Water Harmony
Erasmus+

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Biological processes nitrogen & phosphorus

Martin Oldenburg
University of Applied Science Ostwestfalen-Lippe
37671 Hoexter, An der Wilhelmshoehe 44
martin.oldenburg@hs-owl.de

Learning objective

- Knowledge about the processes of the removal of nitrogen and phosphorus from wastewater by biological processes
- Knowledge about systems with enhanced biological treatment processes

Nitrogen in wastewater

- Nitrogen in domestic wastewater is mainly from human excreta

$$CON_2H_4 + 3\ H_2O \xrightarrow{\text{Urease}} 2\ NH_4^+ + OH^- + HCO_3^-$$

- Hydrolysis from urea to Ammonia (ammonification) takes often place in sewer systems

Pathways of nitrogen

- Incorporation in biomass by degradation of organic matter
- Necessity of elimination:
  - Load per person: 10 g N/(cap*d)
    this is a concentration of 65 g/m³ with a volume of 150 l/(cap*d)
  - Nitrogen content of grown sludge: 0.07 gN/g MLSS
  - Sludge production rate:
    40 g BOD/(cap*d) * 1 g MLSS/g BOD_5 = 40 g MLSS/(cap*d)
    40 g MLSS/(cap*d) * 0.07 g N/g MLSS = 2.8 gN/(cap *d)
  - Nitrogen removal by incorporation:
    2.8 /0.150 l/(cap*d) = 18 gN/m³
  - Nitrogen which has to be eliminated:
    65 – 18 g N/m³ = **37 g N/m³**

⇒ **Targeted nitrogen elimination is necessary!**

Pathways of nitrogen

- “excess” of nitrogen not bound in biomass has to be eliminated in two steps
- first step:
  conversion of ammonia to nitrate – Nitrification
  conversion of nitrate to nitrogen – Denitrification
- Removal of nitrogen from domestic wastewater only by denitrification
- After biological treatment an residual organic nitrogen remains, which is incorporated in non-biodegradable organic substances
  approx. 1 - 2 g N/m^3

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Nitrification

$$NH_4^+ + 2\,O_2 \Rightarrow NO_3^- + H_2O + 2\,H^+ + \text{energy}$$

- Characteristics of nitrification process:
  - High energy demand : 4,6 g O_2 per g NH_4-N
    with integration of biomass growth: 4,25 g O_2 per g NH_4-N
  - Production of 2 mol H^+ per mol NH_4-N
- Energy from the reaction above will be used for the production of new biomass (growth)
- Source for carbon for the production of biomass is anorganic (CO_2/CO_3^{2-})
- **Nitrifiers are autotrophic bacteria!!**

Nitrification

- **Nitritation** (oxidation of Ammonium) by **Nitrosomonas**

  $$NH_4^+ + 1{,}5\ O_2 \rightarrow NO_2^- + H_2O + 2\ H^+$$ (+243-352 kJ/mol)

  $$15\ CO_2 + 13\ NH_4^+ \rightarrow 10\ NO_2^- + 3\ C_5H_7NO_2 + 4\ H_2O + 23\ H^+$$

  $$\mu_{max} = 0{,}47 * 1{,}103^{(T-15)}\ [d^{-1}]$$

- **Nitratation** (oxidation of niitrite) by **Nitrobacter**

  $$NO_2^- + 0{,}5\ O_2 \rightarrow NO_3^-$$ (+63 - 80 kJ/mol)

  $$5\ CO_2 + NH_4^+ + 10\ NO_2^- + 2\ H_2O \rightarrow 10\ NO_3^- + C_5H_7NO_2 + H^+$$

  $$\mu_{max} = 0{,}79 * 1{,}071^{(T-15)}\ [d^{-1}]$$

- **Total**

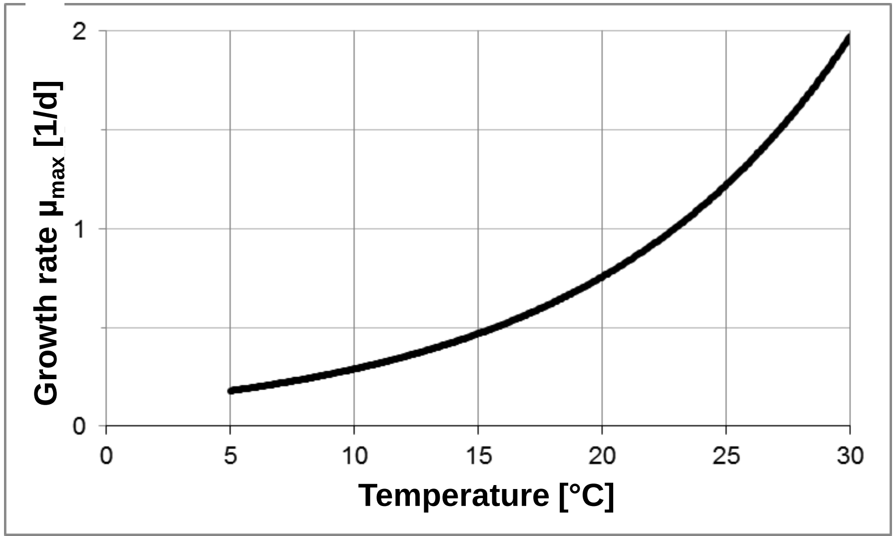
  $$NH_4^+ + 2\ O_2 \rightarrow NO_3^- + H_2O + 2\ H^+$$ (4,57 g O_2/g NH_4-N)

  $$NH_4^+ + 1{,}98\ HCO_3^- + 1{,}86\ O_2 \rightarrow 0{,}98\ NO_3^- + 0{,}02\ C_5H_7NO_2 + 1{,}88\ H_2CO_3 + 1{,}04\ H_2O$$

  (4,25 g O_2/g NH_4-N)

Effect of temperature on nitrification

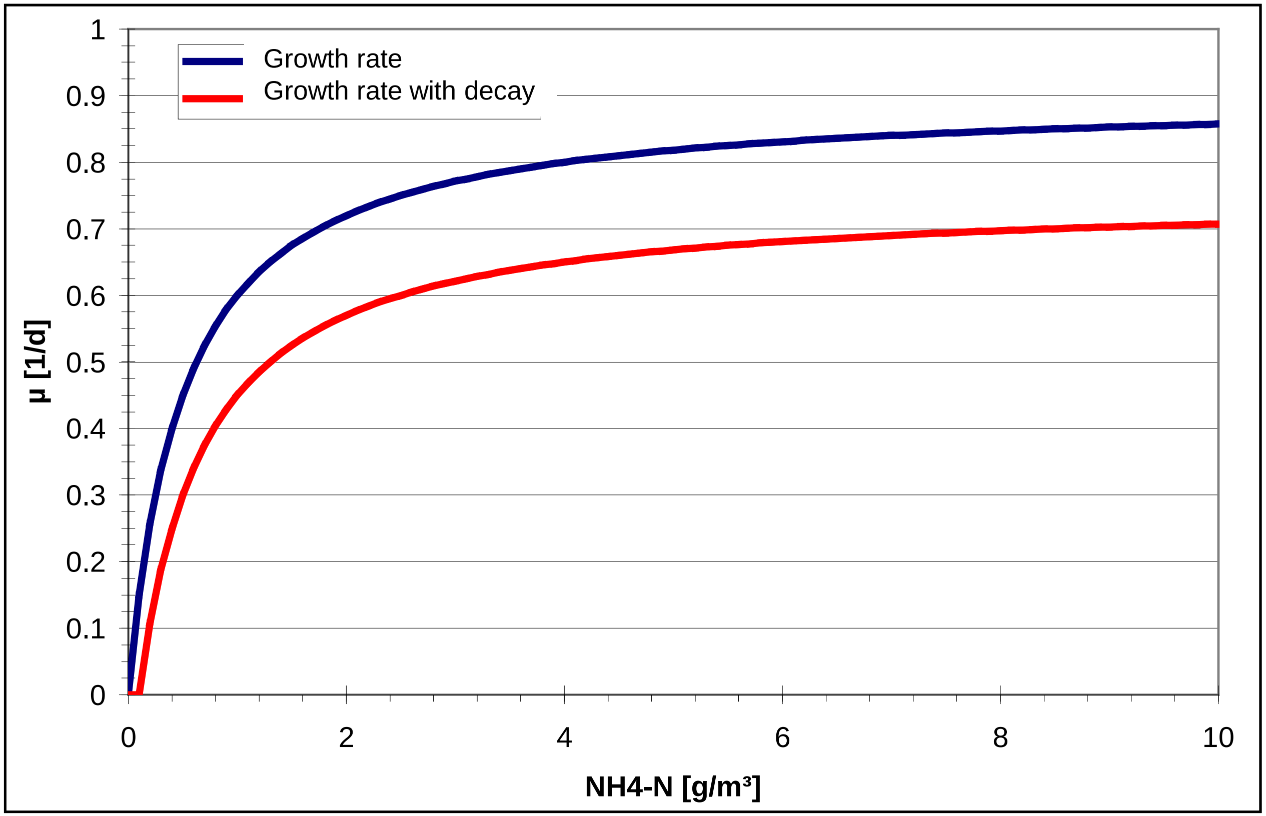
	Growth rate				Sludge age
Temp.	Nitrosomonas		Nitrobacter		
[°C]	[1/d]	[h]	[1/d]	[h]	[d]
10	0,29	82,8	0,58	41,4	3,44
20	0,76	31,6	1,04	23,1	1,32
30	1,97	12,2	1,87	12,8	0,53



Kinetics Nitrification

$$\mu = \mu_{max} \bullet \frac{S_{NH}}{K_{NH} + S_{NH}} - b_A$$

Parameter	Unit	Range	common
Maximum growth rate μ_{max} (T = 20 °C)	1/d	0,6 – 0,8	0,8
Half-saturationK_{NH}	g/m³	0,5 – 1,0	1,0
Decay rate b_A	1/d	0,05 – 0,15	0,15
O_2-Half saturation	g/m³	0,15 – 2,0	0,4



Denitrification

- Denitrification:
  Reduction of oxidised nitrogen-compounds (nitrite, nitrete) to nitrogen (N_2) by heterotrophic bacteria due to the absence of oxigen (anoxic conditions)
- *„Respiration with oxygen “:*

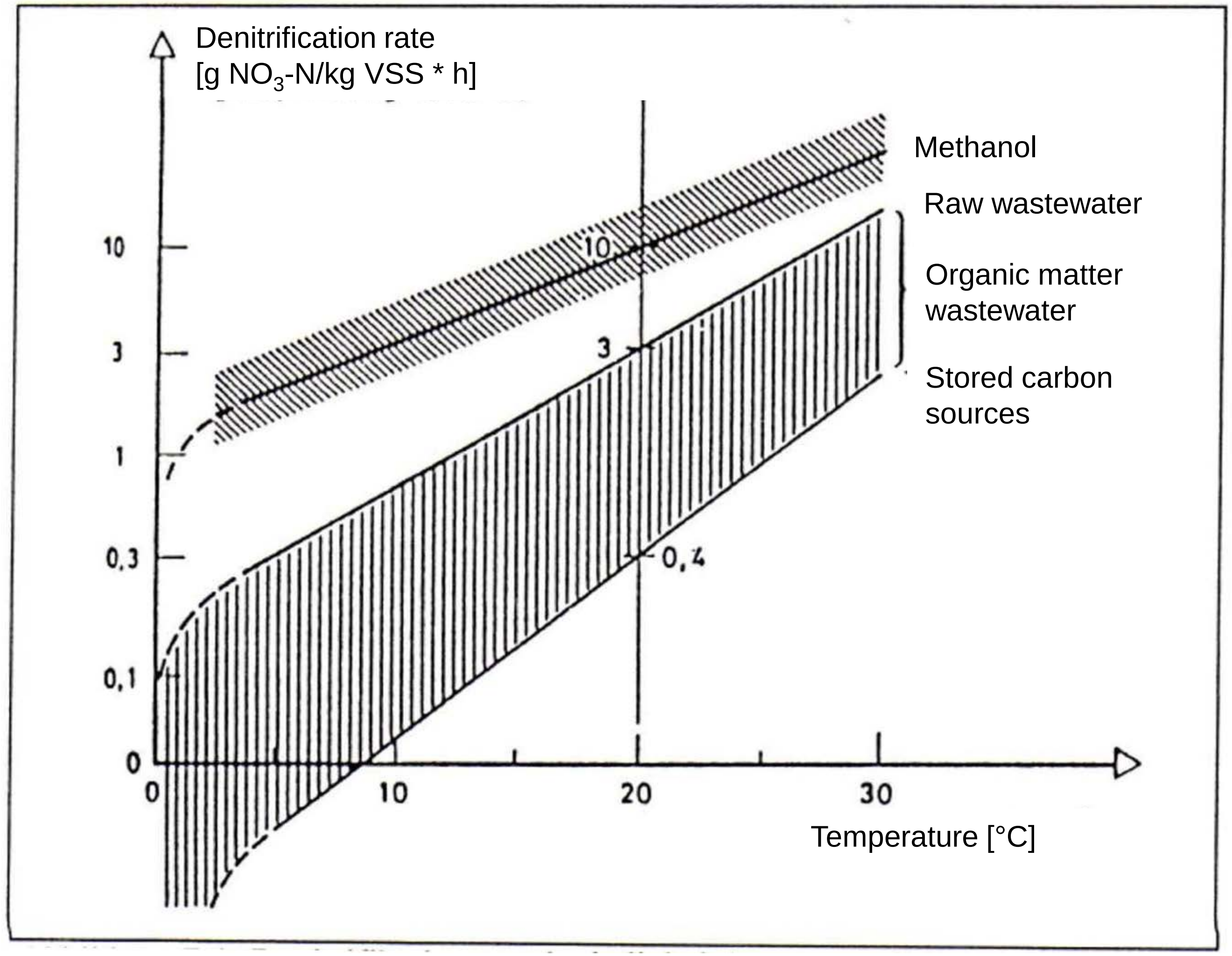
$$2CH_3OH + 3\,O_2 \Rightarrow CO_2 + 4\,H_2O$$

- *„Respiration with nitrate “:*

$$5\,CH_3OH + 6\,NO_3^- \Rightarrow 5\,CO_2 + 7\,H_2O + 3\,N_2 + 6\,OH^-$$

- Energy yield at „respiration of nitrate“ 10 % lower than using oxygen ⇒ aerobic conditions are preferred instead of aerobic condition by bacteria
- Most of heterotrophic bacteria are able to do both degradation processes
- Yield of buffer capacity (1 mol/mg NO_3-N)

Dependency of denitrification on substrate



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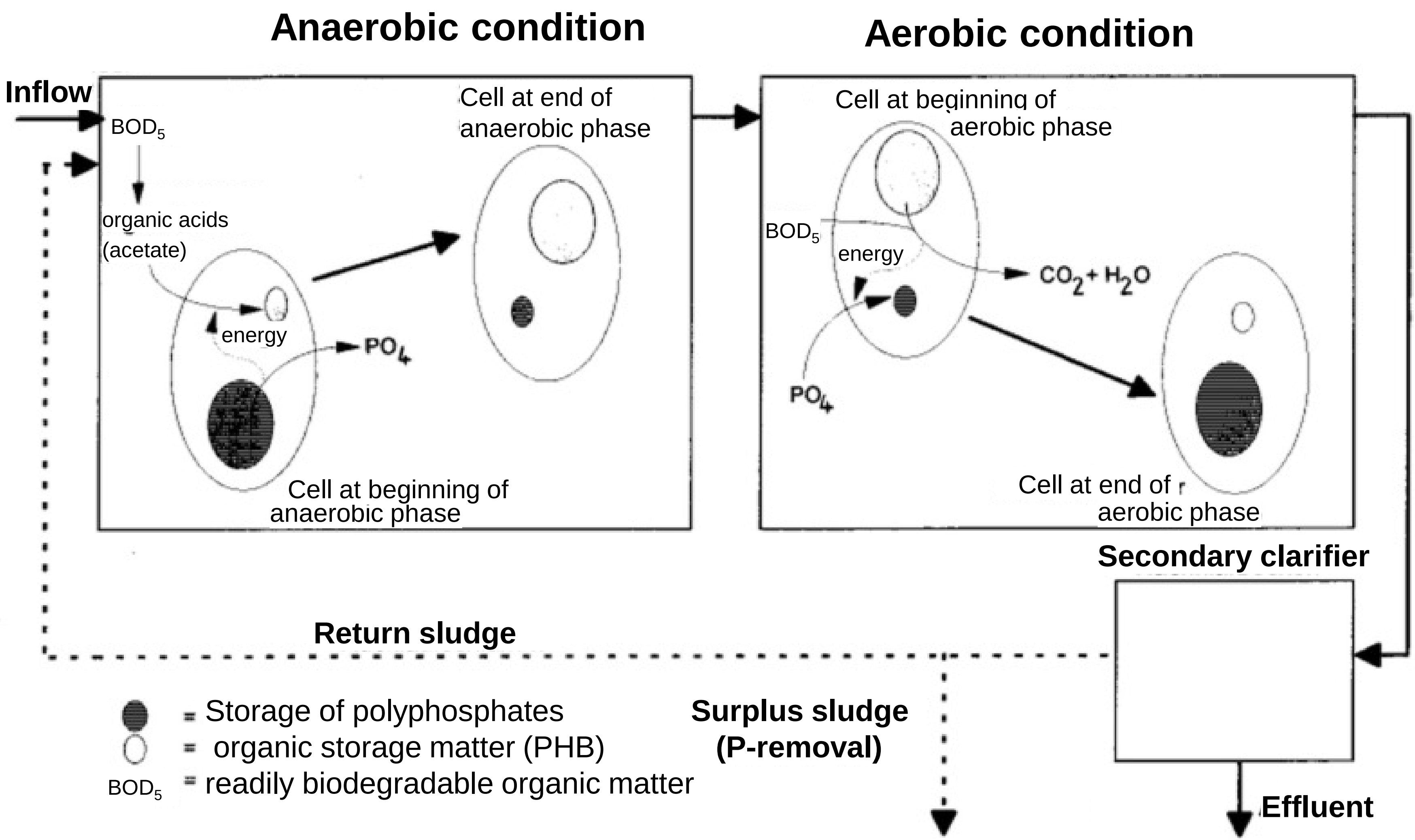
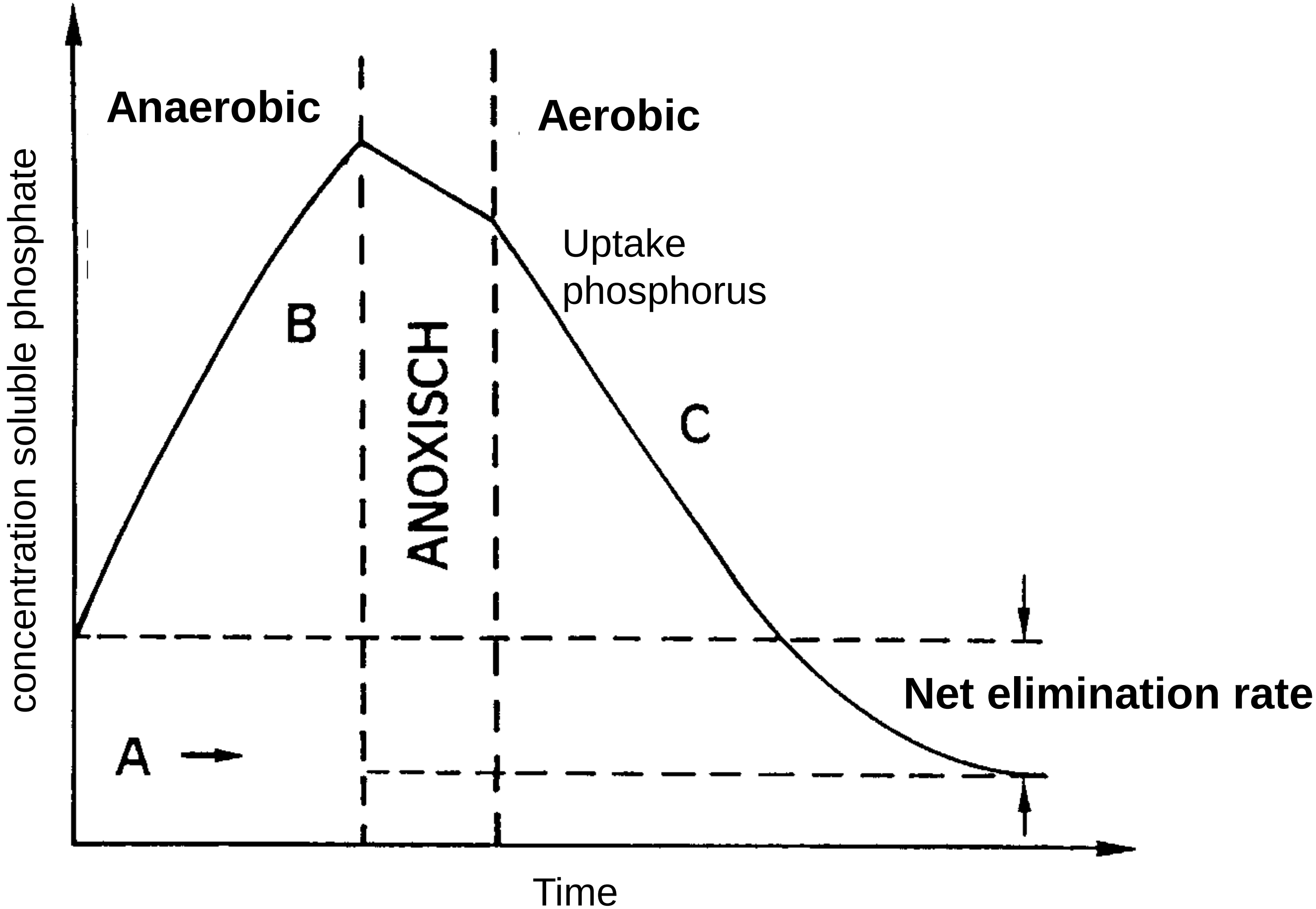
Enhanced biological phosphorus removal

- Principle
  - Sequencing alternation of anaerobic and aerobic conditions
  - Accumulation of phosphorus by organisms (PAO)
  - P-content in sludge
    increase from 1,5 - 2 % to 3 - 5 %
- Processes
  - Anaerobic condition
    - Degradation of polyphosphate with energy yield (P-removal)
    - Fermentation of readily biodegradable substances (formation of organic acids)
    - Uptake of organic acids for the formation of intracellular storage compounds
  - Aerobic conditions
    - Degradation of storage compounds and yield of energy
    - Uptake of phosphate (degradation of polyphosphates)

Enhanced biological phosphorus removal (EBPR)

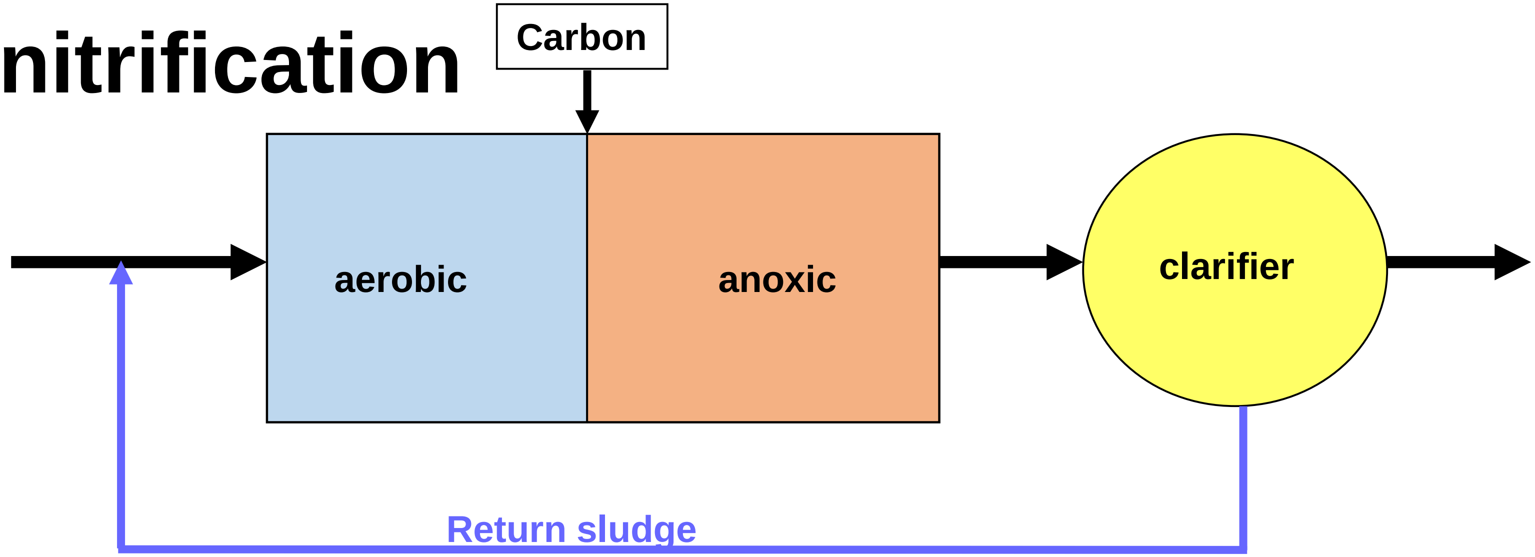


Enhanced biological phosphorus removal (EBPR)



„Net elimination rate “ is caused by the incorporation of phosphorus into the grown surplus sludge.

Post-Denitrification



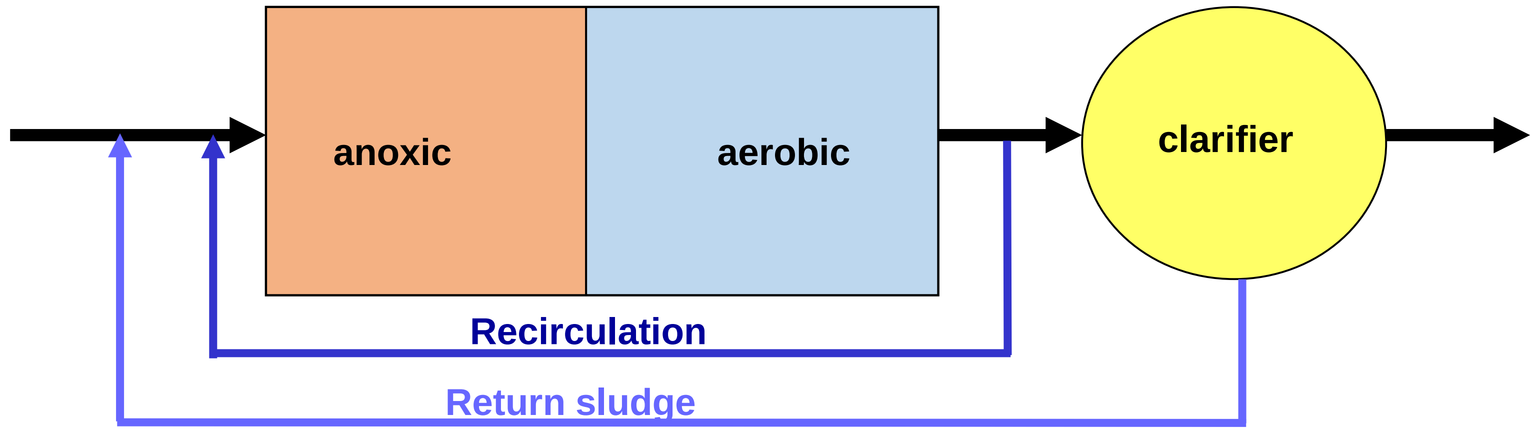
- \+ nearly every NO_3-N-effluent concentration can be achieved
- \+ no internal recirculation
- \+ suitable for biofilm systems

- \- Costs for chemicals due to dosing of carbon source
- \- Risk of formation of nitrite
- \- Risk of enhanced concentrations of organic matter (COD) in the effluent

Aerobic - Nitrification | Anoxic - Denitrifikation | Sedimentation

Wastewater | Return sludge | Recirculation

Pre-Denitrification



\+ optimal use of organic carbon (BOD5) from wastewater
\+ small volumes for denitrification due to high denitrification rates
\+ alternating zones (aerated/non-aerated) for different loadings and times
\+ easy to control

\- High internal flow rates

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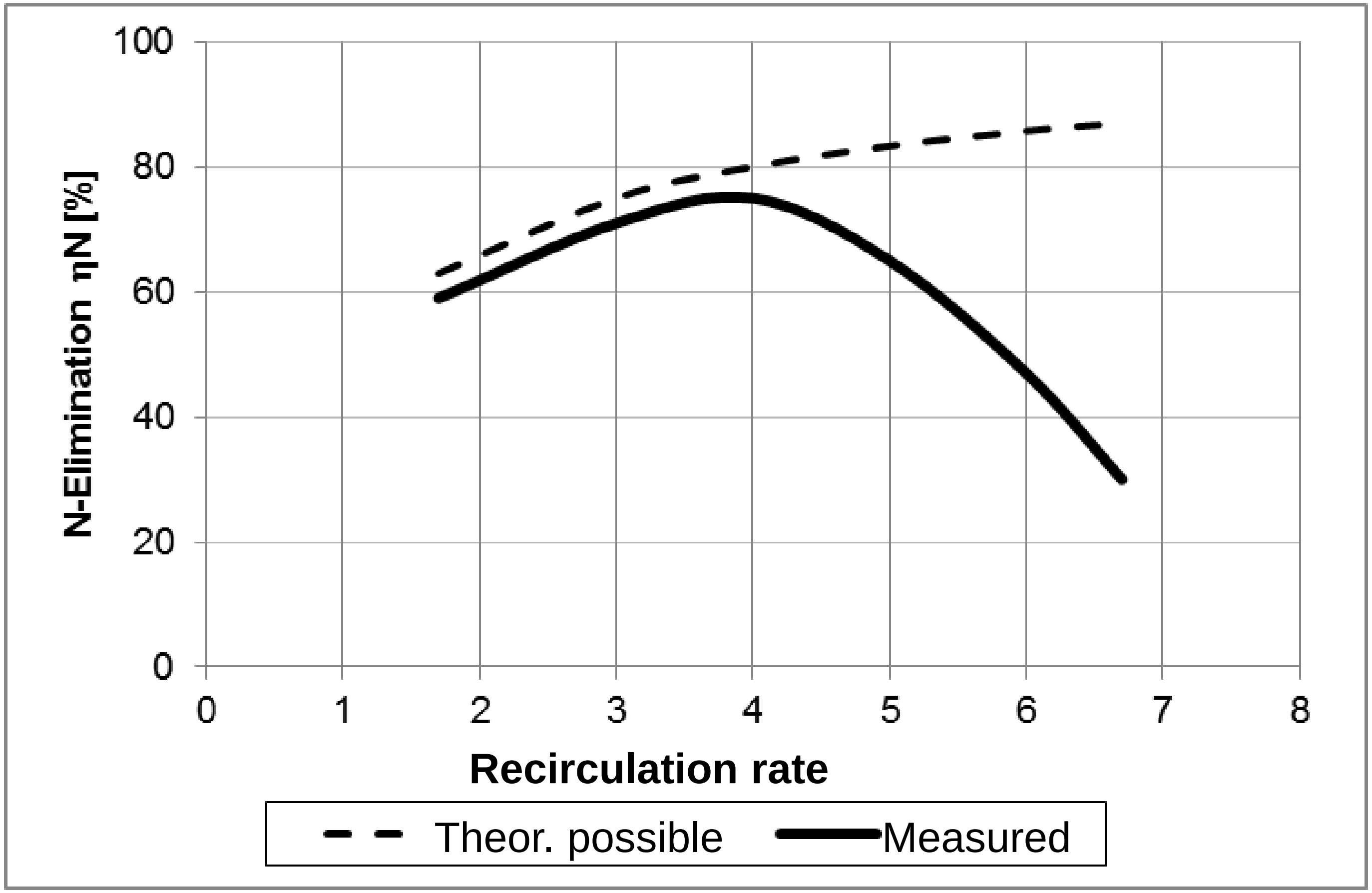
Pre-Denitrification

Elimination rates with pre-Denitrification

Recirculation rate RR

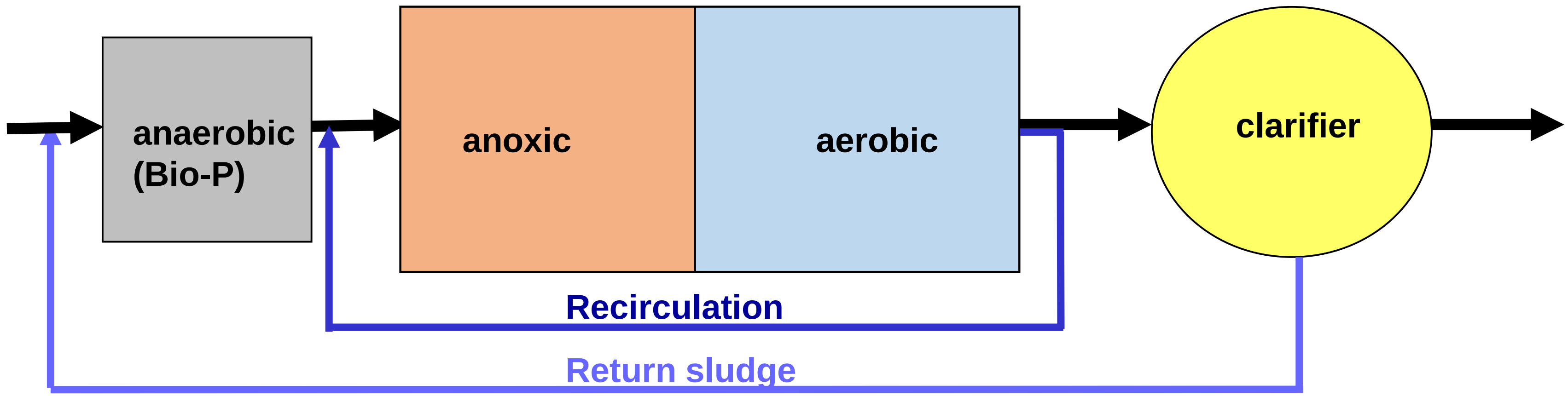
$$RR = \frac{S_{NO3,D}}{S_{NO3,eff}}$$

$$\eta_{DN} \leq 1 - \frac{1}{1+RF}$$

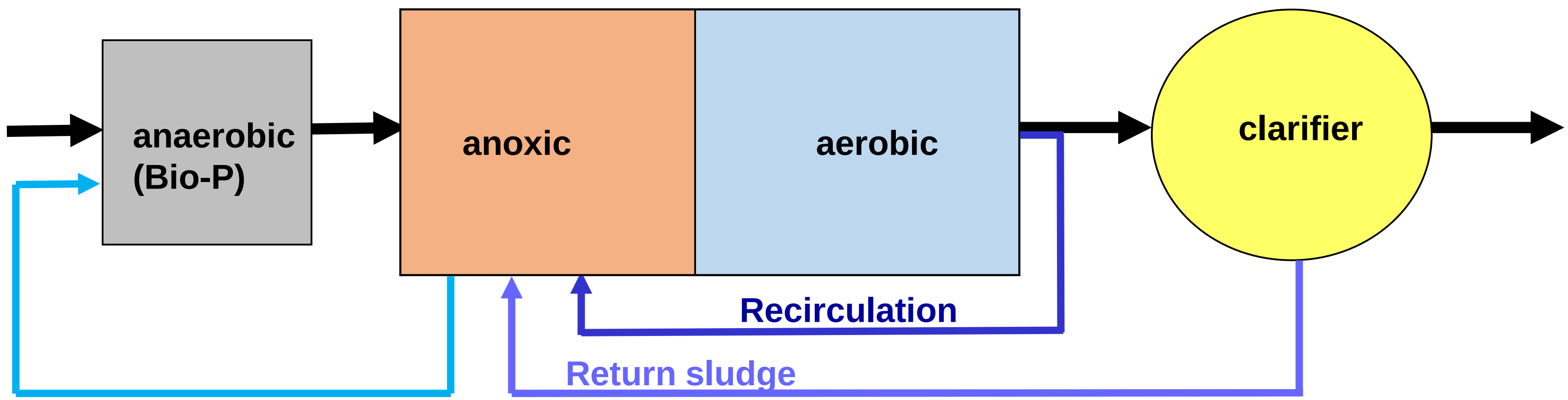


Pre-Denitrification with EBPR

Modified Bardenpho-, Phoredox-, A2/O-process

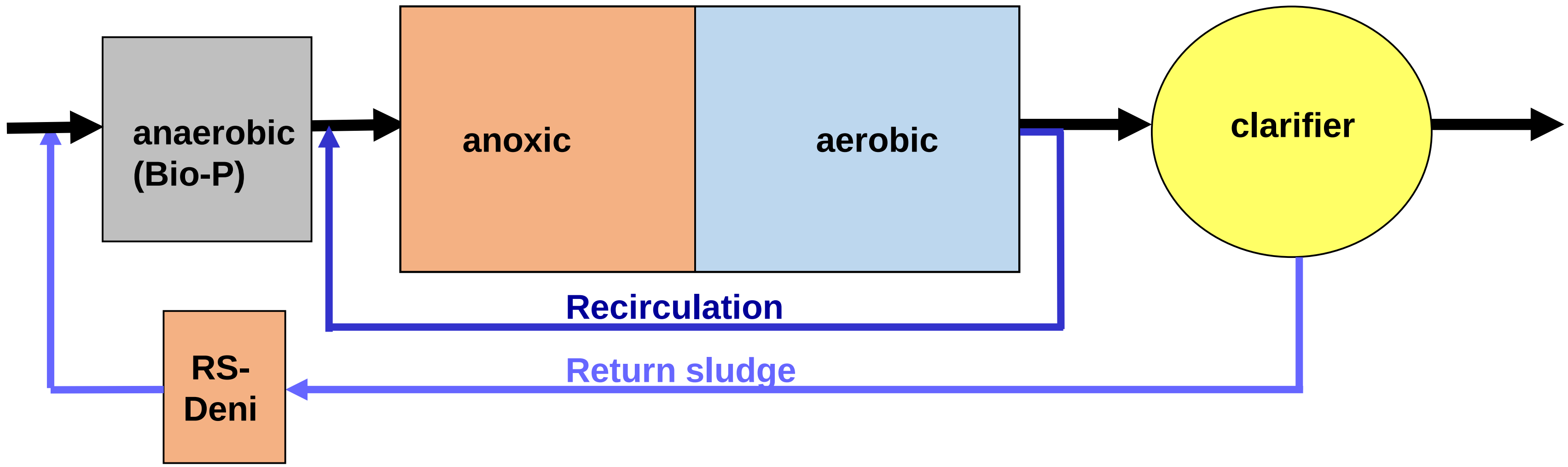


Modified UCT-process

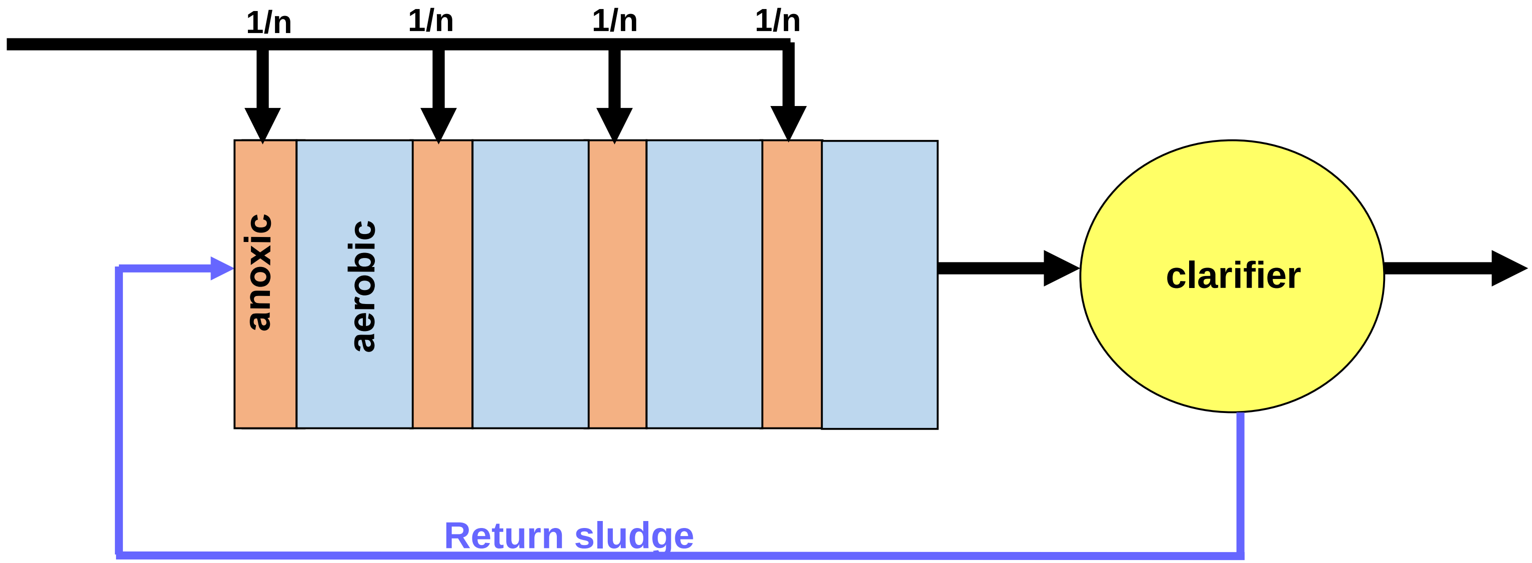


Pre-Denitrification with EBPR

modified Johannesburg-process

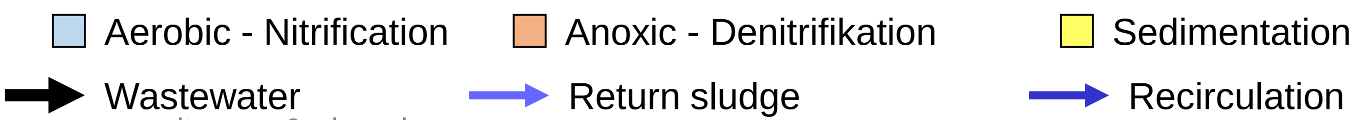


Cascade Denitrification

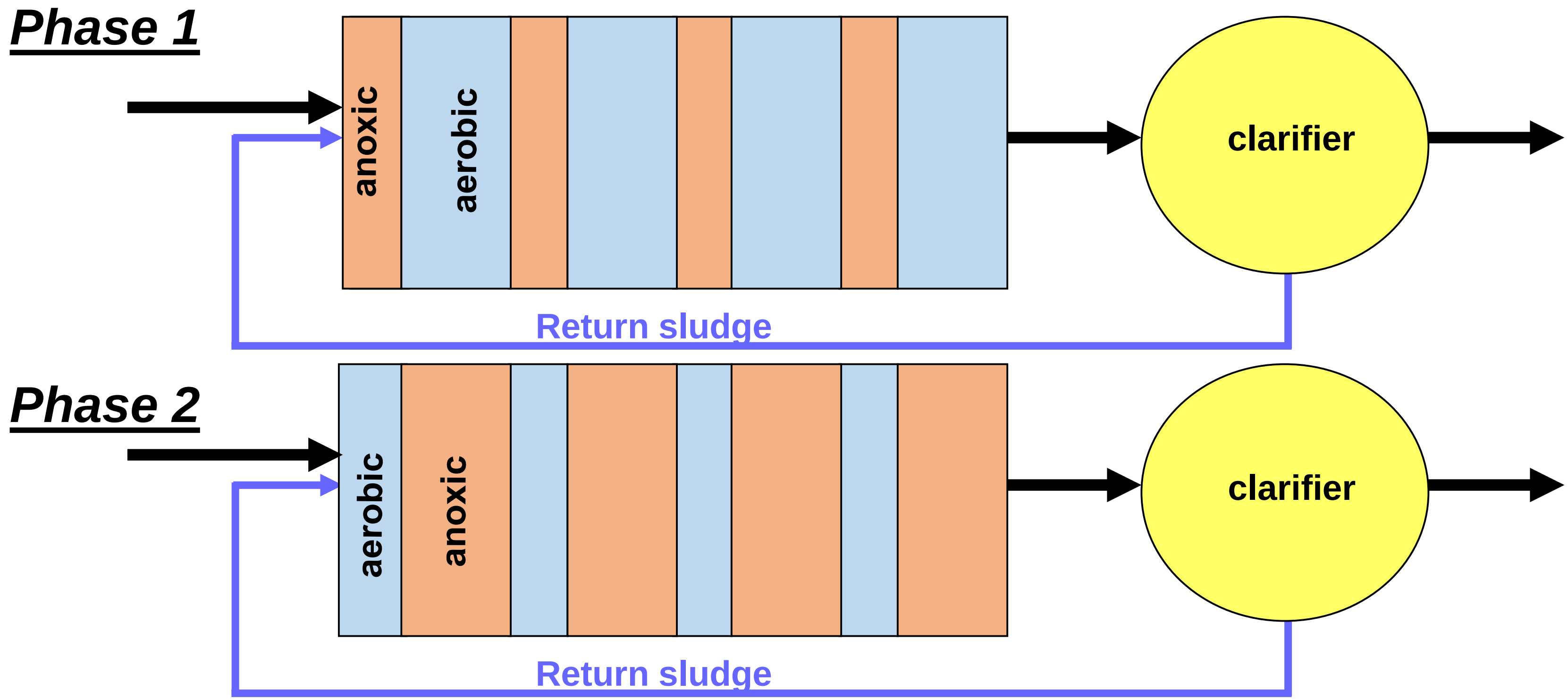


+ no internal recirculation flows
+ cascade reactor
+ higher mass of sludge

- Distribution of inflow difficult
- EBPR only in a small amount

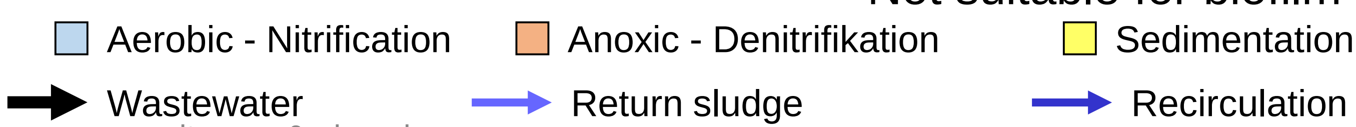


Intermittant Denitrification

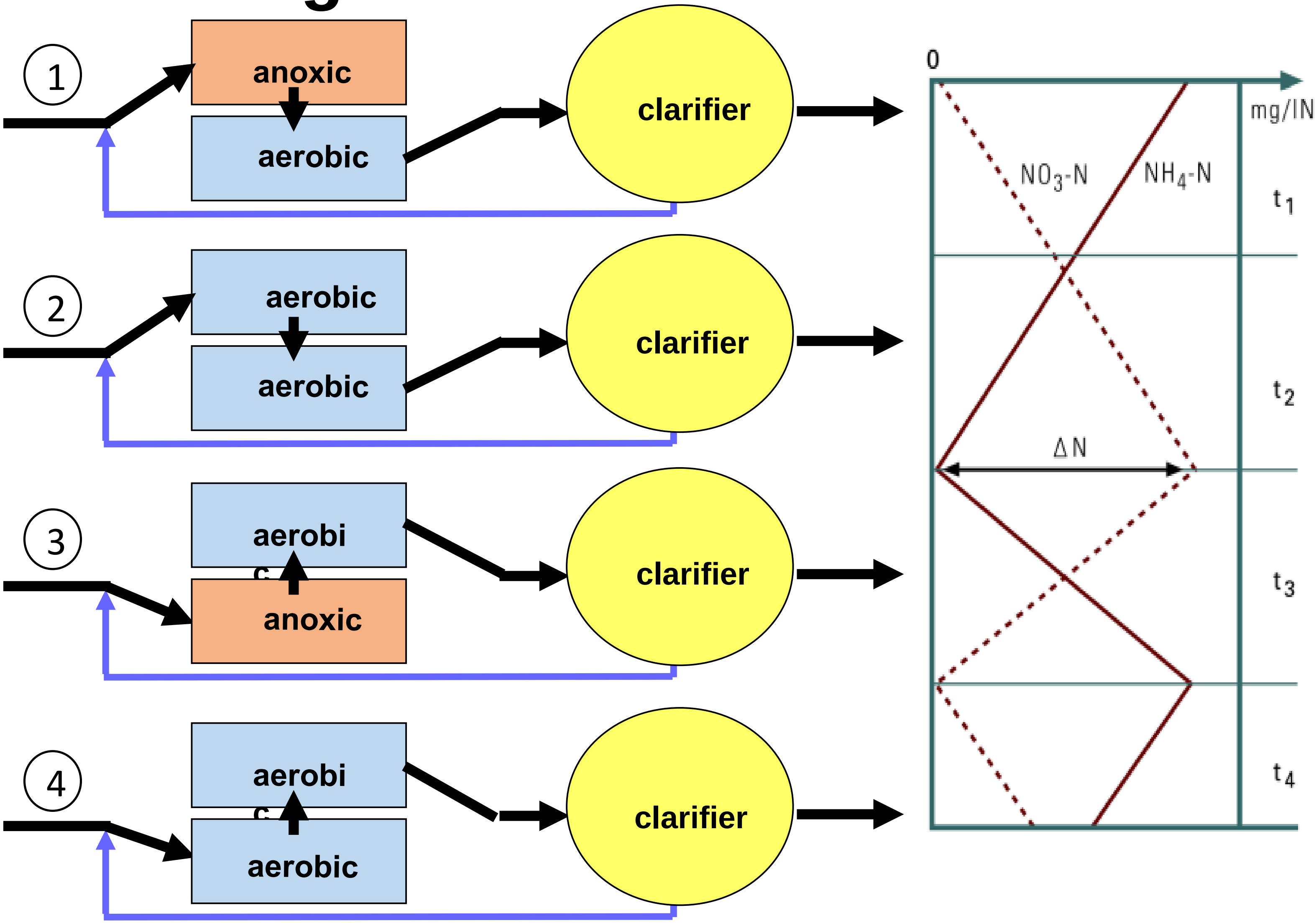


+ high flexibility to changing inflow conditions
+ low effluent concentrations can be achieved

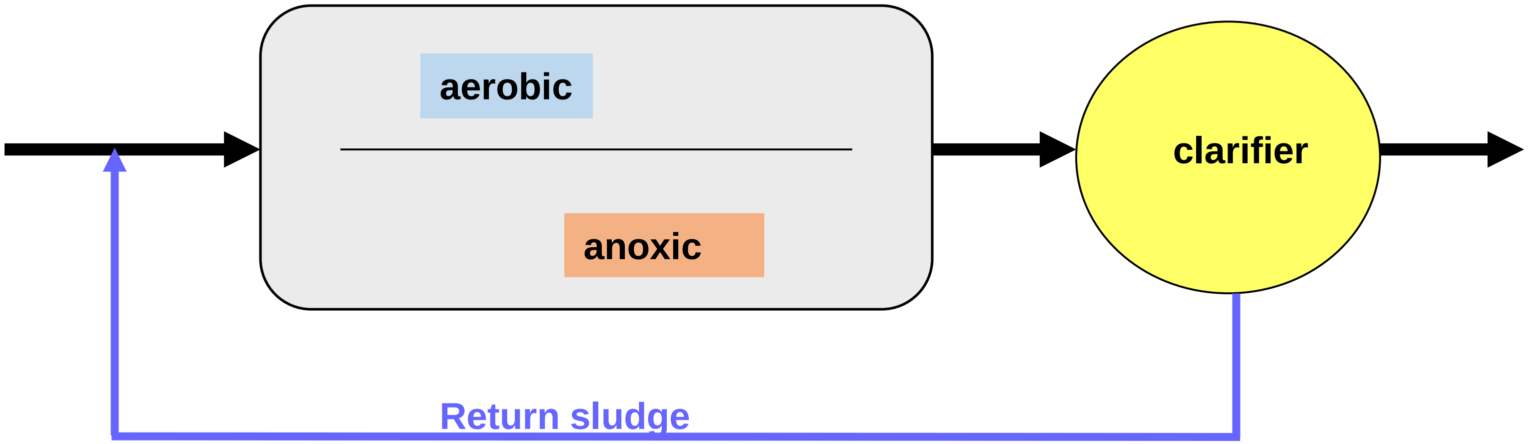
- high effort for mechanical engineering
- high area and volume demands
- Separation of aeration and mixing
- Not suitable for biofilm systems



Alternating Denitrification



Simultaneous Denitrification



- \+ high flexibility to changing inflow conditions
- \+ no internal recirculation necessary
- \+ robust operation
- \+ mainly for small plants

- \- Completely mixed systems, small reaction rates
- \- Large tank volumes (often also for sludge stabilisation)
- \- Oxygen will be displaced from nitrification to denitrification zones

Aerobic - Nitrification | Anoxic - Denitrifikation | Sedimentation

Wastewater | Return sludge | Recirculation

Simultaneous Denitrification