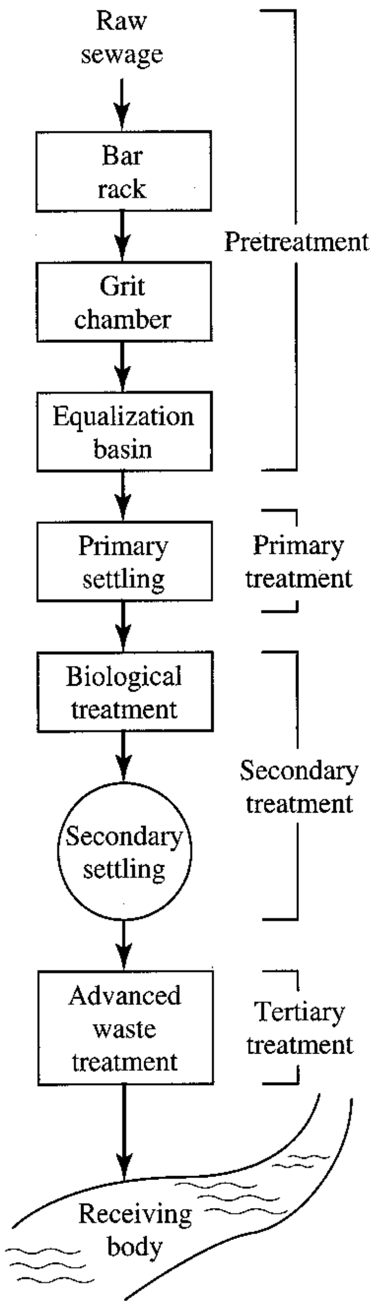
Wastewater treatment processes

Municipal wastewater treatment systems



- Pretreatment: removes materials that can cause operational problems, equalization optional
- Primary treatment: remove ~60% of SS and ~35% of BOD
- Secondary treatment – remove ~85% of BOD and SS
- Advanced (tertiary) treatment – more BOD and SS, N, P, others

Bar racks (screens)

- Purpose: to remove large objects that would damage or foul pumps, valves, and other mechanical equipment

http://www.infobarscreens.com

Grit chamber

- Grits: inert dense materials such as sand, broken glass, silt, and pebbles
- Purpose: to remove grits that can abrade pumps and other mechanical devices

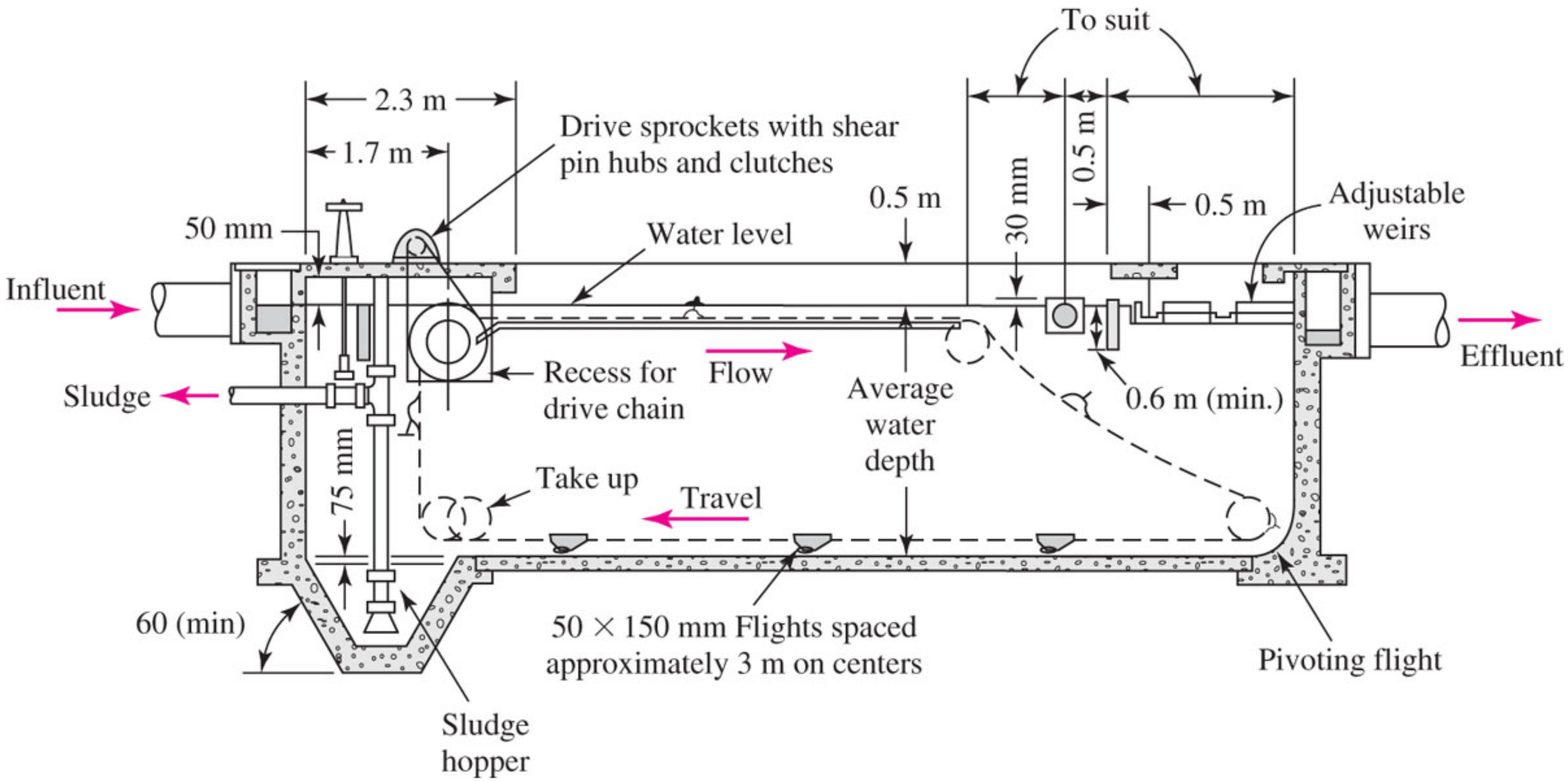
Flow equalization

- The flow rate and strength of wastewater varies from hour to hour
- High flow rate and strength in the morning, low at night; high flow rate and low strength during storm events
- Flow equalization is to achieve nearly constant wastewater flow rate and strength → better performance of wastewater treatment and reduce the size and cost

Primary sedimentation basins

- Removal of suspended solids by settling
- This removes some BOD as well!
- Removes ~60% of SS and ~35% of BOD
- Sludge settled at the bottom and collected by mechanical devices
- Floating materials such as oil and grease are also removed

Primary sedimentation basins



Primary sedimentation basins

- Design parameters
  - Retention time: ~2 hr
  - Overflow rate, v_0

$$v_o = \frac{Q}{A_c}$$

Q = water flow rate (m^3/s)

A_c = surface area of the sedimentation basin (m^2)

  - Weir loading, WL

$$WL = \frac{Q}{L_{weir}}$$

L_{weir} = weir length (m)

* Large, dense particles: better settling properties

→ higher v_0 and WL allowed

Primary sedimentation basins

- Rectangular or circular

http://www.mlive.com

http://www.lgam.info

Primary sedimentation basins

Q: Calculate the retention time, overflow rate, and weir loading of the primary sedimentation basin with following design parameters.

Flow = 0.150 m^3/s

Width = 10.0 m

Weir length = 75.0 m

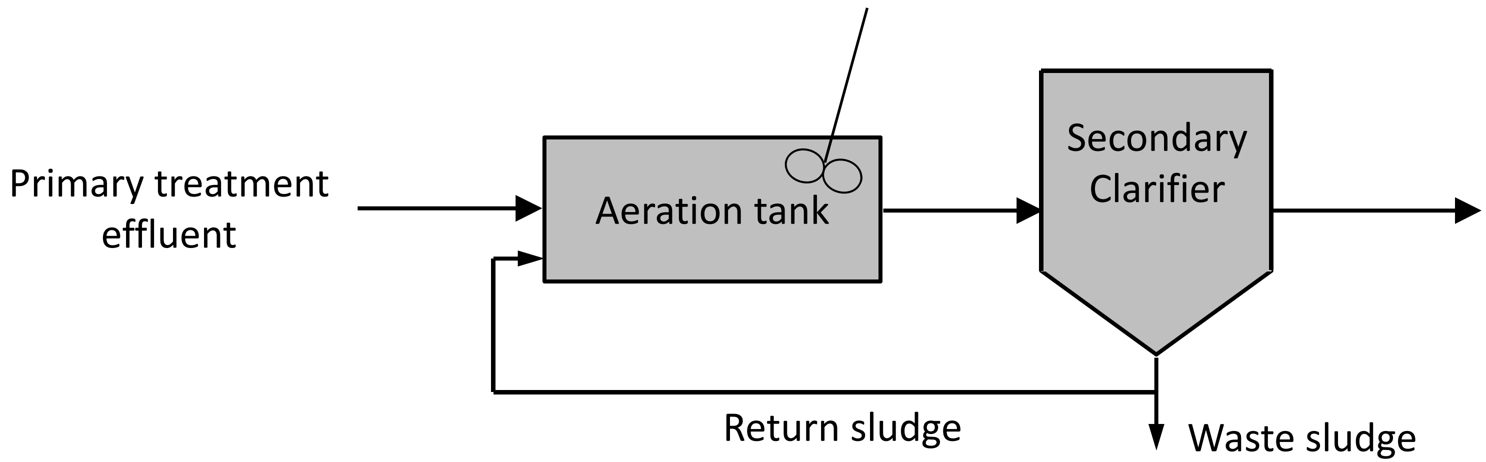
Length = 40.0 m

Water depth = 2.0 m

Secondary treatment

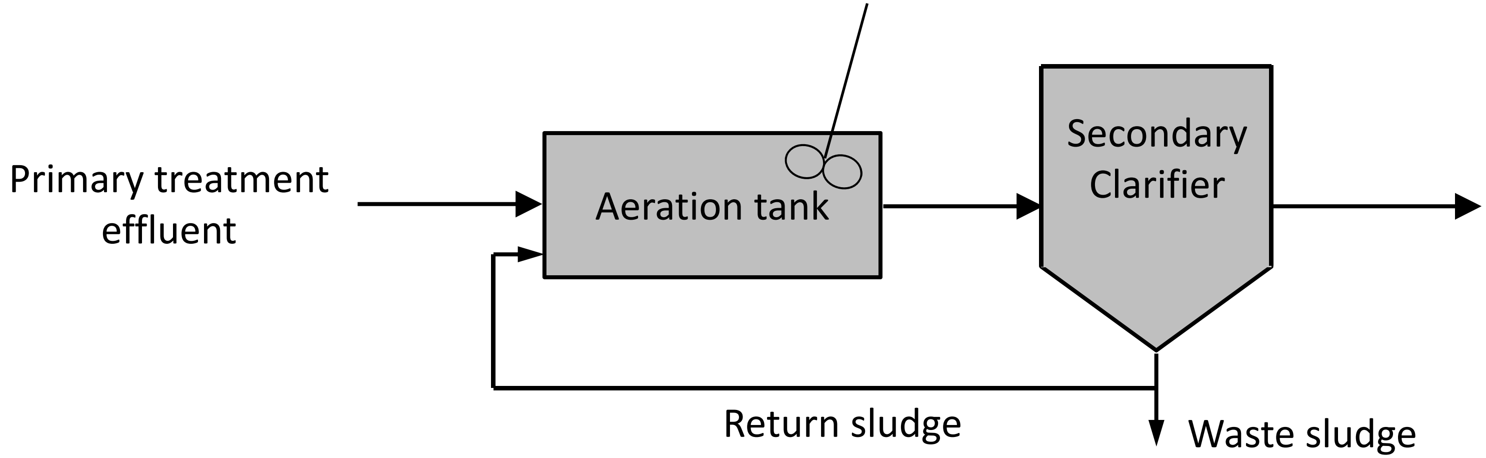
- Goal: provide BOD removal beyond what is achieved in primary treatment
  - Removal of soluble BOD
  - Additional removal of SS
- How: by providing favorable conditions for microbial activities
  - Availability of high density of microorganisms
  - Good contact between organisms and wastes
  - Favorable temperature, pH, nutrients, carbon source (food)
  - Oxygen (or other electron acceptors)
  - No or little toxic chemicals present

Activated sludge process



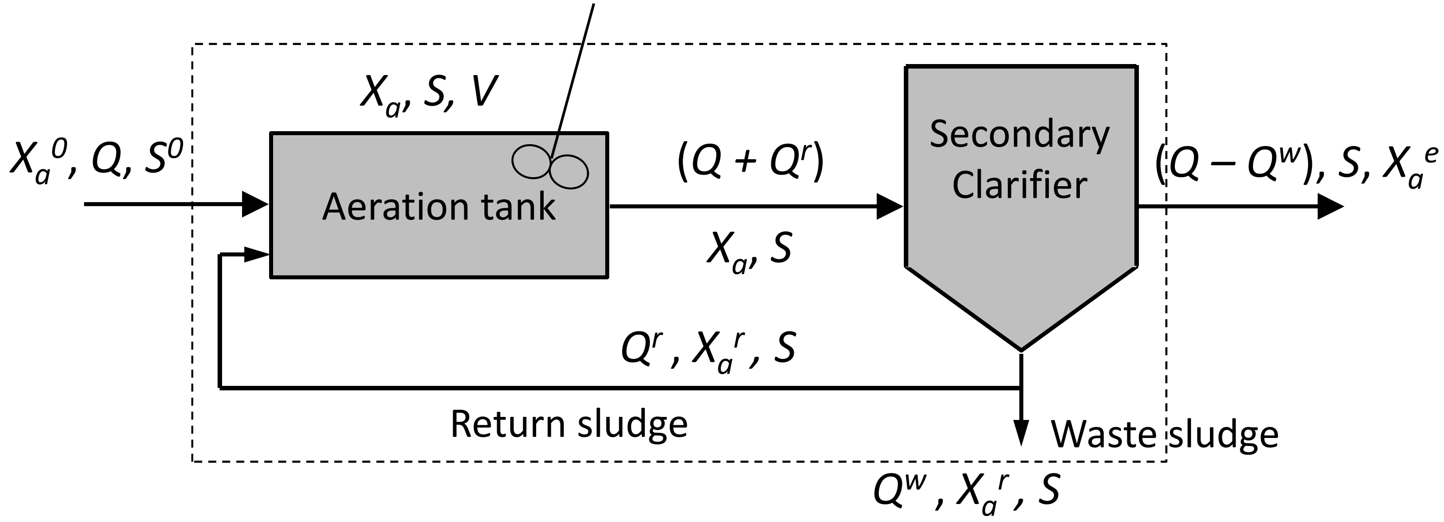
- A biological wastewater treatment technique using suspended microorganisms (dispersed growth)
- Aeration tank: a mixture of wastewater and microorganisms is agitated and aerated
- Wastewater BOD is removed by active microorganisms

Activated sludge process



- Secondary clarifier: the microorganisms (also called biosolids or sludge) are separated from water by gravity
- Most of the settled sludge is returned to the aeration tank (Why? - We need a high population of microorganisms)
- A fraction of the settled sludge is wasted (Why? – microorganisms grow!)

Analyzing activated sludge process



Assumption:

i) Steady-state

ii) The aeration tank is a CSTR

iii) All reactions occur in the aeration tank

Analyzing activated sludge process

- Mass balance for substrate:

$$0 = Q^0 S^0 - (Q^e S + Q^w S) + r_{ut} V$$

- Mass balance for microorganisms:

$$0 = 0 - (Q^e X_a{}^e + Q^w X_a{}^w) + [Y(-r_{ut})V - bX_a V]$$

This can be rearranged to:

$$\frac{Q^e X_a{}^e + Q^w X_a{}^w}{X_a V} = \frac{Y(-r_{ut})}{X_a} - b$$

Analyzing activated sludge process

- Solids retention time (SRT), θ_x

$$\theta_x = \frac{X_a V}{Q^e {X_a}^e + Q^w {X_a}^w}$$

Therefore,

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

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

We've seen this!!

Analyzing activated sludge process

- Mass balance for substrate:

$$0 = Q^0 S^0 - (Q^e S + Q^w S) + r_{ut} V$$

This can be rearranged to ($Q^0 = Q^e + Q^w$):

$$-r_{ut} = \frac{Q^0 (S^0 - S)}{V} = \frac{(S^0 - S)}{\theta}$$

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

We've seen something similar to this!!

Other important operation parameters

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

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

X = total suspended solids (MLSS) in aeration tank (mg/L)

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

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

Other important operation parameters

- Sludge production, $P_{X,VSS}$

$$P_{X,VSS} = Y_{obs}(Q)(S^0 - S) + QX_i{}^0$$

$$= QY(S^0 - S)\frac{1 + (1 - f_d)b\theta_x}{1 + b\theta_x} + QX_i{}^0$$

$P_{X,VSS}$ = daily net sludge production (g VSS/d)

Y_{obs} = observed yield (g VSS/g substrate)

- Oxygen requirements, R_o

$$R_o = Q(S^0 - S) - 1.42P_{X,bio}$$

$P_{X,bio}$ = daily biomass production (g VSS/d);

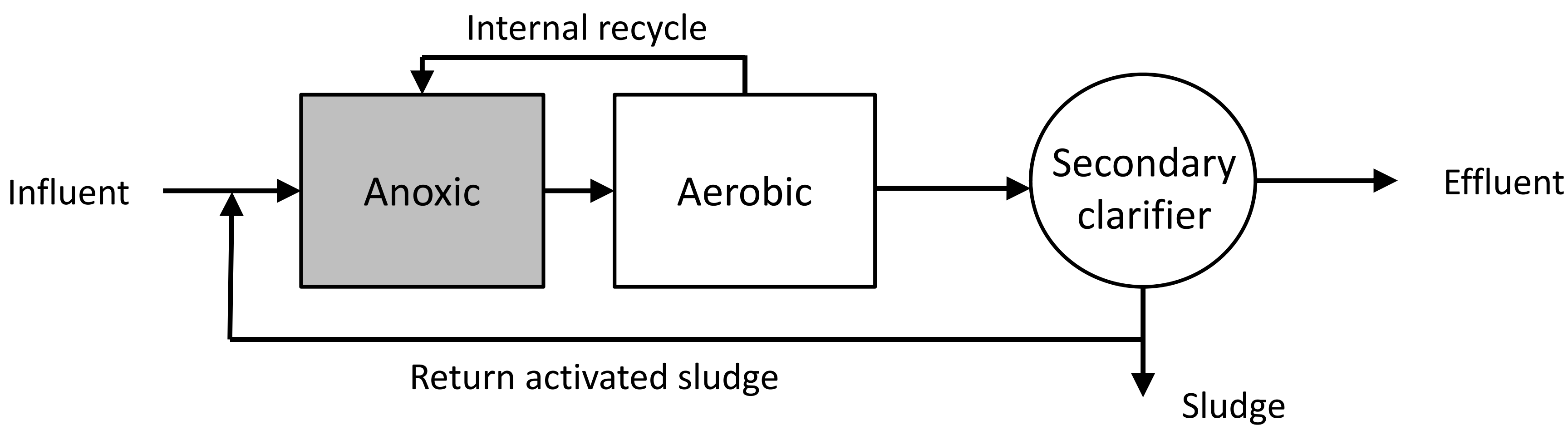
= $P_{X,VSS} - QX_i^0$

Biological nutrient removal

- The secondary treatment process can be modified to improve nutrient removal by microorganisms
- Nitrogen removal
  - Nitrification ($NH_4^+ \rightarrow NO_3^-$): needs high DO & low BOD
  - Denitrification ($NO_3^- \rightarrow N_2$): needs low DO & some BOD
- Phosphorus removal
  - If microorganisms are exposed to alternating periods of anaerobic & aerobic conditions, they tend to accumulate excessive phosphorus at aerobic conditions

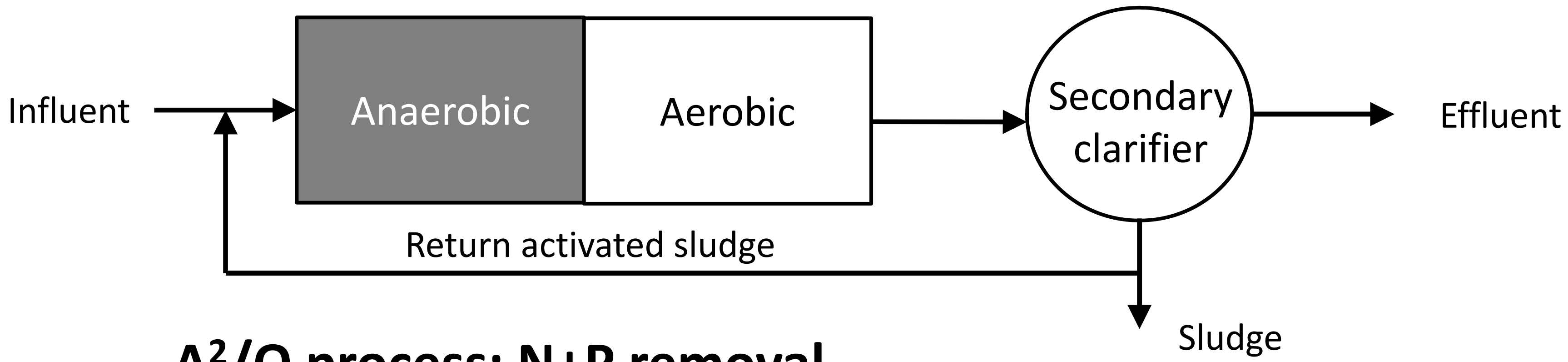
Biological nutrient removal

- Examples of modified secondary treatment processes for biological nutrient removal
  - **Modified Ludzack-Ettinger (MLE) process: N removal**

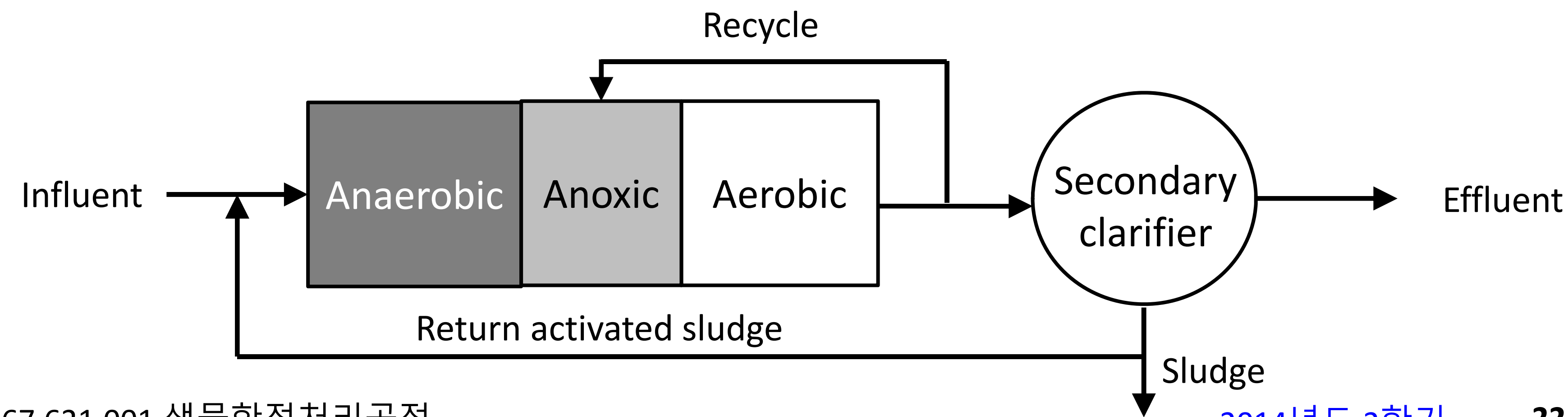


Biological nutrient removal

– **A/O process: P removal**

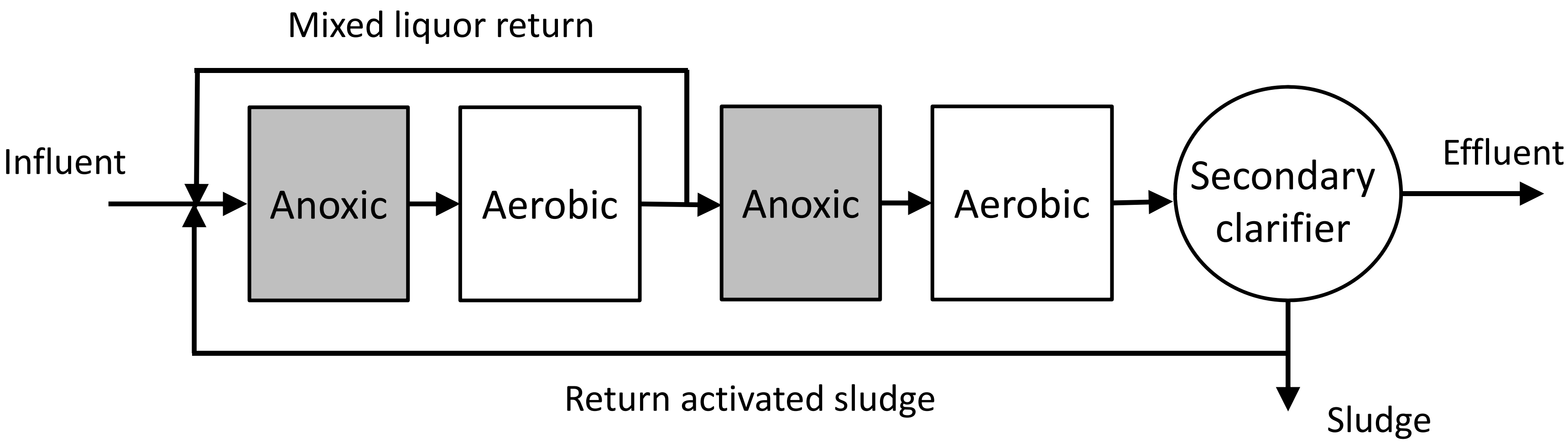


– **A²/O process: N+P removal**



Biological nutrient removal

– **Bardenpho process: N+P removal**

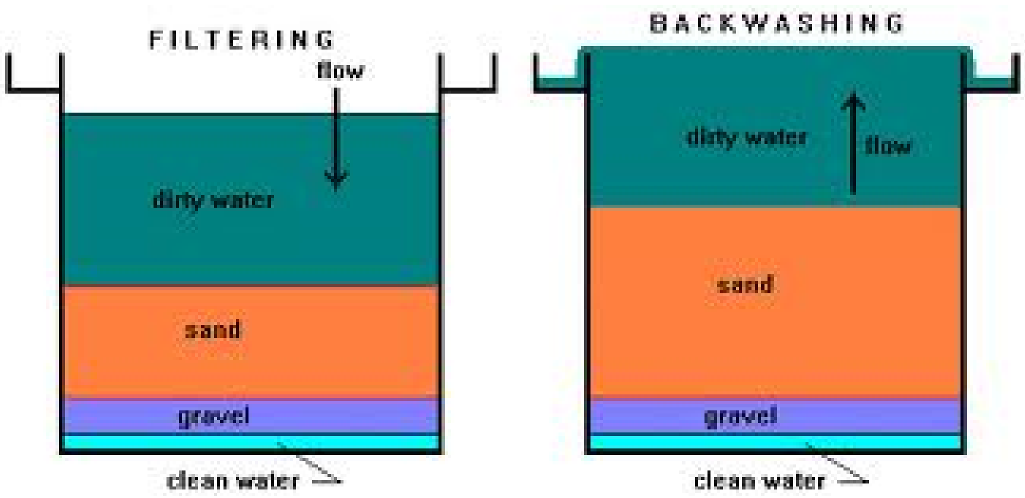


Tertiary (advanced) treatment

- Goal: to improve the quality of the secondary treatment effluent
- Many of the Korean wastewater treatment plants now have advanced treatment process
- Further BOD and SS removal, nutrient removal, TDS removal, or the removal of refractory organic compounds
- Different processes can be used depending on the major target

Tertiary (advanced) treatment

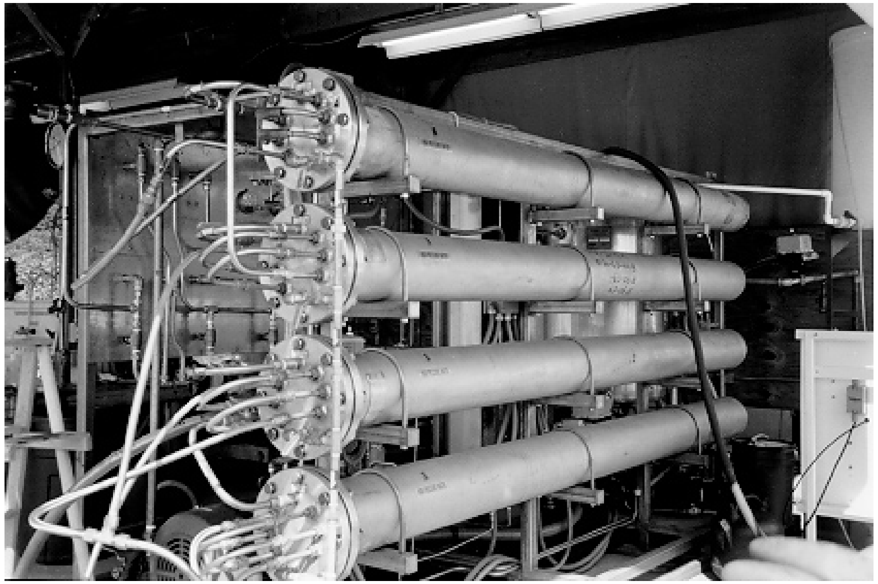
- Available tertiary treatment technologies
  - Granular filtration
    - Additional removal of SS
    - Sand is most frequently used



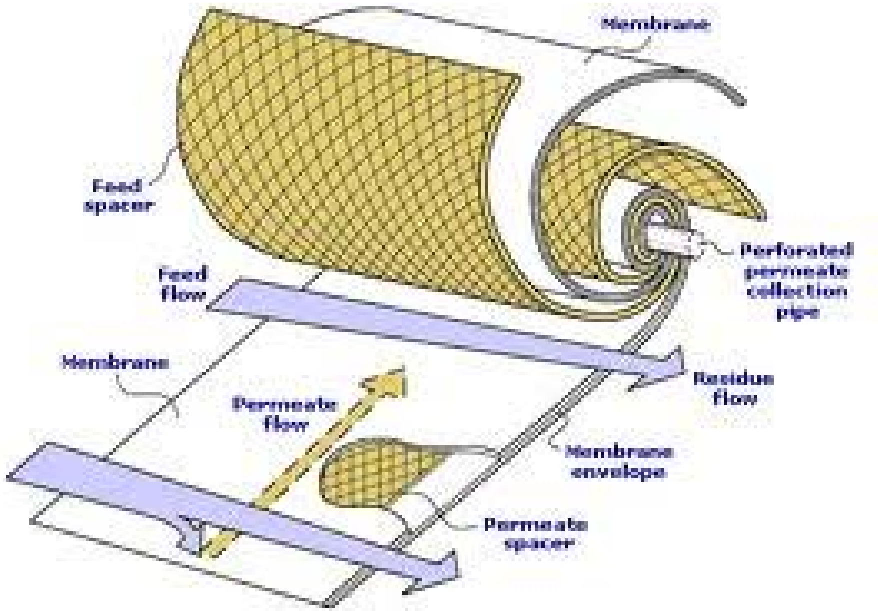
http://www.rpi.edu

Tertiary (advanced) treatment

- Available tertiary treatment technologies
  - Membrane filtration: additional removal of SS



http://www.clu-in.org



http://www.onlinembr.info

Tertiary (advanced) treatment

- Available tertiary treatment technologies
  - Chemical phosphorus removal
    - Use chemicals (ferric chloride, alum, lime, …) to precipitate P from secondary effluent
    - Using ferric chloride:

$$FeCl_3 + HPO_4{}^{2-} \rightleftharpoons FePO_4 \downarrow + H^+ + 3Cl^-$$

    - Using alum

$$Al_2(SO_4)_3 + 2HPO_4{}^{2-} \rightleftharpoons 2AlPO_4 \downarrow + 2H^+ + 3SO_4{}^{2-}$$

    - Using lime:

$$5Ca(OH)_2 + 3HPO_4{}^{2-} \rightleftharpoons Ca_5(PO_4)_3OH \downarrow + 3H_2O + 6OH^-$$

Tertiary (advanced) treatment

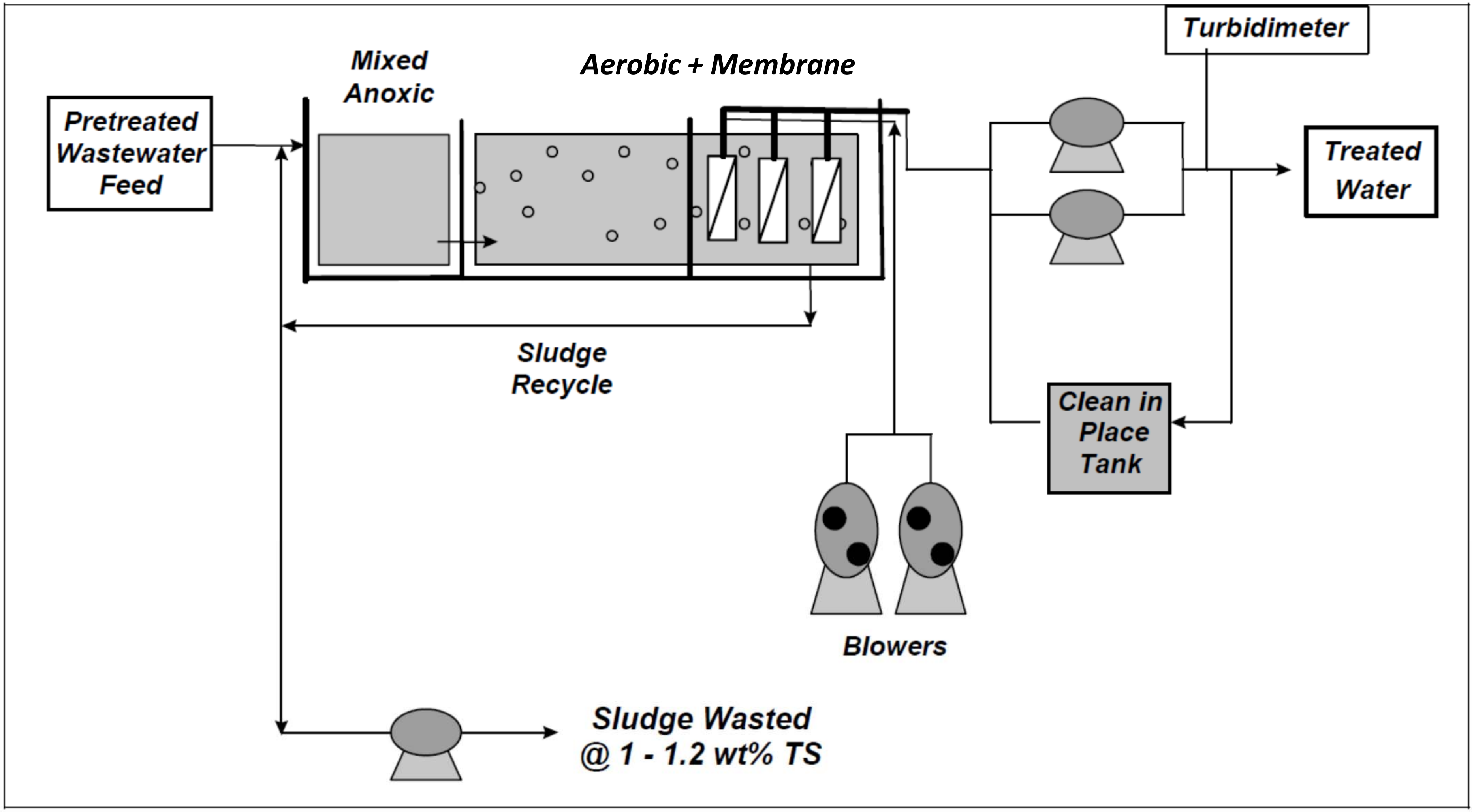
- Available tertiary treatment technologies
  - Activated carbon adsorption: removal of refractory organic compounds

http://www.chemvironcarbon.com

Membrane bioreactors

- Concept
  – Utilizing a suspended-growth bioreactor and microfiltration as one unit process
  – Effect: secondary treatment (aeration tank + clarifier) + tertiary treatment (granular media filtration)
  – High removal efficiencies of BOD, SS, bacteria, and nutrients can be obtained

Membrane bioreactors - example

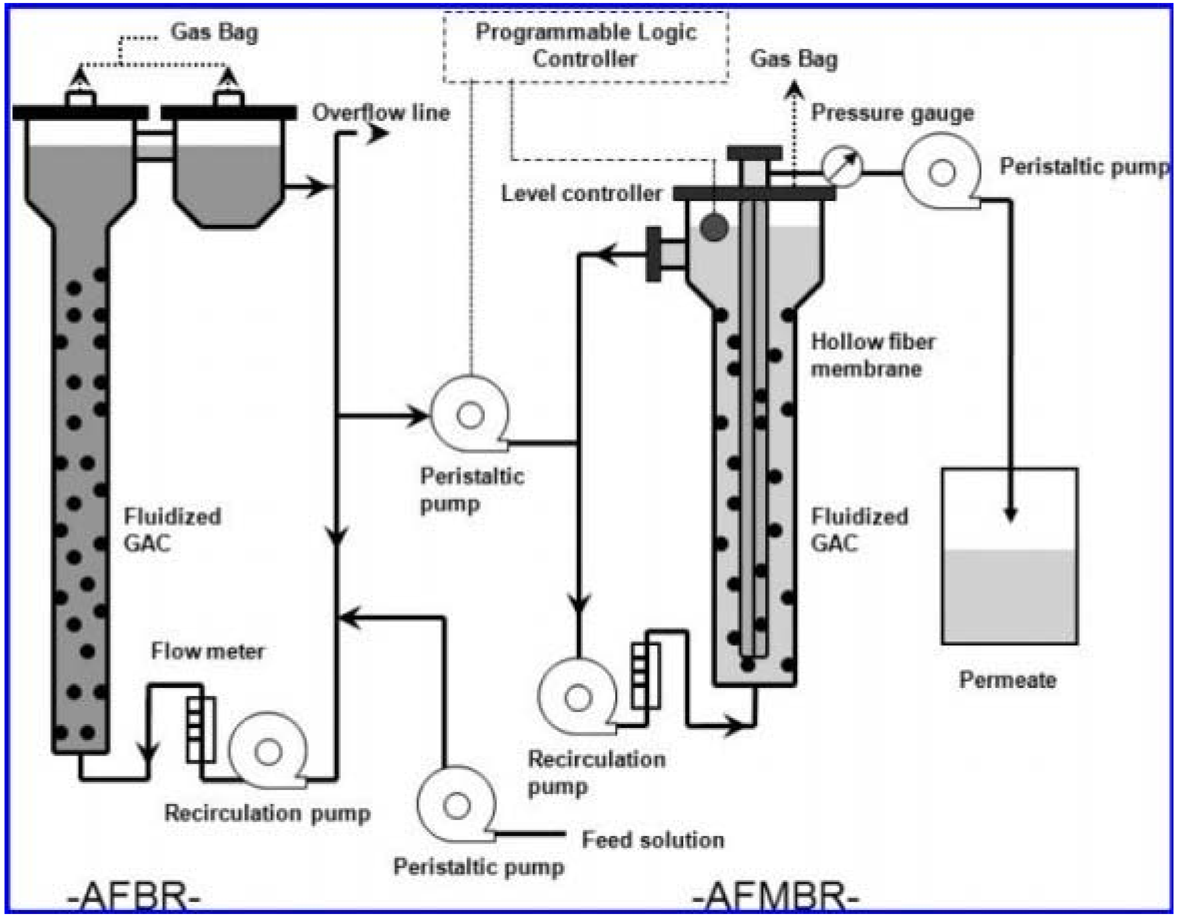


From USEPA

Membrane bioreactors

- Advantages
  - Better effluent quality (can be directly reused)
  - Smaller space requirements (can maintain higher biomass concentration → higher volumetric OLR, with appropriate F/M → lower HRT → smaller reactor volume)
- Disadvantages
  - Higher capital & operating costs
    - Operating costs for membrane cleaning, fouling control, and replacement
    - Energy costs for air scouring
    - Becoming more and more economically viable with the advances in membrane technologies

Membrane bioreactors



Kim et al. (2011)

Anaerobic fluidized bed membrane bioreactor (AFMBR)

- GAC scours the membrane → fouling control
- Additional organic removal by GAC
- Methane (fuel) production