# *Aeration of Activated Sludge, BNR, and ENR*

**Maryland Center for Environmental Training**
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Aeration of Activated Sludge, BNR and ENR Processes

7 Contact hours
9 CC10 Hours

Various technologies are used to aerate activated sludge processes, including Biological Nutrient Removal (BNR) and Enhanced Nutrient Removal (ENR) processes. Various aeration options currently used, available, and evolving for activated sludge, BNR. And ENR processes will be covered in this course. Specifically, types of aeration diffusers (mechanical, fine bubble, and membranes) and blowers (positive, multistage, single stage, and high speed) will be addressed. The influence of MCRT and MLSS will also be addressed as to the efficiency ease (or difficulty) and cost of aeration. Airflow rate requirements and their calculations will be discussed in depth. Diffuser fouling and scaling issues will be discussed. Finally, helpful operating hints will be provided based on experiences from operating facilities.

l. Identify applicable aeration technologies in wastewater treatment;
2. Explain how to calculate aeration requirements for biological wastewater treatment;
3. Discuss how aeration systems are sized, including diffusers and blowers; and
4. Identify potential issues in aeration systems based on lessons learned from operating facilities.

Agenda

A. Introduction (8:00 am – 8:30 pm)
B. Types of aeration devices (8:30 am – 9:30 pm)
   - Options
   - Pros and cons
   - Selection
C. Types of blowers (9:30 am – 10:30 pm)
   - Options
   - Pros and cons
   - Selection
D. Calculation of aeration requirements (10:30 am – 12:30 pm)
   - OTR
   - SOTR
   - SOTE
   - Airflow rate
E. Lunch (12:30 pm – 1:30 pm)
F. Operating considerations (1:30 pm – 2:30 pm)
   - Diffusers
   - Blowers
   - MCRT considerations
   - MLSS considerations
   - Cost considerations
G. Troubleshooting (2:30 pm – 3:30 pm)
   - Fouling
   - Scaling
H. Post Test/Evaluations (3:30 pm – 4:00 pm)




# Aeration of Activated Sludge, BNR, and ENR Processes

MCET
ENVIRONMENTAL, HEALTH, AND SAFETY TRAINING

**Presented by**
**Ed Jones**

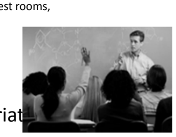
Maryland Center for Environmental Training
College of Southern Maryland
La Plata, MD



## Process Training Sessions

Before class starts, please:
- –**Sign in** on Attendance Sheet
- –**Fill out** Registration Form, if appropriate

During class, please:
- –**Asks questions**
  - – Feel free to get up and leave the classroom at any time (i.e., rest rooms, phone calls, etc.)
- –**Answer questions** on post test



After class, please:
- –**Fill out** a Class Evaluation
- –**Pick up** Attendance Card, if appropriat

## Housekeeping

- 1–day class
- Start class – 8:00 am
- 10-minute Breaks – every hour
- Lunch ~ 11:30 am – 12:30 pm
- End class ~ 3:30 to 4:00 pm

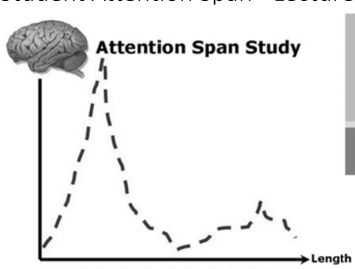


## Instructor Expectations

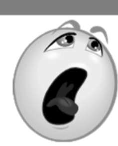
- Begin and end class on time
- Be interactive – participate at your own comfort level
- Share experiences and needs
- <u>Less lecture, more discussions</u>
- Keep it simple
- ***<u>Make this an enjoyable and informative experience!</u>***



## Student Attention Span - Lectures







Source: based on a study by Richard Mayer

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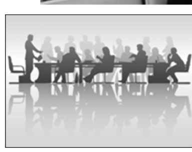
## How this Class is Structured

- This 1-day class will be more class discussion, less lecture
- The workshop will be structured around three teaching components:
  - Establishing rapport (Trainer as facilitator)
  - Stimulating student interest (Trainer as motivator)
  - Structuring classroom experiences (Trainer as designer)



## Discussions

- Student involvement in class discussions is encouraged:
  - To keep students attentive
  - To help students retain information



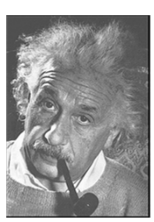


## The <u>Guiding</u> Expectation

**"Things should be made as simple as possible -- but no simpler."**

**Albert Einstein**

image source: www.physik.uni-frankfurt.de/~jr/physpiceinstein.html



## Ground Rules

- Discussion is encouraged; share experiences
- Use terms we all can understand
- Everyone is different, so please show respect for others in the room
- Express opinions - of things, not people
- Maintain confidences



## Ice Breaker

- Before we start, let's introduce ourselves.
  - Name,
  - What do you do, and
  - What are your learning needs?



## Class Outline

- Activated Sludge
  - Brief History
  - Oxygen needs for BOD Removal and Nitrification
- Aeration Systems
  - Air Production, Distribution, and Diffusers
  - Oxygen Transfer
  - Aeration Strategies
- BNR/ENR Processes
- Phosphorus Removal – A2O

## Introduction

Definitions and Acronyms



## Wastewater Characteristics

- Q – Flow, GPD, gallons/day (or gpm, MGD, gallons/hour)
- BOD – Biochemical Oxygen Demand, mg/l
  - cBOD – Carbonaceous BOD
  - nBOD – Nitrogenous BOD
- COD – Chemical Oxygen Demand, mg/l
- DO – Dissolved Oxygen
- Suspended Solids, mg/l:
  - TSS – Total Suspended Solids
  - VSS – Volatile Suspended Solids



## Biological Treatment

- AS – Activated Sludge
  - MLSS – Mixed Liquor Suspended Solids
  - MLVSS – Mixed Liquor Volatile Suspended Solids
  - WAS – Waste Activated Sludge
  - RAS – Recycled Activated Sludge
- AS Process Control:
  - DT – Detention Time , Tank volume/flow rate, V/Q, hours
  - MCRT/SRT – Mean Cell/Solids Retention Time, days
  - F:M – Food-to-Mass ratio, BOD/MLVSS
  - SV – Sludge Volume after 30 minutes
  - SVI – Sludge Volume Index, SV x 10,000/MLSS

## Biological Treatment

- BNR/ENR – Biological/Enhanced Nutrient Removal
  - Anaerobic – Soluble BOD uptake and Phosphorus Release
  - Anoxic – Denitrification
  - Aerobic - Nitrification
  - IR or NR– Internal Recycle /Nitrate Recycle



## Microorganisms

- **Aerobic** (Oxic) - Organisms requiring, or not destroyed, by the presence of free oxygen
- **Anoxic**: Organisms requiring , or not destroyed, by the absence of free oxygen; nitrates ($NO_3$) are present.
- **Anaerobic** - Organisms requiring, or not destroyed, by the absence of free oxygen and $NO_3$
- **Facultative** - Organisms able to function both in the presence or absence of free oxygen
- **Heterotrophic** - Organisms that use organic materials as their source of cell carbon
- **Autotrophic** - Organisms able to use carbon dioxide and other inorganic matter as their source of carbon
- **Filamentous** – Bulking organisms that grow in thread or filamentous form



## Introduction

Class Objectives and Focus

## Objectives of Today's Class

- To identify technologies for aerating activated sludge, BNR, and ENR processes:
  - ✓Oxygen transfer from air to water
  - ✓Operating practices
  - ✓Aeration issues and troubleshooting
- To discuss performances of aeration devices:
  - ✓ Blowers
  - ✓ Air distribution piping
  - ✓ Aerators/Diffusers
- To explain how to calculate oxygen requirements (lbs/day; scfm)



## Participant Focus

- What information can you use at your work location?
  - Current **aeration technologies**
  - Aeration – **practical process limits and control**
  - Aeration processes - **operating and trouble shooting guidelines** and recommendations
- What information can you contribute to the discussion?
  - **Blower and diffuser applications**
  - Problems with **air distribution piping**

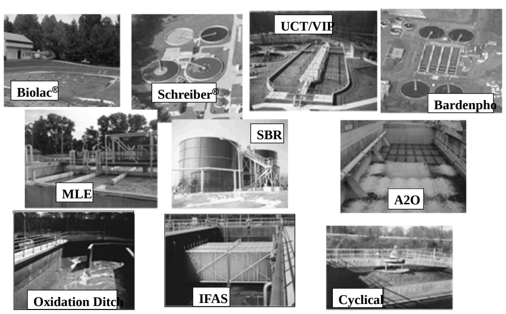


## Today's Focus is on Aeration & Oxygen Transfer…

…for Removal of Carbon, Nitrogen, and Phosphorus…




…in Activated Sludge Processes






## Activated Sludge Process

Early History

## History: Pre-Activated Sludge

- 1690 – Sewers (Paris, France)
- 1860 – Septic Tank (Louis Moureas)
- 1868 – Trickling Sand Filter Process (Edward Frankland)
- **1882 – Aeration of sewage (Argus Smith)**
- 1911 – Chlorination (London, England)
- **1912 – Activated Sludge Process – USA (Lawrence Experimental Station; Clark and Gage)**
- **1914 – Activated Sludge Process – England (Ardern and Lockett)**



## Early History of Activated Sludge

- In 2012, in the US, Clark and Gage at the Lawrence Experimental Station began looking at aerating suspended solids in wastewater
- Lawrence Experimental Station became known as "the Mecca of sewage purification"



## Early History of Activated Sludge

- In 1912, Dr. Gilbert Fowler from the University of Manchester (England);
  - Began his activated sludge studies in Europe
  - Traveled to the Lawrence Experimental Station (LES) in Massachusetts, (USA)

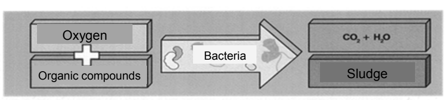
## Early History of Activated Sludge

- From 1913 – 1915, in England;
  - Lab-scale suspended biomass experiments were performed in England by Edward Ardern and his co-worker, William Lockett under the direction of Dr. Gilbert Fowler
  - In separate studies, Walter Jones of Jones and Attwood, Ltd. developed practical applications of the activated sludge process



## Activated Sludge

- Growth and retention of suspended biological solids using oxygen to remove:
  - Soluble Organics (cBOD, COD)
  - Organic Solids (TSS, VSS)
  - Nutrients
    - Nitrogen
    - Phosphorus






## Early History of Activated Sludge

- 1914/1915 - Ardern and Lockett published their research findings on aeration of suspended solids (e.g., MLSS)
  - Added the concept of recycling sludge
  - First to use the term “activated sludge”
- 1915 First full-scale activated sludge plant in Salford, England
  - 80,000 gpd at fill-and-draw operation (SBR)
  - 12,000 gpd at continuous-flow operation (Plug-flow)

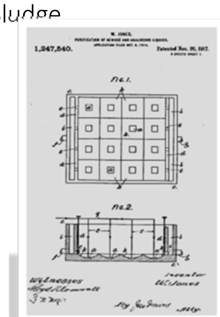
## Early History of Activated Sludge

- 1913 English patents by Jones and Attwood, Ltd
  - 25 cents/capita royalties paid by most WWTPs



## Early History of Activated Sludge

- Walter Jones' U.S. activated sludge patent 1,947,540 was issued in 1917 and expired in 1934
- The last of the Jones' US patents expired in 1935





## Early History of Activated Sludge

- 1915-1921 Ten full-scale plants in UK
- 1916-1927 Nine full scale plants in US
  - San Marcos, TX (1916)
  - Cleveland, OH (1916)
  - Houston (north), TX (1917)
  - Houston (south), TX (1918)
  - Des Plaines, IL (1922)
  - Calumet, In (1922)
  - Milwaukee, WI (1925)
  - Chicago IL and Indianapolis, IN (1927)

## Early History of Activated Sludge

- Late 1920s – Patent infringement suits were filed by Activated Sludge, Ltd. (ASL), the licensed patentee for Jones and Attwood, Ltd. against US cities of Chicago, Milwaukee, Cleveland, and Indianapolis
- Lawsuits and threats of litigation led to:
  - Shutdown of several activated sludge plants in the US
  - Delays in designing activated sludge processes until ASL patents expired (e.g., 1935)/lawsuits exhausted (e.g., late 1940s)
- Both Chicago and Milwaukee paid large settlements (~$1.0 million each) to ASL in the 1940s



## Early History of Activated Sludge

- Until 1995, U.S. patents were issued for a term of seventeen years, beginning on the issuance date
- Today, a patent's term still begins on the issuance date, but normally expires twenty years from filing date



## Early History of Activated Sludge

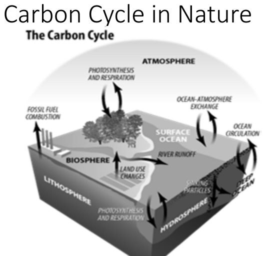
- Most activated sludge development in the US was delayed until the 1950s due to:
  - Process royalties and patent legalities
  - WWI and WWII
  - Example: Blue Plains – High rate activated sludge process was put into service in 1959

## Activated Sludge Applications

BOD Removal and Nitrification



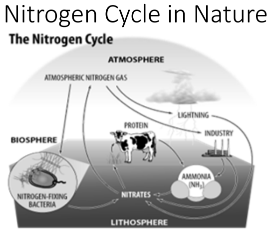
## Carbon Cycle in Nature




Carbon ($CBOD_5$) + Oxygen ($O_2$) —Heterotrophs→ $CO_2$

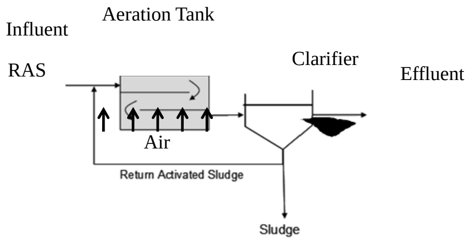


## Nitrogen Cycle in Nature



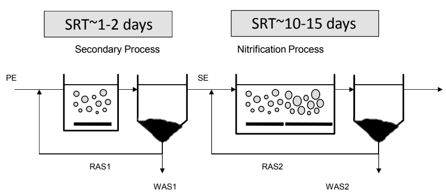

Nitrogen (TKN) + Oxygen ($O_2$) —Autotrophs→ Nitrate ($NO_3$-N)

## Typical Activated Sludge Process






## Two Sludge System for BOD Removal and Nitrification in Wastewater (1970s)




Blue Plains, DC Water 370 MGD

Western Branch, WSSC 30 MGD



## Oxygen Requirements

- Oxygen Requirements
  - $BOD_5$ – 1.0 – 1.2 lb $O_2$ / lb $BOD_5$ oxidized
    - Typically assume all BOD oxidized
  - TKN – 4.6 lb $O_2$ / lb TKN oxidized to nitrate
    - Some TKN is assimilated by biomass and not oxidized

- Total $O_2 = 1.1*(BOD_{in}-BOD_{out}) + 4.6*(TKN_{in}-TKN_{oxidized})$

## Aeration

- Conventional biological processes are aerobic
- Many organisms in the activated sludge and fixed film processes need free oxygen ($O_2$) to convert food into energy for their growth
- Typical Dissolved Oxygen (DO) concentrations:
  - BOD removal - normal 1 to 2 mg/L
  - "Nitrification" - 2 to 4 mg/l



## Aerobic Processes

- Aerobic processes require $O_2$ for removal of organics (BOD) and conversion of ammonia-N to Nitrate-N (nitrification)
- Oxygen can be supplied by air or pure $O_2$
- Oxygen can be delivered through mechanical (surface) or diffused aerators

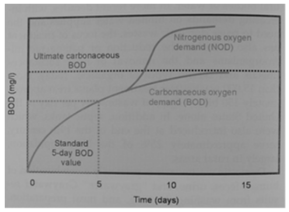


## Aeration

- BOD Removal
- Nitrification – convert $NH_3$ to $NO_3$

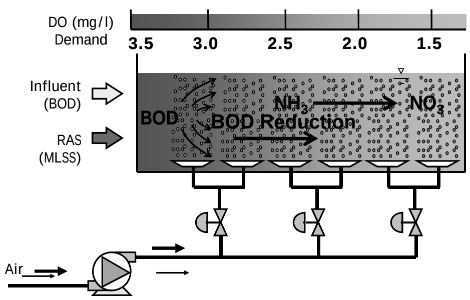
## Oxygen Requirements

- Biological treatment:
  - cBOD removal – from organic matter and suspended solids
  - nBOD removal – Nitrification, convert ammonia nitrogen to nitrate nitrogen (before denitrification)






## BOD Removal and Nitrification






## Aeration Systems

Overview

## Aeration

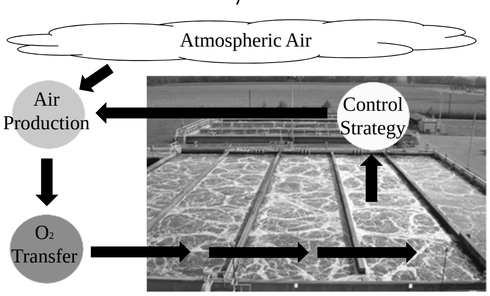


# What is Aeration?

- The purpose of aeration:
  - To dissolve oxygen into wastewater so that activated sludge microorganisms can utilize it while they break down organic material
- Aeration is also used for:
  - Mixing purposes
  - To enhance biological growth



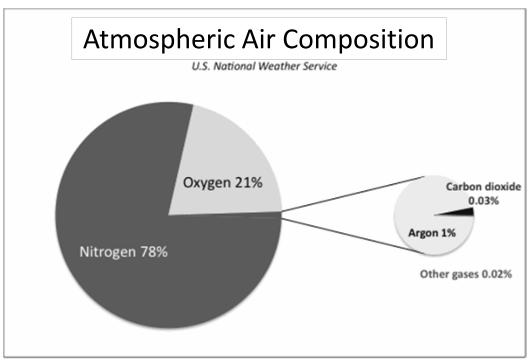
## What is an Aeration System?



## Composition of Atmospheric Air

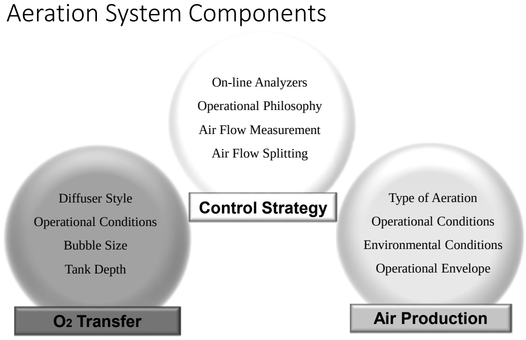
- **Atmosphere air contains a mixture of gases**:
  - 78% nitrogen,
  - 21% oxygen,
  - 0.93% argon,
  - 0.03% carbon dioxide - although this is increasing
  - water vapor (1% - 4%)
  - trace amounts of other gases








## Aeration System Components



## Activated Sludge Aeration

Blowers



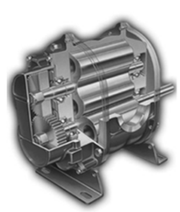
## Types of Blowers

- Positive Displacement
- Multistage Centrifugal
- Single Stage Centrifugal (integral gear)
- High Speed Direct Drive (turbo)



## Positive Displacement Blowers

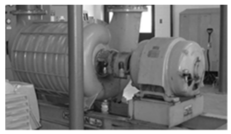
- Typically rotary lobe type
- Long operational history
- Higher pressure / variable pressure
- Many manufacturers
- Lower efficiency
  - Slip around lobes
  - Additional power to overcome pressure drop across inlet/discharge silencers/filters
- Noisy
- Vibration can be high
- Good for variable pressures



Courtesy of Dresser-Roots

## Multistage Centrifugal Blowers

- Multiple impellers in series increase air pressure
- Historically used at medium to large WWTPs
- Have good track record / reliable operation
- Efficient operation at design point
- Limited efficient turndown
  - Inlet throttling
- Can be noisy





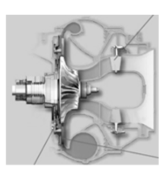
## Multistage Centrifugal Blower Manufacturers

- Most installations are Lamson or Hoffman (both now owned by Gardner-Denver)
- Other manufacturers include:
  - Ingersoll Rand (Hibon)
  - Houston Service Industries (HSI)
  - Continental Blowers
  - Spencer



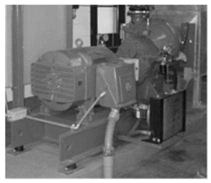
## Single Stage Centrifugal Blowers

- Single machined impeller
- Standard induction motor (constant speed)
- Gearing system increases motor speed to impeller (20–30,000 rpm)
- Used at small to large WWTPs
- Proven / reliable operation
- Efficient over wide range of air flows
- Somewhat noisy
- Little vibration
- Complex lubrication system



## Single Stage Centrifugal Blower Manufacturers

- Most installations are Turblex (Siemens)
- Other manufacturers include:
  - Roots-Dresser
  - Atlas-Copco
  - Howden





## Single Stage Centrifugal Blower Control

- Inlet guide vanes modulate to vary air flow
  - Turblex uses variable diffusers on discharge
  - Efficient turndown below 50%
  - Vanes and diffusers controlled with mechanical actuator

**Variable Inlet Guide Vanes**

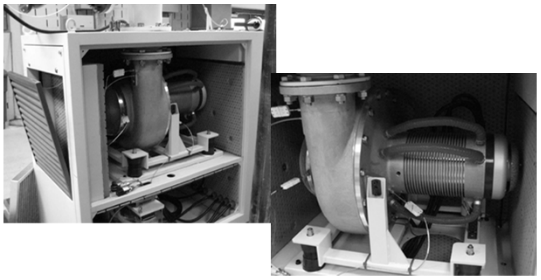
**Variable Diffusers**



## High Speed Direct Drive Blowers

- New to municipal market (1st unit installed in US in 2004)
- Motor / blower speed varied with VFD
  - Efficient turndown
  - VFD and controls integrated into blower package
  - Permanent magnet motors used for higher efficiency at higher speeds
- Blower and motor directly coupled
  - Entire unit built by manufacturer ("core")

## High Speed Direct Drive Blowers





## High Speed Direct Drive Blowers

- Bearings require no lubrication
  - Air foil bearing - inlet air creates air foil around shaft
  - Magnetic bearing - electronic control system continuously monitors and adjusts magnets to position shaft
- Used at small to medium WWTPs
  - Limited max size
- Very quiet and very little vibration
- Small footprint



## High Speed Direct Drive Blower Manufacturers

- **APG-Neuros (most US installations)**
- ABS
- HSI
- K-Turbo
- Turblex
- Pillar
- Gardner-Denver

Courtesy of HSI

## Selection of Blower Technology

- Positive Displacement
  - Small plants (< 5 mgd)
  - Variable depth reactors (SBRs)
  - Start-up flows/loads << design
  - Lower efficiency
- Multi-Stage Centrifugal
  - Applicable to varying plant sizes (1 mgd - 100 mgd+)
  - Significant loss in efficiency away from B.E.P.
  - Lower capital cost than single stage

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## Selection of Blower Technology

- Single Stage Centrifugal
  - Medium – large plants (15 mgd +)
  - Higher capital cost
  - Very efficient through operating range
- High Speed Single Stage Centrifugal
  - Small – medium plants (< 20 mgd)
  - Capital cost comparable to multistage
    - More efficient through operating range
  - New technology

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## Provide Sufficient Turndown Capability

- Turndown required to:
  - Meet minimum aeration demands without overaeration
  - Avoid gaps in operating range
- Positive displacement & single stage (blowers
  - Typically can turndown well below 50% of design point
  - Blowers of identical capacity provide sufficient overlap
  - Can specify multiple sizes is start-up flows << design

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## Multistage & High Speed Single Stage Blowers – Turndown Considerations

- Typically can turndown to 40%-45% of design point
- Blowers of identical capacity result in insufficient overlap
  - Example – (4) 1,000 scfm blowers w/ 40% turndown
  - 600 – 1,000 scfm – 1 blower operating
  - 1,200 scfm – 2,000 scfm – two blowers operating
  - **Cannot provide air between 1,000 – 1,200 scfm!**
- Specify two sizes of blowers
  - Typically 2 small + 2 large (150% of small) to provide sufficient turndown and overlap



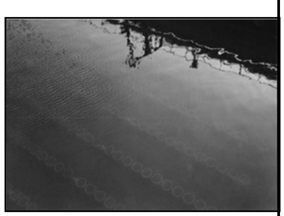
## Activated Sludge Aeration

Aeration Devices

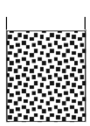


## Gas transfer devices

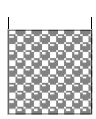
Mechanical (surface) aerators of activated sludge process treating wastewater



Fine bubble



Fine bubble diffuser



Course bubble diffuser

## Mechanical Aerators

Two basic types commonly used
- Low speed surface aerators
- Submerged turbine aerators

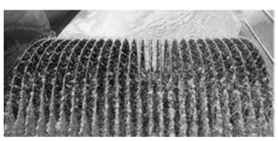
Low speed surface aerators
- Most common type in AS
- $O_2$ transfer rate low
- Dissipate heat quickly

Submerged turbine aerators
- Higher gas transfer efficiencies
- High energy requirements



## Low-Speed Surface Aerators

- Floating
- Vertical
- Disc
- Brush





## What is diffused aeration?

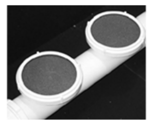
- Diffused aeration is a subsurface form of aeration:
  - Air is introduced in the form of very small bubbles
  - Air flows from a pipe into diffusers located at the bottom of a tank
  - These diffusers have numerous small openings (known as pores) through which air flows into the wastewater in the tank.

Coarse bubble diffuser

Fine bubble diffusers

## What is diffused aeration?

- Diffusion devices have been classified as either fine bubble or coarse bubble based on how efficiently they transferred oxygen to the wastewater.
- Fine and coarse bubble, diffused aeration systems have been classified based on the physical characteristics of the equipment.





## Diffused Aeration

- Coarse Bubble Diffusers
  - Low efficiency (SOTE – 5% - 8%)
    - Typically ~ 0.75% / foot submergence
- Fine Bubble Diffusers
  - High efficiency (SOTE – 15% - 40%)
    - Typically ~ 2% / foot submergence

Coarse bubble diffuser

Fine bubble diffusers



## What is coarse bubble aeration?

- The common types of coarse bubble diffusers are fixed orifices, valved orifices, and static tubes
- The bubble sizes of these diffusers are larger than the porous diffusers
- Lower oxygen transfer efficiencies (OTE) can be expected with coarse bubble diffusers

## Coarse Bubble

- Application
  - Nearly every process and wastewater
  - Industrial applications - zero maintenance
  - Stainless steel construction
  - 30 year design life
- Efficiency
  - Spiral roll
  - 0.7-0.9% SOTE per ft submergence
  - 3-4 lb oxygen/kwh
  - 60% greater power than fine bubble fixed
- Maintenance
  - Near zero maintenance
  - Required maintenance - hardware, grit, diffusers
  - Inspection every 3-5 years



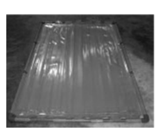
## Coarse Bubble Diffusers

- Perforated Pipe
- Single Drop
  - Commonly used for channel aeration
  - Diffusers on individual drop legs
    - Can remove individual diffusers in-situ



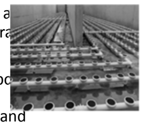
# What is fine bubble aeration?

- In a fine bubble aeration system, several diffusers are mounted or screwed into a header pipe that may run along the length or width of the tank or on a short manifold mounted on a movable pipe
- These diffusers come in various shapes and sizes, such as discs, tubes, domes, plates, and membrane panels.



# What is fine bubble aeration?

- Fine pore diffusers (discs, tubes, domes, and plates) a usually made from ceramic, plastic, or flexible perfora membranes
- Although many materials can be used to make fine po diffusers, only these few are being used due to cost considerations, specific characteristics, market size, and other factors





## Fine Bubble

- Application
  - Nearly every process and wastewater
  - Media sensitivity
  - Low oil membrane disc
  - Membrane 8-10 year minimum life
  - Ceramic 10–20 year life w/ PM
- Efficiency
  - Most efficient device
  - Greater than 2-3% SOTE per ft submergen
  - 8-10 lb oxygen/kwh
- Maintenance
  - Required maintenance - hardware, grit, leaks, diffusers
  - Ceramic annual cleaning
  - Membrane cleaning every 2 - 3 years

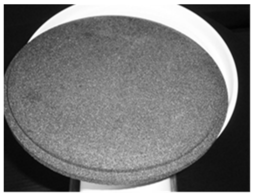


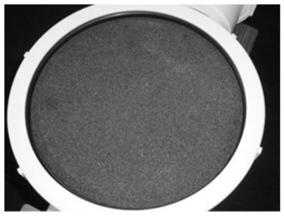
## Fine Bubble Diffusers

- Ceramic Discs
- Ethylene Propylene Diene Monomer (EPDM) Membrane Discs
- Polyurethane Membrane Panel Diffusers
- Tubular Diffusers

## Ceramic Diffuser

- Contoured profile
- Uniform air distribution
- Peripheral o-ring seal
- Fused alumina oxide

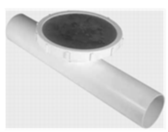




- Refracton or Filtros
- Parity with competition

## EPDM Membrane Disc Diffusers

- ITT Sanitaire
  - 9” disc
  - Most established diffuser in diffused aeration market
  - PVC diffuser and piping
- Aquarius
  - 9” disc similar to Sanitaire
  - Ex-Sanitaire executives

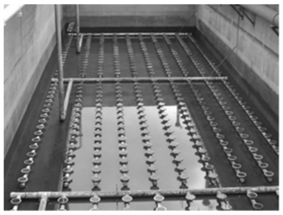




## EPDM Membrane Disc Diffusers

- Siemens (US Filter/Envirex)
  - 9” DualAir Disc
  - Two membrane discs/saddle
- SSI (Stamford Scientific)
  - 9” & 12”discs
  - PTFE (Teflon) coated EPDM diffusers
    - Anti-fouling claimed
- Environmental Dynamics, Inc. (EDI)
  - 9” disc

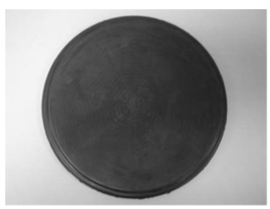
## Fine Bubble





## Membrane Diffuser

- Better Q/C in manufacture, tighter tolerances
- A longer life through better chemistry
- Guaranteed longevity
- Better effective flux ratio (EFR)
- 19.7% better
- Results in 5% greater oxygen transfer efficiency



## Jet Aeration

- Often used in “swing” zones
  - Liquid mixing through recirculation pumping during anoxic operation
- Consist of FRP piping
  - Liquid header and air header
- Requires pumping and blower equipment
- Less efficient than fine bubble diffusers
- Siemens, Fluidyne, MTS

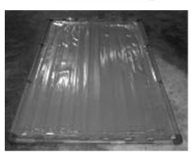

## Diffuser Density

- Diffuser density = Diffuser area / basin floor area
  - Also presented as AT/AD
    - Area tank/area diffusers
- Typical diffuser density is between 5% and 20% floor coverage
  - ~ 25% maximum for 9" EPDM diffusers to allow access
  - < 5% - poor mixing
- 9" EPDM membrane ~ 0.41 $ft^2$/diffuser



## Polyurethane Membrane Panel Diffusers

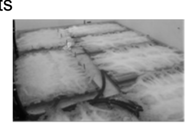
- Aerostrip
  - Supplied by AquaConsult (Austria)
- Parkson HiOx Panel
  - Supplied by Parkson (Fort Lauderdale)
  - 4' x 12' standard panels
  - 25% - 55% floor coverage
  - ~ 40 US installations
    - < 1 to 50 mgd





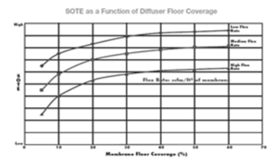
## Polyurethane Membrane Panel Diffusers

- Greater SOTE Claimed
  - Smaller pores, greater diffuser densities
- Smaller pores – increased pressure loss through diffusers
  - Increased SOTE offset be increased pressure requirements may cause surge issue with existing blowers
  - Membrane flexing required



## Polyurethane Membrane Panel Diffusers

- Greater diffuser densities than discs
  - Typical nitrification/BNR processes
    - Maximum diffuser density < 20%
    - Limited benefit
  - May be applicable to high-rate processes & MBR






## Tubular Diffusers

- Environmental Dynamics, Inc. (EDI)
  - EPDM membrane standard
    - Urethane & polymer available
- SSI (Stamford Scientific)
  - EPDM, PTFE coated or silicone
- OTT Systems
  - OTT GmbH & Company (German)
  - All 304 SS piping (PVC unavailable)
  - EPDM or silicone membrane available
  - 1.6 – 6.6 ft diffuser lengths



## Ceramic vs. Membrane

- Ceramic
  - Alumina oxide
  - Lower operating pressure
  - Higher capital cost
  - Continuous air req'd
  - Structure unaffected by WW
  - Higher fouling potential
  - Can be cleaned in-situ

- Membrane
  - Low oil EPDM
  - Higher pressure & SOTE
  - Lower capital cost (20-30%)
  - Intermittent air compatible
  - Finite life
  - Lower fouling potential
  - Lowest life cycle cost (5-10%)

## Activated Sludge Aeration

Air Piping



## Activated Sludge Aeration

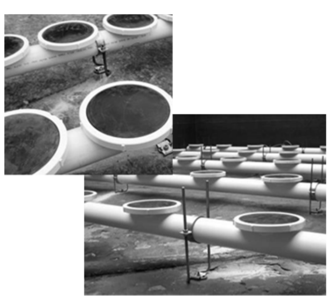
"The Best Diffuser In The World Is Of Little Benefit Without A Sound Piping System To Support It."

-Anonymous

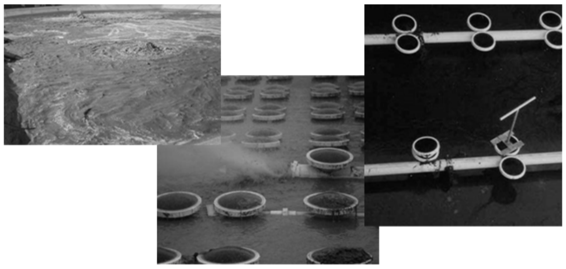


## Making a Good Air Piping System

- Air distributor joints
- Air distributor supports
- Diffuser holder
- Diffuser element



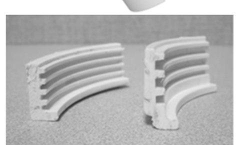
## Why Is This Important?





## The Joint

- The weakest link in the system with greatest potential for leaks or failure
- Heavy duty boltless fixed union style
- Larger joint retainer ring than competition
- 120% greater thread depth
- 110% greater flange thickness



AQUARIUS

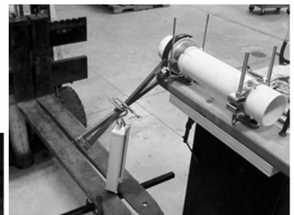


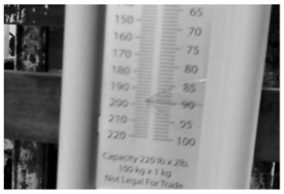
## The Joint

- Can use a strap wrench
- O-ring compressed on 4 vs 2 sides, less chance for leakage
- Anti-rotation feature lugs which grip the o-ring
- Anti rotation design does not stress the joint
- Increased installation rate

## The Joint

- Installation hand tight plus quarter turn improves joint integrity
- Withstands 200 ft-lbs torque

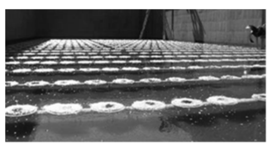






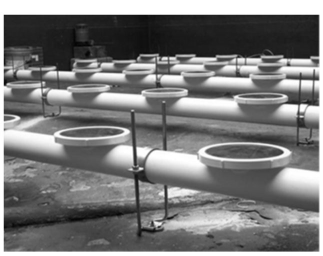
## The Joint

- Eliminates nut, bolt and gasket sets
- Full 360 degree movement of one pipe section relative to another
- Allows contractor absolute ability to level the grid



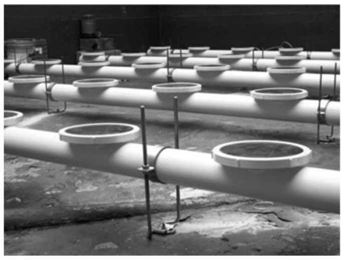
## The Support

- All supports are guide style to accommodate expansion/contraction
- Single anchor bolt along centerline of pipe
- Infinitely adjustable over the height range of the support
- One clamp bolt elevation sets all of them in the grid



## The Support

- 7'-6" spacing
- Infinitely adjustable over the height range of the support
- One clamp bolt elevation sets all of them in the grid



## The Support

- Locating plate can go either direction, eliminating contractor installation error and loose supports

Aeration of BNR/ENR Processes 107

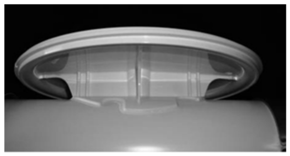
## The Support

- Locating plate deflects less under the same anchor bolt torque
- Support stays anchored
- Aquarius can withstand 70% greater torque without damaging deflection
- Critical if 1/2" anchor bolts are required


Aeration of BNR/ENR Processes 108

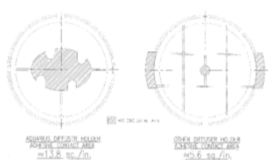
## Diffuser Holder

- Lower profile, less lateral stress
- Factory sonic and solvent welded to the piping insures a positive air seal and bond
- Aides in leveling the system, simplifies installation
- 1 element connection to the distributor vs 3
- Tighter diffuser spacing possible, no pod "feet" to interfere with supports



## Diffuser Holder

- 146% greater holder/pipe contact area, better torque and impact resistance
- All 3 elements have to be at same close tolerance elevation to bond effectively

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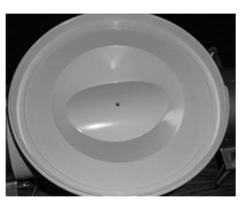


## Aeration Systems

Aeration and Oxygen Transfer



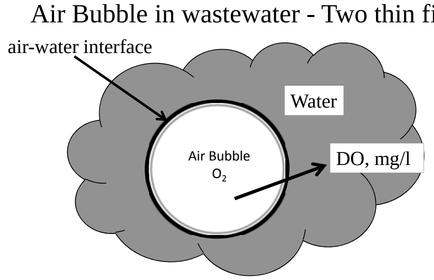
## Major Air Transfer Theories

- Existence of two thin films, one on each side of the air-water bubble interface is the basis of most theories
- Steady-state (static?) theories developed between 1924 – 1951 are still in use today
- More dynamic theories to account for turbulence and asymmetric air bubble shapes are being developed



## Major Air Transfer Theories

Air Bubble in wastewater - Two thin films



## Major Air Transfer Theories

- **Two Film Theory**
  - Lewis and Whitman (1924)
  - Passage through the two films is a slow molecular diffusion process
  - The liquid film is free from turbulence (?)
  - Transfer rate is controlled by the resistance in liquid film (i.e., oxygen saturation)
  - Transfer across the interface is at steady state (?)



## Major Air Transfer Theories

- **Penetration Theory**
  - Higbie (1935)
  - Steady-state assumption is not assumed
  - Gas molecules penetrate the gas-liquid interface quickly
    - Gas accumulates at the interface to create a high concentration gradient at the liquid layer
    - High initial concentration gradient produces quick diffusion rate in the liquid layer and decreases with time to reach a linear steady state gradient
    - Constant exposure time of each stagnant film



## Major Air Transfer Theories

- **Surface Renewal Theory**
  - Danckwerts (1951)
  - Based on a concept requiring constant exposure time of each stagnant film
  - Turbulence of liquid extended to the surface of the air bubble

## Activated Sludge Aeration

- Activated sludge processes are the most popular method of biological wastewater treatment (since the 1950s)
- Process reliability is dependent upon the aeration system to supply dissolved oxygen to the mixed-liquor suspended solids



## Activated Sludge Aeration

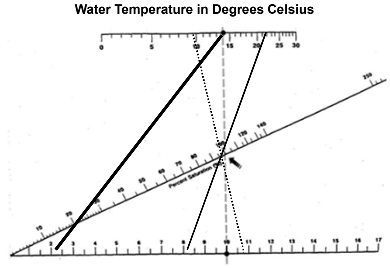
- Aeration is the most energy intensive aspect of wastewater treatment
- Aeration consumes as much as 40% to 60% of the energy requirements in a WWTP
- The current strategies/trends are to:
  - Use more energy efficient fine bubble aeration systems
  - Automate air production in Nitrification processes using ammonia probes



## Why is Aeration Important?

- Dissolved oxygen is the most important substrate in activated sludge processes
- Oxygen is sparingly soluble in water; it may be the growth-limiting substrate
- For activated sludge, the *critical oxygen concentration* is about 10% to 50% of the saturated DO (dissolved oxygen concentration).

# D.O. - Percent Saturation in Water




Source: Department of Fisheries and Aquatic Sciences, University of Florida



## Factors affecting Transfer Rate

- {C*- $C_L$} = "driving force"
- C* (saturation oxygen concentration: maximum solubility of the gas in liquid)
  - Constant at a given T and P
  - Available in tables and charts
- $C_L$: Oxygen concentration at a given time



## Factors affecting Transfer Rate

- Oxygen transfer is usually limited by the liquid film surrounding the gas bubbles:

$$m_{O_2} = k_L a \left(C^* - C_L\right)$$

Where:
- $m_{O_2}$ is the rate of oxygen transfer per volume of reactor
- $k_L$ is the oxygen transport coefficient
- $a$ is the gas-liquid interfacial area per volume of reactor
- $k_L a$ is the volumetric oxygen transfer coefficient
- $C^*$ is saturated DO (dissolved oxygen) concentration
- $C_L$ is the actual DO concentration in the liquid

## Factors affecting Transfer Rate

- $K_L a$
  - Both "$K_L$" and "a" correlate with aeration transfer rate
  - Most variable factor in oxygen transfer in wastewater
  - The two quantities are multiplied together
    - $K_L$ - determined by Liquid side (essentially overall mass transfer coefficient); function of turbulence
    - a - total surface area of bubbles in bioreactor
    - The two factors can't be separated…!

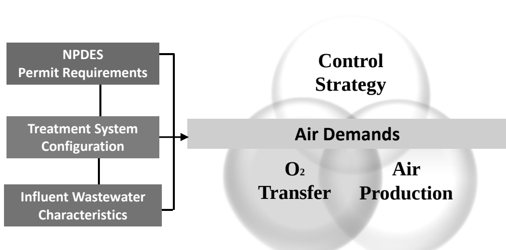


## Activated Sludge Aeration

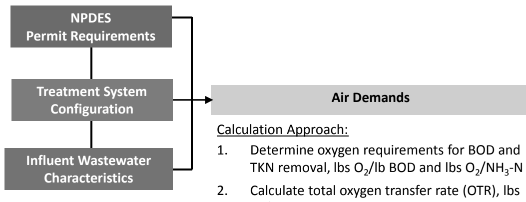
Air Demand Calculation



## Aeration System Capacity



## Aeration System Capacity




Calculation Approach:

1. Determine oxygen requirements for BOD and TKN removal, lbs $O_2$/lb BOD and lbs $O_2$/$NH_3$-N
2. Calculate total oxygen transfer rate (OTR), lbs $O_2$/day
3. Identify oxygen transfer efficiency (OTE), %
4. Calculate air demand requirements, cfm



## Information Required to Determine Aeration Requirements

- Design loadings to biological process
  - Minimum, current average and peak design $BOD_5$ & TKN loads
    - Primary effluent where applicable!
    - Include sidestreams where applicable
    - Typically base aeration system on max day air demand
- Site conditions
- Expected effluent quality
- Aeration basin geometry
- Aeration device characteristics



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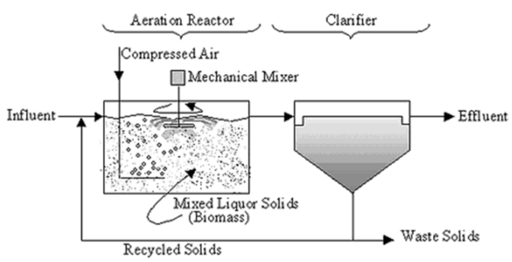
    - Primary effluent where applicable!
    - Include side streams where applicable
    - Base aeration system on max day air demand
- Site conditions
- Expected effluent quality
- Aeration basin geometry
- Aeration device characteristics

## Airflow Rate Calculation

1. Determine Process BOD and TKN Removal Oxygen Requirements
2. Determine Daily Oxygen Transfer Rate (OTR)
3. Determine Oxygen Transfer Efficiency (OTE), %
4. Calculate Airflow Rate, cfm



## Activated Sludge Aeration
## Basic Process Configuration






## 1. Oxygen Requirements

- Oxygen Requirements, lbs/day
  - $BOD_5$ – 1.0 – 1.2 lb $O_2$ / lb $BOD_5$ oxidized
    - Typically assume all BOD oxidized
  - TKN – 4.6 lb $O_2$ / lb TKN oxidized to nitrate
    - Some TKN is assimilated by biomass and not oxidized

## 2. Oxygen Transfer Rate (OTR)

- OTR = $1.2*(BOD_{in}-BOD_{out}) + 4.6*(TKN_{in}-TKN_{oxidized})$

## Air Demand Requirements, lbs/day

| Treatment | Equation | lb $O_2$/lb oxidized | OTR Factor |
|---|---|---|---|
| Organic Removal | $BOD_{oxidized} = BOD_{inf} - BOD_{eff}$ | 1.0 – 1.2 | 1.2 x $BOD_{oxidized}$ |
| Nitrification | $TKN_{oxidizable} = TKN_{inf} - TKN_{assimilated}$<br>$TKN_{oxidized} = TKN_{oxidizable} - TKN_{eff}$ | 4.6 | 4.6 x $TKN_{oxidized}$ |

| NPDES Effluent Requirement | OTR Equation |
|---|---|
| $BOD_5$ Limit | 1.2 x $BOD_{oxidized}$ |
| $BOD_5$ + $NH_3$-N Limit [1] | 1.2 x $BOD_{oxidized}$ + 4.6 x $TKN_{oxidized}$ |

1. Typical design condition



## 3. Standard Oxygen Transfer Efficiency (SOTE)

- Manufacturer typically provides data (certified curves)
- Dependent on:
  - Diffuser type
    - Smaller pores, ↑ SOTE
  - Basin geometry & depth
    - Increased Depth, ↑ SOTE
  - Diffuser flux rate
    - Increased flux, ↓ SOTE
  - Diffuser density
    - Increased Density, ↑ SOTE

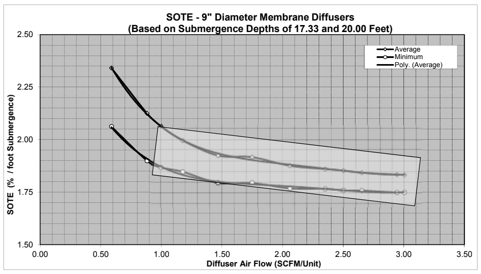


## Air Transfer Efficiencies

- Manufacturer typically provides efficiency data (certified curves)
- Clean water OTE

| Item | Criteria | Impact on OTE |
|---|---|---|
| Diffuser Type | ↓ Pore Size | ↑ |
| Tank Geometry | ↑ Submergence | ↑ |
| Diffuser Arrangement | ↑ Density | ↑ |
| Air Flow per Diffuser | ↑ Flux Rate | ↓ |

## Typical SOTE for 9" Sanitaire EPDM Diffuser






## Diffuser Flux Rate

- Efficiency increases with decreased flux rate
  - Minimum flux ~ 0.6 – 0.7 scfm/diffuser to avoid poor air distribution
  - Decreased flux rate = more diffusers
    - Additional costs, spacing constraints
- Maximum diffuser flux ~ 3.0 scfm/diffuser
  - Decreased efficiency at greater flux
  - Increased pressure requirements
  - Increased wear potential
- Typically design flux rates range between 1.0 and 3.0 scfm/diffuser



## 4. Airflow Rate, cfm

- $$Q_{airflow}\ (scfm) = \frac{SOTR\ (lb/d)\ /\ SOTE\ (\%)}{Y_{air,\ std} \times f_{O2,\ std} \times 1440}$$
  - $Y_{air,\ std}$ = specific weight of standard air (0.0752 lb/ft$^3$)
  - $f_{O2,\ std}$ = mass fraction of oxygen in standard air (0.21)
- SCFM – standard cubic feet per minute
  - Volume of air required at standard conditions to provide the required mass of oxygen - 20°C, 14.7 psia, 36% R.H.
  - Must be adjusted to site pressure, temperature and humidity conditions to determine actual volumetric flow rate

## mple - Compute Air Requirements

- 10 MGD Flow
- 100 mg/l BOD
- 25 mg/l $NH_3$
- 1.2 lb $O_2$/lb BOD
- 4.6 lb $O_2$/lb $NH_3$
- Effluent Requirements:
  - BOD - < 5 mg/l
  - $NH_3$ - < 0.1 mg/l



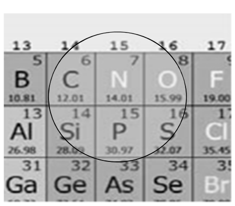
## BOD and Nutrient Removal

Regulatory Drivers



## Nutrients

**Part of the Periodic Table**




- ✓ Both Phosphorus and Nitrogen are considered essential for plant and animal life
- ✓ Both are called nutrients

## Nutrients

- TN – Total Nitrogen ($NH_3 + N_{org} + NO_3 + NO_2$)
- TP – Total Phosphorus ($PO_4 + P_{org} + P_{poly}$)
- Nutrients stimulate algae production in receiving waters and need to be removed
- Typical raw wastewater concentrations:
  - ✓ TN – 25 to 40 mg/l
  - ✓ TP – 3 to 6 mg/l



## Regulatory Drivers

- 1972 Clean Water Act
  - EPA: Given authority to set nutrient water quality standards
- Chesapeake Bay Regulations
  - Biological Nutrient Removal Program (1980s – 1990s)
  - Enhanced Nutrient Removal Program (>2000)



## Regulator Drivers

1972 Clean Water Act (CWA)

## Clean Water Act (CWA)

- The 1972 Clean Water Act:
  - Set the basic structure for regulating point source discharges of pollutants into US waterways
  - Gives EPA authority to set **water quality standards** for contaminants:
    - Attain water quality levels that make surface waters safe to fish and/or swim in
    - Restore and maintain the chemical, physical, and biological integrity of the nation's waterways

Aeration of BNR/ENR Processes 145

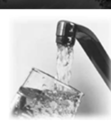
## Clean Water Act (CWA)

- Water Quality Concerns:
  - BOD (Biological treatment)
  - TSS (Sedimentation and filtration)
  - Coliforms (Disinfection)
  - Nutrients:
    - Nitrogen (Nitrification and denitrification)
    - Phosphorus (Physical incorporation, biological uptake, and chemical precipitation)

Aeration of BNR/ENR Processes 146

## Water Use

- WWTP discharge standards are set to meet water quality standards:
  - In waterways
    - Aquatic and marine life
    - Water contact sports
      - Swimming
      - Boating
      - Fishing
  - For downstream water users:
    - Domestic water supplies
    - Industrial water supplies
    - Agriculture water supplies



Aeration of BNR/ENR Processes 147

## Clean Water Act (CWA)

- EPA can/will impose more stringent **water quality discharge standards** for contaminants:
  - If chemical, physical, and biological integrity of the receiving water requires more removal (e.g., BNR to ENR program in the Chesapeake Bay)
  - As new technologies become available to offer cost effective solutions to water quality problems (e.g., automated SBRs for WWTPs < 0.5 MGD)



## Clean Water Act (CWA)

- The CWA makes it unlawful for any person to discharge any pollutant from a point source into navigable waters unless a NPDES discharge permit is obtained
- NPDES - **N**ational **P**ollutant **D**ischarge **E**limination **S**ystem
- WWTPs are self-monitored
  - Monthly "Discharge Monitoring Reports" (DMRs)
- EPA has delegated monitoring responsibility to states



## Goals of Wastewater Treatment

- Removal of:
  - **Suspended solids and organic matter** (TSS, cBOD, and nBOD) to limit pollution
  - **Nutrients** (TP and TN) to limit eutrophication
  - **Microbiological contaminants** to eliminate infectious diseases
- Required levels of treatment are based on issued discharge permit limitations

## Wastewater Constituent Removal

- **TSS and cBOD Removal** in primary clarifiers and secondary bioreactors/clarifiers
- **TP removal** in primary, secondary, and tertiary
  - Particulate removal
  - Biological uptake
  - Chemical precipitation
- **Nitrification**: Ammonia-N conversion to nitrate-N
- **Denitrification**: Nitrate-N conversion to nitrogen gas

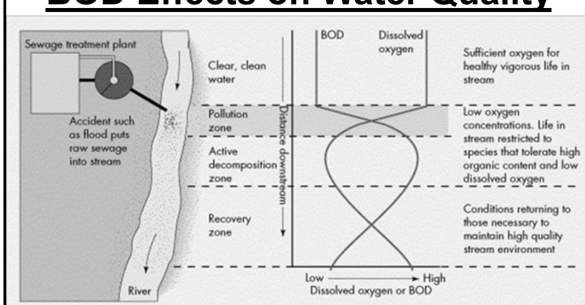


## Key Wastewater Constituents

- BOD – Biochemical Oxygen Demand
  - Typically, a five-day test is used to determine the quantity of oxygen used by microorganisms.
  - The higher the BOD concentration, the greater the wastewater strength (organic matter or food).
  - Raw sewage concentrations - 150 to 300 mg/l
  - Valid five-day BOD testing conditions:
    - BOD incubator temperature - 20°C
    - DO uptake - 2.0 mg/l
    - DO remaining after five days -1.0 mg/l



## BOD Effects on Water Quality



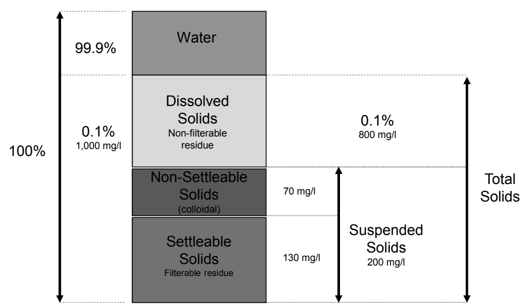

All streams have capacity to degrade organic waste; problems occur when stream is overloaded

## Key Wastewater Constituents

- TSS – Total Suspended Solids
  - Substances in wastewater that can be removed by physical means
  - Sedimentation and filtration unit processes are used to remove TSS from wastewater
  - Raw sewage concentrations -150 to 300 mg/l
  - Valid TSS testing conditions:
    - Temperature in a drying oven - 103°C
    - VSS burn off at 550°C



## Wastewater Solids






## Key Wastewater Constituents

- pH
  - An expression of the intensity of basic or acidic conditions, 0 (most acidic) to 14 (most basic); 7 neutral
  - Microorganisms most active 6.5 - 8.0
  - Nitrification is inhibited at pH 6.0 or less
- Alkalinity
  - Measure of wastewater ability to buffer pH change
  - Nitrification is inhibited when alkalinity < ~ 60 mg/L
- Pathogenic organisms
  - Total Coliform and E-coli indicators
  - Numbers are limited in permit

## Nutrients

- TN – Total Nitrogen
  - Soluble and particulate
    - Org-N - Organic nitrogen
    - $NH_3$ – Ammonia
    - $NO_2$ – Nitrite
    - $NO_3$ – Nitrate
- TP – Total Phosphorus
  - Soluble and particulate
    - $PO_4$ – Ortho-phosphorus
    - Org-P – Organic Phosporus
    - Poly-P - Polyphosphates



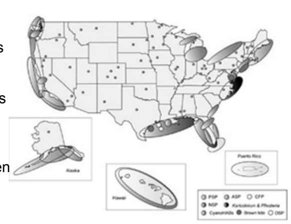
## Nutrients

- TN – Total Nitrogen (Org-N + $NH_3$ + $NO_2$ + $NO_3$)
- TP – Total Phosphorus ($PO_4$ + Org-P + Poly-P)



## Extent of N and P Impacts

- 14,000 Nutrient-related Impairment Listings in 49 States
- ~80% of Assessed Continental U.S. Coastal Waters exhibit eutrophication
- ~50% of streams have medium to high levels of nitrogen and phosphorus



Occurrence of Algae throughout the U.S.

## Regulator Driver

Chesapeake Bay Regulations



## Nutrient Removal

- **Why remove Nutrients (nitrogen and phosphorus):**
  - Nutrients contribute to algae growth
  - Excess algae growth (Eutrophication) causes water quality issues:
    - Loss of water clarity
    - Limitation on sunlight penetration
    - Oxygen depletion
    - Fish and marine life die-off
    - Submerged aquatic vegetation (SAV) die-off



## Nutrient Removal

| Nutrient | Removal Process |
|---|---|
| Nitrogen | • Nitrification<br>  • Ammonia Conversion<br>  • $NH_3^+$-N to $NO_3^-$N<br>  • Oxygen and alkalinity needed<br>• Denitrification<br>  • Nitrate Removal<br>  • $NO_3^-$-N to Nitrogen gas ($N_2$)<br>  • Carbon source needed |
| Phosphorus | • Physical Incorporation<br>• Biological Uptake<br>  • Conventional<br>  • Excess<br>• Chemical Precipitation |

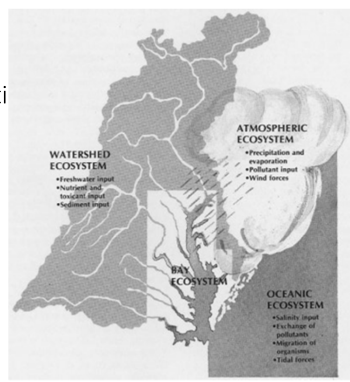
## Nutrient Removal

| FORM | Removal Mechanism | LOT[1], mg/L |
|---|---|---|
| **TN** | | **< 1.5** |
| $NH_3$-N | Nitrification | < 0.1 |
| $NO_3$-N | Denitrification | < 0.1 |
| Org-N: | | |
| Particulate | Solids Separation | < 0.5 |
| Soluble | Ammonification | 0.5 – 1.0 |
| **TP** | | **< 0.05** |
| Particulate | Solids Separation | < 0.05 |
| Soluble | Biological uptake and chemical precipitation | < 0.05 |

[1] LOT – Limit of Technology



## Ecosystems Affecting the Bay






## Chesapeake Bay Watershed

- The largest estuary system in the contiguous United States
- Watershed is almost 64,000 square miles
- Surface area of the Bay is 3,830 square miles
  - Of these, 153 square miles are tidal fresh waters
  - 3,562 square miles constitute the mixing zone
  - 115 square miles are salt waters

## The Chesapeake Bay Program

- In 1983, the Chesapeake Bay Program (CBP) creat
  - In a 1987 Agreement, water quality targets (40% le than 1985 conditions) for 2000 were established
- Chesapeake Bay 2000 Agreement
  - USEPA, MD, VA, DC, PA and the Chesapeake Bay Commission – Signatories to agreement
  - USEPA has the lead on setting water quality standa for the Bay
  - States develop plans (Tributary Strategies) and implement actions
  - 2010 - Target Date to meet water quality standards, remove the Bay from the impaired waters list, and to avert the need for TMDLs
- **Beyond 2010 – TMDLs and consent decrees**
  - **2017 is new interim target date**
  - **2025 is new target date**



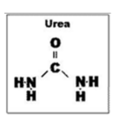

## Nutrient Removal - Basics

- In Bay watershed, **Nutrients (nitrogen and phosphorus)** contribute to algae growth
- Excess nutrients lead to excess algae growth
- Excess algae growth depletes oxygen and blocks sunlight penetration in water
- Submerged aquatic vegetation (SAV) dies off due to lack of sunlight (photosynthesis)
- Marine organisms die-off due to lack of DO

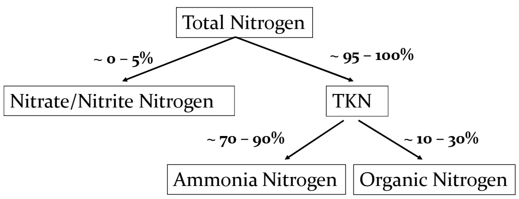


## Sources of Nitrogen in Wastewater

- Human Wastes
  - Digested/wasted food (Proteins)
    - Vegetables
    - Meats
  - Urea (converted Ammonia)
- Cleaning products (Ammonia)



## Forms of Nitrogen in Wastewater






## Forms of Nitrogen

| FORM | REMOVAL PROCESS |
| --- | --- |
| • Organic-N | • Converts to ammonia forms; **a small soluble portion is non-reactive (1.0 mg/l)** |
| • Ammonia(um) ($NH_3/NH_4^+$) | • Most abundant form; converts to nitrites/nitrates under aerobic conditions (nitrification) |
| • Nitrite ($NO_2^-$)/Nitrate ($NO_3^-$) | • Converts to $N_2$ under anoxic (no oxygen) conditions (denitrification) |



## Forms of Nitrogen

- Ammonia(um) ($NH_3/NH_4^+$)
- Organic Nitrogen (Org-N)
- Nitrogen Gas ($N_2$)
- Nitrite ($NO_2^-$)
- Nitrate ($NO_3^-$)

*TKN (Un-oxidized)*

*$NO_x$ (Oxidized)*

Total Nitrogen (TN) = TKN + $NO_x$

TKN = Total Kjeldahl Nitrogen

## Sources of Phosphorus in Wastewater

- Human Wastes
  - Digested/wasted food
  - Water softening products
- Organo-phosphorus flame retardants in children's clothing
- Corrosion and Scale Control
  - Sodium Hexametaphosphate



## Phosphorus Compounds

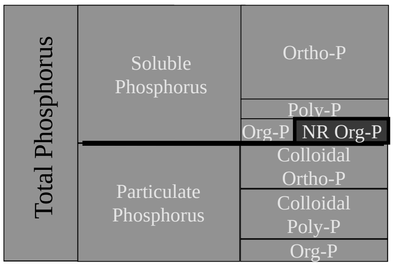
- Commercial sources: Phosphate/Apatite rock
  - hydroxylapatite $Ca_5(PO_4)_3OH$
  - fluorapatite $Ca_5(PO_4)_3F$
  - chlorapatite $Ca_5(PO_4)_3Cl$
- Uses:
  - $H_3PO_4$ - Phosphoric Acid – soft drinks, fertilizers, and water conditioning (stabilization)
  - Sodium phosphates (ortho and poly) – water conditioning:
    - $Na_3PO_4$ – Trisodium phosphate
    - $Na_5P_3O_{10}$ - Sodium tripolyphosphate
  - Calcium phosphates:
    - $Ca(H_2PO_4)_2 \cdot H_2O$ - Additive in baking powder and fertilizers
    - $CaHPO_4 \cdot 2H_2O$ - Additive in animal food and toothpowder



## Forms of Phosphorus

| FORM | REMOVAL PROCESS |
|---|---|
| • Organic-P | • Converts to polyphosphate and orthophosphate forms; **a small soluble portion is non-reactive (0.05 mg/l)** |
| • Orthophosphate | • Most abundant form; chemically reactive and consumed by biological growth |
| • Polyphosphates | • Possibly reacts with metal salts; can be used for biological growth |

## Forms of Phosphorus






## Wastewater Nutrients, mg/l

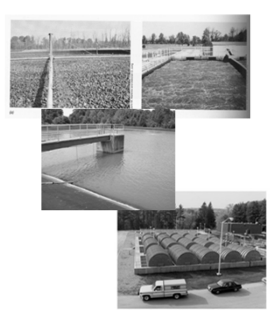
- TN – Total Nitrogen ($NH_3$ + $N_{org}$ + $NO_3$ + $NO_2$)
- TP – Total Phosphorus ($PO_4$ + $P_{org}$ + $P_{poly}$)

| Raw Wastewater Concentrations, mg/l | | |
|---|---|---|
| Nutrient | WWTPs, Average | Bay WWTPs Range |
| TN | 35 – 40 | 30 - 45 |
| TP | 4.0 – 6.0 | 3.0 – 7.0 |



## Wastewater Treatment

- **Secondary (Biological) Treatment**
  - Purpose - BOD removal - Nitrification
  - Processes
    - **Activated sludge (suspended growth)**
    - **Fixed film (attached growth)**
    - Stabilization Ponds
  - Disposal of sludge and scum



## Biological (Secondary) Treatment

- Influent contains high levels of organic material
  - Biological Oxygen Demand – (~150 mg/l)
  - Organic nitrogen – (~20 mg/l)
  - Organic phosphorus – (~2 mg/l)
- Three common biological treatment processes:
  - **Activated sludge**
  - **Trickling filters/RBCs**
  - Stabilization ponds (Lagoons)



## Activated Sludge

- **Secondary treatment** - the biological treatment of wastewater:
  - Activated sludge is a type of secondary treatment
  - Removes a high level of biodegradable organic pollutants (BOD) to protect receiving water quality that sedimentation (Primary) alone can't provide
- **Activated Sludge** - a mixture of bacteria, fungi, protozoa (single cell), and metazoan (multi-cell) microorganisms maintained in suspension by aeration or mixing



## Nutrient Removal

BNR Program

## BNR Program

- EPA created the Chesapeake Bay Program in 1983; first Chesapeake Bay agreements signed in 1987
- BNR Programs initiated by Bay states
- For WWTPs greater than 0.5 mgd:
  - 95% of wastewater discharged into the Bay
  - Grant funding available for WWTP upgrades
- WWTP discharge goals:
  - Reduce TP from ~ 6 mg/l to < 3.0 mg/l
  - Reduce TN from ~ 20 mg/l to < 8.0 mg/l

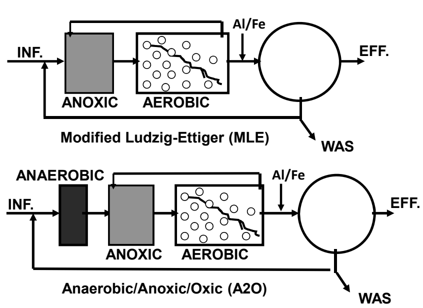


## BNR Program

- To reduce total phosphorus concentrations, most WWTPs began adding chemicals like $FeCl_3$ or alum
- To reduce total nitrogen concentrations, most WWTPs initiated a capital improvement project to add "Pre" anoxic zones to already existing nitrification processes for partial denitrification



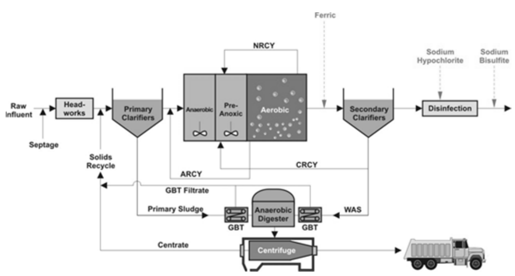
## Biological Nutrient Removal



BNR

Aeration of BNR/ENR Processes 184

Typical BNR Activated Sludge System

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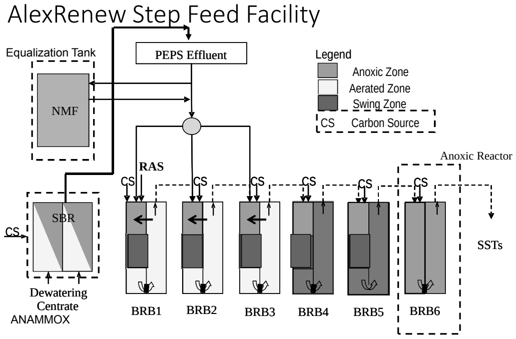
Modified Ludzack-Ettinger - MLE

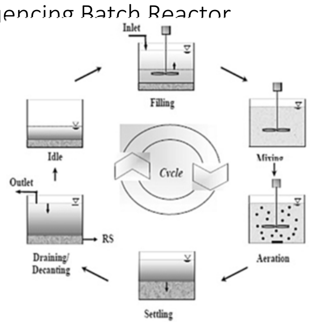
Aeration of BNR/ENR Processes 186

## AlexRenew Step Feed Facility






## Sequencing Batch Reactor

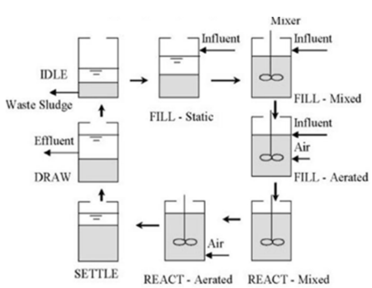



Denitrification

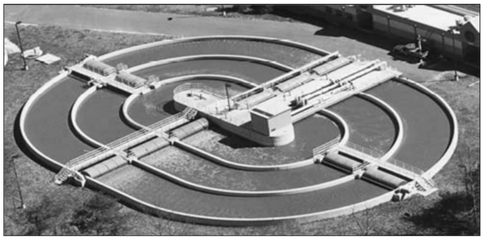
Nitrification



## Sequencing Batch Reactor



# Oxidation Ditch





## BNR Processes

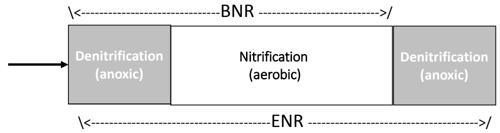
| Process | Nitrogen | Phosphorus | Comments |
|---|---|---|---|
| MLE | Good | None | - Moderate basin volume |
| Step Feed | Good | None | - No nitrate recycle |
| SBR | Moderate | Inconsistent | - No nitrate recycle |
| A2O | Good | Good | - Moderate basin volume<br>- Sensitive to DO in return |
| Oxidation Ditch | Excellent | Good | -Long HRT and SRT<br>- Tight DO controls necessary |



## Nutrient Removal

BNR to ENR

## Common BNR/ENR Configurations




- BNR:
  - Modified Ludzack-Ettinger (MLE)
  - Anaerobic/Anoxic/Oxic (A2O)
  - University of Cape Town Process (UCT)
- ENR:
  - Enhanced MLE/4-stage Bardenpho
  - MLE with Denitrification Filter

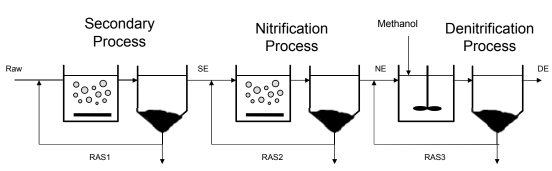


## Milestones

- 1968 Barth proposes 3-sludge, activated sludge process for nutrient removal
- 1970 Savage patents denitrification filter
- 1973 Barnard in South Africa develops the Modified Ludzack-Ettinger process, which becomes the standard for the wastewater industry

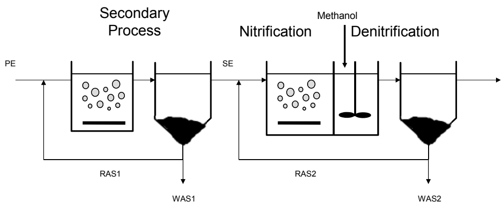


## Three Stage System for BOD Removal and Nitrogen Removal to <3 mg/L




Western Branch WWTP, WSSC 30 MGD (late 1980s)

## Two Sludge System for BOD Removal and Nitrogen Removal to <5 mg/L




Blue Plains, DC Water 370 MGD (beginning early 1990s)

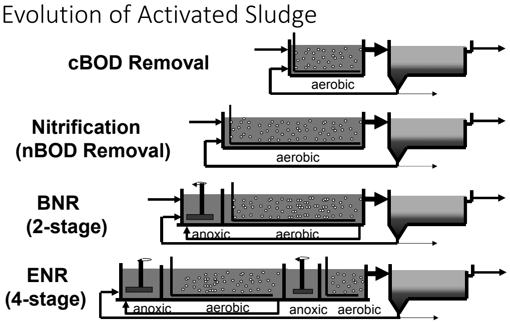


## Milestones

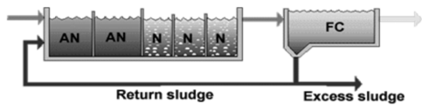
- 1975 Barnard patents Bardenpho® process
- 1976 Specter patents AO® and A2O® processes
- 1977 Jervis develops fluidized bed denitrification reactor
- 1980 University of Cape Town (UCT) process developed



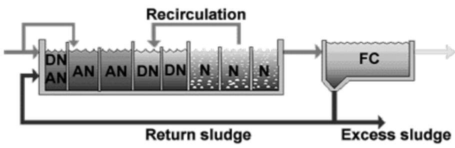
## Evolution of Activated Sludge



## A/O Process (Anaerobic/Oxic)



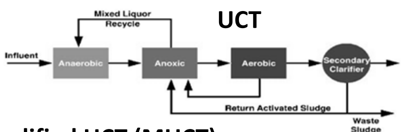

## A2/O (Anaerobic/Anoxic/Oxic)



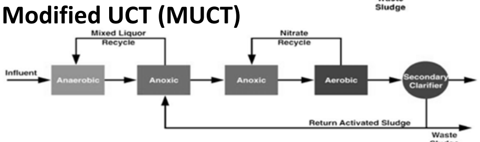



## UCT Processes

### UCT




### Modified UCT (MUCT)




For biological uptake of phosphorus and partial removal of nitrogen



## ENR Program

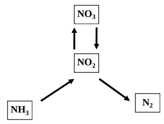
- New Chesapeake Bay Agreement enacted in 2000; ENR Program began in that same year
- For WWTPs greater than 0.5 mgd
  - 95% of wastewater discharged into the Chesapeake Bay
  - Grant funding available for upgrades
- WWTP discharge reduction goals:
  - Reduce TP from < 3.0 mg/l to < 0.3 mg/l
  - Reduce TN from < 8.0 mg/l to < 3.0 mg/l

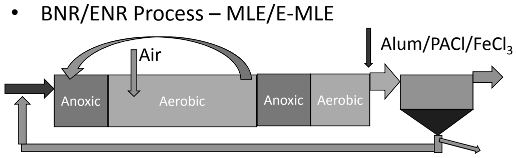
## Nutrient Removal Strategies

- Nitrification (*Nitrosomonas, Nitrobacter, and Nitrospria*)

  $NH_3 + O_2 \rightarrow NO_2^- \rightarrow NO_3^-$
- Denitrification

  $NO_3^- + \text{organics} \rightarrow CO_2 + N_2$
- BNR/ENR Process – MLE/E-MLE






## Nutrient Discharge Limits - TP

Typical **Total Phosphorus** Standards, mg/l

- Moderate 1.0 - 2.5 (BNR): after 1983

  **Bay Target < 0.3 (ENR): after 2000**
- **Potomac River < 0.18 (ENR)**
- Very Severe < 0.1
- LOT/SOA(a) < 0.05

(a) Limit of Technology/State of the Art



## Nutrient Discharge Limits - TN

Typical **Total Nitrogen** Standards, mg/l

- Moderate 3.0 – 5.0 (BNR): after 1983

  **Bay Target < 3.0 (ENR): after 2000**
- Severe < 2.5
- Very Severe < 1.5
- LOT/SOA(a) < 1.0

(a) Limit of Technology/State of the Art

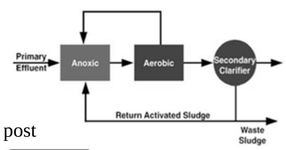
## Milestones

- 1975 Barnard patents Bardenpho® process
- 1976 Specter patents AO® and A2O® processes
- 1977 Jervis develops fluidized bed denitrification reactor
- 1980 University of Cape Town (UCT) process developed

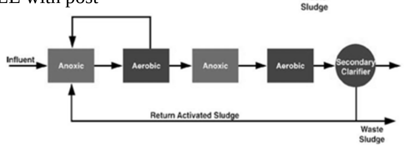


## Example of BNR to ENR

MLE

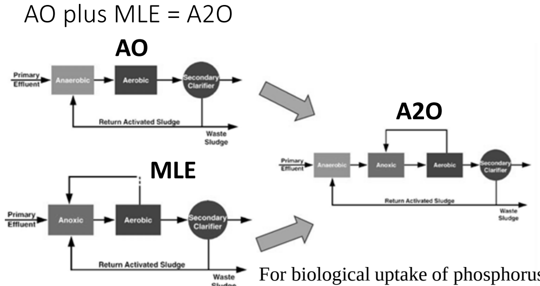



Enhanced MLE with post anoxic zone



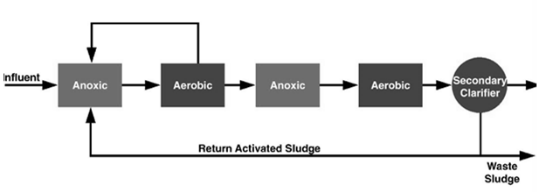



## AO plus MLE = A2O




For biological uptake of phosphorus and partial removal of nitrogen

## Bardenpho
(Enhanced Modified Ludzack Ettinger)



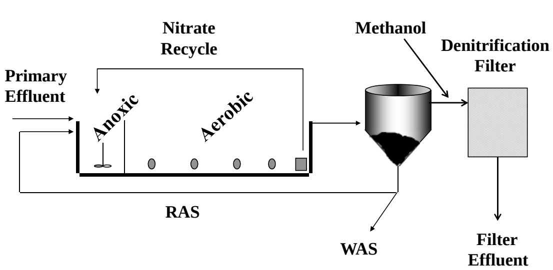



## Enhanced Nutrient Removal (ENR)

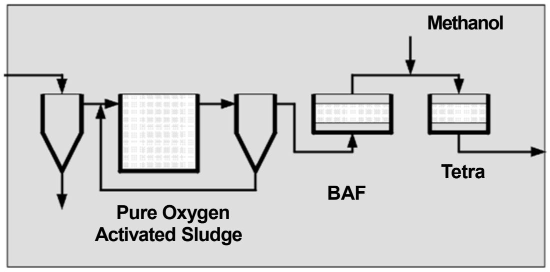
- Over the past two decades, BNR facilities have been upgraded with automation and new technologies to improve nitrogen removal efficiencies:
  - Integrated Fixed Film Activated Sludge (IFAS) to enhance nitrification
  - Mixed Bed Bio-reactors (MBBR)
  - Biological Aeration Filters (BAF) for nitrification
  - Tertiary denitrification filters



## MLE With Denitrification Filter



## Patapsco WWTP
## Baltimore, MD



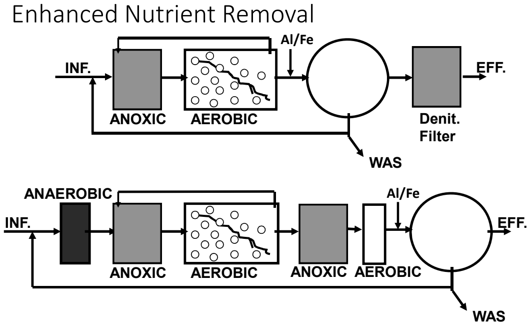



## ENR Program

- To further reduce total phosphorus concentrations, most WWTPs began adding increased quantities of chemicals
- To further reduce total nitrogen concentrations, most WWTPs initiated a capital improvement project to add "Post" anoxic zones to already existing BNR facilities



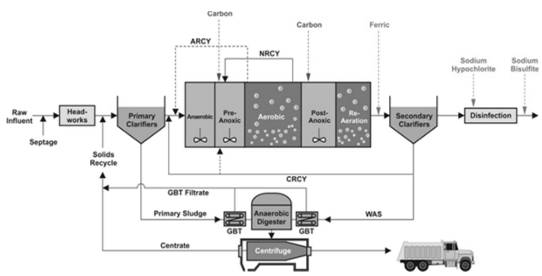
## Enhanced Nutrient Removal



## ENR

Aeration of BNR/ENR Processes 214

## Typical ENR Activated Sludge System




Aeration of BNR/ENR Processes 215

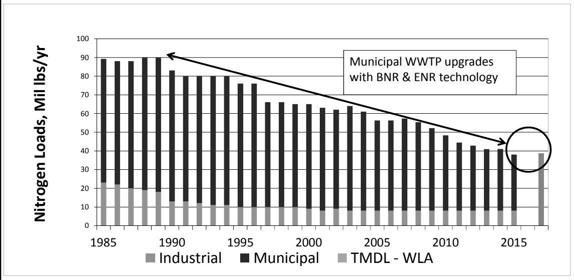
## ENR Processes

| Process | Nitrogen | Phosphorus | Comments |
|---|---|---|---|
| Enhanced MLE (Bardenpho) | Excellent | None | - Large basin volume<br>- Need for methanol |
| Modified UCT | Good | Excellent | -Separate anoxic zone for RAS<br>- Several nitrate recycle streams<br>- Increased complexity |
| 5-stage Bardenpho | Excellent | Good | - Larger reactor volume<br>- Need for methanol |
| Oxidation Ditch | Excellent | Good | -Long HRT and SRT<br>- Tight DO controls necessary |

Aeration of BNR/ENR Processes 216

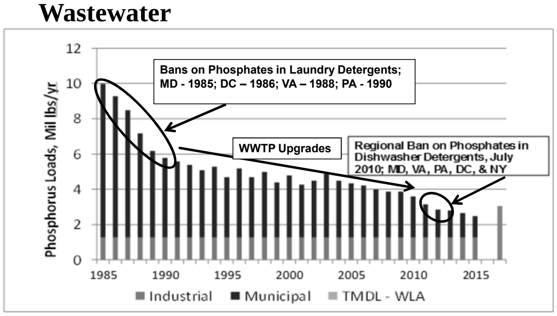
## TN Loadings to the Chesapeake Bay Wastewater

**(Million pounds/year)**



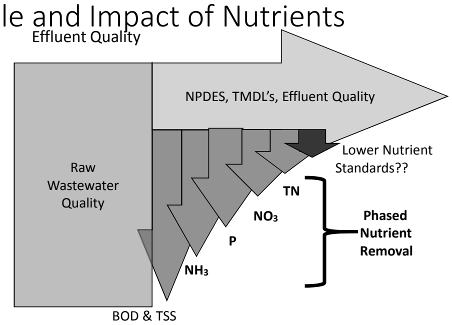



## TP Loadings to the Chesapeake Bay Wastewater






## Role and Impact of Nutrients



## How will future regulations affect Activated Sludge Processes?

Regulatory Challenges:

- Clean Water Act (CWA)
- Chesapeake Bay Program
- State Ordinances
  - Nutrients
  - Sludge
- Local Ordinances



## BNR/ENR

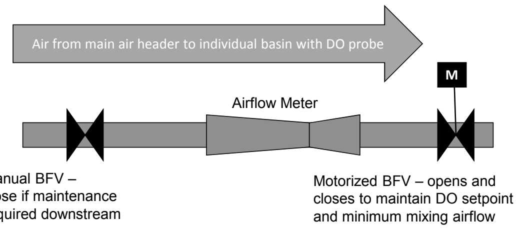
Aeration Control



## DO-Related Process Controls

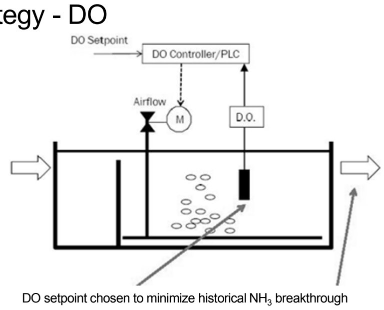
- Main header pressure
- Blower speed
- Number of blowers
- DO control valve positions
- DO probes
- Ammonia probe(s) (optional)

## DO Control: Opening or Closing a MOV to Maintain a DO Setpoint






## Typical MLE Aeration Basin Control Strategy - DO






## New Aeration Basin Control Strategies

- Ammonia-based DO control
- Nitrate-based DO control

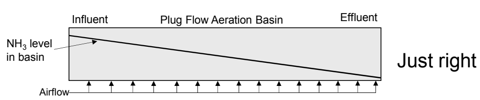
## Objective of Ammonia-Based Aeration Control

- Aeration options:
  - Full nitrification
  - **Incomplete nitrification**
  - Reduce effluent ammonia peaks
- Potential benefits of incomplete nitrification include:
  - Decreased energy expenses (for aeration)
  - Possibly increased denitrification with less supplemental carbon addition
  - Possibly improved Bio-P removal



## Ammonia-Based DO Control

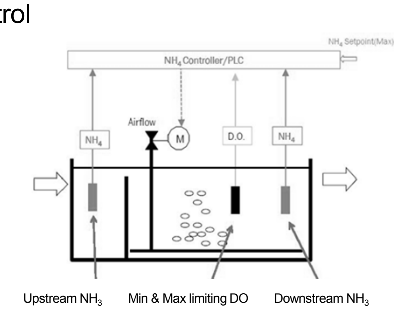
- Operator selects effluent ammonia setpoint
  - Complete nitrification, $NH_3$-N ~ 0.1 mg/L
  - Incomplete nitrification, $NH_3$-N ≤ 1.0 to 2.0 mg/L



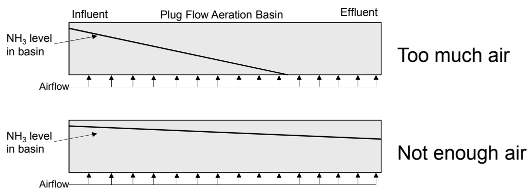

- When effluent ammonia is greater than setpoint, controller increases DO
- When effluent ammonia is below setpoint, controller decreases DO



## Ammonia Feed Forward – Feedback Control



## Ammonia-Based DO Control



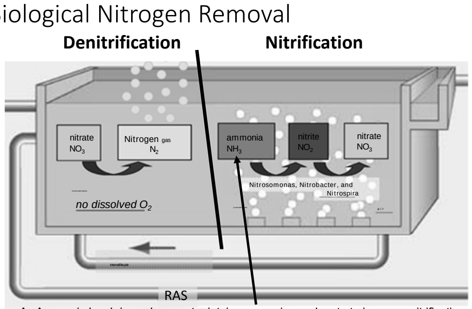



## Ammonia-Based DO Control

- As ammonia concentration increases above set point in the nitrification zone (e.g., ammonia breakthrough)
  - Increase aeration
  - To increase nitrification
  - To decrease ammonia concentration



## Biological Nitrogen Removal



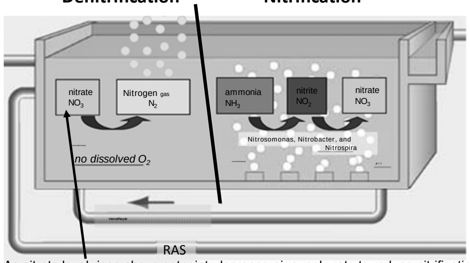
## Nitrate-Based DO Control

- As nitrate concentration increases above set point in the denitrification zone (e.g., incomplete denitrification)
  - Decrease aeration in nitrification
  - To decrease nitrification
  - To decrease nitrate concentration in recycle flow
  - To fully denitrification



## Biological Nitrogen Removal

**Denitrification** **Nitrification**




As nitrate level rises above setpoint, decrease air supply rate to reduce nitrification



## BNR/ENR

Nitrogen Removal

## Keys to Successful Nitrogen Removal

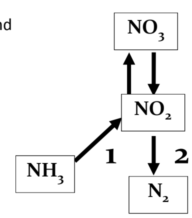
- **Nitrification**
  - Adequate Aerobic SRT – **Keep Solids High!**
  - Adequate D.O./oxygen transfer
  - Adequate Alkalinity/pH
- **Denitrification**
  - **Successful nitrification**
  - Anoxic zones
  - No D.O
  - Carbon



## Nitrogen Removal - Basics

**Nitrification** + **Denitrification** = Nitrogen Removal

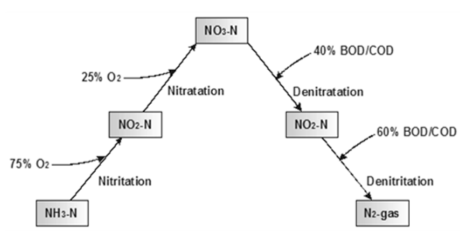
- BNR/ENR converts TKN nitrogen (primarily ammonia) in wastewater to nitrite/nitrate and ultimately ***nitrogen gas***
- BNR/ENR requires two processes:
  - **1: Nitrification ($O_2$ & $HCO_3$ required)**
  - **2: Denitrification (Carbon required)**





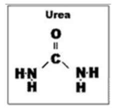

## Simultaneous Nitrification and Denitrification (SNDN)

Traditional pathway of biological nitrogen removal



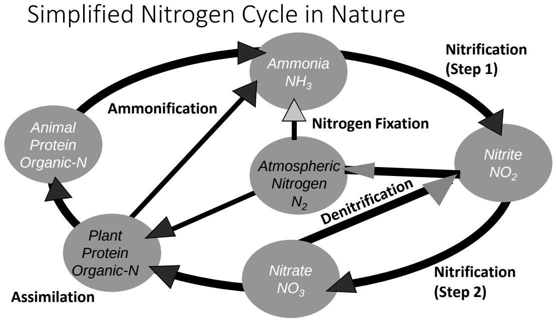
## Sources of Nitrogen in Wastewater

- Human Wastes
  - Digested/wasted food (Proteins)
    - Vegetables
    - Meats
  - Urea (converted Ammonia)
- Cleaning products (Ammonia)



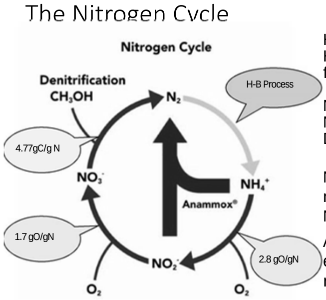



## Simplified Nitrogen Cycle in Nature






## The Nitrogen Cycle




H-B process:
Haber-Bosch nitrogen fixing (chemical) process

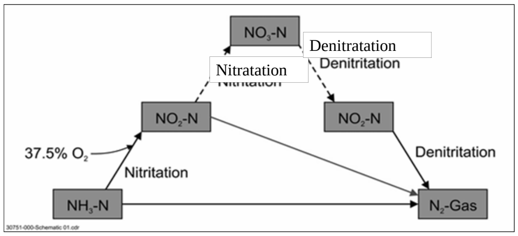
N/DN Uses $O_2$ for Nitrification, Carbon for Denitrification

N/DN can be reduced if not going all the way to Nitrate

Anammox bacteria can eliminate carbon while reducing oxygen to 60%

Nitrification by slow growing temperature sensitive autotrophs

## Deammonification
“ANAMMOX”






## Nitrogen removal

Nitrification



## Nitrification Control Parameters

### Temperature

- Nitrifiers lose about ½ their activity for each 10ºC temperature drop
- In winter, put additional aeration tanks on line, or increase MLSS
- Either action will increase MCRT

## Nitrification Control Parameters

### Dissolved Oxygen

- Maintain MLDO at 2.0 – 4.0 mg/L

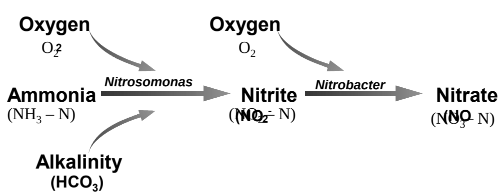
### pH / Alkalinity

- Maintain MLpH > 6.8
- Maintain alkalinity residual of at least 70 mg/L



## Two-step Nitrification

- For 125 years, nitrification was believed to be solely a two-step process:





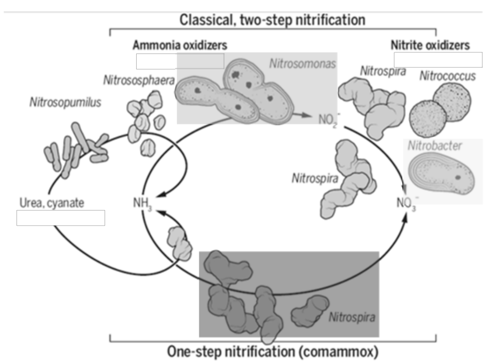

## Two-step Nitrification

- Two-step nitrification depends on two organisms e.g., *Nitrosomonas* and *Nitrobacter*, which was the basis for hundreds of studies on wastewater nitrification
- A single microbe capable of catalyzing both nitrification steps may actually be a benefit by conserving more energy

## One-step Nitrification - Comammox

- **Comammox** (COMplete AMMonia Oxidixer) is the name for a single organism that can convert ammonia into nitrite then nitrate
- Existence of comammox organisms were first predicted in 2006
- In 2015, the presence of comammox organisms was confirmed within *Nitrospira*
- The Nitrogen cycle has since been updated

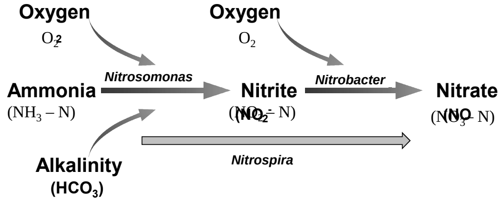




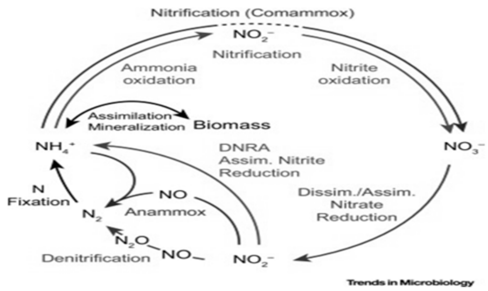



## Nitrification

*The oxidation (as by bacteria) of ammonia and organic nitrogen to nitrites ($NO_2$) and then further oxidation of nitrites to nitrates ($NO_3$).*



## Nitrogen Cycle in Wastewater






## Environmental Conditions for Nitrification

- Nitrifying (Autotrophic) Bacteria
- $CO_2$ Carbon Source for Growth
- Sufficient SRT > 10 days
- Adequate Oxygen ~ 2.0 mg/l
- Adequate Alkalinity to prevent pH drop > 70 mg/l
- Process operating pH range – 6.5 to 8.0
- No Toxics or inhibitory compounds
- Temperature has a significant impact on process



## Nitrification Process Controls

- Temperature
- Flow
- Wasting rate
- SRT
- DO in aeration zone
- pH/Alkalinity in aeration zone
- $NH_3$-N and $NO_x$-N probes:
  - End of aerobic zone
  - Plant effluent
  - At end of anoxic zones

## Optimizing Nitrification

- Minimize influent $BOD_5$
- Optimize dissolved oxygen in aerobic zones
- Optimize internal recycle
- Last step: add alkalinity only if needed



## Obstacles to Achieving Nitrification

- Inadequate aeration capability
- Inadequate biomass quantity (MCRT)
- Poor clarifier hydraulics limiting MLSS in tanks
- Poor sludge settling/excessive filamentous bacteria
- Insufficient alkalinity
- Inhibitory chemicals



## Nitrification Configurations

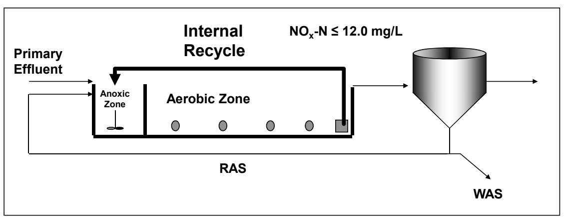
- Suspended Growth
  - Extended aeration AS
  - Oxidation ditch
  - Step feed AS
  - Sequencing Batch Reactor (SBR)
- Fixed Film
  - Up flow Biological Aerated Filters (BAF)
  - Moving Bed Biofilm Reactors (MBBR)
  - Integrated Fixed Film Activated Sludge (IFAS)

## BNR/ENR

Internal Recycle



## Let's Focus on Internal Recycle






## Internal Recycle

- Internal recycle flow rates determine nitrate concentrations in BNR process effluent
  - The higher the recycle flow rate, the lower the effluent nitrate concentrations
  - Process effluent nitrate concentration "set points" can be used to control internal recycle flow rates

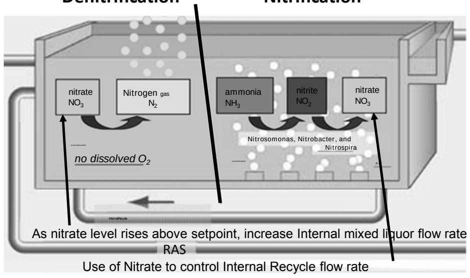
## Nitrate-Based Internal Recycle Control

- As nitrate concentrations increase above set point in the nitrification zone (e.g., excess effluent nitrates)
  - Increase internal recycle from nitrification to denitrification
  - To decrease nitrates in nitrification effluent
  - To fully denitrify



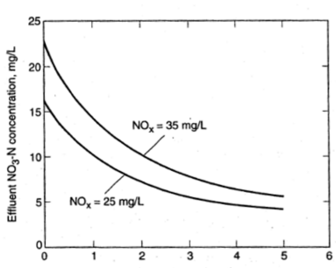
## Biological Nitrogen Removal

**Denitrification** **Nitrification**

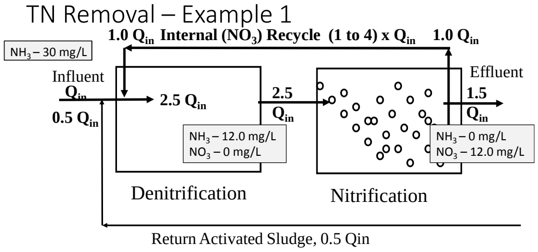





## Impact of Internal Recycle on BNR Effluent TN



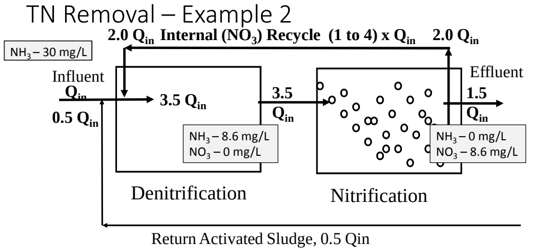
## TN Removal – Example 1




Assume all $NO_3$–N returned to Denitrification is converted to $N_2$
Assume all $NH_3$-N is converted to $NO_3$-N in Nitrification.
What is the $NH_3$-N concentration in Denitrification? $NH_3\text{-N} = \frac{30\ \text{mg/L}}{2.5/1} = 12.0$ mg/l



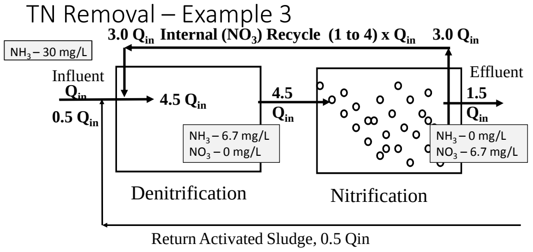
## TN Removal – Example 2




Assume all $NO_3$-N returned to Denitrification is converted to $N_2$
Assume all $NH_3$-N is converted to $NO_3$-N in Nitrification.
What is the $NH_3$-N concentration in Denitrification? $NH_3\text{-N} = \frac{30\ \text{mg/L}}{3.5/1} = 8.6$ mg/l

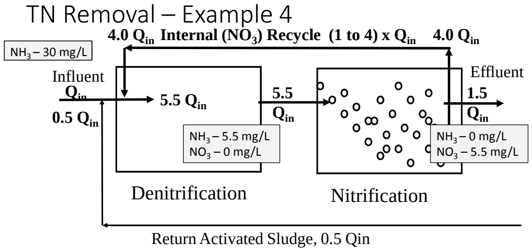


## TN Removal – Example 3




Assume all $NO_3$-N returned to Denitrification is converted to $N_2$
Assume all $NH_3$-N is converted to $NO_3$-N in Nitrification.
What is the $NH_3$-N concentration in Denitrification? $NH_3\text{-N} = \frac{30\ \text{mg/L}}{4.5/1} = 6.7$ mg/l

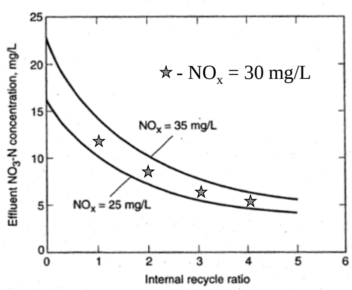
## TN Removal – Example 4




Assume all $NO_3$-N returned to Denitrification is converted to $N_2$
Assume all $NH_3$-N is converted to $NO_3$-N in Nitrification.
What is the $NH_3$-N concentration in Denitrification? $NH_3\text{-N} = \frac{30 \text{ mg/L}}{5.5/1} = 5.5$ mg/l



## Impact of Internal Recycle on BNR Effluent TN






## Denitrification

Note: (Almost) all nitrates returned to the pre-anoxic zone are denitrified

The "goal" $NO_3$-N concentration in the effluent from the pre-anoxic zone should be between 0 and 0.5 mg/L.

# Phosphorus Removal



## Phosphorus Removal

- Source control: Bans on phosphates in detergents (1980s and 2010)
- Background removal:
  - Physical incorporation (Clarifiers)
  - Biological uptake (Aeration)
- Chemical addition with metal salts (Clarifiers):
  - $Al^{+++}$ (Alum, PACl) or $Fe^{+++}$ ($FeCl_3$)

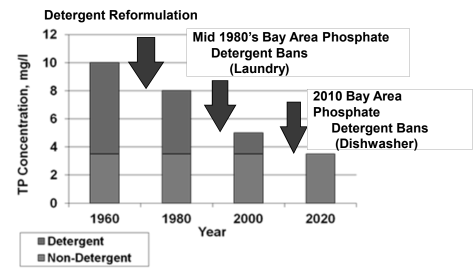


## Phosphate Bans in Detergents

**In the mid-1980's, Maryland, Pennsylvania, Virginia, and the District of Columbia instituted bans on phosphates in laundry detergents.**

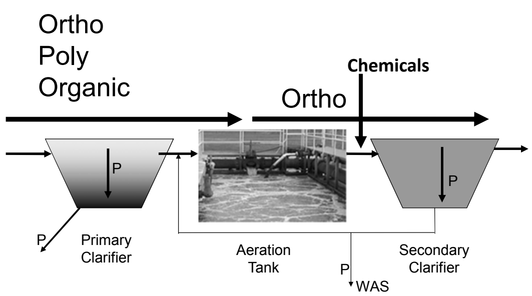

**Nearly 25 years later, a second regional ban became effective on phosphates in automatic dishwasher detergents.**

## Typical Phosphorus Concentrations Raw Wastewater (@ 30% I/I)






## Phosphorus Removal at WWTPs



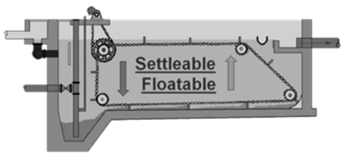



## Background Removal

- Physical removal of particulate phosphorus
- Conventional Biological Uptake
  - To satisfy biological needs
- Enhanced Biological uptake
  - Stress induced
  - Release of phosphorus under anaerobic conditions
  - Uptake of phosphorus under aerobic conditions

## Physical removal of Particulate Phosphorus

- Removal of settleable solids provides some phosphorus removal
- Primary sedimentation – 10 to 25%






# Phosphorus Removal at WWTPs

- Removal of Ortho-P:
  - Biological uptake
  - Enhanced biological uptake
  - Chemical precipitation
  - Chemical adsorption



## Biological Uptake

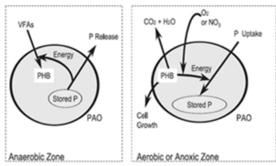
- Conventional Biological Uptake
  - To satisfy biological needs (1.5 to 2.0% by weight)
- Enhanced Biological uptake (5 to 7% by weight)
  - Stress induced
  - Release of phosphorus under anaerobic conditions
  - Uptake of phosphorus under aerobic conditions

## Enhanced Biological P Removal

- Enhanced bio-P removal depends on:
  - Anaerobic conditions (zero dissolved oxygen and zero nitrate)
  - Volatile fatty acids (VFA, rbCOD)
  - Solids management (SRT, WAS, and side streams)

PAO - Phosphate Accumulating Organisms

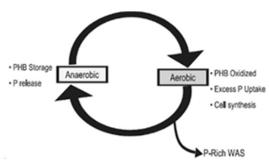
PAO Able to <u>store soluble organics</u> as Polyhydroxybutyrate (PHB)





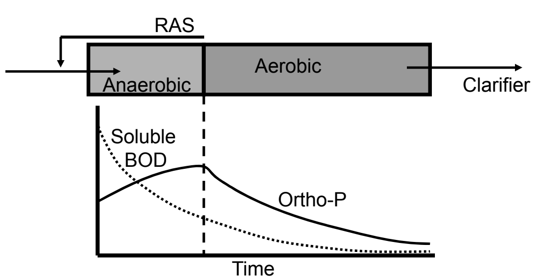

## Enhanced Biological P Removal

- Step 1: Anaerobic Phase
  - BOD removal
  - Phosphorus release
- Step 2: Aerobic Phase
  - Phosphorus uptake and creation of new PAOs
  - Phosphorus removal by sludge wasting



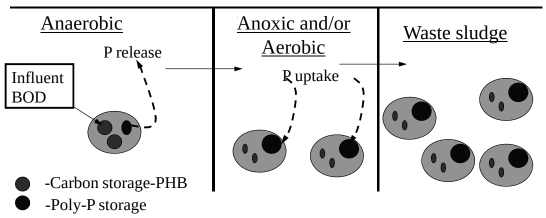



## Enhanced Biological P Removal



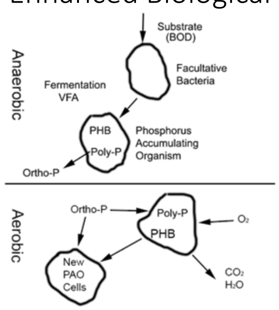
## Enhanced Biological P Removal

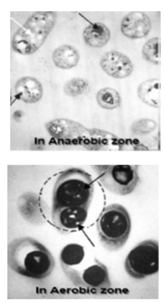
P is removed by phosphorus accumulating organisms (PAOs) and exits system in waste sludge






## Enhanced Biological P Removal



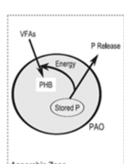






## Enhanced Biological P Removal

Anaerobic Conditions

**Heterotrophic Bacteria Break Down Organics**
- **Fermentation**
  - **Volatile Fatty Acids (VFAs)**
  - **Acetate (Acetic Acid)**

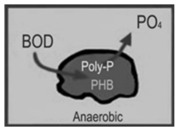



Also:
Selection of **PAO - Phosphate Accumulating Organisms**
(Able to Out-Compete Other Aerobic Heterotrophic Bacteria for Food When Anaerobic)

## Enhanced Biological P Removal

### Anaerobic Conditions

PAO Take Up VFAs and Covert them to Polyhydroxybutyrate (PHB)




PAO Able to <u>store soluble organics</u> as Polyhydroxybutyrate (PHB)

Ortho-P is Released Into Solution

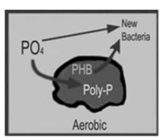


## Enhanced Biological P Removal

### Aerobic Conditions

Rapid Aerobic Metabolism of Stored Food (PHB) Producing New Cells

<u>$PO_4$</u> Used in Cell Production
Excess <u>Stored</u> as Polyphosphate
("Luxury Uptake")





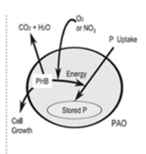

## Enhanced Biological P Removal

### Aerobic Conditions

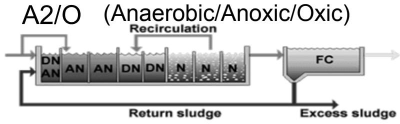
$PO_4$ Used in Cell Production
Excess Stored as Polyphosphate

Biomass 5 to 7% P by Weight

(Normal 1.5 to 2 %)

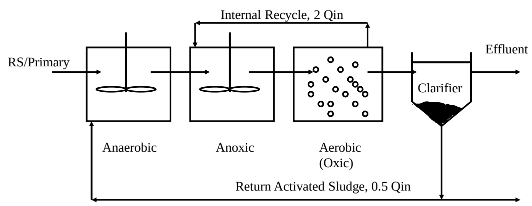



A2/O (Anaerobic/Anoxic/Oxic)



## A20 Process

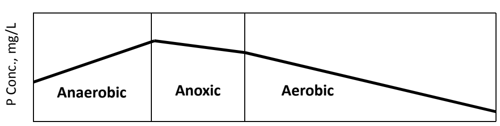
with Anaerobic Zone for Phosphorus Release




| STAGE | PURPOSE |
|---|---|
| Anaerobic | Soluble BOD uptake and phosphorus “release” zone. |
| Anoxic | Denitrification and nitrogen gas release zone |
| Aerobic (Oxic) | Nitrification and phosphorus “uptake” zone |



## Phosphorus Profile – A2O




**Anaerobic zone**
**P - Release**

**Anoxic and Aerobic zones**
**P - Uptake**



## Phosphorus Removal with Chemicals

Ortho Phosphates
*React with*
Metal Salts and Alkalinity
*To form*
Insoluble Phosphorus Compounds

## Phosphorus Removal with Chemicals

- Precipitation and adsorption with chemical addition:
  - Ferric chloride
  - Aluminum sulfate
  - Polyaluminum chlorides (PACl)
- With effluent filtration, TP concentrations can be reduced to ~ 0.05 mg/l



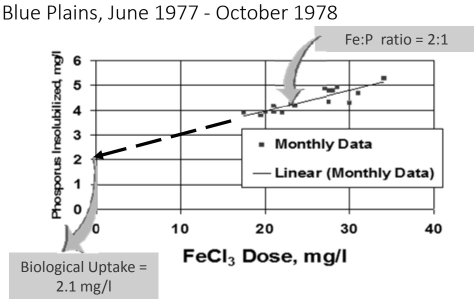
## Phosphorus Removal with Chemicals

**Chemical precipitation** – two mechanisms:

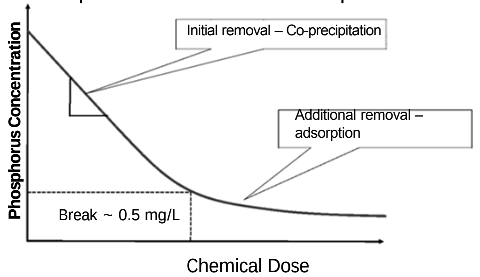
- **Precipitation** (Remove TP to ~ 0.5 mg/l)
  - $\underline{2}Al + 3OH + PO_4$ ----> $\underline{2}Al(OH)_3PO_4$
- **Adsorption** (Remove TP < 0.5 mg/l to ~ 0.05)
  - $x\ (Al + 3OH)$ ---> $x\ (AlOH_3)$
  - $x\ (AlOH_3) + PO_4$ ----> $x\ (Al(OH)_3)\cdot PO_4$
  - x > 2; more chemical required as $PO_4$ levels drop
- Both reactions form Metal (Al or Fe)-Phosphate-Hydroxide sludge



## Precipitation of Phosphorus
Blue Plains, June 1977 - October 1978



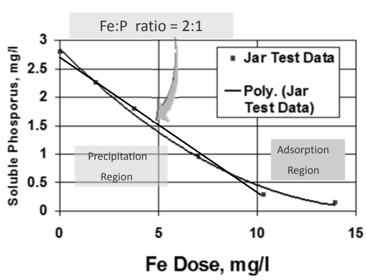
## Precipitation and Adsorption of P






## Precipitation and Adsorption of P

Blue Plains - June 1977



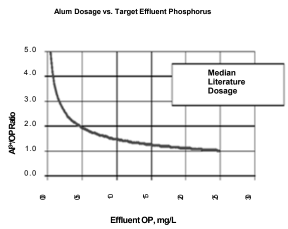



## Chemicals used for Phosphorus Precipitation

| *Chemical* | *Formula* | *Removal mechanism* | *Effect on pH* |
|---|---|---|---|
| Ferric Chloride | $FeCl_3$ M.W. = 162.3 | Metal hydroxides | Removes alkalinity |
| Aluminum Sulfate (Alum) | $Al_2(SO4)_3.14.3(H_2O)$ M.W. = 599.4 | Metal hydroxides | Removes alkalinity |
| Ferrous sulfate (pickle liquor) | $Fe_2SO_4$ | Metal hydroxides | Removes alkalinity |
| Poly Aluminum Chloride | $Al_nCl_{(3n-m)}(OH)_m$ $Al_{12}Cl_{12}(OH)_{24}$ | Metal hydroxides | none |
| Lime | $CaO$, $Ca(OH)_2$ | Insoluble precipitate | Raises pH above 10 |

## Phosphorus Removal w/Chemicals

- Add chemical to precipitate phosphorus
- Alum & ferric chloride
- Consumes alkalinity
- **Increases sludge production**



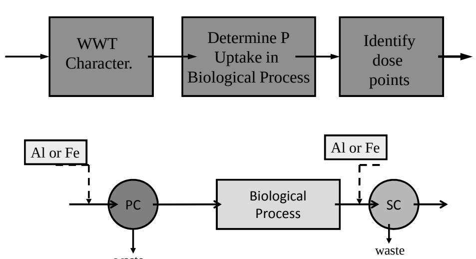



## Chemical Addition Rates

- Dependent on:
  - TP Discharge Limitations
  - Influx TP Loading
  - Biological P Removal Rates
  - Chemical to P Molar Ratios:
    - Al/Fe Salts, Range: 1.6- 2.1 to reach 0.5 mg/l P > 3.0 to reach < 0.25 mg/l P
      > 5.0 to reach < 0.2 mg/l P
      >10 to reach < 0.15 mg/l P
    - Dependent on Alkalinity



## Chemical Addition Only Phosphorus Removal

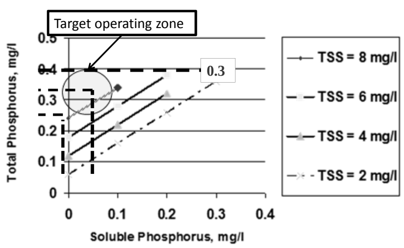


## Gravity Filtration Application

- Removes Residual Bio-Floc
- Removes Residual Chemical/Bio Floc
- Removes Residual Coagulation Particles in Phys-Chem Treatment

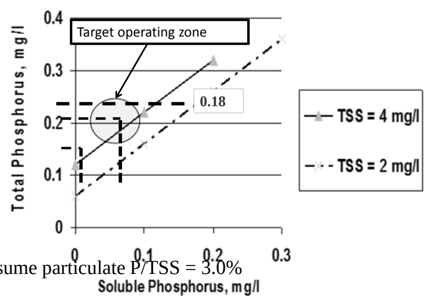
Aeration of BNR/ENR Processes 298

## Effluent TP versus Effluent TSS




Assume particulate P/TSS = 3.0%

## Effluent TP versus Effluent TSS




Assume particulate P/TSS = 3.0%

## Summary

Helpful Hints - Final Comments



## Summary

- Fine bubble diffused aeration devices typically provide the greatest aeration efficiency
  - Sanitaire EPDM discs most established product
  - Aquarius makes a good product
- Membrane panel diffuser manufacturers promise greater efficiencies
  - Increased pressure negates impact of increased SOTE
  - Most effective in denser configurations then typical design



## Summary

- Single stage blowers provide greatest operating efficiency through various load conditions
  - High speed blowers are rapidly establishing themselves in wastewater market
- Automated DO control using ammonia probes in the nitrification process and PLCs to control blower VFDs:
  - Ensures meeting permit conditions
  - Provides cost efficient operations

## Questions?



# Thank You

"Anyone who can solve the problems of water will be worthy of two Nobel prizes – one for peace and one for science."

- John F. Kennedy

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