CE421/521 Environmental Biotechnology

Nitrogen and Phosphorus Cycles
Lecture 9-26-06
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Nitrification Kinetics

$$\mu = \frac{\mu_{\max} S_{NH4}}{K_S + S_{NH4}} \cdot \frac{S_{O2}}{K_O + S_{O2}}$$

where
μ_{max} = maximum specific growth rate, h-1
K_S = half saturation coefficient for ammonia, mg/L as NH_4-N
K_O = half saturation coefficient, mg/L as O2
Yield = mg biomass formed/mg ammonia utilized

Nitrification Kinetics

	Nitrosomonas		Nitrobacter	
parameter	range	typical (@ 20°C)	range	typical (@ 20°C)
μ_{max}	0.014 - 0.092	0.032	0.006 - 0.06	0.034
K_S	0.06 - 5.6	1.0	0.06 - 8.4	1.3
K_O	0.3 - 1.3	0.5	0.3 - 1.3	0.68
Yield	0.04 - 0.13	0.1	0.02 - 0.07	0.05

Optimum pH for nitrifiers is around 8.0, range 7.5 - 8.5 (higher than for most other biological processes).

Nitrifiers are sensitive to

- d______________ o_______________
- t________________
- p___
- i________________________

$$\mu = \frac{\mu_{\max} S_{NH4}}{K_S + S_{NH4}} \cdot \frac{K_I}{K_I + I}$$

where I = concentration of inhibitor, mg/L
K_I = inhibition coeficient, mg/L

Effects of Temperature

- derivation of the
- A_______________ equation

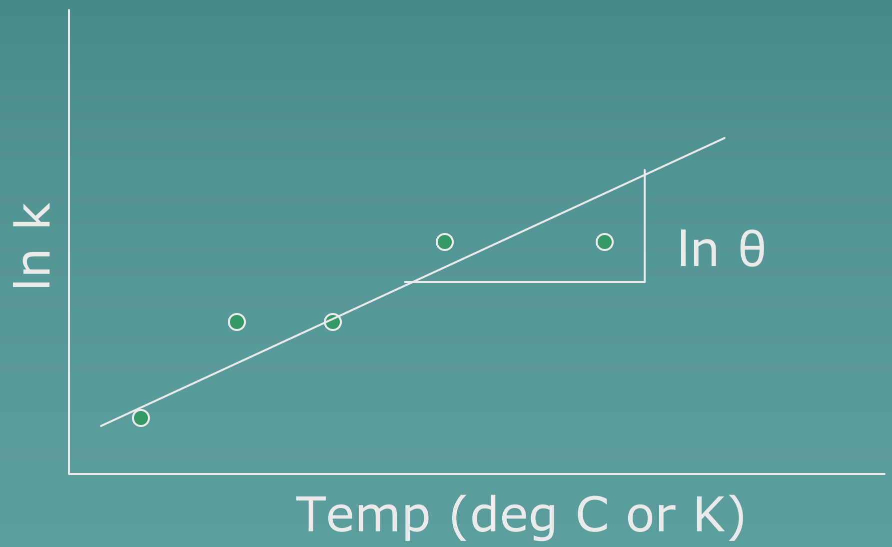
$$k = Ae^{\frac{-\mu}{RT}}$$

$$k_2 = k_1 \theta^{(T_2 - T_1)}$$

- where $k_{1,2}$ = reaction rate coefficient at temperature $T_{1,2}$
- θ = t______________ c_____________

Typical Theta Values

theta values	Nitrosomonas	Nitrobacter
μ_{max}	1.098 - 1.118	1.068 - 1.112
K_S	1.125	1.157
k_d	1.029 - 1.104	1.029 - 1.104



Calculating Theta

- given the following measured data, calculate the theta value

T, °C	b, h^{-1}
10	0.0037
20	0.0095
30	0.0229
40	0.0372

DENITRIFICATION

1. A_________________________ nitrate reduction: NO3- ➔ NH4+ nitrate is incorporated into cell material and reduced inside the cell
2. D_______________________ nitrate reduction (denitrification)
   - NO3- serves as the t____________ e_______________ a_________________ (TEA) in an anoxic (anaerobic) environment

nitrate reductase		nitrite r.		nitric oxide r.		nitrous oxide r.	
NO_3^-	➔	NO_2^-	➔	NO	➔	N_2O	➔ N_2

summarized as:

NO_3^- ➔ NO_2^- ➔ N_2

DENITRIFICATION

- requires o________________ m____________________(example: methanol)
- kinetics for denitrification similar to those for heterotrophic aerobic growth

$$\mu = \frac{\mu_{\max} S}{K_S + S} \cdot \frac{NO_3^-}{K_{NO3} + NO_3^-}$$

DENITRIFICATION

$$6NO_3^- + 5CH_3OH \rightarrow 3N_2 + 5\,CO_2 + 7\,H_2O + 6\,OH^-$$

- calculate COD of methanol:

- calculate alkalinity:

Nitrogen Removal in Wastewater Treatment Plants

- Total Kjeldahl Nitrogen (TKN) = o____________ n____________ + a_______________
- (measured by digesting sample with sulfuric acid to convert all nitrogen to ammonia)
- TKN ~ 35 mg/L in influent
- p_____________ t_____________ removes approximately 15%
- additional removal with biomass w_______________

Methods for Nitrogen Removal

1. Biological
   - n________________
   - d_________________
   - ANAMMOX: ammonium is the electron donor, nitrite is the TEA

$$NH_4^+ \quad + \quad NO_2^- \quad \rightarrow \quad N_2 \quad + \quad 2\ H_2O$$

   Suitable for high ammonia loads (typically greater than 400 mg/L) and low organic carbon

2. Chemical/Physical
   1. air s________________
   2. breakpoint c____________________
   3. ion e_______________________
   4. reverse o_____________________

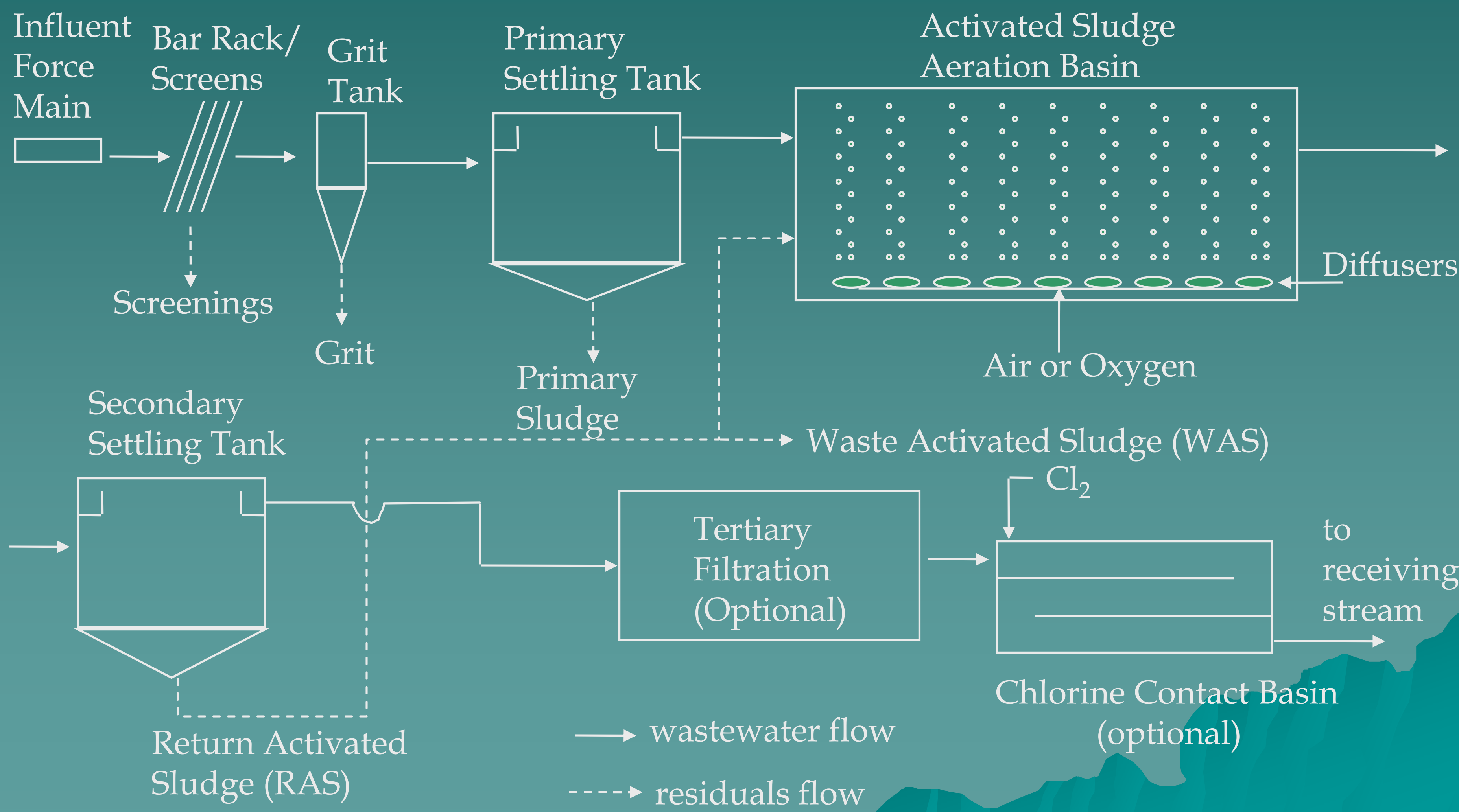
Concerns for nitrogen discharge:

1. T___________________
2. D___________________ of DO
3. E_______________________________
4. Nitrate in d___________________ water – causes methemoglobinemia (blue baby) oxidizes hemoglobin to methemoglobin

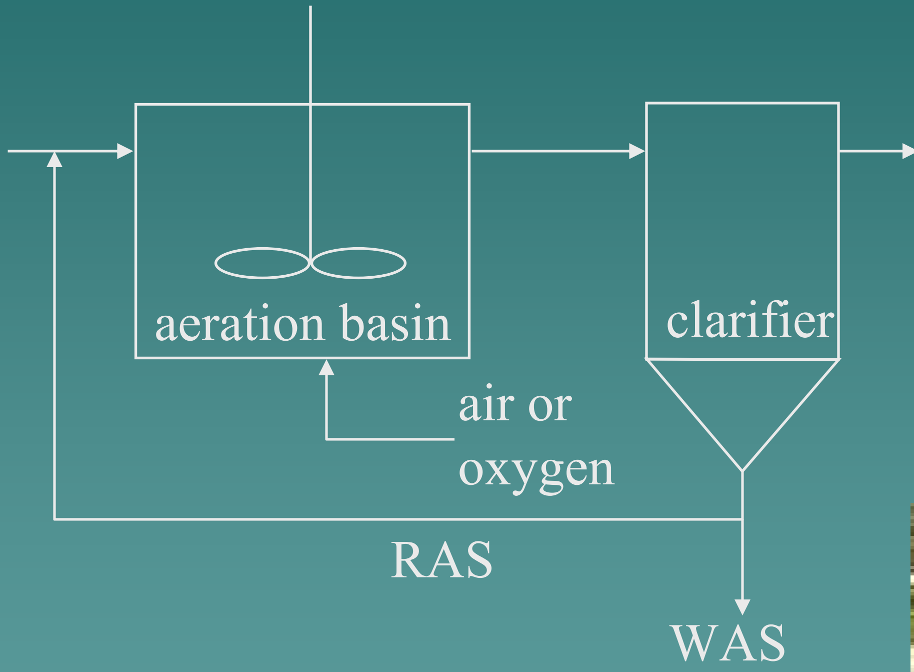
System Configurations

- Completely mixed activated sludge (CMAS)
- Conventional activated sludge (CAS)
- Sequencing Batch Reactor (SBR)
- Extended aeration, oxidation ditch, others

Activated Sludge Wastewater Treatment Plant

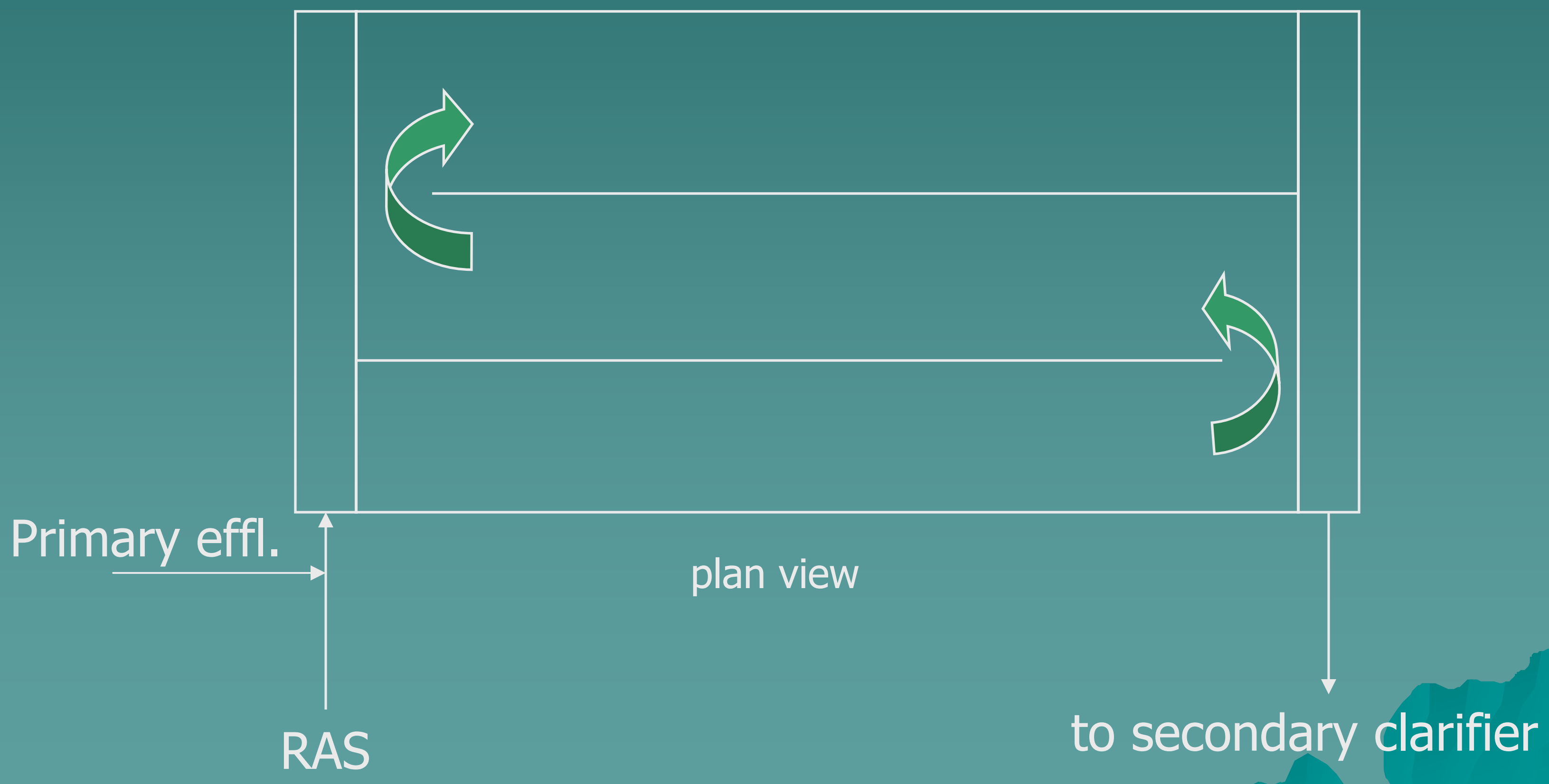


Completely Mixed Activated Sludge (CMAS)



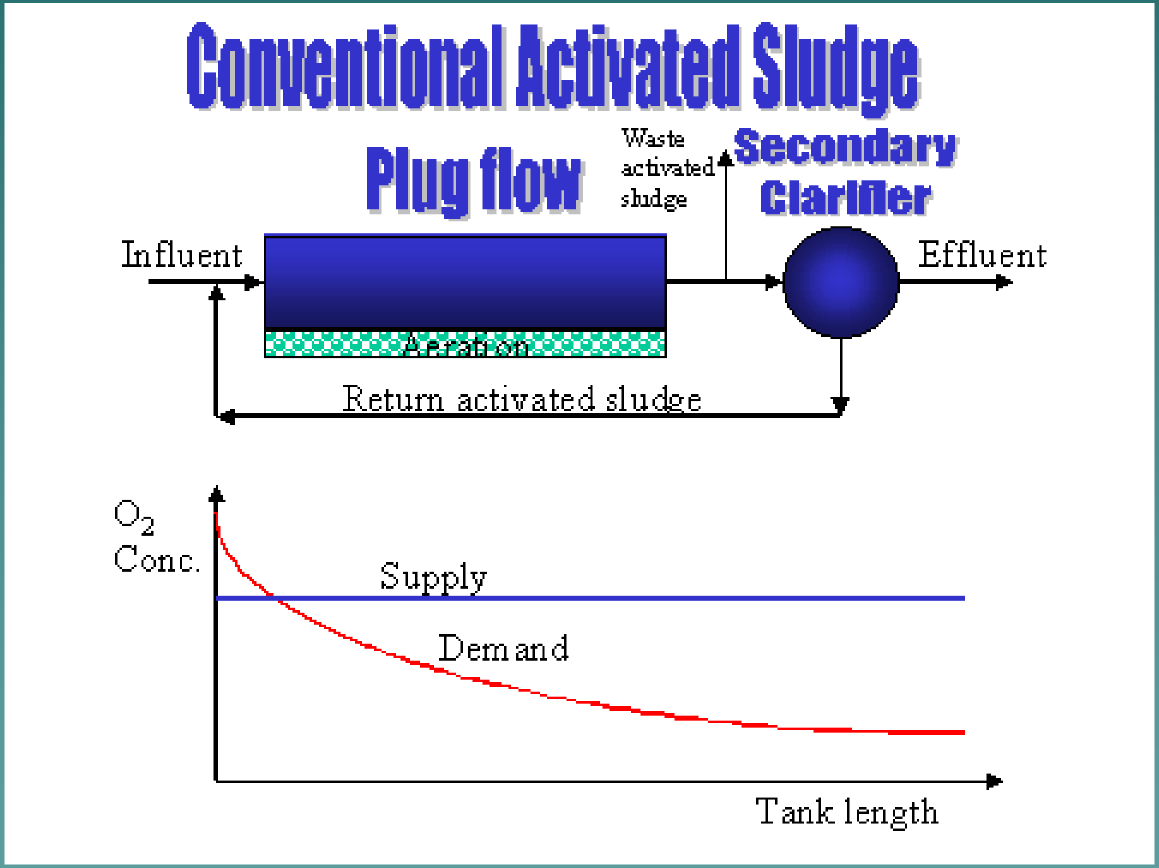
Completely Mixed Activated Sludge (CMAS)

Conventional (plug flow) Activated Sludge (CAS)

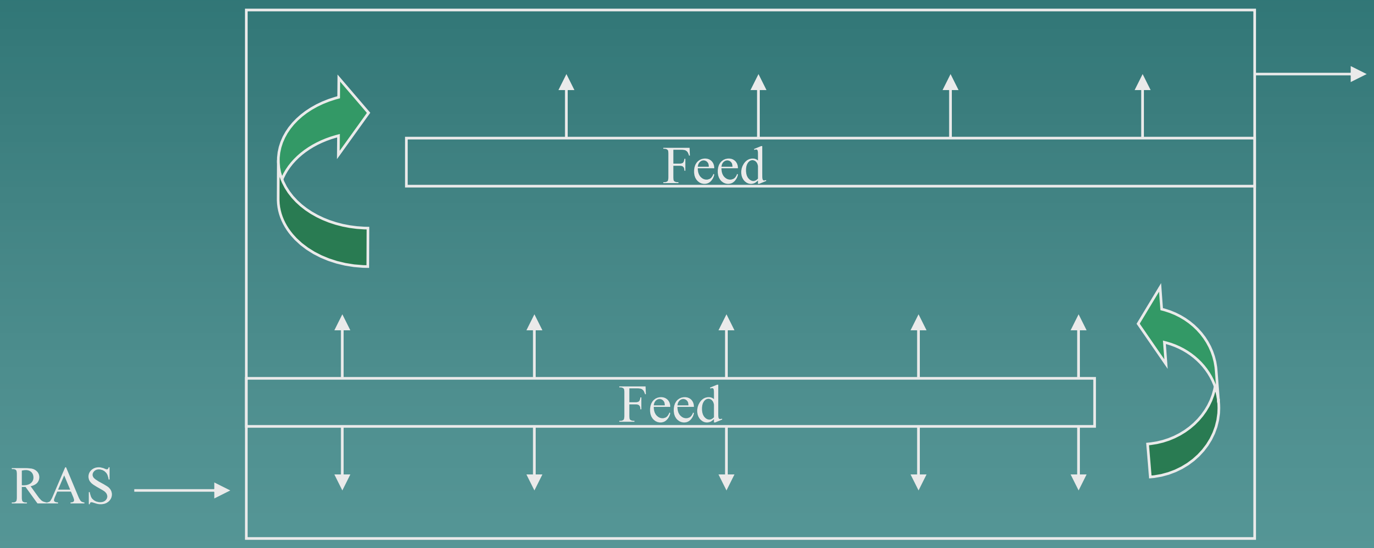


Conventional Activated Sludge

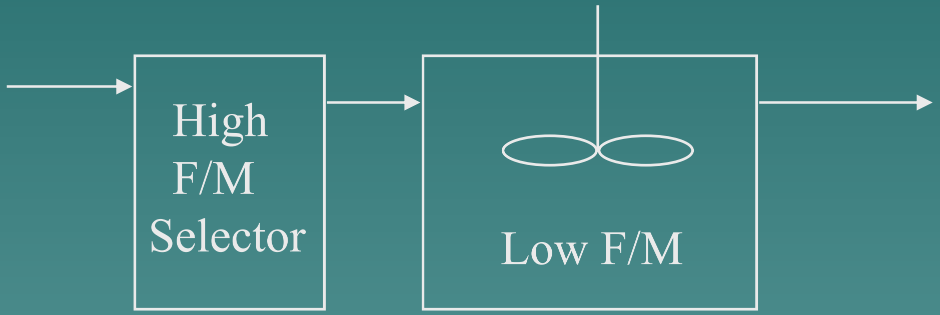
Conventional Activated Sludge



Step Feed Activated Sludge

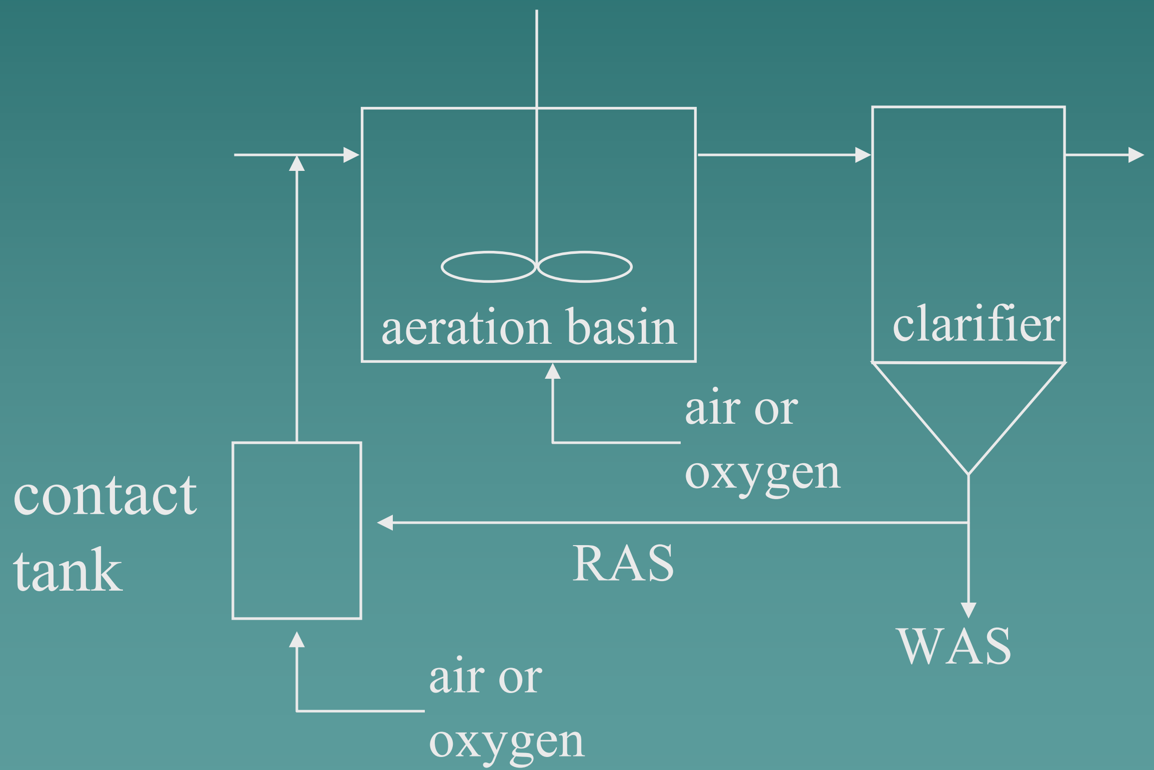


CMAS with Selector

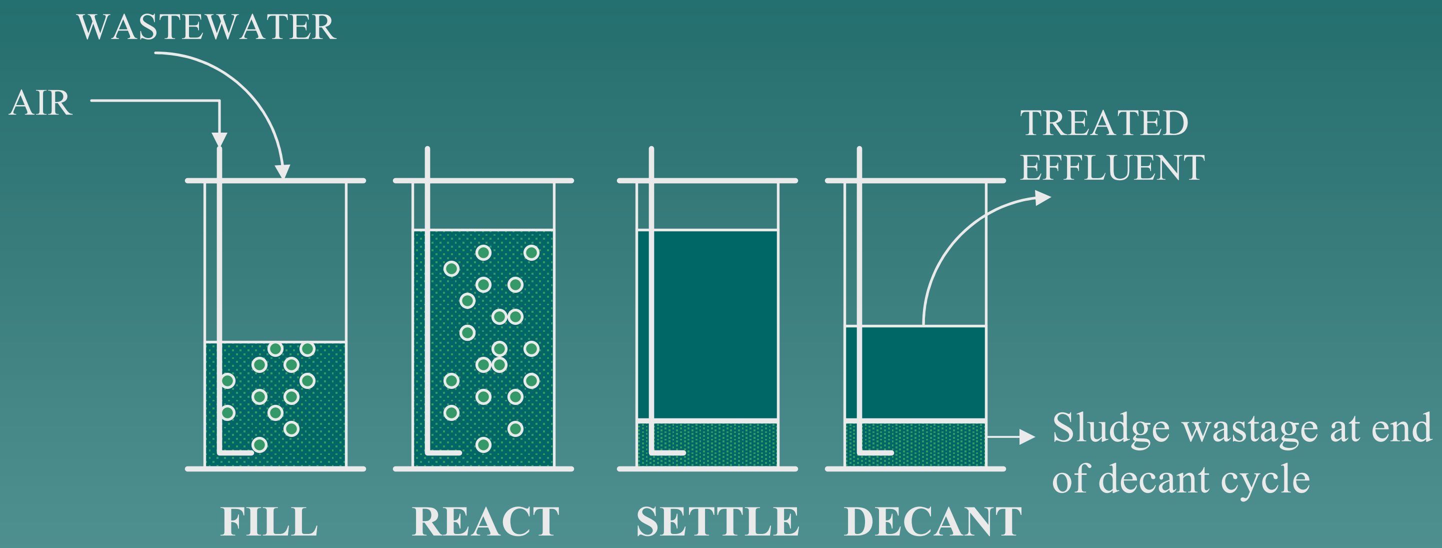


CMAS with Selector

Contact Stabilization Activated Sludge



Sequencing Batch Reactor



Phosphorus

- limiting n___________________________ in algae (at approximately 1/5 the nitrogen requirement)
- 15% of population in US discharges to l________________________
- wastewater discharge contains approximately 7- 10 mg/L as P
- o__________________________
- i____________________: orthophosphate

Removal of Phosphorus

- Chemical precipitation:
  - traditional p____________________________ reactions

$Al^{+3} + PO_4^{-3} \rightarrow AlPO_4$

$Fe^{+3} + PO_4^{-3} \rightarrow FePO_4$

  - as s_____________________ (magnesium ammonium phosphate, MAP)

$Mg^{+2} + NH_4^{+} + PO_4^{-3} \rightarrow MgNH_4PO_4$

Struvite as a problem

- Scale build-up chokes pipelines, clogs aerators, reduces heat exchange capacity
- Canned king crab industry
- Kidney stones

Struvite as a Fertilizer

- Nonburning and long lasting source of nitrogen and phosphorus
- Found in natural fertilizers such as guano
- Heavy applications have not burned crops or depressed seed germination (Rothbaum, 1976)
- Used for high-value crops

For ISU study on removing ammonia from hog waste see:
www.public.iastate.edu/~tge/miles_and_ellis_2000.pdf



Full Scale ASBR

- 2300 head operation in central Iowa, USA
- methane recovery for energy generation
- site for full-scale study for struvite precipitation

Biological P Removal

- Discovered in plug flow A.S. systems
- Requires anaerobic (low DO and NO_3^-) zone and aerobic zone
- Biological “battery”
- Grow phosphate accumulating organisms (PAO) with 7% P content
- Need to remove TSS

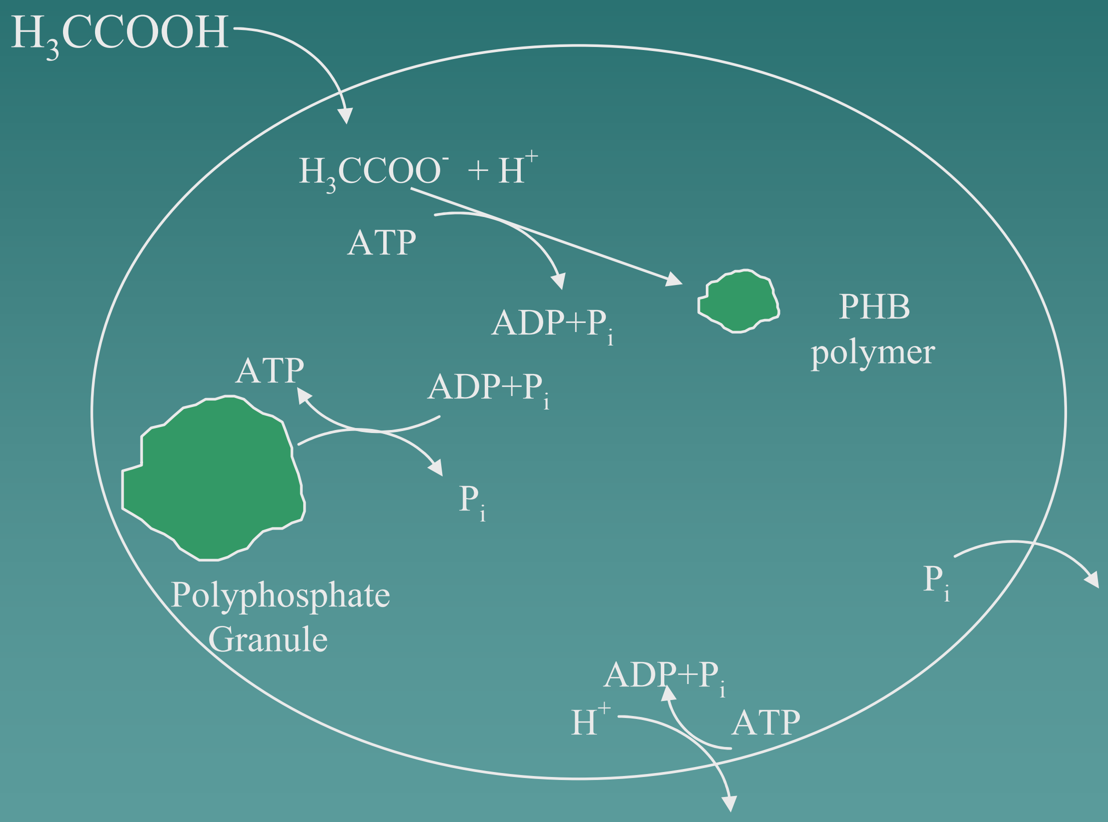
Key Reactions in Anaerobic Environment

- Uptake of acetic acid
- Storage polymer (PHB) is formed
- Polyphosphate granule is consumed
- Phosphate is released

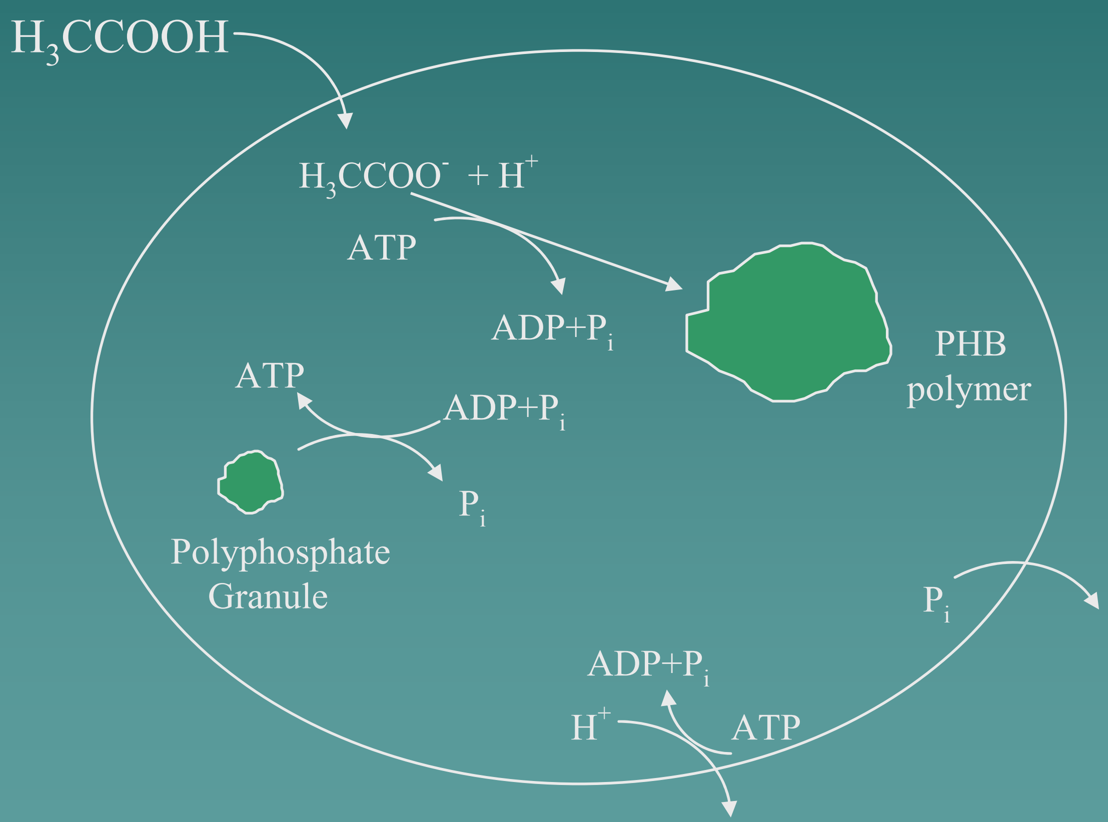
Key Reactions in Aerobic Environment

- Energy (ATP) is regenerated as bacteria consume BOD
- Phosphorus is taken into the cell and stored as poly-P granule
- When BOD is depleted, PAO continue to grow on stored reserves (PHB) and continue to store poly-P

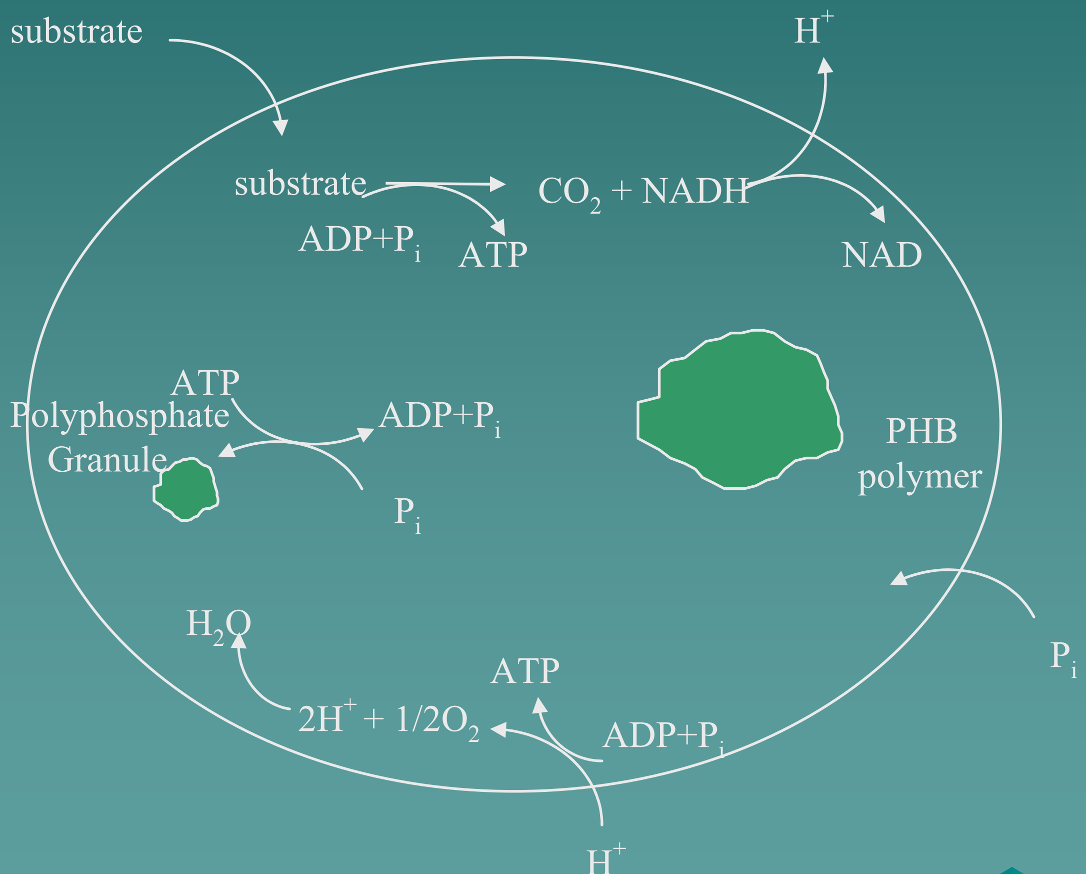
Anaerobic Zone (initial)



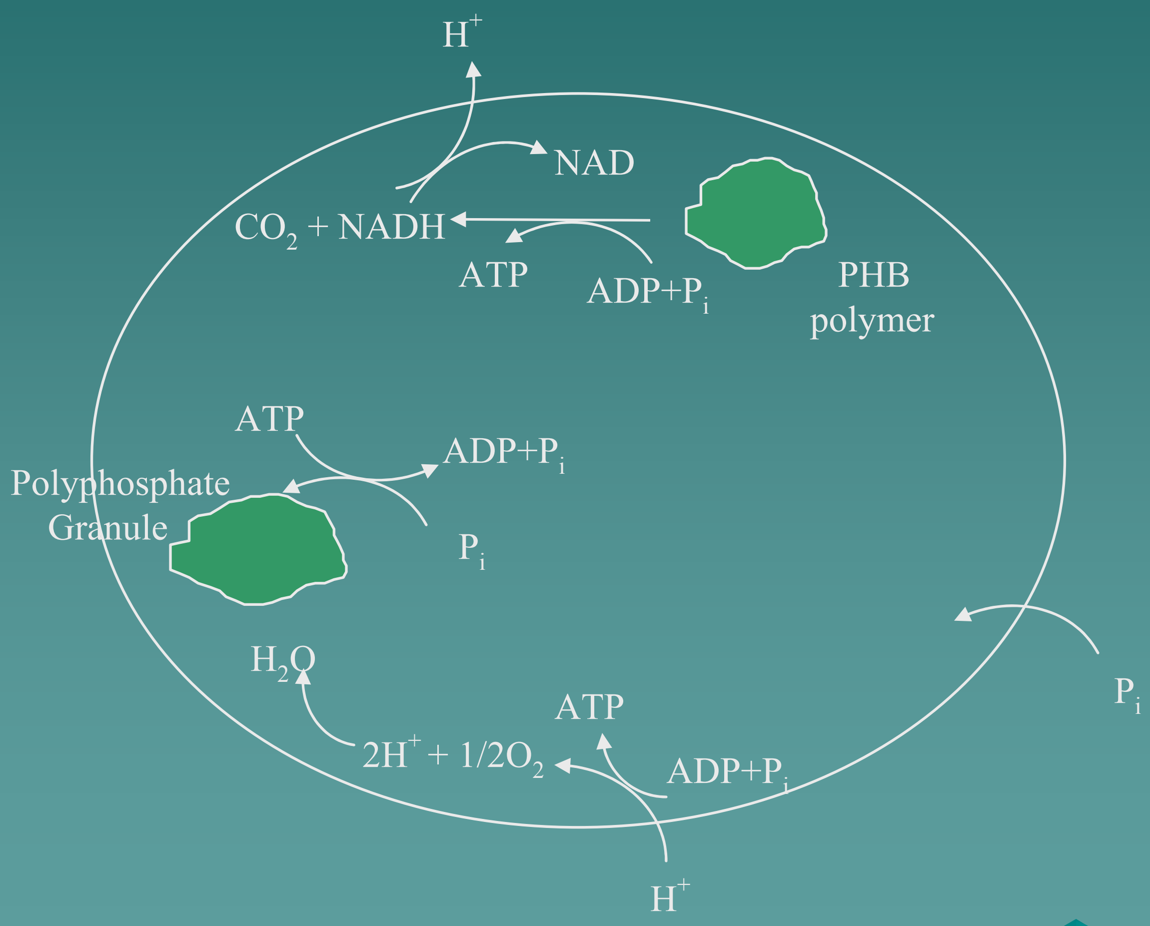
Anaerobic Zone (later)



Aerobic Zone (initial)



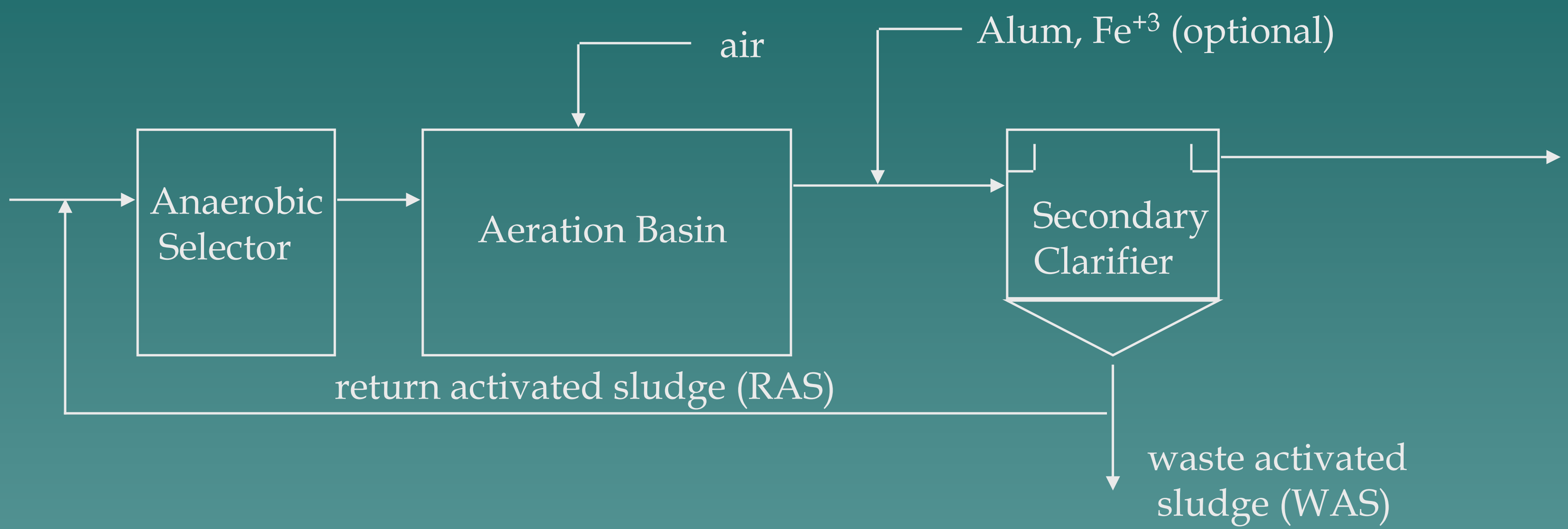
Aerobic Zone (later)



Bio-P Operational Considerations

- Need adequate supply of acetic acid
- Nitrate recycled in RAS will compete for acetic acid
- May need a trim dose of coagulant to meet permit
- Subsequent sludge treatment may return soluble phosphorus to A.S.

A/O EBPR



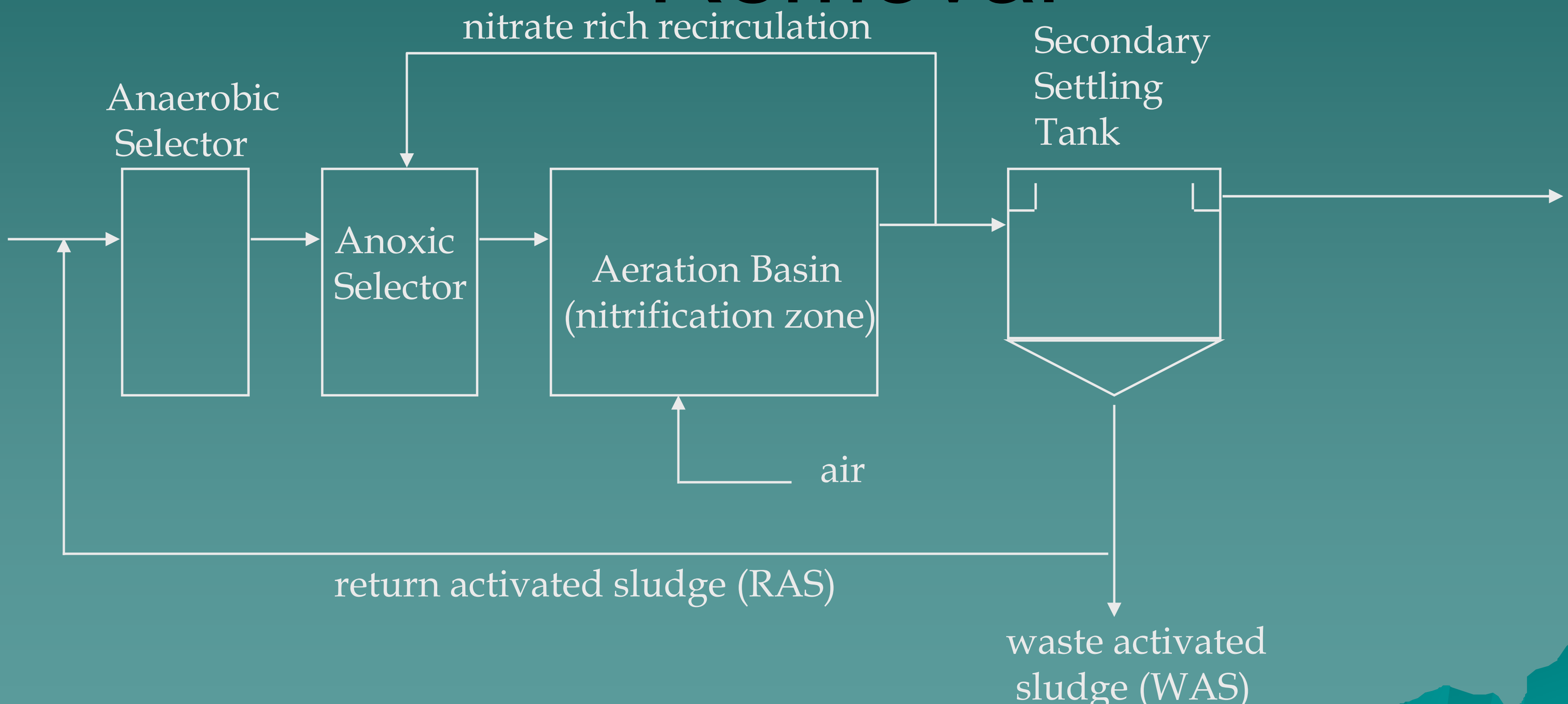
Phosphate Storage "Battery"

Anaerobic Selector	Aeration Basin
Release of phosphorus Uptake of acetic acid	Uptake of phosphorus Formation of phosphorus storage granules (up to 7% P)
ATP $\rightarrow$ ADP	ADP $\rightarrow$ ATP

Combined N and P Removal

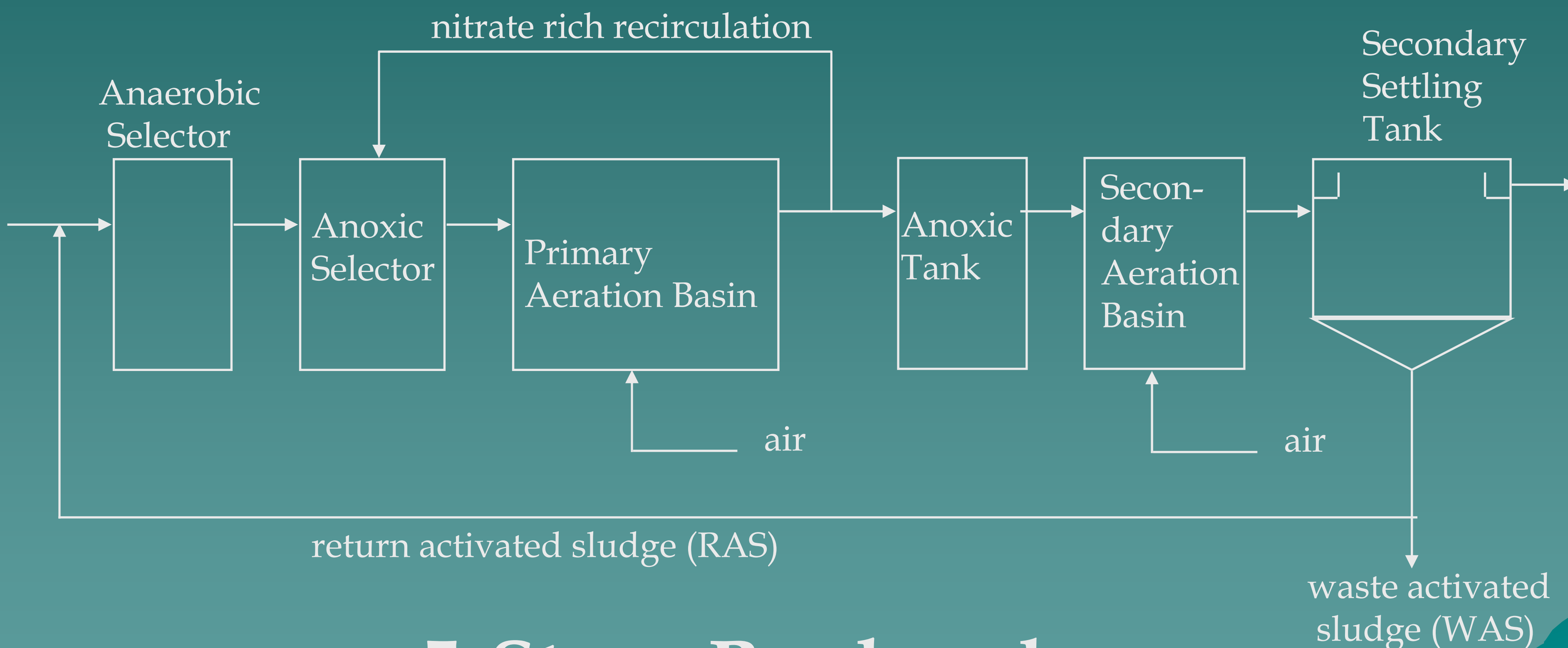
- Competition between bio-P and denitrification
- BOD becomes valuable resource
  - required for both N and P removal
- Operation depends on treatment goals
- One reaction will limit
  - difficult to eliminate all BOD, N, and P
- Commercial models (BioWin, ASIM, etc.) useful to predict performance

Combined Biological Phosphorus & Nitrogen Removal



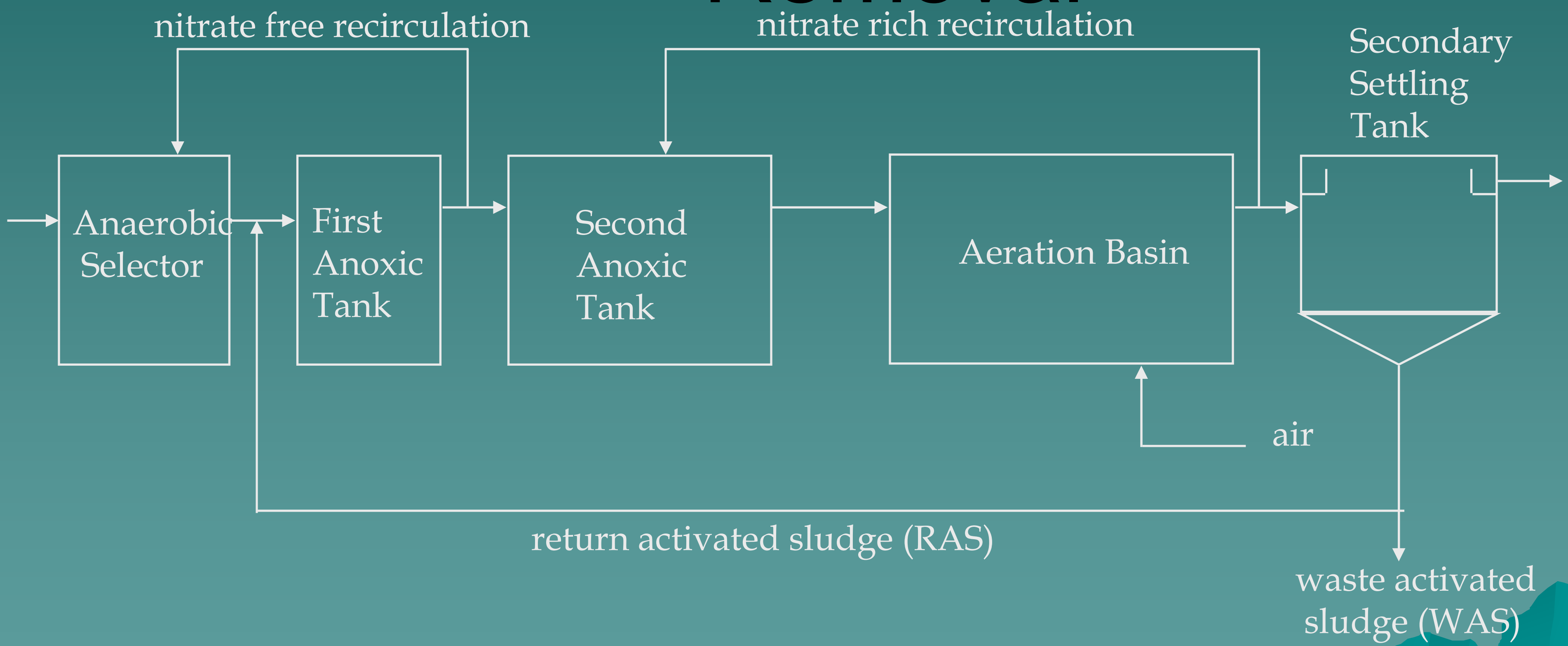
A^2O

Combined EBPR & Nitrogen Removal



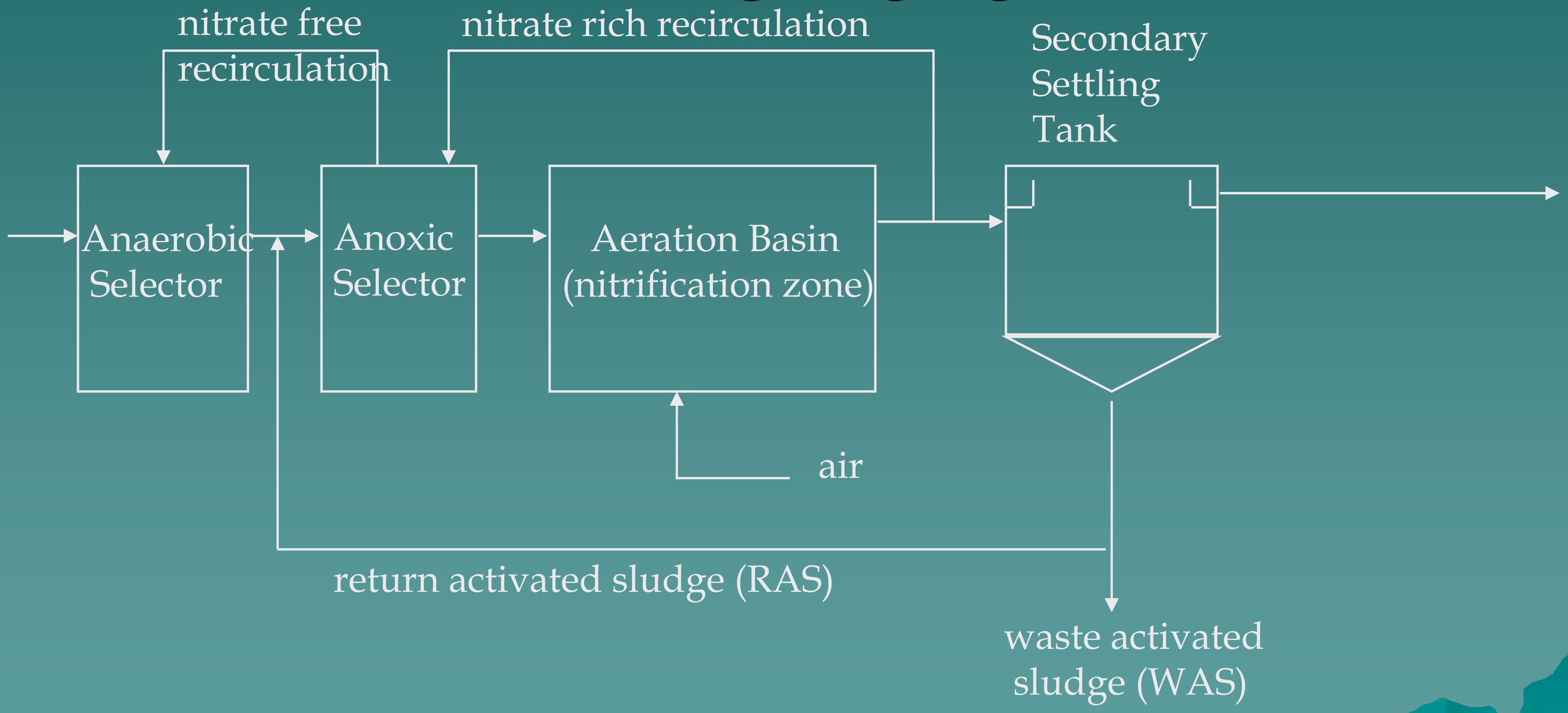
5-Stage Bardenpho

Combined Biological Phosphorus & Nitrogen Removal



Modified UCT

Combined Biological Phosphorus & Nitrogen Removal



Virginia Initiative Plant (VIP)

Sulfur

- inorganic: SO_4^{-2} S° H_2S
- organic: R — O — SO_3^{-2}

four key reactions:

1. H_2S o____________________ — can occur aerobically or anaerobically to elemental sulfur (S°)
   - a___________________ : *Thiobaccilus thioparus* oxidizes S-2 to S°
     - S^{-2} + ½ O_2 + $2H^+$ ➔ S° + H_2O
   - a_______________________: — phototrophs use H2S as electron donor
     - filamentous sulfur bacteria oxidize H_2S to S° in sulfur granules: *Beggiatoa, Thiothrix*

Sulfur

2. Oxidation of E________________ Sulfur (Thiobacillus thiooxidans at low pH)

$$2S° \quad + \quad 3\,O_2 \quad + \quad 2\,H_2O \rightarrow 2\,H_2SO_4$$

3. A_________________________ sulfate reduction: proteolytic bacteria breakdown organic matter containing sulfur (e.g. amino acids: methionine, cysteine, cystine)

4. D_________________________ sulfate reduction: under anaerobic conditions

— s______________ r_________________ b__________________ (SR

$$SO_4^{-2} \quad + \quad \text{Organics} \rightarrow S^{-2} \quad + \quad H_2O \quad + \quad CO_2$$

$$S^{-2} \quad + \quad 2H^{+} \rightarrow H_2S$$

- *Desulvibrio* and others
- Sulfate is used as a TEA & l_____ m_____________ w____________ organics serve as the electron donors
- Low cell y________________
- P____________________ of SRB depends on COD:S ratio, particularly readily degradable (e.g., VFA) COD
- SRB compete with m_______________________ for substrate: high COD:S favors methanogens, low COD:S favors SRB

Crown Sewer Corrosion

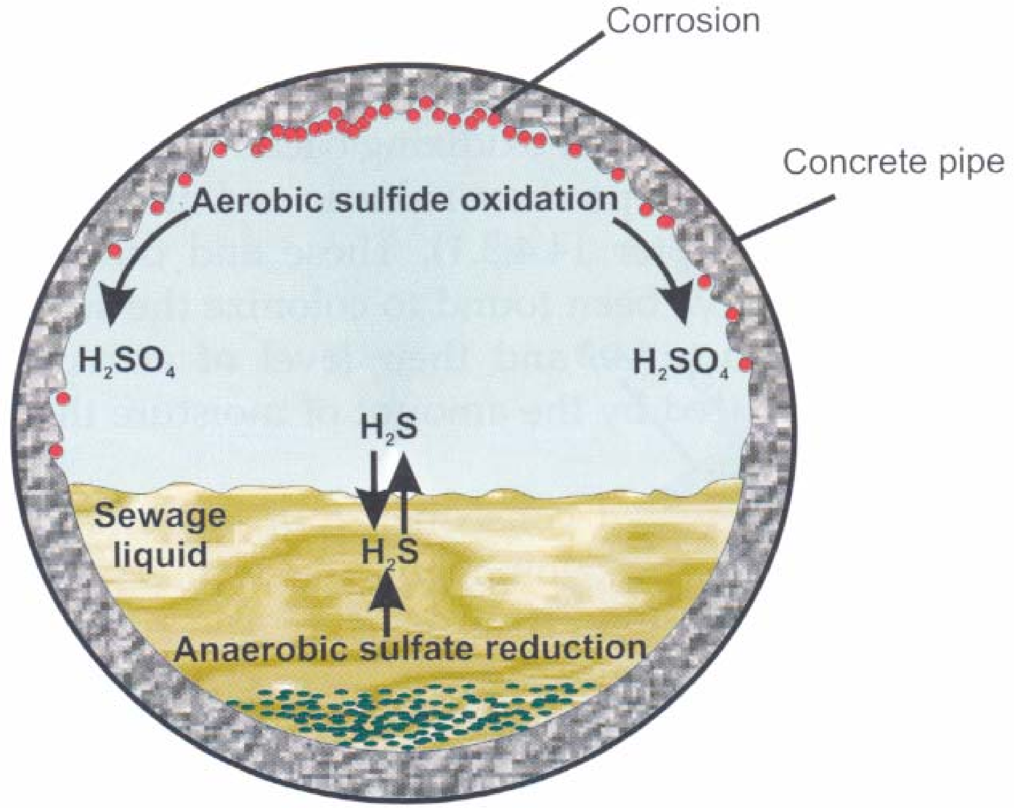


FIGURE 15.3 Cross section showing microbial involvement in the corrosion of a concrete sewer pipe. (Adapted from Sydney *et al.*, 1996.)