parural water Association

2015 Annual Conference

Penn Stater Hotel & Conference Center
State College, PA

March 24-27 2015

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Welcome!

HOW DO I RUN THIS DAMN BNR PLANT MY ENGINEER DESIGNED

We're Glad You're Here!

Please, put your cell phones on vibrate during sessions and, take calls to the hallway

HOW DO I RUN THIS DAMN BNR PLANT MY ENGINEER DESIGNED

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www.entecheng.com

http://pixabay.com/en/photos/pacman/

Nitrification / Denitrification

Enhanced Biological Phosphorus Removal

Overall Objectives

- Understand the Activated Sludge Biological Process
  - Emphasis on Nutrient Removal

- Understand Control Parameters for Biological Nutrient Removal (BNR)

- Discuss operations and troubleshooting of your BNR plant

PRESENTATION

- Section 1: Quick Review
- Section 2: Activated Sludge Treatment Process
- Section 3: Aerobic Process for Nitrification
- Section 4: Anoxic Process for Denitrification
- Section 5: Anaerobic Process, Bio-Phosphorus Removal
- Section 6: Control Parameters for the BNR Processes
- Section 7: Operational Changes

Section 1 – Quick Review

Contaminants	Low (mg/L)	Medium (mg/L)	High (mg/L)
TSS	**120**	**210**	**400**
BOD	**110**	**190**	**350**
Nitrogen (total as N)	**20**	**40**	**70**
Organic	8	15	25
Free Ammonia	12	25	45
Nitrites	0	0	0
Nitrates	0	0	0
Phosphorus (total as P)	**4**	**7**	**12**
Organic	1	2	4
Inorganic	3	5	10

Nutrient – Pollution Concerns

- DO Depletion
- Toxicity (NH_4^+ and NO_2^-)
- Eutrophication
  - Plant and algae growth
- Nitrate in Groundwater
  - Methemoglobinemia
    - Blue Baby Syndrome

Chesapeake Bay Strategy

- Chesapeake Bay Strategy
  - Existing WWTP not designed to limit nutrients
  - Limit Total Nitrogen (TN) and Total Phosphorus (TP) discharges

0.4 MGD X 6.0 mg/L TN X 8.34 X 365 days

= 7,306 # TN per year

0.4 MGD X 0.8 mg/L TP X 8.34 X 365 days

= 974 # TP per year

PART A - EFFLUENT LIMITATIONS, MONITORING, RECORDKEEPING AND REPORTING REQUIREMENTS

I. B. **For Outfall** 001, **Latitude** [redacted], **Longitude** [redacted], **River Mile Index** [redacted], **Stream Code** [redacted]

Receiving Waters: [redacted]

Type of Effluent: Sewage

1. The permittee is authorized to discharge during the period from Permit Effective Date through Permit Expiration Date.

2. Based on the anticipated wastewater characteristics and flows described in the permit application and its supporting documents and/or amendments, the following effluent limitations and monitoring requirements apply (see also Additional Requirements and Footnotes).

Parameter (1)	Effluent Limitations					Monitoring Requirements	
	Mass Units (lbs)		Concentrations (mg/L)			Minimum (2) Measurement Frequency	Required Sample Type
	Monthly	Annual	Minimum	Monthly Average	Maximum		
Ammonia---N	Report	Report		Report		1/week	24-Hr Composite
Kjeldahl---N	Report			Report		1/week	24-Hr Composite
Nitrate-Nitrite as N	Report			Report		1/week	24-Hr Composite
Total Nitrogen	Report	Report		Report		1/month	Calculation
Total Phosphorus	Report	Report		Report		1/week	24-Hr Composite
Net Total Nitrogen	Report	41,095 (3)				1/month	Calculation
Net Total Phosphorus	Report	5,479				1/month	Calculation

Samples taken in compliance with the monitoring requirements specified above shall be taken at the following location(s): Outfall 001

Footnotes:
(1) See Part C for Chesapeake Bay Requirements.
(2) This is the minimum number of sampling events required. Permittees are encouraged, and it may be advantageous in demonstrating compliance, to perform more than the minimum number of sampling events required.
(3) The permittee is authorized to use 9,315 lbs/year as Total Nitrogen (TN) Offsets toward compliance with the Annual Net TN mass load limitation (Cap Load), in accordance with Part C. These offsets may be applied through the Compliance Year or during the Truing Period. The application of Offsets must be reported to DEP as described in Part C. The offsets are authorized for the following pollutant load reduction activities.

- Connection of 372.6 EDUs to the public sewer system after January 1, 2003, in which 25 lbs/year of TN offsets are granted per EDU

Contaminants		Influent (mg/L)	
TSS		200	
BOD		200	
Nitrogen (total as N)		35	
Phosphorus (total as P)		7	

hydrogen 1 **H** 1.0079																		helium 2 **He** 4.0026
lithium 3 **Li** 6.941	beryllium 4 **Be** 9.0122												boron 5 **B** 10.811	carbon 6 **C** 12.011	nitrogen 7 **N** 14.007	oxygen 8 **O** 15.999	fluorine 9 **F** 18.998	neon 10 **Ne** 20.180
sodium 11 **Na** 22.990	magnesium 12 **Mg** 24.305												aluminium 13 **Al** 26.982	silicon 14 **Si** 28.086	phosphorus 15 **P** 30.974	sulfur 16 **S** 32.065	chlorine 17 **Cl** 35.453	argon 18 **Ar** 39.948
potassium 19 **K** 39.098	calcium 20 **Ca** 40.078		scandium 21 **Sc** 44.956	titanium 22 **Ti** 47.867	vanadium 23 **V** 50.942	chromium 24 **Cr** 51.996	manganese 25 **Mn** 54.938	iron 26 **Fe** 55.845	cobalt 27 **Co** 58.933	nickel 28 **Ni** 58.693	copper 29 **Cu** 63.546	zinc 30 **Zn** 65.39	gallium 31 **Ga** 69.723	germanium 32 **Ge** 72.61	arsenic 33 **As** 74.922	selenium 34 **Se** 78.96	bromine 35 **Br** 79.904	krypton 36 **Kr** 83.80
rubidium 37 **Rb** 85.468	strontium 38 **Sr** 87.62		yttrium 39 **Y** 88.906	zirconium 40 **Zr** 91.224	niobium 41 **Nb** 92.906	molybdenum 42 **Mo** 95.94	technetium 43 **Tc** [98]	ruthenium 44 **Ru** 101.07	rhodium 45 **Rh** 102.91	palladium 46 **Pd** 106.42	silver 47 **Ag** 107.87	cadmium 48 **Cd** 112.41	indium 49 **In** 114.82	tin 50 **Sn** 118.71	antimony 51 **Sb** 121.76	tellurium 52 **Te** 127.60	iodine 53 **I** 126.90	xenon 54 **Xe** 131.29
caesium 55 **Cs** 132.91	barium 56 **Ba** 137.33	57-70 *	lutetium 71 **Lu** 174.97	hafnium 72 **Hf** 178.49	tantalum 73 **Ta** 180.95	tungsten 74 **W** 183.84	rhenium 75 **Re** 186.21	osmium 76 **Os** 190.23	iridium 77 **Ir** 192.22	platinum 78 **Pt** 195.08	gold 79 **Au** 196.97	mercury 80 **Hg** 200.59	thallium 81 **Tl** 204.38	lead 82 **Pb** 207.2	bismuth 83 **Bi** 208.98	polonium 84 **Po** [209]	astatine 85 **At** [210]	radon 86 **Rn** [222]
francium 87 **Fr** [223]	radium 88 **Ra** [226]	89-102 **	lawrencium 103 **Lr** [262]	rutherfordium 104 **Rf** [261]	dubnium 105 **Db** [262]	seaborgium 106 **Sg** [266]	bohrium 107 **Bh** [264]	hassium 108 **Hs** [269]	meitnerium 109 **Mt** [268]	ununnilium 110 **Uun** [271]	unununium 111 **Uuu** [272]	ununbium 112 **Uub** [277]		ununquadium 114 **Uuq** [289]				

*Lanthanide series	lanthanum 57 **La** 138.91	cerium 58 **Ce** 140.12	praseodymium 59 **Pr** 140.91	neodymium 60 **Nd** 144.24	promethium 61 **Pm** [145]	samarium 62 **Sm** 150.36	europium 63 **Eu** 151.96	gadolinium 64 **Gd** 157.25	terbium 65 **Tb** 158.93	dysprosium 66 **Dy** 162.50	holmium 67 **Ho** 164.93	erbium 68 **Er** 167.26	thulium 69 **Tm** 168.93	ytterbium 70 **Yb** 173.04
**Actinide series	actinium 89 **Ac** [227]	thorium 90 **Th** 232.04	protactinium 91 **Pa** 231.04	uranium 92 **U** 238.03	neptunium 93 **Np** [237]	plutonium 94 **Pu** [244]	americium 95 **Am** [243]	curium 96 **Cm** [247]	berkelium 97 **Bk** [247]	californium 98 **Cf** [251]	einsteinium 99 **Es** [252]	fermium 100 **Fm** [257]	mendelevium 101 **Md** [258]	nobelium 102 **No** [259]

Sources of Nitrogen

- Nitrogen is a naturally occurring element that is essential for growth and reproduction in all living organisms.

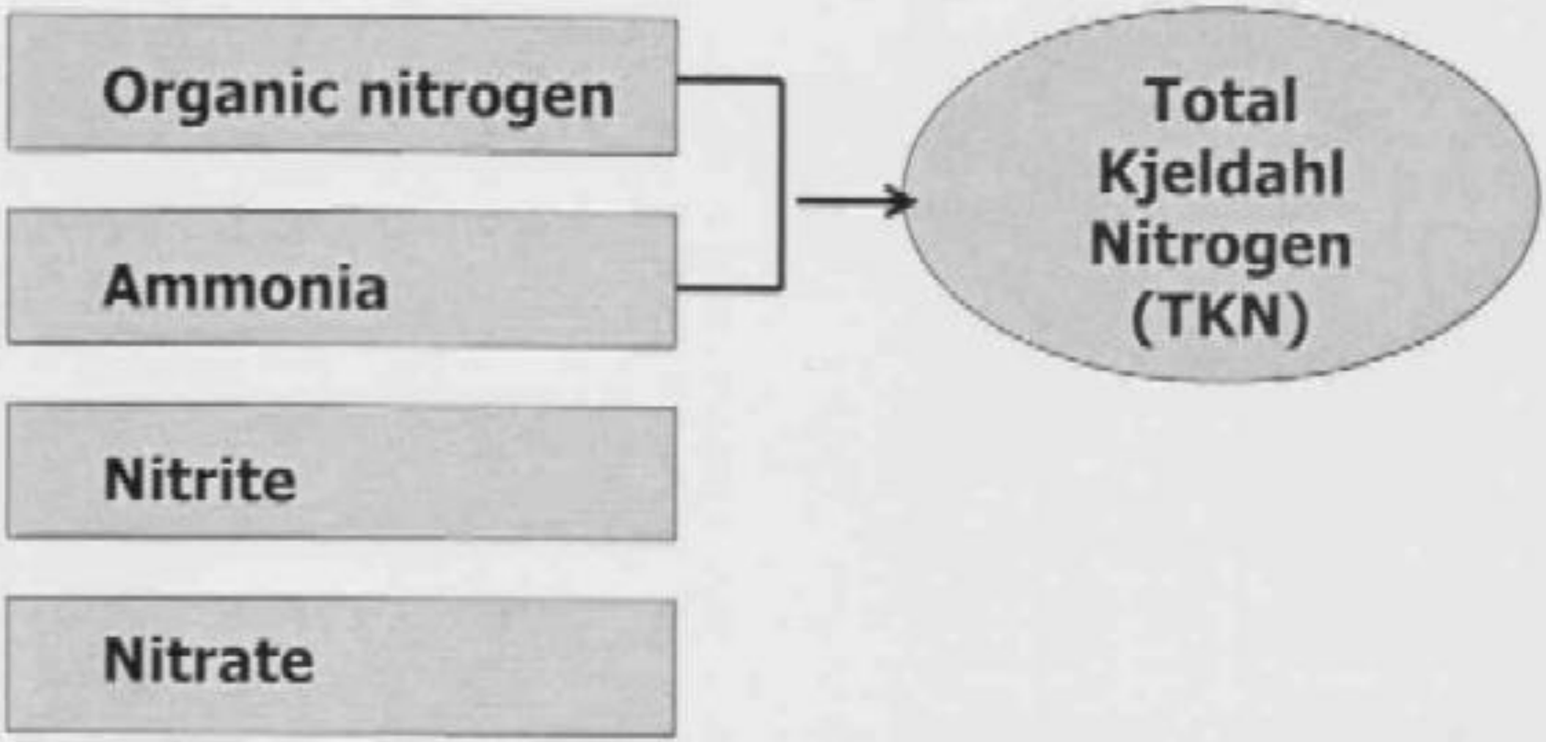
Forms of Nitrogen

- Organic Nitrogen
- Ammonia (NH_3) / Ammonium ion (NH_4^+)

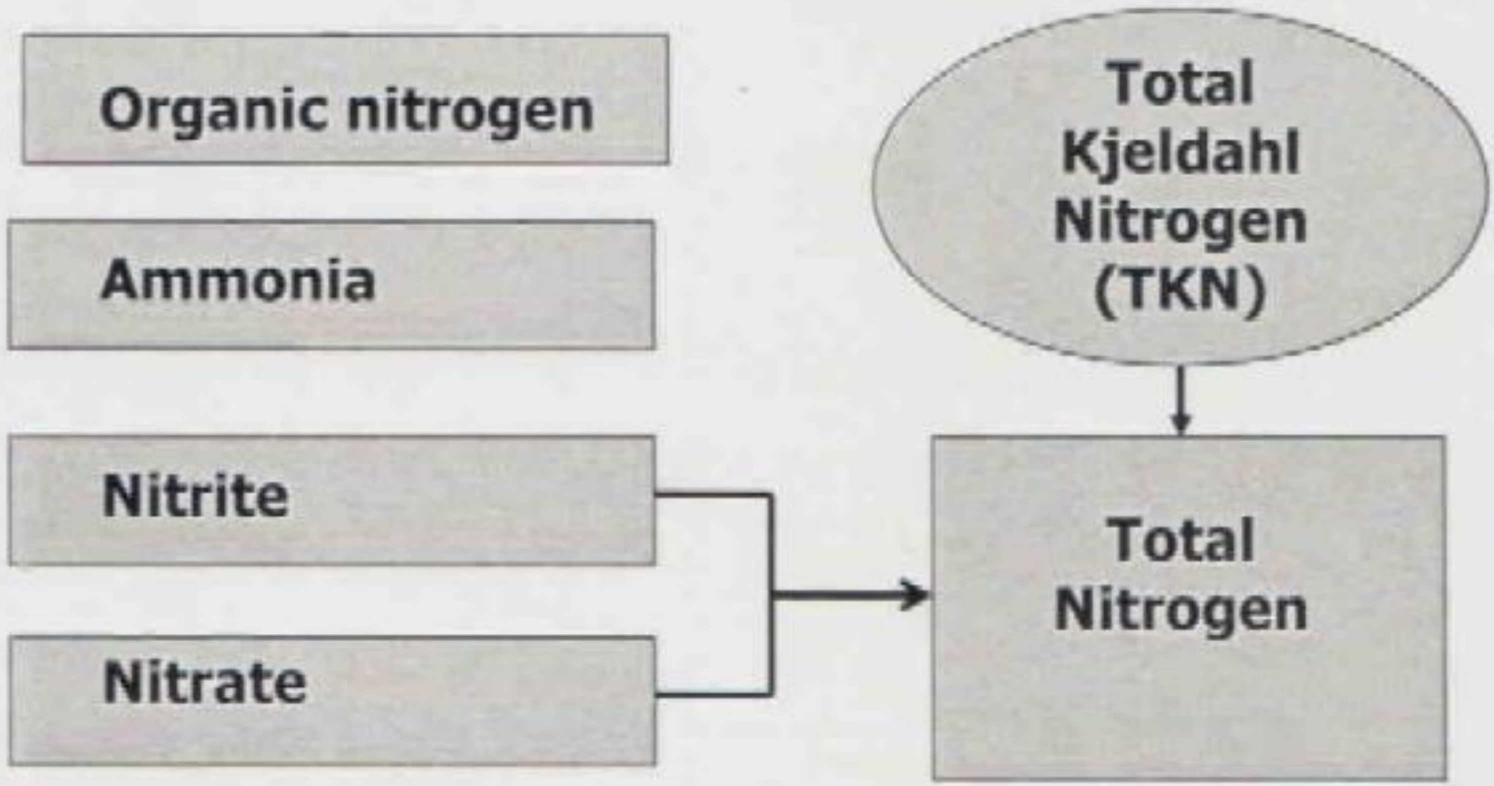
- Nitrite (NO_2^-)
- Nitrate (NO_3^-)

- Nitrogen Gas (N_2)

Groups of nitrogenous compounds



Groups of nitrogenous compounds



Sources of Phosphorus

- Phosphorus is a key component in the process of energy metabolism by cells and the cell membrane
- Phosphorus is found in:
  - Fertilizers
  - Detergents / Cleaning Products
  - Human / Animal Waste

Forms of Phosphorus

- **Orthophosphates**
  - Phosphate ion (PO_4^{3-})
    - Simplest form; available for biological
    - Form that is precipitated; chemical removal
    - 70% - 90% of TP
  - Phosphoric Acid (H_3PO_4)
  - Dihydrogen Phosphate ($H_2PO_4^-$)
  - Hydrogenophosphate (HPO_4^{2-})

- **Polyphosphates (condensed phosphates)**
  - Complex forms of inorganic orthophosphates

Forms of Phosphorus

- **Organic Phosphates**
  - Soluble
    - Biodegradable
    - Non-Biodegradable (refractory)
  - Particulate

Section 2 – Activated Sludge Treatment Process

Biological Treatment

The Biological Treatment Process

- The biological treatment process uses various forms of bacteria, protozoa and other aquatic life to remove pollutants.

- Typical pollutants removed include:
  - Biochemical Oxygen Demand (BOD)
  - Total Suspended Solids (TSS)
  - Nitrogen
  - Phosphorus

Variations of Activated Sludge

- Conventional — BOD Removal with 6-8 Hour Detention
- Step Aeration — BOD Removal with 6-8 Hour Detention
- Contact Stabilization — BOD Removal with 5 Hour Detention
- Extended Aeration — BOD & Ammonia Removal, 12-24 hr.
- Oxidation Ditch — BOD & Ammonia Removal, 18-24 hr.
- Batch Process
  - 18-24 detention, BOD & Ammonia Removal
    - Sequential Batch Reactor (SBR)
    - Intermittent Cycle Extended Aeration System (ICEAS)

Variations of the Activated Sludge Process for Nutrient Removal

- Detention Times of 18-24 or more hours
  - Sequential Batch Reactor (SBR)
  - Intermittent Cycle Extended Aeration System (ICEAS)
  - Vertical Loop Reactor (VLR)
  - Orbal Process
  - Modified Ludzak-Ettinger (MLE)
  - Four and Five Stage Bardenpho
  - Membrane Biological Reactor (MBR)
  - Etc……….

What's the Difference ?

- Activated Sludge Process for BOD & NH_3
  - Strictly Aerobic (aeration) Process
- Activated Sludge Process for Nutrient Removal
  - Aerobic Zones
  - Anoxic Zones
  - Anaerobic Zones

Contaminants	Low (mg/L)	Medium (mg/L)	High (mg/L)
BOD	110	190	350
TSS	120	210	400

PART A - EFFLUENT LIMITATIONS, MONITORING, RECORDKEEPING AND REPORTING REQUIREMENTS

I. A. For Outfall 001 , **Latitude** [redacted] , **Longitude** [redacted] , **River Mile Index** [redacted] , **Stream Code** [redacted]

Discharging to [redacted]

which receives wastewater from [redacted]

1. The permittee is authorized to discharge during the period from Permit Effective Date through Permit Expiration Date.

2. Based on the anticipated wastewater characteristics and flows described in the permit application and its supporting documents and/or amendments, the following effluent limitations and monitoring requirements apply (see also Additional Requirements, Footnotes and Supplemental Information).

Parameter	Effluent Limitations						Monitoring Requirements	
	Mass Units (lbs/day) (1)		Concentrations (mg/L)				Minimum (2) Measurement Frequency	Required Sample Type
	Average Monthly	Weekly Average	Minimum	Average Monthly	Weekly Average	Instant. Maximum		
Flow (MGD)	Report	Report Daily Max					Continuous	Metered
pH (S.U.)			6.0			9.0	1/day	Grab
Total Residual Chlorine				0.5		1.6	1/day	Grab
CBOD5	28	44		25	40	50	1/week	8-Hr Composite
Total Suspended Solids	33	50		30	45	60	1/week	8-Hr Composite
Fecal Coliform (CFU/100 ml) May 1 - Sep 30	200/100 mL Geometric Mean and not greater than 1,000/100 mL in more than 10% of the samples tested						1/week	Grab
Fecal Coliform (CFU/100 ml) Oct 1 - Apr 30	2000/100 mL as a geometric mean						1/week	Grab

Samples taken in compliance with the monitoring requirements specified above shall be taken at the following location(s):

at Outfall 001

BOD

- Wastewater contains organic materials (food) that are decomposed by microorganisms.

- Use oxygen in the process; AEROBIC
  - The amount of oxygen consumed in breaking down the waste is known as **biochemical oxygen demand** (BOD)

TSS

- Total suspended solids (TSS) include all particles suspended in water which will not pass through a filter

http://water.me.vccs.edu/courses/env211/tss.htm

Section 3 – Aerobic Process for Nitrification

Contaminants	Low (mg/L)	Medium (mg/L)	High (mg/L)
TSS	**120**	**210**	**400**
BOD	**110**	**190**	**350**
Nitrogen (total as N)	**20**	**40**	**70**
Organic	8	15	25
Free Ammonia	12	25	45
Nitrites	0	0	0
Nitrates	0	0	0

PART A - EFFLUENT LIMITATIONS, MONITORING, RECORDKEEPING, AND REPORTING REQUIREMENTS

I. **For Outfall 001, Latitude [redacted], Longitude [redacted], River Mile Index [redacted], Stream Code [redacted]**

Discharges to [redacted]

which receives wastewater from [redacted]

A. The permittee is authorized to discharge during the period from 5/1/2009 through 4/30/2014.

B. Based on the anticipated wastewater characteristics and flows described in the permit application and its supporting documents and/or amendments, the following effluent limitations and monitoring requirements apply (see also Additional Requirements, Footnotes and Supplemental Information).

Discharge Parameter	Effluent Limitations						Monitoring Requirements	
	Mass Units (lbs/day)[1]		Concentrations (mg/L)				Minimum [3] Measurement Frequency	Required Sample Type
	Monthly Average	Weekly Average	Minimum	Monthly Average	Weekly Average	Instantaneous Maximum [2]		
Flow (MGD)	Report						Continuous	Meter
PH (Std Units)			6.0			9.0	1/Day	Grab
Fecal Coliform (5/1 – 9/30)	200/100mL geo mean and not greater then 1,000/100ml in more than 10% of the samples tested						2/Week	Grab
(10/1 – 4/30)	2,000/100mL geo mean						2/Week	Grab
$CBOD_5$ 5/1-10/31	93	142		15	23	30	2/Week	24 Hr Comp
11/1-4/30	154	247		25	40	50	2/Week	24 Hr Comp
TSS	185	278		30	45	60	2/Week	24 Hr Comp
Total Residual Chlorine				0.18		0.58	1/Day	Grab
Ammonia-N 5/1-10/31	9.3	14		1.5	2.3	3.0	2/Week	24 Hr Comp
11/1-4/30	28	43		4.5	6.9	9.0	2/Week	24 Hr Comp
Dissolved Oxygen			6.0				1/Day	Grab

Samples taken in compliance with the monitoring requirements specified above shall be taken at the following location(s):

Outfall 001

NITRIFICATION

- Two-step biological conversion
  - The conversion of ammonium (NH_4^+) to nitrite (NO_2^-), and finally to nitrate (NO_3^-)
    - Nitrosomonas; rate limiting step
    - Nitrobacter; max growth rate is higher

- Nitrification bacteria grow much slower than heterotrophic bacteria.
  - Need longer hydraulic retention time
  - Need longer solids retention time

NITRIFICATION

$$NH_4^+ + 1.5\ O_2 \longrightarrow NO_2^- + H_2O + 2\ H^+$$

Oxygen Required = 3.43 lb / lb N Oxidized

Alkalinity Required = 7.14 lb as $CaCO_3$ / lb N Oxidized

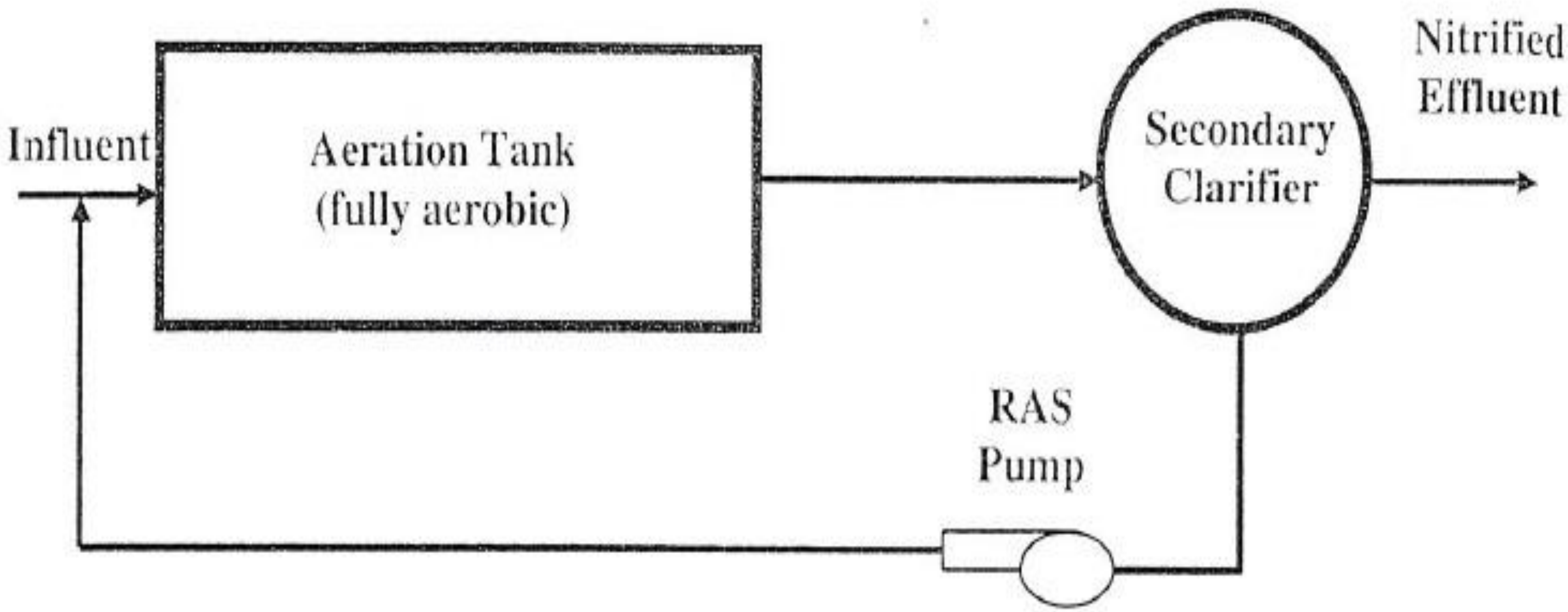
$$NO_2^- + 0.5\ O_2 \longrightarrow NO_3^-$$

Oxygen Required = 1.14 lb / lb N Oxidized

For Both Reactions

Oxygen Required = 4.57 lb / lb N Oxidized

Alkalinity Required = 7.14 lb as $CaCO_3$ / lb N Oxidized



BOD Removal & Nitrification

Environmental Factors

- Temperature
- DO Concentration
- pH and Alkalinity
- Toxicity / Inhibition
  - Sensitive
  - Heavy metals
  - Un-ionized ammonia

Temperature

Temperature, C	Effect on Nitrification
28 to 32	Optimal temperature range
15 to 16	Approximately 50% of maximum rate
10	Significant reduction in rate, approximately 20% of rate at 30C
< 5	Nitrification ceases

Temperature and MCRT

Temperature, C	MCRT (Mean Cell Residence Time), Days
10	30
15	20
20	15
25	10
30	7

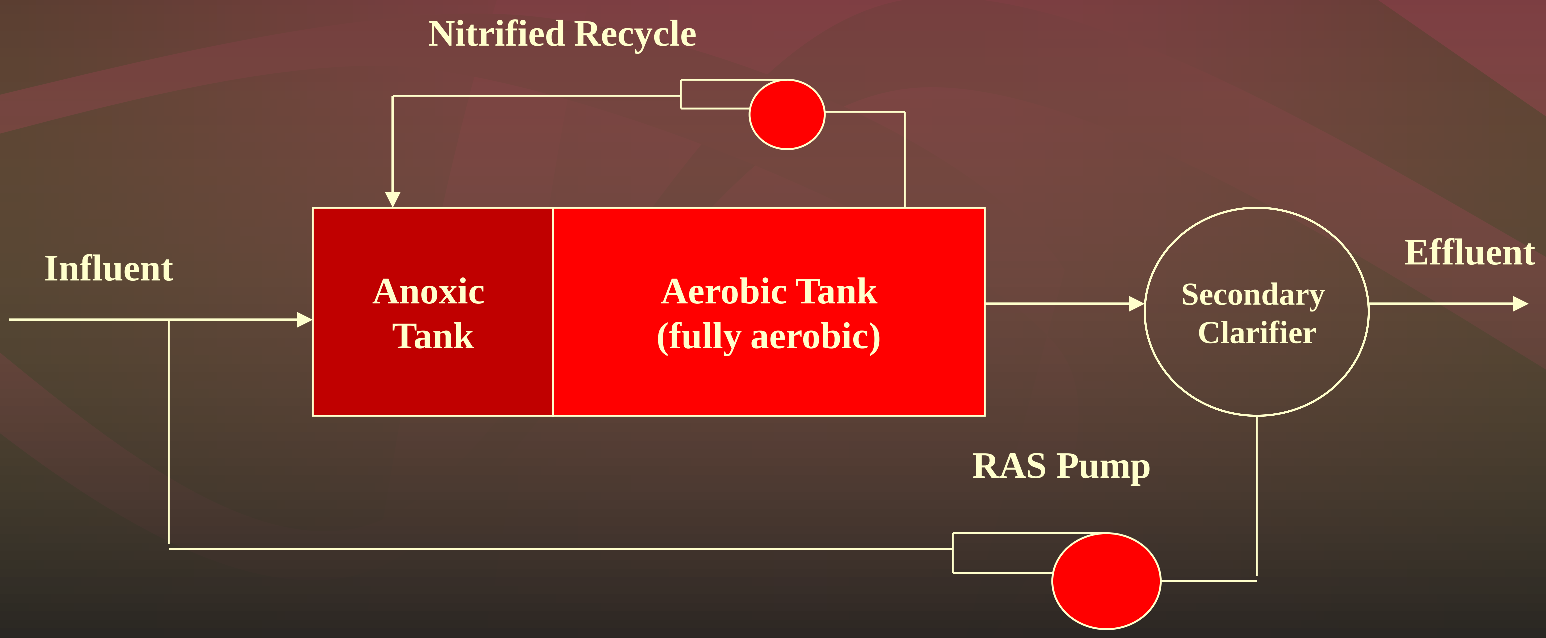
Oxygen Consumed (Theoretical) During Nitrification

Biochemical Reaction	O_2 Consumed, lb
1 lb NH_4^+ to 1 lb NO_2^-	3.43
1 lb NO_2^- to 1 lb NO_3^-	1.14
1 lb NH_4^+ to 1 lb NO_3^-	4.57

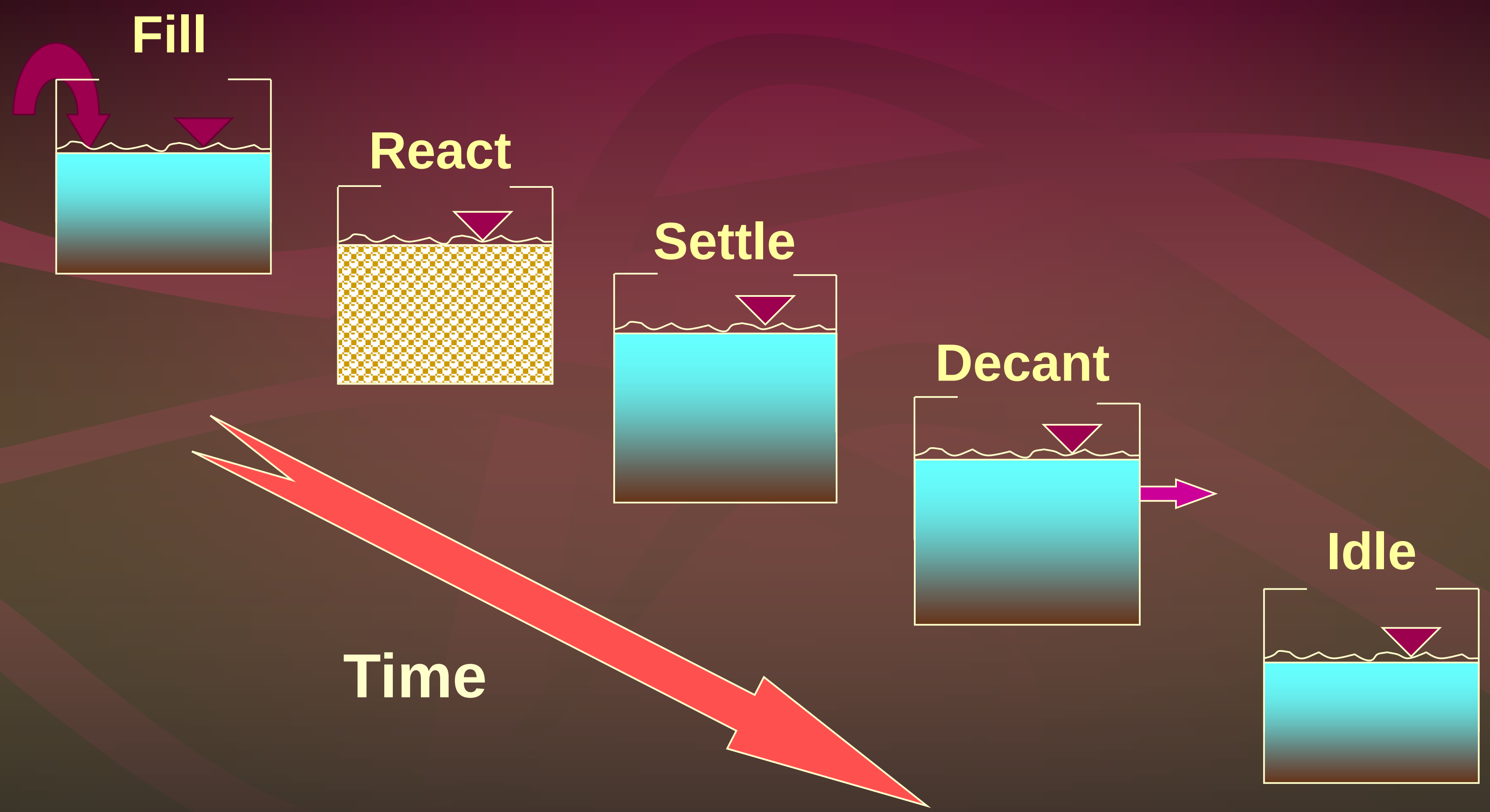
DO Concentration and Nitrification Achieved (Laboratory)

DO Concentration	Nitrification Achieved
< 0.5 mg/l	Little, if any, nitrification achieved
0.5 to 1.5 mg/l	Nitrification occurs, but inefficiently
2.0 mg/l	Significant nitrification occurs
3.0 mg/l	Maximum nitrification

Modified Ludzack-Ettinger (MLE) Process



The Sequencing Batch Reactor



Section 4 – Anoxic Process for Denitrification

Contaminants	Low (mg/L)	Medium (mg/L)	High (mg/L)
TSS	**120**	**210**	**400**
BOD	**110**	**190**	**350**
Nitrogen (total as N)	**20**	**40**	**70**
Organic	8	15	25
Free Ammonia	12	25	45
Nitrites	0	0	0
Nitrates	0	0	0

NITRIFICATION

$NH_4^+ + O_2 \rightarrow NO_2^-$

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

Outfall 001, Continued (from beginning of fourth year through Permit Expiration Date)

Parameter	Effluent Limitations						Monitoring Requirements	
	Mass Units (lbs/day) [(1)]		Concentrations (mg/L)					
	Average Monthly	Daily Maximum	Minimum	Average Monthly	Daily Maximum	Instant. Maximum	Minimum [(2)] Measurement Frequency	Required Sample Type
Fecal Coliform (CFU/100 ml) Oct 1 - Apr 30	XXX	XXX	XXX	2,000 Geo Mean	XXX	10,000	2/week	Grab
UV Transmittance (mjoules/cm²)	XXX	XXX	XXX	Report	XXX	XXX	1/day	Measured
Nitrate-Nitrite as N	147	XXX	XXX	8.0	XXX	16.0	2/week	24-Hr Composite
Total Nitrogen *	Report	XXX	XXX	Report	XXX	XXX	1/month	Calculation
Ammonia-Nitrogen May 1 - Oct 31	119	XXX	XXX	6.5	XXX	13.0	2/week	24-Hr Composite
Ammonia-Nitrogen Nov 1 - Apr 30	357	XXX	XXX	19.5	XXX	39.0	2/week	24-Hr Composite
Total Kjeldahl Nitrogen	Report	XXX	XXX	Report	XXX	XXX	1/month	24-Hr Composite
Total Phosphorus	47.7	XXX	XXX	2.6	XXX	5.2	2/week	24-Hr Composite
Total Copper	0.23	0.36	XXX	0.013	0.020	XXX	1/week	24-Hr Composite
Total Lead	0.09	0.16	XXX	0.005	0.009	XXX	1/week	24-Hr Composite
Total Zinc	2.0	3.3	XXX	0.11	0.18	XXX	1/week	24-Hr Composite

Samples taken in compliance with the monitoring requirements specified above shall be taken at the following location(s):

at Outfall 001

* Total Nitrogen = Nitrate-Nitrite as N + Total Kjeldahl Nitrogen, where Nitrate-Nitrite as N and Total Kjeldahl Nitrogen are measured in the same sample.

DENITRIFICATION

- The conversion of nitrate (NO_3^-) to nitrogen gas (N_2)
  - Can use Oxygen, Nitrate, or Nitrite as their terminal electronic acceptor (oxygen source)

Nitrification / Denitrification

- Steak, Cheeseburger, and 3-day old nachos.

O_2

NO_x

SO_x

DENITRIFICATION

NO_3 + **Org. Carbon** → $N_2 + CO_2 + OH + H_2O$

$CO_2 + OH$ → HCO_3

NO_3 → NO_2 → NO → N_2O → N_2

2.86 lbs oxygen recovered / lb NO_3-N

3.57 lbs alkalinity recovered / lb NO_3-N

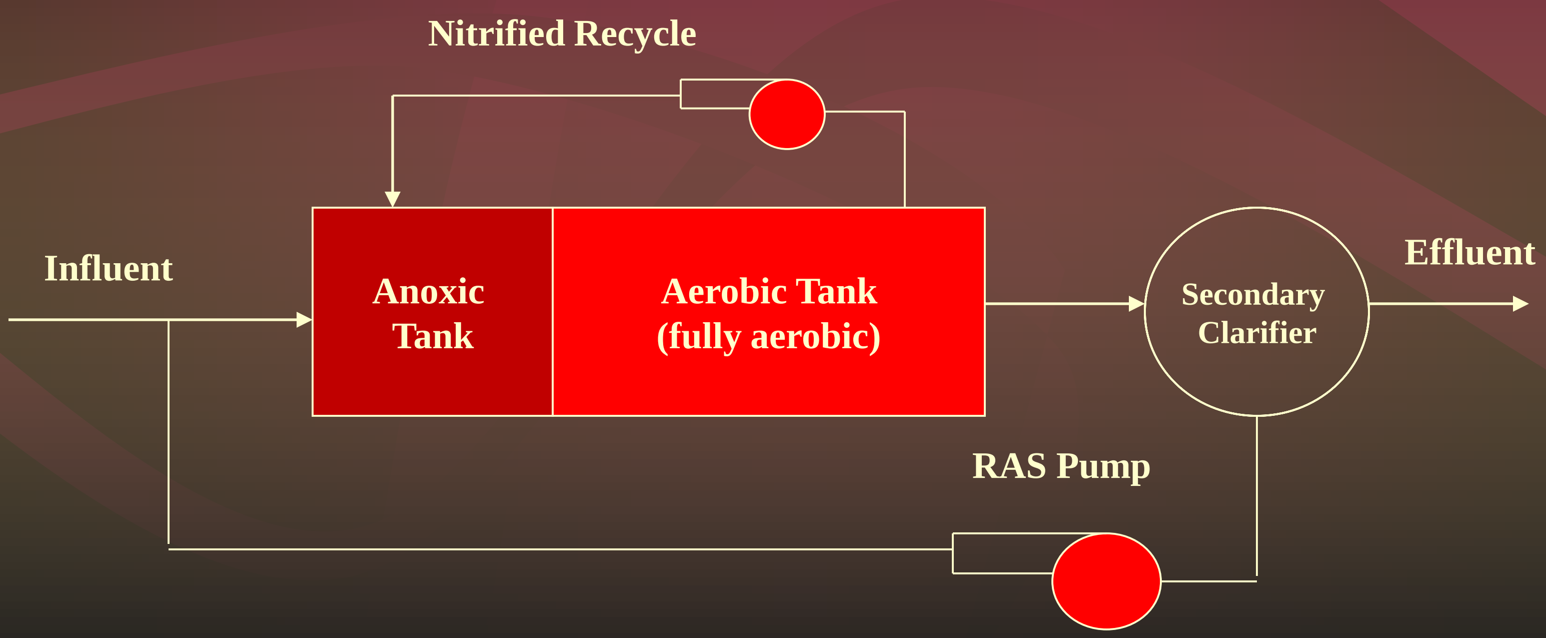
Operational Factors Affecting Denitrification

- Presence of substrate (soluble cBOD)
- Absence of O_2 ; Little to No Dissolved Oxygen
  - Less than 0.3 mg/L
- Presence of NO_3 or NO_2
- Active population of denitrifiers
  - Usually not a problem

DENITRIFICATION – Carbon Augmentation

- Methanol
- Ethanol
- Acetic Acid
- Molasses
- Food processing organic waste (sugars)
  - Soft drink wastes
- Engineered substances

Modified Ludzack-Ettinger (MLE) Process



What is Nitrified Recycle ?

- This BNR Treatment is Backwards
  - First, NH_3 goes to NO_3 in the Aeration Tank
  - Second, NO_3 goes to N gas in the Anoxic Tank
  - Anoxic Tank is First, Aeration Tank is second
- Recycle Brings the NO_3 back to Anoxic
  - WHY ? Denitrification needs BOD from influent

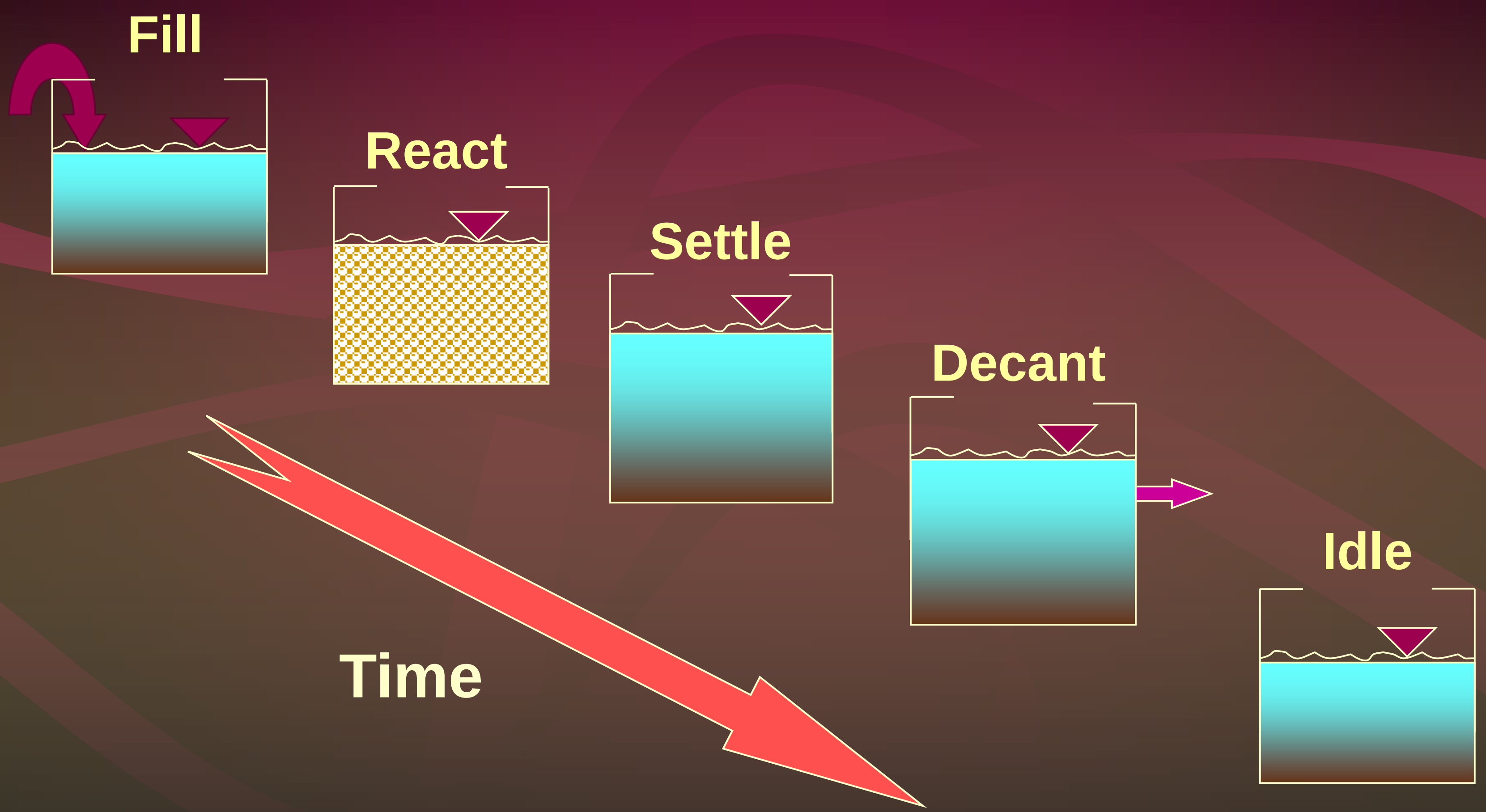
Adjusting Nitrified Recycle

- Typically 200% to 400% of Influent Rate
  - Over 500% has no benefit
  - Can return DO to Anoxic Tank
    - Keep end of Aeration at a low DO
- Recycle Brings the NO3 back to Anoxic
  - If NO3 is high in effluent
    - Increase NIR
    - NO3 will equalize when Soluble BOD utilized
  - If NO3 is low
    - Reduce NIR, it will save energy

Measure Nitrification/Denitrification to Balance DO

Form	ML Effluent Filtrate Concentration, mg/l		
	NH_4^+	NO_2^-	NO_3^-
Complete	< 1	< 1	>1<7
More DO	< 1	> 1	< 1
More DO	> 1	< 1	> 1
Less DO, Carryover to Anoxic Zone	< 1	< 1	> 10

The Sequencing Batch Reactor



Simultaneous Nitrification / Denitrification

- The occurrence of nitrification and denitrification at the same time in a single reactor without distinct aerated and non-aerated zones is commonly referred to as simultaneous nitrification-denitrification (SND).

- Treatment systems exhibiting SND typically have relatively long SRTs, aeration equipment that creates non-uniform flows, such as mechanical aerators, and an operating procedure to limit oxygen input (Daigger, 2013).

Section 5 – Anaerobic Process for Enhanced Bio-phosphorus Removal

Contaminants	Low (mg/L)	Medium (mg/L)	High (mg/L)
TSS	**120**	**210**	**400**
BOD	**110**	**190**	**350**
Nitrogen (total as N)	**20**	**40**	**70**
Organic	8	15	25
Free Ammonia	12	25	45
Nitrites	0	0	0
Nitrates	0	0	0
Phosphorus (total as P)	**4**	**7**	**12**
Organic	1	2	4
Inorganic	3	5	10

hydrogen 1 **H** 1.0079																		helium 2 **He** 4.0026
lithium 3 **Li** 6.941	beryllium 4 **Be** 9.0122												boron 5 **B** 10.811	carbon 6 **C** 12.011	nitrogen 7 **N** 14.007	oxygen 8 **O** 15.999	fluorine 9 **F** 18.998	neon 10 **Ne** 20.180
sodium 11 **Na** 22.990	magnesium 12 **Mg** 24.305												aluminium 13 **Al** 26.982	silicon 14 **Si** 28.086	phosphorus 15 **P** 30.974	sulfur 16 **S** 32.065	chlorine 17 **Cl** 35.453	argon 18 **Ar** 39.948
potassium 19 **K** 39.098	calcium 20 **Ca** 40.078		scandium 21 **Sc** 44.956	titanium 22 **Ti** 47.867	vanadium 23 **V** 50.942	chromium 24 **Cr** 51.996	manganese 25 **Mn** 54.938	iron 26 **Fe** 55.845	cobalt 27 **Co** 58.933	nickel 28 **Ni** 58.693	copper 29 **Cu** 63.546	zinc 30 **Zn** 65.39	gallium 31 **Ga** 69.723	germanium 32 **Ge** 72.61	arsenic 33 **As** 74.922	selenium 34 **Se** 78.96	bromine 35 **Br** 79.904	krypton 36 **Kr** 83.80
rubidium 37 **Rb** 85.468	strontium 38 **Sr** 87.62		yttrium 39 **Y** 88.906	zirconium 40 **Zr** 91.224	niobium 41 **Nb** 92.906	molybdenum 42 **Mo** 95.94	technetium 43 **Tc** [98]	ruthenium 44 **Ru** 101.07	rhodium 45 **Rh** 102.91	palladium 46 **Pd** 106.42	silver 47 **Ag** 107.87	cadmium 48 **Cd** 112.41	indium 49 **In** 114.82	tin 50 **Sn** 118.71	antimony 51 **Sb** 121.76	tellurium 52 **Te** 127.60	iodine 53 **I** 126.90	xenon 54 **Xe** 131.29
caesium 55 **Cs** 132.91	barium 56 **Ba** 137.33	57-70 *	lutetium 71 **Lu** 174.97	hafnium 72 **Hf** 178.49	tantalum 73 **Ta** 180.95	tungsten 74 **W** 183.84	rhenium 75 **Re** 186.21	osmium 76 **Os** 190.23	iridium 77 **Ir** 192.22	platinum 78 **Pt** 195.08	gold 79 **Au** 196.97	mercury 80 **Hg** 200.59	thallium 81 **Tl** 204.38	lead 82 **Pb** 207.2	bismuth 83 **Bi** 208.98	polonium 84 **Po** [209]	astatine 85 **At** [210]	radon 86 **Rn** [222]
francium 87 **Fr** [223]	radium 88 **Ra** [226]	89-102 **	lawrencium 103 **Lr** [262]	rutherfordium 104 **Rf** [261]	dubnium 105 **Db** [262]	seaborgium 106 **Sg** [266]	bohrium 107 **Bh** [264]	hassium 108 **Hs** [269]	meitnerium 109 **Mt** [268]	ununnilium 110 **Uun** [271]	unununium 111 **Uuu** [272]	ununbium 112 **Uub** [277]		ununquadium 114 **Uuq** [289]				

*Lanthanide series	lanthanum 57 **La** 138.91	cerium 58 **Ce** 140.12	praseodymium 59 **Pr** 140.91	neodymium 60 **Nd** 144.24	promethium 61 **Pm** [145]	samarium 62 **Sm** 150.36	europium 63 **Eu** 151.96	gadolinium 64 **Gd** 157.25	terbium 65 **Tb** 158.93	dysprosium 66 **Dy** 162.50	holmium 67 **Ho** 164.93	erbium 68 **Er** 167.26	thulium 69 **Tm** 168.93	ytterbium 70 **Yb** 173.04
**Actinide series	actinium 89 **Ac** [227]	thorium 90 **Th** 232.04	protactinium 91 **Pa** 231.04	uranium 92 **U** 238.03	neptunium 93 **Np** [237]	plutonium 94 **Pu** [244]	americium 95 **Am** [243]	curium 96 **Cm** [247]	berkelium 97 **Bk** [247]	californium 98 **Cf** [251]	einsteinium 99 **Es** [252]	fermium 100 **Fm** [257]	mendelevium 101 **Md** [258]	nobelium 102 **No** [259]

Don't I Remove Phosphorus Now?

- Influent phosphorus = 4 mg/L to 12 mg/L

- Without phosphorus removal
  - 5% to 10%: Primary Settling / Secondary Clarification
  - 20% to 25%: Bacteria growth in Activated Sludge process
    - 200 mg/L BOD removes 2 mg/L TP

Final effluent: 3 mg/L to 4 mg/L TP

(Further) Phosphorus Removal

- **Chemical Precipitation**
  - Iron
  - Aluminum
  - Calcium
- **Enhanced Biological Phosphorus Removal (EBPR)**
- **Physical**
  - Filtration
  - Membrane Technologies

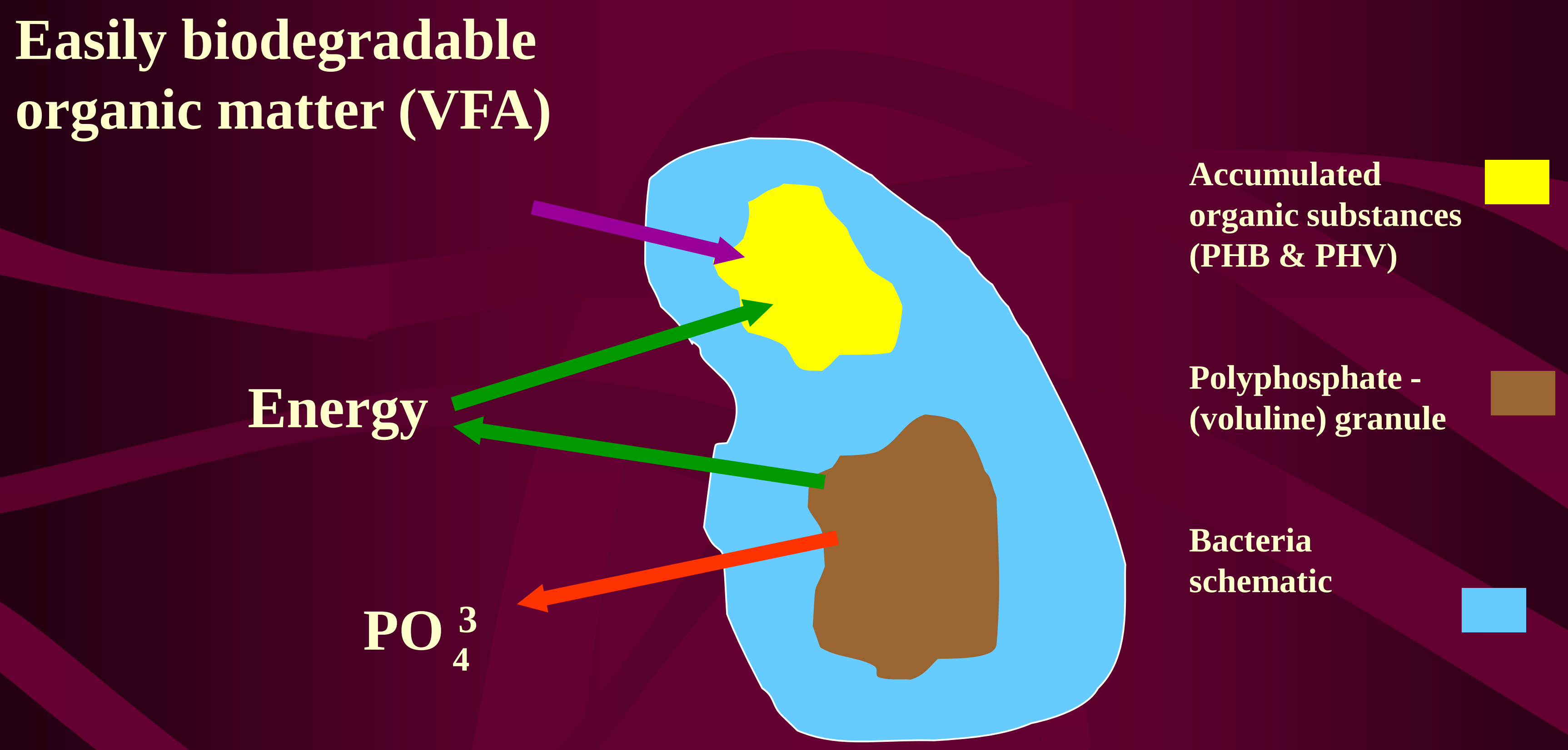
Biological Phosphorus Removal

- **Advantages**
  - Less sludge production compared to chemical precipitation
  - More easily dewatered than Alum sludge
  - Less chemical usage
- **Disadvantages**
  - Dependability
  - More Phosphorus release in sludge handling
  - May require chemical backup

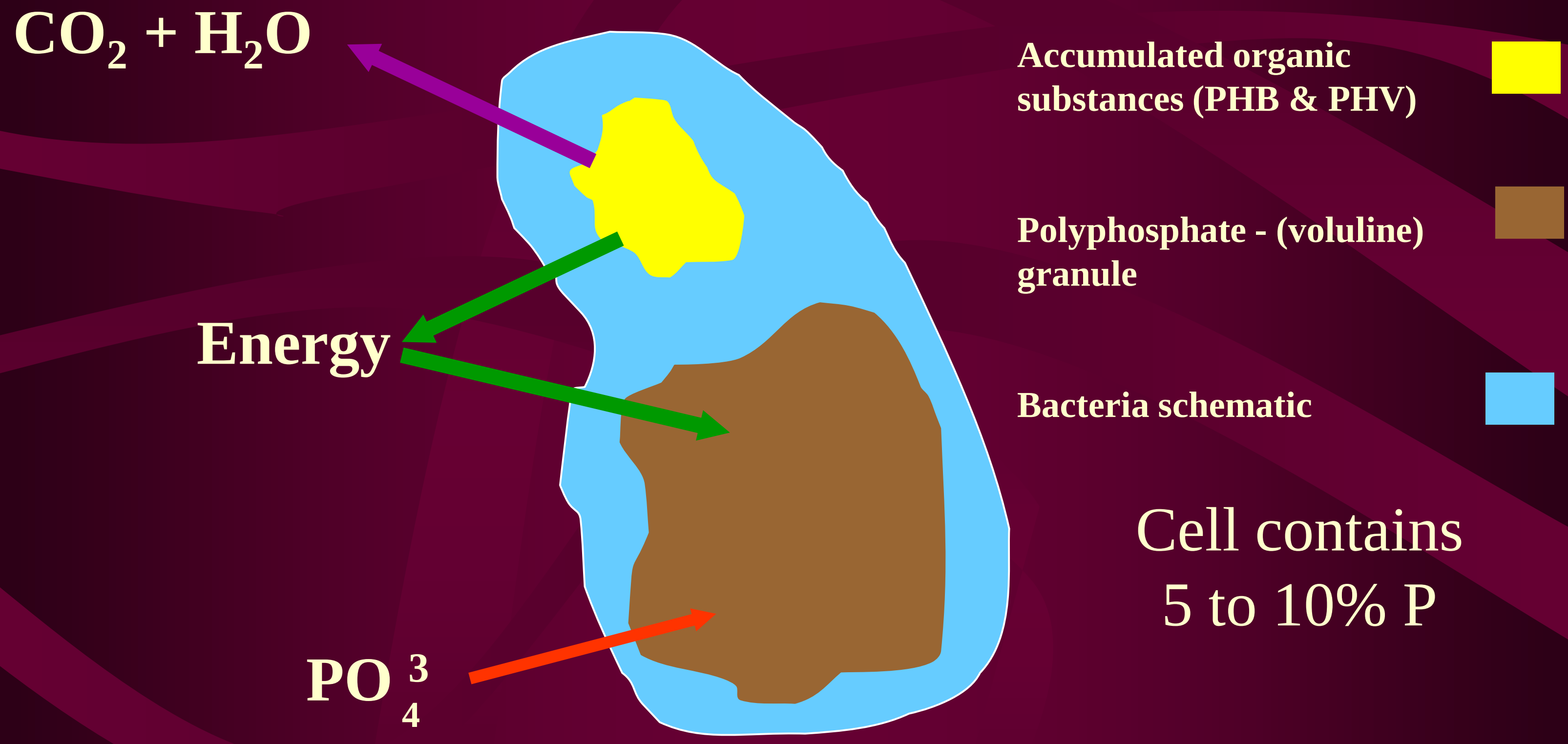
Enhanced Biological Phosphorus Removal (EBPR)

- Volatile fatty acid (VFA) production (anaerobically)
- Phosphorus release by bio-P bacteria (anaerobic conditions)
- Excess phosphorus uptake by bio-P bacteria

Phosphorous Release
Anaerobic Zone



Phosphorus Uptake
Aerobic Zone



Enhanced Biological Phosphorus Removal

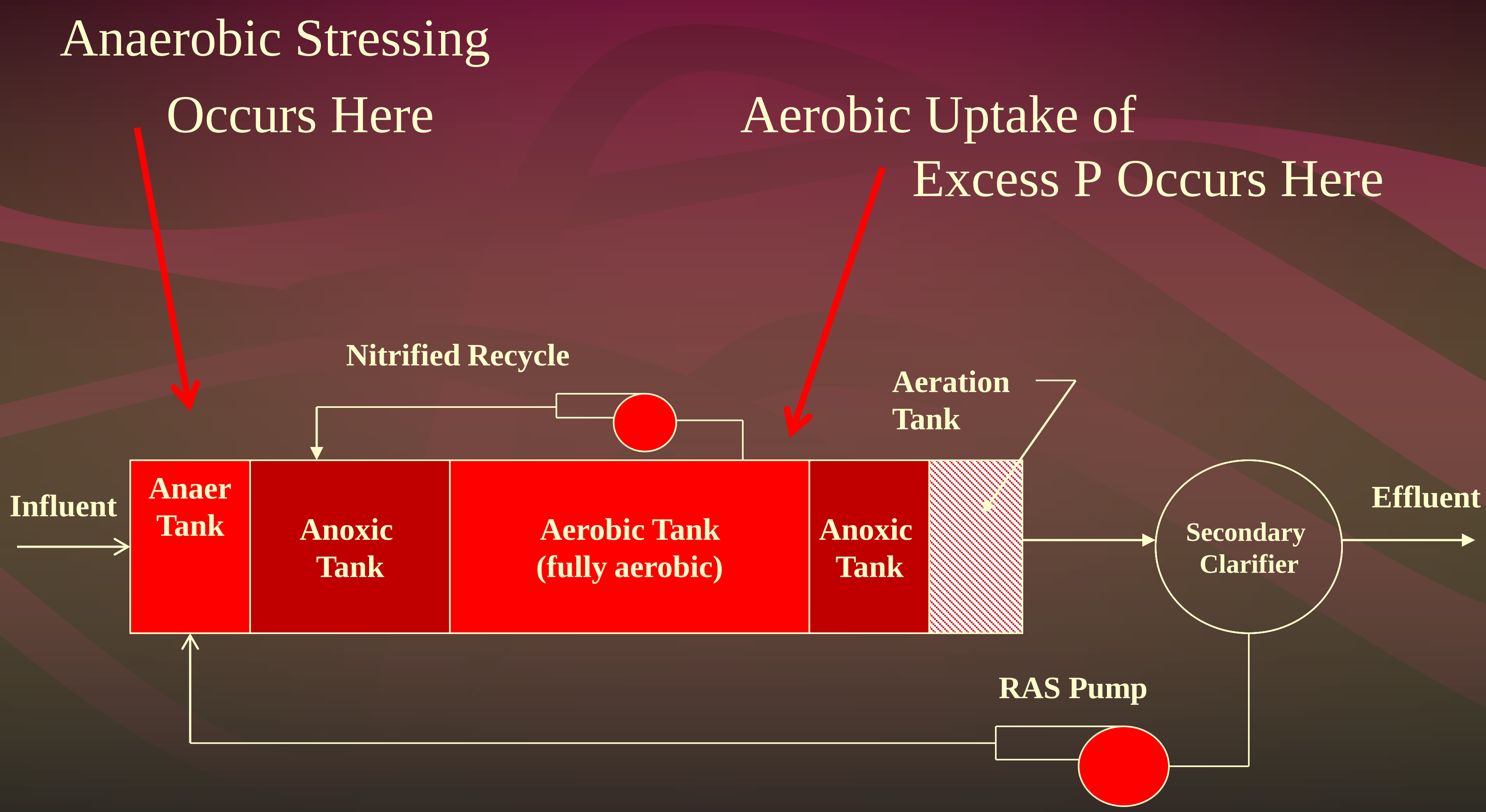
EBPR Treatment Processes

- Biological Alternatives (anaerobic zone)
  - Modified Bardenpho Process (5-stage)
  - SBR Process
  - Operationally Modified Activated Sludge Process (i.e. oxidation ditch)

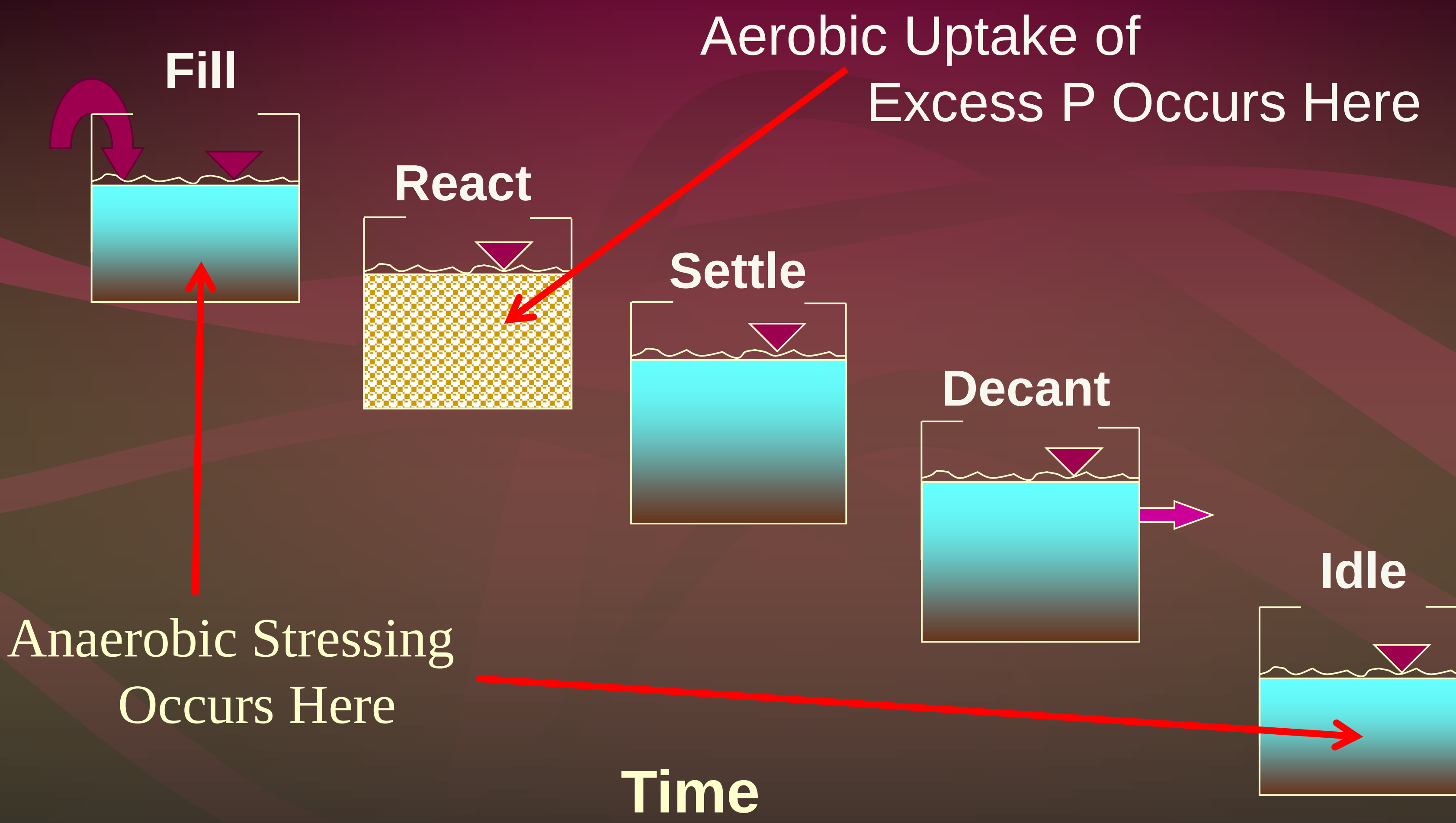
EBPR Summary

- Its all about Anaerobic Action
  - STRESS THE BACTERIA
- Bacteria Use P as a nutrient
  - Consume 1 part P for every 100 parts BOD
- Anaerobic Stressing changes the ratio
  - Consume 2 to 5 parts P for every 100 parts BOD
- Can Remove P to Levels below 0.5 mg/l

Bardenpho Process (Five-Stage)

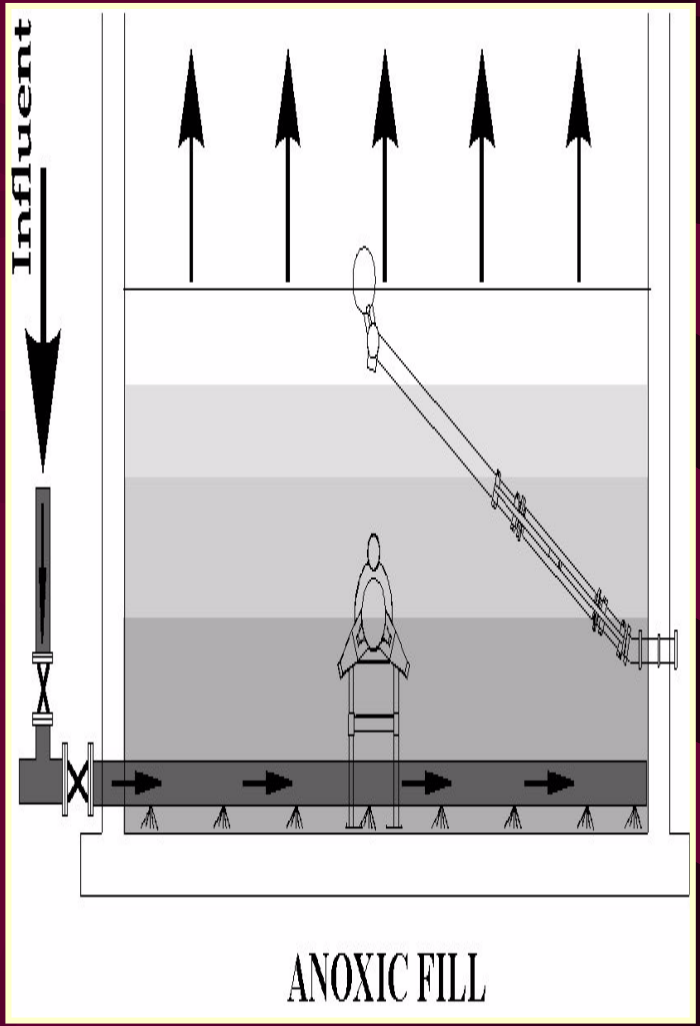


The Sequencing Batch Reactor



Anaerobic/Anoxic Fill

- **To remove nitrate, promote VFA production & growth of Bio-P bacteria, and to control aerobic filamentous organisms.**
  - **Static Fill**
  - **Mixed Fill**
  - **Design Time = 50% to 100% of Fill Time**



Section 6 – Control Parameters for the BNR Processes

Control Parameters

- Nitrification performance is impacted by a complex relationship between several key parameters, including SRT (MCRT), F:M ratio, DO concentration in the aeration basin, MLVSS, hydraulic retention time, temperature and available alkalinity.

- Denitrification is impacted by F:M ratio, DO concentration, temperature, MLVSS and hydraulic detention time.

Sequential Batch Reactors

Standard Operating Procedures

Routine Process Control Measurements

Parameter	Chemical formula	Location of sample	Frequency of sample	Recommended range	Corrective Action level	Corrective Actions
Ammonia	NH3-N	Effluent	Twice per week	< 1mg/1	1.5 mg/1	1. Low DO level in aeration tank 2. Low MLSS in aeration tank 3. Low alkalinity in effluent 4. Low temperature of effluent
Nitrite	NO2-N	Effluent	Twice per week	< 1mg/1	1.5 mg/1	1. Low DO level in aeration tank 2. Low MLSS in aeration tank 3. Low alkalinity in effluent 4. Low temperature of effluent
Nitrate	NO3-N	Effluent	Twice per week	>1<10mg/l	> 8 mg/1	1. High DO level during Anerobic / Anoxic Cycles. 2. Low MLSS in aeration tank
Alkalinity	CaC03	Effluent	Twice per month	> 100 mg/1	< 100 mg/1	1. Add Alkalinity with Chemical to influent or Anoxic Tank
pH	Units	Effluent	Daily	6.9-7.2	< 6.9	1. Add Alkalinity with Chemical to influent or Anoxic Tank
Temperature	ºC	Influent	Daily			
Temperature	ºC	Effluent	Twice per week		< 14"C	1. Adjust MLSS to higher level as temperature drops seasonaly
Temperature	ºC	Effluent	Twice per week		< IO"C	1. Continue Adjusting MLSS to higher level as temperature drops.
Dissolved Oxygen	mg/l	SBR during Anoxic Cycles		< 0.3 mg/1	> 0.3 mg/1	1. Reduce DO (reduce air volume)at end aeration, prevent DO carryover. 2. Increase MLSS to raise Biomass DO Demand
Dissolved Oxygen	mg/l	SBR during React Fill		> 1mg/1	>3 mg/1	1. Reduce DO (reduce air volume)at end of aeration to prevent high DO. 2. Increase MLSS to raise Biomass DO Demand
Dissolved Oxygen	mg/l	SBR during React		>2<3mg/l	>3 mg/1	1. Reduce DO (reduce air volume)at end of aeration to prevent high DO. 2. Increase MLSS to raise Biomass DO Demand
MLSS	mg/l	SBR 5 minutes prior to Settle	Once per week	3,000- 3,500 mg/1 Range is Plant Specific		1. Increase Rate of sludge wasting for high MLSS. 2. Reduce Rate of sludge wasting for low MLSS
Settled Sludge Volume	SSV_{30}	SBR 5 minutes prior to Settle	Twice per week (each tank)	350 ml/liter		1. Increase Rate of sludge wasting for high SSV. 2. Reduce Rate of sludge wasting for low SSV. 3. Sludge Bulking (high SSV) indicates overation or possible filaments.
Microscopic Examination of MLSS sample		SBR 5 minutes prior to Settle	Once per week			Look for good active population of free Swimmers, Stalked Ciliates and a few rotifers. Define population at best performance.

What's the Most Listed Control ?

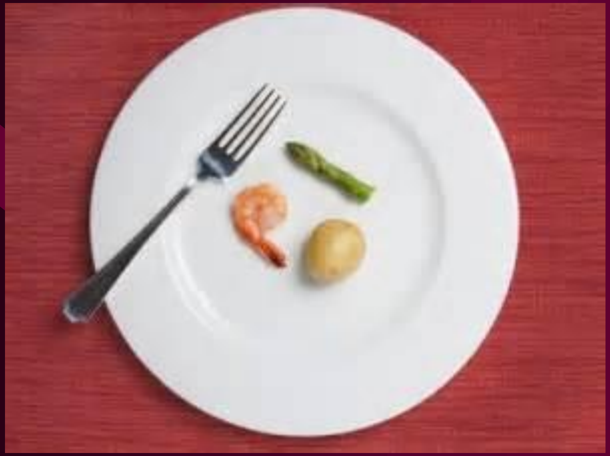
• Low MLSS / Sludge Wasting	14	
• High DO	4	
• Low Alkalinity	4	
• Low DO	2	
• High MLSS	2	
• Low Temperature	2	You can't fix that !
• SVI	1	
• Microscopic Biology	1	

MLSS / MLVSS / F:M

Mixed Liquor and F/M

- Mixed Liquor Suspended Solids (MLSS) consist mainly of microorganisms and non-biodegradable suspended matter.

- F/M Ratio is the balance of food (BOD) and organism mass (bugs).



How to Measure F / M

- <u>BOD LOADING</u>

  BOD (lbs) = Inf. Flow (MGD) X Inf. CBOD (mg/l) X 8.34

- <u>MLVSS</u>

  MLVSS (lbs) = Aeration Volume (MG) X MLVSS (mg/l) X 8.34

F/M = BOD (lbs) / MLVSS (lbs)

- Typical F/M ratios is from 0.2 to 0.5 in conventional activated sludge plant; secondary standards. A typical F:M for a BNR would be 0.05 to 0.1

Example Problem for F:M

- Facility Flow = 1.2 MGD
- Influent CBOD= 230 mg/l

1.2 X 230 X 8.34 = 2,302 Lbs Food

- Aeration Vol. 250,000 gal / 1,000,000 = 0.25MG

- MLVSS = 2,500mg/l

0.25 X 2,500 X 8.34 = 5,215 Lbs Micro

2,301 F / 5,212 M = 0.44 F/M Ratio

F:M Really Controls MLVSS

- Influent BOD typically cannot be controlled. Rearrange the formula to determine required MLVSS.

$$MLVSS = \frac{\text{BOD, lbs.}}{\text{F:M}}$$

Example Problem for MLVSS

- Facility Flow = 1.2 MGD
- Influent CBOD= 230 mg/l = 2,302 Lbs FOOD
- Aeration Vol. = 0.25MG
- Target F:M 0.075 (For BNR)

$$\text{Mass Lbs.} = \frac{2{,}302 \text{ Lbs. F}}{0.075 \text{ F/M}} = 30{,}693 \text{ Lbs. M}$$

$$\text{MLVSS mg/l} = \frac{30{,}693 \text{ Lbs. Micro.}}{0.25 \text{ X } 8.34}$$

MLVSS mg/l = 14, 720 mg/l

The Problem with 14,720 MLVSS

- Facility Flow = 1.2 MGD
- Influent CBOD= 230 mg/l = 2,302 Lbs FOOD
- Aeration Vol. = 0.25MG Need 1.25 MG

$$\text{Mass Lbs.} = \frac{2{,}302 \text{ Lbs. F}}{0.075 \text{ F/M}} = 30{,}693 \text{ Lbs. M}$$

$$\text{MLVSS mg/l} = \frac{30{,}693 \text{ Lbs. Micro.}}{1.25 \times 8.34}$$

MLVSS mg/l = 2,944 mg/l

What's the best MLVSS & F:M ?

- The one that works for you !

- Generally Speaking :
  - If the BOD is good but NH_3 or NO_2 is high
    - Lower F:M
      - Ex. 0.075 lowered to 0.6 (Raise the MLVSS)
  - As the wastewater temperature drops
    - Raise the MLVSS (Lower the F:M)

Sludge Wasting

- Sludge Wasting Controls MLVSS
  - Waste More……..MLVSS goes down
  - Waste Less………MLVSS goes up

- Waste Too much
  - No Microorganisms….No Treatment !

- Don’t Waste Enough
  - Solids will go out in the effluent
  - Probably see Turbidity & High TSS first

Dissolved Oxygen (DO)

DO High? Low? Make up your Mind !

High D.O.

- Removes BOD
- Converts NH3 to NO2
- Converts NO2 to NO3
- Assimilates P
  - after Anaerobic Stress
- Keeps the Odors down

Low D.O.

- Anoxic Treatment
  - Denitrification
  - DO< 0.5
  - Converts NO3 to N gas
  - Takes the N out of the water
- Anaerobic Treatment
  - 0.0 DO & 0.0 NOx
  - Stresses Poly P Bacteria
  - P release Anaerobic Zone
  - No Anaerobic Odor

How to Control D.O.

- Best with in Tank Probe & SCADA Trend
  - Manual measurements miss too much

- Blowers on VFD
  - Automatic Adjustment of DO Level
  - Best in MLE & Bardenpho

- Blower Timers work well on SBR
  - Can also work on Extended Air

Process Control Techniques

More D.O…… IS NOT BETTER !

$$OTR = SOTR \left(\frac{B\ Cs - Cw}{Cs^{20}} \right) O^{T-20}$$

OTR = Oxygen Transfer Rate

Cs = Oxygen Saturation in Tank

Cw = Oxygen Concentration in Tank

Bigger the difference between Cs & Cw, the higher the OTR

Nitrifiers are perfectly happy with a DO = 2 to 3 mg/l

ALKALINITY

What is Alkalinity again?

- Measure of water's capacity to absorb hydrogen ions without significant pH change.
  - i.e., neutralize acids.
- One of the most common alkalis used to provide alkalinity in wastewater treatment is caustic soda.

NITRIFICATION

$$NH_4^+ + 1.5\ O_2 \longrightarrow NO_2^- + H_2O + 2\ H^+$$

Oxygen Required = 3.43 lb / lb N Oxidized

Alkalinity Required = 7.14 lb as $CaCO_3$ / lb N Oxidized

$$NO_2^- + 0.5\ O_2 \longrightarrow NO_3^-$$

Oxygen Required = 1.14 lb / lb N Oxidized

For Both Reactions

Oxygen Required = 4.57 lb / lb N Oxidized

Alkalinity Required = 7.14 lb as $CaCO_3$ / lb N Oxidized

DENITRIFICATION

NO_3 + **Org. Carbon** → $N_2 + CO_2 + OH + H_2O$

$CO_2 + OH$ → HCO_3

NO_3 → NO_2 → NO → N_2O → N_2

2.86 lbs oxygen recovered / lb NO_3-N

3.57 lbs alkalinity recovered / lb NO_3-N

Section 7 – Operational Changes by the Operator

Decision Making

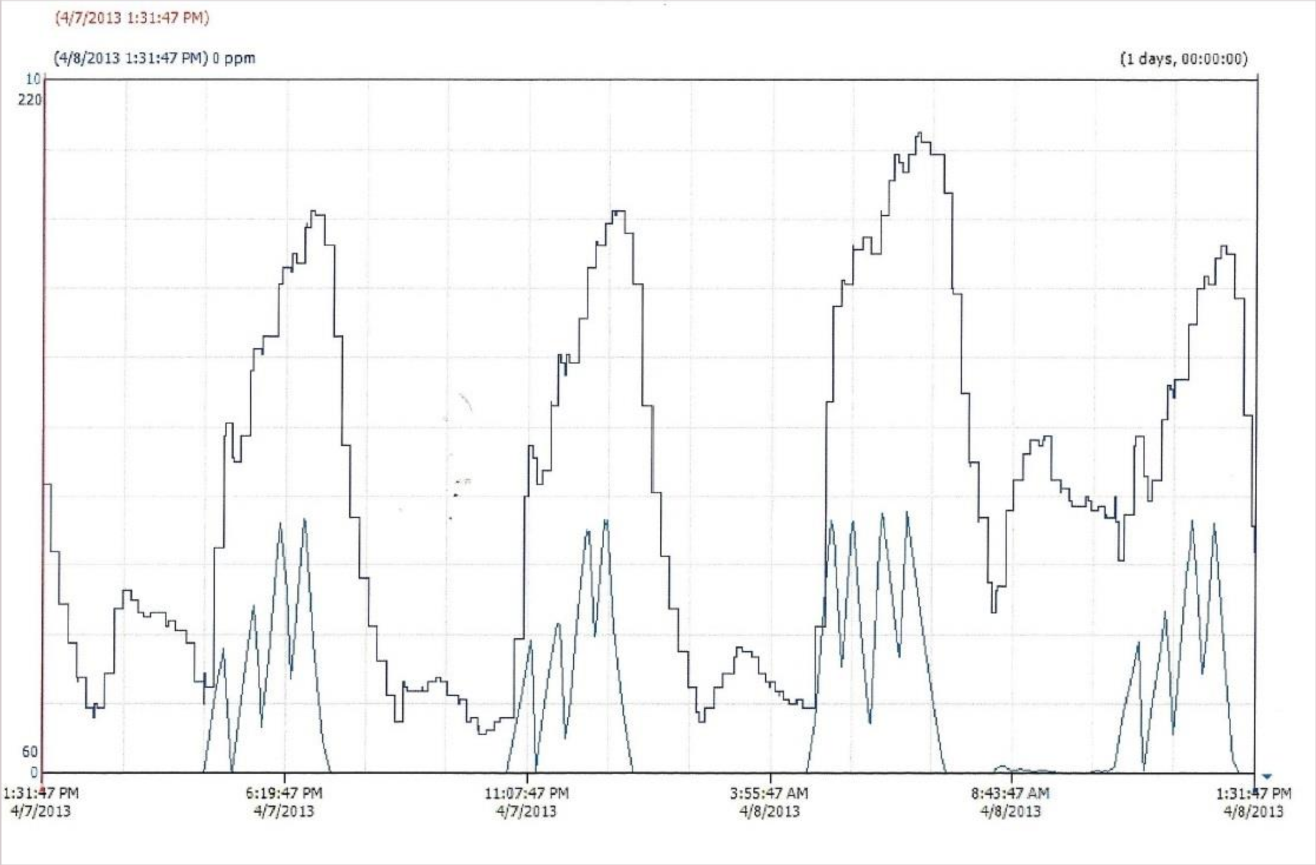
- Data, data and more data (more data = less operational costs)

- Synchronized influent and effluent (prior to disinfection) sampling
  - Composite as well as grabs
  - BOD / COD
  - Ammonia, TKN, NO3 and NO2
  - Phosphorus
  - Soluble and insoluble forms

BNR – Slug Loads / Recycle

- Sludge Thickening
- Digestion
  - Anaerobic
  - Aerobic
- Dewatering
- Filter backwash
- Septage Receiving

Instrumentation



BNR Instrumentation

- Purpose – Supplement the operators knowledge of the system
- Measure metrics that can be applied to decision making
- Automate decision making

OPERATOR INPUT ON SETPOINTS IS CRITICAL

BNR Instrumentation

- Total Suspended Solids Meter
- Dissolved Oxygen Measurement
- pH Measurement
- Oxidation-Reduction Potential
- Ammonia and Ammonium
- Nitrate / Nitrite
- Phosphorus / Orthophosphate

BNR Instrumentation

- DO monitoring has made the biggest impact
- pH and ORP are consistent and stable monitoring devices
- Other instruments are relatively new and continue to advance

Sludge Quality

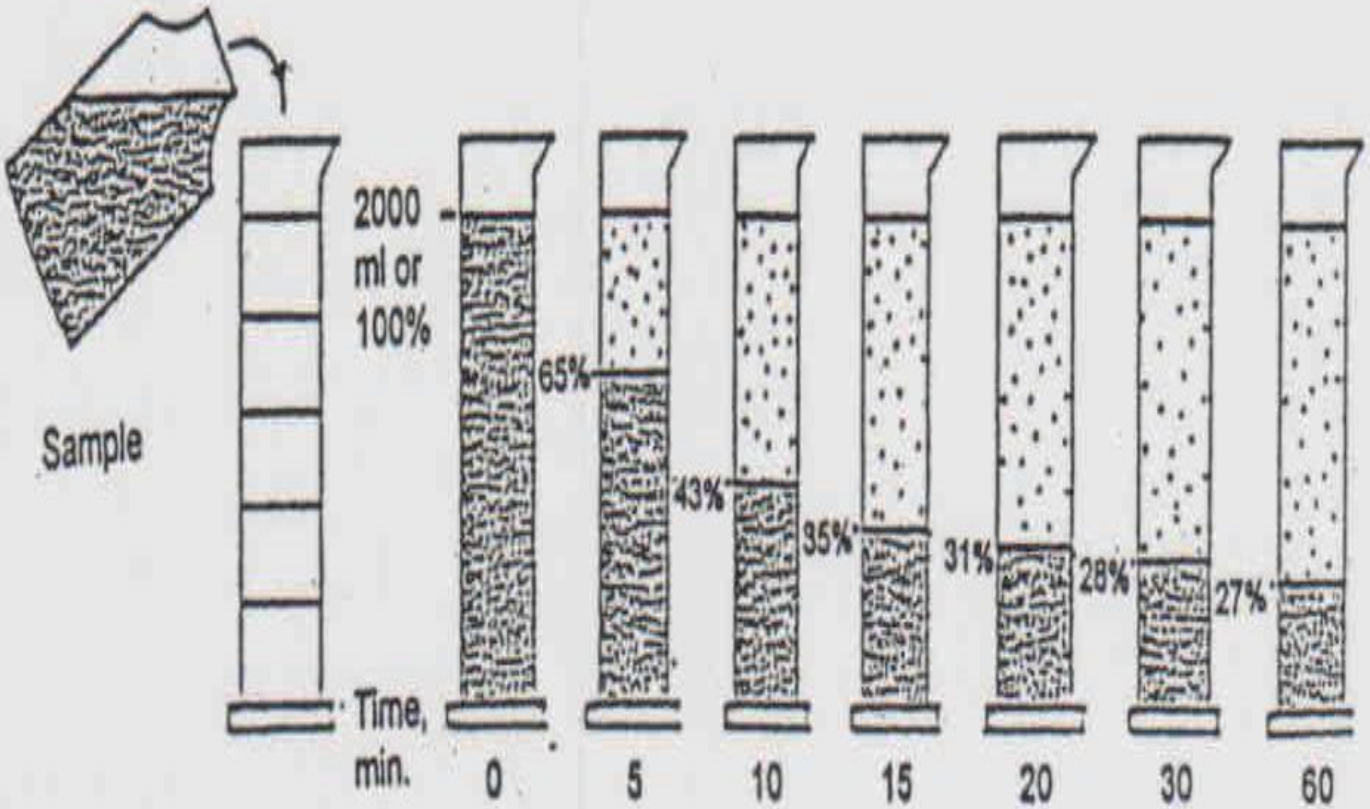
SVI

- Sludge Volume Index (SVI) is a regularly calculated value by wastewater treatment operators in attempt to determine sludge quality, and it is used as an indirect indicator of bulking sludge.

- SVI (mL/g) = 30-minute settleability test result (mL/L) x 1,000 MLSS (g/L)

1. Mix sample and pour into 2000 ml graduate

2. Record settleable solids, %, at regular intervals.



1. Collect a sample of mixed liquor or return sludge.

2. Carefully mix sample and pour into 2000 ml graduate. Vigorous shaking or mixing tends to break up floc and Procedures slower settling or poorer separation.

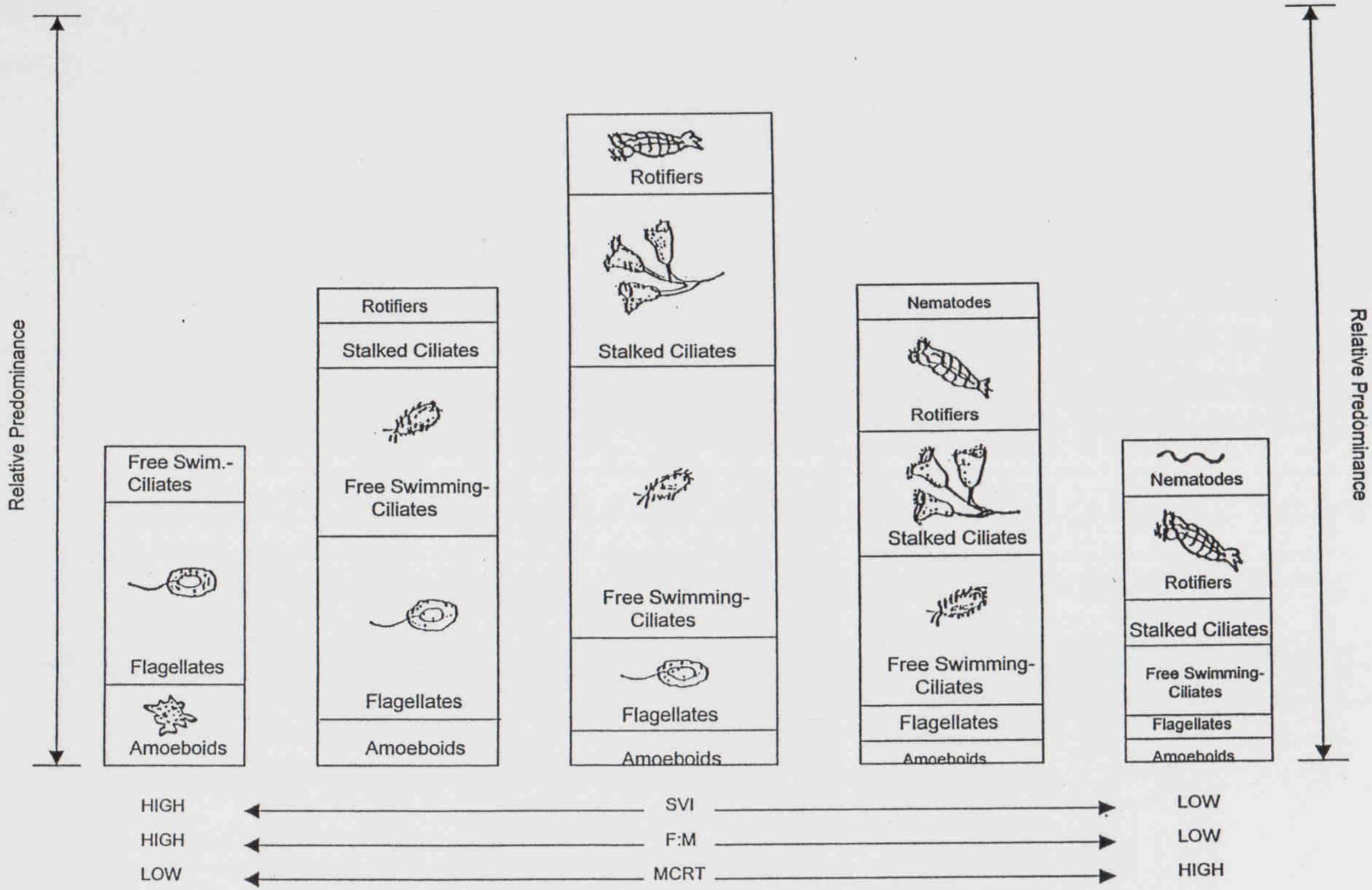
NOTE: If a 1000 ml graduate is used, the percent settleable solids is easier to record.

SVI

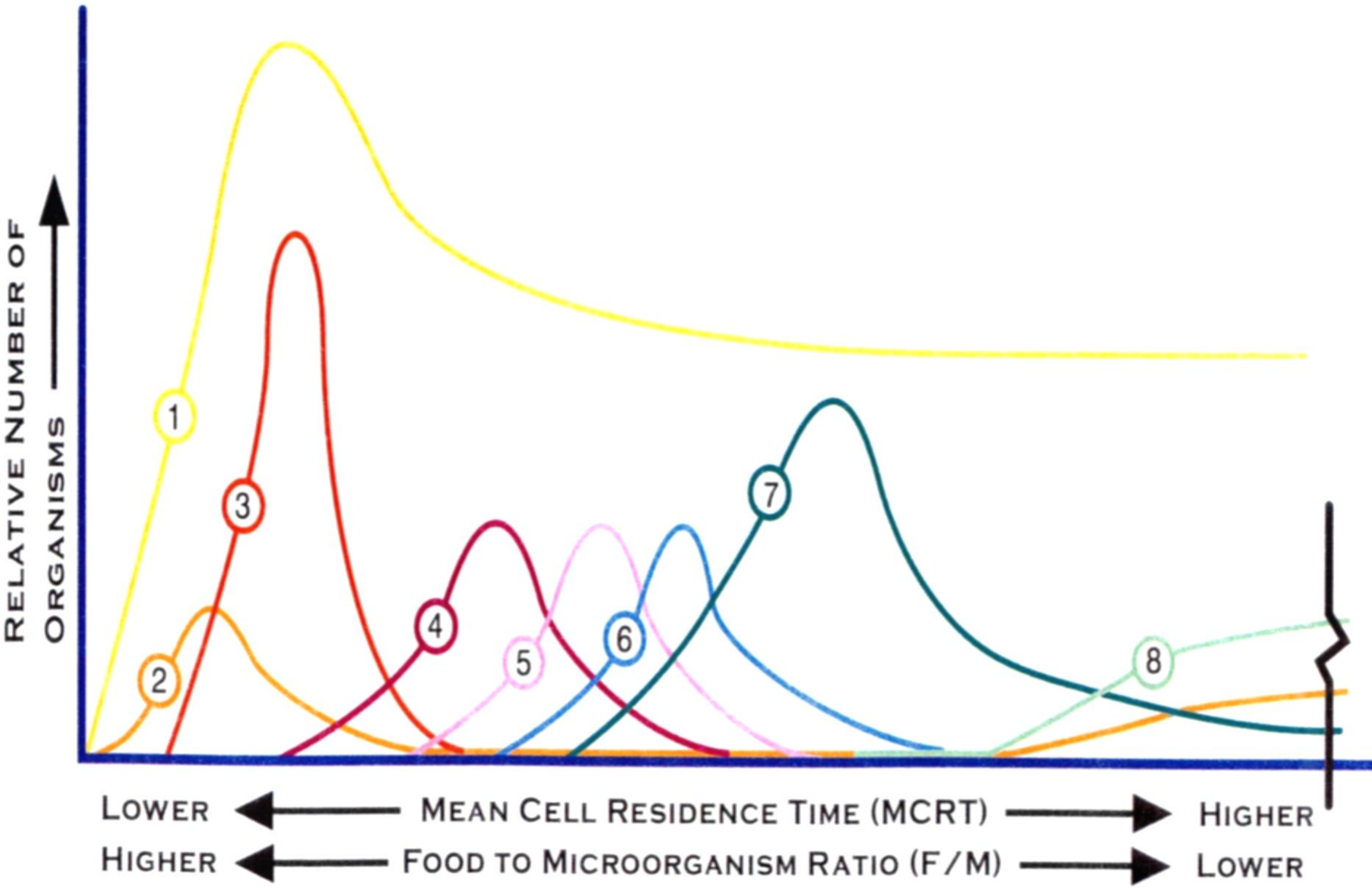
- SVI = 80 mL/g or less.
  - Rapid settling characteristics
- SVI = 100 to 200 mL/g.
  - Clear, good-quality effluent with an SVI in this range
- SVI = 250 mL/g or higher.
  - At this elevated SVI, the sludge settles very slowly and compacts poorly in the settleability test


Settleometer
SSV
1000
900
800
700
600
500
400
300
200
100
JUL 16 2007

The Microscope



Relative Predominance
Free Swim.-Ciliates
Flagellates
Amoeboids
Rotifiers
Stalked Ciliates
Free Swimming-Ciliates
Flagellates
Amoeboids
Rotifiers
Stalked Ciliates
Free Swimming-Ciliates
Flagellates
Amoeboids
Nematodes
Rotifiers
Stalked Ciliates
Free Swimming-Ciliates
Flagellates
Amoeboids
Nematodes
Rotifiers
Stalked Ciliates
Free Swimming-Ciliates
Flagellates
Amoeboids
Relative Predominance
HIGH SVI LOW
HIGH F:M LOW
LOW MCRT HIGH



Relative Number of Organisms
1
2
3
4
5
6
7
8
Lower
Mean Cell Residence Time (MCRT)
Higher
Higher
Food to Microorganism Ratio (F/M)
Lower

1. **Bacteria** · Feed on soluble materials directly and solublize organic particles
2. **Amoeba Protozoa** · Primarily feed on solid particles and soluble organics, but some are photosynthestic
3. **Flagellated Protozoa** · Primarily feed on bacteria, solid particles and soluble organics, but some are photosynthestic
4. **Free-Swimming ciliated protozoa** · feed primarily on dispersed bacteria, either individual cells or small clumps
5. **Crawling ciliated protozoa** · feed on individual bacterial cells or small clumps dislodged from bacterial flocs
6. **Carnivorous free-swimming ciliated protozoa** · feed on other protozoa
7. **Stalked ciliated protozoa** · feed primarily on individual bacterial cells, but may be carnivorous such as *Suctoria*
8. **Metazoa (Phylum listed)** · feed on detritus and small plankton organisms

Stalk Ciliated Protozoa

Troubleshooting Scenarios

Scenario 1 – Nitrification

- Your extended aeration WWTP typically is excellent at both BOD and TKN removal but you recently notice that the BOD and TKN values have been slowly but steadily increasing.

- Is there more information that we need?
- What are some of the probable causes?

Scenario 2 – Nitrification and Denitrification

- Your SBR WWTP is nitrifying (even better than normal) but your NO2+NO3-N is very high and the solids during clarification are rising.

- Is there more information that we need?
- What are some of the probable causes?

Scenario 3 – Phosphorus Removal

- Your WWTP is typically producing TP effluent numbers below 0.8 mg/L but on April 9, 2013 – the TP was 8 mg/L in the effluent.

- Is there more information that we need?
- What are some of the probable causes?

Detailed References

- *Biological Nutrient Removal (BNR) Operation in Wastewater Treatment Plants*. WEF Manual of Practice No. 29. Virginia: Water Environment Federation, 2005. Print.

- Gerardi, Michael. *Nitrification and Denitrification in the Activated Sludge Process*. New York: John Wiley and Sons, Inc., 2002. Print.

- *Wastewater Engineering: Treatment and Disposal, 4th Edition*. Metcalf and Eddy, McGraw-Hill, 2003. Print.

- *Water Supply and Pollution Control, 6th Edition*. Viessman and Hammer, 1998. Print.

QUIZ (15 Minutes)

- Thank you