ENV-405 Session 2
Wastewater treatment
Lecture 3 Nov 18

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Today's content:

1. Phosphorus removal (chemical and biological)
2. Activated sludge! Dimensioning calculation

Phosphorus removal: chemical or biological removal works on orthophosphate

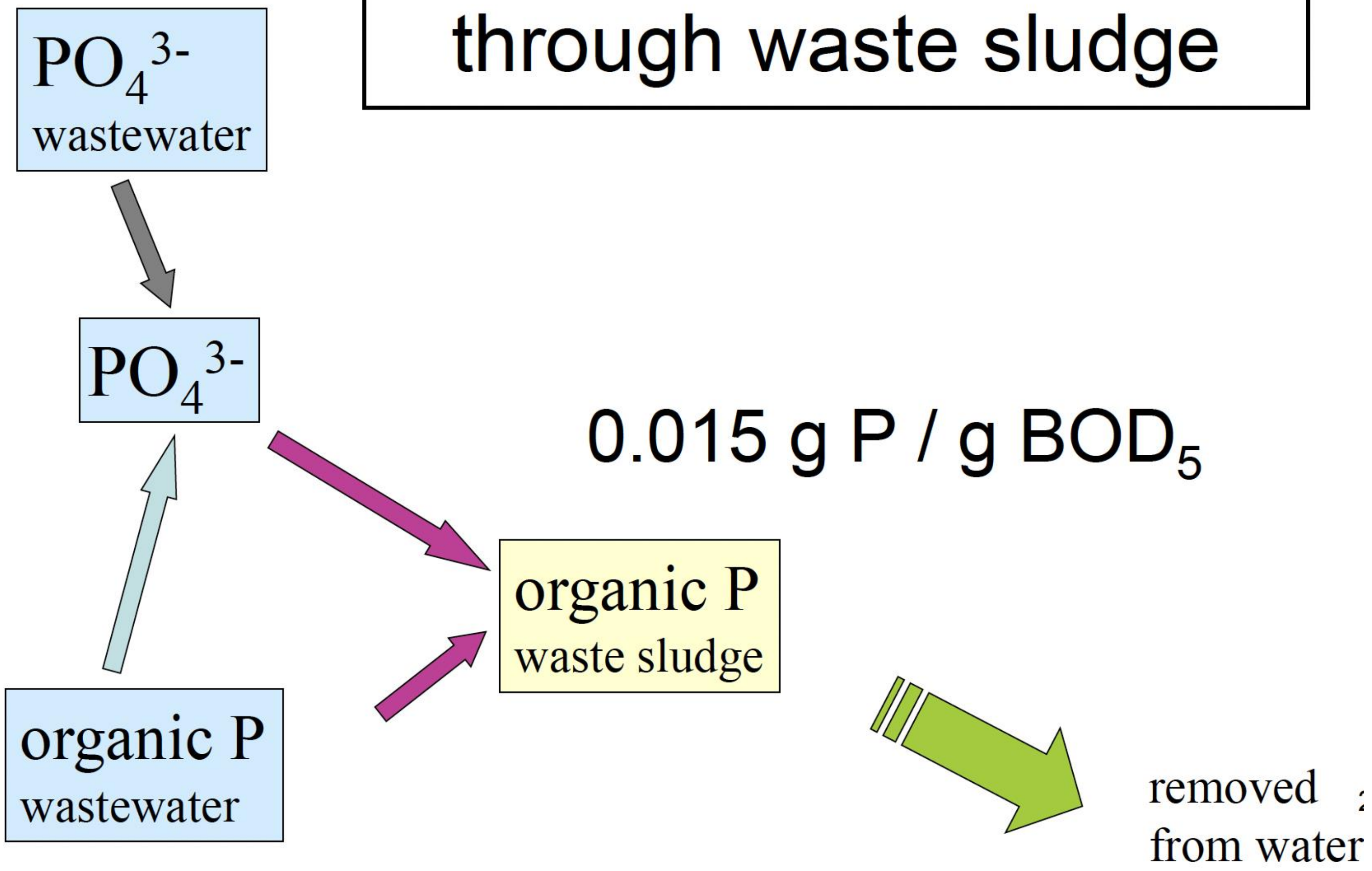
- **Orthophosphate (PO_4^-), Organic P**
- Organic phosphorus in wastewater typically includes complex molecules like phospholipids, nucleic acids, and phosphate esters. These are not directly removed by the simple metal-phosphate precipitation reaction. Instead:

Co-precipitation / Enmeshment (Primary Method): Physical removal of particulate and colloidal OP occurs as sticky, vast metal hydroxide flocs are formed, acting as a net to physically trap, bind, and settle the organic compounds.

Hydrolysis / Degradation: Biological removal breaks down complex dissolved OP molecules into simpler, readily precipitable inorganic orthophosphate using microbial enzymes, allowing for traditional chemical removal.

Similar to N removal, partial P is assimilated to biomass during C removal.

Phosphorous removal through waste sludge



PO_4^{3-} wastewater

PO_4^{3-}

organic P wastewater

organic P waste sludge

0.015 g P / g BOD_5

removed from water

Chemical phosphorous removal

- **Worldwide:** chemical P removal is still more common overall because of its robustness and ease of retrofitting into existing plants.
- for about 30 years in Switzerland: 60% equipped with chemical dephosphatation and about 75% of wastewater treated
- Uses metal salts (e.g., alum, ferric chloride) to precipitate phosphorus.

HOMEWORK

Step 1: Precipitation

Precipitation is the chemical reaction that transforms the dissolved phosphorus into a solid, insoluble compound.

iron chloride ($FeCl_3$)

iron sulfate ($FeSO_4$) Need oxidation

aluminium sulfate ($Al_2(SO_4)_3$)

Main reaction

$Me^{3+} + H_nPO_4^{(3-n)-} \leftrightarrow MePO_4 + nH^+$

Side reaction

$Me^{3+} + 3HCO_3^- \leftrightarrow Me(OH)_3 + 3CO_2$

Annual costs of three types of precipitants*

Precipitant	Quantity (t / y)	Unit costs (CHF / t)	Annual costs (CHF)
$FeCl_3$	91,8	250.-	22'950.-
$FeSO_4$	129,6	90.-	11'700.-
$Al_2(SO_4)_3$	146,0	210.-	30'700.-

* Hypothesis: WWTP treating wastewater of 10'000 cap with a load of 4 g/cap/d

Step 2: Coagulation

the process of rapidly destabilizing the fine solid particles.

- Formation of primary particles (Ø: 10-50 μm) from colloids (Ø: <1 μm) formed by precipitation
- destabilization can be produced in three ways: bridges between colloids; trapping by adsorption on big particles; decrease of electrostatic repulsion due to cations

Step 3: Flocculation

is the physical process where the destabilized particles (microflocs) are brought into contact with one another to grow into larger, heavier, and more easily settleable masses called **flocs**.

- Formation of flocs (Ø: >100 μm) due to collisions between primary particles in the tank with agitation
- a reversible process
- degree of flocculation depends on: hydraulic retention time; number of flocculation tanks; type of precipitant

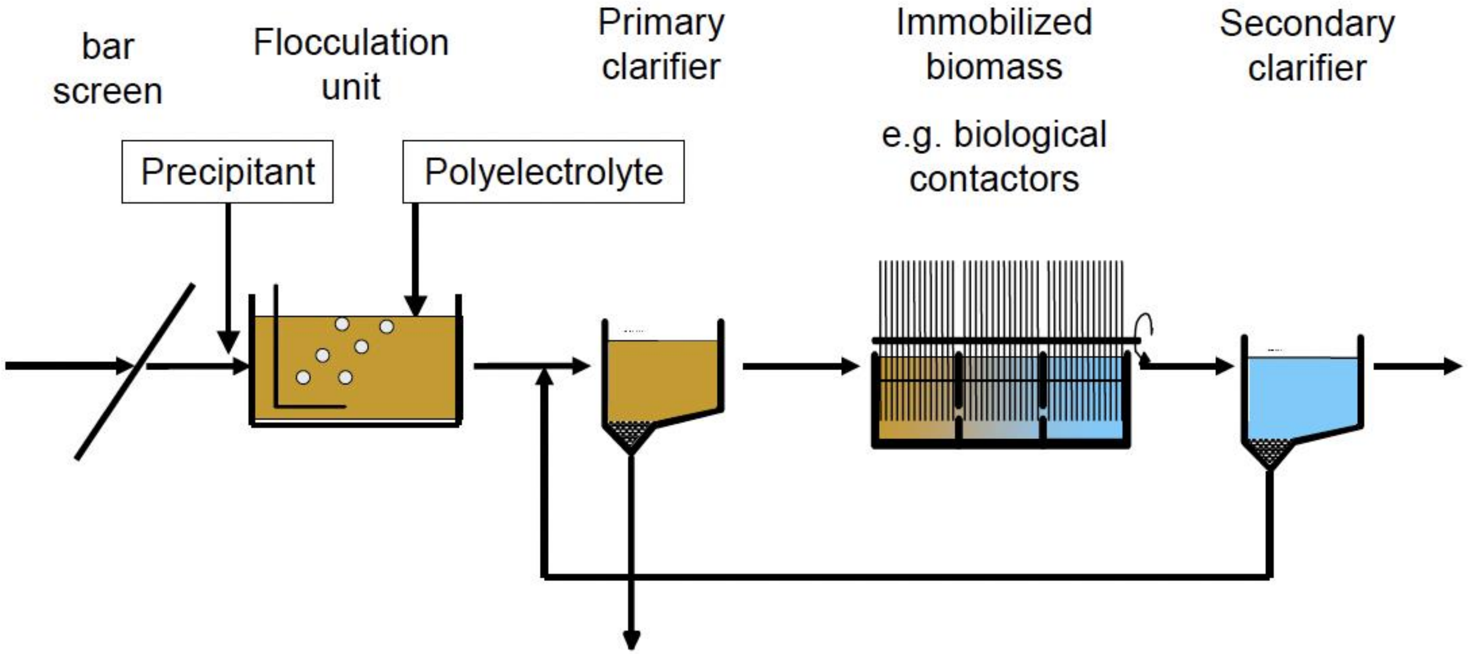
Chemical precipitation for **P removal** can occur at various points in the treatment train, primarily in:

- Primary Clarification (Pre-precipitation): Chemicals are added to the raw wastewater before or into the primary clarifiers.

- Biological Reactor / Secondary Treatment (Co-precipitation or Simultaneous Precipitation): Chemicals are added directly to the mixed liquor (the water and microorganisms) in the aeration basin or biological reactor.

- Tertiary Treatment (Post-precipitation or Effluent Polishing): Chemicals are added to the water exiting the secondary clarifier, followed by a dedicated clarification or filtration step.

Pre-precipitation



- Before or in the primary sedimentation tank.
- New insoluble precipitates along with general suspended solids, are removed as part of the primary sludge.

- Advantage:

- reduce the P load entering the biological treatment stage, which can protect the efficiency of the secondary treatment (e.g., additional bio P removal).

- It also generally requires a lower chemical dose for a given removal efficiency compared to other points, because P concentration is at its highest in the inflow, the precipitation reaction is more efficient and requires a lower molar ratio of metal ion to phosphorus.

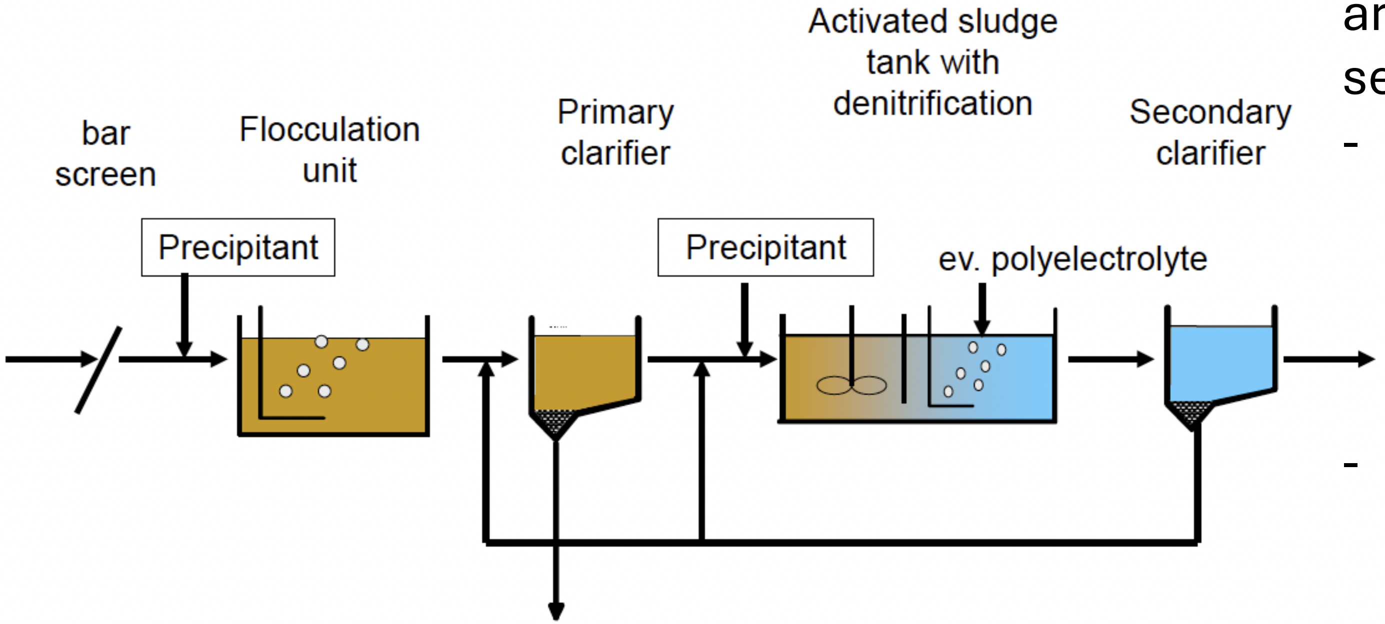
Disadvantage:

-Lower BOD/COD for denitrification.

targets only orthophosphate, not other forms of phosphorus, organic phosphorus.

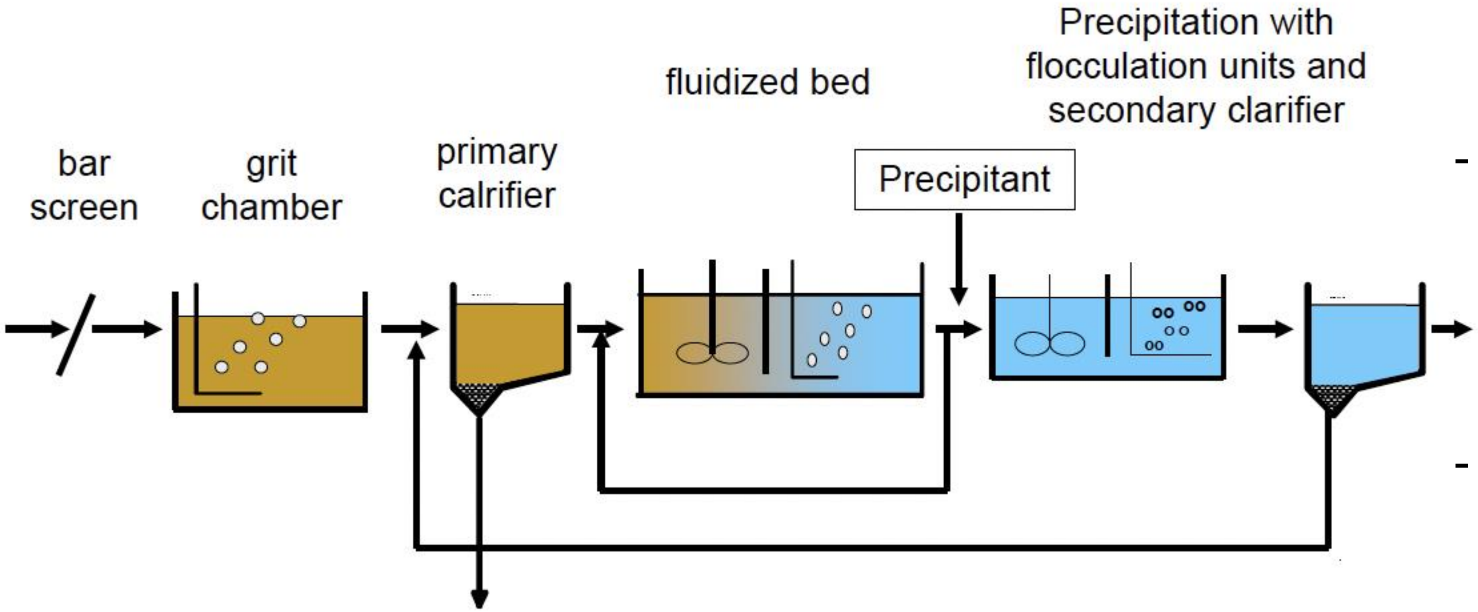
-Increased Primary Sludge Volume

Simultaneous precipitation



- Added directly to the aeration tank before the secondary clarifier.
- The chemical precipitates P within the biological floc. The resulting metal phosphate precipitates are removed with the activated sludge in the secondary clarifier.
- **Advantage:** It is often the simplest to implement as it utilizes the existing rapid mixing, flocculation, and sedimentation processes of the secondary treatment system, avoiding the need for dedicated downstream units.
- It enhances the settling of the biological sludge but increases the volume and mass of secondary sludge.
- Inhibition of Biological Processes The metal ions (Fe or Al) added can be toxic or inhibitory to some of the beneficial microorganisms.
- **Alkalinity Consumption:** Alum and ferric salts are acidic and consume the water's natural alkalinity. This can lower the pH in the aeration basin, which may hinder the performance of other sensitive biological processes like **nitrification**.
- **Difficult Phosphorus Recovery:** The phosphorus is chemically bound within a large volume of mixed biological and chemical sludge, making its recovery or reuse significantly more challenging than other P-removal methods.

Post-precipitation



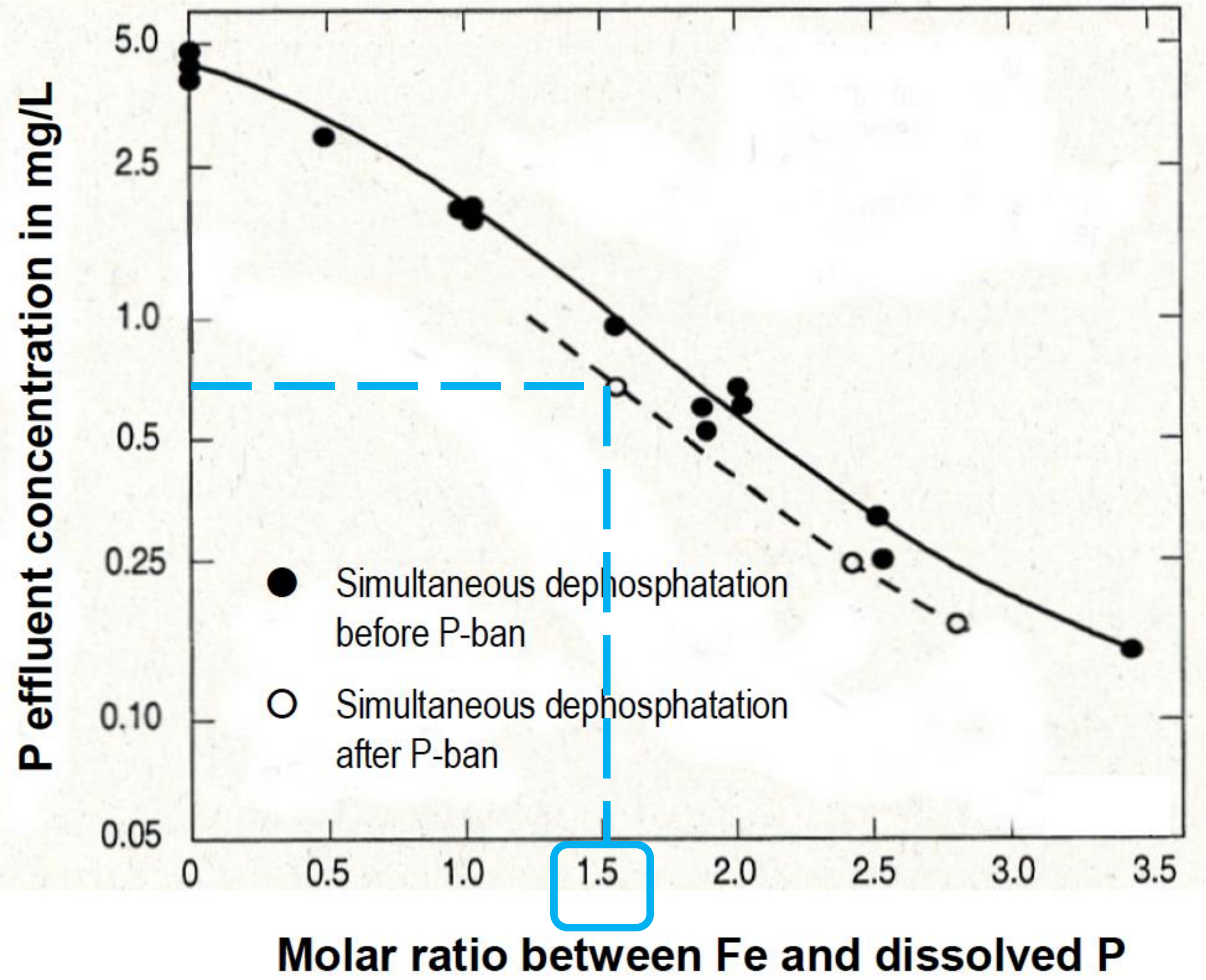
- Added to the inlet of the secondary clarifier, followed by a dedicated tertiary clarification, filtration unit, or separate chemical reaction tank.

- This method is used when **very stringent effluent phosphorus limits** (typically below 1.0 mg/L) must be met, as it provides the most precise control over the final effluent quality.

- A high dose of chemical is used to ensure the lowest possible residual P concentration in the final discharge.

- **High Capital Cost: dedicated facilities** for mixing, flocculation, and a final solids separation step (like a tertiary clarifier or filter).
- **Highest Chemical Dose** Achieving very low residual P concentrations (polishing) typically requires a **high ratio of chemical to phosphorus**, leading to the highest operational chemical costs of all the options.
- **Phosphorus Limitation for Downstream Processes** Removing too much P in the tertiary stage can lead to a **phosphorus-limited effluent**. If the plant includes advanced downstream processes (e.g., a denitrification filter) that rely on a small amount of P for bacterial growth, their performance can be hindered.

Relationship between molar Fe-P ratio and P concentration reached in WWTP effluent



Ban on Phosphates in Detergents: Switzerland imposed a ban on phosphates in **laundry detergents** in **1986**. This was a key step in reducing phosphorus entering the wastewater system.

Use this number in HOMEWORK

Enhanced Biological Phosphorus Removal

- P can be removed by chemical precipitation or by enriching phosphorus-accumulating organisms (PAO)

- Chemical precipitation
  - Addition of Fe or Al as chloride or sulfate salts
  - Toxic sludge
  - Increases operating $$.
  - Increases sludge production – *(you will see from the homework example)*.

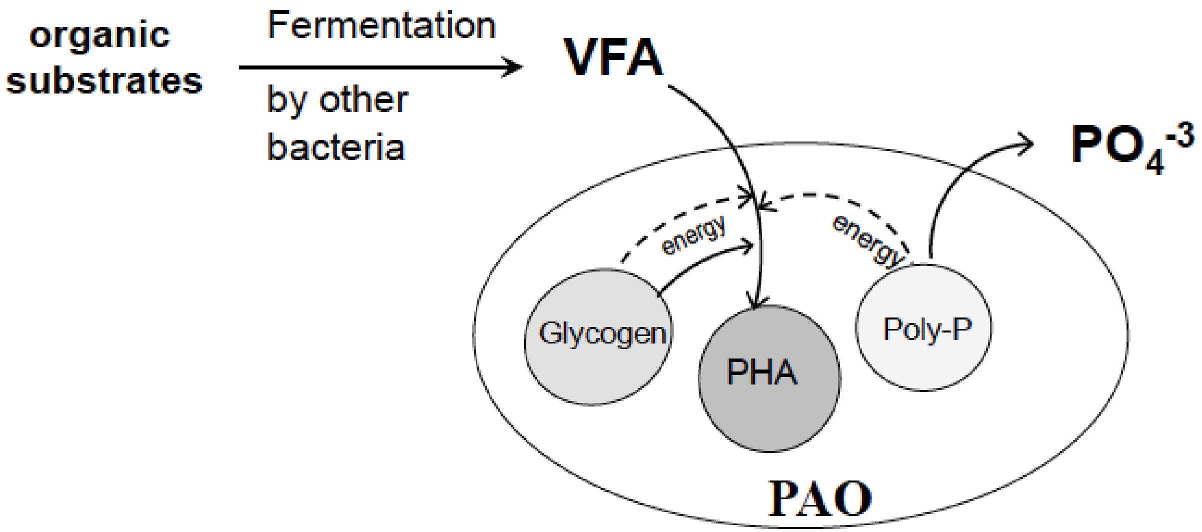
- Enhanced Biological Phosphorus Removal
  - growth of **phosphorus-accumulating organisms** (PAOs; sometimes called polyphosphate-accumulating organisms).
  - Relies on both oxic and anoxic bioreactors

PAO: phosphorus accumulating organisms

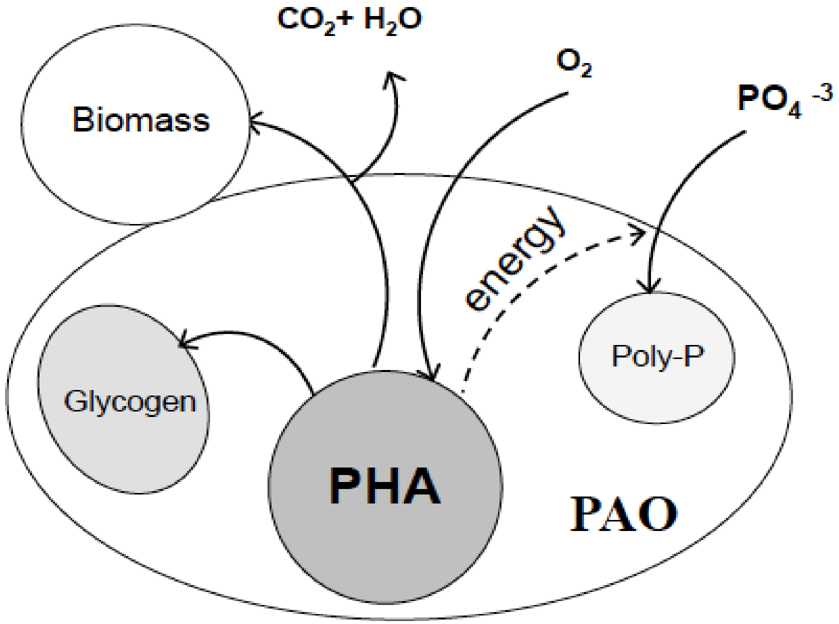
- When microbes face unbalanced nutrient growth conditions, they evolved strategies to accumulate extra nutrients inside the cells for future use! We try to use this strategy to “trick” microbes into taking up extra phosphorus from the WWT!

Anaerobic condition

Aerobic condition



$$2C_2H_4O_2 + (HPO_3) + H_2O \longrightarrow (C_2H_4O_2)_2 + PO_4^{3-} + 3H^+$$



$$C_2H_4O_2 + 0.16\ NH_4^+ + 1.2\ O_2 + 0.2\ PO_4^{3-} \longrightarrow 0.16\ C_5H_7NO_2 + 1.2\ CO_2 + 0.2\ (\ HPO_3) + 0.44\ OH^- + 1.44\ H_2O$$

To help understand:
Poly-P is a strong energy source, similar to the triple P bonds in ATP for the cells.
PHA is a great food, it's the carbon substrate for generating more energy for growth (only when it's paired with O2!). The synthesis of PHA itselves requires ATP.

How is this trait evolved in nature?

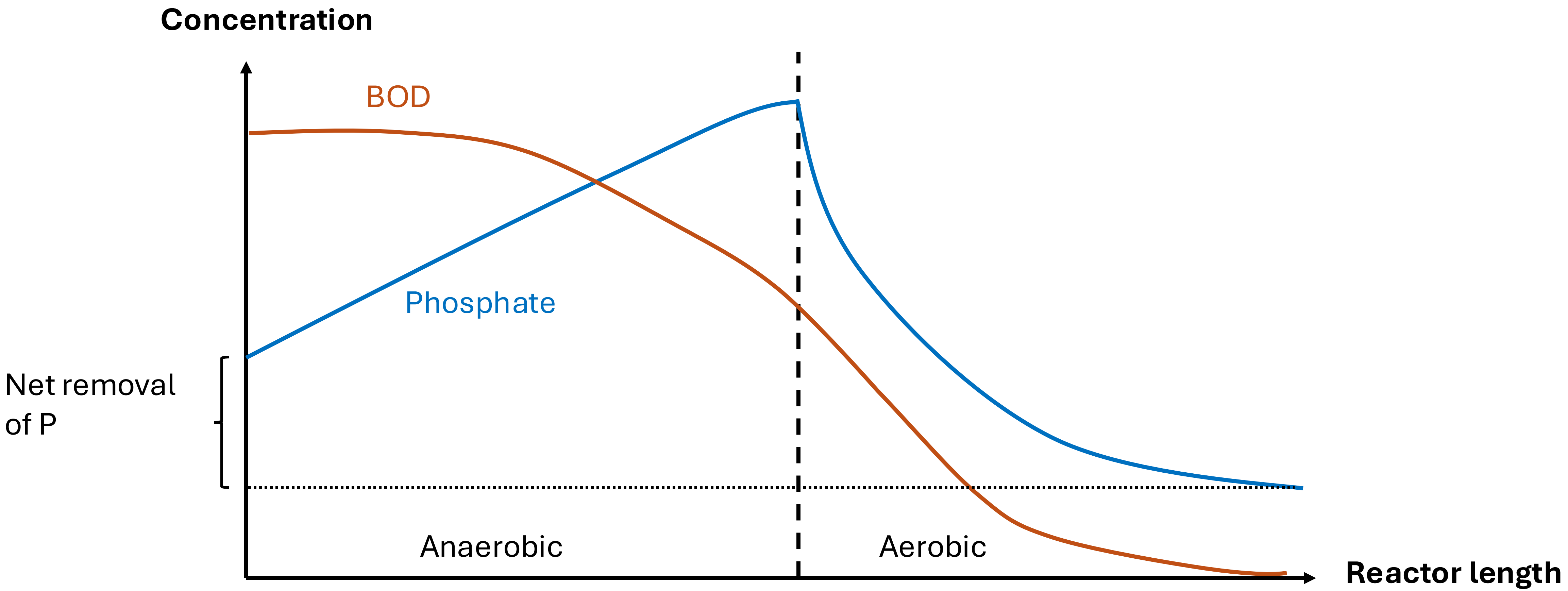
Condition	PAO Action	PAO Advantage
Anaerobic (No Oxygen/ No Nitrate)	PAOs are one of the few organisms that can still consume **volatile fatty acids (carbon)** in this zone. They get the energy to do this by **breaking down their stored polyphosphate (P)**, releasing P back into the water. The VFA food is stored as a carbon reserve (PHA).	They **outcompete** most other microbes for the carbon food due to polyP energy. So the PAOs feast while others starve.
Aerobic (With Oxygen)	The PAOs, having used up their polyP energy, now have a big reserve of carbon (PHA). They rapidly use **oxygen** to "burn" this carbon for growth energy. They also use the *extra* energy to **over-accumulate P** back into their cells as.	They rebuild their energy reserves (**Poly-P**), ensuring they can repeat the resource-hoarding process when the anaerobic conditions return. This large energy store helps them grow and divide more successfully than their rivals.

Inplementation of biological P removal

- The hyperaccumulation of P is a response to the selective pressure of the anaerobic "feast" (carbon uptake using poly-P energy) followed by the aerobic "famine" (phosphate uptake to replenish stores).

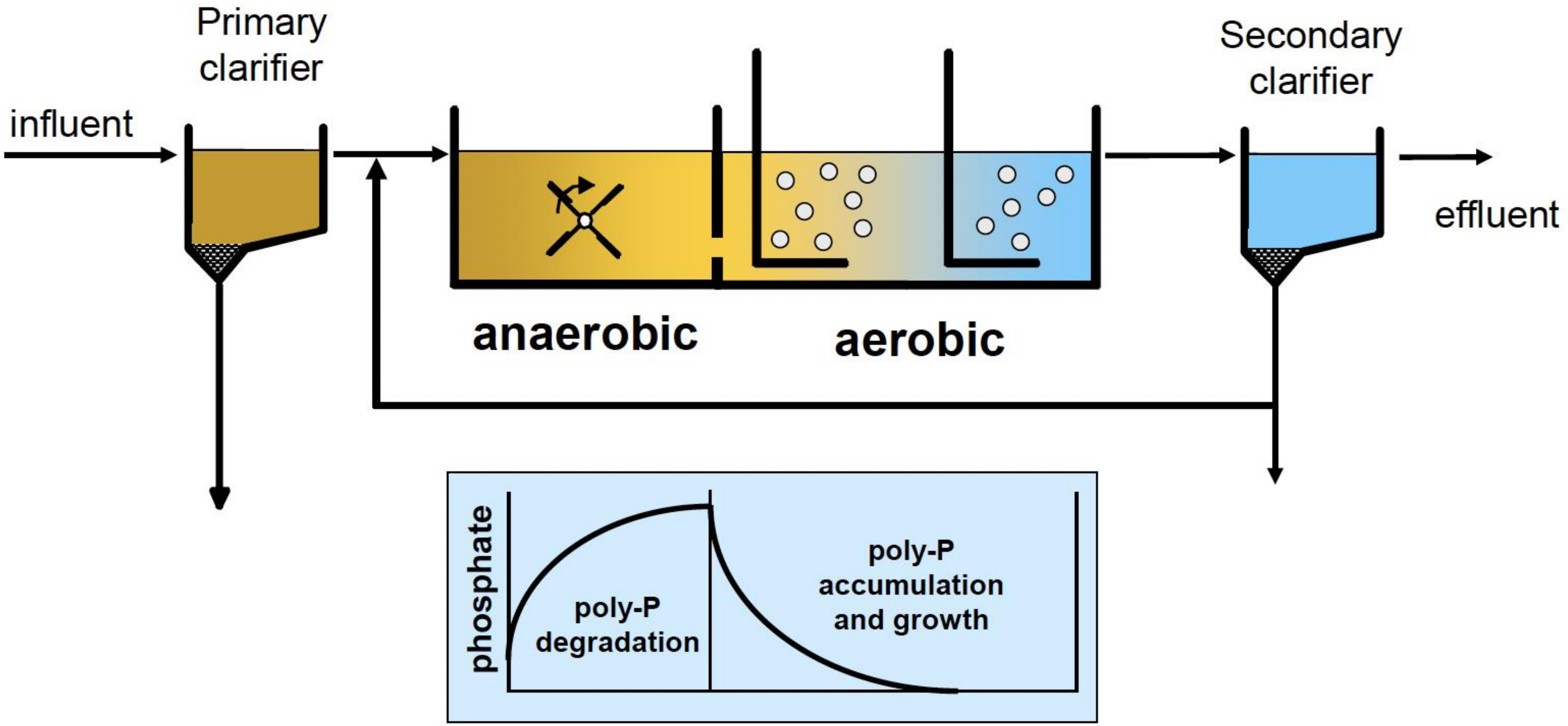
- PAOs need alternation of anaerobic and aerobic phases
- Some PAOs can also denitrify, hence there should be **absence of nitrate during anaerobic phase**
- PAOs need VFAs for PHA formation, hence there should be presence of easily biodegradable organic compounds in anaerobic zone

Enhanced biological Phosphorus removal (EBPR)



The A/O process
for biological dephosphatation

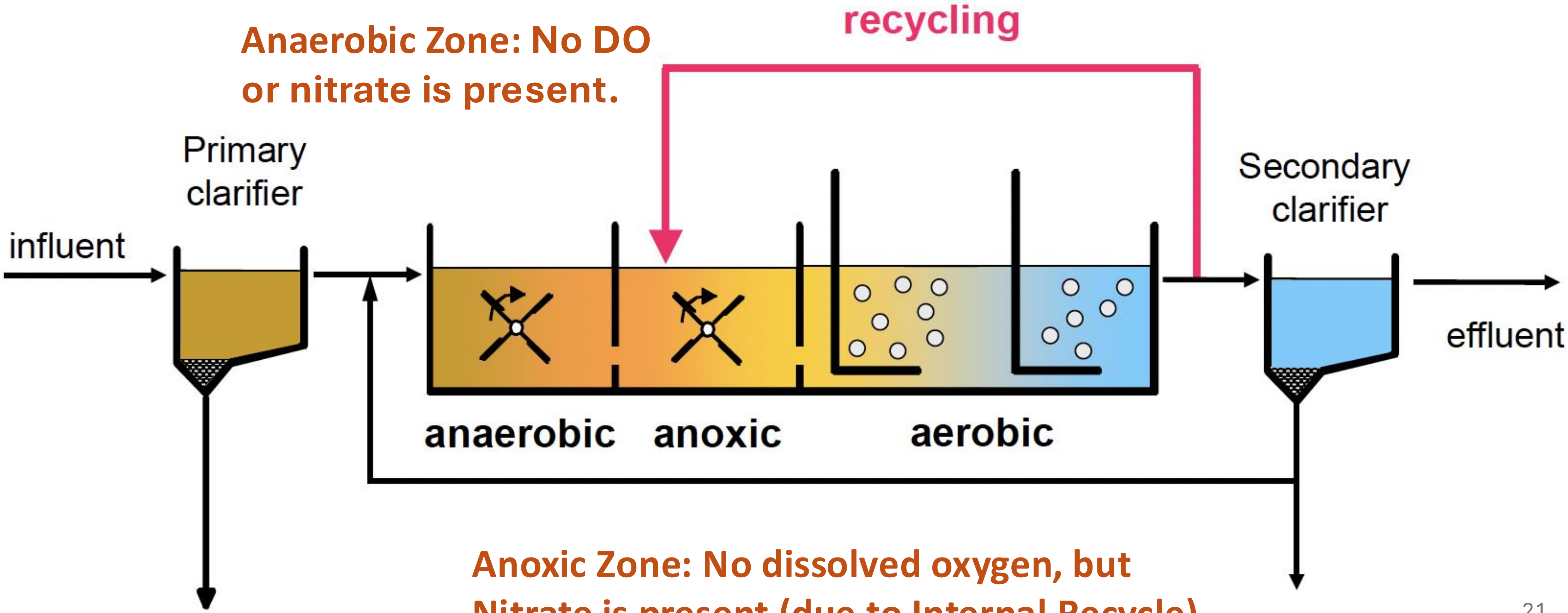
Enhanced Biological Phosphorus Removal (EBPR) and BOD/COD removal (nitrification happens, but denitrification is limited).



The A^2/O process

for biological dephosphatation

Simultaneous Biological Nitrogen and Phosphorus Removal and BOD/COD removal.



Anaerobic Zone: No DO or nitrate is present.

Anoxic Zone: No dissolved oxygen, but Nitrate is present (due to Internal Recycle)

PAO-GAO Glycogen-Accumulating Organisms Competition

- **Same Appetite, Different Outcome:** Both PAOs and GAOs consume volatile fatty acids (VFA) in the anaerobic zone, like acetate.

- **Wasted Food:** When GAOs consume VFAs, they store the carbon internally as PHA (like PAOs do), but they get their energy by breaking down stored glycogen, not by releasing poly-P.

- **Result:** The available VFA food is split between the PAOs (which remove P) and the GAOs (which **do not** remove P). This limits the VFA available for the PAOs, slowing their growth and their capacity to over-accumulate P in the subsequent aerobic phase

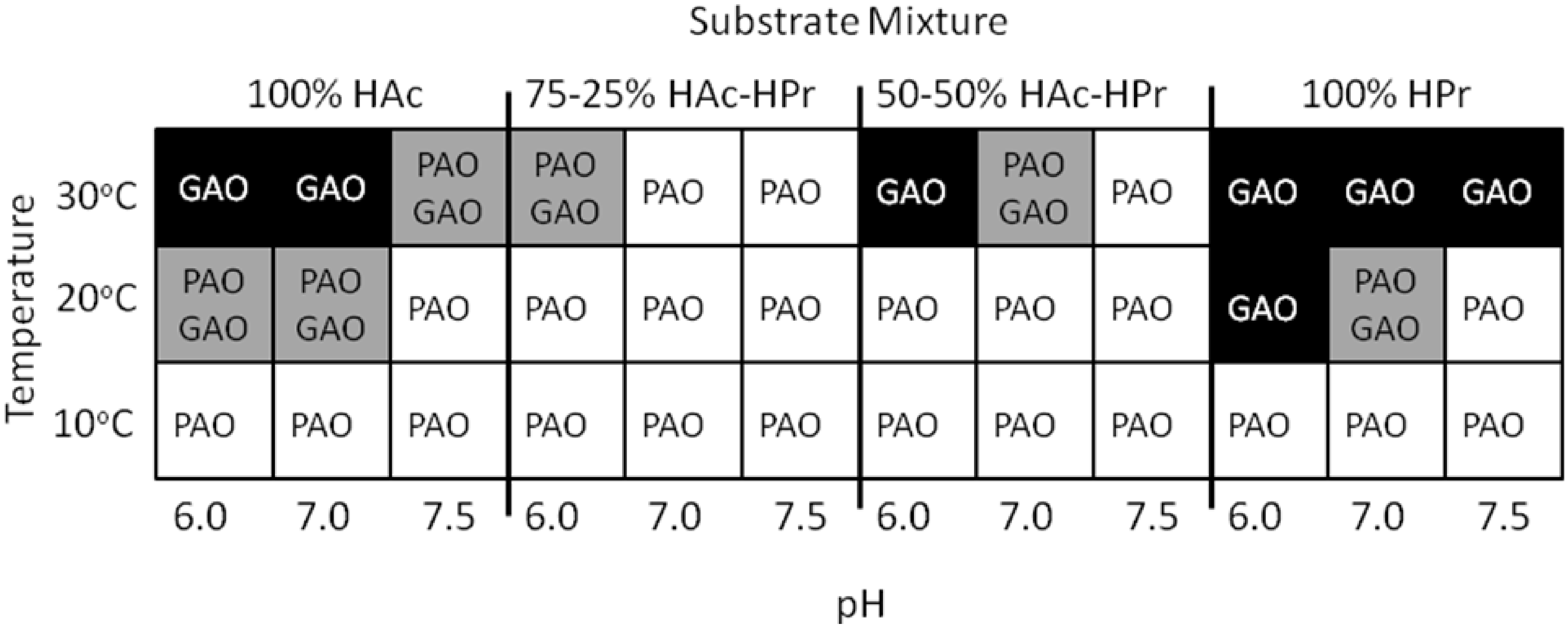
PAOs and GAOs are always present simultaneously. Our goal is to limit GAO growth.

PAO-GAO Competition

Four factors can be controlled to influence PAO-GAO competition

a) type of carbon source
   i. Acetate and propionate used by PAOs
   ii. GAOs are more complex and may use only one
b) phosphate to COD (P:COD) ratio in the influent
   i. GAO can compete when P:COD < 0.2 g PO_4-P/g COD
   ii. Occurs when phosphate limited for extensive periods
c) pH
   i. PAOs dominate in systems with pH above 7
   ii. GAO acetate uptake rate decreases as pH increases
d) Temperature
   i. PAOs compete better relative to GAOs at lower temperatures

Summary of PAO-GAO Competition



Temperature	100% HAc			75-25% HAc-HPr			50-50% HAc-HPr			100% HPr		
pH	6.0	7.0	7.5	6.0	7.0	7.5	6.0	7.0	7.5	6.0	7.0	7.5
30°C	GAO	GAO	PAO GAO	PAO GAO	PAO	PAO	GAO	PAO GAO	PAO	GAO	GAO	GAO
20°C	PAO GAO	PAO GAO	PAO	PAO	PAO	PAO	PAO	PAO	PAO	GAO	PAO GAO	PAO
10°C	PAO	PAO	PAO	PAO	PAO	PAO	PAO	PAO	PAO	PAO	PAO	PAO

Figure 7.43 The population distributions of phosphate accumulating organisms (PAOs) and glycogen accumulating organisms (GAOs) as a function of the nature of the substrate (acetic acid (HAc) to propionic acid (HPr) ratio), pH, and temperature. Grey boxes represent coexistence; black and white boxes represent predominance of the organism listed. After Lopez-Vazquez et al.[23]

BREAK!

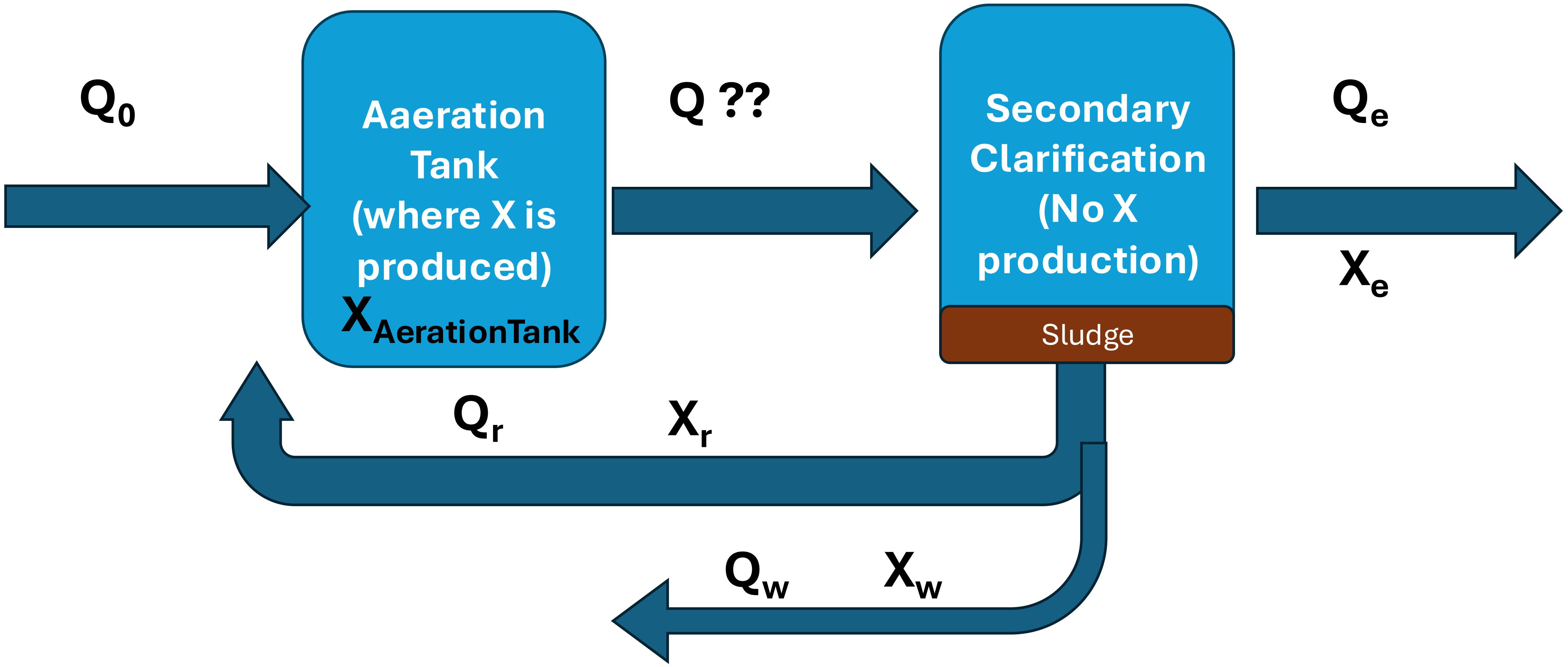
Activated sludge process, Recap:

A biological method for treating wastewater that uses a mixture of air and microorganisms in an **aeration tank** to break down organic matter and ammonia. Activated sludge = sludge that has been “activated” by aeration, containing a thriving population of microorganisms that can treat wastewater.

After the aeration tank, the mixture moves to a settling tank, or clarifier, where the microorganisms (activated sludge) settle to the bottom, leaving cleaner water.

A portion of the settled sludge is then recycled back into the aeration tank to continue the process, while the excess is removed.

Mass balance



Q_0

Aaeration Tank (where X is produced)

$X_{AerationTank}$

Q ??

Secondary Clarification (No X production)

Sludge

Q_e

X_e

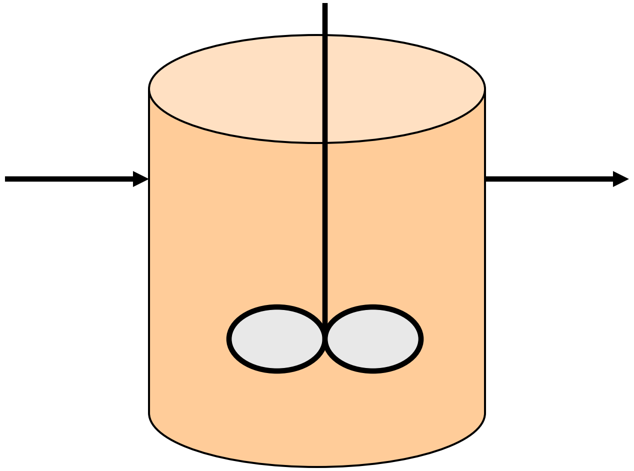
Q_r

X_r

Q_w

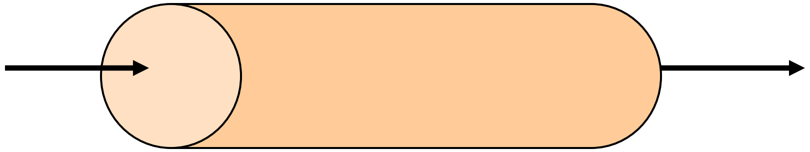
X_w

Previous questions: microorganisms growth in CSTR (continuous stirred-tank reactor), or sometimes called chemostat



Continuous-stirred
tank reactor (CSTR)

Ideal Reactor Types

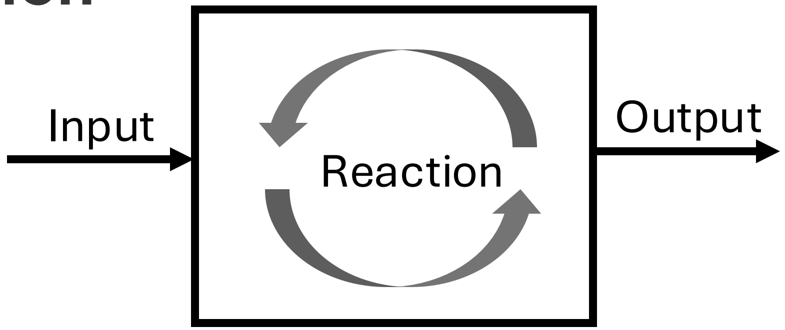


Plug-flow reactor (PFR)

Reactor Mass Balance

Rate of mass accumulation in control volume
= Rate(s) of mass in − Rate(s) of mass out + Rate(s) of mass generation

Or simply:
Accumulation = Input – Output + reaction



- **Reaction** term is determined by kinetics, stoichiometry, and reactor configuration.

Continuous stir-tank reactor (CSTR)

- continuous inflow = outflow
- complete mixing
- concentration in the reactor is uniform and equal to the effluent concentration

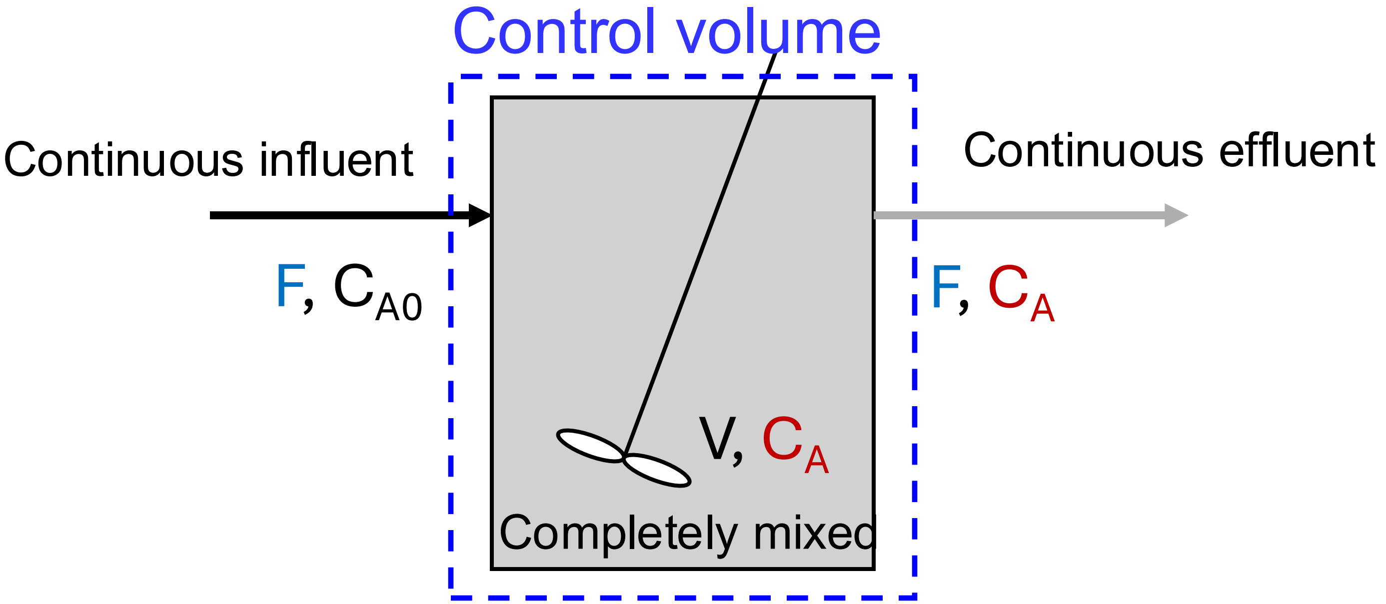
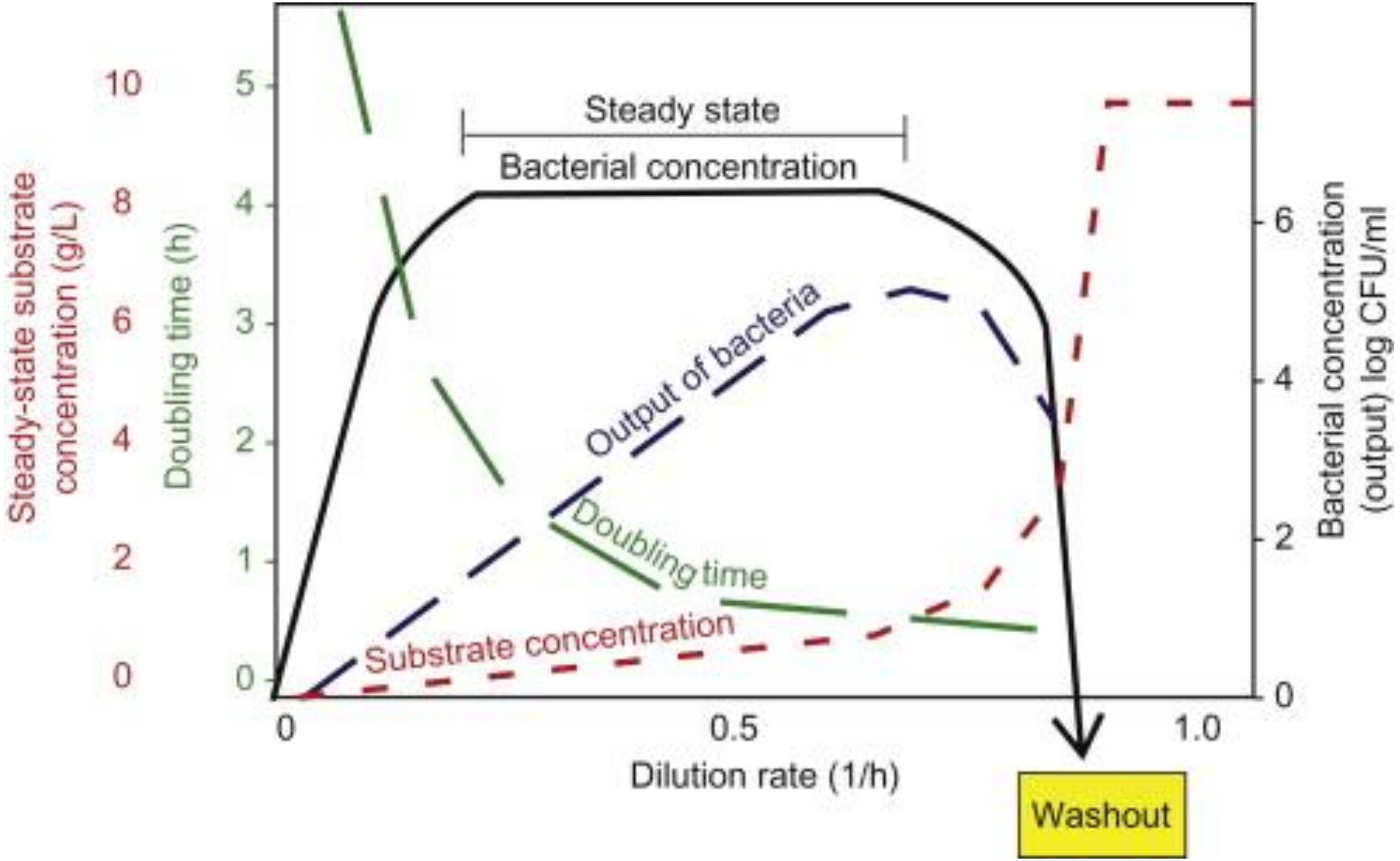


Illustration of washout and steady state



Dimensioning of the biological reactor of an activated sludge WWTP with nitrification, denitrification and chemical dephosphatation.

“Dimensioning”: the engineering design process of determining the required dimensions and capacity of the units.

We will treat the treatment systems rather “superficially”, meaning only consider **steady-state (i.e., continuous flow) and largely based on mass balance**.

Historically activated sludge systems have been dimensioned with the organic load, also known as food to microorganisms ratio:

$$B_{SS,BOD} = \frac{Q_0 \; C_{0,BOD}}{V_{AT} \; X_{AT}} \quad \text{in kg BOD}_5 \text{ / kg SS / d}$$

$$\boxed{V_{AT} = \frac{Q_0 \; C_{0,BOD}}{B_{SS,BOD} \; X_{AT}}}$$

Mass of BOD_5 or COD entering the system per day (Food) / Mass of the mixed volatile suspended solids (microorganisms)

Low F/M Ratios (e.g., 0.05- 0.15 /day): Leads to a low-growth, low-substrate environment. Favors the growth of slow-growing **filamentous organisms** (e.g., *M. parvicella*), which often cause **sludge bulking** (poor settling).

High F/M (0.4 - 1.0 / day) : High Rate process. **higher oxygen demand** in the aeration tank.
Leads to a high-growth, high-substrate environment.
Favors the growth of **floc-forming bacteria** and **high F/M filamentous organisms**.
Results in **high excess sludge production**.

Optimal Ratios (e.g., 0.2- 0.4/day): Characterizes the **Conventional Activated Sludge** process. Generally promotes a balance between floc-forming and filamentous organisms, leading to **good sludge settling**.

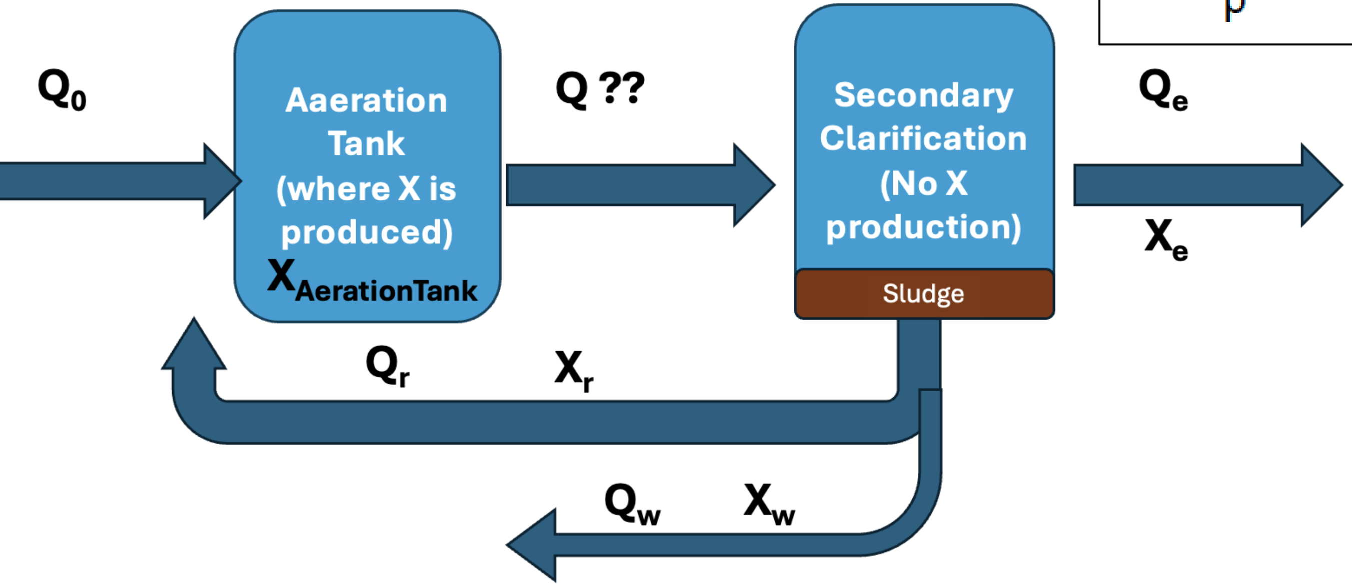
F/M is inversely correlated to the SRT:
Lower F/M provide the necessary retention time for the **nitrifying bacteria.**

Sludge age:

$$\theta_X = \frac{V_{AT} \cdot X_{AT}}{Q_0 \cdot X_e + Q_w \cdot X_w} \quad \text{in days (d)}$$

<u>with :</u>

V_{AT}	volume of activated sludge tank
X_{AT}	SS in activated sludge tank
Q_0	inflow rate in activated sludge tank
X_e	SS in effluent
Q_p	waste sludge flow rate
X_p	SS concentration in waste sludge



Q_0

Aaeration Tank (where X is produced)

$X_{AerationTank}$

Q ??

Secondary Clarification (No X production)

Sludge

Q_e

X_e

Q_r X_r

Q_w X_w

$$\boxed{\theta_X = \frac{V_{AT} \cdot X_{AT}}{Q_0 \cdot X_e + Q_w \cdot X_w} \quad \text{in days (d)}}$$

$$Q_0 \cdot X_e + Q_w \cdot X_w = SP_d \quad \text{in kg SS / d}$$

Daily sludge production SP_d

Specific sludge production SP_c

$$SP_d = SP_c Q_0 C_{0,BOD} \quad \text{in kg SS / d}$$

Specific sludge production due to BOD oxidation

+

Specific sludge production due to chemical dephosphatation :

With iron salts :

Empirical math equations

HOMEWORK

$$SP_{c,P} = 6.8 \times \frac{C_{0,P}}{C_{0,BOD}}$$ in kg SS / kg BOD

With aluminum salts :

$$SP_{c,P} = 5.3 \times \frac{C_{0,P}}{C_{0,BOD}}$$ en kg SS / kg BOD

Here it completes the derivation of food to microorganisms ratio, and the equation to calculate the aeration tank volume:

$$\theta_X = \frac{V_{AT} \cdot X_{AT}}{\boxed{Q_0 \cdot X_e + Q_w \cdot X_w}}$$

$$= SP_d = SP_c Q_0 C_{0,BOD}$$

$$\theta_X = \frac{V_{AT} \cdot X_{AT}}{SP_c \cdot Q_0 \cdot C_{0,BOD}}$$

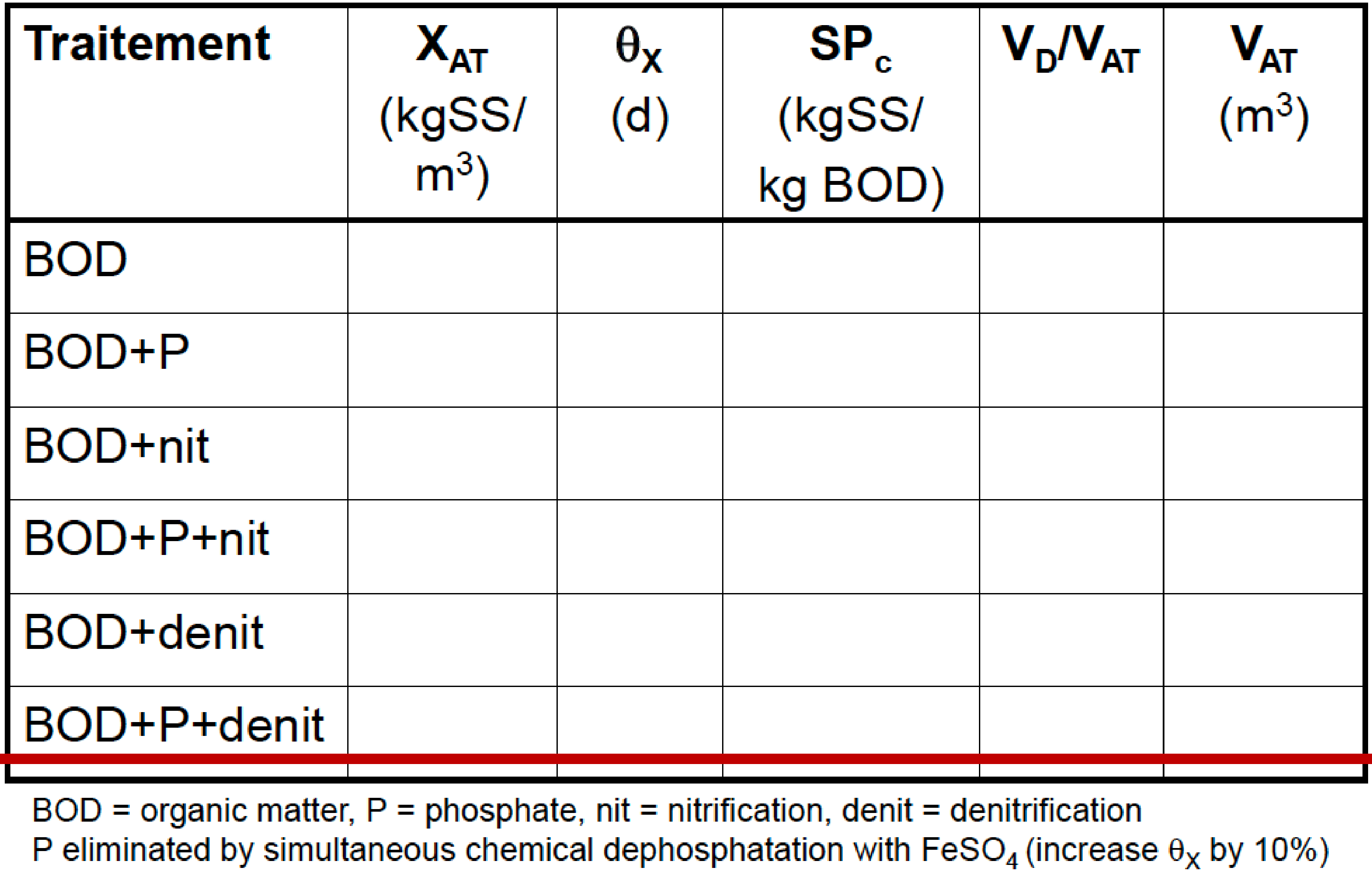
$$B_{SS,BOD} = \frac{Q_0 \; C_{0,BOD}}{V_{AT} \; X_{AT}} \Rightarrow \boxed{B_{SS,BOD} = \frac{1}{SP_c \cdot \theta_{{}_{10}X}}}$$

$$B_{SS,BOD} = \frac{1}{SP_c \cdot \theta_X} = \frac{Q_0 C_{0,BOD}}{V_{AT} X_{AT}}$$

$$\boxed{V_{AT} = \frac{Q_0 C_{0,BOD} SP_c \theta_X}{X_{AT}}}$$

HOMEWORK

Let's see the effect of adding nitrification, denitrification, and chemical dephosphatation on the volume requirement of the aeration tank!



Traitement	X_{AT} (kgSS/m^3)	θ_X (d)	SP_c (kgSS/kg BOD)	V_D/V_{AT}	V_{AT} (m^3)
BOD					
BOD+P					
BOD+nit					
BOD+P+nit					
BOD+denit					
BOD+P+denit					

BOD = organic matter, P = phosphate, nit = nitrification, denit = denitrification
P eliminated by simultaneous chemical dephosphatation with $FeSO_4$ (increase θ_X by 10%)

Treating wastewater of 10'000 PE with primary treatment and a secondary treatment at 10 °C :

Influent flow rate	Q_0	3'500 m^3/d
BOD in AT influent	$C_{0,BOD}$	130 g BOD_5/m^3
SS in AT influent	$X_{0,SS}$	100 g SS/m^3
SS in effluent	$X_{e,SS}$	15 g SS/m^3
TKN in influent	$C_{0,TKN}$	30 g $N\text{-}TKN/m^3$
N_{tot} in effluent	$C_{e,Ntot}$	10 g N/m^3
P_{tot} in influent	$C_{0,Ptot}$	7 g P/m^3

<u>P.S. elimination by waste sludge :</u>

N : 0.045 g N/g BOD_5

P : 0.015 g P/g BOD_5

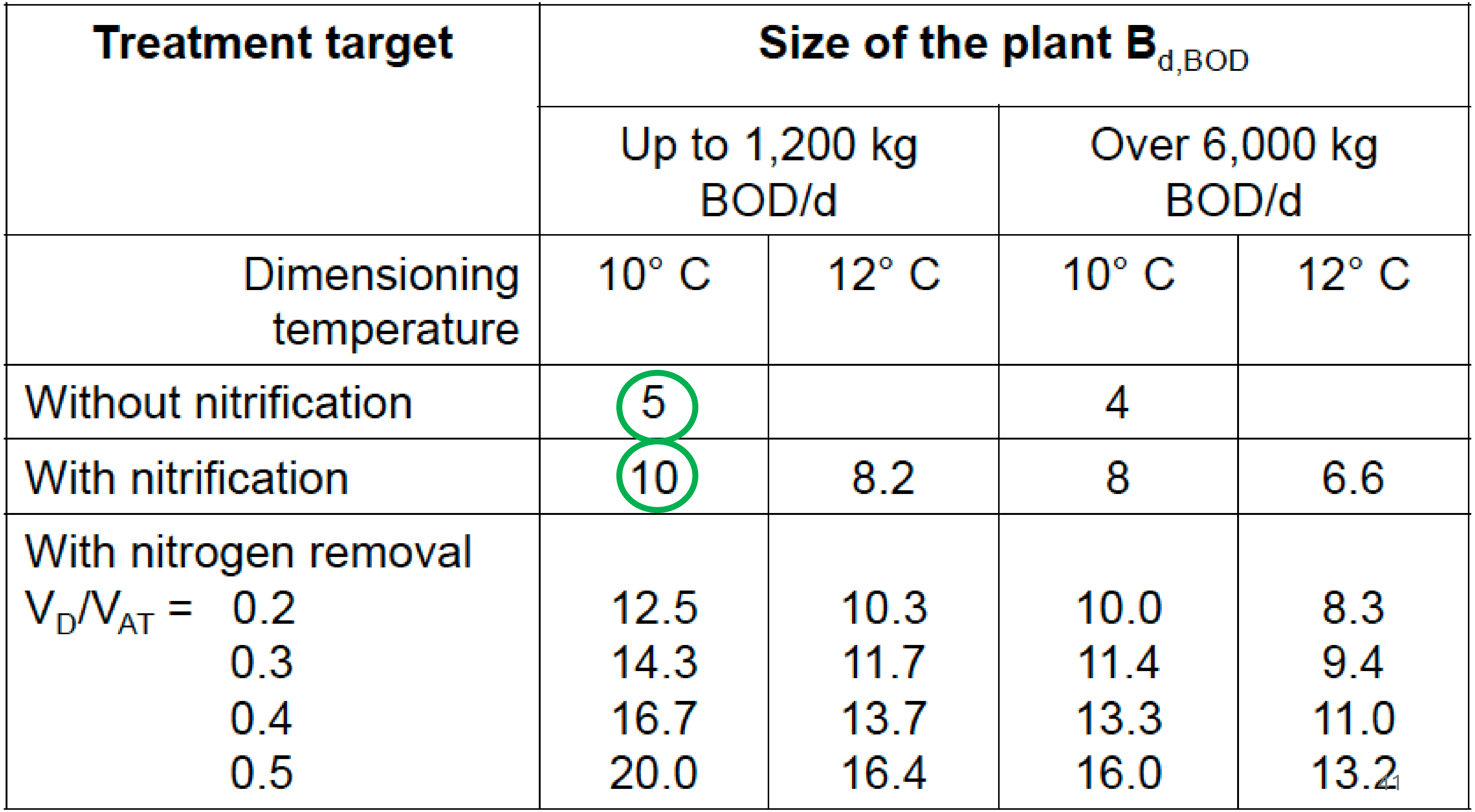
HOMEWORK: these are the values from PC effluent, not the wastewater inflow.

~25% of BOD is removed by PC.

~50% of TSS is removed by PC.

~10% of TKN is removed by PC.

Look for θ_x: dependent on the treatment target and the temperature as well as the plant size



Treatment target	Size of the plant $B_{d,BOD}$			
	Up to 1,200 kg BOD/d		Over 6,000 kg BOD/d	
Dimensioning temperature	10° C	12° C	10° C	12° C
Without nitrification	5		4	
With nitrification	10	8.2	8	6.6
With nitrogen removal				
V_D/V_{AT} = 0.2	12.5	10.3	10.0	8.3
0.3	14.3	11.7	11.4	9.4
0.4	16.7	13.7	13.3	11.0
0.5	20.0	16.4	16.0	13.2

This is for Denitrification, we come back to this:

Look for $SP_{c,BOD}$ [kg SS/kg BOD_5] at ~ 10 °C

0.76 ≈

$X_{0,SS}$/ $C_{0,BOD}$	Sludge age θ_X in days					
	4	**8**	**10**	**15**	**20**	**25**
0.4	0.79	0.69	0.65	0.59	0.56	0.53
0.6	0.91	0.81	0.77	0.71	0.68	0.65
0.8	1.03	0.93	0.89	0.83	0.80	0.77
1.0	1.15	1.05	1.01	0.95	0.92	0.89
1.2	1.27	1.17	1.13	1.07	1.07	1.01

A **higher $X_{0,SS}/c_{0,BOD}$ ratio** means a higher concentration of inert solids relative to the organic “food”. This increases the total mass of sludge that must be handled, regardless of the biological reactions.

Decreasing on this direction due to internal degradation if sludge stays longer

$$SP_{c,BOD} = \left(0.75 + 0.6 \times \frac{X_{0,SS}}{C_{0,BOD}} - \frac{0.102 \times \theta_X \times F_T}{1 + 0.17 \times \theta_X \times F_T}\right)$$

$F_T = 1.072^{(T-15)}$ (F_T = temperature factor for endogenous respiration)

No need to use this equation for our purpose, just do a quick extrapolation from the table.

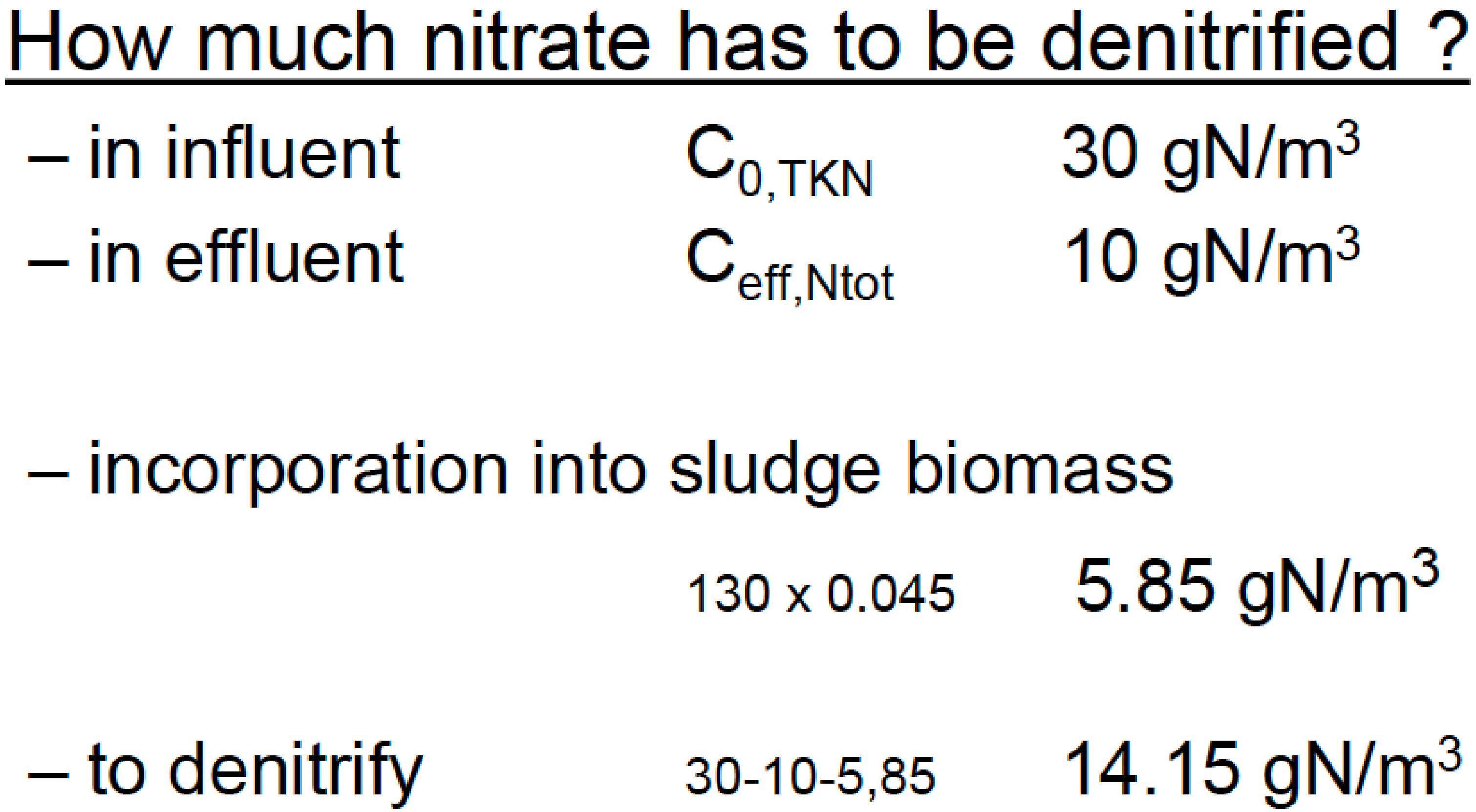
HOMEWORK

Concentration of biomass X_{AT} in treatment tank [kg SS/m^3] with Primary Clarification

• Without nitrification	2.5 – 3.5
• With nitrification (and denitrification)	2.5 – 3.5
• With chemical phosphate removal (simultaneous)	3.5 – 4.5

We take the middle values 3 and 4

To get the θ_x for denitrificaton processes, we need the parameter V_d/V_{AT} from denitrification capacity needed "r_{den}"



How much nitrate has to be denitrified ?

– in influent	$C_{0,TKN}$	30 gN/m^3
– in effluent	$C_{eff,Ntot}$	10 gN/m^3
– incorporation into sludge biomass		
	130 x 0.045	5.85 gN/m^3
– to denitrify	30-10-5,85	14.15 gN/m^3

To get the θ_x for denitrificaton processes, we need the parameter V_d/V_{AT} from denitrification capacity needed "r_{den}"

Denitrification Volume Ratio: *the relative size of the anoxic (denitrification) zone compared to the total reactor volume.*

- Denitrification capacity

r_{den} in kg $N\text{-}NO_3/kg\ BOD_5$

$$r_{den} = \frac{N \cdot to \cdot denitrify}{BOD_5 \cdot in \cdot influent} = \frac{14.15 N - NO_3/m^3}{130 g BOD_5/m^3}$$

$$\boxed{\mathbf{r_{den}} = 0.11\ kg\ N\text{-}NO_3/kg\ BOD_5}$$

r_{den} in pre-anoxic zone denitrification	V_D / V_{AT}
0.11	0.2
0.13	0.3
0.14	0.4
0.15	0.5

Look for θ_x: dependent on the treatment target and the temperature as well as the plant size

This is for Denitrification:

Treatment target	Size of the plant $B_{d,BOD}$			
	Up to 1,200 kg BOD/d		Over 6,000 kg BOD/d	
Dimensioning temperature	10° C	12° C	10° C	12° C
Without nitrification	5		4	
With nitrification	10	8.2	8	6.6
With nitrogen removal				
V_D/V_{AT} = 0.2	12.5	10.3	10.0	8.3
0.3	14.3	11.7	11.4	9.4
0.4	16.7	13.7	13.3	11.0
0.5	20.0	16.4	16.0	13.2

Traitement	**X_{AT}** (kgSS/ m^3)	**θ_X** (d)	**SP_c** (kgSS/ kg BOD)	**V_D/V_{AT}**	**V_{AT}** (m^3)
BOD	3	5	0.99	---	**751**
BOD+P	4	5.5	1.34	---	**838**
BOD+nit	3	10	0.88	---	**1335**
BOD+P+nit	4	11	1.24	---	**1552**
BOD+denit	3	12.5	0.85	0.20	**1611**
BOD+P+denit	4	13.8	1.21	0.20	**1899**

BOD = organic matter, P = phosphate, nit = nitrification, denit = denitrification
P eliminated by simultaneous chemical dephosphatation with $FeSO_4$ (increase θ_X by 10%)

Nitrification process drastically increased the volume requirements !

Necessary total recirculation flow ratio for denitrification

– to denitrify	30-10-5.85	14.15 gN/m^3
– to nitrify	30-5.85	24.15 gN/m^3

➔ % of nitrate to recirculate :

14.15 / 24.15 = 59% (η_N=0.59)

$$r = \frac{1}{(1-\eta_N)} - 1 = 1.44$$

The long θ_x for nitrification comes with historical reason, when the design is on the safe side: Safety factor (SF) for nitrification

$$\mathbf{SF = \mu_{max}(T) \cdot \theta_X > 1}$$

$$\Rightarrow \mu_{max}(T) = \mu_{max}(T_{20}) \cdot e^{\theta_T (T-20)}$$

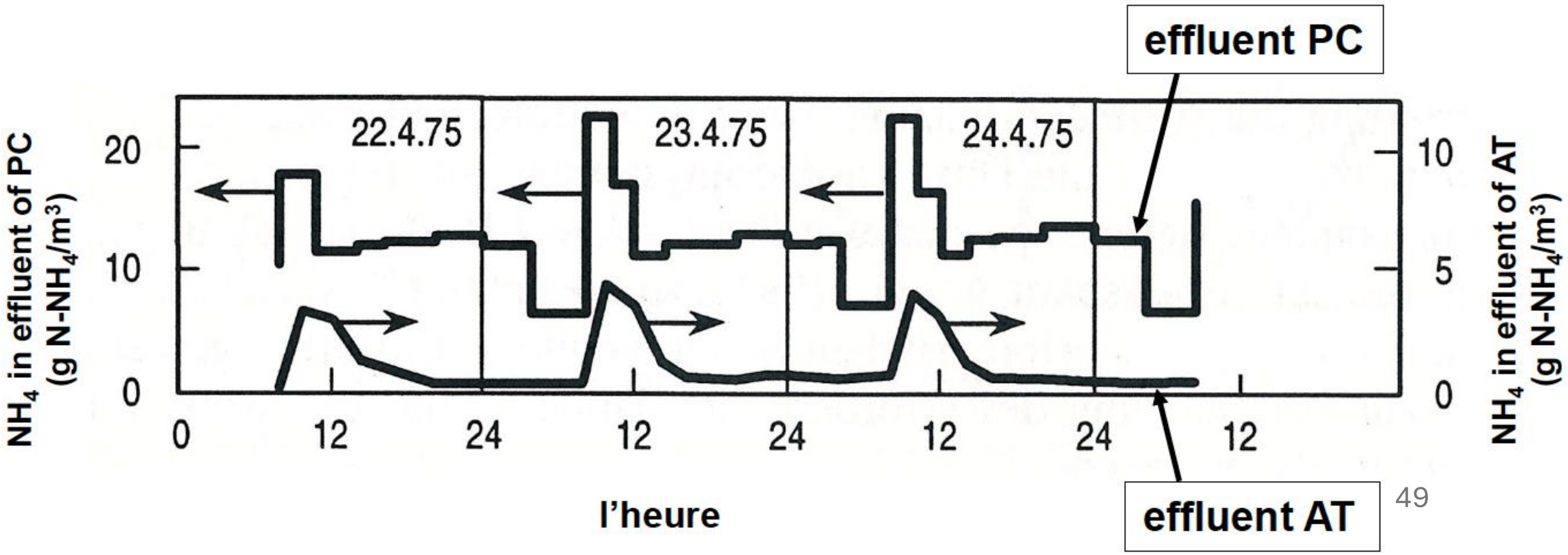
$$\Rightarrow \theta_X = \frac{V_{AT} \cdot X_{AT}}{Q_0 \cdot X_e + Q_w \cdot X_w}$$

Our example:

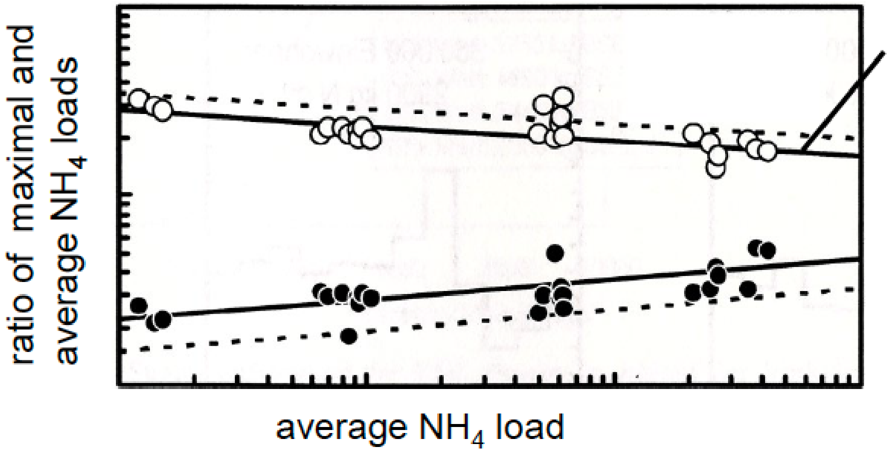
$$\left.\begin{array}{l} T = 10°C \\ \mu_{max}(T_{20}) = 0.85\ h^{-1}* \\ \theta_T = 0.11* \\ \theta_X = 10\ d \end{array}\right\} \begin{array}{l} SF = \mu_{max}(T_{20}) \cdot e^{\theta_T (T-20)} \cdot \theta_X \\ = 0.85 \cdot e^{0.11(10-20)} \cdot 10 \\ = 2.83 \end{array}$$

*values for genus *Nitrosomonas*

The daily variations of the hourly ammonium loads:



$$SF_{dim} = \frac{B_{d,NH_4,max}}{B_{d,NH_4,ave}}$$



$$\frac{B_{d,NH_4,max}}{B_{d,NH_4,ave}} = 3.37 \times B_{d,NH_4,ave}^{-0.08}$$

$$SF_{dim} \approx 3.37 \cdot \left(B_{d,NH_4,ave}\right)^{-0.08} \cdot 1.25 = \mu_{max} \cdot \theta_X$$

$$\theta_X = \frac{3.37 \cdot \left(B_{d,NH_4,ave}\right)^{-0.08} \cdot 1.25}{\mu_{max}\left(T_{20}\right) \cdot e^{\theta_T (T-20)}}$$

Our example:

$$\left.\begin{array}{l} TKN = 30 \text{ g N/m}^3 \\ Q_0 = 3500 \text{ m}^3\text{/d} \end{array}\right\} \quad \begin{array}{l} SF_{dim} \approx 3.37 \cdot (3500 \text{x} 0.03)^{-0.08} \cdot 1.25 \\ \qquad \approx 2.9 \\ \theta_X = 2.9 / 0.28 = 10 \text{ d} \end{array}$$