Slide#17 solution

$S = \frac{K_s(1+k_d\theta_c)}{\theta_c(\mu_m - k_d) - 1}$

$10.0\ mg/L = \frac{100\ mg/L \times \left(1+0.050\ day^{-1} \times \theta_c\right)}{\theta_c(2.5-0.050)\ day^{-1} - 1}$

$10.0\ mg/L \times 2.45\ day^{-1} \times \theta_c - 10\ mg/L = 100\ mg/L + 100\ mg/L \times 0.050\ day^{-1} \times \theta_c$

$19.5\ mg/L - day \times \theta_c = 110\ mg/L$

$\boldsymbol{\theta_c = 5.6\ days}$

Slide#18 solution

$$X = \frac{\theta_c Y(S_0 - S)}{t_0(1 + k_d\theta_c)}$$

$$t_0 = \frac{\theta_c Y(S_0 - S)}{X(1 + k_d\theta_c)} = \frac{5.6\ days \times 0.50 \times (84 - 10)\ mg/L}{2000\ mg/L \times (1 + 0.050\ day^{-1} \times 5.6\ days)} = 0.081\ day$$

$$t_0 = \frac{Q}{V},\ V = Qt_0 = 0.150\ m^3/s \times 86400\ s/day \times 0.081\ day = \mathbf{1050\ m^3}$$

Wastewater treatment II

Today's lecture

- Secondary wastewater treatment
  - Kinetics of microorganism growth
  - Activated sludge process: concept
  - Activated sludge process: applying reactor analysis!

- Wastewater as a resource

Kinetics of microorganism growth

- Monod equation

$$\mu = \frac{1}{X}\frac{dX}{dt}\bigg|_{growth} = \frac{\mu_m S}{K_s + S} = \mu_m\left(\frac{S}{K_s + S}\right)$$

"saturation type" kinetics

μ = specific growth rate (d^{-1})

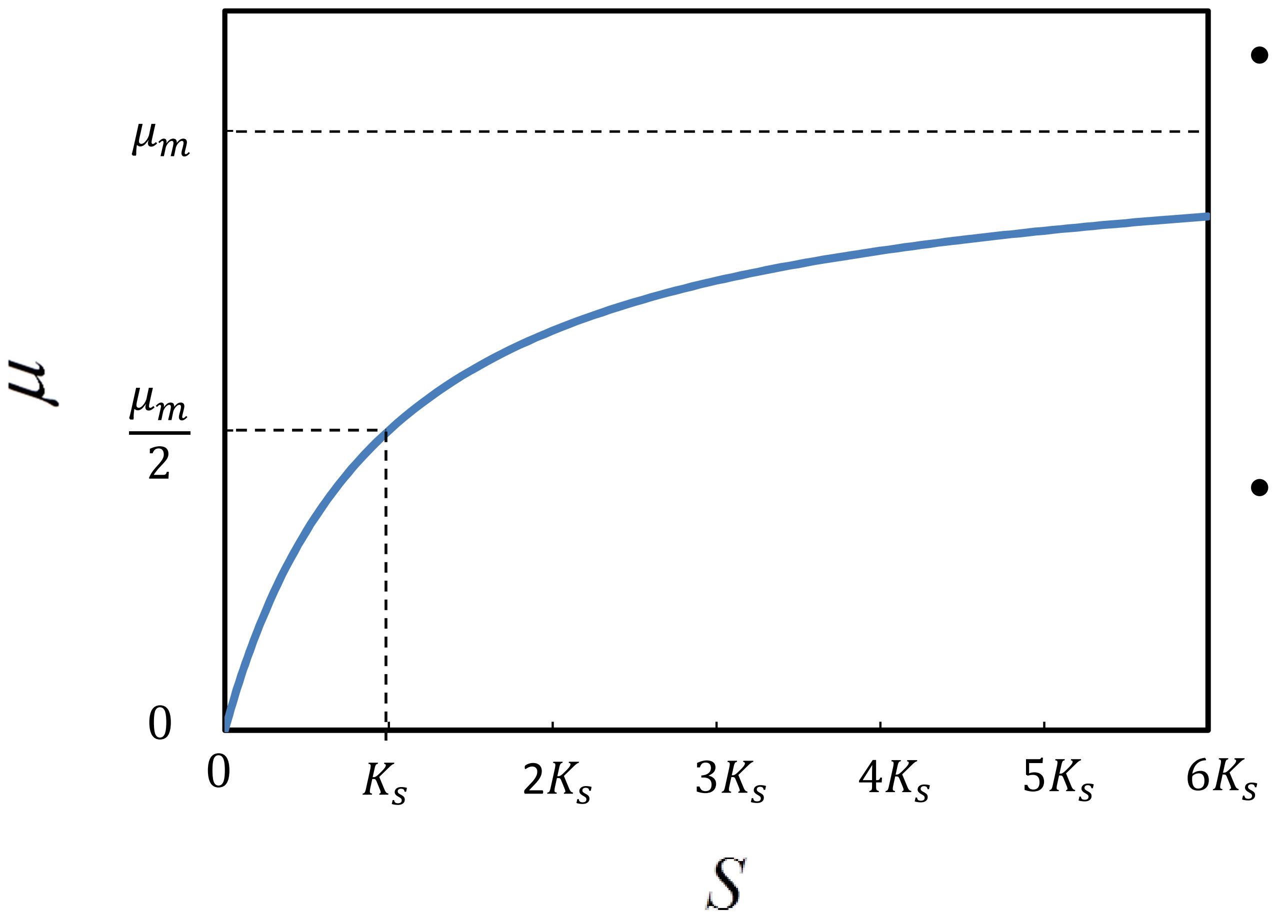
X = biomass concentration (mg/L)

μ_m = maximum specific growth rate (d^{-1})

S = food (substrate) concentration (mg/L)

K_s = half saturation constant (mg/L)

Kinetics of microorganism growth



- $S >> K_s$: $\mu = \mu_m$ (maximum growth rate); the growth rate is independent of S
- $S << K_s$: limited food supply; the growth rate is proportional to S

Net biomass growth rate

- Overall change in biomass concentration
  - Microorganisms not only grow, but also die or get eaten! (this is called as "decay")
  - So:

(net biomass growth rate)

= (rate of growth by substrate utilization) – (rate of decay)

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

growth *decay*

r_g = net biomass growth rate (mg/L/d)

k_d = decay rate constant (d^{-1})

Kinetics of substrate degradation

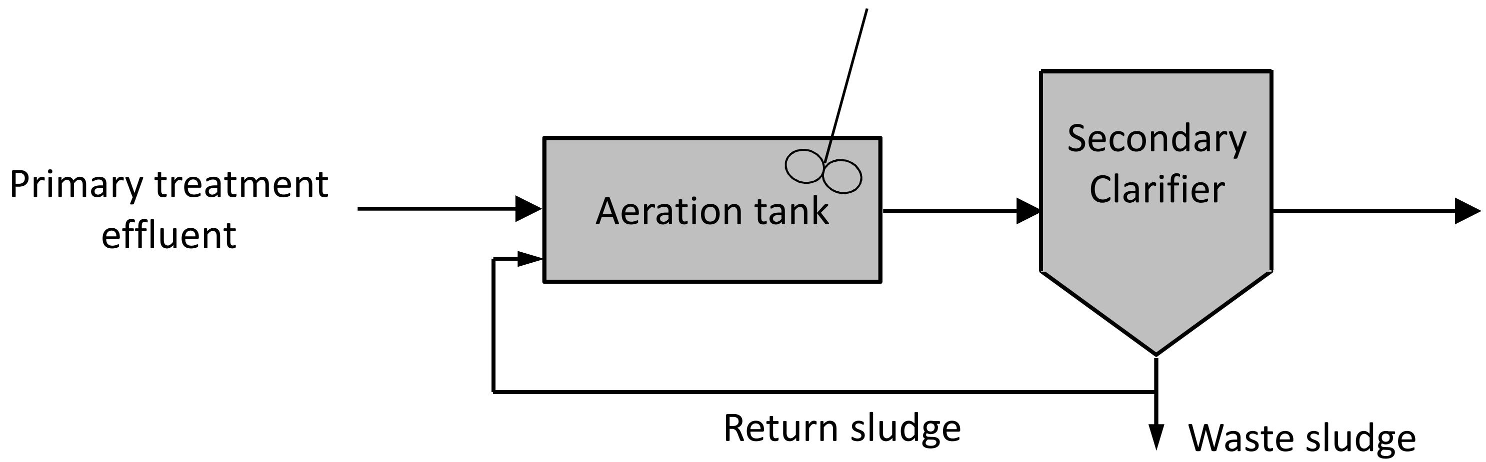
- Substrate utilization (=degradation) rate
  - Microorganisms utilize food (substrate) to grow
  - A fraction of the utilized substrate is converted to biomass (microorganisms are not 100% efficient!)

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

r_{su} = substrate utilization rate (mg/L/d)

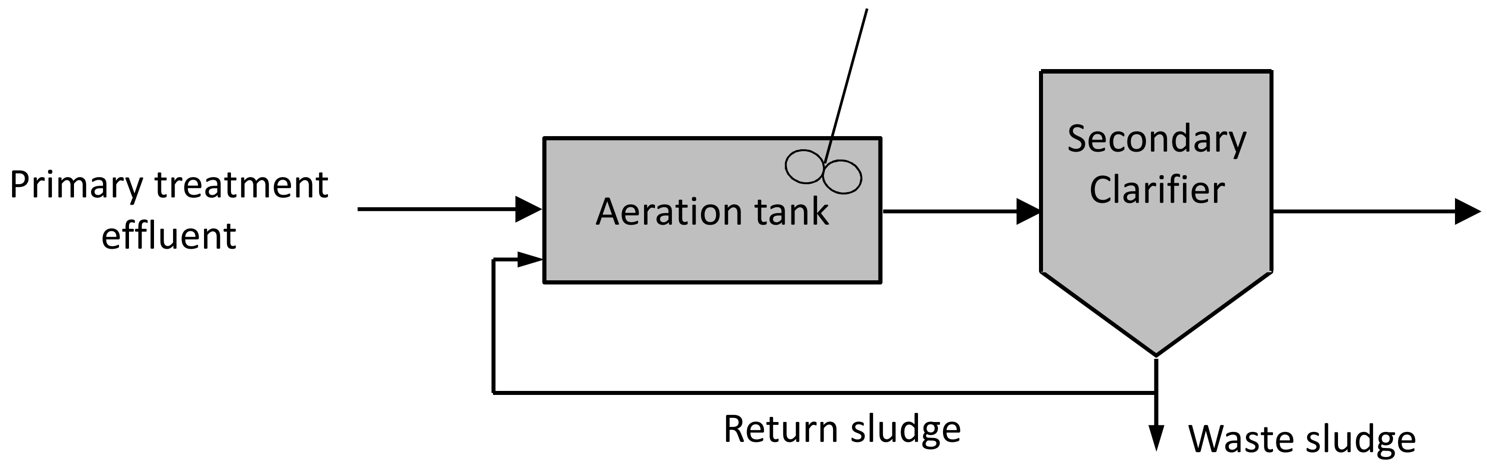
Y = yield coefficient (mg biomass/mg substrate)

Activated sludge process – concept



- 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 – concept



- 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!)

Solids retention time (SRT)

- Recall hydraulic retention time

  t_0 = the time that fluid elements stay in the system

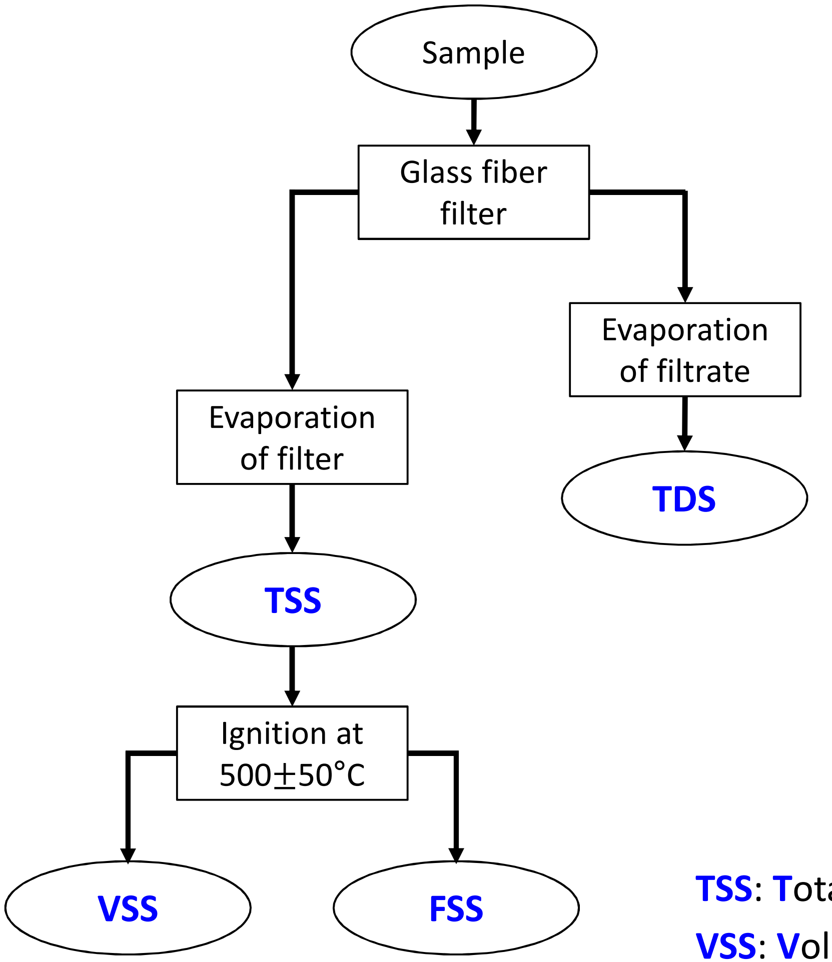
  $= V/Q$

- Solids retention time (or mean cell residence time)

  θ_c = the time that microorganisms stay in the system

- $t_0 \neq \theta_c$ if sludge is returned to the aeration tank (Why??)

Suspended solids in AS process



- **TSS**
  - A measure of the amount of all suspended solids
- **VSS**
  - For activated sludge process, a measure of the amount of microorganisms
  - Microorganisms are suspended solids which volatilize at 500°C

TSS: **T**otal **S**uspended **S**olids

VSS: **V**olatile **S**uspended **S**olids

FSS: **F**ixed **S**uspended **S**olids

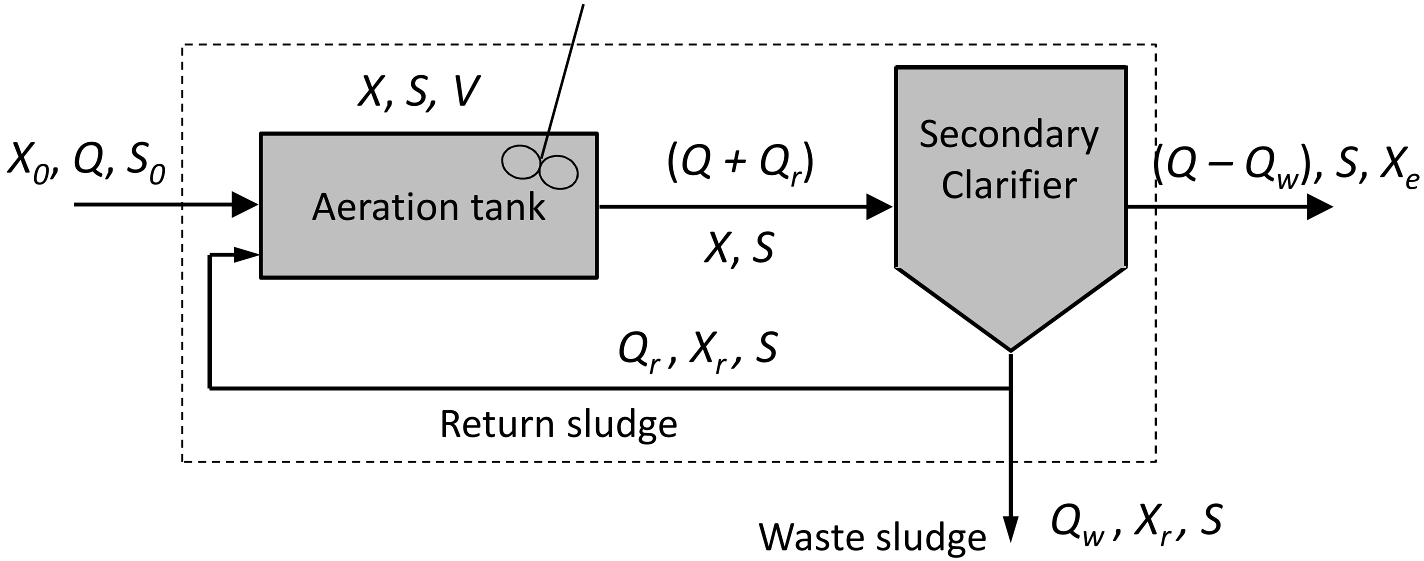
TDS: **T**otal **D**issolved **S**olids

Analyzing activated sludge process

- Let's analyze the activated sludge process using two basic knowledge:
  - Monod kinetics (the reaction)
  - The system configuration (mass balance)

- We have two substances to analyze:
  - BOD (=substrate=food): the performance of the activated sludge process to treat wastewater
  - Microorganisms (measured as VSS): those that consume BOD; also related to sludge production

Control volume and assumptions



X, X_e, X_r: microorganism concentrations in aeration tank, effluent, and return sludge (measured as VSS)

Assumptions:

i) Steady-state

ii) The aeration tank is a CMFR

iii) All reactions occur in the aeration tank

Mass balances

- Mass balance for substrate:

$$QS_0 - V\frac{\mu_m SX}{Y(K_s + S)} = (Q - Q_w)S + Q_w S \quad \textbf{(A)}$$

- Mass balance for microorganisms:

$$QX_0 + V\left(\frac{\mu_m SX}{K_s + S} - k_d X\right) = (Q - Q_w)X_e + Q_w X_r$$

Solving the mass balance equations

<u>Additional assumption</u>: The influent and effluent VSS is negligible

- Mass balance for microorganisms

$$QX_0 + V\left(\frac{\mu_m SX}{K_s + S} - k_d X\right) = (Q - Q_w)X_e + Q_w X_r$$

$$\Rightarrow \quad \frac{\mu_m S}{K_s + S} = \frac{Q_w X_r}{VX} + k_d \qquad \textbf{(B)}$$

Representation of SRT

When the effluent VSS is negligible, we find:

$$\theta_c = \frac{VSS\ in\ the\ aeration\ tank}{VSS\ mass\ flow\ out\ of\ the\ system} = \frac{VX}{Q_w X_r}$$

(B): $$\frac{\mu_m S}{K_s + S} = \frac{1}{\theta_c} + k_d$$

(A): $$\frac{\mu_m S}{K_s + S} = \frac{QY}{VX}(S_0 - S) \quad \Rightarrow \quad \frac{1}{\theta_c} + k_d = \frac{Y}{t_0 X}(S_0 - S)$$

Solutions

Effluent substrate concentration

$$S = \frac{K_s(1 + k_d\theta_c)}{\theta_c(\mu_m - k_d) - 1}$$

Aeration tank VSS concentration

$$X = \frac{\theta_c Y(S_0 - S)}{t_0(1 + k_d\theta_c)}$$

- SRT (θ_c) is a key design and operation parameter
- The effluent substrate concentration, *S*, is independent of the influent substrate concentration, S_0
- Higher S_0 → higher VSS in the aeration tank → more substrate biodegradation → same *S*

Analyzing activated sludge process

Q1: A completely mixed activated sludge process receives a primary effluent at a flowrate of 0.150 m^3/s with a BOD_5 of 84.0 mg/L. Calculate the solids retention time required to meet a secondary effluent standard of 10.0 mg/L BOD_5.

Following microbial growth parameters apply:

K_s = 100 mg/L BOD_5

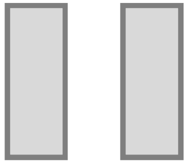
μ_m = 2.5 day^{-1}

k_d = 0.050 day^{-1}

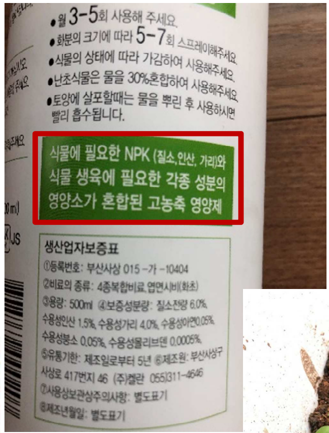
Y = 0.50 mg VSS/mg BOD_5

Analyzing activated sludge process

Q2: For the given activated sludge process, calculate the volume of the aeration tank to maintain VSS concentration of 2000 mg/L in the aeration tank.




YONHAP NEWS


●월 3-5회 사용해 주세요.
●화분의 크기에 따라 5-7회 스프레이해주세요.
●식물의 상태에 따라 가감하여 사용해주세요.
●난초식물은 물을 30%혼합하여 사용해주세요.
●토양에 살포할때는 물을 뿌린 후 사용하시면 빨리 흡수됩니다.
식물에 필요한 NPK (질소, 인산, 가리)와 식물 생육에 필요한 각종 성분의 영양소가 혼합된 고농축 영양제
생산업자보증표
①등록번호: 부산사상 015 -가 -10404
②비료의 종류: 4종복합비료, 엽면시비(화초)
③용량: 500ml ④보증성분량: 질소전량 6.0%, 수용성인산 1.5%, 수용성가리 4.0%, 수용성아연0.05%, 수용성붕소 0.05%, 수용성몰리브덴 0.0005%,
⑤유통기한: 제조일로부터 5년 ⑥제조원: 부산사상구 사상로 417번지 46 (주)켈란 055)311-4646
⑦사용상보관상주의사항: 별도표기
⑧제조년월일: 별도표기

Wastewater as a resource

- A new paradigm: wastewater is not a WASTE, but a valuable RESOURCE

- Wastewater

  = water + organic matter (energy) + nutrients (N/P) + α

Water reuse

- Non-potable reuse: cooling water, irrigation, recreational use, toilet water, etc.
- Potable reuse
  - Produce high-quality water from wastewater by (tertiary + α) treatment
  - Indirect potable reuse: discharge treated water to reservoir/aquifer that is used as drinking water source
  - Direct potable reuse: supply the treated water directly as drinking water

연합뉴스

창원시, 10개 공공시설 버리는 물 재활용...중수도 설치

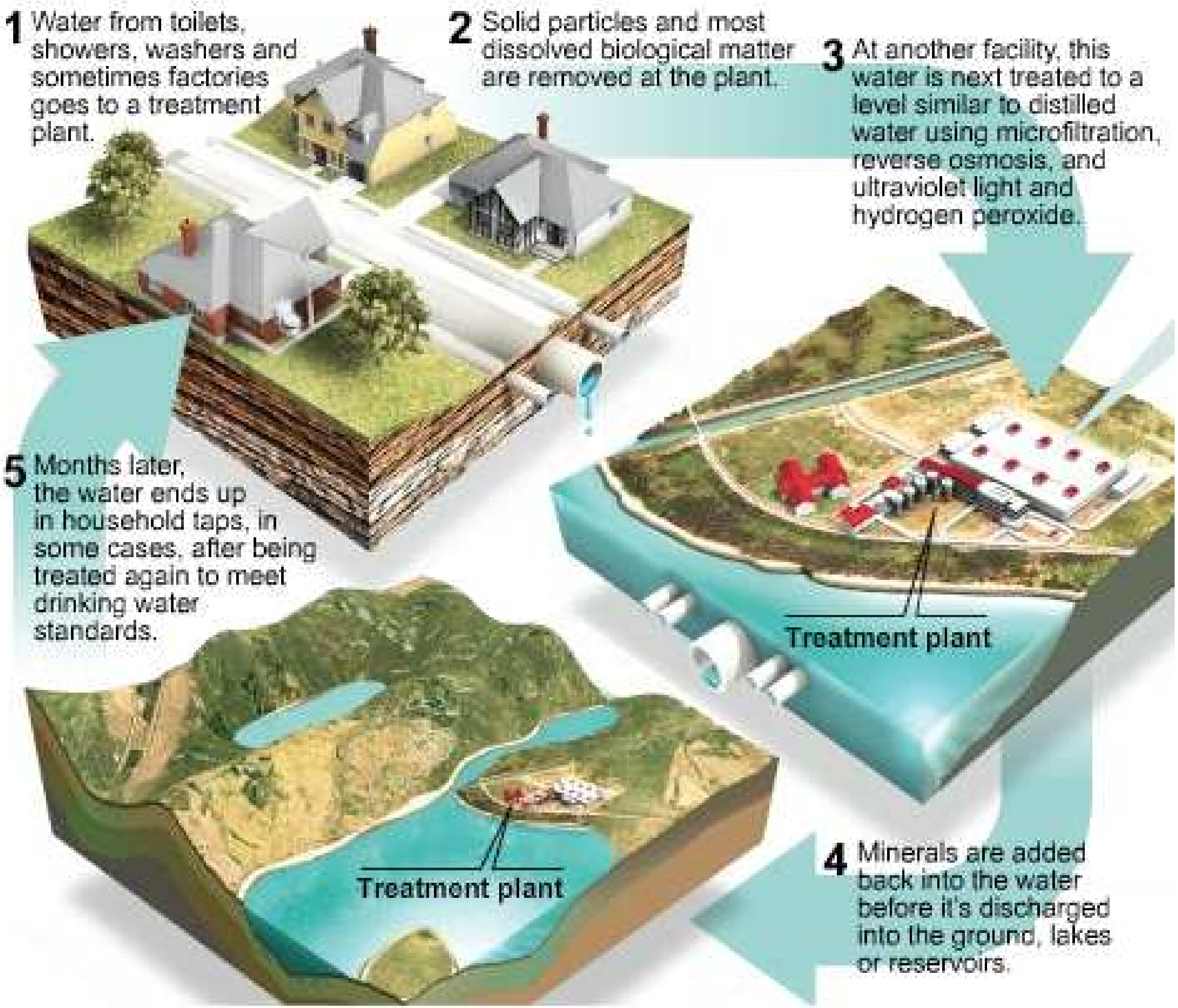
송고시간 | 2019-05-09 11:23

| 오수 모아 정화한 뒤 청소·화장실용 사용

창원시 중수도 시설 설치 공공기관
[창원시청 제공]

(창원=연합뉴스) 이정훈 기자 = 경남 창원시는 공공기관을 중심으로 한번 쓴 물을 재활용하는 물 순환시스템인 중수도를 구축한다고 9일 밝혔다.

올해부터 2023년까지 국비와 시비 200억원을 들여 창원스포츠파크, 마산회원구청, 마산종합운동장, 창원축구센터 등 10개 공공건물에 중수도 시설을 설치한다.

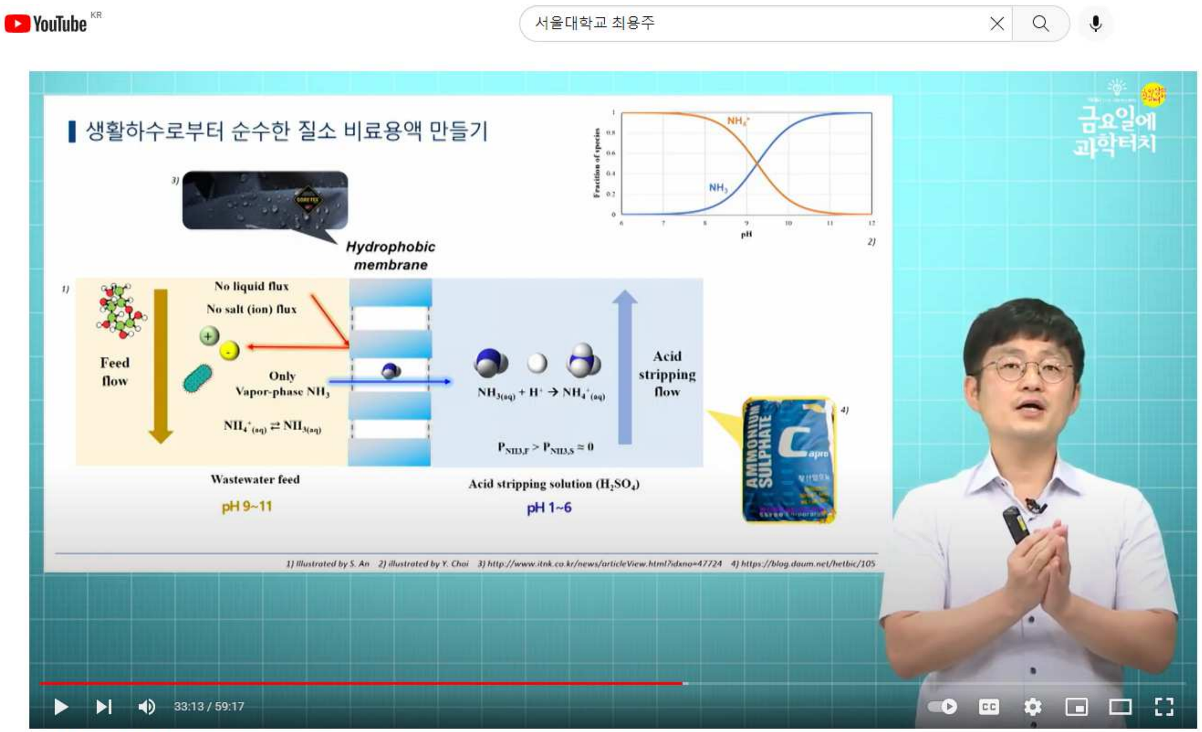

1 Water from toilets, showers, washers and sometimes factories goes to a treatment plant.
2 Solid particles and most dissolved biological matter are removed at the plant.
3 At another facility, this water is next treated to a level similar to distilled water using microfiltration, reverse osmosis, and ultraviolet light and hydrogen peroxide.
Treatment plant
4 Minerals are added back into the water before it's discharged into the ground, lakes or reservoirs.
Treatment plant
5 Months later, the water ends up in household taps, in some cases, after being treated again to meet drinking water standards.

Wastewater as an energy source

- Wastewater treatment is a high energy process: accounts for ~2% of the national energy consumption
- Make the process “energy neutral” or “energy positive” → lots of energy savings!
- Several ways to use energy in wastewater
  - CH_4 gas production from wastewater → heat / electricity generation
  - Electricity generation directly from wastewater (microbial fuel cells)
  - Using heat value of wastewater

Nutrient recovery from wastewater

- Use effluent of primary/secondary treatment for irrigation
- Recover N/P from wastewater to produce fertilizers



금요일에 과학터치 본강연(편집본)
210702 금요일에 과학터치 본강연(편집본) 서울대학교 최용주 교수

Suggested readings

[ENG] pp. 557 – 570, 592 – 594

[KOR] pp. 542 – 556, 581 – 582

Next class

Air pollution I

- Units of measurement
- Types of air pollutants
- Indoor air pollution, smog

Wastewater treatment I

Today's lecture

- Wastewater characteristics
- Wastewater treatment process overview
- Wastewater treatment unit processes
  – Pretreatment: bar racks, grit removal, flow equalization
  – Primary treatment
  – Secondary treatment
  – Tertiary treatment

Significance of wastewater contaminants

- **Biodegradable organics**: can cause anaerobic conditions in the environment
- **Suspended solids**: can cause sludge deposits and anaerobic conditions in the environment
- **Pathogens**: transmit disease
- **Nutrients**: can cause eutrophication
- **Heavy metals**: toxicity to biota and humans
- **Refractory organics**: toxicity to biota and humans
- **Dissolved solids**: interfere with reuse, damage the aquatic ecosystem

Characteristics of domestic wastewater

Typical Composition of Untreated Domestic Wastewater

Constituent	Weak	Medium (all mg · L^{-1} except settleable solids)	Strong
Alkalinity (as $CaCO_3$)[a]	50	100	200
BOD_5 (as O_2)	100	200	300
Chloride	30	50	100
COD (as O_2)	250	500	1000
Suspended solids (SS)	100	200	350
Settleable solids (in mL · L^{-1})	5	10	20
Total dissolved solids (TDS)	200	500	1000
Total Kjeldahl nitrogen (TKN) (as N)	20	40	80
Total organic carbon (TOC) (as C)	75	50	300
Total phosphorus (as P)	5	10	20

[a]This amount of alkalinity is the contribution from the waste. It is to be added to the naturally occurring alkalinity in the water supply. Chloride is exclusive of contribution from water-softener backwash.

Industrial wastewater

- Significant variation in wastewater characteristics
- Some industry may generate certain toxic pollutants

Examples of Industrial Wastewater Concentrations for Nonconventional Pollutants

Industry	Pollutant	Concentration ($mg \cdot L^{-1}$)
Coke by-product (steel mill) 코크스 제조 부산물(제강 공정)	Ammonia (as N)	200
	Organic nitrogen (as N)	100
	Phenol	2000
Metal plating 금속 도금	Chromium (VI)	3–550
Nylon polymer	COD	23,000
	TOC	8800
Plywood-plant glue waste 합판 접착제 폐액	COD	2000
	Phenol	200–2000
	Phosphorus (as PO_4)	9–15

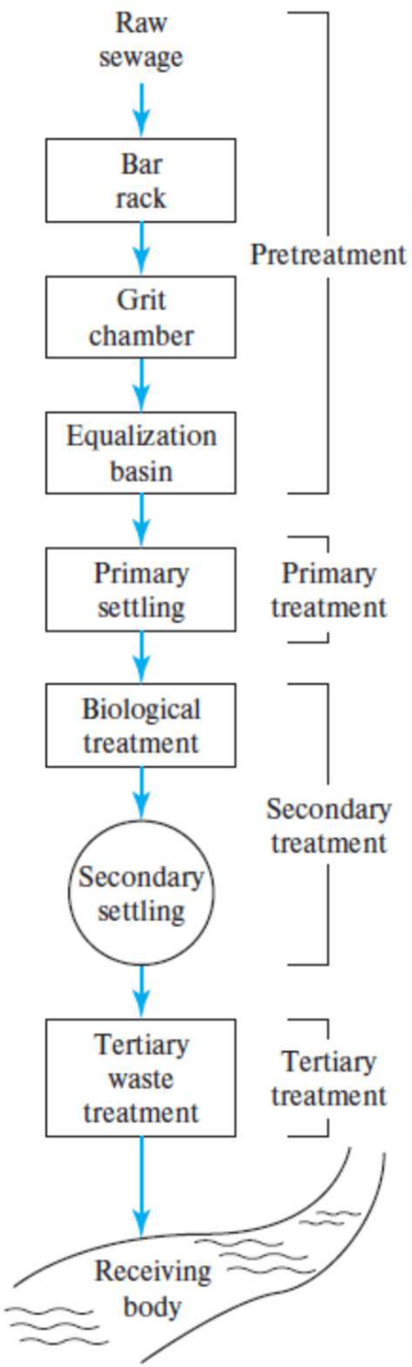
- May need pretreatment to prevent high loading to the wastewater treatment plant

Municipal wastewater treatment

- Major goal: remove BOD and suspended solids (SS)
  - US (1970's): "fishable and swimmable water", 30/30 rule
  - Currently we are also concerned with protecting aquatic ecosystem
  - Current Korean standard: BOD ≤ 10 mg/L, SS ≤ 10 mg/L

- Additional goal: remove N, P, pathogens, total dissolved solids (TDS), trace pollutants (heavy metals, EDCs, PPCPs, …)

Municipal wastewater treatment



Municipal wastewater treatment process

- 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
- Tertiary (advanced) treatment – additional removal of BOD & SS, N & P, and others

Bar racks (screens)

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

Grit chamber

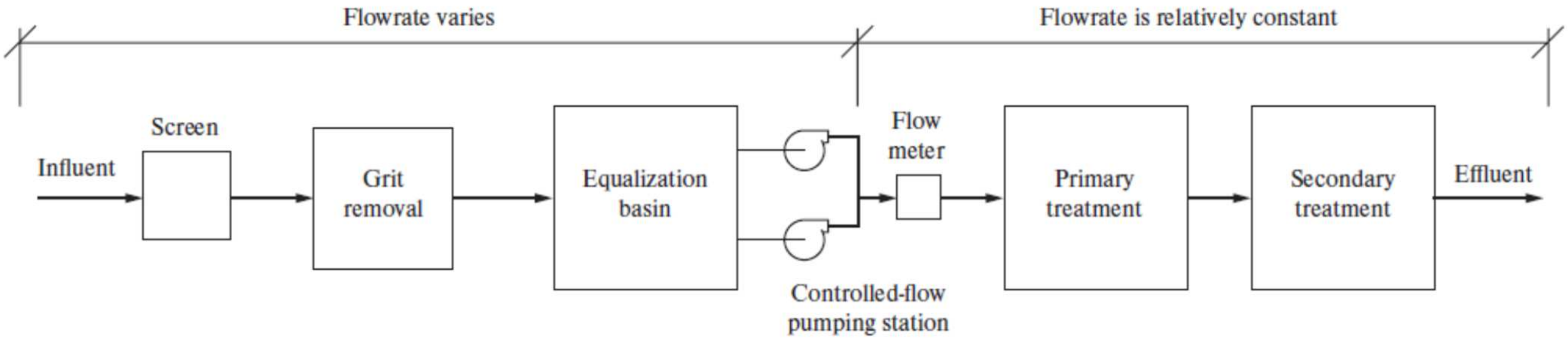
- Goal: remove “grit”
- Grit
  - Inert dense material such as sand, broken glass, silt, and pebbles
  - Abrades pumps and other mechanical devices in the following treatment processes
  - Relatively high density → settles down easily

“Vortex type” grit chamber

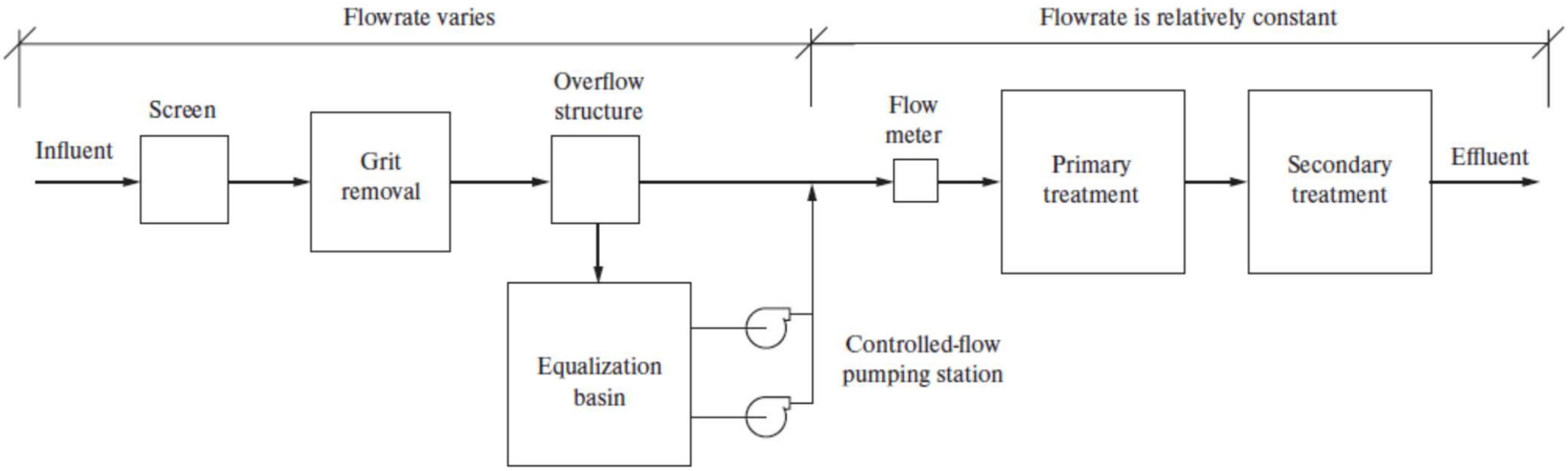
Flow equalization

- 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

In-line (a) vs. off-line (b) flow equalization



(a)



(b)

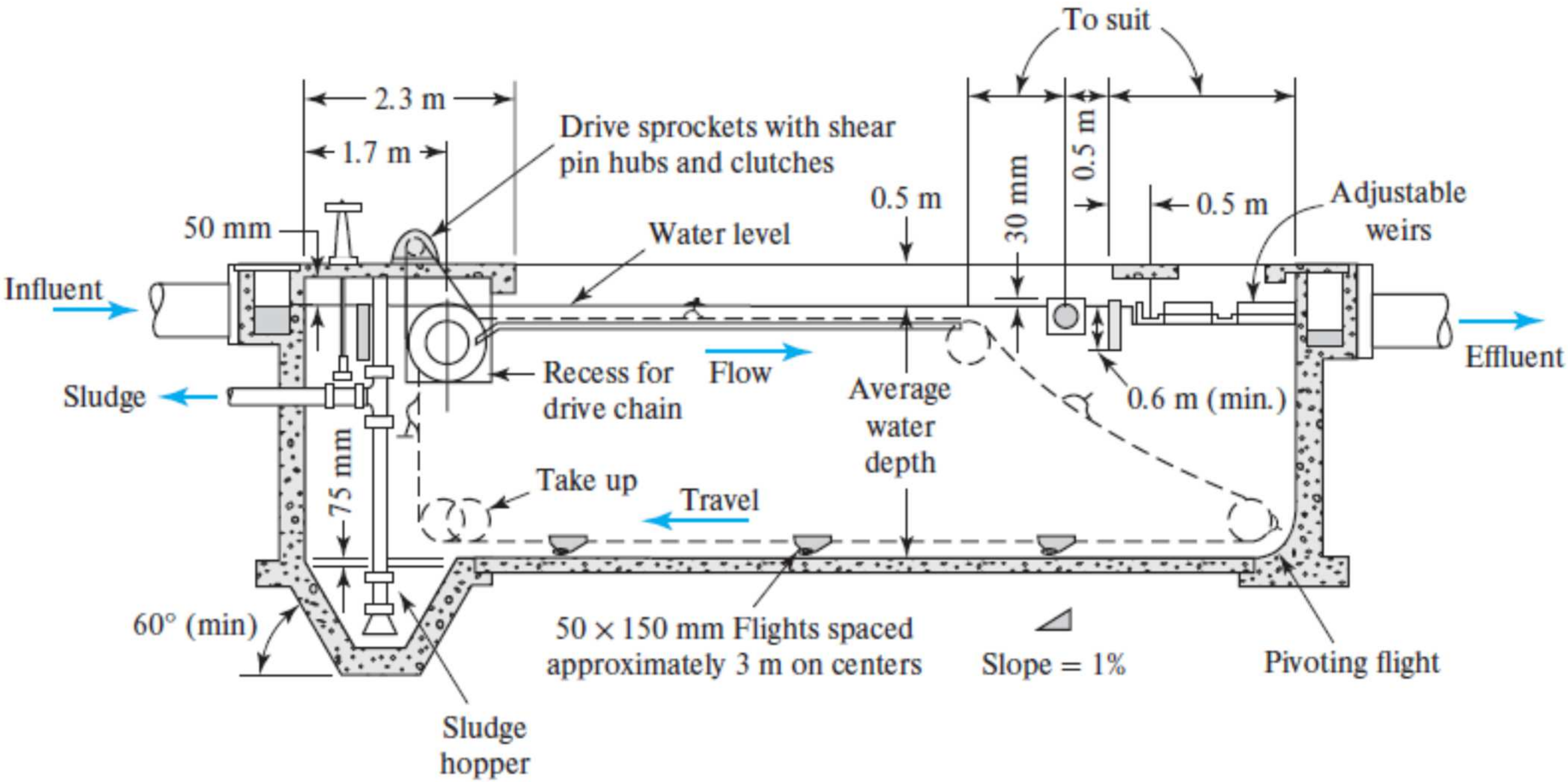
Primary sedimentation basins

- Removal of suspended solids by settling
- This removes some BOD as well!
- Removes ~60% of SS and ~35% of BOD
- Sludge (= mass of settled solids) is produced
- Floating materials such as oil and grease are also removed
- Design parameters (recall water treatment!): retention time (~2 hr), overflow rate

Primary sedimentation basins

- Rectangular or circular

Primary sedimentation basins



Secondary treatment

- Goal: provide BOD removal beyond what is achieved in primary treatment
  - Removal of soluble BOD
  - Additional removal of SS

- How??
  - Use microorganisms to convert organic wastes into stabilized compounds
    - → Bring the naturally-occurring process (self-purification) into an engineering setting
    - → Provide more favorable condition so that things occur much faster

Favorable conditions for biodegradation

- 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

Dispersed vs. fixed growth

- Dispersed (suspended) growth
  - Activated sludge
  - Oxidation ponds
- Fixed (attached) growth
  - Trickling filters
  - Rotating biological contactors (RBCs)

Dispersed growth systems

- Activated sludge
  - Most common
  - Large plants

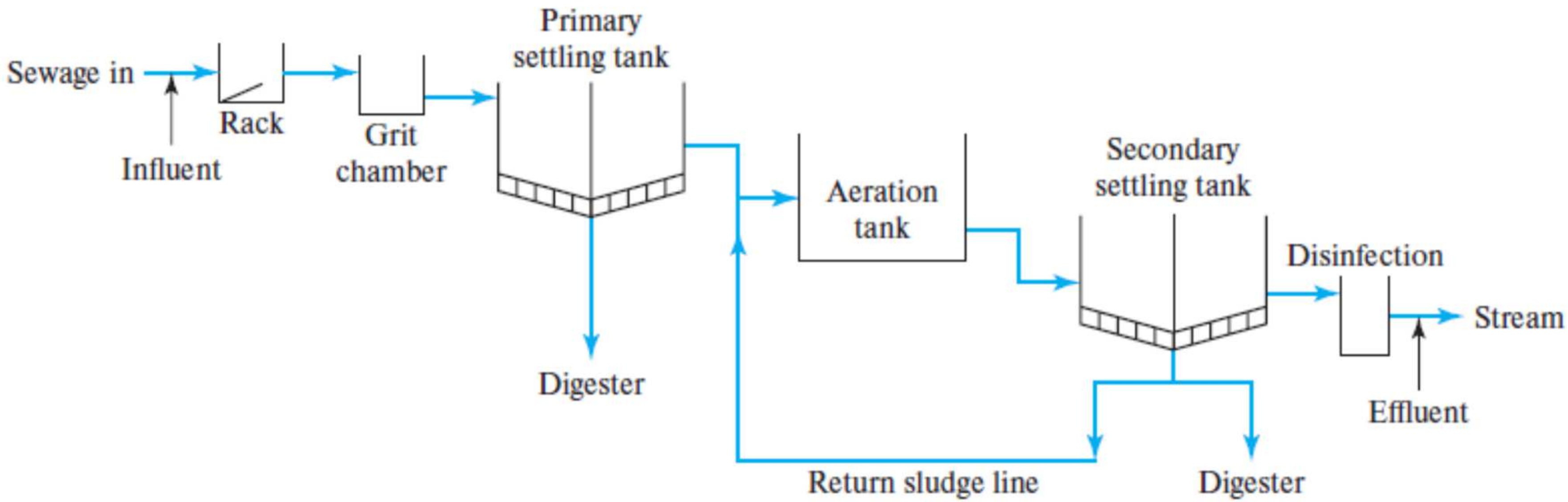
- Oxidation pond
  - For small communities
  - Low energy & maintenance cost

Fixed growth systems

- Trickling filter
  - Water trickles through the porous media

- Rotating biological contactor
  - The water gets oxygen when exposed to the air

Conventional activated sludge plant



Tertiary (advanced) treatment

- Goal: to improve the quality of the secondary treatment effluent
- Many of the Korean wastewater treatment plants now have tertiary 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 advanced treatment processes
  - **Granular filtration**
    - Additional removal of SS (including microorganisms)
    - Similar to water treatment
  - **Membrane filtration**
    - Additional removal of SS
    - Microfiltration is mostly commonly used for advanced treatment of wastewater

Tertiary (advanced) treatment

– **Carbon adsorption**
  - Removal of non-biodegradable organic compounds (contributes to COD, but not to BOD)
  - Activated carbon is most commonly used as an adsorbent

– **Chemical phosphorus removal**
  - Use chemical precipitants such as ferric chloride ($FeCl_3$), alum ($Al_2(SO_4)_3$), lime ($Ca(OH)_2$)

Suggested readings

[ENG] pp. 541 – 557, 576 – 580

[KOR] pp. 525 – 543, 563 – 568

Next class

Wastewater treatment II

- Activated sludge process
- Sludge treatment and disposal
- Thinking differently – wastewater as a resource