

Wastewater treatment processes overview II

Today's lecture

- Biological nutrient removal (BNR) processes
 - Nitrification: oxidation of ammonia-N
 - Denitrification: reduction of nitrate-N to N_2
 - Anammox
 - Enhanced biological P removal

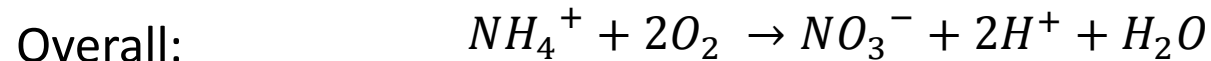
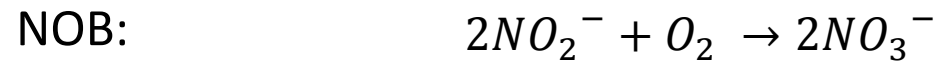
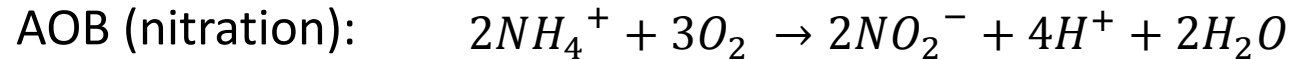
Biological oxidation of nitrogen

- Necessity for $\text{NH}_4\text{-N}$ & $\text{NO}_2\text{-N}$ oxidation
 - The effect of ammonia on receiving water with respect to DO concentrations and fish toxicity
 - The need to provide nitrogen removal to control eutrophication
 - The need to provide nitrogen control for water-reuse applications
- **Nitrification**
 - Two-step biological process: $\text{NH}_4\text{-N} \rightarrow \text{NO}_2\text{-N}$ & $\text{NO}_2\text{-N} \rightarrow \text{NO}_3\text{-N}$
 - The first step [$\text{NH}_4\text{-N} \rightarrow \text{NO}_2\text{-N}$] is termed as “nitritation”
 - Different type of microorganisms are involved for each step

Nitrification – processes & microbiology

- Process
 - Both suspended & attached growth applicable
 - Suspended growth nitrification processes
 - Note nitrifying bacteria are less competent than aerobic heterotrophs → need maintaining low BOD conc. to activate them!
 - So: operate the reactor **at higher SRT** than what's needed for BOD removal
- Microbiology
 - Ammonia-oxidizing bacteria (AOB) & nitrite-oxidizing bacteria (NOB) --- aerobic chemoautotrophs
 - AOBs: *Nitrosomonas* (+*Nitrosospira*)
 - NOBs: *Nitrobacter* (+*Nitrococcus*, *Nitrospina*, *Nitrospira*)

Nitrification stoichiometry

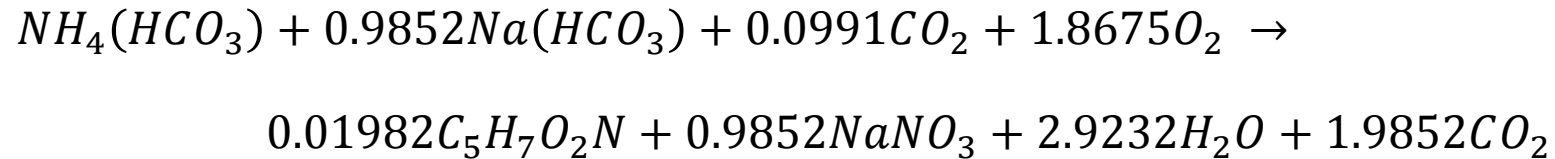


*Note: This is the stoichiometry for **energy reaction (NOT considering biomass growth)***

- Oxygen requirement: 2 mole O_2 /1 mole NH_4^+
= 4.57 g O_2 /g NH_4 -N oxidized
- Alkalinity consumption: 2 eq alkalinity/1 mole NH_4^+
= 7.14 g Alk as $CaCO_3$ /g NH_4 -N oxidized
- Nitrification cell yield: 0.10~0.15 for AOB & 0.04~0.07 for NOB
- Considering biomass production, the O_2 requirements and alkalinity consumption is slightly less than the calculated values above (**why??**)

Nitrification stoichiometry

ex) Assuming $Y=0.12$ g VSS/g $\text{NH}_4\text{-N}$ for AOB and $Y=0.04$ g VSS/g $\text{NO}_2\text{-N}$ for NOB, the overall stoichiometry is:



→ 1.8675 mole O_2 /1 mole NH_4^+

1.9852 eq Alk/1 mole NH_4^+

Environmental factors affecting nitrification

- **DO concentration**
 - Nitrifying bacteria are more sensitive to DO than heterotrophs
 - Nitrite oxidation is inhibited more at low DO than ammonia oxidation
→ elevated $\text{NO}_2\text{-N}$ concentration at low DO
- **pH**
 - Optimum at pH of 7.5~8.0
 - Ammonia oxidation rate reduces significantly at $\text{pH} < 7.0$
 - Possibly due to the reduction of free ammonia (NH_3) concentration
 - **Sufficient alkalinity is needed!**
 - For wastewater with high NH_4^+ concentrations and low alkalinity, addition of alkalinity may be needed (lime, soda ash, NaHCO_3 , ...)

Environmental factors affecting nitrification

- **Toxicity**
 - AOB is sensitive to a wide range of organic & inorganic compounds
 - Show significantly reduced ammonia oxidation rate in the presence of toxic substances
- **Free ammonia & nitrous acid inhibition**
 - $\text{NH}_3\text{-N}$ & HNO_2
 - High pH: $\text{NH}_3\text{-N}$ \uparrow / low pH: HNO_2 \uparrow

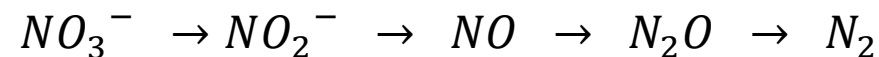
Denitrification

- **Biological reduction of nitrate (NO_3^-) or nitrite (NO_2^-) to nitrogen gas (N_2)**
- **Denitrification required**
 - To complete the biological nitrogen removal process
 - Otherwise, accumulation of $\text{NO}_3\text{-N}$: health threats!
 - “Blue baby syndrome”
 - Korean regulation: $< 10 \text{ mg NO}_3\text{-N/L}$
- **Usually by heterotrophic bacteria**
 - Wide range of heterotrophs – mostly facultative aerobes
 - Some autotrophs are capable of nitrate/nitrite reduction
 - Use Fe^0 , Fe^{2+} , S^{2-} , S^0 , ..., or NH_4^+

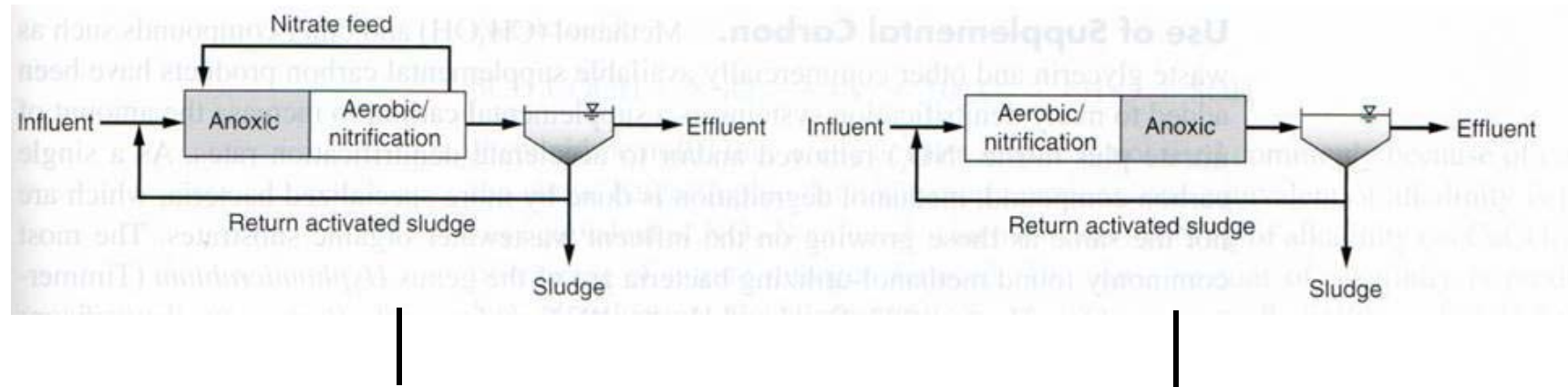


Denitrification

- Two modes of nitrate removal in biological processes
 - **Assimilatory nitrate reduction**
 - Reduction of $\text{NO}_3\text{-N}$ to $\text{NH}_4\text{-N}$ for use in cell synthesis when $\text{NH}_4\text{-N}$ is not available
 - Independent of DO concentration
 - **Dissimilatory nitrate reduction:** much more significant!
 - Nitrate/nitrite serves as an electron acceptor
 - When DO is absent or limited
 - Mostly facultative bacteria
 - Nitrate reduction proceeds through a series of intermediate products:



Denitrification processes



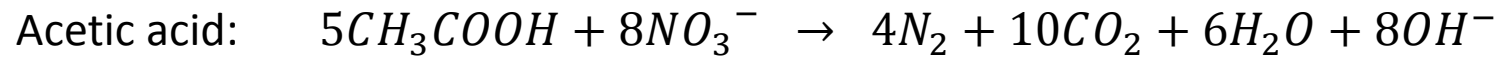
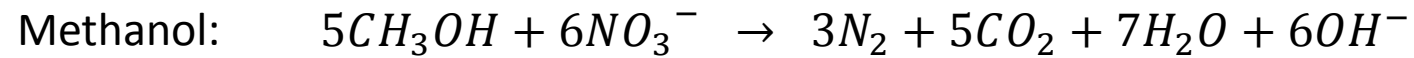
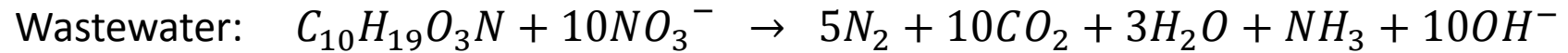
- **Preanoxic denitrification**

- Electron donor provided by influent
- MLE (Modified Ludzak-Ettinger) process: most common for biological nitrogen removal in municipal wastewater treatment

- **Postanoxic denitrification**

- BOD not available in anoxic reactor: denitrification by endogenous decay
- Much slower rate than preanoxic
- Often external carbon source is added (e.g. methanol, acetate)

Denitrification Stoichiometry



– Production of alkalinity

- 3.57 g Alk as $CaCO_3$ produced per g NO_3^- -N (or NO_2^- -N) reduced
- 50% of alkalinity consumed by nitrification can be recovered

DeN - Organic substrate requirements

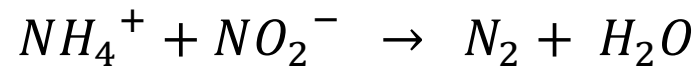
- A sufficient amount of organic substrate (e^- donor) should be available
 - **bsCOD or BOD as an important design parameter**
 - **Sources of e^- donor for denitrification**
 - 1) bsCOD in the influent
 - 2) bsCOD produced during biological hydrolysis
 - 3) bsCOD produced during endogenous decay
 - 4) External source such as methanol or acetate
 - ~4 g BOD required per g $\text{NO}_3\text{-N}$ reduced
 - actual requirement depending on operating conditions and the type of e^- donor
 - Especially important to determine the BOD requirements when external carbon source is provided

Simultaneous nitrification and denitrification

- In activated sludge floc (suspended growth) or biofilm (attached growth)
- Local conditions in the floc or biofilm may be different from bulk liquid
- **High DO at the exterior and low DO inside** → conditions for nitrification and denitrification may develop in a single floc or biofilm
- Can be significant if optimal conditions are developed

Anammox process

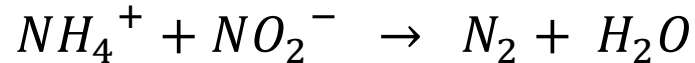
- **Anaerobic ammonia oxidation**
- **Anaerobic oxidation of ammonia to produce nitrogen gas**



e⁻ donor *e⁻ acceptor*

- **Requires aerobic nitrification of ammonia to NO₂⁻ for the process to occur (~55% conversion of NH₄-N to NO₂-N)**
- **By autotrophic bacteria**
 - No organic carbon consumption during the process

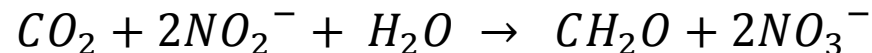
Anammox process



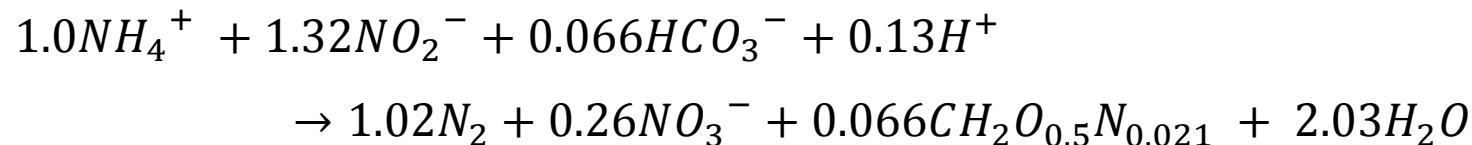
- **Proposed metabolic model** (Van de Graaf et al., 1997)
 - 1) Reduction of nitrite to hydroxylamine (NH_2OH)
 - 2) Condensation of hydroxylamine with ammonium to hydrazine (N_2H_4)
 - 3) Oxidation of hydrazine to nitrogen gas

- **Some formation of NO_3 -N from NO_2 -N**

- To provide the reducing power to fix CO_2



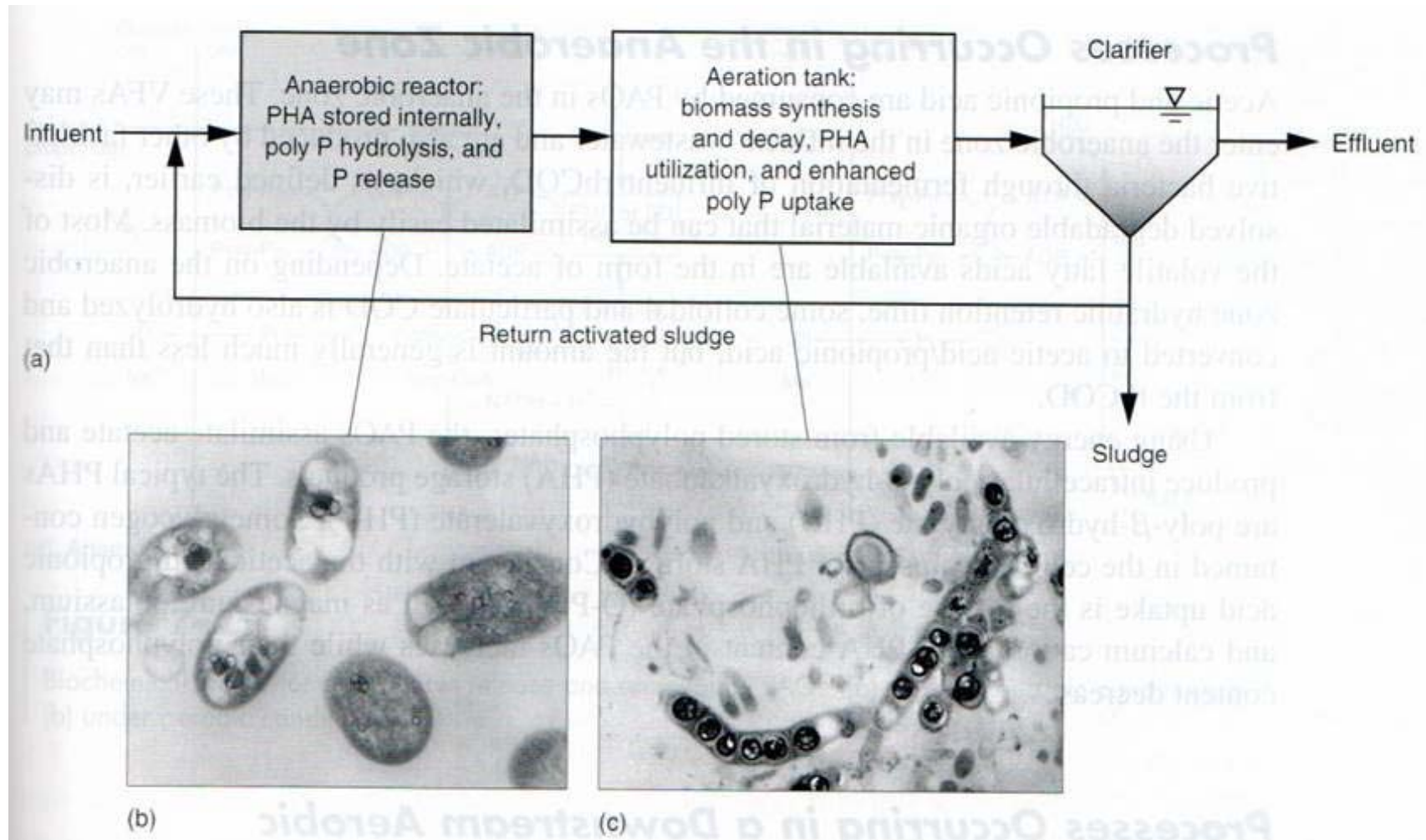
- **Overall reaction** (Strous et al., 1999)



Enhanced biological P removal

- Involves incorporation of P in the biomass produced in the treatment system and subsequent removal of the biomass as waste sludge
- Biomass of heterotrophic bacteria contains ~ 0.015 g P/g VSS
 - Insufficient to remove P from influent wastewater (only 10~20% of total)
- Use **phosphorus accumulating organisms (PAOs)** for ***enhanced* biological phosphorus removal (EBPR)**
- Reduced chemical costs and less sludge production compared to chemical precipitation

Enhanced biological P removal



EBPR – Process description

- Place an anaerobic tank ahead of the aeration tank
 - Provide selectivity for growth of PAOs
- In the anaerobic tank, PAOs consume energy stored in the form of polyphosphates
 - The energy generated is used to convert volatile fatty acids into carbohydrate storage products (PHA)
- In the aerobic tank, PAOs consume COD & stored PAH for biomass growth
 - Use some of the energy for enhanced P uptake to store polyphosphates
- So:
 - Anaerobic tank: PHA accumulation & P release
 - Aerobic tank: excessive P uptake & PHA utilization
- PAOs form very dense floc with good settleability – additional benefit

EBPR – Process description

- **Process occurring in the anaerobic zone**
 - Volatile fatty acids (VFAs) are produced by fermentation
 - VFAs are assimilated by PAOs into PHAs by energy available from stored polyphosphates
 - Typical PHAs: poly- β -hydroxybutyrate (PHB) & polyhydroxyvalerate (PHV)
 - Some glycogen contained in the cell is also used
- **Processes occurring in the aerobic/anoxic zone**
 - Stored PHA is metabolized to provide energy for cell growth
 - Some glycogen is produced from PHA metabolism
 - Soluble orthophosphate in solution is taken up by PAOs to form polyphosphates in the existing cells and the new cells
 - Portion of the biomass is wasted \rightarrow P removal
 - The process can occur in the anoxic zone as well (NO_3^- or NO_2^- as e^- acceptors)