Wastewater Treatment

1. Wastewater Microbiology

1.1 Role of Microorganisms in wastewater treatment

- The microorganisms convert the colloidal and dissolved carbonaceous organic matter into gases and protoplasm.
- Since protoplasm has a specific gravity slightly greater than that of water, it can be removed from the treated water by gravity settling.

1.2 Classification of Microorganisms

By carbon source

- Heterotrophs: organic materials
- Autotrophs: CO_2

By energy source

- Phototrophs: sun light
- Chemotrophs: organic or inorganic oxidation/reduction reaction
- Organotrophs: organic materials
- Lithotrophs: inorganic compounds

By ability to use oxygen

- Obligate aerobes:
- Facultative anaerobes:
- Obligate anaerobes:

* Denitrifiers
* electron acceptor (hydrogen acceptor)

By preferred temperature

- Psychrophiles: grow best < 20 ^oC
- Mesophiles: 25-40 ^oC

- Thermophiles: 45-60 °C
- Stenothermophiles: > 60 °C
- Facultative thermophiles: Meso + Thermo

1.3 Biological Decomposition of Waste

- Aerobic decomposition
- Anoxic decomposition
- Anaerobic decomposition

See Table 5.1 (P.345)

1.4 Population Dynamics

Bacterial growth requirements

- A terminal electron acceptor
- Macronutrients (C, N, P)
- Micronutrients (Trace metals, Vitamins ?)
- Appropriate environment (Moisture, Temperature, pH)

Growth in Pure Culture (see Fig., 5.3., p.347)

- Lag phase
- Accelerated growth phase
- Log growth phase (exponential growth phase)
- Stationary phase
- Death phase

Growth in Mixed Culture (see Fig., 5.4, p.349)

- Competition for food
- Predator-Prey relationship

Monod Equation

- For the large numbers and mixed cultures of microorganisms in wastewater treatment systems, it is convenient to measure biomass rather than the numbers of organisms

- In the log-growth phase, the rate expression for biomass increase is,

$$\frac{dX}{dt} = \mu \cdot X$$

where X = concentration of biomass, [M/L^3];
dX/dt = growth rate of the biomass, [M/L^3,T]; and
μ = growth rate constant, [1/T].

- Due to the difficulty of direct measurement of μ in mixed culture, Monod develop a method. (assumption: the rate of food utilization, e.g., the rate of biomass production, is limited by the rate of enzyme reactions and eventually not increase infinitely, but reach maximum value)

$$\mu = \frac{\mu_m \cdot S}{K_s + S}$$

where μ_m = maximum growth rate constant, [1/T];
S = concentration of limiting food in solution, [M/L^3]; and
K_s = half saturation constant, [M/L^3].

- Typical type of Monod model (see Fig., 5.6, p.351)
If $\mu = \mu_m/2$, then $S = K_s$.

When S >> Ks, $\mu = \mu_m$ and $\frac{dX}{dt} = \mu_m \cdot X$ (1st order reaction)

When S << Ks, $\mu = \frac{\mu_m \cdot S}{K_s}$. This condition is food-limited, thus, S and X can be considered to be constant, then, $\frac{dX}{dt} = \frac{\mu_m \cdot S}{K_s} \cdot X = \mu'$ (zero order reaction)

- If the decay of microbial mass is a 1sr order reaction then,

$$\frac{dX}{dt} = \frac{\mu_m \cdot S \cdot X}{K_s + S} - k_d \cdot X$$

- If all of the food in the system were changed to biomass, the rate of food utilization (dS/dt) = the rate of biomass production (dX/dt). However,

$$-\frac{dS}{dt} = \frac{1}{Y}\cdot\frac{dX}{dt}$$

where Y = yield coefficient, [biomass/food utilized].

$$-\frac{dS}{dt} = \frac{1}{Y}\cdot\frac{\mu_m \cdot S \cdot X}{K_s + S}$$

2. Characteristics of Domestic Wastewater

Physical Characteristics of Domestic Wastewater

- Odor
- Color
- Temperature : higher than that of the water supply
- Turbidity

Chemical Characteristics of Domestic Wastewater

- BOD_5
- COD
- TKN: Total Kjeldahl Nitrogen = organic + ammonia
- TP: Total Phosphorus = ortho + poly + organic

3. Municipal Wastewater Treatment Systems

Categories (see Fig. 5.10, p.362)

- Primary treatment:
  to protect WWTP equipment
  may not be included
  Settle or Float
  60% of SS and 35% of BOD_5

- Secondary treatment
  Biological process – to speed up the natural process
  Soluble BOD_5 and SS
  more than 85% of BOD_5 and SS
  not enough for N, P, heavy metals, pathogens.
- Advanced treatment
  Chemical treatments: precipitation, disinfection
  Physical treatments: filtration
  Biological treatments: wetland treatment, soil-crop treatment

4. Unit Operations of Pretreatment

Bar Racks

- to remove large objectives (e.g., logs, rags) that would damage pumps, valves, etc.
- Fig. 5.11, p.365
- Mechanical cleaned racks: 5-40mm, 0.6-1.2m/sec, min. velocity 0.3-0.6m/s to prevent grit accumulation, 2 channels should be

Grit Chambers (침사지)

- Grit: inert dense materials (e.g., sand, broken glass, silt, and pebbles, etc.) that can damage mechanical devices and settle and clog
- Velocity controlled (horizontal-flow grit chamber) : sedimentation
- Overflow rate (v_o) be set at 0.33 – 0.70 times of v_s.
- Example 5.2 (p.366)

Communitors

- to macerate rags, papers, plastics, etc. by revolving cutting bars
- Fig. 5.13, p.368.

Equalization (유량 조정조)

5. Primary Treatment

- Sedimentation tank (see Fig. 5.14, p.373)
- Settled solids are "raw sludge"
- Floating materials (e.g., grease, oil, etc.) are collected by "skimming system".
- The Stokes equation cannot be used because the flocculating particles are continually changing in size, shape, and specific gravity (thus, Type II, Ch. 3)
- Example 5.4 (p.374)

6. Unit Processes of Secondary Treatment

Overview

- to remove (1) the soluble BOD and (2) suspended solids

The conventional aerobic secondary biological treatment

- the availability of many microorganisms
- good contact between these microorganisms and the organic materials
- the availability of oxygen
- the maintenance of other favorable environmental conditions

- Trickling filter
- Activated sludge
- Oxidation ponds(or lagoons)
- Rotating Biological Contactor (RBC)

<u>Trickling Filter (Fig. 5.15, p.375)</u>

- A rock filter (25-100mm in media diameter, diameter up to 60m, less than 3m deep)
- Secondary clarifier (or final clarifier)
- Under high organic loading, clogging and anaerobic zone problem
- Synthetic media to increase surface area, void ratio, height of the filter (upto 12m)
- m^3/day,m^2; m/day; kg/day,m^3
- Recirculation (to increase contact efficiency, to dampen loading variations, to increase DO, to improve flow distribution, to prevent biological slimes from drying out) : may or may not improve treatment efficiency.
- Two-stage tricking filter (Fig. 5.17, p.378): same medium or different media

<u>Activated Sludge (Fig. 5.18, 19, p.382, 383)</u>

- Activated sludge : individual organisms clump together (flocculation) to form an active mass of microbes (biological floc)

- Mixed liquor : the mixture of activated sludge and wastewater in the aeration tank
- Return sludge(반송슬러지): to maintain the high population of microbes
- Aeration : surface agitation or bottom diffusion (about $8m^3$-air/m^3-wastewater)
- Waste activated sludge(잉여슬러지): a portion of the microorganisms discarded from the process
- Mean cell residence time (or solids residence time, SRT, sludge age) : the average amount of time that microorganisms are kept in the system
- Process modifications (see, Table 5.10, p. 385)

Model for Completely Mixed Activated Sludge Process (Fig. 5.21, p.387)

- Under steady-state conditions, the mass balance for biomass

Biomass in influent + Biomass accumulated
= Biomass in effluent + Biomass wasted

$$Q \cdot X_o + V \cdot \left(\frac{\mu_m \cdot S \cdot X}{K_s + S} - k_d \cdot X \right) = \left(Q - Q_w \right) \cdot X_e + Q_w \cdot X_r$$

where Q = wastewater flow rate into the aeration tank, $[L^3/T]$;
X_0 = microorganism concentration entering aeration tank, $[M/L^3]$;
V = volume of aeration tank, $[L^3]$;
μ_m = maximum growth rate constant, [1/T];
S = soluble BOD_5 in aeration tank and effluent, $[M/L^3]$;
X = microorganism concentration in the aeration tank, $[M/L^3]$;
K_s = half velocity constant, $[M/L^3]$;
k_d = decay rate of microorganisms, [1/T];
Q_w = flow rate of liquid containing microorganisms to be wasted, $[L^3/T]$;
X_e = microorganism concentration in effluent from secondary settling tank, $[M/L^3]$; and

X_r = microorganism concentration in sludge being wasted, [M/L^3].

If X_o and X_e are negligible;

$$V \cdot \left(\frac{\mu_m \cdot S \cdot X}{K_s + S} - k_d \cdot X \right) = Q_w \cdot X_r$$

$$\frac{\mu_m \cdot S}{K_s + S} = \frac{Q_w \cdot X_r}{V \cdot X} + k_d$$

and

Hydraulic retention time (θ),

$$\theta = \frac{V}{Q}$$

Mean cell residence time (θ_c)

$$\theta_c = \frac{V \cdot X}{Q_w \cdot X_r}$$ (if X_e is not negligible?)

and

$$S = \frac{K_s \cdot (1 + k_d \cdot \theta_c)}{\theta_c (\mu_m - k_d) - 1}$$ (S is independent of S_o and θ)

- Under steady-state conditions, the mass balance for food (soluble BOD_5)

Food in influent + Food consumed

= Food in effluent + Food in wasted sludge

$$Q \cdot S_o - V \cdot \frac{\mu_m \cdot S \cdot X}{Y \cdot (K_s + S)} = (Q - Q_w) \cdot S + Q_w \cdot S$$

$$Q \cdot S_o - V \cdot \frac{\mu_m \cdot S \cdot X}{Y \cdot (K_s + S)} = Q \cdot S$$

where Y = yield coefficient

$$\frac{\mu_m \cdot S}{K_s + S} = \frac{Q \cdot Y}{V \cdot X} \cdot (S_0 - S)$$

then,

$$\frac{Q_w \cdot X_r}{V \cdot X} = \frac{Q \cdot Y}{V \cdot X} \cdot (S_0 - S) - k_d$$

and

$$X = \frac{\theta_c \cdot Y \cdot (S_o - S)}{\theta \cdot (1 + k_d \cdot \theta_c)}$$

SVI (Sludge Volume Index, Fig., 5.22, p.395)

$$SVI = \frac{SV}{MLSS} \times 1{,}000 \ mg/g$$

where SVI = sludge volume index, mL/g;

SV = volume of settled solids in one-liter cylinder after 30min settling, mL/L; and

MLSS = mixed liquor suspended solids, mg/L.

7. Disinfection

- Chlorine gas (or other form of chlorine) is the most commonly used in U.S.
- Disadvantages (?)
  (1) carcinogenic byproducts
  (2) more effective in killing the predators
  (3) chlorine is toxic to fish

8. Advanced Wastewater Treatment

Filtration

Carbon Adsorption

Phosphorus Removal

- Precipitation

  Using ferric chloride

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

  Using alum

  $$Al_s(SO_4)_3 + 2 \cdot HPO_4^{2-} \rightarrow 2 \cdot AlPO_4 \downarrow + 2 \cdot H^+ + 3 \cdot SO_4^{2-}$$

  Using lime

  $$5 \cdot Ca(OH)_2 + 3 \cdot HPO_4^{2-} \rightarrow Ca(PO_4)_3 OH \downarrow + 3 \cdot H_2O + 6 \cdot OH^-$$

- Biological treatment

Nitrogen Removal

- Nitrification

  $$NH_4^+ + 2 \cdot O_2 \rightarrow NO_3^- + H_2O + 2 \cdot H^+$$

- Denitrification

  $$NO_3^- + organic\ matter \rightarrow N_2 \uparrow + CO_2 + H_2O$$

- Ammonia stripping

  $$NH_4^+ + OH^- \rightarrow NH_3 \uparrow (with\ aeration) + H_2O$$

Struvite Recovery

Struvite ($NH_4MgPO_4 \cdot 6H_2O$)

9. Sludge Treatment and Disposal

- Purifying wastewater creates another problem, e.g., sludge.
- The higher the degree of wastewater treatment, the larger the residue of sludge.
- Sludge treatment and disposal is most complex and costly operation in a municipal wastewater treatment system.
- Sludge contains water as much as 97%.

Sludge Treatment

- Thickening(농축): by gravity or flotation (see Figs. 5.34, 35, p.429)
- Stabilization(안정화): digestion, to convert the organic solids to inert forms (see Figs. 5.39, 40, p.436, 437)
- Conditioning: to separate water easily, by chemicals or heat
- Dewatering(탈수): vacuum, pressure, or drying
- Reduction: incineration or wet oxidation

Sludge Disposal

- Landfill
- Land Spreading: recovery nutrients or reclaiming despoiled land such as strip mine spoils
- Composting
- Incineration