Anaerobic processes
for energy recovery from organic wastes

Today's lecture

- An anaerobic process that is under full-scale operation in the field -- *anaerobic digestion*

- An anaerobic process proposed as a candidate for mainstream domestic wastewater treatment -- *anaerobic fluidized bed membrane bioreactor*

Anaerobic digestion

- **Applications**
  - Stabilization of waste sludge
  - Treatment of high-strength organic wastes
  - Pretreatment step for conventional biological treatment

- **Advantage**
  - Low biomass yield
  - Energy production in the form of methane (of recent interest!)
    - WWTP -- ~2% of total energy cost in USA
    - Target on energy positive treatment of wastewater

- **Disadvantage**
  - Effluent quality usually not as good as aerobic treatment

After construction (Feb 18)

Before construction (Jan 15)

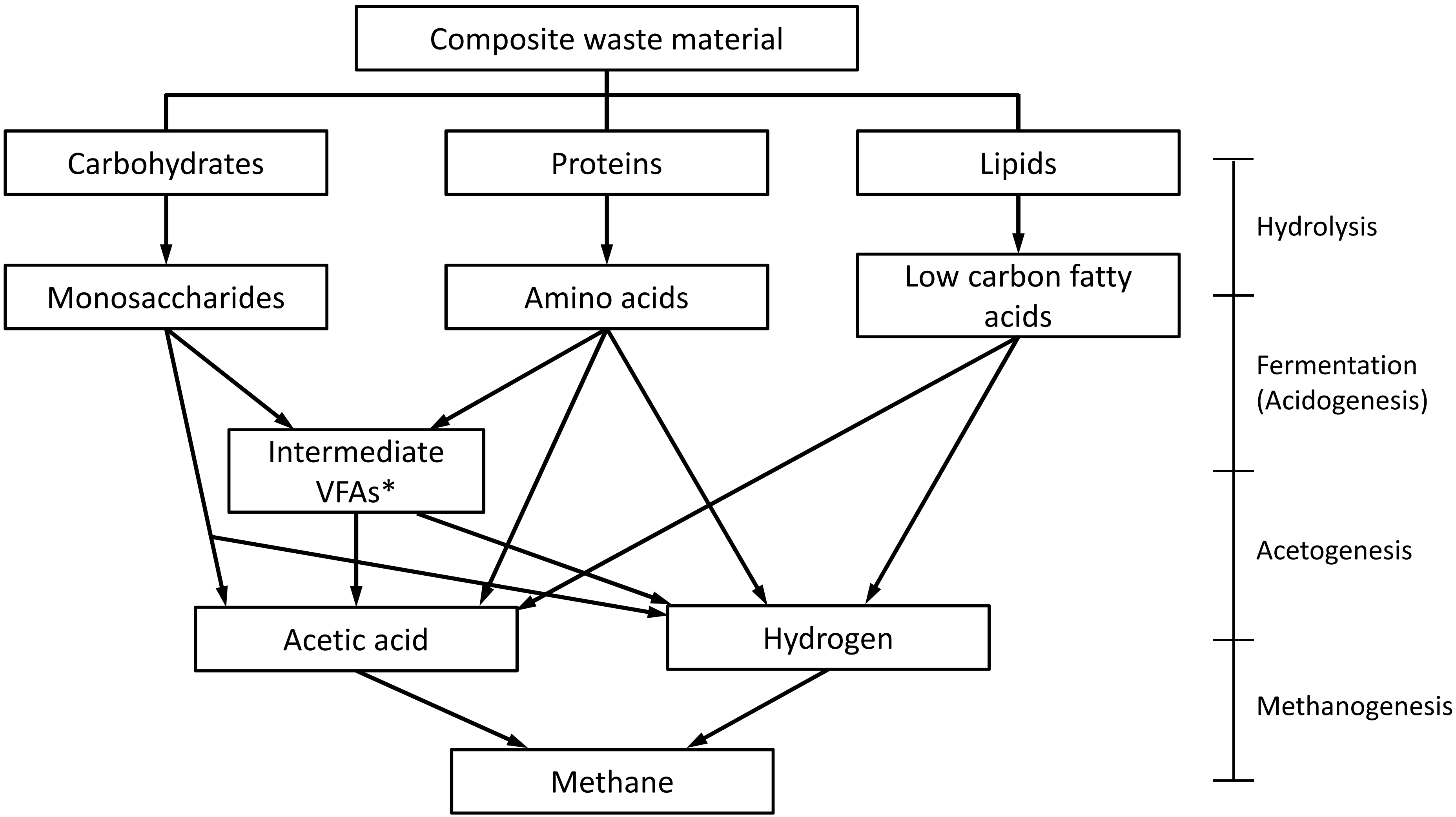
Hongchun energy town, Korea
(animal manure + food waste)

Anaerobic digestion tank

Biogas storage tank

Suyeong wastewater treatment plant,
Busan, Korea
(sewage sludge)

Pathway of anaerobic conversion of wastes



* Intermediate VFAs: Propionate ($C_2H_5COO^-$), Butyrate ($C_3H_7COO^-$), Valerate ($C_4H_9COO^-$)

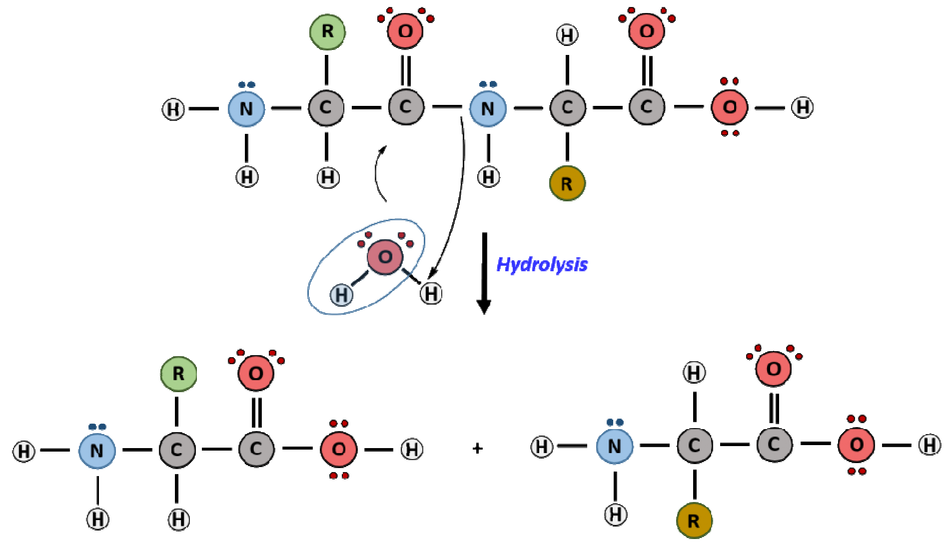
Steps of anaerobic conversion (1)

- **Hydrolysis**
  - Particulates - - - - → Soluble molecules - - - - → Monomers
  - By extracellular enzymes

- **Acidogenesis (fermentation)**
  - Use: sugars, amino acids, fatty acids (both e^- donor & acceptor)
  - Produce: VFAs, CO_2, H_2

- **Acetogenesis**
  - Use: VFAs other than acetate
  - Produce: acetate, H_2, CO_2

#1



Steps of anaerobic conversion (2)

- **Methanogenesis**
  - By methanogens (belongs to domain **Archaea**)
  - Two groups of methanogens
    - *aceticlastic* methanogens: acetate → $CH_4 + CO_2$
    - *hydrogenotrophic* methanogens: $H_2 + CO_2$ → CH_4
  - In anaerobic digestion process, ~72% methane from acetic acid & ~28% from H_2 (→ gas production of ~65% CH_4 & ~35% CO_2)

Syntrophic relationship

- Methanogens – acidogens & acetogens
  - Acidogens & acetogens: produce H_2, acetate, etc.
  - Methanogens: cleans up the acido/acetogenesis end products
    - Acetogens require relatively low H_2 partial pressure

- Often called as *"Interspecies hydrogen transfer"*

COD balance for anaerobic process

(COD utilized) = (Biomass COD) + (Methane COD)

- No e^- acceptor consumed!
- COD of methane = 64 g COD/mole CH_4

  = 2.86 g COD/L CH_4 (@ 0°C, 1 atm)

COD balance for anaerobic process

Q: An anaerobic reactor, which is operated at 35°C and 1 atm, is used to process a wastewater stream with a flow of 3000 m^3/d and a bCOD concentration of 5000 g/m^3. At 95% bCOD removal and a net biomass yield of 0.04 g VSS/g COD, what is the amount of methane produced in m^3/d?

1) Calculate the amount of methane produced per day in terms of COD

(COD utilized) = (Biomass COD) + (Methane COD)

(Methane COD) = (COD utilized) – (Biomass COD)

= (COD utilized) × (1 - 1.42 × Y_n)

$$= 5000\ g/m^3 \times 3000\ m^3/d \times 0.95 \times \{1 - 1.42\ g\ COD/g\ VSS\ \times 0.04\ g\ VSS/g\ COD\}$$

$$= 1.34 \times 10^7\ g\ COD/d$$

2) Calculate the conversion factor b/w methane COD & methane volume @ 35 ^oC and 1 atm

$$V/n = RT/P$$

$$= \frac{1\ mole \times 0.0821\ atm{-}L/mole{-}K \times 308\ K}{1\ atm}$$

$$= 25.3\ L/mole$$

$$\frac{25.3\ L\ CH_4/mole\ CH_4}{64\ g\ COD/mole\ CH_4} = 0.3953\ L\ CH_4/g\ COD$$

3) Calculate the amount of methane produced per day in terms of volume

$$1.34 \times 10^7\ g\ COD/d\ \times 0.3953\ L\ CH_4/g\ COD$$

$$= 5.30 \times 10^6\ L\ CH_4/d$$

$$= \mathbf{5300\ m^3/d}$$

Process kinetics

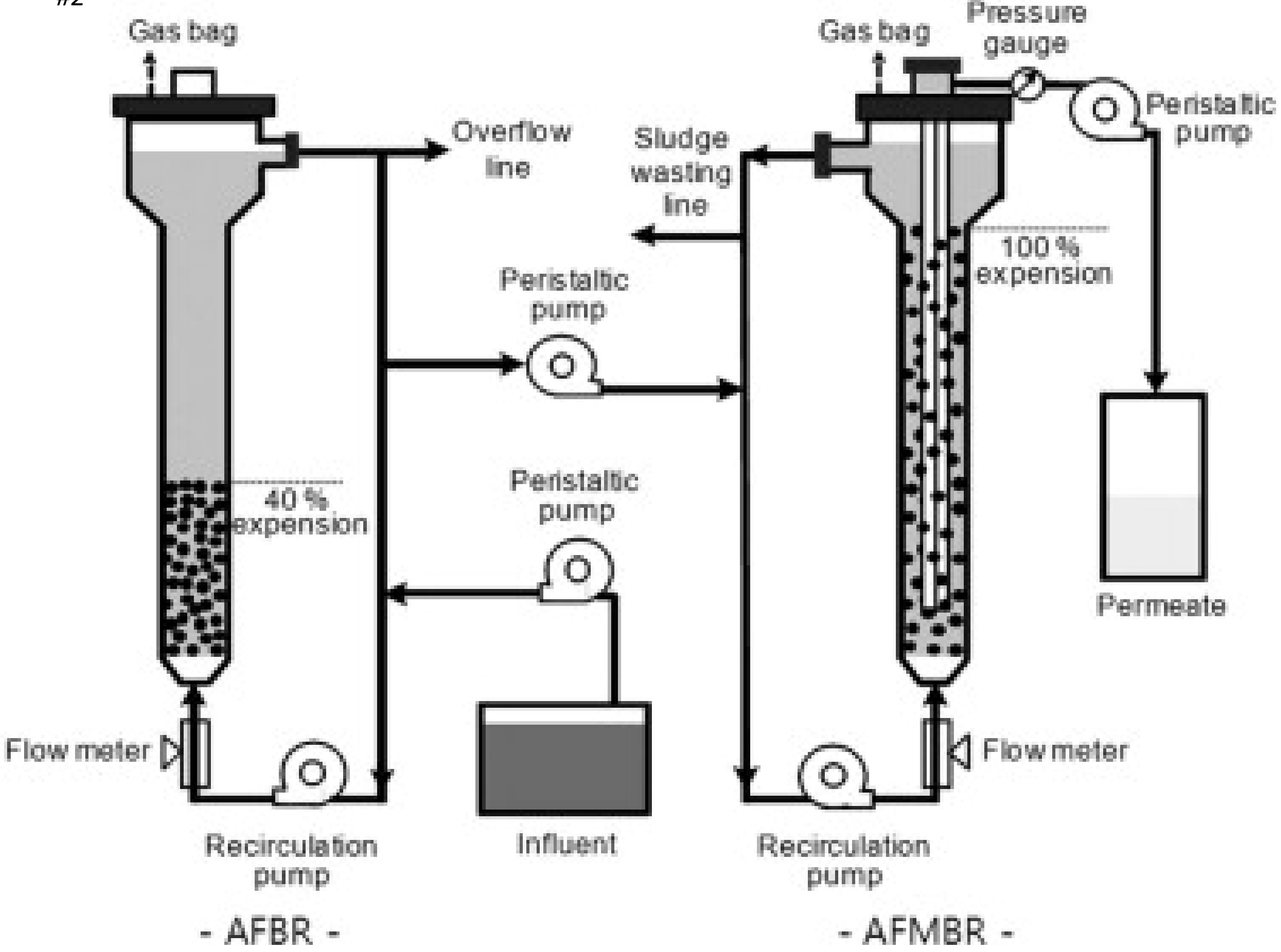
- Low yield coefficients
  - Low energy gain by chemical transformation
  - Fermentation: Y ~ 0.06 g VSS/g COD; b ~ 0.02 d^{-1}
  - Methanogenesis: Y ~ 0.03 g VSS/g COD; b ~ 0.008 d^{-1}
- Consider two steps:
  - Hydrolysis
  - Soluble substrate utilization for fermentation and methanogenesis
    - Methanogenesis the rate-limiting step
- High SRT is needed (around 40 d) due to slow degradation rate

Process stability

- Kinetics of VFA production is faster than utilization (methanogenesis)
- At steady state, sufficient methanogen population is established to maintain low VFA concentration (<200 g/m^3) & pH≥7.0
- Unstable digester operation may develop under transient loading conditions (VFA production > utilization): VFA accumulation & pH drop
- Low pH leads to decline in methanogenic activity: process failure
- Methanogenic inhibition can also occur by acetate accumulation (acetate conc. > 3000 g/m^3)

Anaerobic Fluidized Bed Membrane Bioreactor

#2



AFMBR: Concept & advantages

- Concept
  - Two-step anaerobic process for low-strength wastewater
  - Granular activated carbon (GAC) as media for attached growth
  - Membrane filtration for solid/liquid separation
- Pilot scale demonstration successful, with acceptable effluent quality
- Advantages
  - Those for MBR apply

  \+ Energy recovery (CH_4)

  \+ No aeration requirements

  \+ Removal of refractory organics via GAC adsorption

References

#1) https://wou.edu/chemistry/courses/online-chemistry-textbooks/ch450-and-ch451-biochemistry-defining-life-at-the-molecular-level/chapter-2-protein-structure/

#2) Kim, J., Kim, K., Ye, H., Lee, E., Shin, C., McCarty, P. L., Bae, J. (2011) Environmental Science & Technology, 45(2): 576-581.