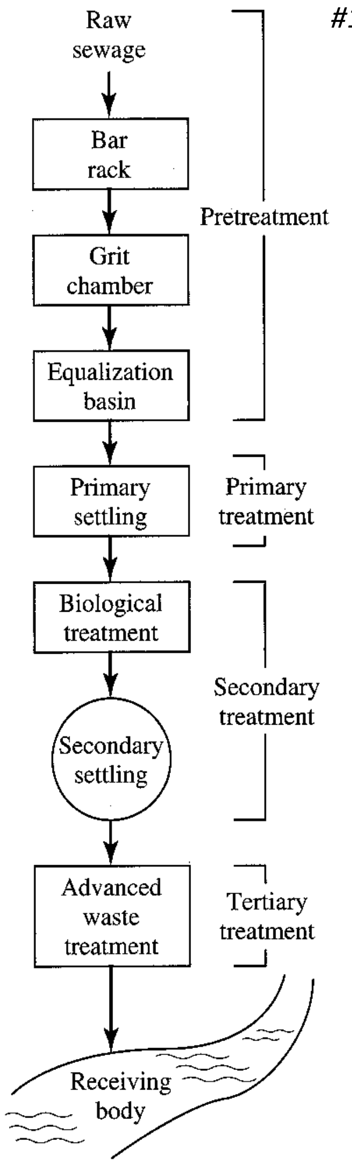
Wastewater treatment overview
Reactions & reactors

Wastewater treatment overview

Overview of wastewater treatment



#1

- **Preliminary**: Removal of wastewater constituents such as rags, sticks, floatables, grit, and grease that may cause maintenance or operational problems with the subsequent processes
- **Primary**: Removal of a portion of the suspended solids and organic matter from the wastewater by gravity
- **Secondary**: Removal of biodegradable organic matter and suspended solids by biological treatment. The conventional secondary treatment process may be modified to enhance nutrient removal (biological nutrient removal, BNR)
- **Tertiary** (≈advanced): Polishing secondary effluent by i) enhanced removal of suspended solids, ii) nutrient removal, iii) removal of dissolved species, iv) removal of refractory organics, etc. Disinfection is also often classified as tertiary treatment.

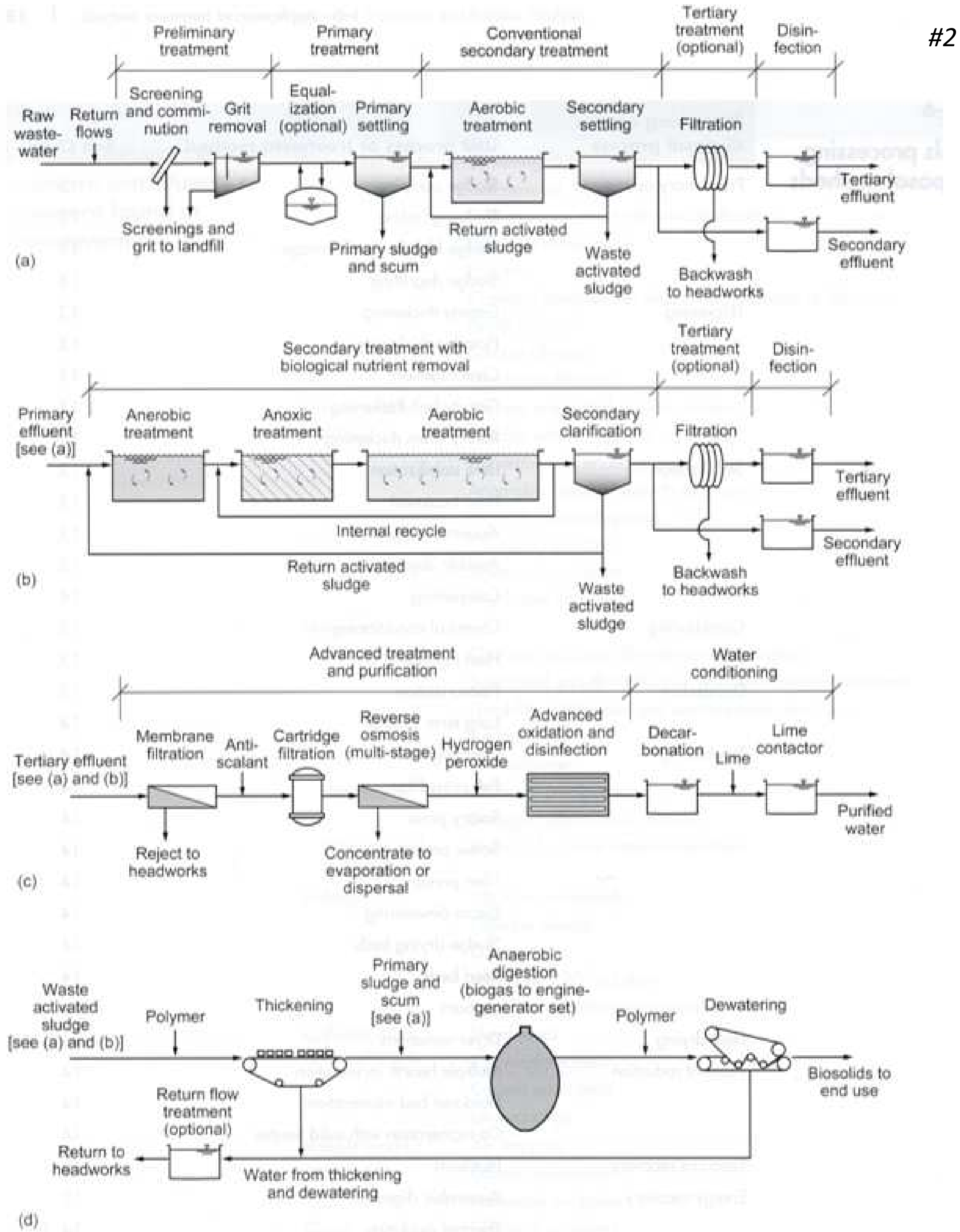
Typical flow diagrams

(a) Conventional secondary treatment

(b) Applying biological nutrient removal

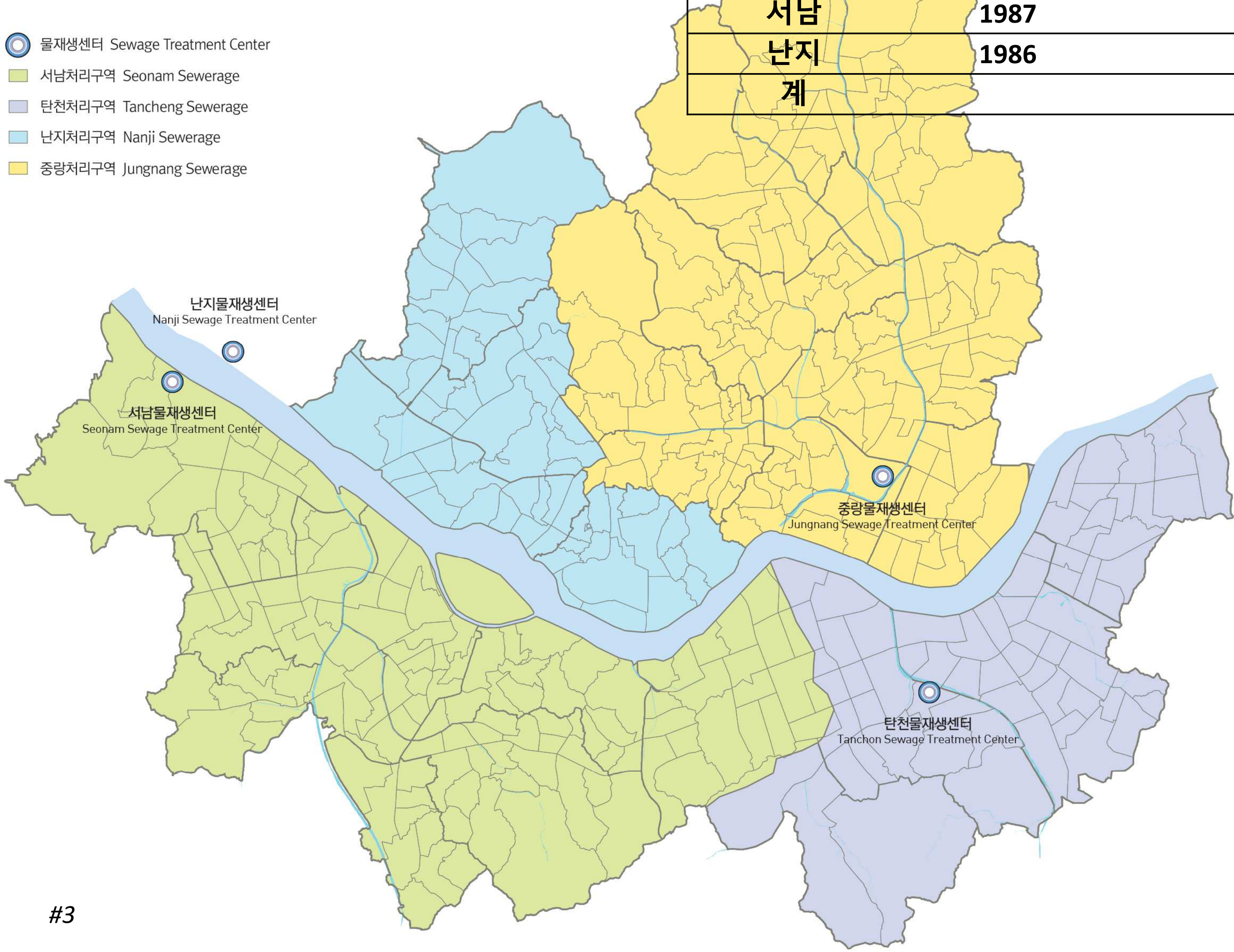
(c) Advanced treatment following secondary treatment (e.g., for water reuse)

(d) Anaerobic treatment of primary and secondary sludge



물재생센터명	최초 설치년도	시설용량(백만 m³/일)
중랑	1976	1.71
탄천	1987	1.10
서남	1987	2.00
난지	1986	1.00
계		5.81

그림 10-7. 물재생센터별 처리구역 2012
Figure 10-7. Area of Sewage Treatment Center Service, 2012

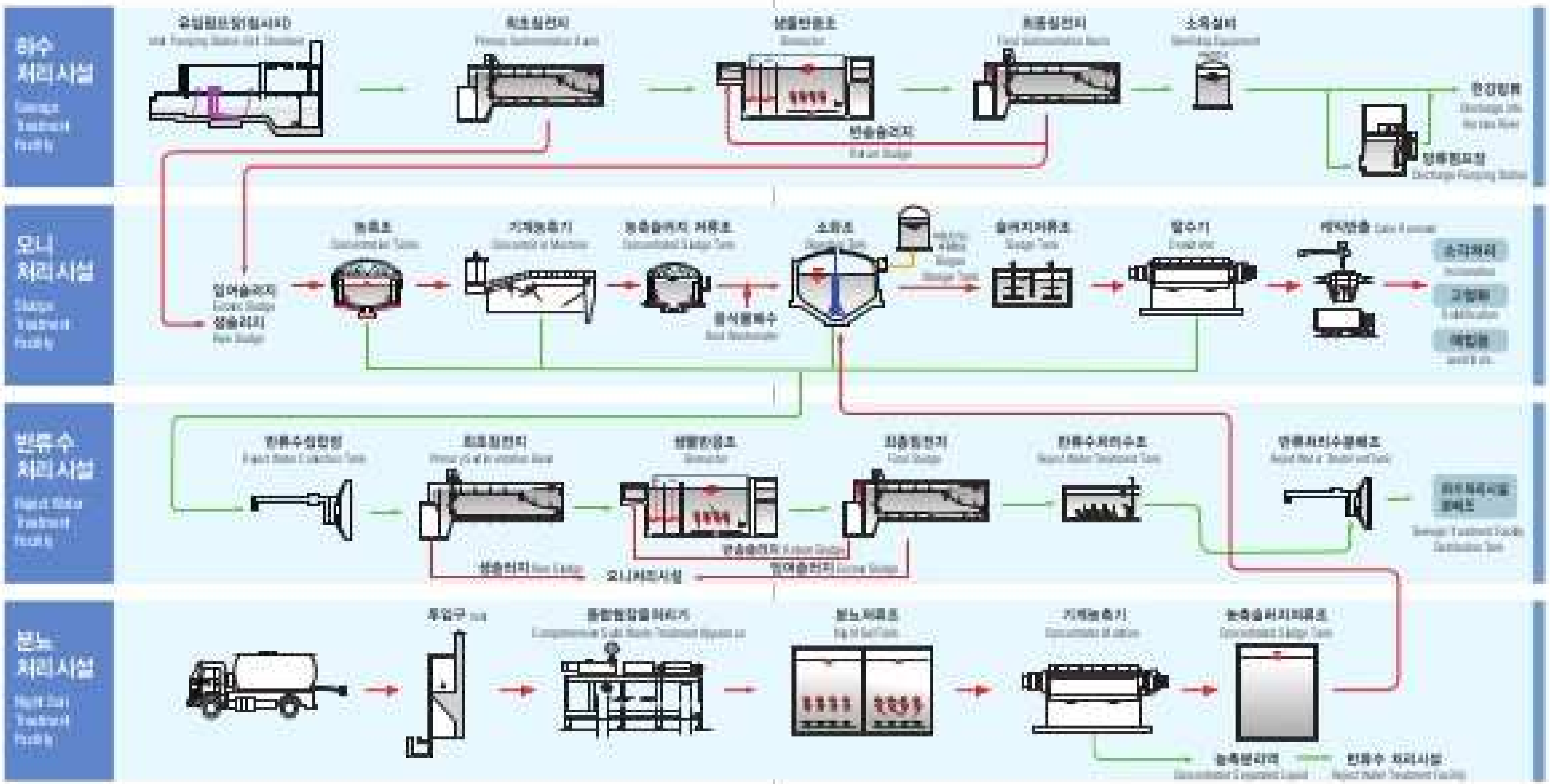


#3

난지물재생센터 공정별 처리계통도

Water recycling process diagram of the Nanji Sewage Treatment Center

#4



탄천물재생센터

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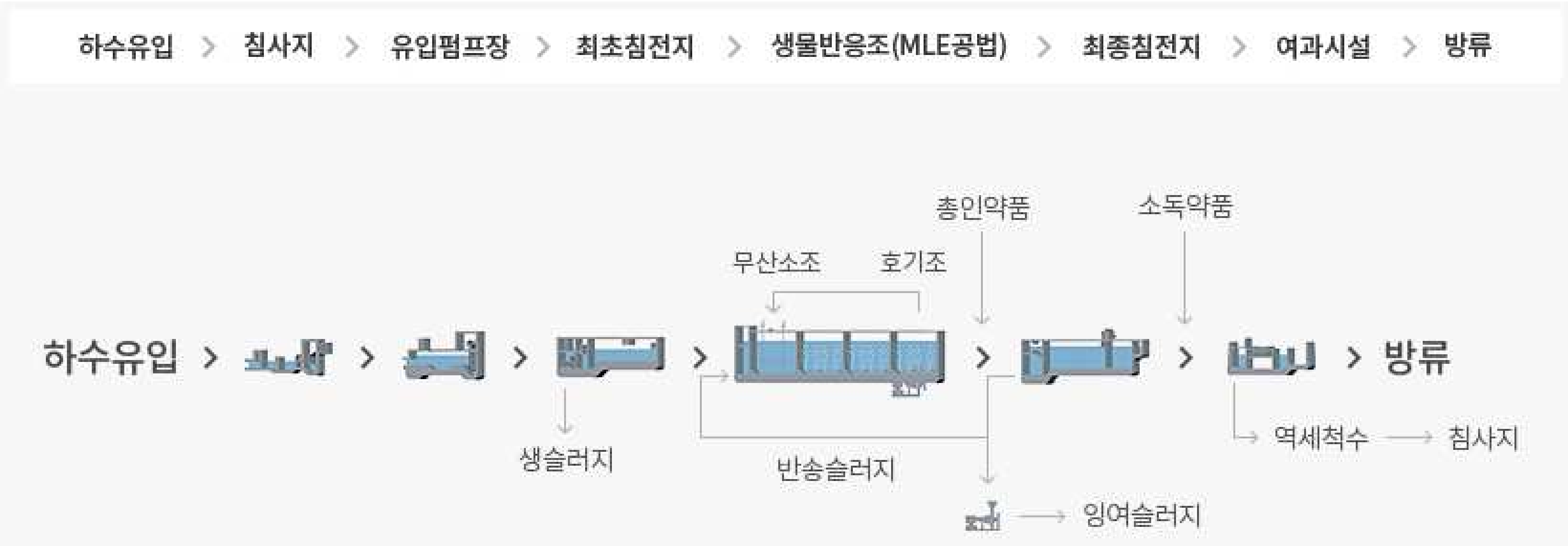


서남물재생센터

#6

Overview of wastewater treatment

- **Wastewater treatment system is a combination of different unit processes**
  - Unit processes for **wastewater** and **residual** treatment

- **Each unit process has different functions, different target constituents, and different mechanisms**
  - Physical, chemical, and biological unit processes

Unit processes - wastewater

[Unit processes to remove constituents of concern from wastewater]

Target constituent	Unit process
Suspended solids	Screening; Grit removal; Sedimentation; High-rate clarification; Flotation; Chemical precipitation with settling, flotation, or filtration; Depth filtration; Surface filtration; Membrane filtration
Biodegradable organics	Aerobic suspended growth processes; Aerobic attached growth processes; Anaerobic suspended growth processes; Anaerobic attached growth processes; Physical-chemical systems; Chemical oxidation; Advanced oxidation; Membrane filtration
Nitrogen	Chemical oxidation (breakpoint chlorination); Suspended-growth nitrification and denitrification processes; Fixed film nitrification and denitrification processes; Air stripping; ion exchange
Phosphorus	Chemical precipitation; Biological P removal
Nitrogen and phosphorus	Biological nutrient removal processes

Unit processes - wastewater

[Unit processes to remove constituents of concern from wastewater (cont'd)]

Target constituent	Unit process
Pathogens	Chemical disinfection (chlorine, chlorine dioxide, ozone, etc.); UV radiation; Heat treatment (pasteurization)
Colloidal and dissolved solids	Membrane filtration; Chemical treatment; Carbon adsorption; Ion exchange
Volatile organic compounds	Air stripping; Carbon adsorption; Advanced oxidation
Odors	Chemical scrubbers; Carbon adsorption; Bio-trickling filters; Compost filters

Unit processes - residuals

[Residuals processing and disposal methods]

Processing or disposal process	Unit process or treatment method
Preliminary operations	Sludge pumping; Sludge grinding; Sludge blending and storage; Sludge degritting
Thickening	Gravity thickening; Flotation thickening; Centrifugation; Gravity belt thickening; Rotary drum thickening
Stabilization	Lime stabilization; Heat treatment; Anaerobic digestion; Aerobic digestion; Composting
Conditioning	Chemical conditioning; Heat treatment
Disinfection	Pasteurization; Long term storage

Unit processes - residuals

[Residuals processing and disposal methods (cont'd)]

Processing or disposal process	Unit process or treatment method
Dewatering	Centrifuge; Belt press filter; Rotary press; Screw press; Filter press; Electro-dewatering; Sludge drying beds; Reed beds; Lagoons
Heat drying	Dryer variations
Thermal reduction	Multiple hearth incineration; Fluidized bed incineration; Co-incineration with solid wastes
Resource recovery	Nutrient recovery processes
Energy recovery	Anaerobic digestion; Thermal oxidation; Production of oil and liquid fuels
Ultimate disposal	Land application; Landfill; Lagooning

Reactions & reactors

Types of reactions

- **Homogeneous reactions**
  - Reactants are distributed uniformly throughout the fluid
  - Reaction rates are the same at any point within the fluid
  - ex: reaction between water-dissolved constituents
  - Reaction rates are usually a function of constituent concentration

- **Heterogeneous reactions**
  - Occur between one or more constituents that can be identified with specific sites
  - ex: reactions occurring at a solid surface, reactions that requires a solid-phase catalyst
  - Reaction rates are usually a function of surface area of a solid phase

Reaction rates

- **Reaction rate, *r***

$$r = \pm \frac{dC}{dt}\bigg|_{reaction}$$

- **Types of rate expressions**

$r = \pm k$	(zero-order)
$r = \pm kC$	(first-order)
$r = \pm k(C - C_s)$	(first-order)
$r = \pm kC^2$	(second-order)
$r = \pm kC_A C_B$	(second-order)
$r = \pm \frac{kC}{K + C}$	(saturation or mixed-order)
$r = \pm \frac{kC}{(1 + r_t t)^n}$	(first-order retarded)

Examples of common rate expressions

Process	Rate expression	Comments
Bacterial conversion in natural systems	$r_c = -kC$	r_c = *rate of conversion, M/L^3/T* k = *first order reaction rate constant, 1/T* C = *concentration of organic material remaining, M/L^3*
Bacterial growth in bioreactors	$\mu = \frac{\hat{\mu}S}{K + S}$	μ = *specific growth rate, 1/T* $\hat{\mu}$ = *maximum specific growth rate, 1/T* S = *concentration of substrate, M/L^3*
Chemical reactions	$r_c = \pm k_n C^n$	r_c = *rate of conversion, M/L^3/T* k_n = *reaction rate constant, (M/L^3)$^{n-1}$/T* C = *concentration of constituent, M/L^3* n = *reaction order*
Natural decay	$r_d = -k_d N$	r_d = *rate of decay, #/T* k_d = *first order reaction rate constant, 1/T* N = *amount of organisms remaining, #*

Examples of common rate expressions

Process	Rate expression	Comments
Gas absorption	$r_{ab} = k_{ab}\frac{A}{V}(C_s - C)$	r_{ab} = *rate of absorption, M/L*^{3}*/T* k_{ab}= *coefficient of absorption, L/T* r_{de} = *rate of desorption, M/L*^{3}*/T* k_{de}= *coefficient of desorption, L/T* r_v = *rate of volatilization, M/L*^{3}*/T* k_v = *volatilization constant, 1/T* C_s = *saturation concentration of constituent in liquid, M/L*^{3} C = *concentration of constituent in liquid, M/L*^{3} A = *area, L*^{2} V = *volume, L*^{3}
Gas desorption	$r_{de} = -k_{de}\frac{A}{V}(C - C_s)$	
Volatilization	$r_v = -k_v(C - C_s)$	

Determination of rxn rate coefficients

- Conduct reaction kinetic studies in a batch reactor to measure concentration changes of the target constituent over time (more than 4-5 time points)

- If the reaction rate expression is known, plot the results according to the corresponding rate expression; if the reaction rate expression is unknown, plot the results for various rate expressions to find the most appropriate one

- Find the best-fit value of *k* from the plot

Linear plots to determine rate coefficients

Type of reaction	Integrated form	Linearized plot
zero-order $r = -k$	$C = C_0 - kt$	C vs. t
first-order $r = -kC$	$-ln(C/C_0) = kt$	$-\ln(C/C_0)$ vs. t
second-order $r = -kC^2$	$1/C = 1/C_0 + kt$	$1/C$ vs. t
saturation $\mathrm{r} = -kC/(K + C)$	$K \cdot ln(C_0/C) + (C_0 - C) = kt$	$(1/t)\ln(C_0/C)$ vs. $(C_0 - C)/t$

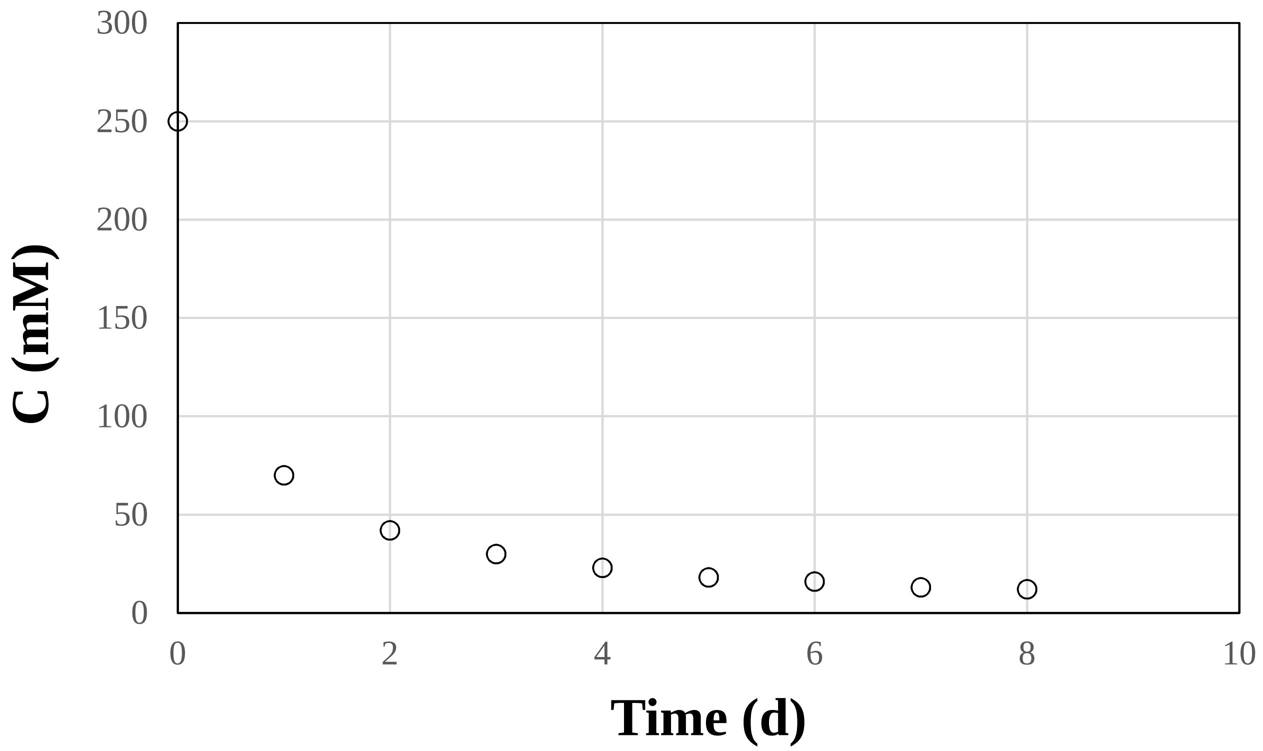
Determination of rxn. rate coefficients

Q: Following set of data was obtained using a batch reactor kinetic study. Determine the order of reaction that most appropriately describe the reaction kinetics. Determine the reaction rate coefficient.

Time, d	Concentration, mM
0	250
1	70
2	42
3	30
4	23
5	18
6	16
7	13
8	12

Determination of rxn. rate coefficients

C vs. t plot



Maybe 1st or 2nd order

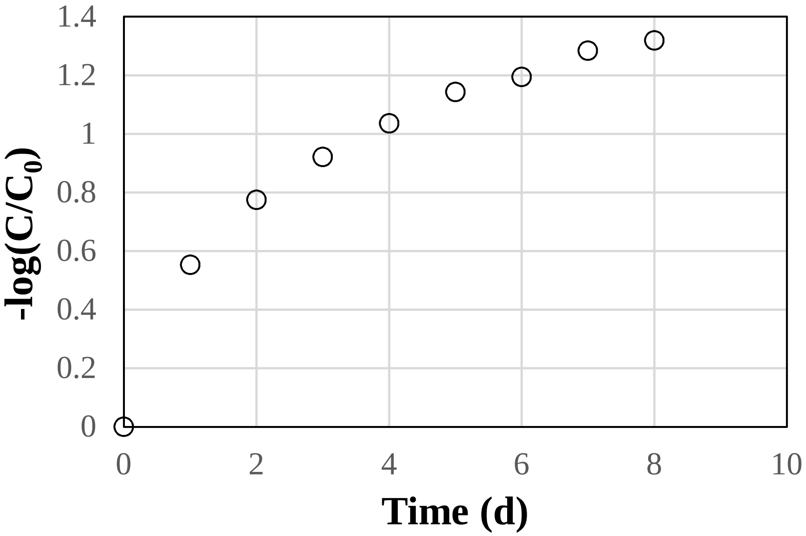
Determination of rxn. rate coefficients

Time, d	Concentration, mM	$-\ln(C/C_0)$	1/C
0	250	0	0.004
1	70	0.553	0.014
2	42	0.775	0.024
3	30	0.921	0.033
4	23	1.036	0.044
5	18	1.143	0.056
6	16	1.194	0.063
7	13	1.284	0.077
8	12	1.319	0.083

Determination of rxn. rate coefficients

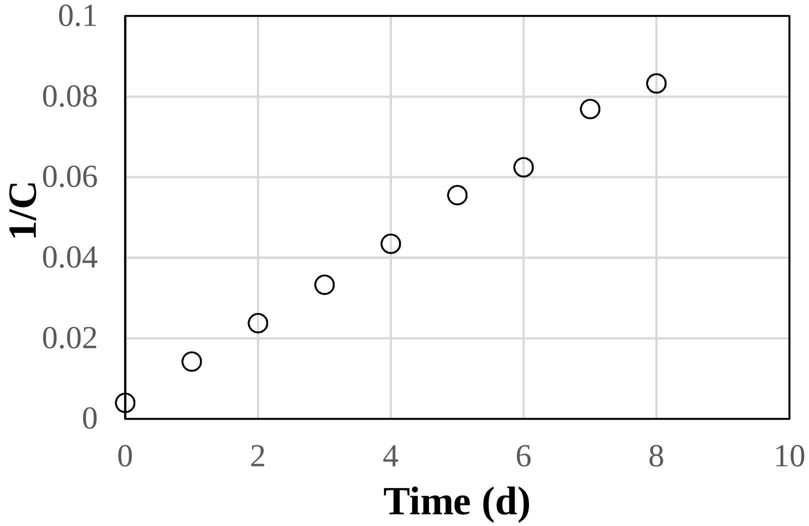
1st order:

$-\log(C/C_0)$ vs. t



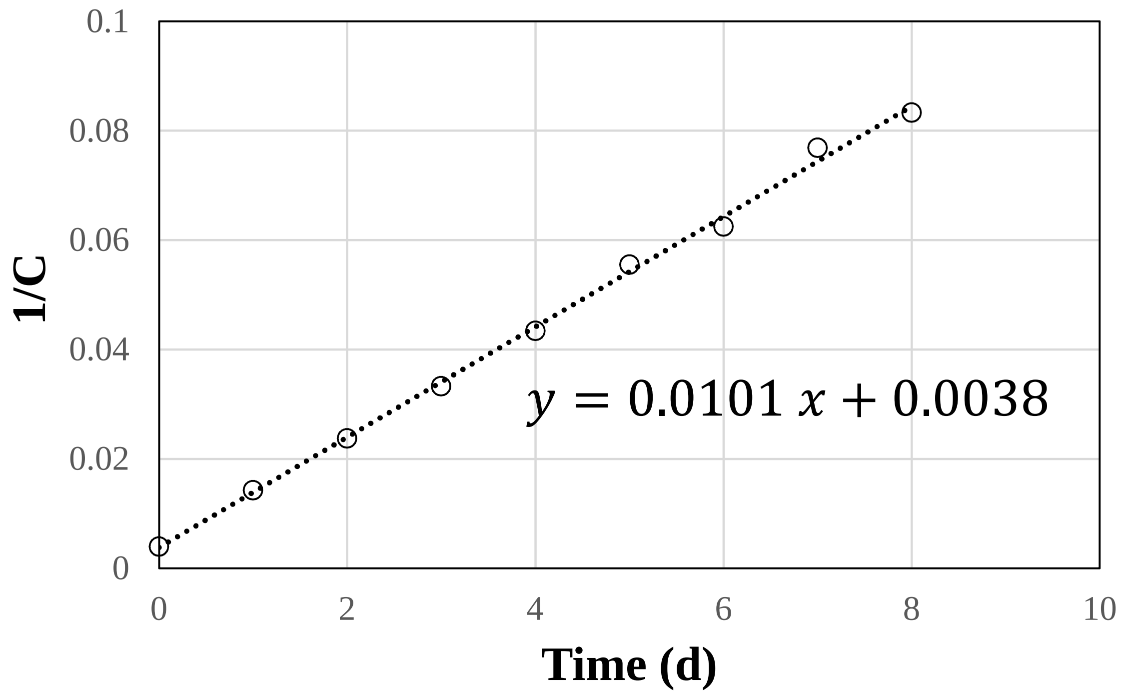
2nd order:

$1/C$ vs. t



⇨ 2nd order

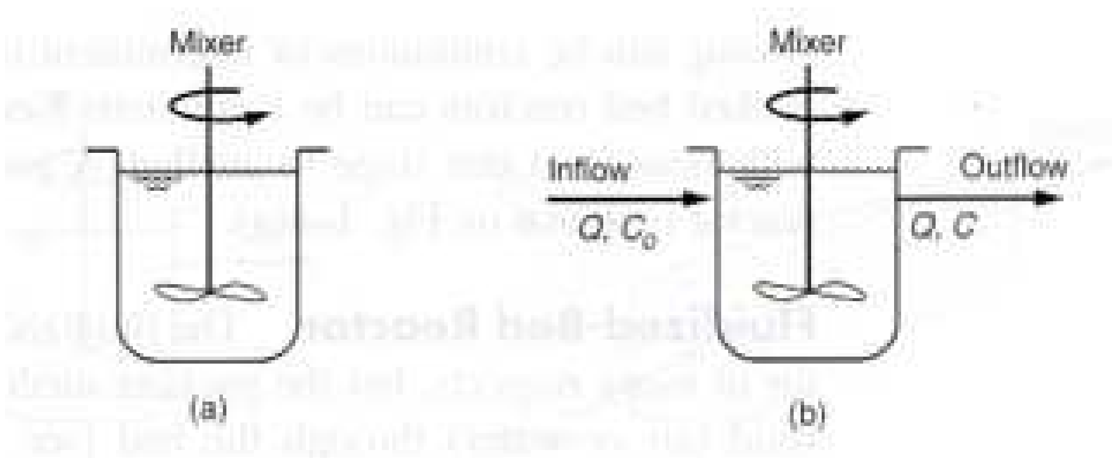
Determination of rxn. rate coefficients



$$k = 0.010\ L/mmole - d$$

Types of reactors

- **Batch reactor**
  - No flow entering/leaving the reactor
  - The liquid contents are mixed completely
- **Continuously stirred tank reactor (CSTR)**
  - Also known as completely-mixed flow reactor (CMFR)
  - Flow enters and leaves the reactor at a constant rate
  - The liquid contents are mixed completely



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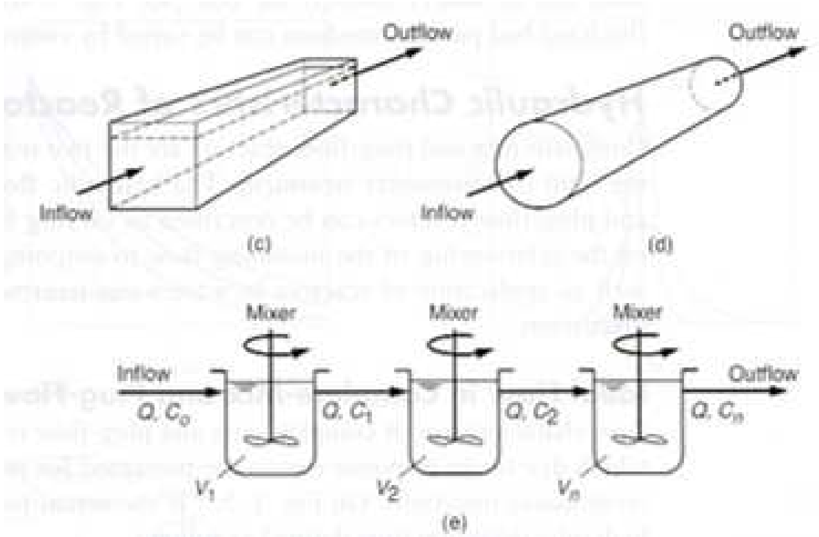
Types of reactors

- **Plug-flow reactor (PFR)**
  - Applies to reactors with high length-to-width ratio
  - Ideal PFR assumes no mixing in the direction of flow and complete mixing in the direction perpendicular to the flow
- **CSTRs in series**
  - Multiple CSTRs are connected in series
  - *n*=1: CSTR; *n*=∞: PFR (*n*=number of CSTRs)



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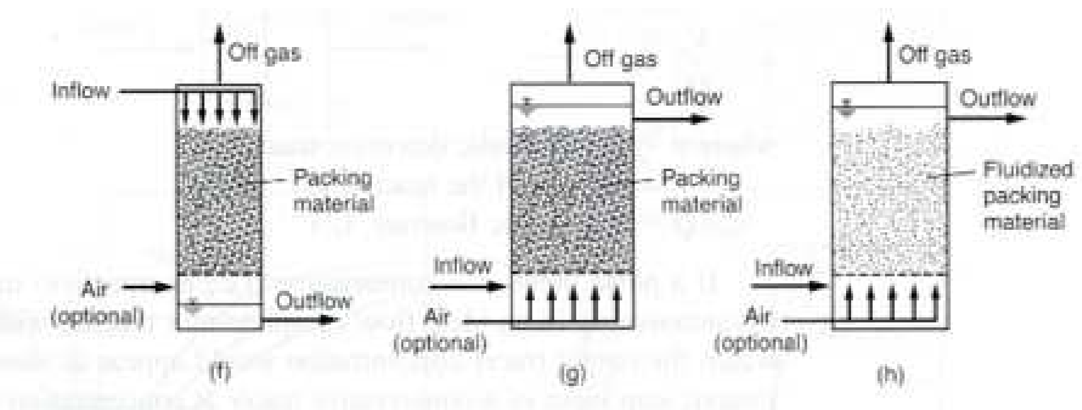
Types of reactors

- **Packed-bed reactors**
  - Filled with packing material (e.g., rock, slag, ceramic, plastics, etc.)
  - Operated in either the downflow or upflow mode
  - Continuous or intermittent dosing
- **Fluidized-bed reactors**
  - Similar to packed-bed reactors
  - Flow is applied in upflow mode, and the packing material is expanded by relatively high flow velocity



#7

References

#1) Davies, M. L., Masten, S. J. (2014) Principles of Environmental Engineering and Science, 3rd ed. McGraw-Hill (figure provided by the publisher).

#2) Metcalf & Eddy, Aecom (2014) Wastewater Engineering: Treatment and Resource Recovery, 5th ed. McGraw-Hill, p. 16.

#3) http://data.si.re.kr/node/96

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#2) Metcalf & Eddy, Aecom (2014) Wastewater Engineering: Treatment and Resource Recovery, 5th ed. McGraw-Hill, p. 23.