

Principles and recent trends in biological wastewater treatment technology

Team E-Kansai

GEC Technical Coordinator

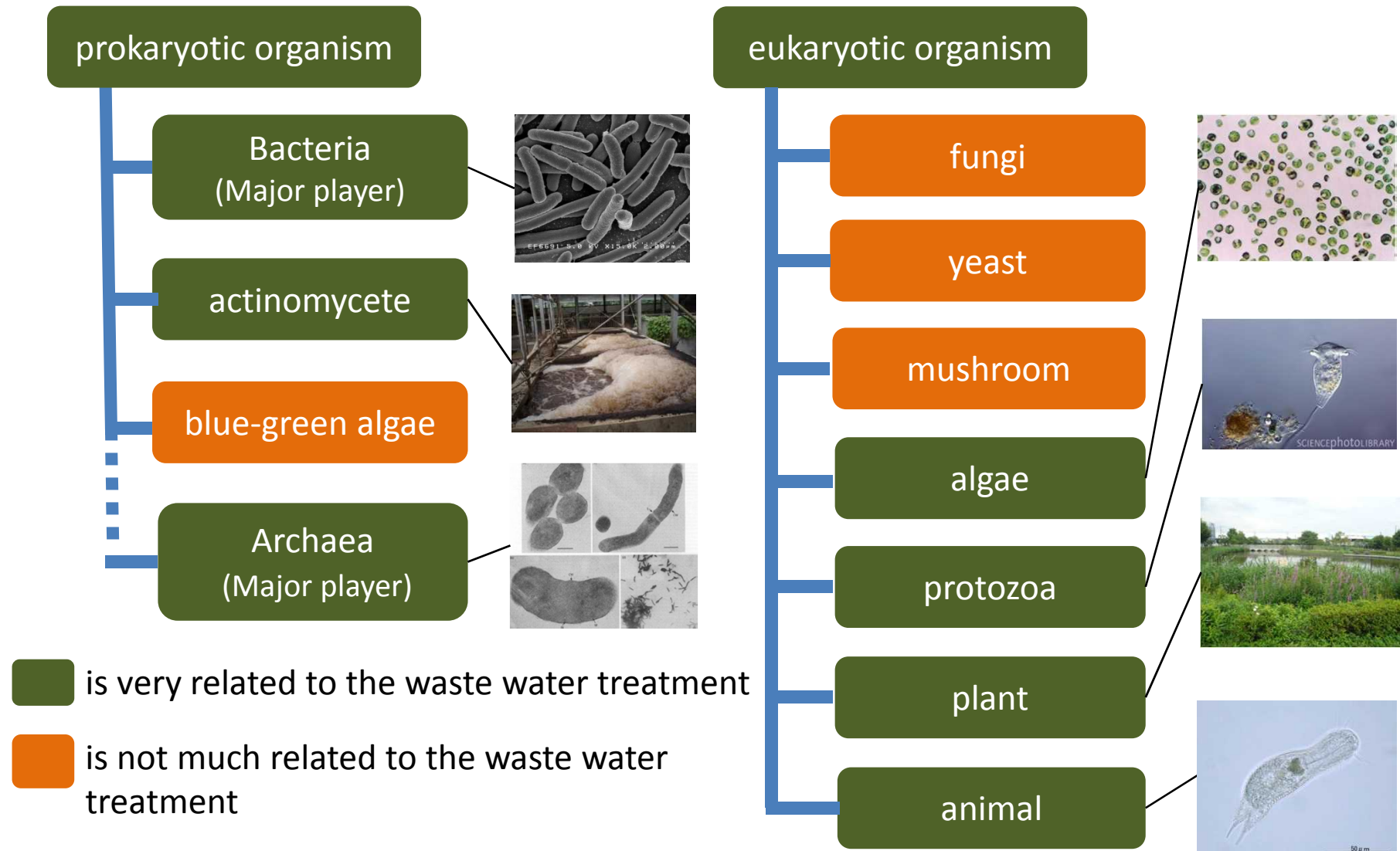
Chuzo Nishizaki

Outline of This Presentation

1. Basics of Microbiology
2. Biological Wastewater Treatment
 - 2-1. Aerobic Treatment
 - 2-2. Anaerobic Treatment
 - 2-3. Facultative Treatment
 - 2-4. Nitrogen and Phosphorus Removal
3. Recent Trends
4. Conclusion

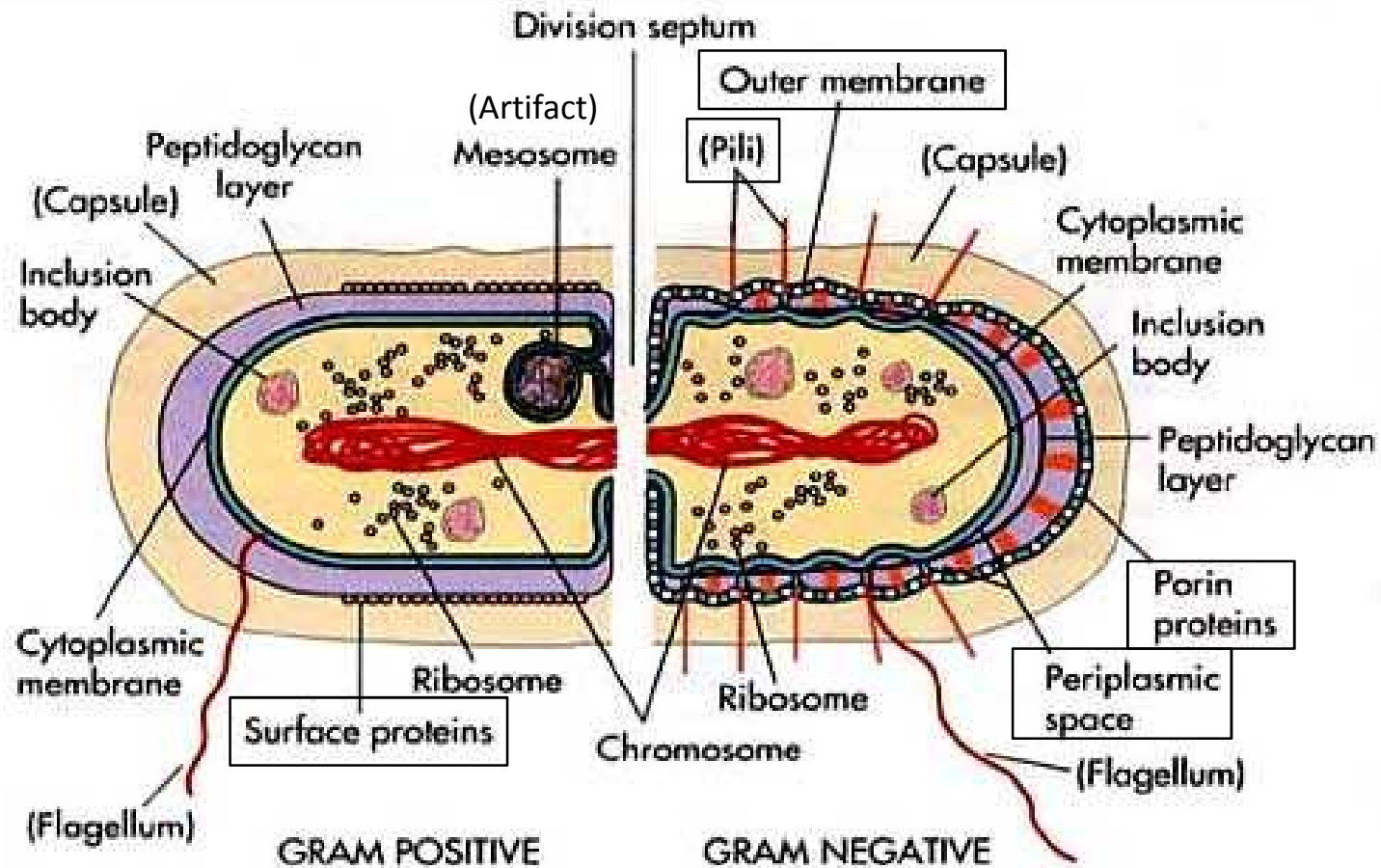
1. Basics of Microbiology

-Organisms related to waste water treatment-



1. Basics of Microbiology

-Structure of Bacterial Cells-



Resource : Murray PR, et al. "Medical Microbiology"

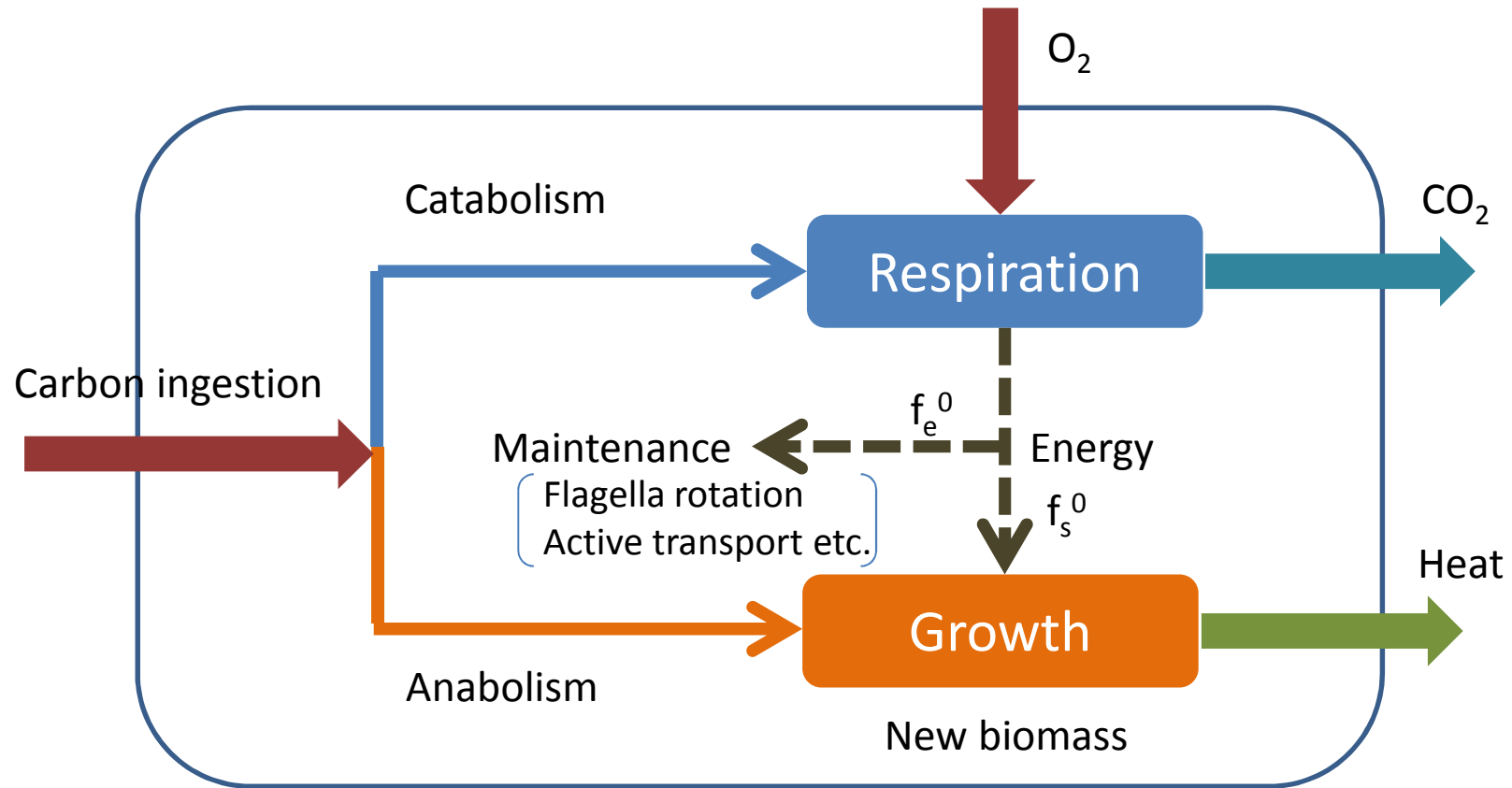
1. Basics of Microbiology

-Bacterial Growth Conditions-

Environmental Factors	Outline
Water	The growth of bacteria is dependent on the existence of water.
pH	- Most microorganisms grow best when the pH is around 7. <i>Nitrosomonas</i> : 7.5~8.0 (optimum pH range) <i>Nitrobacter</i> : 7.3~7.5 (optimum pH range) <i>Thiobacillus</i> and <i>Fungi</i> : 5 (best growing)
Temperature (maximum growth)	Mesophilic bacteria : 20°C - 42°C Thermophilic bacteria : 40°C - 70°C Extreme thermophilic bacteria : 70°C-100°C $q_T = q_{20}(1.07)^{T-20}$ T : Temperature(°C) q_T : Rate of substrate utilization
Nutrients	Macronutrients : C, O, H, N, S, P, K, Ca, Mg and Fe Micronutrients : Mn, Mo, Zn, Co, Cu, Ni, V, B, Cl, Na, Se, Si and W
Dissolved Oxygen	Obligate aerobic bacteria : <i>Pseudomonas sp.</i> etc. Obligate anaerobic bacteria : <i>Clostridium perfringens</i> etc. Facultative anaerobic bacteria : <i>E.coli</i> , <i>Citrobacter</i> , etc.
Light	The growth of photoautotrophic bacteria is dependent of light.

1. Basics of Microbiology

-Metabolism of Heterotrophic Bacteria-

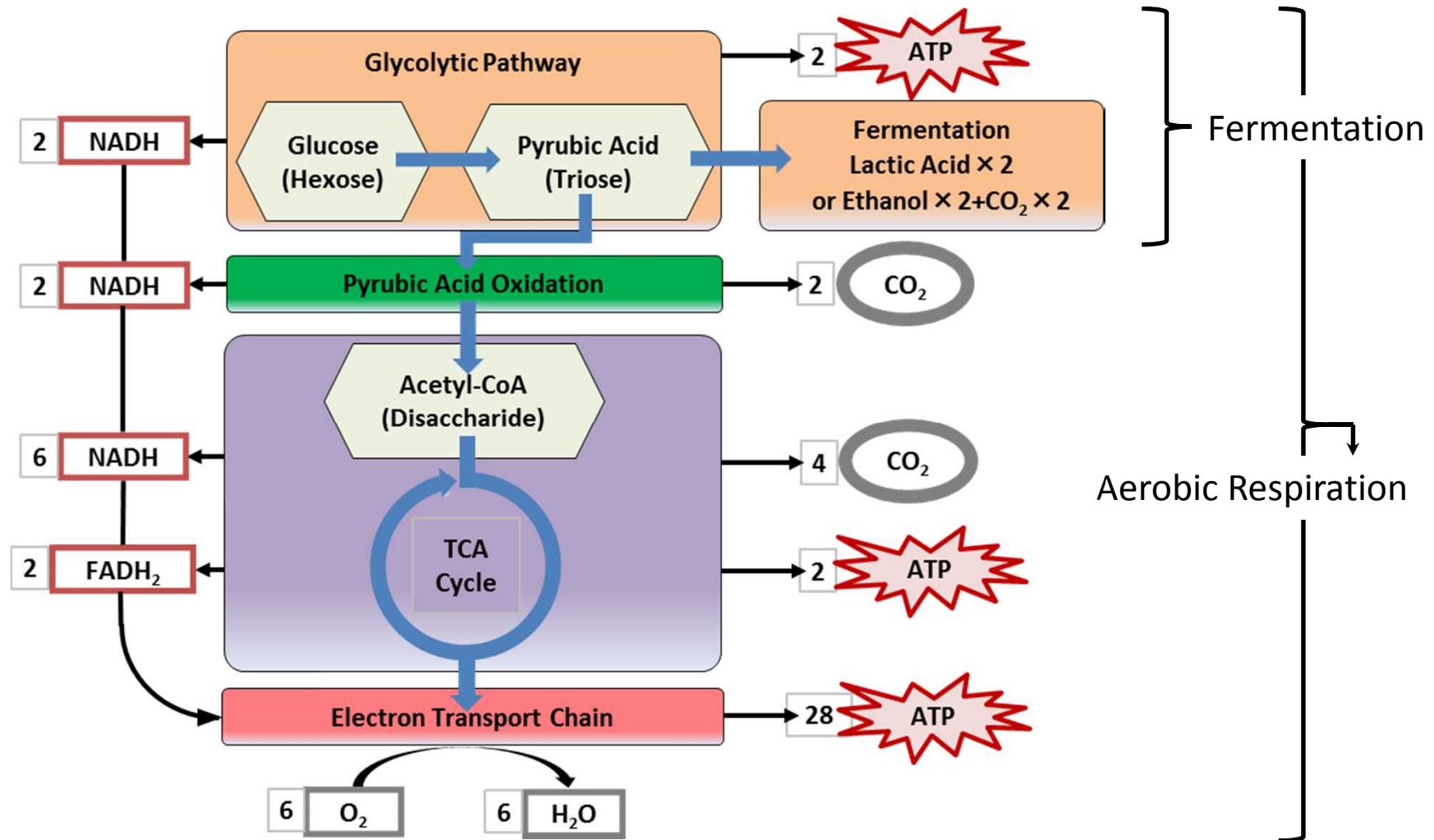


Note : $f_e^0 + f_s^0 = 1$

Source : Strathkelvin Instruments Ltd.

1. Basics of Microbiology

-Glycolytic Pathway and Cell Respiration (Catabolism)-

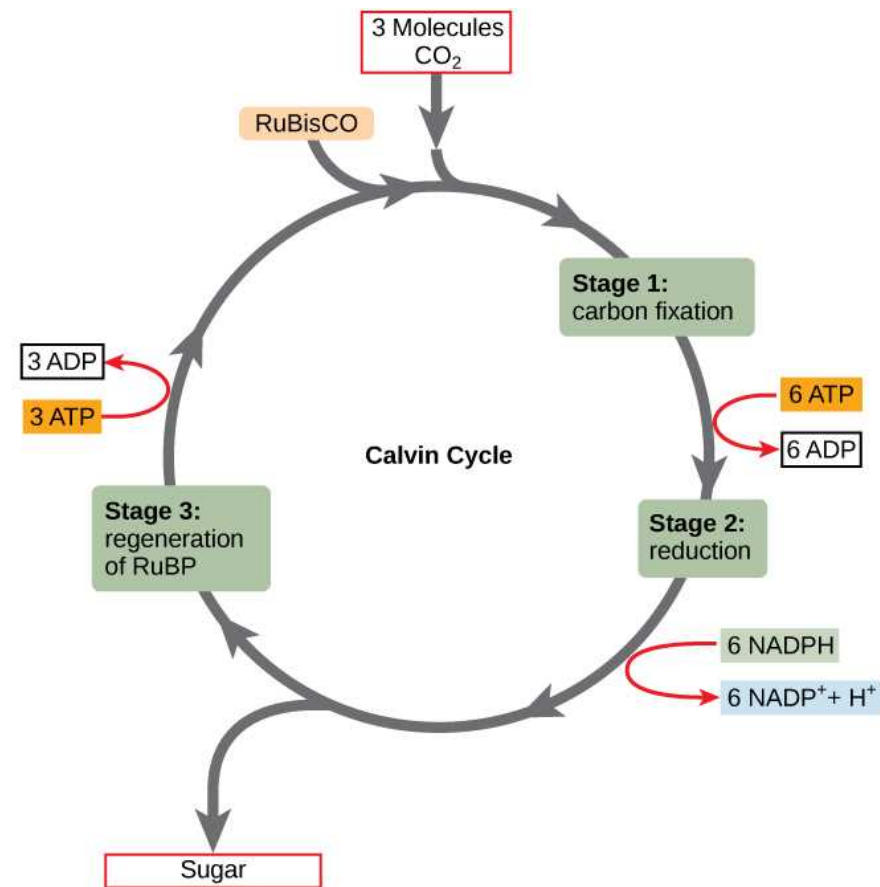


Source : David Sadava, H. Craig Heller et al. : Life : The Science of Biology 8th Edition

1. Basics of Microbiology

-Fixation of Carbon Dioxide (Anabolism)-

Plants and blue-green algae, photosynthetic bacteria is a photoautotrophic organism. Chemoautotrophic bacteria use CO_2 as a carbon source like a photosynthetic organism and grow. Calvin Benson cycle is what is known as a major cycle to assimilate the CO_2 as a carbon source in these autotrophic organisms.



Note : RuBisCO $\rightarrow$ Ribulose 1,5-bisphosphate carboxylase/oxygenase

Resource : Candela Open Courses

1. Basics of Microbiology

-Typical f_s^0 and μ^* Values for Key Bacterial Types-

Organism Type	Electron Donor	Electron Acceptors	Carbon Source	f_s^0 (-)	μ (d ⁻¹)
Aerobic , Heterotrophs	BOD	O ₂	BOD	0.6	8.4
Denitrifiers	BOD	NO ₃ ⁻	BOD	0.5	4
Nitrifying Autotrophs	NH ₄ ⁺	O ₂	CO ₂	0.14	0.92
	NO ₂ ⁻	O ₂	CO ₂	0.10	0.62
Methanogens	acetate	acetate	acetate	0.05	0.3
	H ₂	CO ₂	CO ₂	0.08	0.5
Sulfide Oxidizing Autotrophs	H ₂ S	O ₂	CO ₂	0.2	1.4
Sulfate Reducers	H ₂	SO ₄ ²⁻	CO ₂	0.05	0.29
	acetate	SO ₄ ²⁻	acetate	0.08	0.5
Fermenters	sugars	sugars	sugars	0.18	1.2

μ^* : maximum specific growth rate

Source : Bruce E. Rittmann, Perry L. McCarty : Environmental Biotechnology: Principles and Applications

2. Biological Wastewater Treatment

-Aerobic Treatment-

Oxygen Demand	Reactor Types	Popular Names	Effective Microorganisms
Aerobic	Suspended growth	① Conventional activated sludge process (CAS)	<u>Activated sludge-related bacteria</u> <i>Pseudomonas</i> <i>Flavobacterium</i> <i>Corynebacterium</i> <i>Aeromonas</i> <i>Zoogloea</i> <i>Acinetobacter</i> , ...
		② Oxidation ditch (OD)	
		③ Membrane bioreactors (MBR)	
	Fluidized-bed	④ Carrier-added activated sludge process	
	Packed-bed	⑤ Trickling filter process	
		⑥ Contact oxidation process	
		⑦ Rotating biological contactor (RBC)	

2. Biological Wastewater Treatment

-Anaerobic & Facultative Treatment-

Oxygen Demand	Habitation	Popular Names	Effective Microorganisms
Anaerobic	Suspended growth	⑧ Completely mixed	<u>Acidogenesis</u> <i>Clostridium</i> <i>Bacillus, ...</i> <u>Methanogenesis</u> <i>Methanobacterium</i> <i>Methanosarcina, ...</i>
		⑨ Anaerobic contact	
	Fixed-bed	⑩ Up-flow packed beds	
	Fluidized bed	⑪ Fluidized and expanded beds (AFBR)	
		⑫ Up-flow Anaerobic Sludge Blanket (UASB)	
Facultative	Stabilization pond	⑬ Facultative type	<u>Photoautotrophs</u> <i>Chlorobium, Algae, etc.</i> <u>Heterotrophs</u> <i>Pseudomonas, etc.</i>

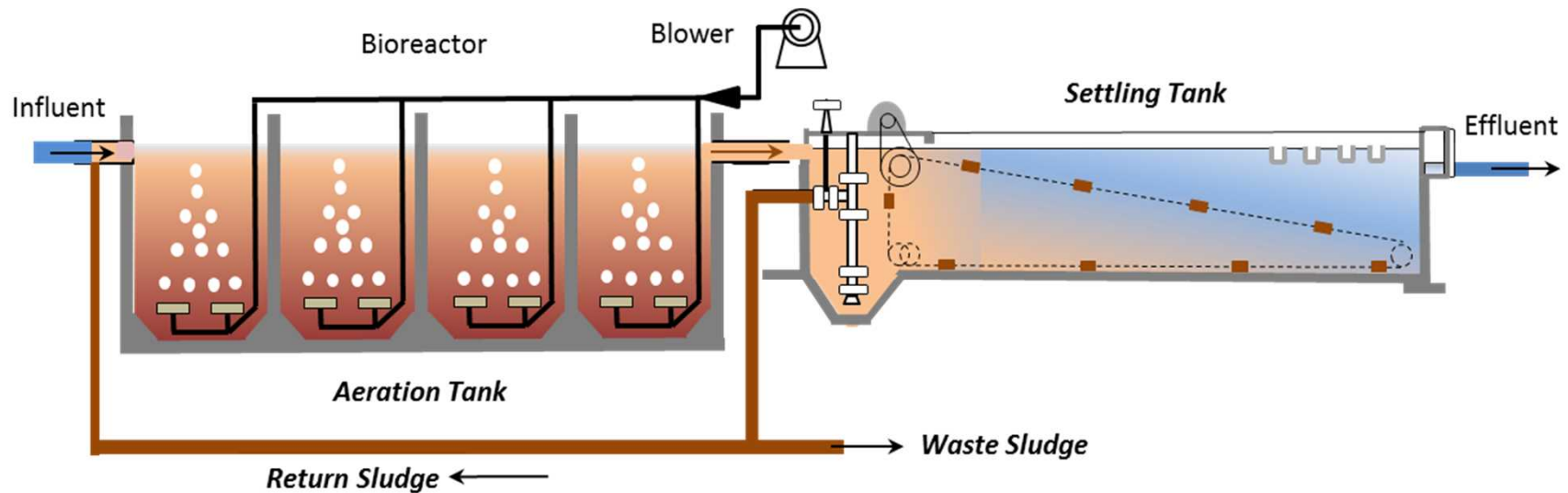
2. Biological Wastewater Treatment -Advanced Treatment-

Removal Object	Popular Name	Effective Microorganisms
Biological Nitrogen Removal	⑭ Wuhrmann process	<u>Ammonia-oxidizing bacteria</u> <i>Nitrosomonas</i>
	⑮ Nitrification liquid circulation process	<u>Nitrite-oxidizing bacteria</u> <i>Nitrobacter</i> <u>Denitrifying bacteria</u> <i>Pseudomonas, Microccus, Paracoccus, Alcaligenes, etc.</i>
	*) Anammox process	<u>Ammonia-oxidizing bacteria</u> <u>Anammox bacteria*)</u>
Biological Phosphorus Removal	⑯ Anaerobic- aerobic ASP	<u>Dephosphorization bacteria*)</u>
Biological Nitrogen and Phosphorous Removal	⑰ Anaerobic-anoxic ASP	<u>Ammonia-oxidizing bacteria</u> <u>Nitrite-oxidizing bacteria</u> <u>Denitrifying bacteria</u> <u>Dephosphorization bacteria*)</u>

Note*) : Ecology has not been fully elucidated

2-1. Aerobic Treatment

① Conventional Activated Sludge Process(CASP)



Conventional Activated Sludge Process



Aeration Tank



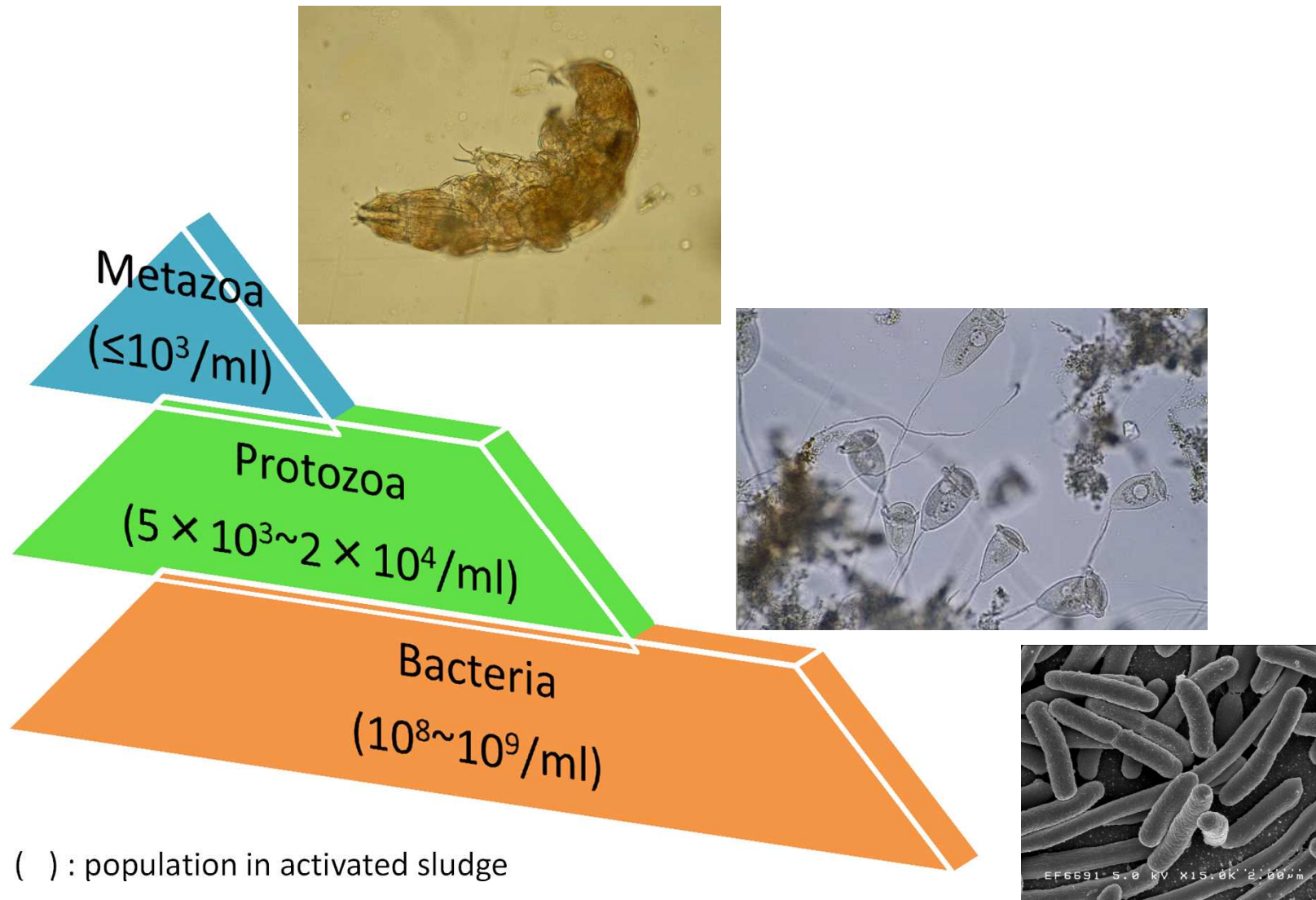
Return Sludge



Effluent

2-1. Aerobic Treatment

① Food Chain in Activated Sludge



2-1. Aerobic Treatment

① The greatest feature of CASP

- CASP greatest feature is that the bacteria (activated sludge) grown by blowing air into sewage in the aeration tank is transported to the sedimentation tank, and then separated into solid and liquid, and again returned to the aeration tank.
- Accordingly, it is possible to manage separately the time required for the bacteria growth (generation time) and hydraulic residence time in the aeration tank (water treatment time).

2-1. Aerobic Treatment

① Advantages and Disadvantages of CASP

Advantages	▪ High reduction of BOD and pathogens (up to 99%) at after secondary treatment
	▪ Can be operated at a range of organic and hydraulic loading rates
	▪ High effluent quality
	▪ Little land required compared to extensive natural system (e.g. Stabilization ponds)
Disadvantages	▪ High energy consumption, a constant source of electricity is required.
	▪ High capital and operating costs
	▪ Requires operation and maintenance by skilled personnel
	▪ Prone to complicated chemical and microbiological problems
	▪ Sludge require further treatment and appropriate discharge

Resource : Sustainable Sanitation and Water Management (SSWM)

2-1. Aerobic Treatment

① Typical Process Operating Factors (ASP)

Process Modification	Volumetric (kg BOD ₅ /m ³ ·d)	MLSS (mg/l)	F/M (kg BOD ₅ /kg MLVSS·d)	BOD Removal Efficiency (%)	SRT (d)
Conventional	0.6	1,000~3,000	0.2~0.5	95	4~10
Contact Stabilization	1.0	A	0.2~0.5	90	4~15
Modified Aeration	1.5~6	300~600	0.5~3.5	60~85 ^B	0.8~4
Extended Aeration	0.3	3000~5000	0.05~0.2	85~95 ^B	>14

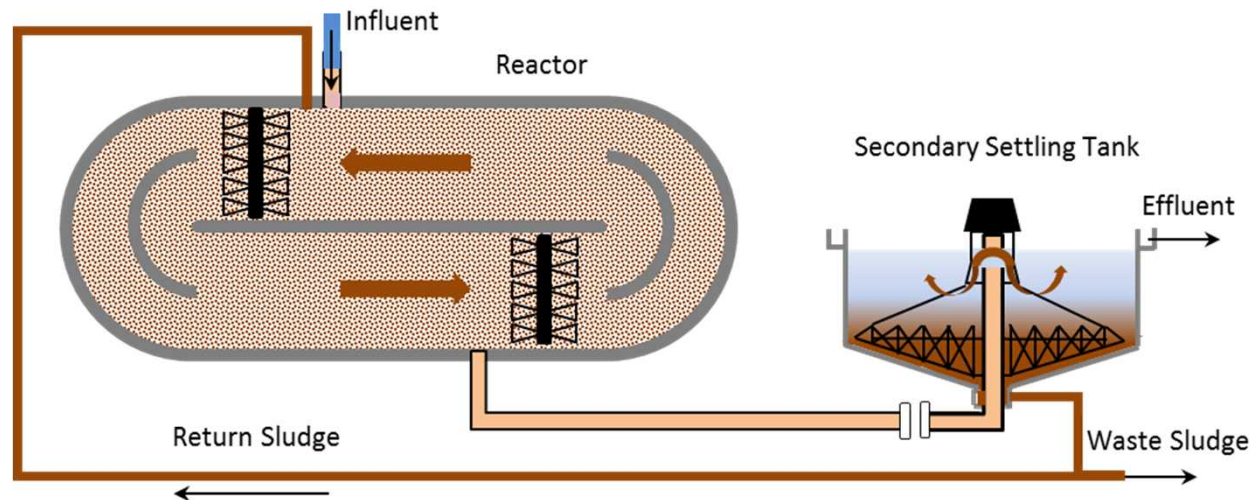
A : Contact Tank→1,000~3,000mg/l ; Stabilization Tank→5,000~10,000mg/l

B : Higher efficiency is based upon soluble effluent BOD₅.

Source : Bruce E. Rittmann, Perry L. McCarty : Environmental Biotechnology: Principles and Applications

2-1. Aerobic Treatment

② Oxidation Ditch (OD)

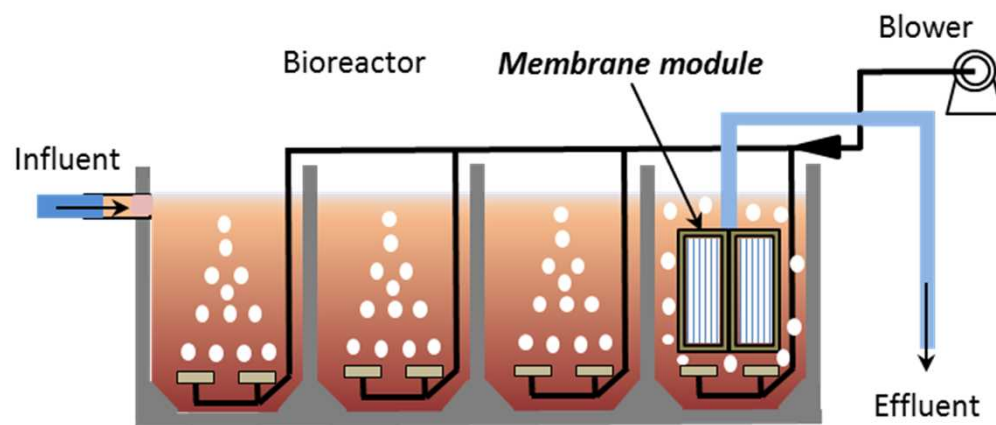


Characteristic of Oxidation Ditch Process

1. Operation management is easy.
2. Even if there is an hourly fluctuation of inflow load and a decrease of water temperature, this process can complete stable organic removal.
3. The amount of excess sludge generated of this treatment method is less than that of the conventional activated sludge process.

2-1. Aerobic Treatment

③ Membrane Bioreactors (MBR)



MBR can be classified into 3 types according to the location for installing the membrane module in convenience.

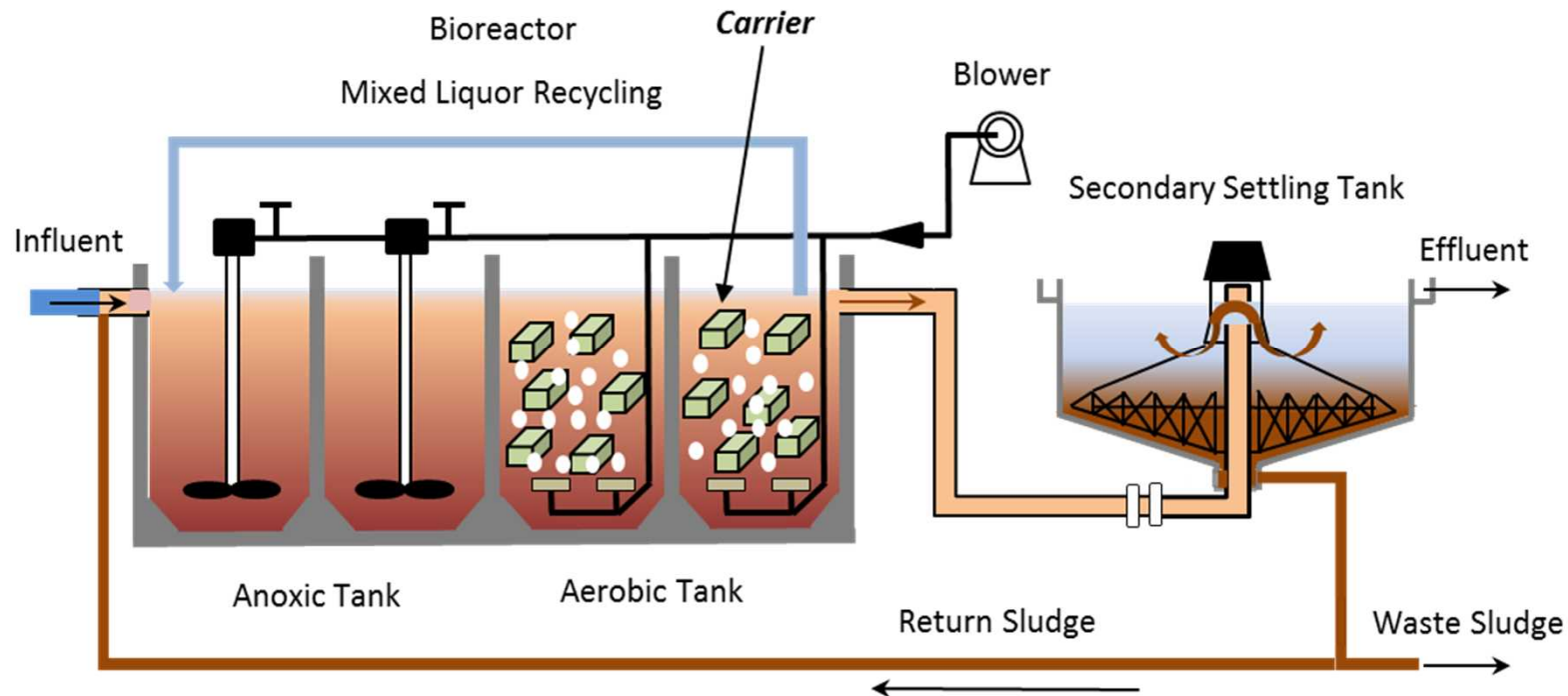
1. Immersion type (integrated)
2. Immersion type (another tank installation)
3. Outside tank type

Characteristic of Membrane Bioreactors

1. Process function is not affected by the change of the sludge settling properties.
2. Since we can keep the MLSS concentration high in the reaction tank , it is possible to make the facility compact.
3. Treated water is clarified, it is also possible to apply directly to recycling.

2-1. Aerobic Treatment

④ Carrier-added Activated Sludge Process

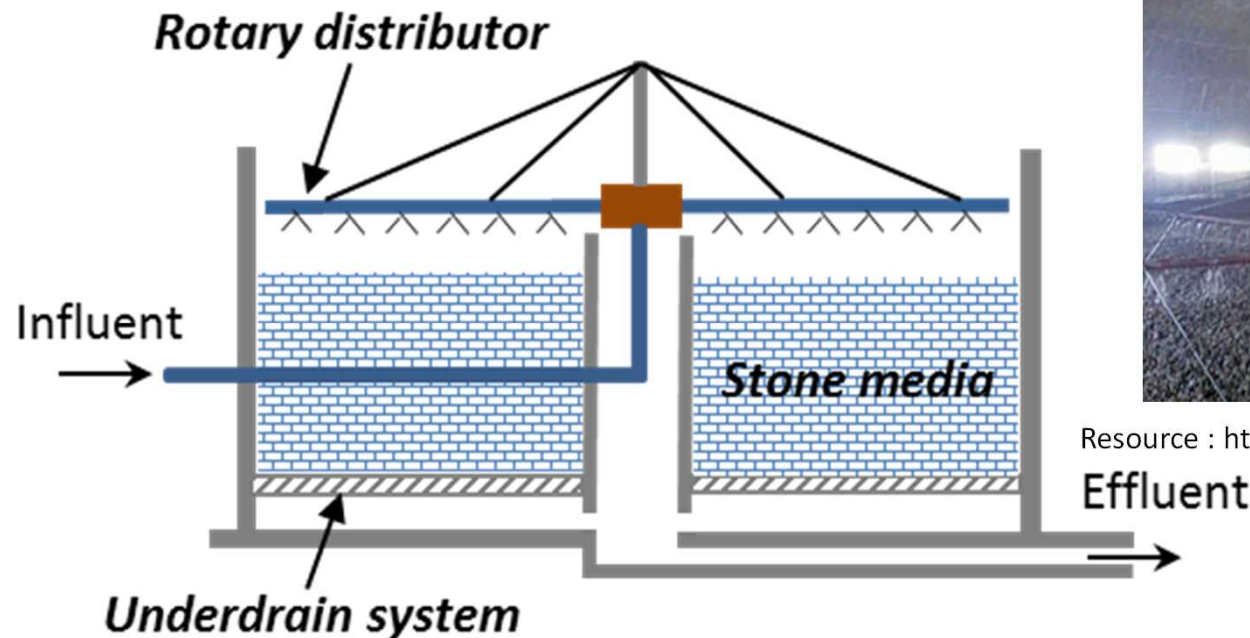


Characteristic of Carrier-added Activated Sludge Process

1. This method can retain microorganisms at a high density, such as nitrifying bacteria in a carrier that is flowing together with the activated sludge.
2. Therefore, by adopting this method, it is possible to compact the reaction tank.
3. This process needs a special solid – liquid separation tool in the bioreactor.

2-1. Aerobic Treatment

⑤ Trickling Filter Process

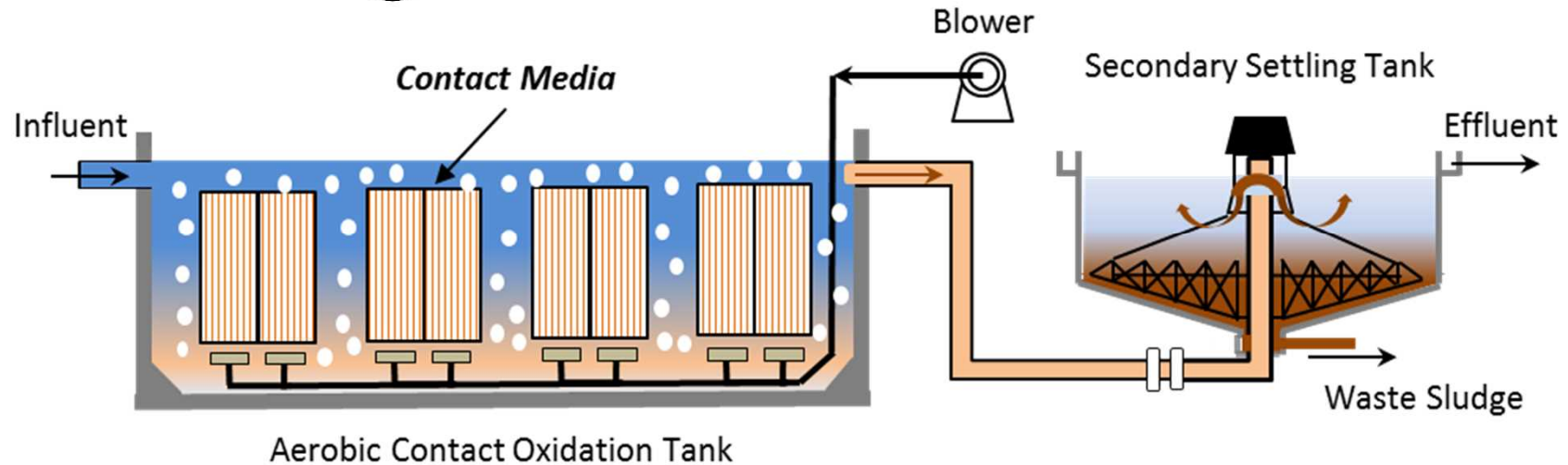


Resource : <http://www.db.pwri.go.jp/pdf/D8113.pdf>

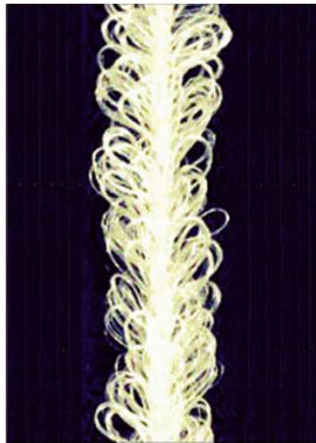
Advantage	▪ Low construction and maintenance costs compared with CAS
	▪ Easy maintenance without the return of the sludge
Disadvantage	▪ The outbreak of filter fly or odor
	▪ Poor transparency of the treated water
	▪ Large head loss

2-1. Aerobic Treatment

⑥ Contact Oxidation Process



Media

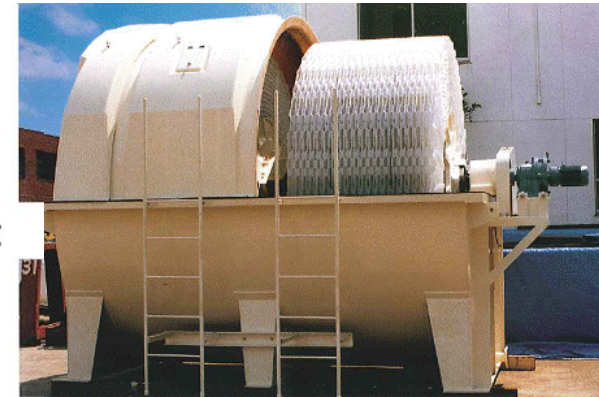
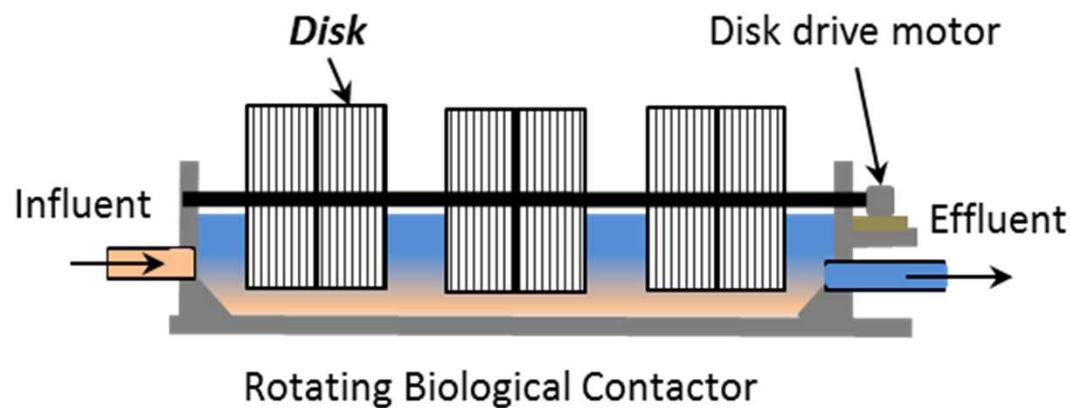


Advantage	▪ Easy maintenance without the sludge returning
	▪ Less generation of waste sludge
Disadvantage	▪ Attention should be paid to sludge deposition of contact oxidation tank.
	▪ Poor transparency of the treated water

Source : KAJIMA AQUATECH CO., LTD.

2-1. Aerobic Treatment

⑦ Rotating Biological Contactors

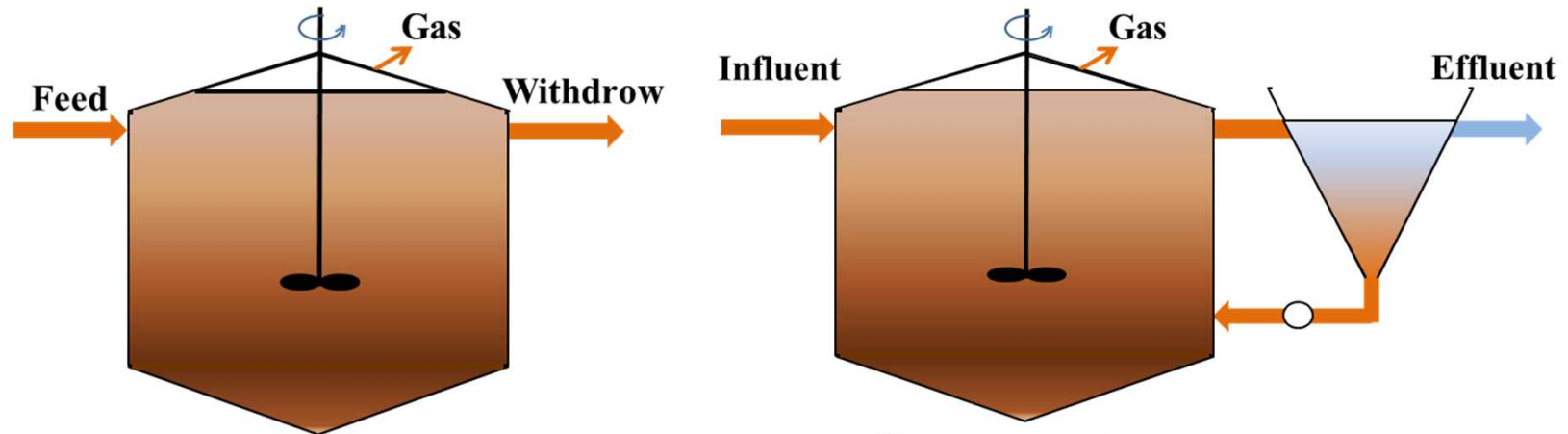


Source : http://www.unido.or.jp/en/technology_db/1677/

Advantage	▪ Low Operating Cost
	▪ Low Sludge Generation
	▪ Easy maintenance without the return of the sludge
Disadvantage	▪ Poor transparency of the treated water
	▪ It is required discharge device as the peeled biofilm does not accumulate in the contact tank.

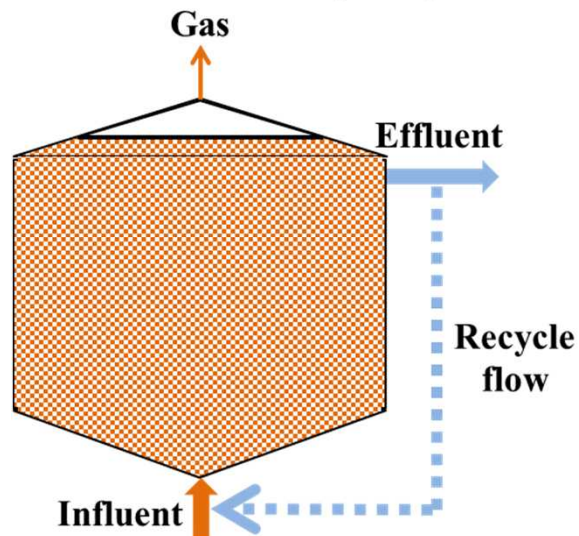
2-2. Anaerobic Treatment

-Configuration of Typical Anaerobic Reactor-

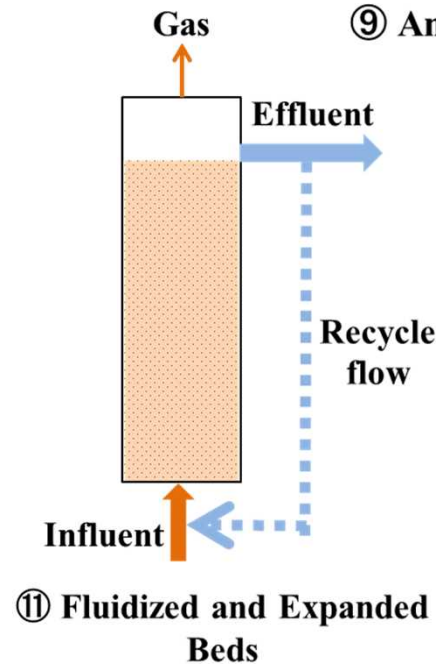


⑧ Completely Mixed

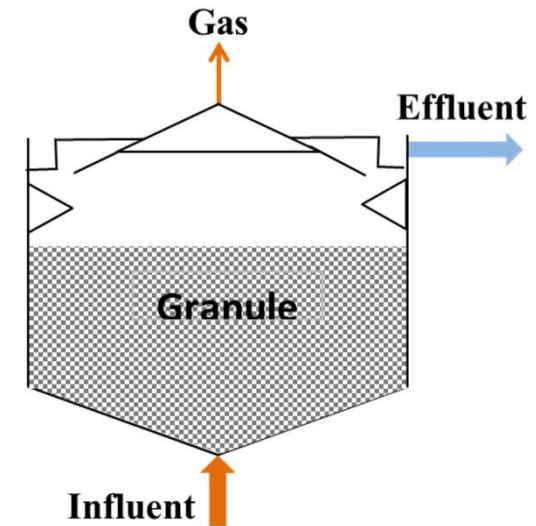
⑨ Anaerobic Contact Process



⑩ Upflow Packed Bed



⑪ Fluidized and Expanded Beds



⑫ UASB Process

2-2. Anaerobic Treatment

-Typical Operating Factors-

Type	Operating Factors
⑧ Completely Mixed	▪ DT=15-25 d at 35°C, Organic loading=1-4 kg-COD_{Cr}/m³/d ▪ This has been used for treatment of municipal sludge.
⑨ Anaerobic Contact Process	▪ HRT=0.5 d, Organic loading=2-2.5 kg-BOD/m³/d ▪ To prevent sludge floating in the sedimentation tank, the system is often provided a degassing device.
⑩ Upflow and Downflow Packed beds	Measures to prevent the bed-clogging: ▪ The SS component of the influent water should be removed in advance. ▪ Periodically carrying out the backwashing
⑪ Fluidized and Expanded Beds (AFBR)	▪ Organic loading=100 kg-COD_{Cr}/m³/d ▪ This combines a suspended-growth system and an attached-growth system.
⑫ Upflow Anaerobic Sludge Blanket (UASB)	▪ Production and maintenance of the granule is the key to the success of this process.

Source : Bruce E. Rittmann, and Perry L. McCarty : "Environmental Biotechnology : Principles and Applications"

2-2. Anaerobic Treatment

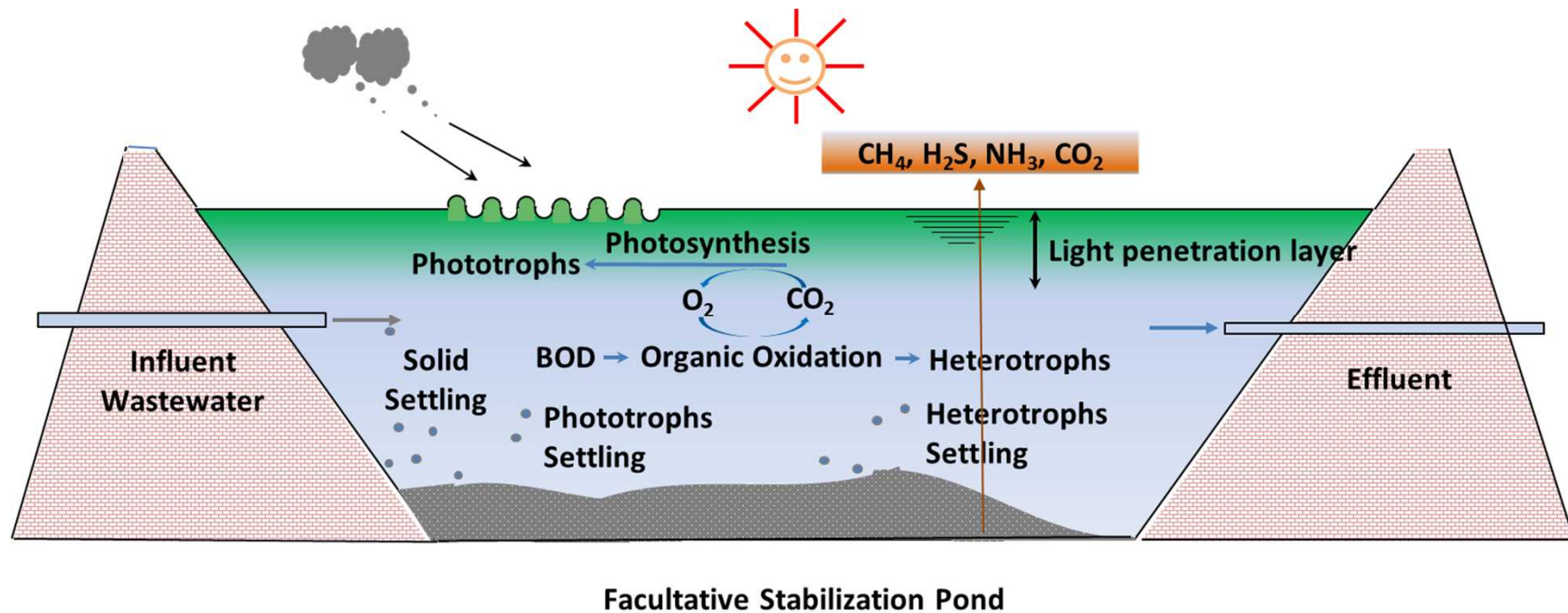
Advantages and Disadvantages of Anaerobic Treatment

Advantages	▪ Low production of waste biological solids
	▪ Low nutrient requirements
	▪ Methane is a useful end product
	▪ Generally, a net energy producer
	▪ High organic loading is possible
Disadvantages	▪ Low growth rate of microorganisms
	▪ Odor production
	▪ High buffer requirement of pH control
	▪ Poor removal efficiency with dilute wastes

Source : Bruce E. Rittmann, and Perry L. McCarty : "Environmental Biotechnology : Principles and Applications"

2-3. Facultative Treatment

⑬ Facultative Stabilization Pond



Source : Bruce E. Rittmann, Perry L. McCarty : Environmental Biotechnology: Principles and Applications

2-3. Facultative Treatment

⑬ Typical Operating Factors of Stabilization Pond

Type	Operating Factors
Anaerobic (Primary Treatment)	BOD loading : $100\text{g-BOD/m}^3/\text{d}$ (below 10°C) $\rightarrow$ BOD removal : 40% BOD loading : $300\text{g-BOD/m}^3/\text{d}$ (above 20°C) $\rightarrow$ BOD removal : 60% Retention time : 1 day (minimum)
Facultative (Secondary Treatment)	Depth : $1 \sim 2\text{m}$ Surface BOD loading : $350 (1.107 - 0.002T)^{T-25}\text{-kg-BOD/ha/d}$ $\rightarrow$ BOD removal : ca.90% Retention time = $2 A_f D / (2 Q_i - 0.001 e A_f)$ day (Minimum 5day below 20°C ; 4day above 20°C) A_f : Facultative pond area (m^2); Q_i : Influent flow (m^3/d) e : Net evaporation rate (mm/d); D : Pond depth(m)
Aerobic (Maturation)	Additional maturation pond(s) may be sometime used (depends on the effluent quality requirements) succeeding the facultative pond.

Resource : Hamzeh Ramadan and Victor M. Ponce : "Design and Performance of Waste Stabilization Ponds"

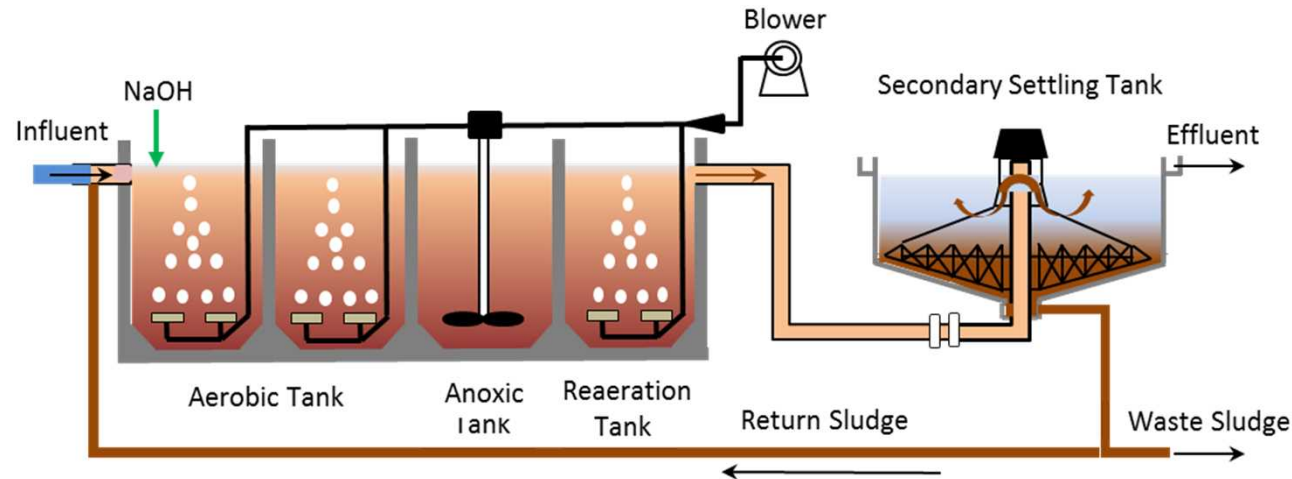
2-3. Facultative Treatment

⑬ Advantages and Disadvantages of Stabilization Pond

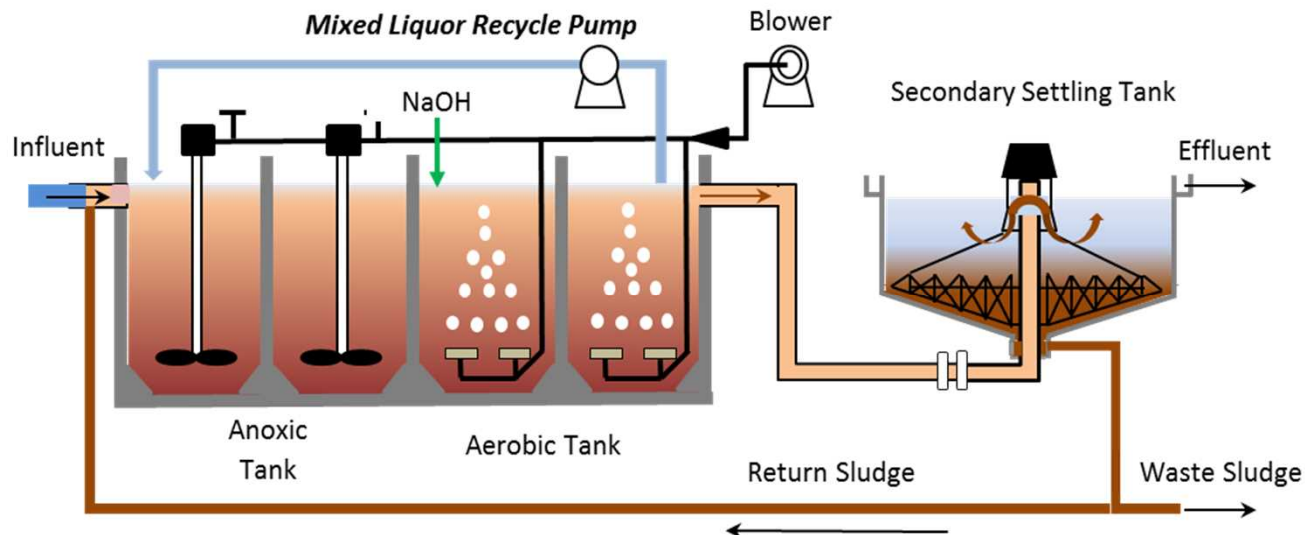
Advantages	Require little energy, with systems designed to operate with gravity flow.
	Easy to operate.
	▪ Moderately effective in removing settleable solids, BOD, pathogens, fecal coliform, and ammonia.
	▪ The quantity of removed material will be relatively small compared to other secondary treatment processes.
Disadvantages	▪ Requires relatively large areas of land.
	▪ Settled sludge and inert material require periodic removal.
	▪ Strong odors occur when the aerobic blanket disappears.
	▪ Burrowing animals may be a problem.

Resource : EPA "Wastewater Technology Fact Sheet-Facultative lagoons"

2-4. Nitrogen and Phosphorus Removal -Denitrification Process-

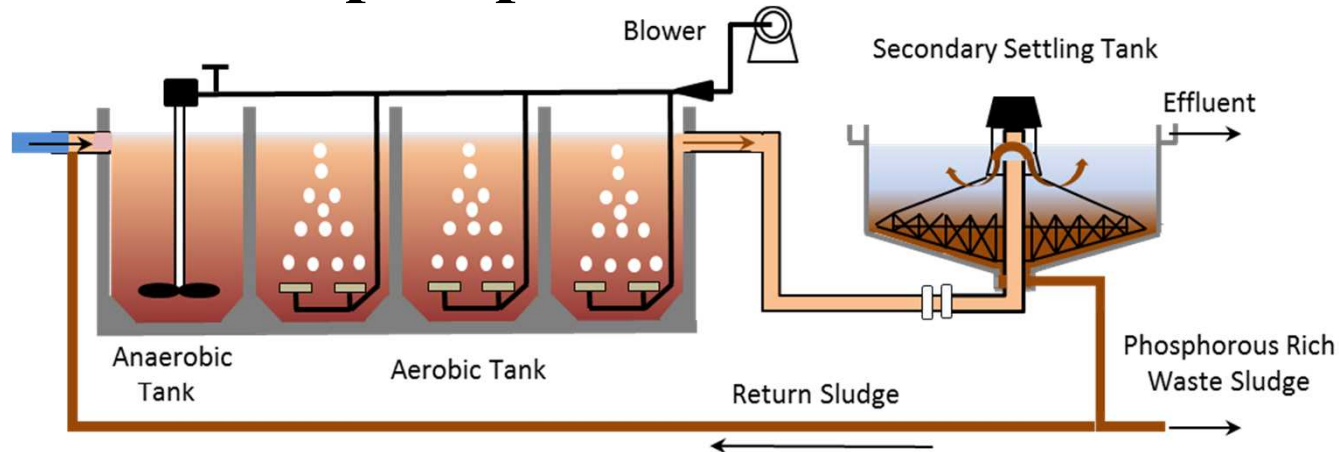


⑭ Wuhrmann Process

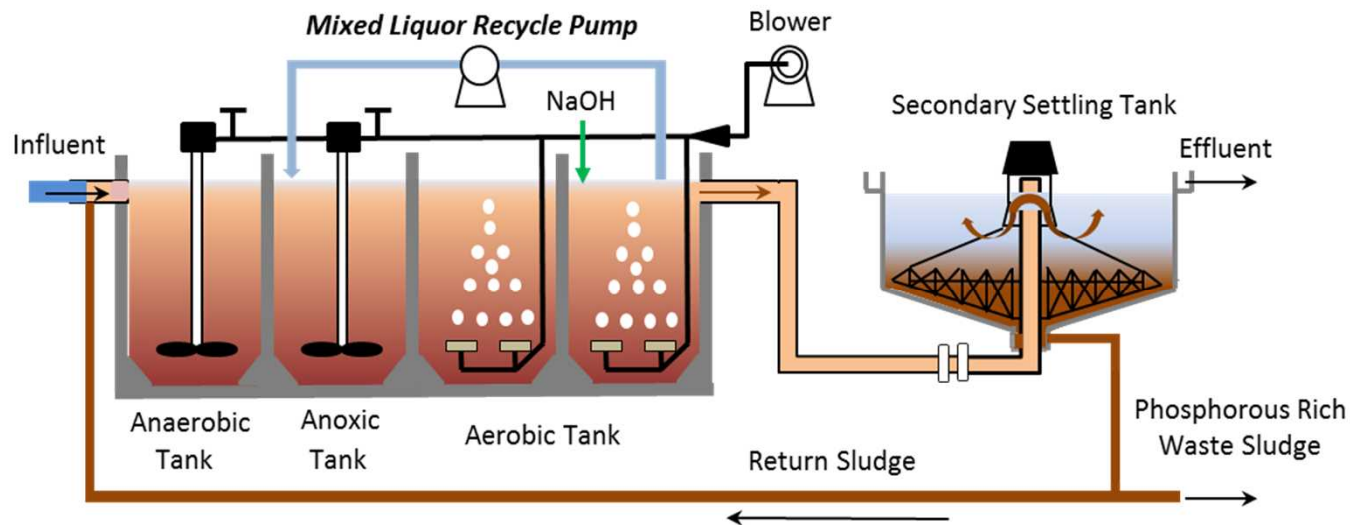


⑮ Nitrification liquid circulation Process

2-4. Nitrogen and Phosphorus Removal -Dephosphorization Process-



⑩ Anaerobic-Aerobic Activated Sludge Process



⑪ Anaerobic-Anoxic Activated Sludge Process

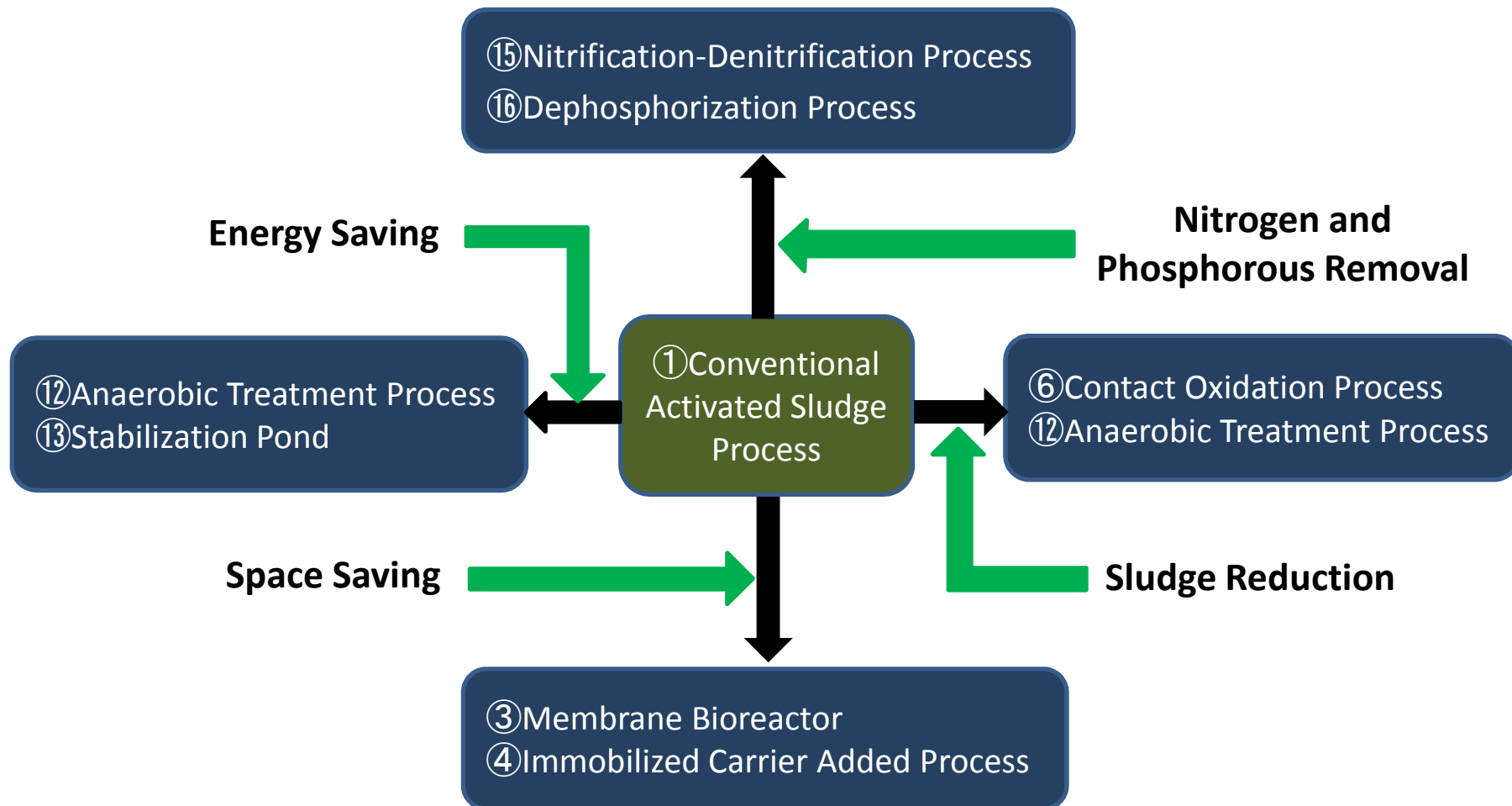
2-4. Nitrogen and Phosphorus Removal

-Characteristics of Typical Treatment Process-

Type	Characteristics
⑭ Wuhrmann process (Post-anoxic)	▪ Denitrification rate is proportional to the endogenous respiration rate in the mixed liquor. ▪ Long detention time required in the post anoxic tank.
⑮ Nitrification liquid circulation Process (Pre-anoxic)	▪ Internal recycle is provided to feed more NO_3^- to the anoxic zone directly from aerobic zone. ▪ Denitrification rate and overall nitrogen removal rate increase.
⑯ Anaerobic-aerobic activated sludge process	▪ The process enhances phosphorus removal while reducing sludge-bulking organisms. ▪ Physical layouts and flow schemes are similar to conventional activated- sludge plants.
⑰ Anaerobic-anoxic-aerobic activated sludge process	▪ This process combines ⑮ and ⑯ processes.
*) Anammox process	▪ In anaerobic conditions, NH_4^+ and NO_2^- is converted into a small amount of nitrate ions and nitrogen gas.

3. Recent Trends

-Biological Wastewater Treatment Technologies-



4. Conclusion

- Basic knowledge of biology is by all means necessary for mastering the biological wastewater treatment technology.
- On the other hand, the waste water treatment technology that meets the needs of the site (Energy saving, Sludge reduction etc.) is required from the site.
- In order to respond to it, we should firstly find out a useful function from the possibility of the infinite with the microorganisms. Then, we need to utilize its function in the process of wastewater treatment to meet the needs of the site.

Thank you for kind attention!



URL : <http://team-e-kansai.jp/en/>