Water Harmony
Erasmus+

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Biological processes
organic matter

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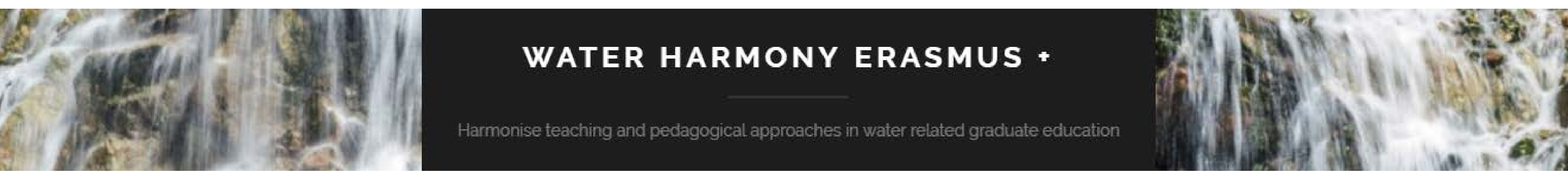


Learning objective

- Knowledge about the processes of biological degradation processes
- Knowledge about biological processes in domestic wastewater treatment
- Context of various degradation processes
- Knowledge about dimension

Main objective of biological wastewater treatment

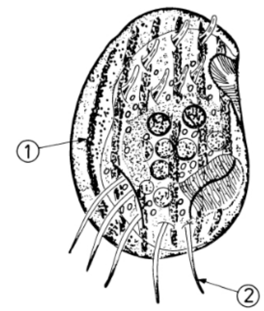
- Substances which have negative impact on water quality have to be converted by simple biological processes into harmless substances:
  - Gases: N_2, CO_2, CH_4
  - Soluble substances: H_2O, NO_3^-, HCO_3^-
  - Solids: Biomass, flocs

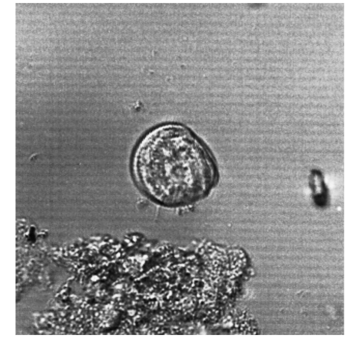
Determination of different food conditions

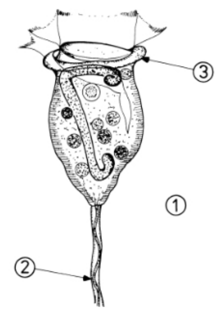
- **<u>Source of Energy</u>**
  - **Chemotrophic:** energy generation of microorganism (MO) by reduction-oxidation processes (chemical conversion)
  - **Phototrophic:** utilisation of electro-magnetic radiation (light)
- **<u>Carbon source</u>** (for generation of biomass):
  - **heterotrophic:** microorganism are using organic compounds
  - **phototrophic:** microorganism are using non organic compounds (CO_2)
- **<u>Donator of hydrogen or electrons</u>** (substance which will be oxidised):
  - **litrotrophic:** MO are using inorganic substances: NH_4^+, NO_2^-, H_2, S_2^-)
  - **organotrophic**: MO are using organic substances
- **<u>Temperature:</u>**
  - **mesophile**: range of growth of MO 20 – 42 °C
  - **thermophile**: range of growth of MO 40 – 70 °C

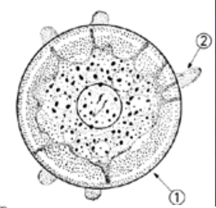
Microorganismn aerobic degradation

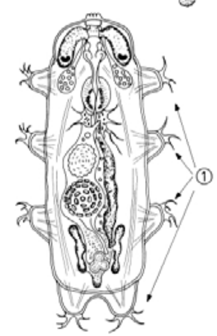
- **Protozoa**
  - **Ciliates**
    unicellular organism
    free swimming organism
    robust, grazing of flocs
  - **Vorticella convalaria**
    good oxygen supply
  - **Mastigophorans**
    flagellates for locomotion
  - **Rotifer**
    multicellular organism
    high generation time and sludge age



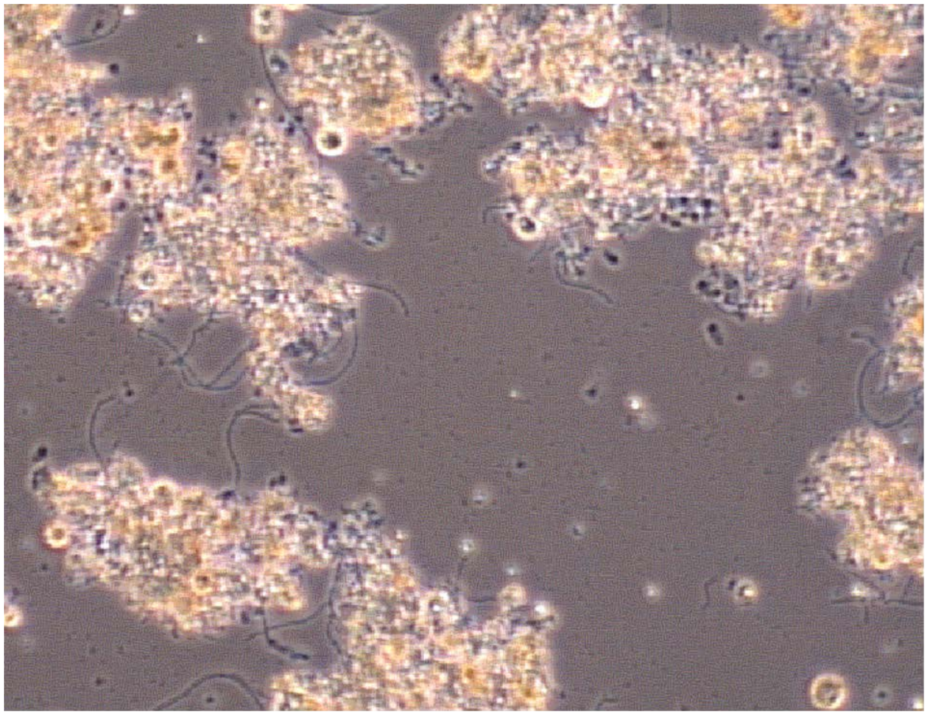


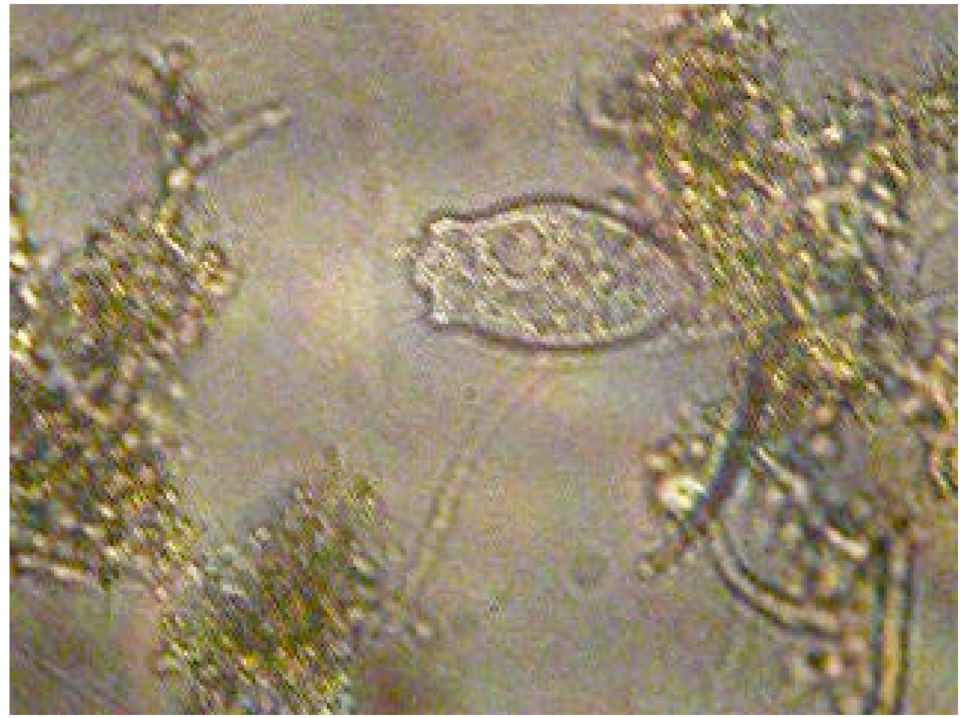






Microorganismen aerobic degradation





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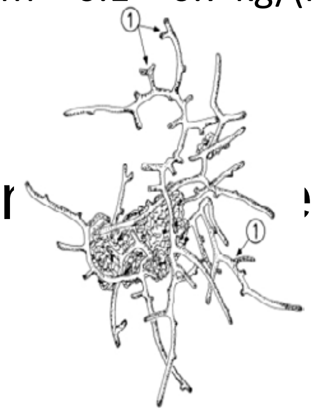
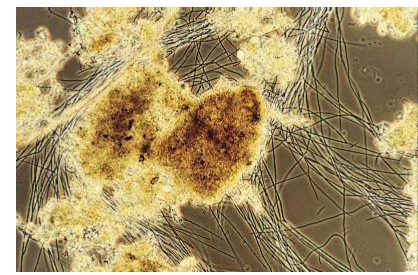
Microorganismen aerobic degradation

- **Filamentous bacteria**
  - Many bacteria may form filaments
  - High number of filamentous bacteria have negative impact on sedimentation
  - Many forms may occur: bulking sludge, floating sludge, foam
  - Bulking sludge when SVI > 150 ml/g
  - Problem on many wwtp's
  - Reasons:
    - Wastewater composition
    - Low F/M-ratio
    - High concentration of fatty acids
    - Low oxygen concentrations

Nocardia

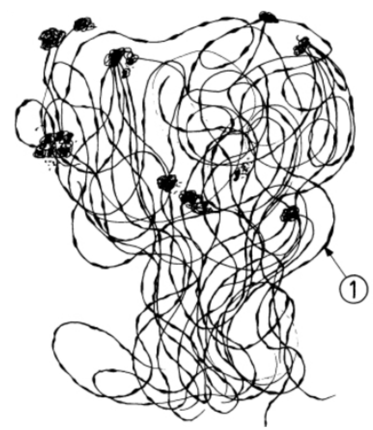
F/M ≈ 0.1 – 0.7 kg/(kg*d)





Microthrix parvicella

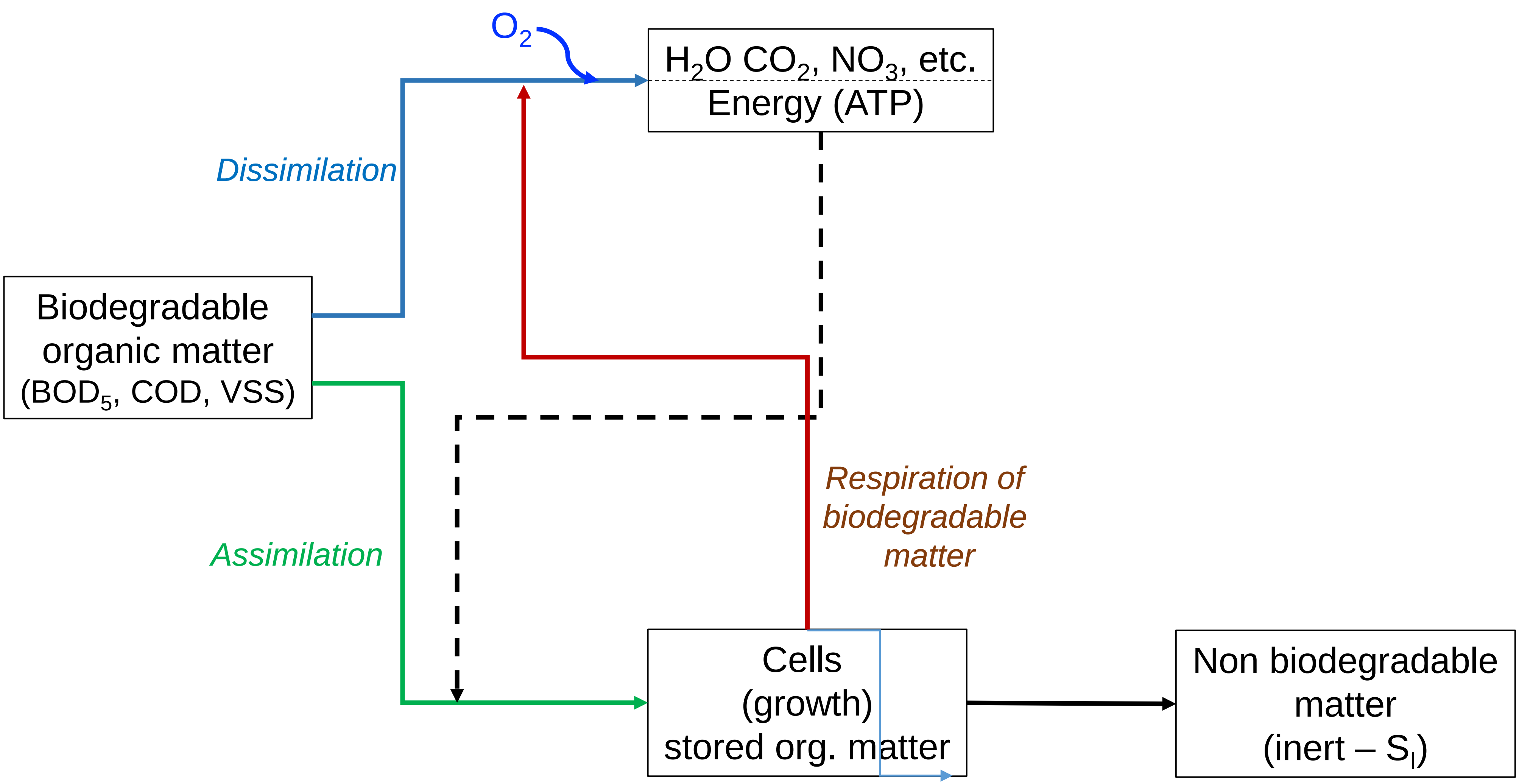
F/M ≈ 0.05 – 0.2 kg/(kg*d)



Aerobic degradation of organic matter

- **Assimilation (**growth)
  while high food supply (high organic loads)
  - High production of biomass ⇒ high sludge growth
  - Low specific rate of oxygen consumption
  - Degradation of substances with high energy yield
- **Dissimilation** (energy metabolism)
  while low food supply (low organic load)
  - Low production of biomass ⇒ less sludge
  - Respiration of stored organic material
  - High rate of specific oxygen consumption
  - Extensive degradation of organic substances

Scheme of aerobic degradation of organic matter



Aerobic degradation of organic matter

Energy metabolism (Dissimilation)

$$CH_2O + O_2 \Rightarrow CO_2 + H_2O + \text{Energy}$$

Growth of biomass (Assimilation)

$$5\ CH_2O + NH_3 + \text{Energy} \Rightarrow C_5H_7NO_2 + 3\ H_2O$$

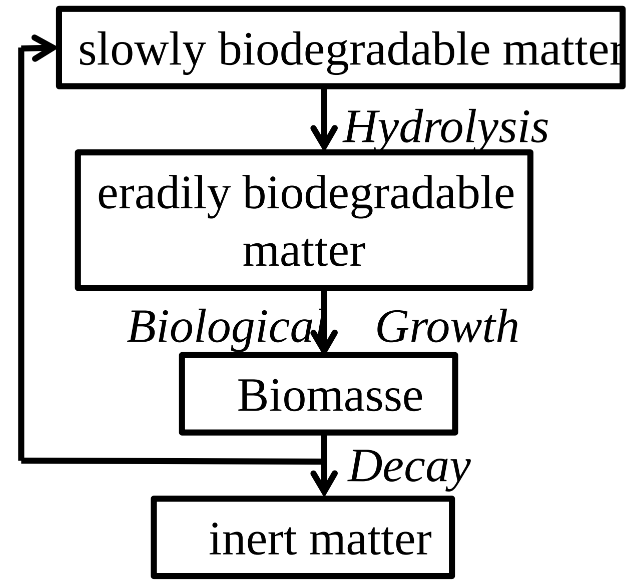
Total reaction (outside view)

$$15\ CH_2O + 5\ O_2 + 2\ NH_3 \Rightarrow 2\ C_5H_7NO_2 + 5\ CO_2 + 11\ H_2O$$

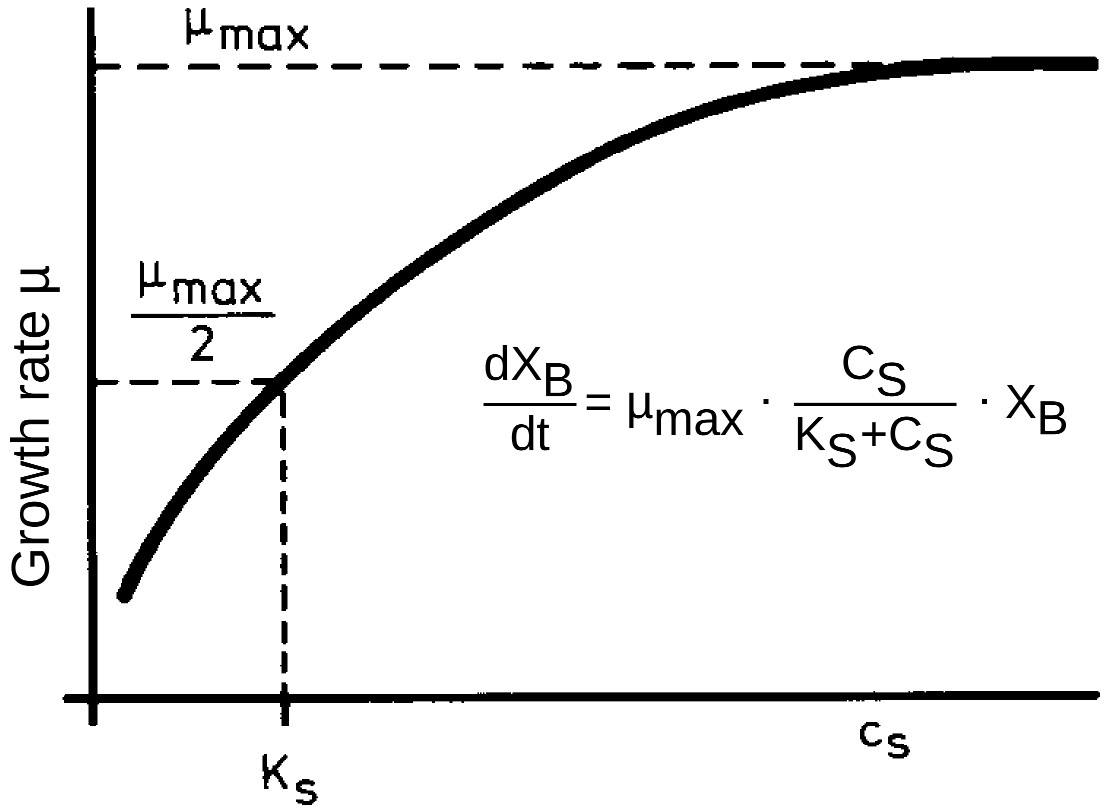
450 g | 160 g | 34 g | Biomass 226 g

Conversion processes

- **Main processes during degradation of organic matter**
  - Adsorption and sorption of organic matter at and in microorganisms
  - Transport into the cells (resorption, osmotic processes)
  - Storage of organic substances and products inside cells
  - Conversion into biomass, intermediate products, CO_2, H_2O



Monod Kinetics

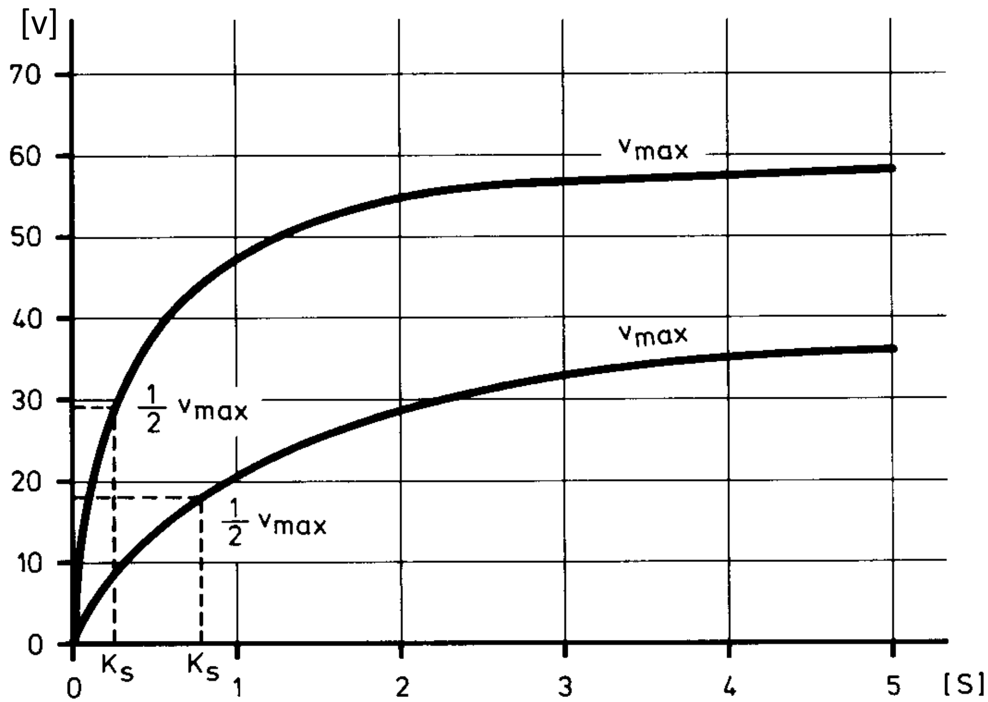


$$\frac{dX_B}{dt} = \mu_{max} \cdot \frac{C_S}{K_S + C_S} \cdot X_B$$

X_B	Biomass [g/m³]
μ	growth rate [1/d]
μ_{max}	maximum growth rate [1/d]
C_S	Concentration substrate [g/m³]
K_S	Half saturation coefficient [g/m³] (Concentration of substrate at $\mu_{max}/2$)

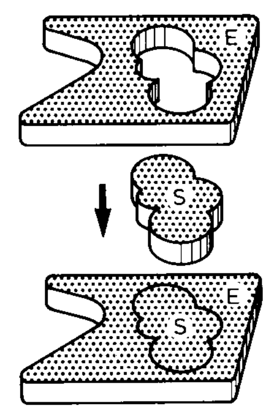
- Degradation of organic matter is controlled by enzymes
- For readily biodegradable substances enzymes are still present $\Rightarrow$ immediate and rapid degradation

Reaction kinetics



$$\frac{dC_S}{dt} = v_{max} \cdot \frac{C_S}{K_S + C_S} \cdot X_B$$

v	reaction rate [g/(m³*d)]
v_{max}	max. reaction rate [g/(m³*d)]
S	Concentration of substrate [g/m³]
K_S	Half saturation coefficient [g/m³] (Concentration of substrate at $v_{max}/2$)



- Substrate and Enzymes form a Enzyme-Substrate-Complex
- Rate of enzyme reaction is similar to the concentration of enzyme-substrate-complex
  ⇒ **Michaelis-Menten equation**

Kinetics

- Bacterial growth by division of cells
- Growth rate

$$\frac{dX_B}{dt} = \mu \cdot X_B \qquad X_B(t) = X_{B,0} \cdot e^{(\mu \cdot t)}$$

X_B = concentration of biomass [g/m³]
t = time [d]
μ = growth rate [1/d]

- Decay

$$\frac{dX_B}{dt} = -b \cdot X_B \quad X(t) = X_{B,0} \cdot e^{(-b \cdot t)}$$

b = decay rate [1/d] $\approx 0.05 – 0.10 * \mu_{max}$

- Generation time t_d: period, in which duplication occurs

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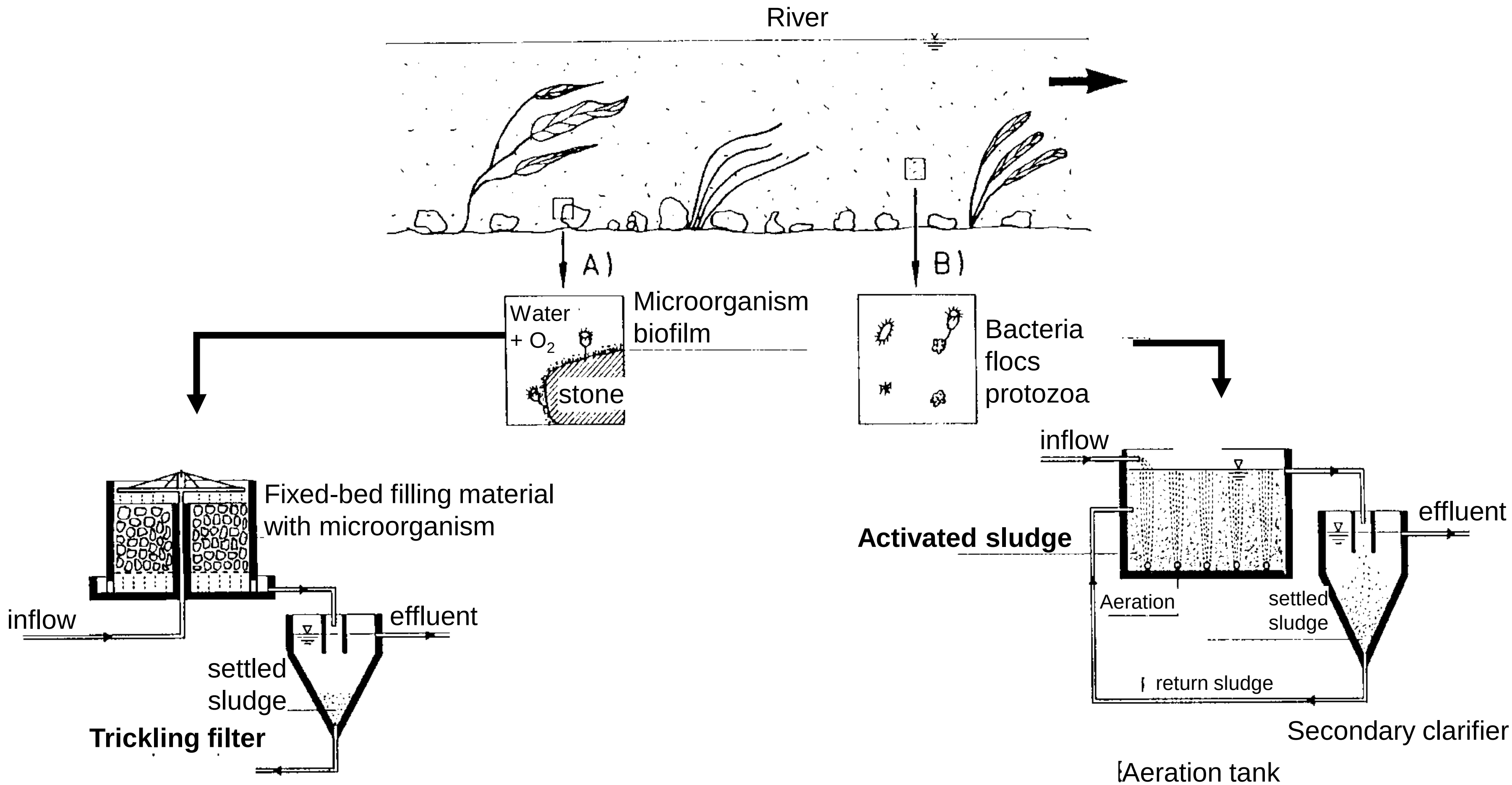
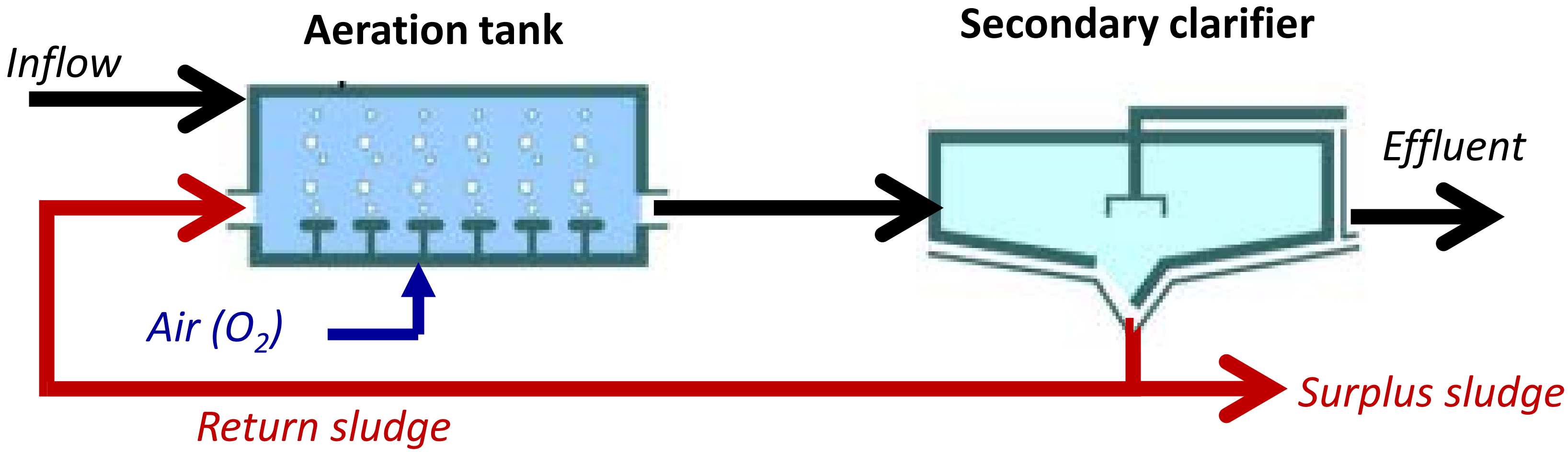
Self-purificaion processes and technical application



- Strengthening of natural self-purification processes by technidal applications

Activated sludge system



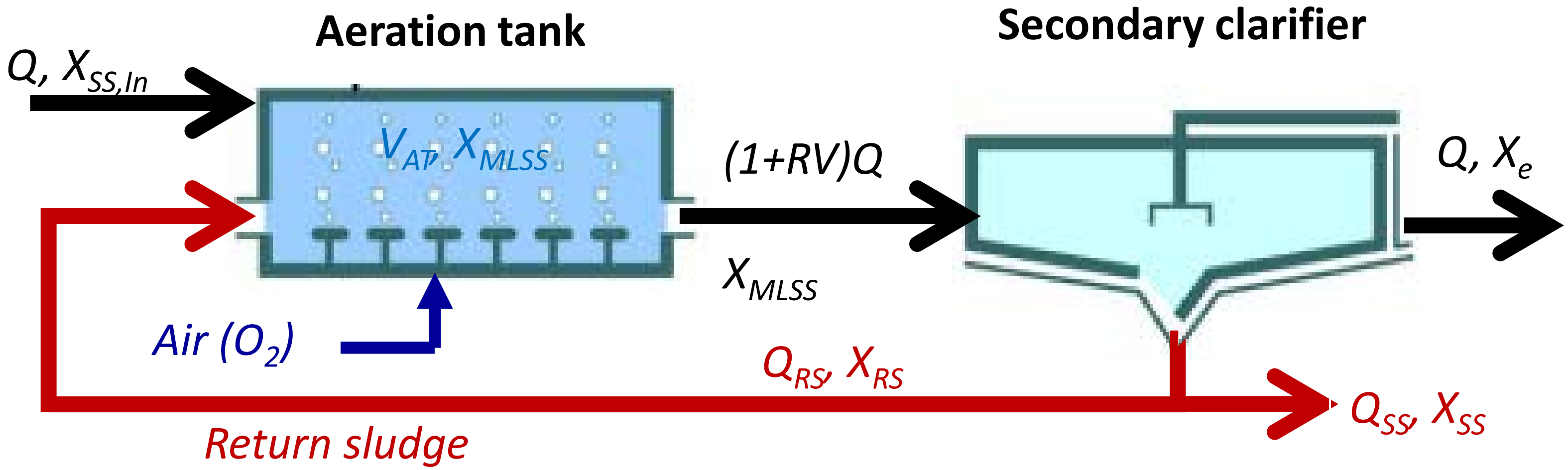
Aeration tank: organic matter = substrate for microorganism
microorganism and oxygen (air)
⇒ growth of microorganism ⇒ wastewater treatment

Secondary clarifier: separation of sludge by sedimentation, thickening of sludge
⇒ non biodegradable soluble substance and rest of suspended solids

Return sludge: Return of sedimentated sludge
⇒ decoupling of retention time from sludge retention time

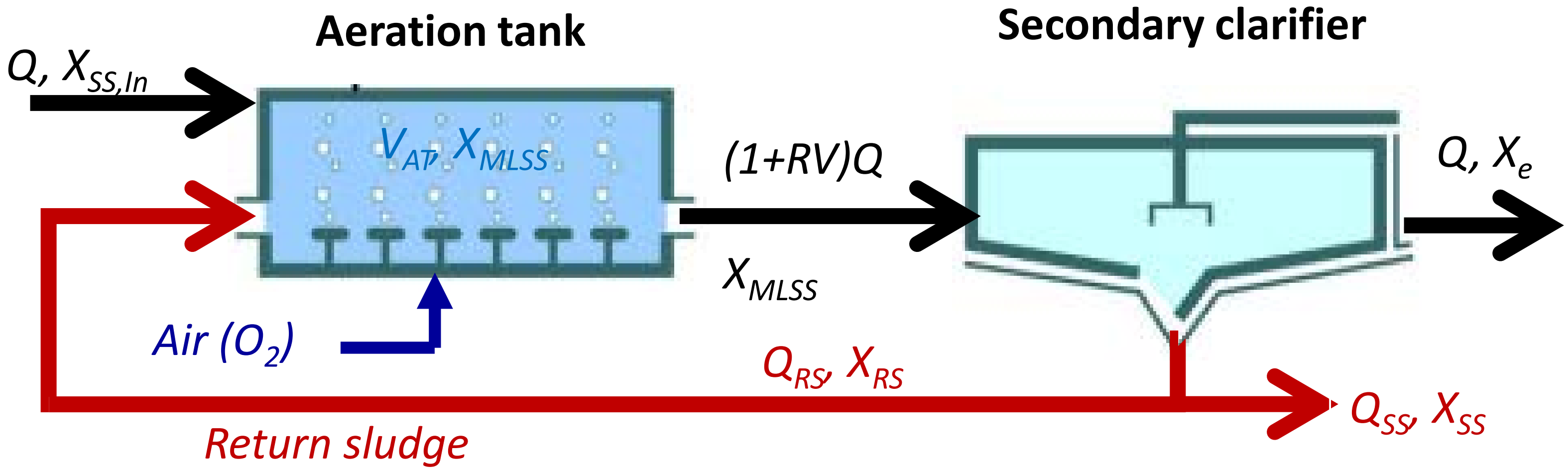
Surplus sludge: removal of grown sludge
⇒ control of mixed liquor

Activated sludge system



Q	inflow into aeration tank
$X_{SS,IN}$	suspended solid inflow
V_{AT}	Volume aeration tank
X_{MLSS}	mixed liquor concentration
X_e	solid concentration effluent
Q_{RS}	flow of return sludge
X_{RS}	solid concentration return sludge
Q_{SS}	flow of surplus sludge
X_{SS}	suspended solids in effluent

Activated sludge system



Flow balance secondary clarifier:

$$Q_{RS} = RV * Q$$

$$RV = \frac{Q_{RS}}{Q}$$

$$(1+RV)*Q = Q + Q_{RS}$$

Solid balance secondary clarifier[1)]:

$$B_{MLSS} = B_{xe} + B_{XRS}$$

$$(1+RV)*Q*X_{MLSS} = Q*X_e + Q_{RS}* X_{RS}$$

$$(1+RV)*Q*X_{MLSS} = Q_{RS}* X_{RS}$$

Xe ≈ 0 g/m^3

$$X_{MLSS} = \frac{Q_{RS} * X_{RS}}{(1+RV)*Q}$$

$$X_{MLSS} = \frac{RV * X_{RS}}{(1+RV)}$$

Parameters activated sludge system

- **F/M ratio**

$$B_{BOD} = \frac{B_{d,BOD,}}{X_{MLSS} \cdot V_{AT}} \left[\frac{\text{kg BOD}_5}{\text{kg MLSS} * \text{d}}\right]$$

$$B_{COD} = \frac{B_{d,COD}}{X_{MLSS} \cdot V_{AT}} \left[\frac{\text{kg COD}}{\text{kg MLSS} * \text{d}}\right]$$

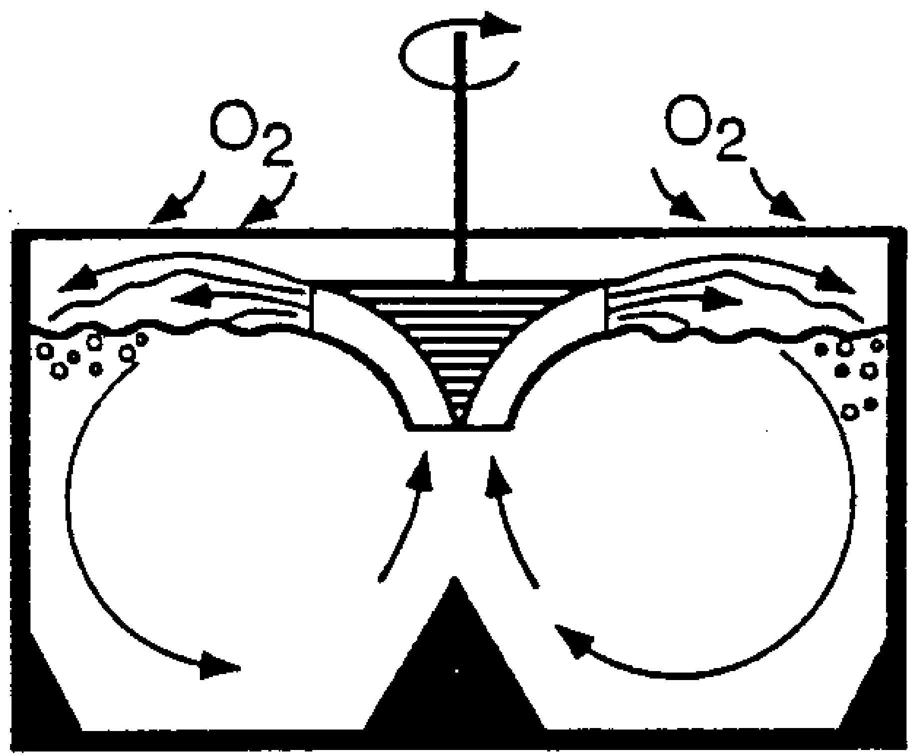
- **Sludge age**

(medium retention time of sludge in activated sludge system)

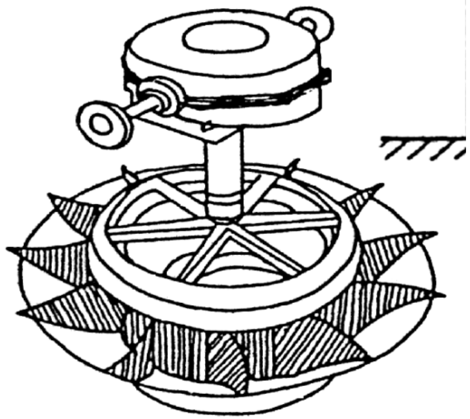
$$t_{MLSS} = \frac{X_{MLSS} * V_{AT}}{SS_d} = \frac{X_{MLSS} * V_{AT}}{X_{SS} \cdot Q_{SS} + X_e \cdot Q} \text{ [d]}$$

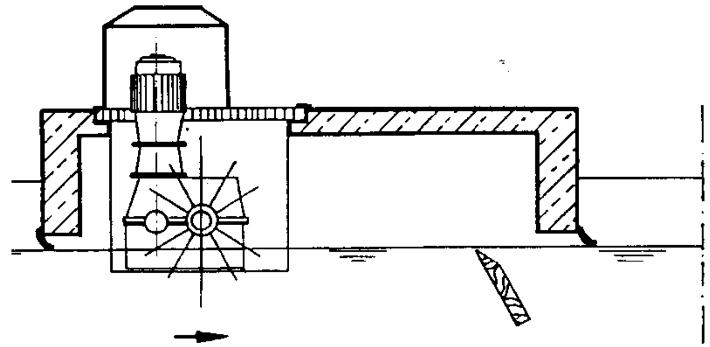
Aerators activated sludge system

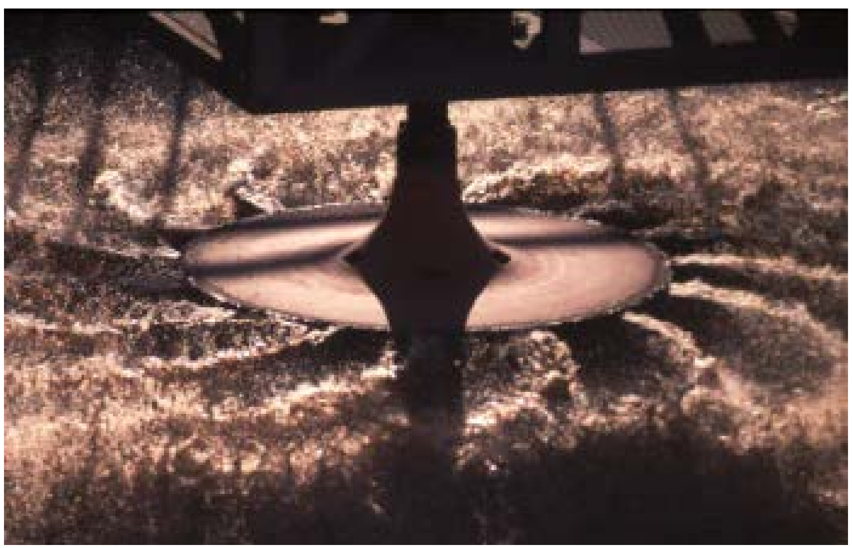
- Surface aerators



Aerators activated sludge system

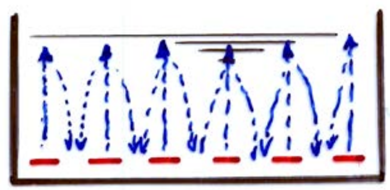


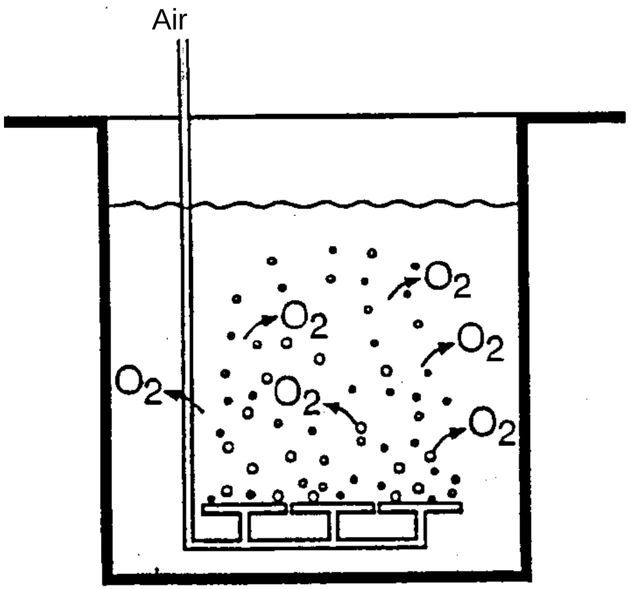


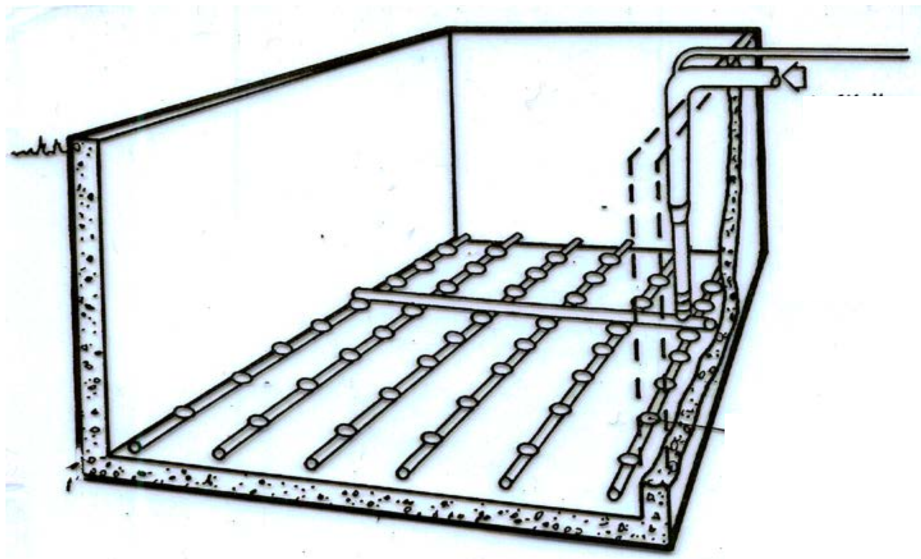


Input of oxygen into activated sludge systems

- Bubble or pressure aeration by aerators (diffusors)
  - Aeration and mixing
  - Different forms of aerators
  - Different sizes of bubbles







Aerators in activated sludge systems

Plate aerator

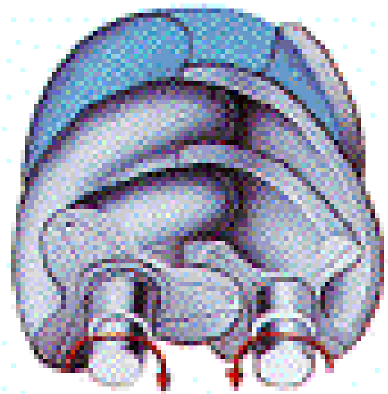
Disc aerators

Diffusors

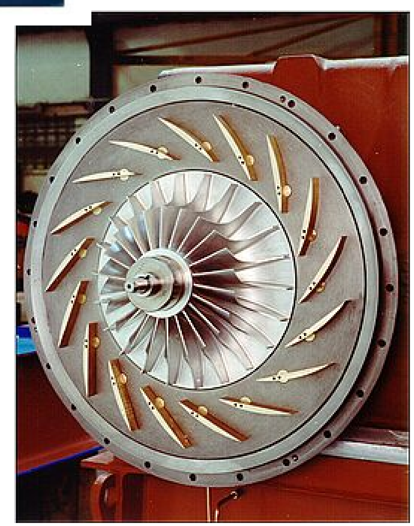
Air compressors

Rotary piston compressor

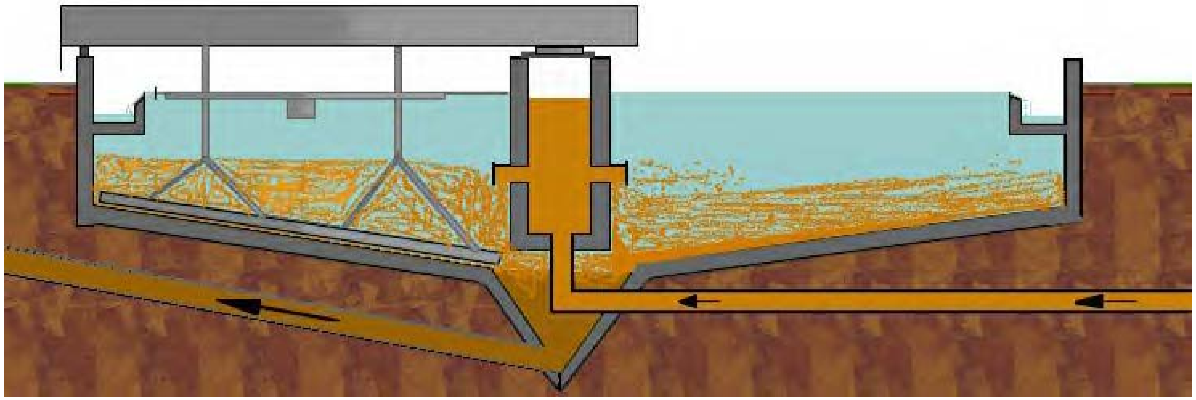
Screw compressor



Turbo compressor

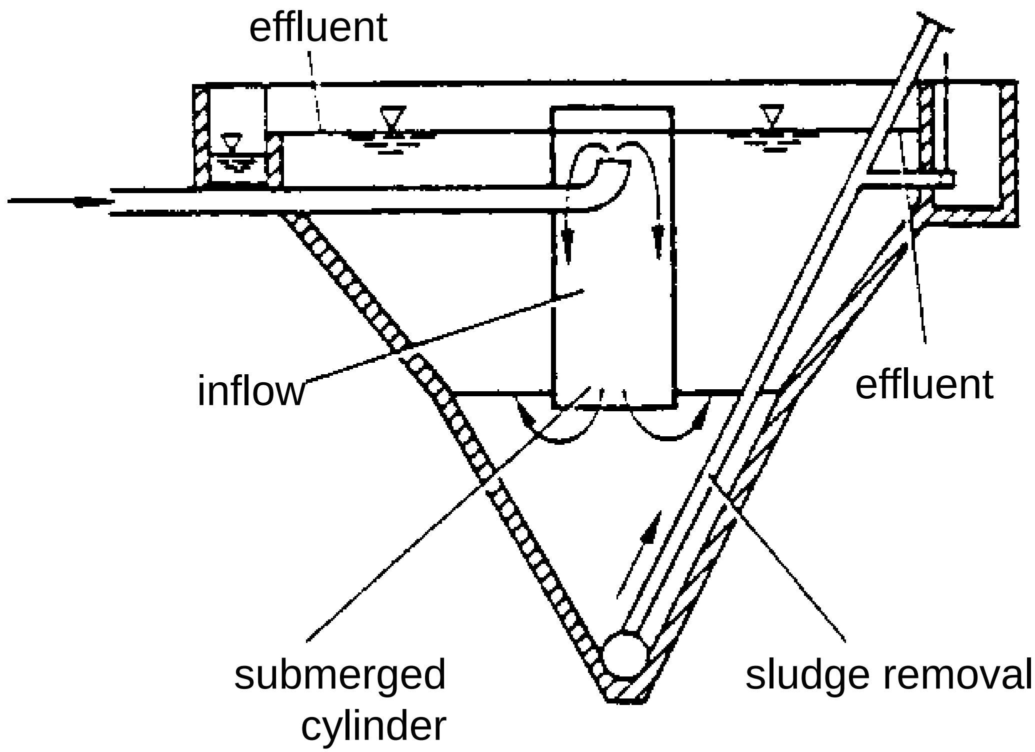


Secondary clarifier



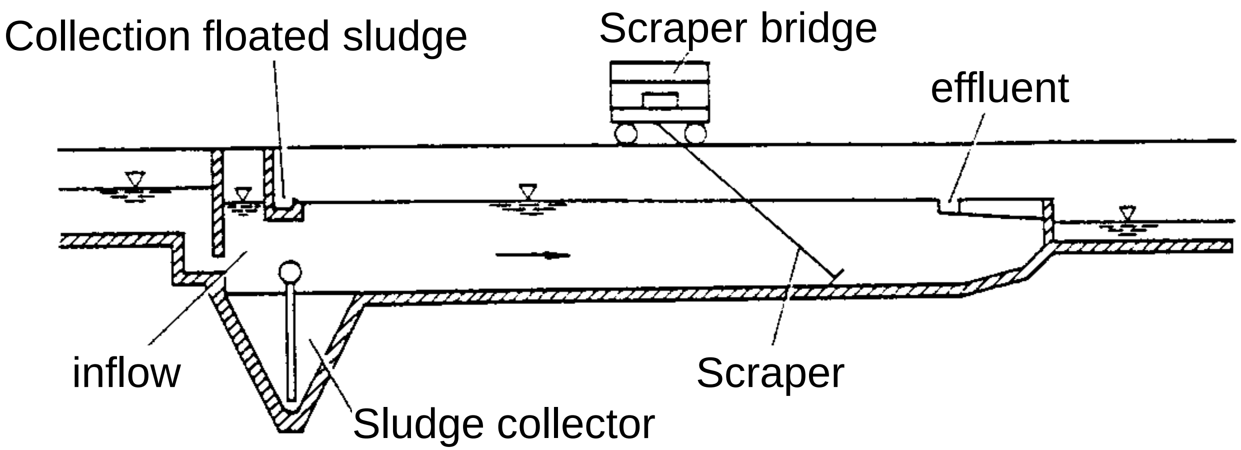
- Tasks:
  - Separation of mixed liquor (solid-liquid separation)
  - Low concentration of suspended solids in the effluent
  - Regular distribution of the inflow on the tank
  - Avoidance of hydraulic short-cuts and turbulences
  - Thickening of sludge
  - Storage of sludge during stormwater inflow

Secondary clarifier – vertical loading



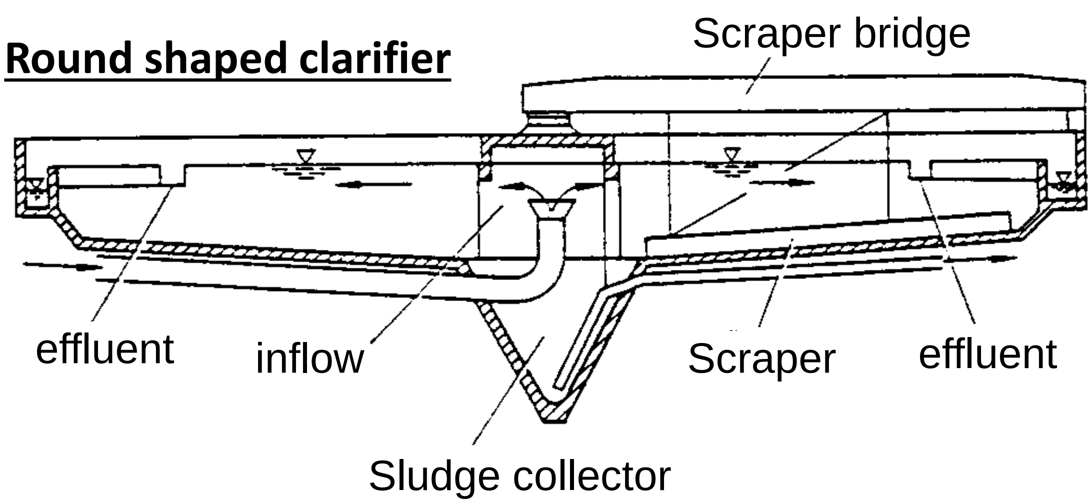
+ Good separation of sludge
- High capital costs due to depth
- Mainly for small treatment plants

Secondary clarifier – horizontal loading



- \+ Low demand of space
- \+ Continious sludge recycling
- \+ Low capital costs
- \- High loading of weirs
- \- Constant velocity of water

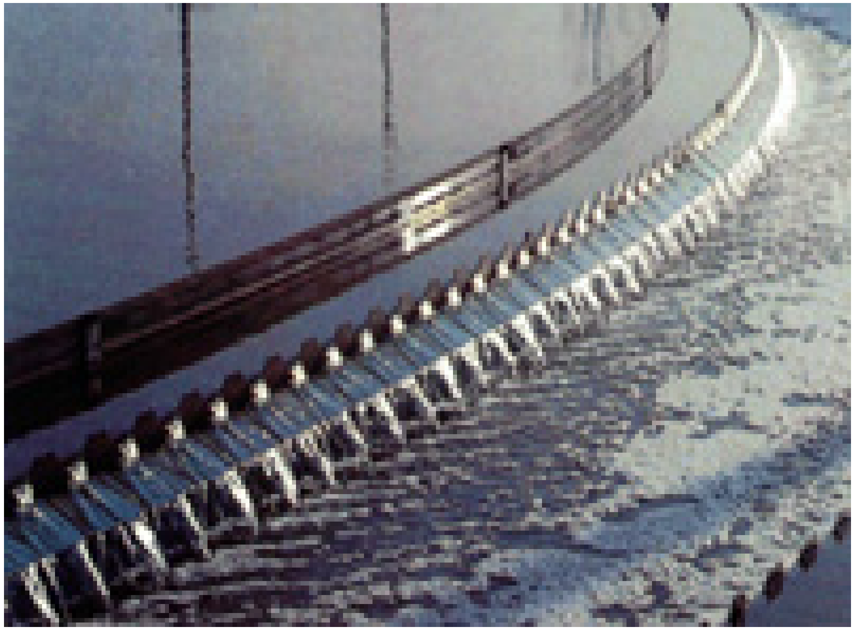
Round shaped clarifier



- \+ Simple inflo construction
- \+ Continious sludge recycling
- \+ Low capital costs
- \+ Simple water and sludge
- \+ Low loading of weirs
- \- High demand of space esp. for various tanks

Secondary clarifier – effluent constructions

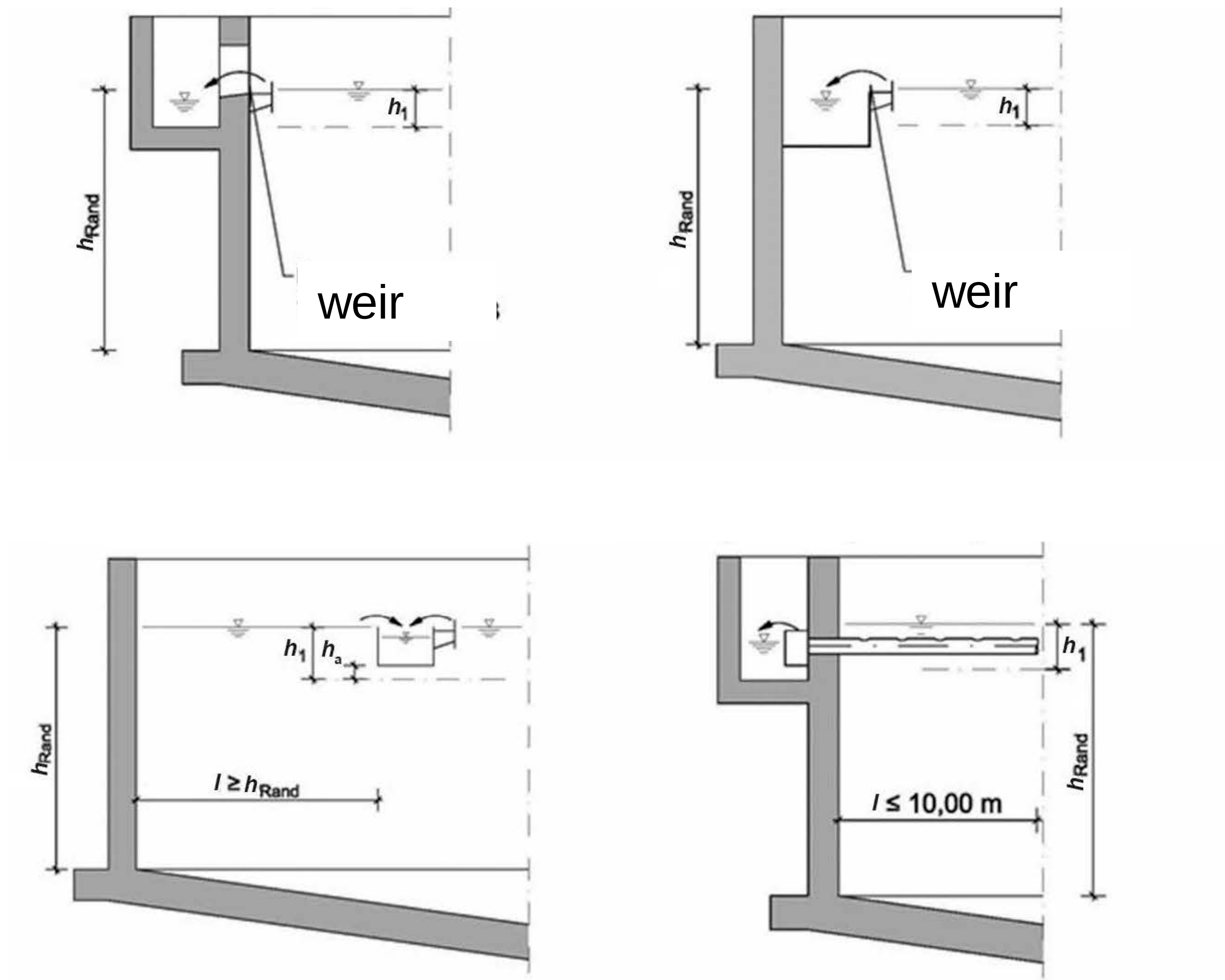
Overfall weir



Overfall weir with submerged wall

Floating sludge

Secondary clarifier – effluent constructions



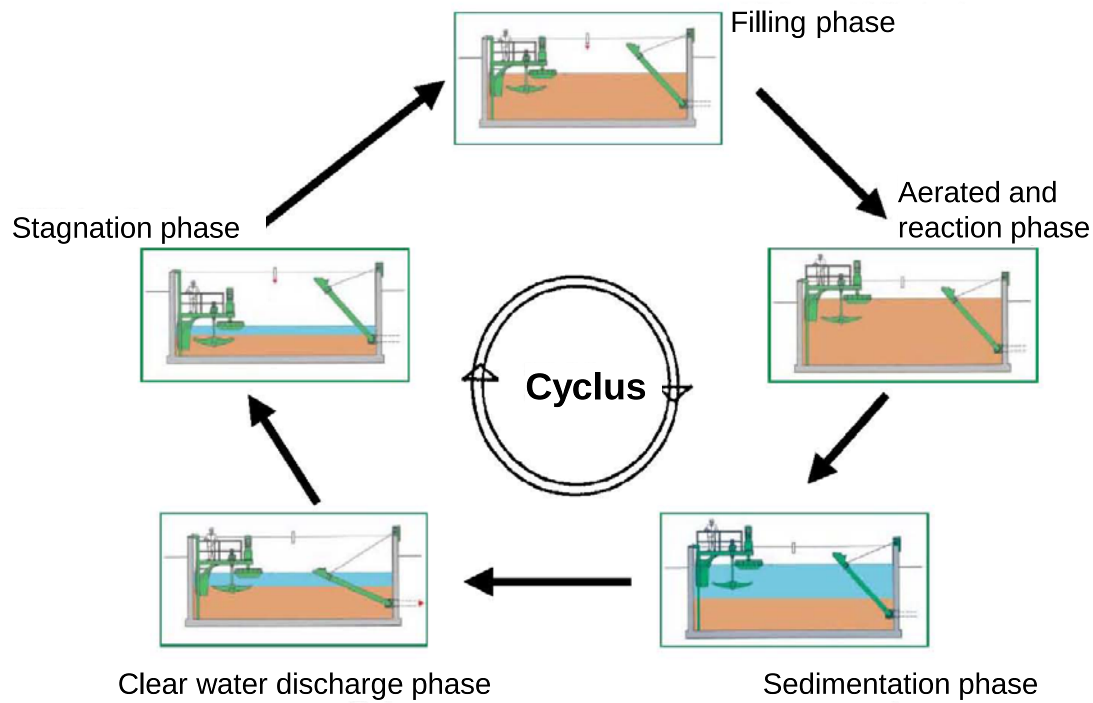
Secondary clarifier – sludge collection

Round shaped tank with scraper bridge

Rectangular tank with lifted scraper shield

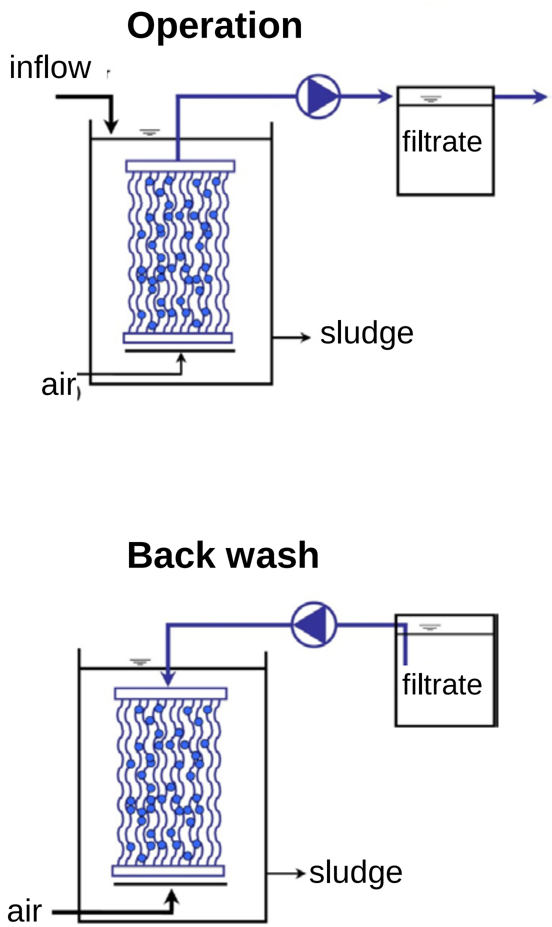
Sequencing batch reactor (SBR)

- Non constant water level and volume in in the reactor
- Different reaction phases in one reactor
- No constant inflow
- Control of the duration of the different phases

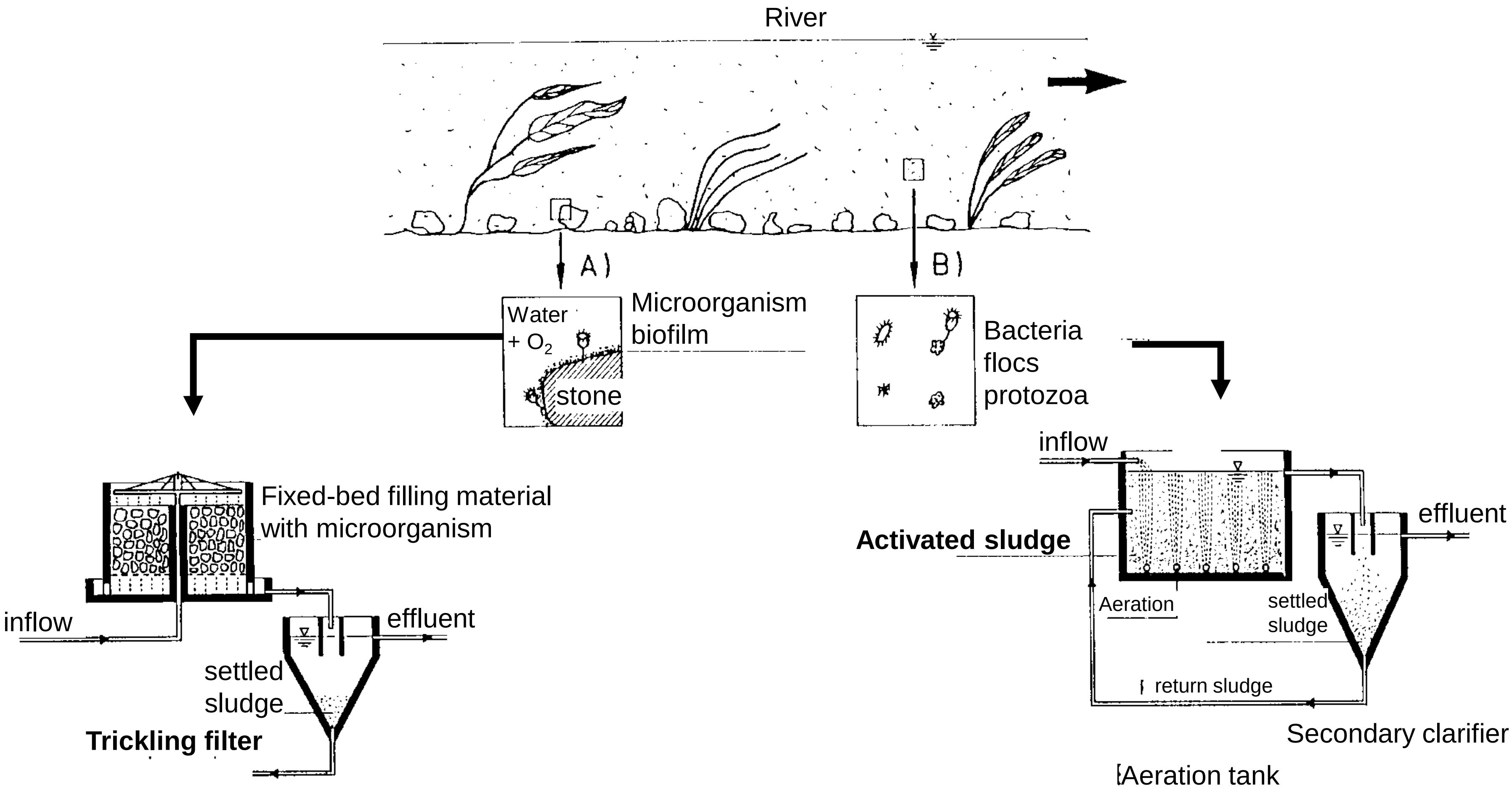


Sequencing batch reactor (SBR)

Membrane biological reactors (MBR)



Self-purificaion processes and technical application



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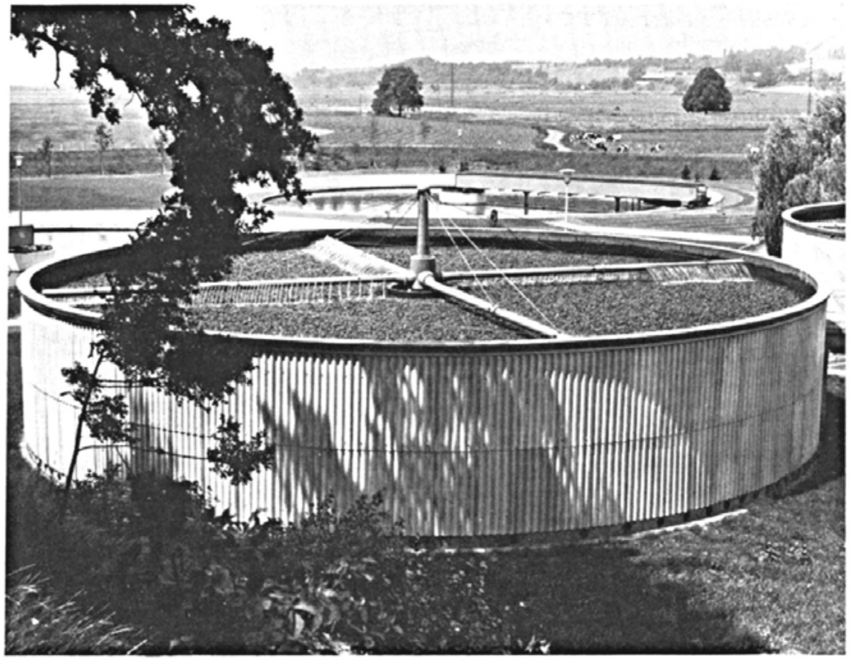
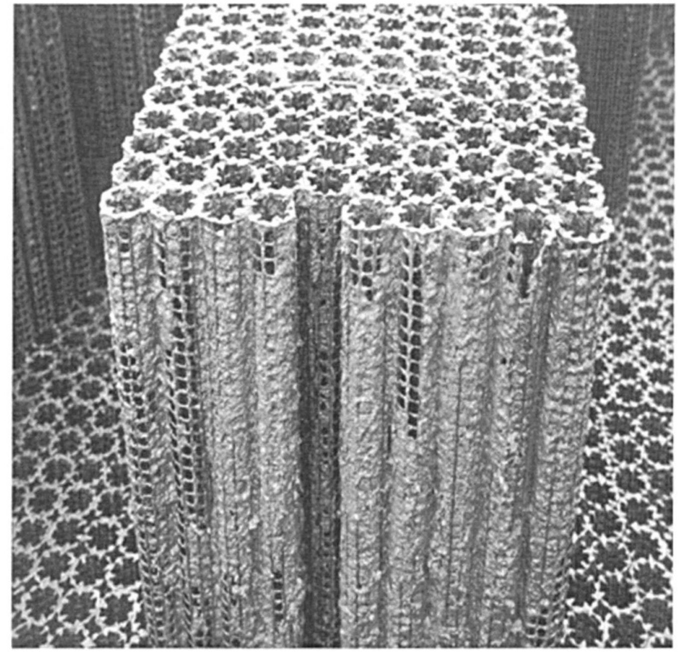
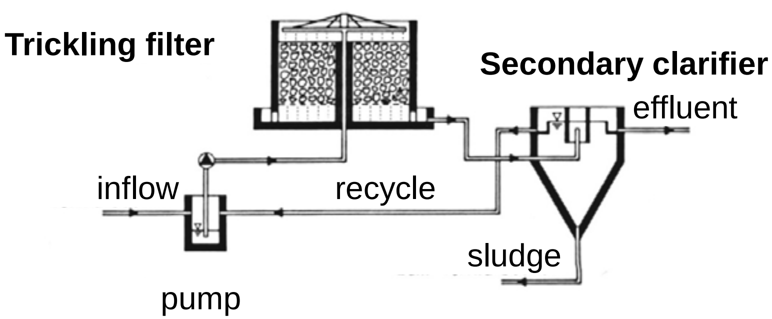
Trickling filter



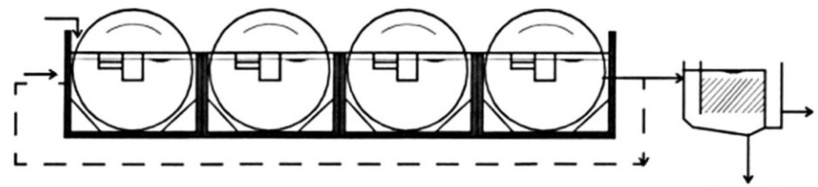




Trickling filter

- Obligate aerob => only removal of orgnanic matter and nitrifikation
- Mass of active sludge can‘t be determined
- Retention time of wastewater: approx. 10 – 20 minutes
- Distribution of biomass in the trickling filter has a gradient
  upper part: high loads and high acitivity
  lower part: microoganism with longer generation time
- Thickness of biofilm depends on the load
- Surplus sludge will be washed out
- Recycle can increase effluent quality
- Mainly on small wwtp‘s (< 10.000 cap)
  often as combined plants with activated sludge systems or pond systems

Rotating biological contactor (RBC)



Energy profit of bacteria degrading glucose

- Aerobic:

  $C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$

  Energy profit - 1,100 kJ

- Anaerobic:

  $C_6H_{12}O_6 \rightarrow 3\ CH_4 + 3\ CO_2$

  Energy profit - 172 kJ

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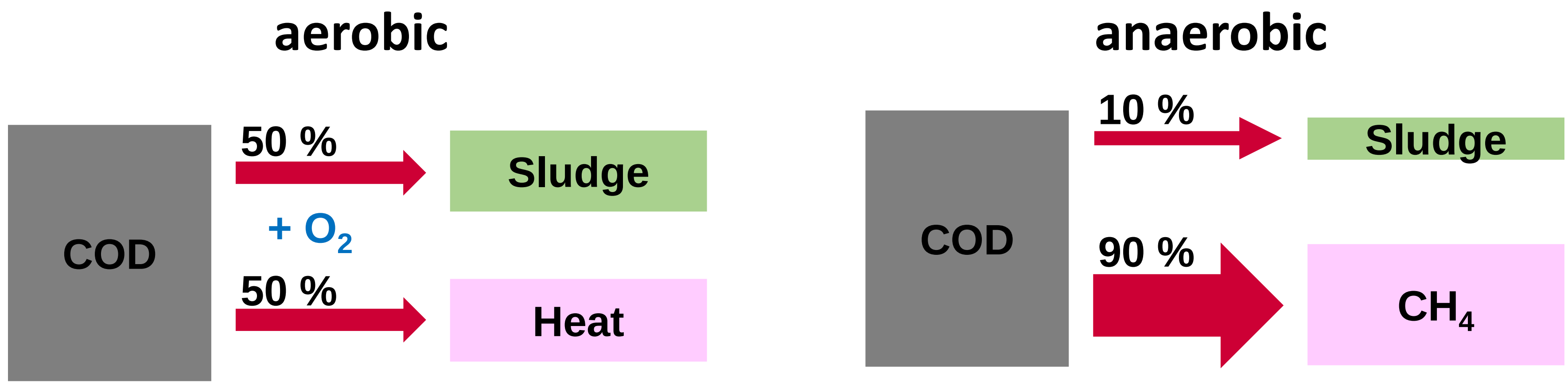
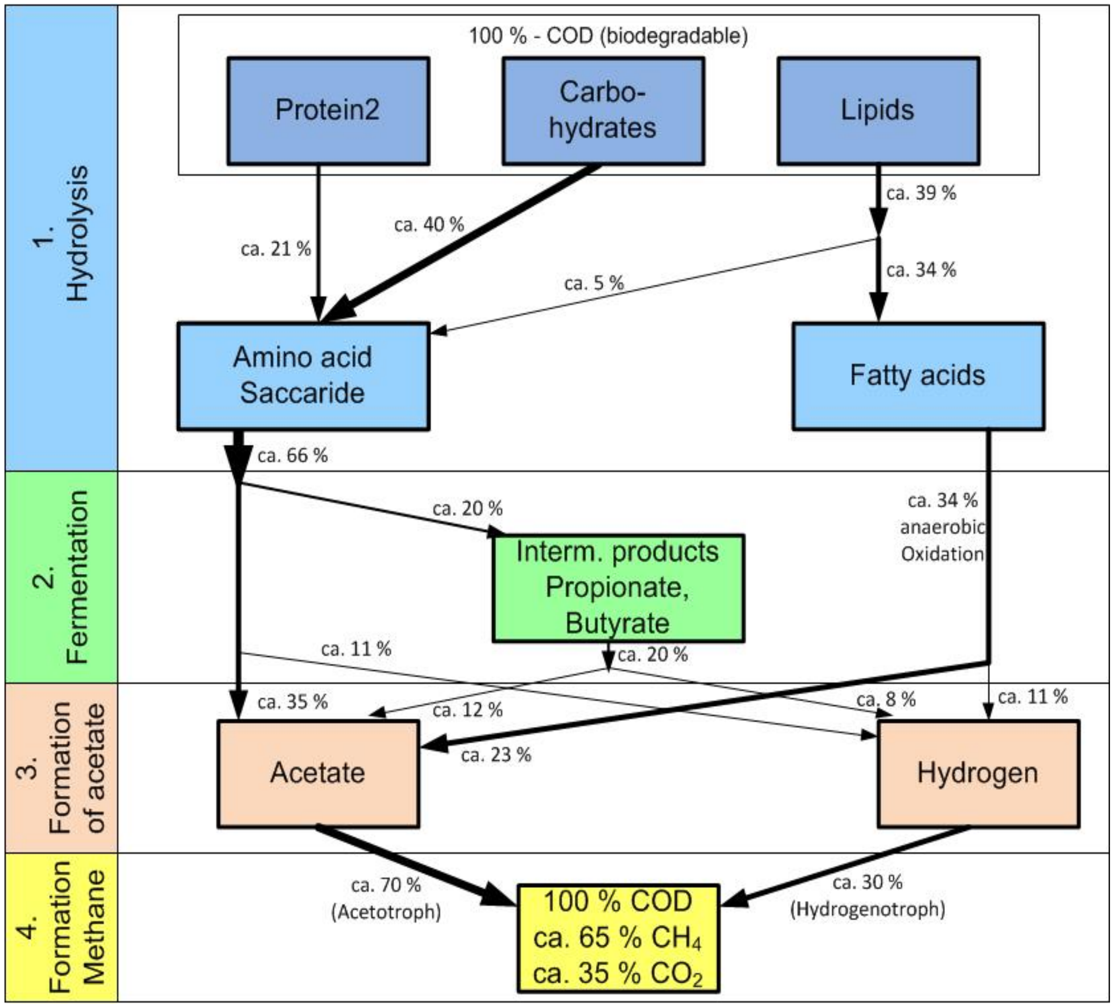
COD-Balance

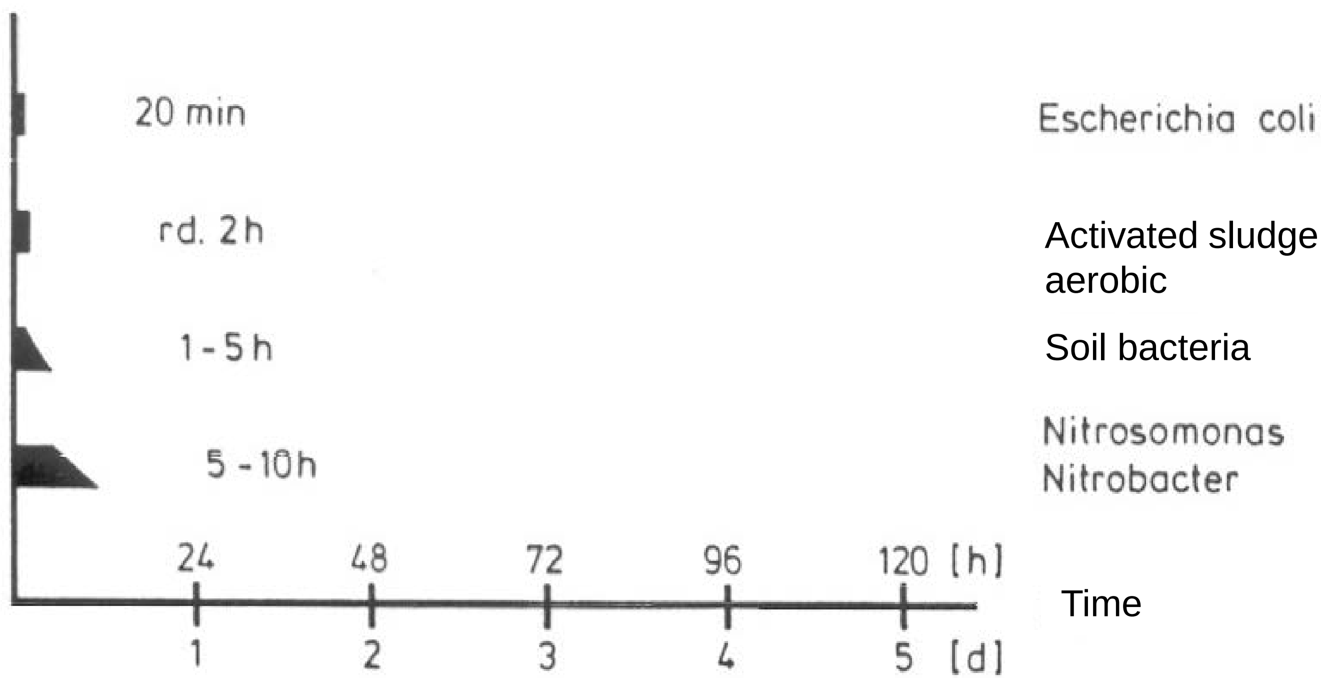
- Comparison aerobic and anaerobic degradation



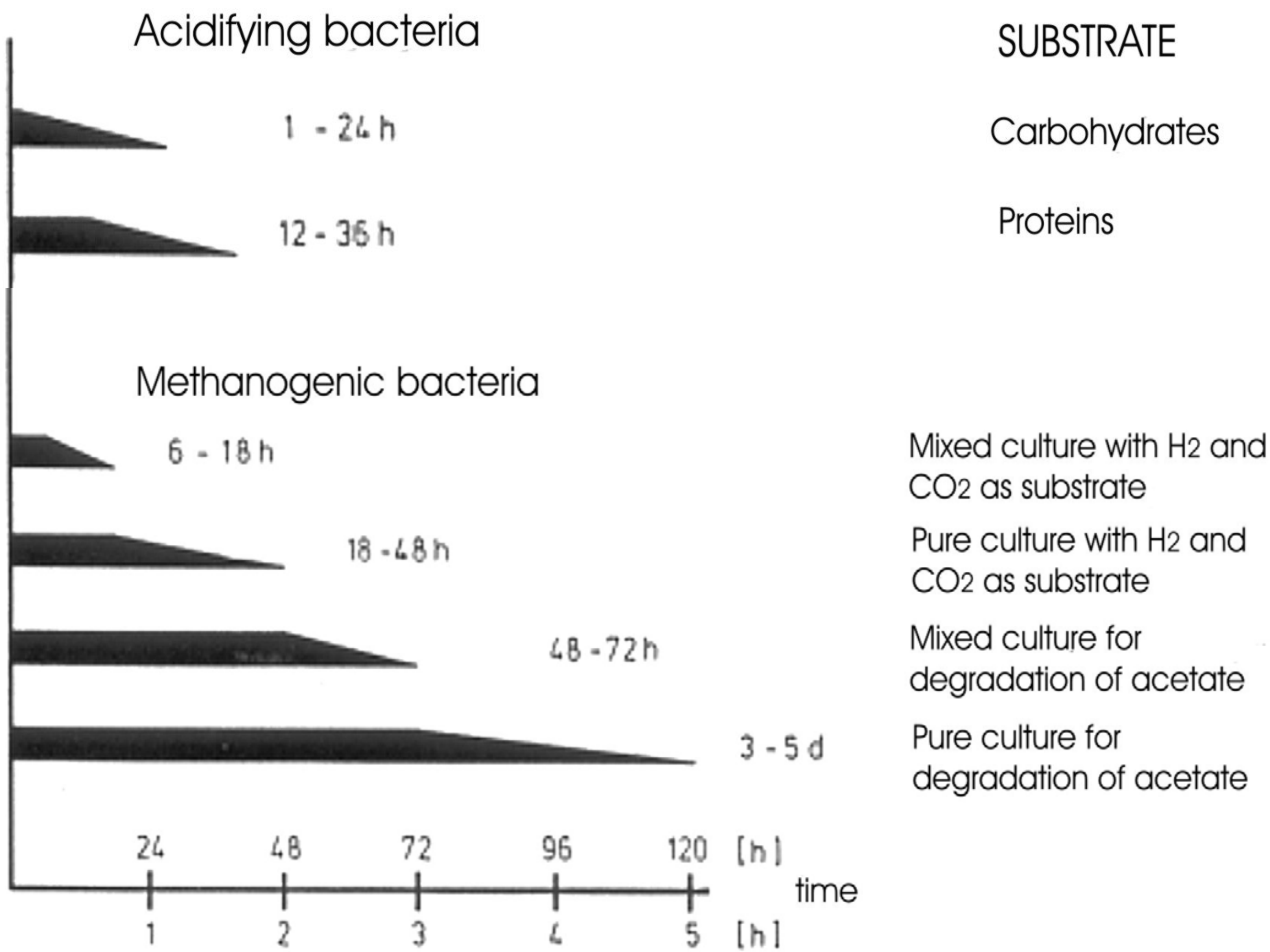
Scheme of anaerobic degradation



Generation time of aerobic bacteria



Generation time of anaerobic bacteria



Advantages anaerobic treatment

- + Appropriate for high COD-concentrations
- + High volumetric load => Small volumes required
- + Low sludge production
  (3 –10-lower than with aerobic treatment)
- + Low energy demand, no aeration necessary
- + Yield of biogas
- + Lower cost than for aerobic treatment
- + Degradation of substances which are non-biodegradable under aerobic conditions
- + Suitable for hot climate conditions

Disadvantages anaerobic treatment

- Efficiency of degradation of organic substances only up to 70 – 80 %,
  => aerobic post-treatment required
- Balance of volatile fatty acids
- Long adaptation phases necessary
- Sensitivity towards oszillating temperature, pH-value, changing concentrations and loads
- Detailed monitoring systems required
- Sometimes pH-control required

Structure of anaerobic technologies

- Anaerobic Technologies
  - Without accumulation of biomass
  - With accumulation of biomass
    - Separation and recycling
      - internal
      - external
    - Biofilm material
      - mobile
      - immobile
    - Aggregation of
      - Pellets
      - Flocs