# Biological wastewater treatment I

# Today's class

- Conventional activated sludge process

  : *Most common approach for BOD removal*

  – Design parameters

  – Settling problems

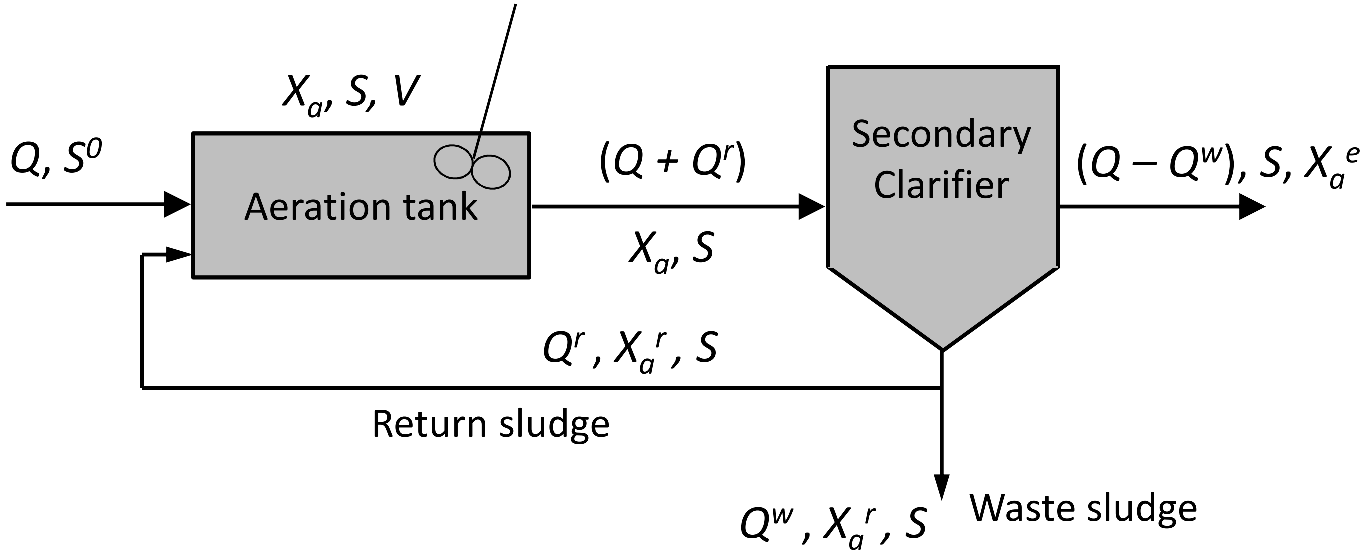
- Biological nutrient removal

  : *Conventional strategies to improve N removal efficiency in the secondary treatment*

  – Nitrification

  – Denitrification

# Analyzing activated sludge process




Remember:

$$S = K\frac{1 + b\theta_x}{\theta_x(Y\hat{q} - b) - 1}$$

$$X_a = \frac{\theta_x}{\theta}\frac{Y(S^0 - S)}{1 + b\theta_x}$$

→ SRT a key parameter

# Aeration tank & clarifier

# Other important design parameters

- **Food-to-microorganism ratio (F/M)**

with respect to TSS:

$$F/M = \frac{Q^0 S^0}{VX}$$

with respect to VSS:

$$F/M_v = \frac{Q^0 S^0}{VX_v}$$

*$X$ = total suspended solids (TSS) in aeration tank (mg/L)*

*$X_v$ = volatile suspended solids (VSS) in aeration tank (mg/L)*

- **Volumetric organic loading rate (OLR)**: the amount of BOD or COD applied to the aeration tank volume per day

$$Volumetric\ OLR = \frac{Q^0 S^0}{V}$$

# Sludge settling problems

- Major cause of the exceedance of the effluent standard for SS & BOD/COD

- **Bulking sludge**
  - Sludge blanket not stable; large quantities of SS carried along with the clarifier effluent
  - Filamentous bulking: growth of filamentous organisms
  - Viscous bulking: production of excessive amount of extracellular biopolymers

- **Air bubbles captured in flocs**
  - Nocardioform foam: excessive growth of "Nocardioform" bacteria, which have hydrophobic cell surfaces and thus collects air bubbles
  - Rising sludge: due to internal gas production in flocs (most often N2 production by denitrification)

# Biological oxidation of nitrogen

- Necessity for $NH_4$-N & $NO_2$-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: $NH_4$-N → $NO_2$-N & $NO_2$-N → $NO_3$-N
  - The first step [$NH_4$-N → $NO_2$-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

AOB (nitration): $2NH_4{}^+ + 3O_2 \rightarrow 2NO_2{}^- + 4H^+ + 2H_2O$

NOB: $2NO_2{}^- + O_2 \rightarrow 2NO_3{}^-$

Overall: $NH_4{}^+ + 2O_2 \rightarrow NO_3{}^- + 2H^+ + H_2O$

*Note: This is the stoichiometry for* ***energy reaction*** *(**NOT** accounting for 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 $NH_4$-N for AOB and Y=0.04 g VSS/g $NO_2$-N for NOB, the overall stoichiometry is:

$$NH_4(HCO_3) + 0.9852Na(HCO_3) + 0.0991CO_2 + 1.8675O_2 \rightarrow$$

$$0.01982C_5H_7O_2N + 0.9852NaNO_3 + 2.9232H_2O + 1.9852CO_2$$

→ 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 $NO_2$-N concentration at low DO

- **pH**
  - Optimum at pH of 7.5~8.0
  - Ammonia oxidation rate reduces significantly at 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**
  - $NH_3$-N & $HNO_2$
  - High pH: $NH_3$-N ↑ / low pH: $HNO_2$ ↑

# 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 $NO_3$-N: health threats!
  - "Blue baby syndrome"
  - Korean regulation: < 10 mg $NO_3$-N/L

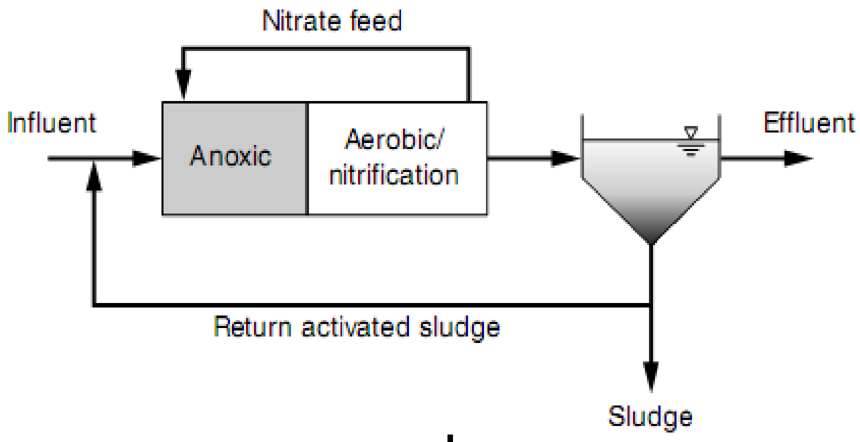
- **Usually by heterotrophic bacteria**
  - Wide range of heterotrophs – mostly facultative aerobes
  - Some autotrophs are capable of nitrate/nitrite reduction
    - Use $Fe^0$, $Fe^{2+}$, $S^{2-}$, $S^0$, …, or $NH_4^+$

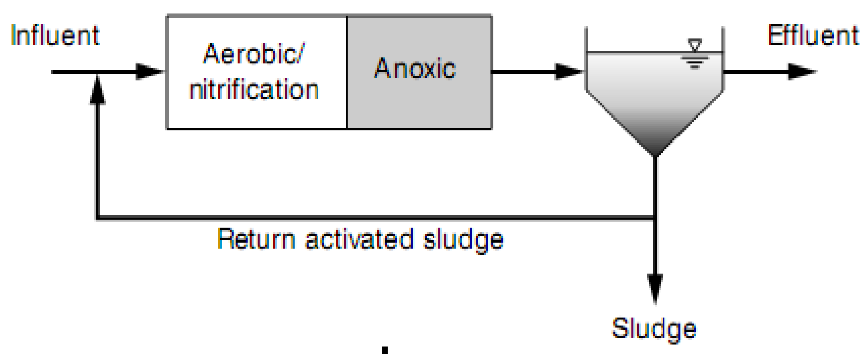
# Denitrification

- Two modes of nitrate removal in biological processes
  - **Assimilatory nitrate reduction**
    - Reduction of $NO_3$-N to $NH_4$-N for use in cell synthesis when $NH_4$-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:

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$$

# 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

Wastewater: $C_{10}H_{19}O_3N + 10NO_3^{-} \rightarrow 5N_2 + 10CO_2 + 3H_2O + NH_3 + 10OH^{-}$

Methanol: $5CH_3OH + 6NO_3^{-} \rightarrow 3N_2 + 5CO_2 + 7H_2O + 6OH^{-}$

Acetic acid: $5CH_3COOH + 8NO_3^{-} \rightarrow 4N_2 + 10CO_2 + 6H_2O + 8OH^{-}$

- **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

# Denitrification: 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 $NO_3$-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