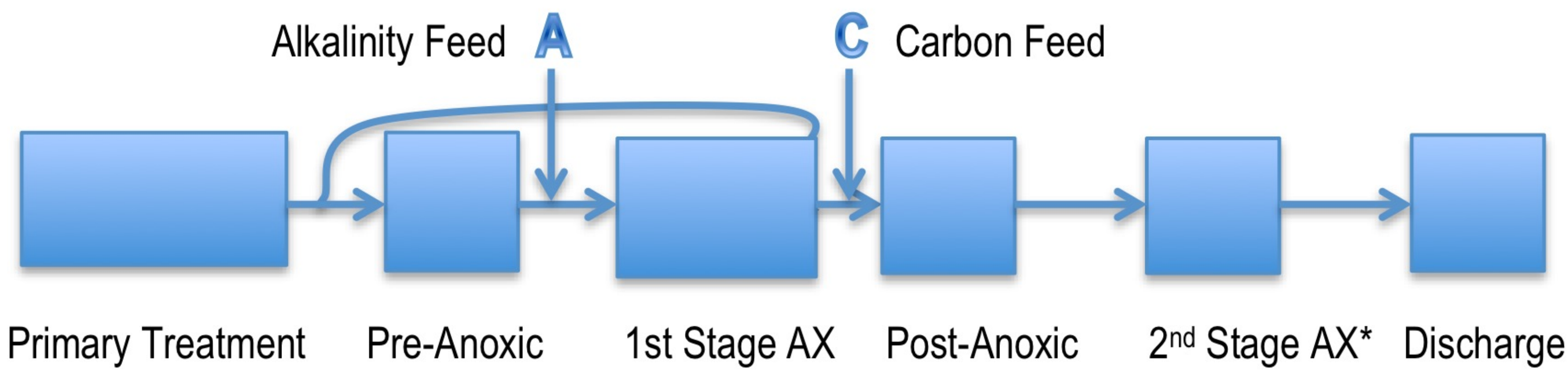
Typical Effluent Quality

- Varies by permit and effluent dispersal method
- Single stage configuration with domestic-strength wastewater:
  - ~ Target <10 mg/L BOD_5 and TSS
  - ~ > 60% TN reduction
  - ~ > 95% ammonia removal
- Two stage configuration:
  - ~ Strict ammonia limits (> 95% removal)
  - ~ Not to exceed limits of < 10 mg/L BOD_5
  - ~ 30-day average limits of ≤ 5 mg/L BOD_5
- Advanced Nitrogen Removal configuration:
  - ~ > 60% TN reduction

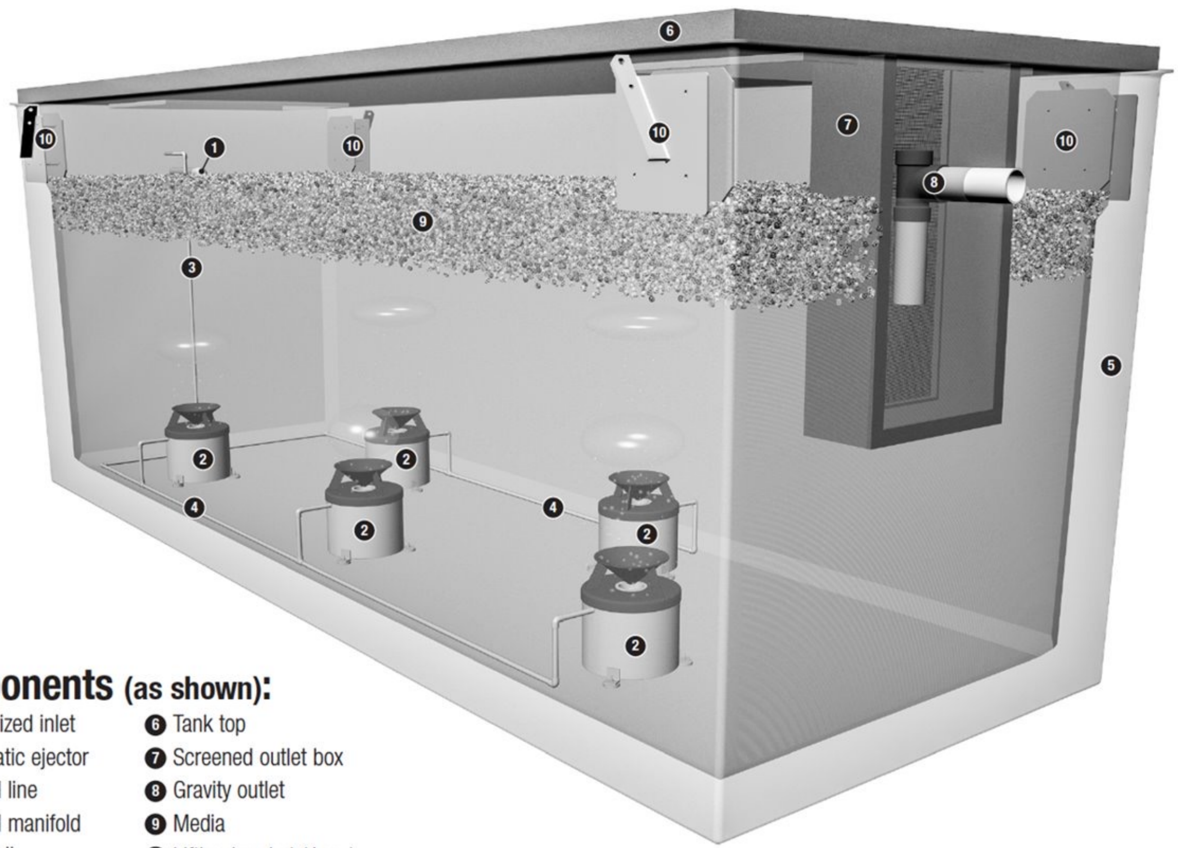
Standard – Removal of Organics



Advanced Removal of Nitrogen



Moving Bed Bioreactors for Denitrification



Components (as shown):

1. Pressurized inlet
2. Pneumatic ejector
3. Air feed line
4. Air feed manifold
5. Tank wall
6. Tank top
7. Screened outlet box
8. Gravity outlet
9. Media
10. Lifting bracket (4 ea.)

To reach concentrations below 10 or 20 mg/L, MBBd units are available from Orenco

Test Center Summary

AdvanTex Effluent Averages	Total N *mg/L*	NH_3-N *mg/L*	Total P *mg/L*	Duration
NSF/ANSI Standard 40	12 (*64%*)	0.9 (*96%*)	-	7 months
NSF/ANSI Standard 40 Testing with UV	13 (*66%*)	1.1	-	6 months
Novatec Nitrogen Removal Testing	10 (*70%*)	-	-	1 year
Rotorua District Council Approval Testing	14(*78%*)	0.2 (*99%*)	8 (*36%*)	13 months
Rotorua 2010	12.7 (*78%*)	0.6 (*96%*)		

AdvanTex Performance Summary #2 AHO-ATX-PERF-TN-1, 2012

Field Testing Summary

AdvanTex Effluent Averages (no. of SFRs)	Total N *mg/L*	NH_3-N *mg/L*	Total P *mg/L*	Duration
NSF Pennsylvania Testing Program (11)	17 (*68%*)	1.7 (*96%*)	-	1-3 years
Virginia Approval Testing Program (13)	15	1.8	-	18 months
Jefferson County, CO Health Dept Permit Testing (43)	15	-	-	2 years 7 months
Skaneateles, NY Demonstration Project (2)	14	0.9	10	2 years 2 months
La Pine, OR Demonstration Project (3)	17 (*74%*)	1.9	9 (*18%*)	2 years 7 months
Rhode Island Demonstration Project (5)	18	-	9	1 year 4 months
Maryland BAT Testing AX20 (12)	17			1 year 5 months
Maryland BAT Testing AX20RT (12)	14	1.3		1 year

AdvanTex Performance Summary #2 AHO-ATX-PERF-TN-1, 2012

Meridian School Data

- Influent average
  TKN = 129 mg/L

- Effluent Average
  TN ≤ 10 mg/L

Summary

- Nitrogen treatment in wastewater protects water ways
- Packed bed filters are an effective way to treat for nitrogen
- The amount of nitrogen treatment depends on the configuration

Solutions for Decentralized Wastewater Treatment

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