Operation of Sequencing Batch Reactors for Nutrient Removal

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Operation of Sequencing Batch Reactors for Nutrient Removal

7 Contact hours
9 CC10 hours

Aerobic Sequence Batch Reactors (SBR) are unique configured, activated sludge plants. Central to the SBR design is the use of a single tank for multiple aspects of wastewater treatment, e.g., BODs, TSS's and nutrient removal. The process operates with a single sludge in a single reactor basin to accomplish both biological treatment and solids-liquid separation. Operators will review the SBR processes and become familiar with process control tests and troubleshooting. Topics in this course will include the history of SBRs, process configurations, process operation and controls, aeration and mixing, performance expectations, troubleshooting, and instrumentation and automation control.

1. Discuss the history of Sequencing Batch Reactors.
2. Describe the process of Sequencing Batch Reactors.
3. Identify process control tests for Sequencing Batch Reactors.
4. Describe the instrumentation and automation control of Sequencing Batch Reactors.

Class Agenda:

I History **(30 minutes)**
  A. Origins – 1915
  B. Resurgence – 1970's
  C. Today
II Process Description
  A. Storage/equalization tank **(30 minutes)**
    a. Minimum of two tanks
    b. Conventional screening and grit removal provided as preliminary treatment
    c. Primary sedimentation is not usually required unless influent suspended solids are excessive
  B. Process configurations **(30 minutes)**
    a. Basic/original
    b. Cyclic Activated Sludge System (CASS™)
    c. Intermittent Cycle Aerated Extended System (ICEAS®)
  C. Process Cycle Periods: **(30 minutes)**
    a. Fill
    b. React
    c. Settle
    d. Draw
    e. Idle
    f. Times per period

- D. Cycle options: **(30 minutes)**
    - a. Flow-paced
    - b. Time-paced

III Process Operation and Control

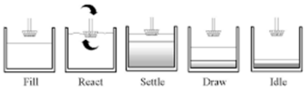
- A. Process control tests **(60 minutes)**
    - a. Organic loadings
    - b. Solids inventory
    - c. Sludge Quality – SSV's and SVI's
    - d. Nutrients
        - i. NH_3
        - ii. NO_x
        - iii. PO_4
    - e. Trouble shooting analyses:
        - i. pH
        - ii. ORP
        - iii. Alkalinity
- B. Aeration and Mixing **(30 minutes)**
- C. Performance expectations: **(30 minutes)**
    - a. BOD5 and TSS removal
    - b. Nutrient Removal
- D. Troubleshooting: **(60 minutes)**
    - a. Observations
    - b. Condition
    - c. Process control analysis
    - d. Possible causes
    - e. Control actions

IV Instrumentation and Automation Control (I&CA) **(60 minutes)**

- A. SCADA
- B. PLC's and RTU's
- C. Sensors and analyzers
- D. Loop controls

V. Summary and Conclusions **(30 minutes)**

Sequencing Batch Reactors



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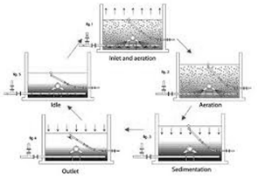


Process Training Sessions

Before class starts, please:
- **Sign in** on Attendance Sheet

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

At the end of class, please:
- Answer questions on Post Test
- Evaluate the class on form provided

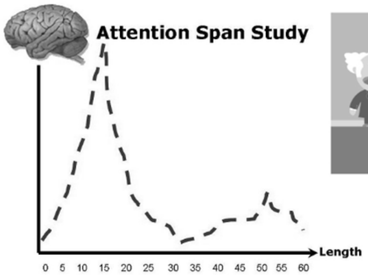
Housekeeping

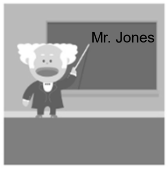
- Start time – 8:00 am
- Please mute/silence cell phones
- 10-minute Breaks – every hour
- Lunch ~ 11:30 am – 12:30pm
- End class ~ 3:30 – 4:00 pm

Instructor Expectations

- Begin and end class on time
- Be interactive
- Share experiences and needs
- **Less lecture, more discussions**
- ***Make this an enjoyable and informative experience!***

Attention Span - Lectures





Source: based on a study by Richard Mayer

Ground Rules

- Discussion is encouraged
- Participate at your own comfort level
- Use terms and examples, we all can understand
- Everyone is different, so please show respect for others in the room
- Listen with an open mind
- Express opinions - of things, not people
- Maintain confidences

Introduction

Class Objectives

Why are we Here?

- This class is intended to aid SBR plant operators improve operations through:
  - Monitoring and process control testing:
    - DO
    - NH_3; NO_X (NO_2, NO_3)
    - PO_4
    - ORP/pH
  - Automation using:
    - Probes
    - Analyzers

Learning Objectives

1. To inform operators on equipment components; cycles and phases; and operational concepts of SBRs
2. To identify process control, monitoring strategies and process adjustments to enhance:
   - BOD and TSS removal
   - Nitrogen removal
   - Phosphorus removal

Agenda

- Overview
  - – Introduction – SBR characteristics
  - – SBR cycles and phases
- ENR and phosphorus removal
  - – Nitrogen removal
  - – Phosphorus removal
- Troubleshooting
  - – Nitrification/denitrification
  - – High decant BOD and TSS
  - – Changes in pH and alkalinity

Ice Breaker and Discussion

- Let's introduce ourselves:
  - – Name
  - – Plant location
- Facilitated discussion:
  - – How well is your SBR plant working?
  - – Is your plant:
    - Automated?
    - Meeting nutrient removal standards?
  - – Is there room for improvement?

(Allow 20 to 30 minutes for reflection and discussion)

SBR Overview

History, SBR Cycles and Phases

Open Sewers – 1800s

Need for Wastewater Treatment

- Epidemics (e.g., cholera) triggered interest in constructing sewage collection systems in large European cities:
  - Berlin: 1830
  - London: 1830
  - Hamburg: 1842

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)
- **1914 – Activated Sludge Process (Ardern and Lockett)**

Early History of Activated Sludge

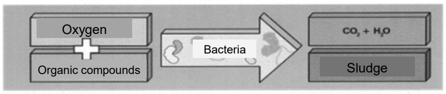
- 1898 - formation of the Royal Commission on Sewage Disposal in England
- In the early 1900's, England and the US were seeking small footprint wastewater treatment solutions
- 1912 - Famous "30:20 + full nitrification" effluent standard was adopted in England
- New stringent BOD_5 effluent standard inspired creation of the activated sludge process

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"

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

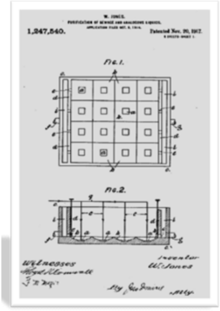
- From 1913 – 1915, in England;
  - Lab-scale suspended biomass experiments were performed in England by Edward Ardern and his co-worker, William Lockett under the direction of Dr. Gilbert Fowler

Early History of Activated Sludge

- In separate studies, Walter Jones of Jones and Attwood, Ltd. developed practical applications of the activated sludge process
- 1913 English patents by Jones and Attwood, Ltd
  - 25 cents/capita royalties paid by most WWTPs

Early History of Activated Sludge

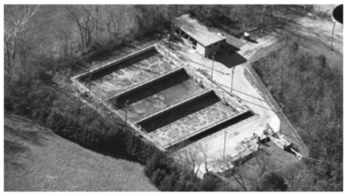
- Walter Jones' U.S. activated sludge patent 1,947,540 was issued in 1917 and expired in 1934
- The last of the Jones' US patents expired in 1935



Early History of Activated Sludge

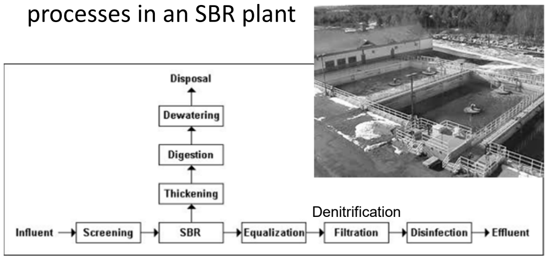
- 1914/1915 - Ardern and Lockett published their research findings on aeration of suspended solids (e.g., MLSS)
  - Added the concept of recycling sludge
  - First to use the term “activated sludge”
- 1915 First full-scale activated sludge plant in Salford, England
  - **80,000 gpd at fill-and-draw operation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

Sequencing Batch Reactors



SBR Unit Processes

- Below is a flow chart of possible unit processes in an SBR plant



SBR Systems

- SBR systems can have either circular, square or rectangular tanks

Sequencing Batch Reactor

- Fill-and-Draw activated sludge process
- Treatment cycle can be adjusted to allow:
    - Aerobic conditions – BOD removal and nitrification
    - Anoxic conditions – denitrification
    - Anaerobic conditions – biological phosphorus release

ENR Stages

- <u>Anaerobic stage</u> - No oxygen nor NO_3-N; Phosphorus is released; enhances greater TP uptake in the aerobic stage
- <u>Anoxic stage</u> – No oxygen; NO_3-N is converted to N_2 gas (Denitrification)
- <u>Aerobic stage</u> – Plenty of oxygen; NH_3-N is converted to NO_3-N (Nitrification)

Microorganisms

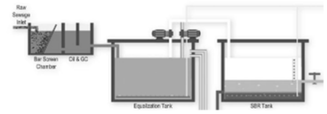
- **Aerobic** (Oxic) - Organisms requiring, or not destroyed, by the presence of free oxygen
- **Anoxic**: Organisms requiring , or not destroyed, by the absence of free oxygen; nitrates ($\underline{NO_3}$) are present.
- **Anaerobic** - Organisms requiring, or not destroyed, by the absence of free 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

SBR Systems

- Typically SBR plants consist of:
  - Equalization basins
  - Two or more treatment basins
  - Preliminary treatment, such as bar screens to remove rags, sticks and other debris

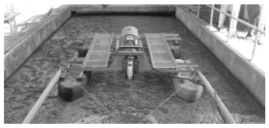
SBR Systems

- It is recommended that SBR systems have an influent-flow equalization tank:
  - To handle wet-weather flow increases
  - To remove scum and grease from a single point prior to plant entry



SBR Systems

- Effluent from the SBR basins should also go into a flow equalization tank
  - Allows effluent to be metered
  - Reducing the adverse effects on disinfection or other downstream processes caused by surging flow



SBR Systems – Process Control

- Process control testing is essential
  - DO, pH and alkalinity testing
  - Nutrient analyses - NH_3, NO_X (NO_2 and NO_3), PO_4
  - Oxidation Reduction Potential (ORP)
- Location of the online probes should be placed to allow easy access
- Probes must be maintained and calibrated

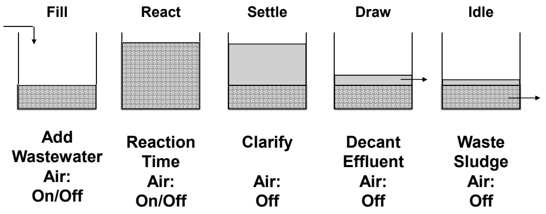
Sequencing Batch Reactor

- Total nitrogen limits of less than 5 mg/l can be achieved
  - Through nitrification in react phase and denitrification in settle and mix-fill phases
  - If more stringent TN discharges are required, then post denitrification filters should be considered
- Phosphorous limits of 2 mg/l or less can be met through biological uptake and chemical addition (aluminum or iron salts)

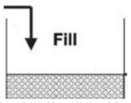
Sequencing Batch Reactor

- The SBR process cycle consists of five stages sequentially operating in the same tank:
  - Filling (Static, mixed or aerated)
  - Reaction (Air on or off; mixers on)
  - Clarify/Settle (Air and mixers off)
  - Decant/Effluent draw (Air and mixers off)
  - Idle (Sludge waste)

Sequencing Batch Reactor

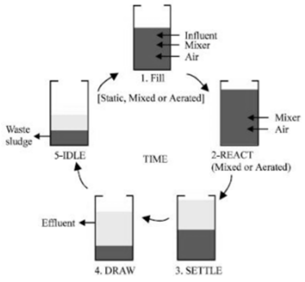


Fill Phase

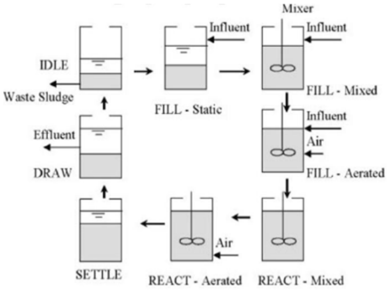


- SBR receives influent wastewater
- Mixing and aeration can be varied:
  - **Static Fill** – No mixing or aeration occurs during fill creating anaerobic conditions; e.g., PO_4 release
  - **Mixed Fill** – Mixers are active, but aerators remain turned off to create anoxic conditions promoting denitrification
  - **Aerated Fill** – Mixers and aerators are both on to convert anoxic conditions to aerobic conditions for PO_4 uptake and to reduce BOD loads before the React Phase

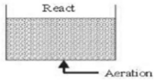
Sequencing Batch Reactor



Sequencing Batch Reactor

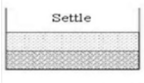


React Phase



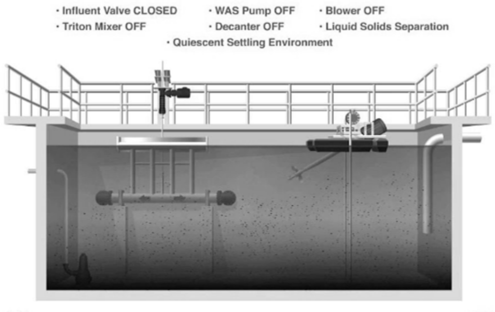
- No more influent enters the basin during this phase
- Mixers and aerators are turned on for:
  - Carbonaceous BOD removal
  - Nitrification
  - Biological phosphorus uptake

Settle Phase

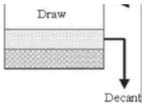


- Aeration and mixing equipment are turned off allowing the activated-sludge to settle
- Sludge blanket must settle enough as to not interfere with the decant phase
- If the sludge settles too slowly, the biomass may be drawn off during the Decant Phase degrading effluent quality

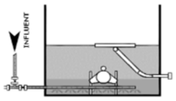
Settle Phase


- Influent Valve CLOSED
- WAS Pump OFF
- Blower OFF
- Triton Mixer OFF
- Decanter OFF
- Liquid Solids Separation
- Quiescent Settling Environment

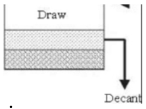
Decant Phase



- A decanter is used to remove the clear supernatant effluent; floating or fixed-arm decanters used:
  - Floating decanters maintain the inlet pipe slightly below the water surface
  - Fixed-armed decanters are cheaper can allow the operator to change the level of the decanter



Decant Phase

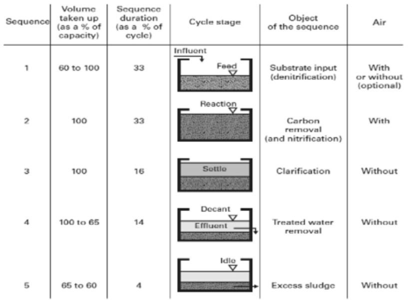


- Decanted volume ~ one-third of the basin volume and equal to influent fill-step volume
- No surface foam or scum is decanted

Idle Phase

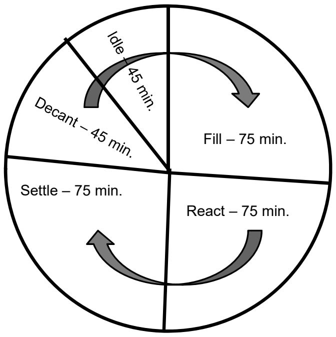
- Occurs between the decant step and the fill step
- Operator should measure the sludge depth in the basin and waste sludge, if necessary
- Important to maintain adequate solids inventories to assure BOD and nutrient removal

Sequencing Batch Reactor



Sequence	Volume taken up (as a % of capacity)	Sequence duration (as a % of cycle)	Cycle stage	Object of the sequence	Air
1	60 to 100	33	Influent Feed	Substrate input (denitrification)	With or without (optional)
2	100	33	Reaction	Carbon removal (and nitrification)	With
3	100	16	Settle	Clarification	Without
4	100 to 65	14	Decant Effluent	Treated water removal	Without
5	65 to 60	4	Idle	Excess sludge	Without

SBR – 5-Hour Cycle



Phase	SBR Cycle and Phase Times		
	4 hours	5 hours	6 hours
Fill	60 minutes	75 minutes	90 minutes
React	60 minutes	75 minutes	90 minutes
Settle	60 minutes	75 minutes	90 minutes
Draw	30 minutes	45 minutes	60 minutes
Idle	30 minutes	30 minutes	30 minutes
Comments	High flows	Average Flows	Low Flows

Nutrient Removal “Driver”

Chesapeake Bay & CWA[1] Regulations

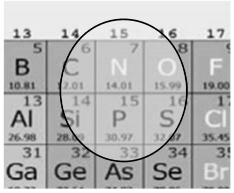
[1] CWA – 1972 Clean Water Act

Nutrients

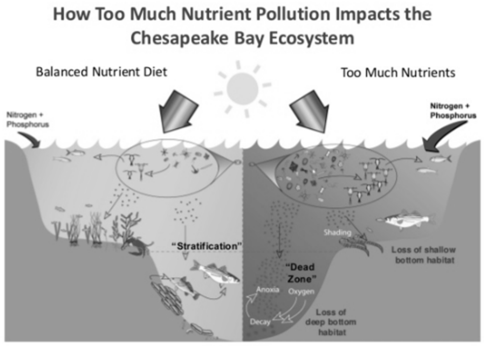
- TN – Total Nitrogen (N_{org} + NH_3 + NO_3 + NO_2)
- TP – Total Phosphorus (PO_4 + P_{org} + P_{poly})

Nutrients - Overview

Part of the Periodic Table



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



Chesapeake Bay Program – May 2016

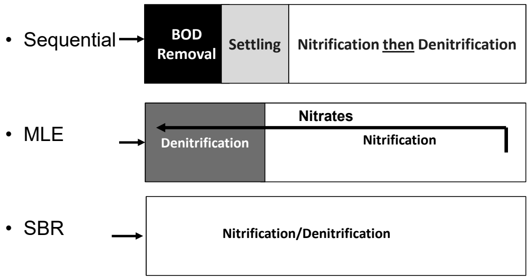
BNR Program

- 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” and/or “Post” anoxic zones to already existing nitrification processes for denitrification

Typical BNR Configurations



- Sequential
- MLE
- SBR

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

Meeting Nutrient Discharge Limits Process Strategies

1. **Multiple barriers for TN removal**
   - Pre-anoxic zone (first stage denitrification)
   - Nitrification – aerobic zone
   - IFAS (enhanced nitrification, optional))
   - Post anoxic zone (second stage denitrification)
   - Denitrification filters (in lieu of post anoxic zone)
2. **Multiple barriers for TP removal**
   - Biological uptake
   - One (maybe two) chemical application points
   - Filtration for TSS (particulate TP) removal

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

Wastewater Discharge Limits

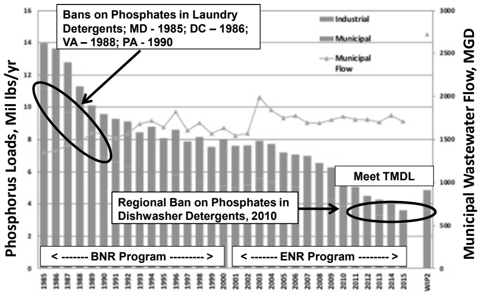
Typical **Total Phosphorus** Standards, mg/l

- Moderate 0.5 - 1.0 (BNR)

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

(a) Limit of Technology/State of the Art

TP Loadings to the Chesapeake Bay - Wastewater



Bans on Phosphates in Laundry Detergents; MD - 1985; DC – 1986; VA – 1988; PA - 1990

Meet TMDL

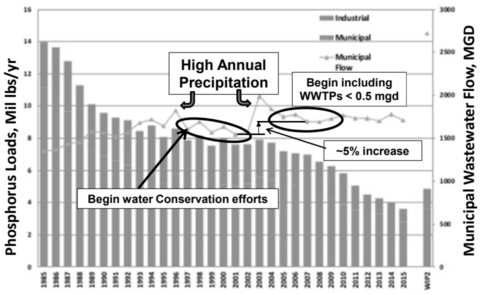
Regional Ban on Phosphates in Dishwasher Detergents, 2010

< ------- BNR Program --------- >

< ------- ENR Program -------- >

Chesapeake Bay Program – May 2016

Wastewater Flows to the Chesapeake Bay



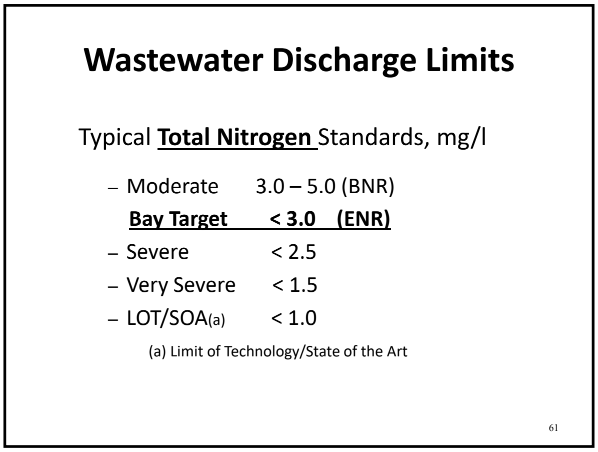
High Annual Precipitation

Begin including WWTPs < 0.5 mgd

~5% increase

Begin water Conservation efforts

Chesapeake Bay Program – May 2016



Wastewater Discharge Limits

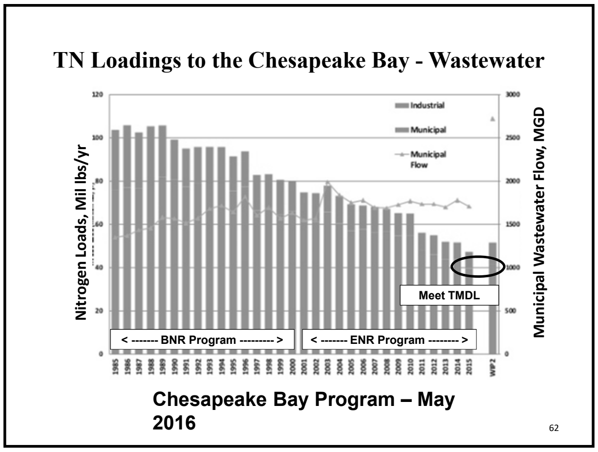
Typical **Total Nitrogen** Standards, mg/l

- Moderate 3.0 – 5.0 (BNR)

Bay Target < 3.0 (ENR)

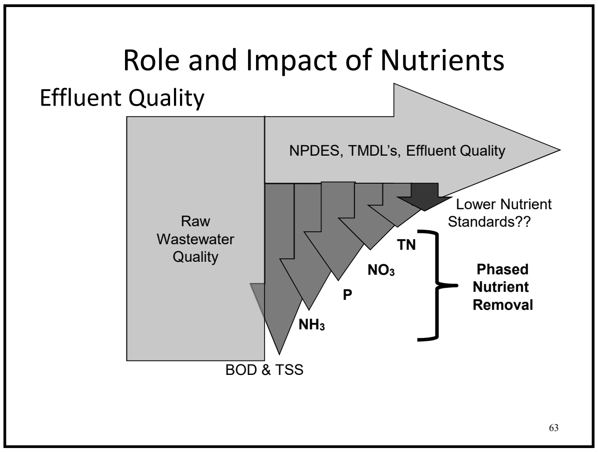
- Severe < 2.5
- Very Severe < 1.5
- LOT/SOA(a) < 1.0

(a) Limit of Technology/State of the Art



TN Loadings to the Chesapeake Bay - Wastewater

Chesapeake Bay Program – May 2016



Role and Impact of Nutrients

Effluent Quality

How will future regulations affect Nutrient Removal Requirements?

Regulatory Challenges:

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

ENR with SBRs

Nitrogen

Forms of Nitrogen

FORM	REMOVAL PROCESS
Organic-N	Converts to ammonia; **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)

Biological Nutrient Removal

- Removes total nitrogen (TN) and total phosphorus (TP) from wastewater
- BNR processes use microorganisms under different environmental conditions:
  - Anaerobic (w/o O_2 and NO_3-N)
  - Anoxic (w/o O_2)
  - Aerobic or oxic (with O_2)

Nitrification Control Parameters

Temperature

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

Nitrification Control Parameters

Dissolved Oxygen

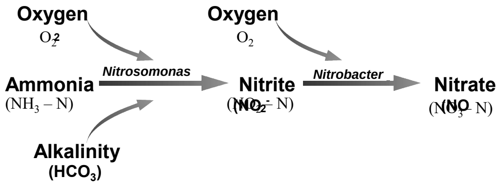
- Maintain MLSS-DO at 2.0 – 4.0 mg/L

pH / Alkalinity

- Maintain MLSS-pH > 6.8
- Maintain alkalinity residual of at least 70 mg/L, preferably 100 mg/L

Two-step Nitrification

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

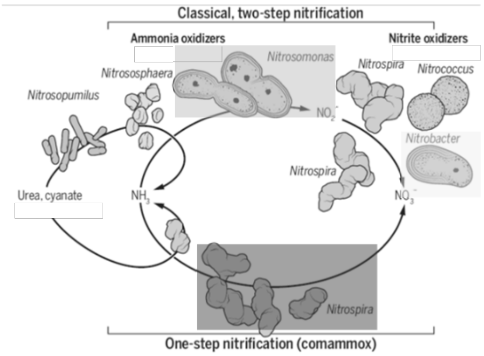


Two-step Nitrification

- 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

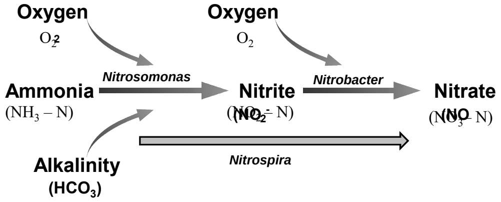
One-step Nitrification - Comammox

- **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

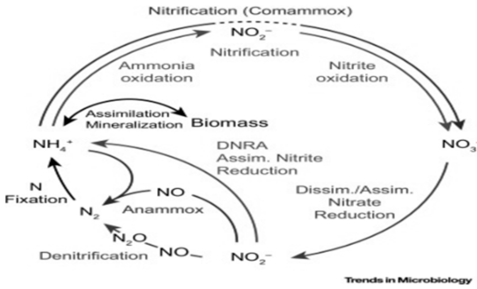


Nitrification

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



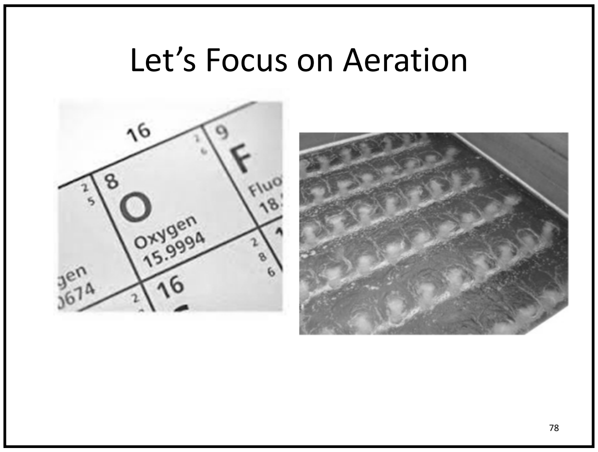
Trends in Microbiology

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

Activated Sludge Environmental Factors

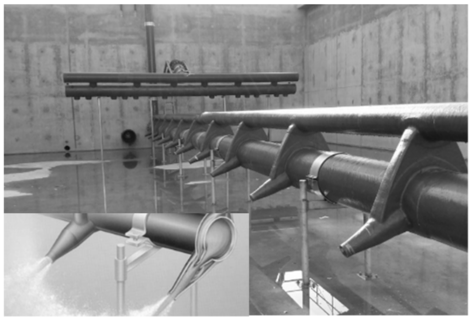
Parameter	Range
Food	Proper amount of food to microorganisms (F:M)
Hydraulic Flow Rate	Within plant design capacity. Excessive flows can result in suspended solids washout
Oxygen	Many of the bacteria in wastewater require between 1 mg/L to 3 mg/L of dissolved oxygen
Temperature	Most microorganisms in wastewater grow best between 10 and 25 degrees C. At >35 to 40 degrees C, thermophilic bacteria will take over
Nutrients	Conventionally a cBOD: Nitrogen: Phosphorus ratio of 100:5:1 is recommended in addition to proper micronutrients such as iron and other trace minerals
pH	Between 6.5-8.5 is recommended
Alkalinity	There needs to be enough buffering capacity to maintain pH. Typically 60 mg/L or more of alkalinity at the end of treatment is desired



Let's Focus on Aeration

Aeration

Jet Aeration Systems

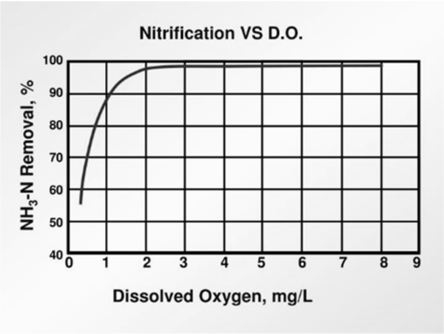


Nitrification- Oxygen Required

- Ammonia oxidation
  - $2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 4H^+ + 2H_2O$
- Nitrite oxidation - $2NO_2^- + O_2 \rightarrow 2NO_3^-$
- Overall: $NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O$ = 4.57 g O2/g N for complete oxidation

Nitrification- Oxygen Required

- Ensure adequate D.O. during peak loads
  - D.O. Profiling
- Increase D.O. as needed – Blower Capacity?
- Ideal to implement automated, real-time D.O. control to maintain minimum D.O.'s in react phase
  - Air delivery to match D.O. demand (load) variations
  - Reduce energy costs
  - Avoid D.O. bleed through to downstream anoxic stages



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Air Demand Requirements, lbs/day

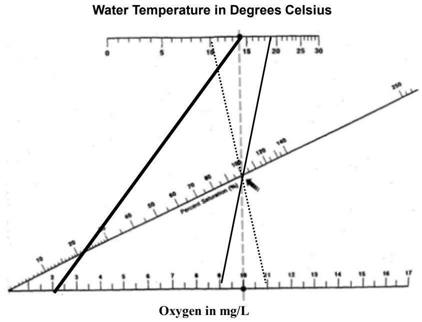
Treatment	Equation	lb O_2/lb $_{oxidized}$
Organic Removal	$BOD_{oxidized} = BOD_{inf} - BOD_{eff}$	1.0 – 1.2
Nitrification	$TKN_{oxidizable} = TKN_{inf} - TKN_{assimilated}$ $TKN_{oxidized} = TKN_{oxidizable} - TKN_{eff}$	4.6

NPDES Effluent Requirement	OTR Equation
BOD_5 Limit	$1.2 * BOD_{oxidized}$
$BOD_5 + NH_3$-N Limit	$1.2 * BOD_{oxidized} + 4.6 * TKN_{oxidized}$

Importance of Dissolved Oxygen

- Oxygen is sparingly soluble in water
- DO is a growth-limiting substrate
- C*ritical oxygen concentration* is about 10% to 50% of DO saturation in water
  - 10% minimum saturation (~ 1.0 mg/l DO) for BOD removal to less than 15 mg/L
  - 20% minimum saturation (~ 2.0 mg/l DO) for complete nitrification

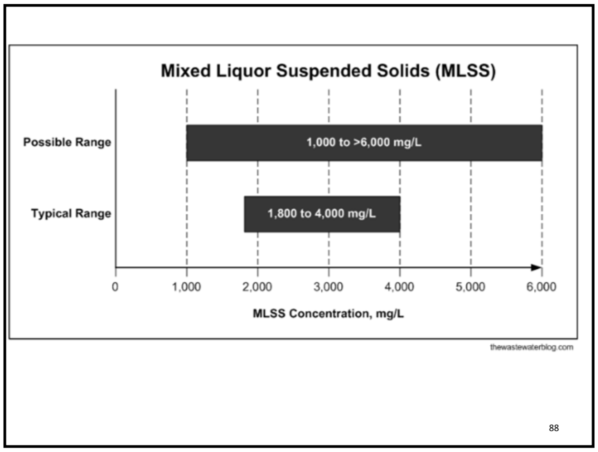
D.O. - Percent Saturation in Water



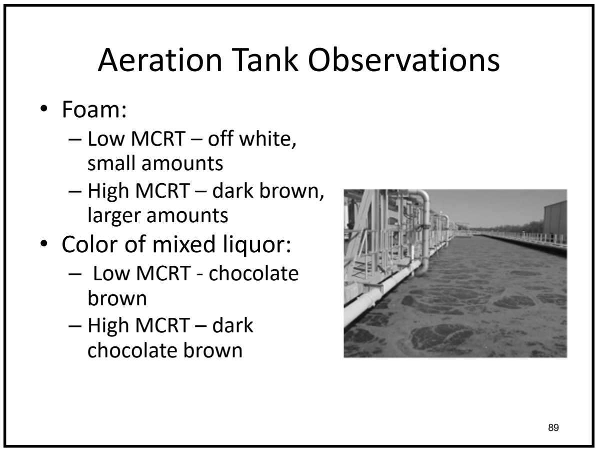
Source: Department of Fisheries and Aquatic Sciences, University of Florida

Activated Sludge Processes

Observations – Aeration Tank

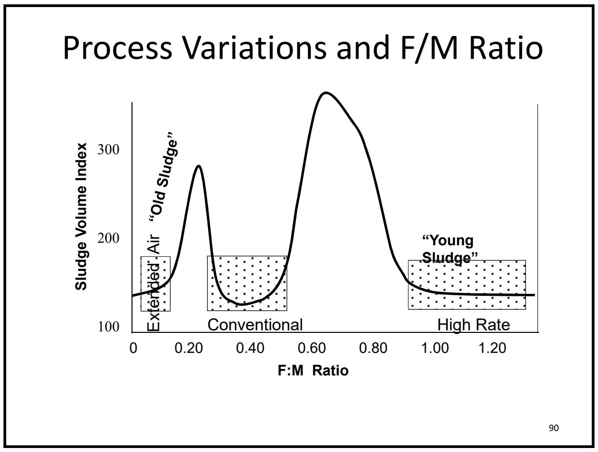


thewastewaterblog.com



Aeration Tank Observations

- Foam:
  - Low MCRT – off white, small amounts
  - High MCRT – dark brown, larger amounts
- Color of mixed liquor:
  - Low MCRT - chocolate brown
  - High MCRT – dark chocolate brown



Process Variations and F/M Ratio

Young Sludge

- **Start-up or High BOD Load**
- **Few Established Cells**
- **Log Growth**
- **High F:M**
- **Low MCRT**

Young Sludge

Poor Flocculation
Poor Settleability
Turbid Effluent

White
Billowing
Foam

High O_2
Uptake Rate

Old Sludge

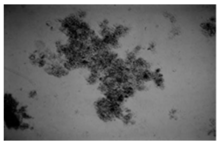
- **Slow Metabolism**
- **Decreased Food Intake**
- **Low Cell Production**
- **Oxidation of Stored Food**
- **Endogenous Respiration**
- **Low F:M**
- **High CRT**
- **High MLSS**

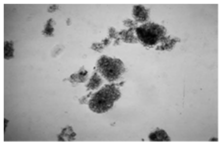
Old Sludge

Dense, Compact Floc

Fast Settling

Straggler Floc





Spray Wash for Foam Control

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 stage
  - Plant effluent
  - At end of anoxic stage

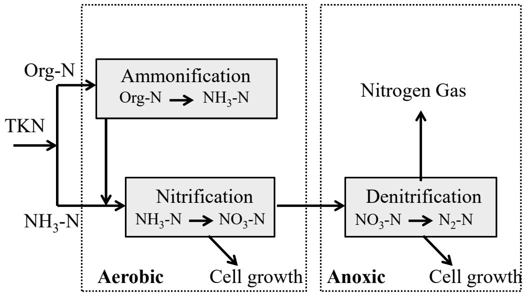
Nitrification-Related Process Instruments and Parameters

- Temperature
- Flow meters
- Flow rates:
  - Influent/Effluent
  - WAS
- Solids ret. time (SRT)
- pH/alkalinity
- ORP
- Airflow distribution
- DO probe(s)
- DO conc., mg/L
- Ammonia probe(s)
- Ammonia conc., mg/L
- Nitrate probe(s)
- Nitrate conc., mg/L

ENR with SBRs

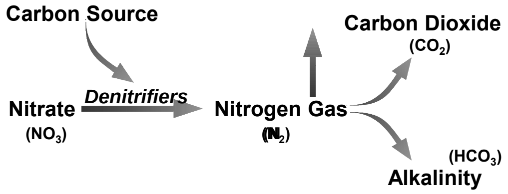
Denitrification

Nitrification-Denitrification



Denitrification

Reduction of nitrates or nitrites commonly by bacteria usually resulting in the escape of nitrogen in the air.



Carbon Source

Carbon Dioxide (CO_2)

Nitrate (NO_3) ***Denitrifiers*** **Nitrogen Gas** (N_2)

(HCO_3) **Alkalinity**

Carbon for Denitrification

- Influent WW Carbon
  - Utilized in first anoxic zone
  - EBPR can compete for carbon
  - Limited carbon available for secondary anoxic zones – and effective denite
- Endogenous Carbon
  - Slow kinetics – limited denite in post-anoxic zones
- Supplemental Carbon
  - Methanol typically used
    - But requires methylotrophic population!
  - Alternatives to methanol – ethanol, acetic acid, glycerin, sugars, mono-propylene glycol, proprietary products

Other Carbon Sources

- Alcohols
  - Methanol
  - Ethanol
- Glycerol/glycerin – (Biodiesel by-products)
- Acetates - (Acetic acid, sodium acetate)
- Carbohydrates - (Sucrose, sugar water, corn syrup)
- MicroC™ – Carbohydrate (1000), glycerin (2000), alcohol based blends (3000)

SBR Nitrification/Denitrificatioin

- TKN enters the SBR during the “Fill-mix” stage
- TKN is converted to nitrates during the “aerated react” stage
- Most nitrates formed remain in the “low-water” remaining after clarification
- Nitrates in the “low-water” are converted to nitrogen gas during the “Fill-mix” stage
- ORP plus nitrate probes would be helpful to determine absence of nitrates

Denitrification-Related Process Instruments and Parameters

- Temperature
- Flow meters
- Flow rates
  - Inflows
  - Internal Recycle
- pH/alkalinity
- ORP
- DO probe(s)
- DO conc., mg/L
- Nitrate probe(s)
- Nitrate conc., mg/L

ORP

Oxidation-Reduction Potential

The electrical potential (mv) required to transfer electrons from one compound to another.

Used as a qualitative measure of the state of oxidation.

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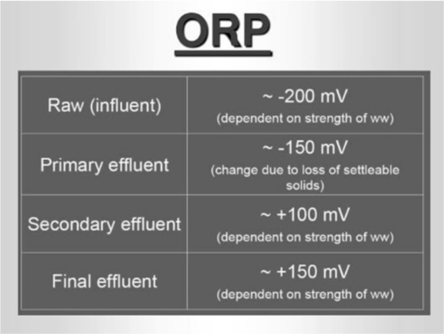

ORP

Raw (influent)	~ -200 mV (dependent on strength of ww)
Primary effluent	~ -150 mV (change due to loss of settleable solids)
Secondary effluent	~ +100 mV (dependent on strength of ww)
Final effluent	~ +150 mV (dependent on strength of ww)

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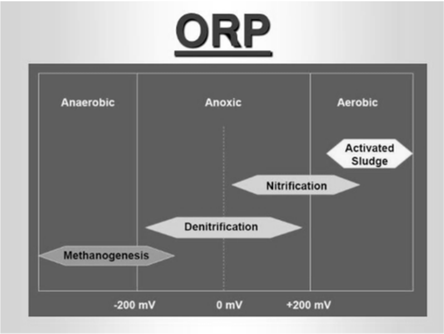
ORP



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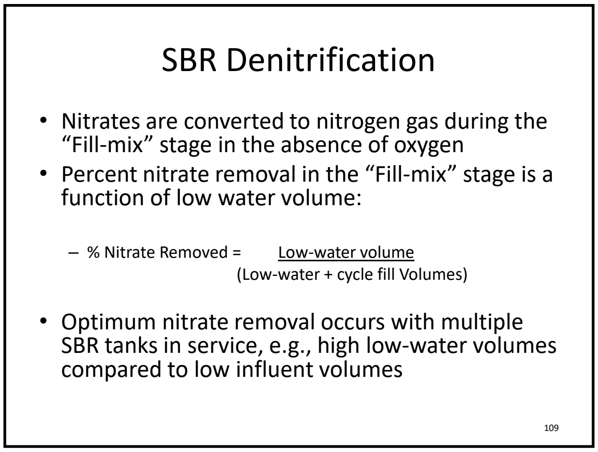
ORP Ranges for Processes

Biochemical Reaction	ORP, mV
Wastewater Treatment:	
Nitrification	+100 to +350
cBOD degradation with air (O_2)	+50 to +250
Denitrification	+50 to -50
Anaerobic Digestion:	
Acid formation (fermentation)	-100 to -225
Methane production	-175 to -400



SBR Denitrification

- Nitrates are converted to nitrogen gas during the “Fill-mix” stage in the absence of oxygen
- Percent nitrate removal in the “Fill-mix” stage is a function of low water volume:
  - % Nitrate Removed = $\frac{\text{Low-water volume}}{\text{(Low-water + cycle fill Volumes)}}$
- Optimum nitrate removal occurs with multiple SBR tanks in service, e.g., high low-water volumes compared to low influent volumes

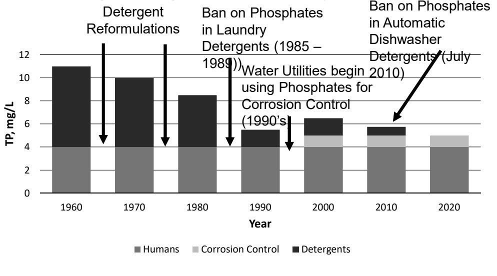
ENR

Phosphorus

Forms of Phosphorus

FORM	REMOVAL PROCESS
Organic-P	Converts to orthophosphate form; **a small soluble portion is non-reactive (e.g., 0.05 mg/l)**
Condensed Phosphates	Converts to orthophosphate form
Orthophosphate	Most abundant form; chemically reactive and consumed by biological growth

Trend – Sources of Phosphorus in Raw Sewage (mg/L) – Chesapeake Bay



Biological Uptake

- Conventional Biological Uptake
  - To satisfy biological needs (2.0 to 3.0% by weight)
- Enhanced Biological uptake (5 to 7% by weight)
  - Stress induced
  - Release of phosphorus under anaerobic conditions
  - Uptake of phosphorus under aerobic conditions

Biological Uptake

- **<u>Assimilation</u>** - Phosphorus removal from wastewater has long been achieved through incorporation of P as an essential element in the biomass

Assimilation

- Microorganisms are 2-3% P (dry weight)
- Removing biological sludge removes P
- Why doesn't P go to 0?
  - Because carbon is limiting, not phosphorus

Phosphorus-Related Process Instruments and Parameters

- Flow meters
- Flow rates:
  - Influent/Effluent
  - WAS
- pH/alkalinity
- ORP

- Phosphate analyzers
- Phosphate conc., mg/L

Biological Uptake

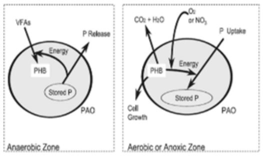
- **<u>Enhanced Biological Phosphorus Removal (EBPR)</u>** - phosphate accumulating organisms (PAOs) store polyphosphate as an energy reserve in intracellular granules
  - Under anaerobic conditions, PAOs release orthophosphate, utilizing the energy to accumulate simple organics and store them as polyhydroxyalkanoates (PHAs) such as poly-β-hydroxybutyrate (PHB)
  - Under aerobic conditions, the PAOs then grow on the stored organic material, using some of the energy to take up orthophosphate and store it as polyphosphate.

Enhanced Biological P Removal (EBPR)

- 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)



EBPR Organisms

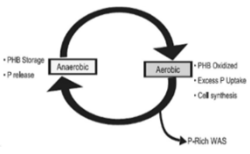
- Originally identified as *Acinetobacter sp. (*later turned out this was incorrect)
- Now generically called “phosphate accumulating organisms” (PAOs)
- Some competing organisms accumulate glycogen (GAOs) instead of P
- PAOs require oxygen for growth (aerobic)

Enhanced Biological P Removal (EBPR)

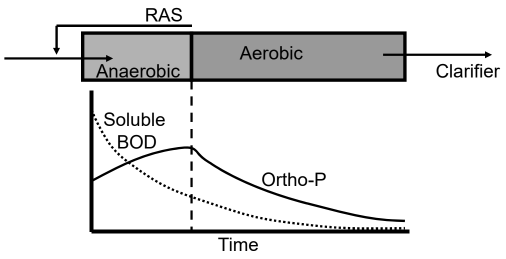
- For EBPR: must be anaerobic, then aerobic
  - P released under anaerobic conditions
  - P then taken up under aerobic conditions
  - 5 mg/L (inf.) → 15 mg/L (anaerobic) → < 1 mg/L (aerobic)
  - Biological removal or biologically mediated chemical precipitation?
  - ~1980 largely agreed it was biological

Enhanced Biological P Removal (EBPR)

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

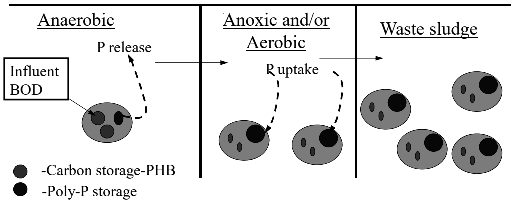


Enhanced Biological P Removal (EBPR)

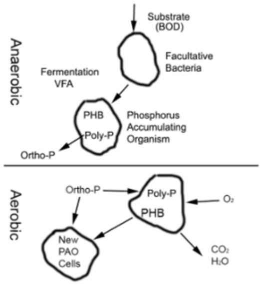


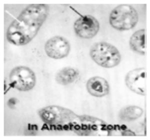
Enhanced Biological P Removal (EBPR)

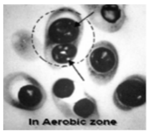
P is removed by phosphorus accumulating organisms (PAOs) and exits system in waste sludge



Enhanced Biological P Removal (EBPR)

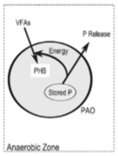






Enhanced Biological P Removal (EBPR)

Anaerobic Conditions

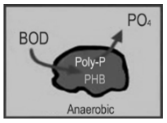


Heterotrophic Bacteria Break Down Organics
- **Fermentation**
  - **Volatile Fatty Acids (VFAs)**
  - **Acetate (Acetic Acid)**

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

Enhanced Biological P Removal (EBPR)

Anaerobic Conditions



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

PAO Able to store soluble organics as Polyhydroxybutyrate (PHB)

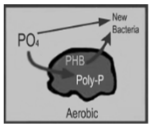
Ortho-P is Released Into Solution

Enhanced Biological P Removal (EBPR)

Aerobic Conditions

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

PO_4 Used in Cell Production
Excess Stored as Polyphosphate
(“Luxury Uptake”)



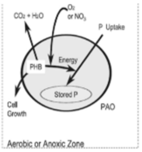
Enhanced Biological P Removal (EBPR)

Aerobic Conditions

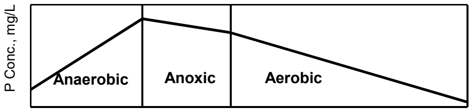
PO_4 Used in Cell Production
Excess Stored as Polyphosphate

Biomass 5 to 7% P by Weight

(Normal 2 to 3 %)



Phosphorus Profile



Anaerobic zone
P - Release

Anoxic and Aerobic zones
P - Uptake

Advantages

- Less chemical costs
- Less chemical storage and handling
- Less chemical sludge disposal

Disadvantages

- Not as reliable (initially – maybe it is now)
- Limitation – need enough BOD
- May be difficult to get < 0.1 mg/L consistently
- Digestion (especially anaerobic) releases P

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

Chemical Precipitation

- Phosphate is an anion: PO_4^{3-}
- Cations can be added to bind with phosphate:
  - Ca^{2+}
  - Al^{3+}
  - Fe^{3+}
- Each forms an insoluble precipitant with alkalinity

Reaction with Lime

- Reaction with lime:

  $5Ca^{2+} + 3PO4^{3-} + OH^{-} \leftrightarrow Ca_5(PO_4)_3(OH)(s)$

  hydroxyapatite
- But when lime is added to water:

  $Ca(OH)_2 \leftrightarrow Ca^{2+} + 2OH^{-}$

  $OH^{-} + HCO_3^{-} \leftrightarrow H_2O + CO_3^{2-}$

  $Ca^{2+} + CO_3^{2-} \leftrightarrow CaCO_3(s)$
- So required dose of lime depends on alkalinity
  - Once carbonate is used up, P will be removed

Co-Precipitation with Metal Salts

Ortho Phosphates

React with

Metal Salts and Alkalinity

To form

Insoluble Phosphorus Compounds

Phosphorus Removal with Chemicals

- Precipitation of PO_4:
  - $FePO_4$ and $AlPO_4$ only exist at very low pH's (< 5.0)
- Co-precipitation: Fe and Al **along with** alkalinity form metal-phosphate-hydroxide flocs
- Adsorption of soluble (PO_4^{-3}) phosphate onto metal hydroxide flocs
- As floc is formed and settles, it also entraps particulate phosphorus

Phosphorus Removal with Chemicals

Chemical Reactions – two mechanisms:

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

Co-Precipitation Iron Reactions

- $FeCl_3 + PO_4^{-3} \text{---}> FePO_4 + 3Cl^{-1}$
- $FeCl_3 + 3HCO_3^{-1} \text{----}> Fe(OH)_3 + 3CO_2 + 3Cl^{-1}$

- Simplified: $Fe + PO_4 \text{------}> FePO_4$
  $Fe + 3OH \text{------}> Fe(OH)_3$

- Combined:
  $\underline{2}Fe + PO_4 + 3OH \text{----}> 2FePO_4(OH)_3$ Complex $\downarrow$

(Mole Ratio = 2.0)

Co-Precipitation Aluminum Reactions

- $Al_2(SO_4)_3 \cdot 14H_20 + 2PO_4^{-3} \text{------}> 2AlPO_4 + 3SO_4^{-2} + 14\ H_2O$
- $Al_2(SO_4)_3 \cdot 14H_20 + 6HCO_3^{-1} \text{------}> 2Al(OH)_3 + 6CO_2 + 14\ H_2$

- Simplified: $Al + PO_4 \text{------}> AlPO_4$
  $Al + 3OH \text{------}> Al(OH)_3$
- Combined:
  $\underline{2}Al + PO_4 + 3OH \text{----}> 2AlPO_4(OH)_3$ Complex $\downarrow$

(Mole Ratio = 2.0)

Chemical Addition – Dosages

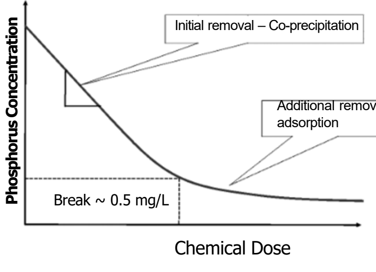
1. Determine incoming TP and biological uptake
2. Assume initial chemical mole ratio of 2:1:
   - **$2Al + PO_4 + 3OH = AlPO_4 + Al(OH)_3$**
     - **1.7 mg/l of Al per mg/l P**
     - **3.3 mg/l of Al_2O_3 per mg/l P**
     - **1.21 GPH of Alum (@8.3% Al_2O_3 or 0.95 lbs Al_2O_3/Gallon) to remove 1 mg/l P in 1 mgd of flow**
   - **$2Fe + PO_4 + 3OH = FePO_4 + Fe(OH)_3$**
     - **3.6 mg/l of Fe per mg/l P**
     - **10.4 mg/l of $FeCl_3$ per mg/l P**
     - **0.9 GPH of $FeCl_3$ (@35% $FeCl_3$ or 1.45 lbs Fe/Gallon) to remove 1 mg/l P in 1 mgd of flow**
3. Adjust dose to meet discharge standard

Chemical Addition – Alkalinity/pH

Chemical addition consumes alkalinity and can depress pH:

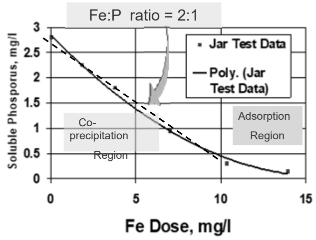
- **$Al_2(SO_4)_3 \times 14H_2O + 6HCO_3^{-1} \text{--->} 2Al(OH)_3 + 6CO_2 + 3SO_4^{-2} + 14H_2O$**
  - $Al + 3OH \text{------>} Al(OH)_3$
  - 5.6 mg/l of $CaCO_3$/mg Al
  - 3.0 mg/l of $CaCO_3$/mg Al_2O_3
- **$FeCl_3 + 3HCO_3^{-1} \text{--->} Fe(OH)_3 + 3CO_2 + 3Cl^{-1}$**
  - $Fe + 3OH \text{------>} Fe(OH)_3$
  - 2.7 mg/l of $CaCO_3$/mg Fe
  - 0.9 mg/l of $CaCO_3$/mg $FeCl_3$

Precipitation and Adsorption of P



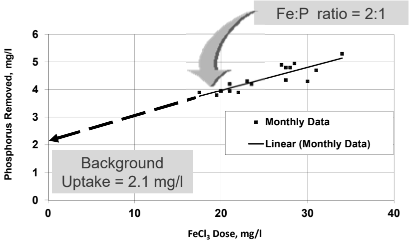
Precipitation and Adsorption of P

Jar Test: Blue Plains - June 1977



Precipitation of Phosphorus

Blue Plains, June 1977 - October 1978



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

Chemical Addition – Effects on pH

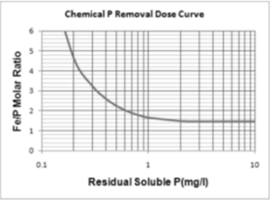
- Alum or iron salts will decrease alkalinity and pH, especially at higher dosages
- Lime raises pH
- PACl will not lower alkalinity or pH

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

Phosphorus Removal w/Chemicals

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



Chemical Addition - Advantages

- Can be used in every single current wastewater application from Lagoons to EBPR (Enhanced Biological Phosphorous Removal)
- Easy plant trials – chemical and feed pumps are the only requirements
- Low capital costs
- Easy to adjust to changing influent concentrations and flows
- Relatively less complicated method of removal

Chemical Addition - Disadvantages

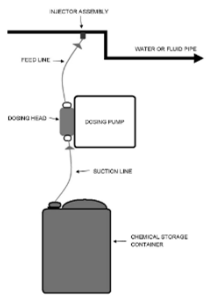
- Operation and Maintenance Costs can be higher due to chemical usage
- Handling and Storage of different chemicals and freeze protection
- Iron Products are not recommended in front of UV disinfection due to staining
- If fed at wrong area, it can reduce nutrient levels to beneficial bacteria and cause die off.
- Possible changes to dewatering chemistries
- Increased sludge production

Metering Pump Definition

- Convey (like any pump)
- Measure (repeated displacement of defined volume)
- Adjust
  - Volume per displacement
  - Frequency of displacements

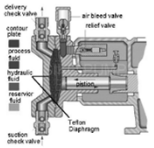
Metering Pumps

- Reciprocating – piston, **diaphragm**, or plunger
- Rotary – **gear**, screw, lobe
- Peristaltic – series of rollers to push through tubing or **hoses**

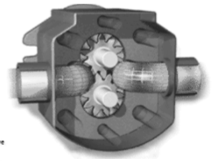


Metering Pumps

Peristaltic



Diaphragm



Gear

Effluent Filtration Applications

- Gravity filters are needed to reduce effluent particulate phosphorus to less than 0.3 mg/L
- Membranes may be needed to reduce effluent particulate phosphorus to less than 0.1 mg/L

Effluent Filtration Application

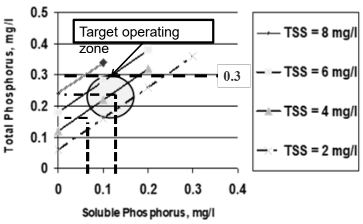
- Assuming that 2-3% of organic solids is P, then an effluent total suspended solids (TSS) of 10 mg/L represents 0.2-0.3 mg/L of effluent P.
- In plants with EBPR the P content is even higher
- Sand filtration or other method of TSS removal (e.g., membrane) is likely necessary for plants with low effluent TP permits

TSS Removal Requirements

TP Limit, mg/L	Max TSS, mg/L
0.1	**3.0**
0.2	**5.0**
0.3	**7.0**
0.4	**9.0**
0.5	**11**

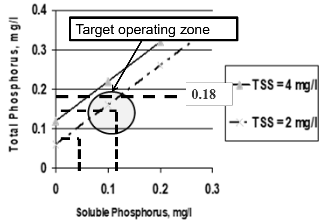
Assume soluble P = 0.05 mg/L; particulate P/TSS = 3.0%

Effluent TP versus Effluent TSS



Assume particulate P/TSS = 3.0%

Effluent TP versus Effluent TSS



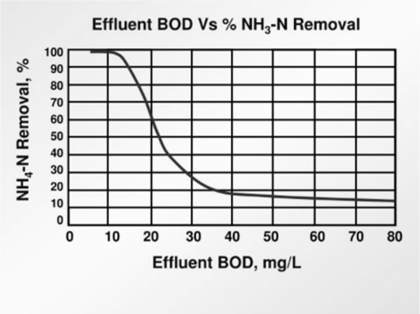
Assume particulate P/TSS = 3.0%

Troubleshooting

Nitrification/Denitrification

Optimizing Nitrification

- Remove BOD_5 ≤ 20 mg/L
- Optimize dissolved oxygen in aerobic zones
- Last step: add alkalinity only if needed



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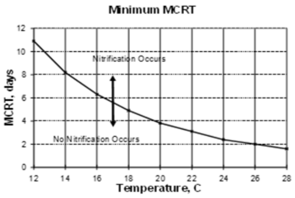
Obstacles to Achieving Nitrification

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

Nitrification Process Monitoring

- Key Factors:
  - Slow growth requires adequate **aerobic SRT or MCRT or CRT**
  - **DO** typically >2mg/L
  - **pH** 6.5-7.5
  - Target effluent alkalinity of 50 to 75 mg/L as $CaCO_3$



- Overall Reaction:
  - $NH_4^+ + 2\,O_2 \rightarrow NO_3^- + 2H^+ + H_2O$

Operational Controls for Nitrification

Nitrifiers Grow Slowly

CRT Must Be Long Enough
> 5 Days (minimum)
Best > 8 Days

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Operational Controls for Nitrification

Aerobic React Time Must Be Long Enough
(> 5 hrs.)

(BOD Removal Must Occur First)

F:M Ratio Must Be Low Enough
(< 0.25)

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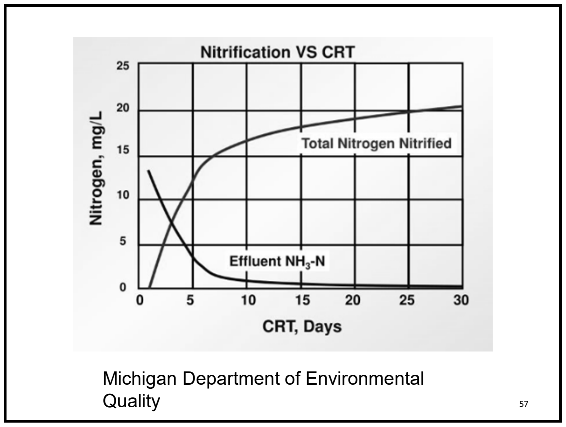

Nitrification VS CRT

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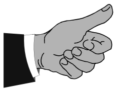
Effect of Temperature on Nitrification

As temperature increases, nitrifier growth rate increases (within the range of 4° C to 35° C).

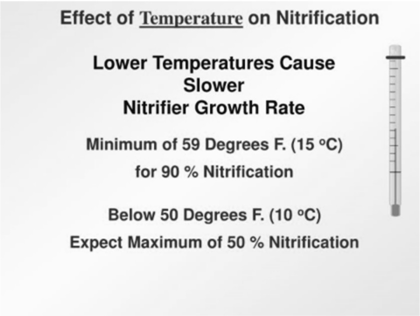
T ↑ μ ↑

As nitrifier growth rate increases, required MCRT decreases.

μ ↑ MCRT ↓



Rule of Thumb:
For every 10°C increase in temperature, nitrifier growth rate doubles, required MCRT is cut in half and required MLSS concentration is also reduced.



Effect of Temperature on Nitrification

Lower Temperatures Cause Slower Nitrifier Growth Rate

Minimum of 59 Degrees F. (15 °C) for 90 % Nitrification

Below 50 Degrees F. (10 °C) Expect Maximum of 50 % Nitrification

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Nitrification – Temperature Impacts

- Need to plan for temperature transitions – especially in areas with significant seasonal changes.
- Build solids inventory, decrease F:M ratio, and increase MCRT/SRT as seasonal (cold weather) changes approach.

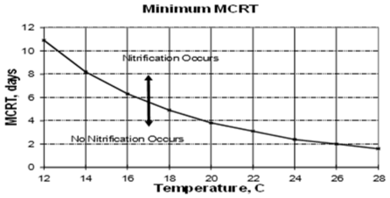
Wastewater Temperature Range (°C)	Target Food to Mass Ratio	Target Average Aeration MLSS (mg/L)	Typical MCRT/SRT, Days	NH$_3$, mg/l
14-18	0.05	3000	15	1 – 2
18-22	0.075	2500	10	0.5 – 1
22-25	0.1	2000	7	0.5 - 1

Nitrification Process Monitoring

- Key Factors:
  1. MCRT – solids inventory
  2. DO concentration
  3. Alkalinity

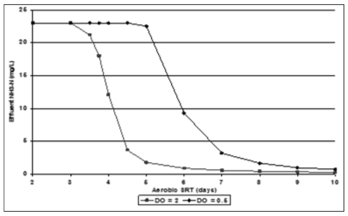
Nitrification Process Monitoring

- **Key Factor 1**
  - Slow growth requires adequate aerobic SRT
  - **MAINTAIN ADEQUATE SOLIDS INVENTORY**



Nitrification Process Monitoring

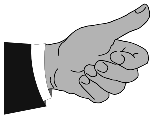
- **Key Factor 2**
  - Maintain target DO concentration



Effect of Dissolved Oxygen Concentration on Nitrification

As dissolved oxygen increases, nitrifier growth rate increases up to DO levels of about 5 mg/L.

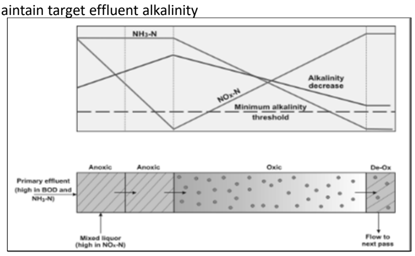
DO ↑ μ ↑



<u>Rule of Thumb</u>:
Maintain dissolved oxygen concentration at 2.0 mg/l or higher for <u>complete</u> nitrification.

Nitrification Process Monitoring

- **Key Factor 3**
  - Maintain target effluent alkalinity



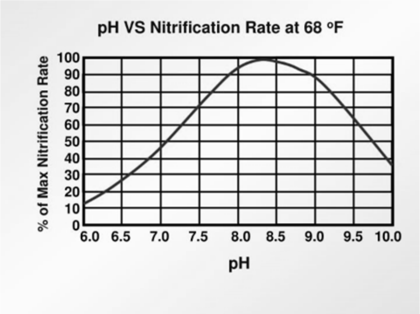
Nitrification- Alkalinity/pH

Nitrifiers utilize inorganic carbon/consume alkalinity:

- Aerobic chemoautotrophs

  $NH_4^+ + 2HCO_3^- + 2O_2 \rightarrow NO_3^- + 2CO_2 + 3H_2O$

- Theoretically, 7.14 g alkalinity as $CaCO_3$ consumed for each g of ammonia nitrogen oxidized to nitrate.
- Typically, lime or caustic soda is added to make up for alkalinity loss.



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Inhibition of Denite Process

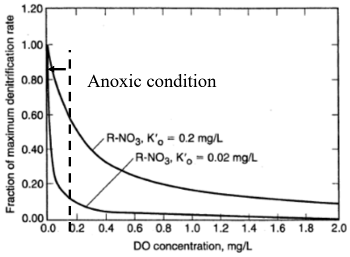
- Environmental Conditions
  - pH
  - Temperature
  - **<u>Aerobic Conditions!</u>** <u>Keep DO< 0.2 mg/L</u>
- Insufficient amount of rbCOD (Carbon Substrate).
- Presence of Chemical Inhibitors:
  - Substrates, intermediates, and products of denitrification
  - Synthetic organic chemicals
  - Heavy metals - Hg, Ni, Pb, etc.

High DO in the Anoxic Zones

- High DO in the anoxic zones may be more of a problem during the winter because more DO can be absorbed by colder water and biological kinetics are reduced.
- Lower the nitrate recycle rate in the winter if necessary

D.O. Control

Reduction in rate of Denite as a function of D.O.
(K’o is oxygen inhibition constant)



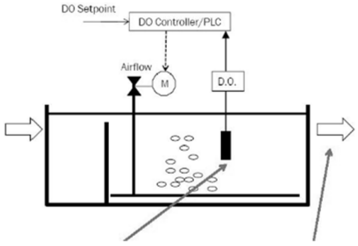
Denitrification Problems

Possible Causes	Solution
Not enough nitrates being returned to anoxic zone	Increase nitrate recycle pump speed
Not enough BOD entering anoxic zone	- Bypass primary clarifiers, or - Add supplemental carbon (for example, methanol) to anoxic zone
BOD entering the anoxic zone breaks down too slowly	Add readily available carbon source such as methanol to anoxic zone or increase the anoxic zone hydraulic retention time
High DO in the anoxic zone	Try to limit backmixing of air from the aerobic zones or decreasing the DO in the AT influent. Decrease nitrate recycle rate if necessary.

Troubleshooting

High/Low Dissolve Oxygen

Typical Aeration Basin Control Strategy - DO



DO setpoint chosen to minimize historical NH_3 breakthrough

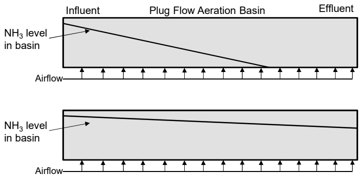
New Aeration Basin Control Strategies

- 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

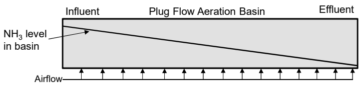


Too much air

Not enough air

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



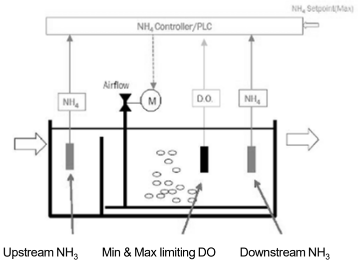
Just right

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

Objective of Ammonia based Aeration control

- Aeration is limited to:
  - Prevent complete nitrification
  - Reduce effluent ammonia peaks
- Potential benefits include:
  - Decreased energy expenses (for aeration)
  - Possibly increased denitrification with less supplemental carbon addition
  - Possibly improved Bio-P removal

Ammonia Feed Forward – Feedback Control



Troubleshooting

High Decant BOD and TSS

Loss of Solids due to High Blankets

- Old sludge (low F/M) – decrease MCRT
- Young sludge (high F/M) – increase MCRT
- Filamentous bulking
- Slime bulking – add nutrients
- Foam trapping – pretreatment for oil & greases

Rapid Sludge Settling

- Monitor with SSVs, SVI, F/M
  - Pin floc
  - Straggler floc
- Probable cause, low F/M – Increase F/M by decreasing MLVSS

High Effluent BOD, TSS, NH_4-N

- Low MLSS – increase
- Low D.O – increase
- High organic loading – increase MLSS and aeration cycle
- High nitrogen loadings and effluent NH_4
  - Increase MLSS and aeration cycle
  - Low D.O.? Nitrifiers? Alkalinity?
  - Short aeration times?

Troubleshooting

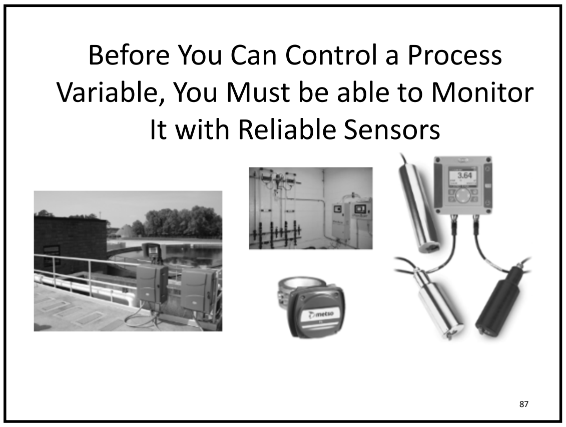
Changes in pH and Alkalinity

pH Alkalinity Changes

- H_2S production
- Respiratory release of CO_2
- Nitrification inhibition
- Nitrification
- Denitrification
- Metal salt addition

IC&A

Overview



Before You Can Control a Process Variable, You Must be able to Monitor It with Reliable Sensors

IC&A Drivers

- Instrumentation, control, and automation (IC&A)
  - Initiated in the 1970s
  - Major push in the 1980s
  - Meet nutrient regulatory requirements
- Improve process performance and cost efficiency
- BNR/ENR processes require effective DO control (enough but not too much)

Process Control

- Operators use a combination of probes and analyzers to monitor **and control** BNR/ENR processes:
  - DO
  - Nitrification (Ammonia profile)
  - Denitrification (Nitrate profile)
  - Phosphorus removal

Process Control Loops

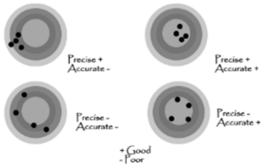
- Monitoring and control of a process
- WWTPs rely on four building blocks:
  - A process model concept
  - Monitoring and control strategies
  - **Sensors that provide accurate and precise on-line data to controllers**
  - Actuators or control elements that implement controller output

Process IC&A - What’s Needed?

- Sensors – Probes and/or analyzers:
  - Accurate
  - Precise
- Communications network – Analog, digital, radio, and/or telemetric
- Controllers:
  - Modules or Remote Terminal Units (RTUs)
  - Programmable Logic Controllers (PLCs)
- Actuators, e.g., valves, pumps, blowers

Accuracy and Precision

- Accuracy: How close is it to the actual reading?
- Precision/Repeatability: Does it provide the same answer each time?



Why Automate?

- Monitor basic information about the processes
- **Accurate and precise instrumentation** is now available to automate system processes
- Eliminate manual measurements, e.g. dependency on delayed lab measurements
- Save time, save money, and increase efficiency
- Allow facilities to operate at limits of technology

Process Control

- WWTPs are never in a steady state; subject to “disturbances”
- A major incentive for automated process control is to minimize impacts of “disturbances” on plant processes:
  - Wastewater influent constituents, their concentrations, and flow rates
  - Discrete events such as rainstorms, peak loadings, and spills

Process Control

- Key factors in automated process control systems:
  - Responsiveness
  - Ability to deal with disturbances
- “A responsive control system” means the controlled variable responds quickly to adjustments in the manipulated variable
- Frequency and magnitude of disturbances should be minimum

Definitions

- **Input Variable** – This variable shows the effect of the surroundings on a process and normally refers to factors that influence the process:
  - *Manipulated inputs:* variables in the surroundings that can be controlled by an operator or the control system
  - *Disturbances:* inputs that can not be controlled by an operator or control system
- **Output variables**- Also known as *control variables;* these are variables that are outputs of the process.

Process Control

- Three physical properties are typically monitored in wastewater:
  1. Liquid flow: Influent/effluent, recirculation, return activated sludge (RAS), sludge wasting quantities, chemical addition
  2. Constituent Concentrations: DO, MLSS, BOD_5, TSS, nutrients, sludge solids
  3. Gas volumes: air, digester gas

Common Controlled Variables

- Aeration
- BOD_5 and TSS loadings
- Ammonia, Nitrate, and Phosphate loadings
- Chemical Addition
- Internal Recycles (MLE processes)
- Low water level and fill level during fill stage (SBR)
- Sludge Wasting Rates

Common Controlled Variables

- Aeration
  - Set DO levels in different sections of process
  - Control aeration time (cyclic aeration)
- BOD_5 and TSS loadings
  - Maximize removal of BOD_5 and TSS before nitrification/denitrification
- Ammonia, Nitrate, and Phosphate mass loadings
  - Avoid overloading unit processes

Common Controlled Variables

- Chemical Addition
  - Methanol, Ferric/Alum, alkalinity feed rates
- Internal Recycles (MLE processes)
  - Set recycle flow rates based on process conditions
- Low water level to fill level (SBRs)
- Sludge Wasting Rate
  - Control Solids Retention Time – One of the most important parameters for advanced BNR

Nitrification-Related Process Instruments and Parameters

- Temperature
- Flow meters
- Flow rates:
  - Influent/Effluent
  - WAS
- Solids ret. time (SRT)
- pH/alkalinity
- ORP
- Airflow distribution
- DO probe(s)
- DO conc., mg/L
- Ammonia probe(s)
- Ammonia conc., mg/L
- Nitrate probe(s)
- Nitrate conc., mg/L

Denitrification-Related Process Instruments and Parameters

- Temperature
- Flow meters
- Flow rates
  - Inflows
  - Internal Recycle
- pH/alkalinity
- ORP
- DO probe(s)
- DO conc., mg/L
- Nitrate probe(s)
- Nitrate conc., mg/L

Phosphorus-Related Process Instruments and Parameters

- Flow meters
- Flow rates:
  - Influent/Effluent
  - WAS
- pH/alkalinity
- ORP
- Phosphate analyzers
- Phosphate conc., mg/L

What are sensors?

- Devices which measure a target variable
- Two components
  - Sensing Element
    - Tracks the variable being measured
    - Sends signal to transmitter
  - Transmitter
    - Converts signal for use on local display
    - Sends signal to controller/SCADA

Sensor image from:
http://www.capitolscientific.com/core/media/media.nl?id=51573&c=1250437&h=767af71ece59e1f9ec11

Sensors – Calibration and Validation

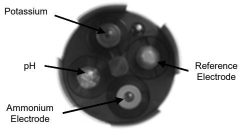
- Example: side-by-side grab sampling with immediate filtration/analysis and comparing grab value with instrument value
- Typically conducted three times per week dependent on plant and sensor

Three Main Sensor Types

- Ion Selective Electrode (ISE) probes
- Wet Chemistry (Colorimetric) analyzers
- Optical (UV) probes

Ion Selective Electrode (ISE)

- Probe-type sensors that use an ISE probe and reference electrode



Images Courtesy of S::CAN

Images Courtesy of WTW

Detection by ISE Probe

- Specific ions adhere to membrane on measurement electrode
- Those ions do not affect reference electrode
- Measure potential (voltage) difference
- Replace cartridge ~ 6-12 months

Nutrient ISE Probes

Brand	Model
YSI	VARiON (IQ SensorNet)
Hach	AN ISE sc
Endress & Hauser	ISEmax

Wet Chemistry (Colorimetric) Analyzers

- Utilize a colorimetric method for measuring a constituent in a sample
- Withdraw a sample from the wastewater flow and pump it to a nearby analyzer

Images Courtesy of HACH®

http://www.capitalh2o.com/image/page_photos/chemscan_front.jpg

Optical (UV) Probes

- Utilize an ultraviolet (UV) light source to measure an absorbance and/or transmittance of UV light waves passing through a sample
- Similar to UV light absorbance spectrophotometers in a lab

Optical (UV) DO Probes

Brand	Model
YSI	FDO (IQ SensorNet)
Hach	LDO Model 2
Endress & Hauser	Oxymax
Insight IG	Model 1000
ATI	Q45D

Why are Sensors important?

- Automate data collection
- Monitor performance when no one is looking
- **Optimize process performance**
- **Minimize energy use and chemical consumption**
- Sensors can be paired with calibrated process models to enhance operations

IC&A Drivers

- Collect and record data for creating reports, profiling process performance, and storing data
- Reduce costs:
  - Operating costs, e.g. chemicals, energy (for aeration), labor
  - Capital costs, e.g., increase nutrient removal capacity by 10% to 30%; possibly reduce future system investments by another 20% to 50%

SBR Systems – Process Control

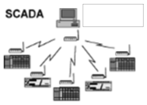
- Any online instrument should be tied into the plant SCADA system, allowing operators to verify and make changes as needed to the SBR control parameters.

Supervisory Control

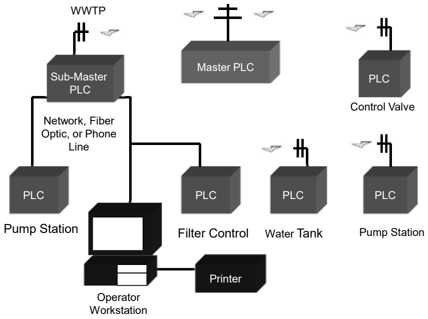
Denotes a control system that manages the activities of several integrated unit operations

A control system that directs and coordinates the activities of several interacting pieces of equipment

- SCADA
- CMMS - Avantis



SCADA System Architecture



Programmable Logic Controller (PLC)

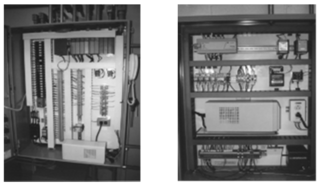
- Introduced around 1970 to replace electromechanical relay controllers
- Microprocessor-based
- Executes instructions/algorithms that implement logic, sequencing, counting, and arithmetic functions for controlling equipment and processes

SCADA System Architecture

- Goals:
  - Graphical Representation of Entire System
  - Continuous Information at Operator Workstations
  - Automatic Control
  - Remote Control
  - Alarming/Paging
  - Trending/Reporting
  - Easily Expandable

Typical Hardware – PLC's

- Programmable Logic Controllers (PLC's) - Standardized on Allen-Bradley and Micrologix controllers

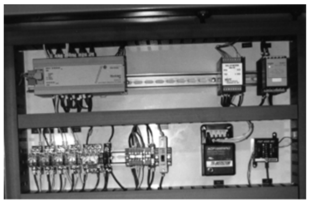


Typical Hardware – Radio Communication

- MAS/MDS radios and modems for Radio Communication

Typical Hardware – Phone Line Communication

- Mille Research modems for Phone Line Communication



Typical Software

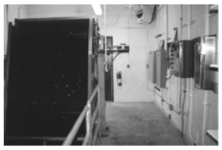
- Standardized on Rockwell Software:
  - RSLogix for programming
  - RSLinx for communications
  - RSView for Operator Interface
  - RSMessenger for Alarm Paging
- LapLink Software allows connection to operator workstation from a remote computer through a dial-up modem

SCADA Economic Advantages

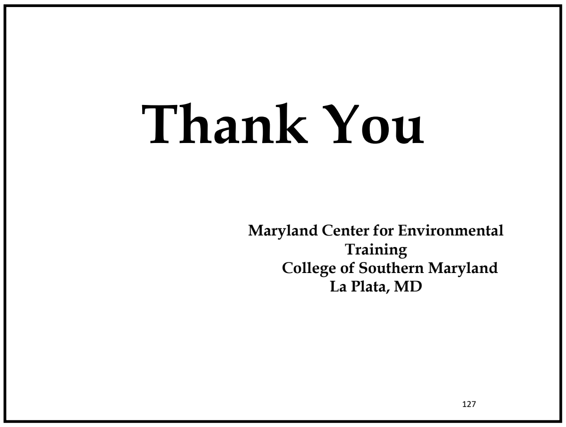
- Implementation of "On-Call" shifts
- Reduced Operator Travel Time

SCADA Economic Advantages

- Greater Speed, Accuracy, and efficiency
- Increased Reliability
- Reduced Maintenance
- Safety and Security



Questions?



Thank You

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