

Content - Questions to be answered

Waste- (water) Treatment

- What is it? From Where & How Much? (quantity & quality)
- Why must wastewater be treated? (Environmental Protection & Legal Framework)
- How to collect wastewater? (drainage system & other concepts)
- **How does a treatment plant work? (conventional, large treatment plants = aerobe intensive systems)**
- What to do with the sludge? (sludge treatment & disposal)
- Any other possibilities of wastewater treatment? (extensive systems)
- Are these sanitation concepts available & appropriate for all over the world? (alternative concepts)
- How to monitor and evaluate the quality of surface waters? (saprobic system)

Task of wwt

- **Remove pollutants** from the wastewater
- Conditioning and **disposal or recycling of sludge** (organic and inorganic residual material)
- Fulfillment of tasks has to be done **economically and reliably**

History:

Year	Phenomenon / Problem	Substance
1920	accumulation of mud	Suspended Solids (SS)
1950	Growth of bacteria	Org. Carbon (Parameter: BOD ₅)
1965	Eutrophication of lakes	P _{tot}
1975	Fish toxins	(Ammonium) NH ₄ ⁺
1980	Agricultural recycling <-> Pollutants	Heavy metals
1990	Eutrophication of sea	(Nitrate) NO ₃ ⁻

Scheme of WWTP

Mechanical treatment

- Screen -> screenings
- Grit chamber, Grease separator
- Primary clarifier (settlement)

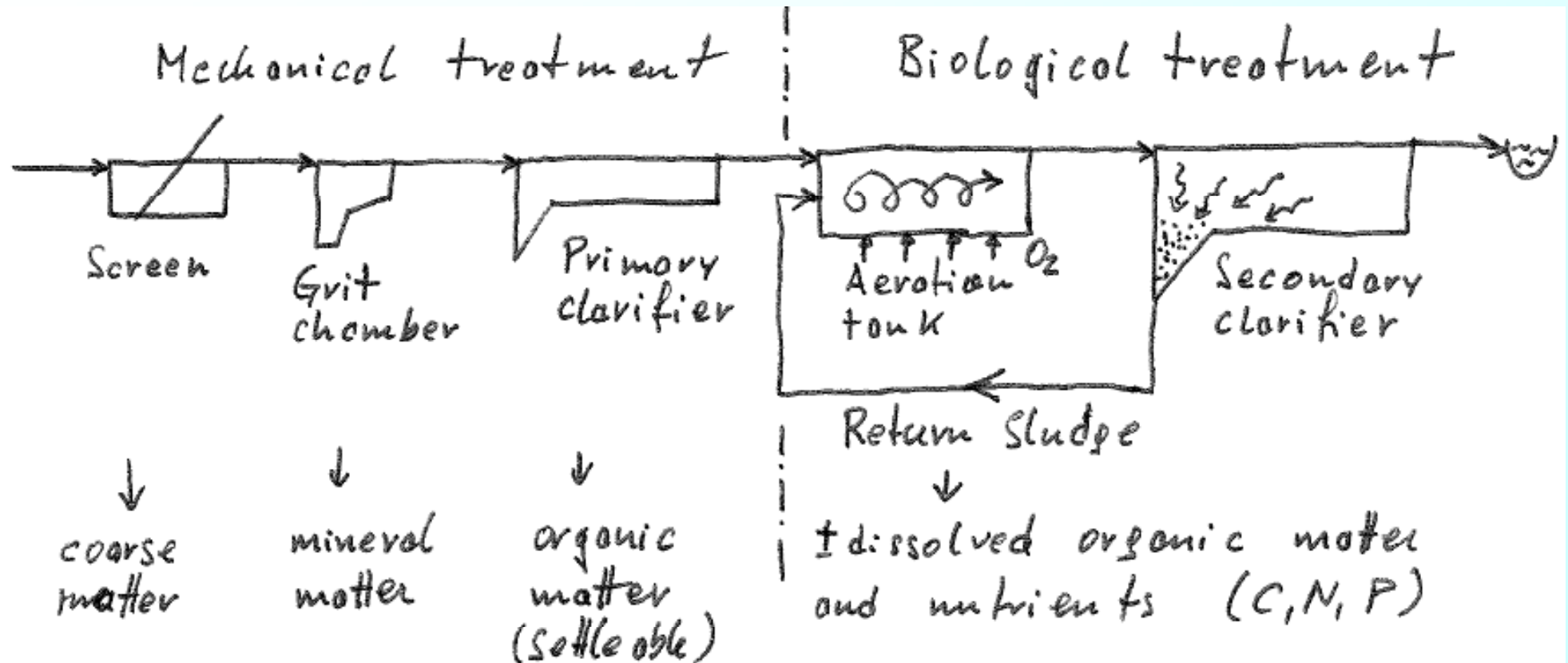
Biological treatment

- Biological reactor (e.g. activated sludge process, trickling filter)
- Secondary clarifier
- Return sludge (only in case of ASP)

Sludge treatment

- Thickener (dewatering)
- Digester (conditioning) → Biogas
- Sludge container
- Recycling / Disposal

Scheme of WWTP



Mechanical Wastewater treatment

Total pollutant load of wastewater consist of about 30 to 40 % undissolved matter.

- biological treatment is energy intensive, it's the task of the mechanical pre-treatment to **reduce the load inflow to the biological treatment.**

Removal of particular matter is done by

- Sieving
- Filtering
- Flotation
- Settlement

Systems used in WWTP are:

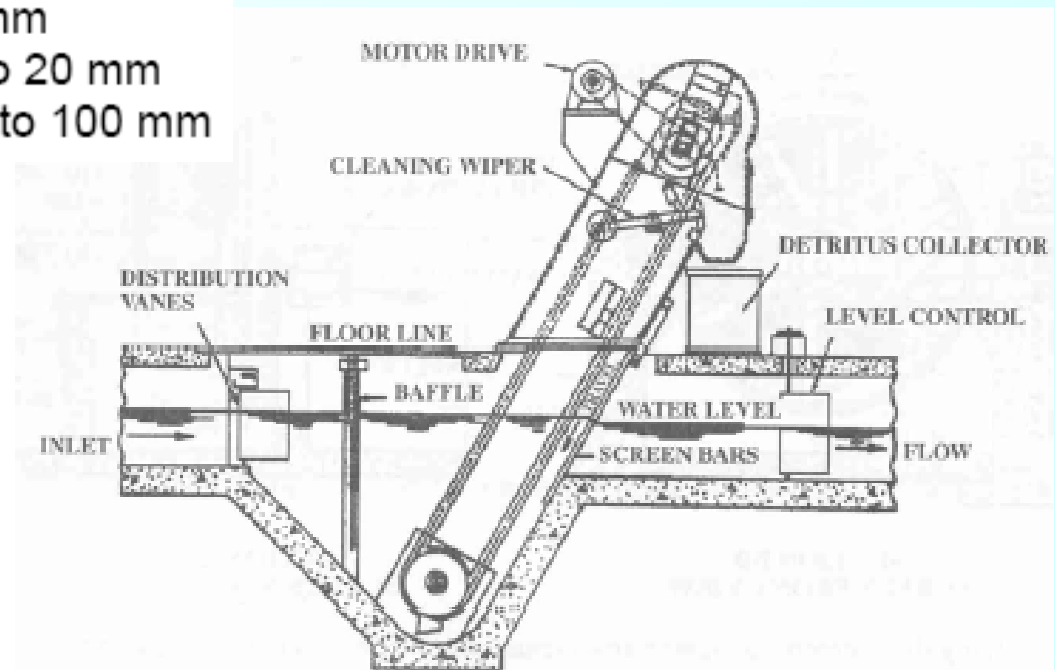
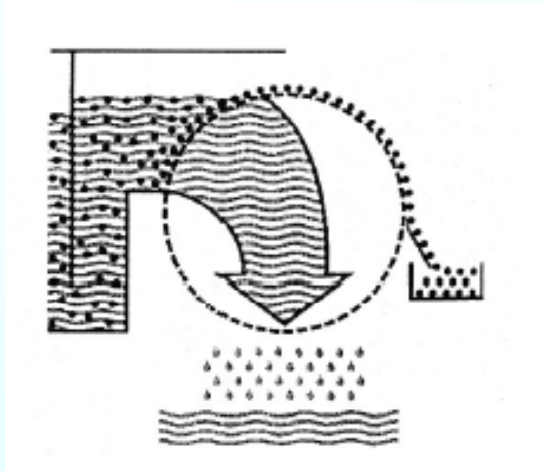
- Screens & Sieves
- Grit and Grease separators
- Settlement and Flotation basins

Screens & Sieves

- is the very first stage of treatment at every conventionally WWTP
- Cleaning of the screen is done automatically and usually triggered by a certain difference of water level.

Finest screening	spacings smaller	8 mm
Fine screening	spacings from	8 to 20 mm
Coarse screening	spacings from	20 to 100 mm

sieves with spacings of e.g. 1 mm



Screens with automatic screenings remover

Screens & Sieves

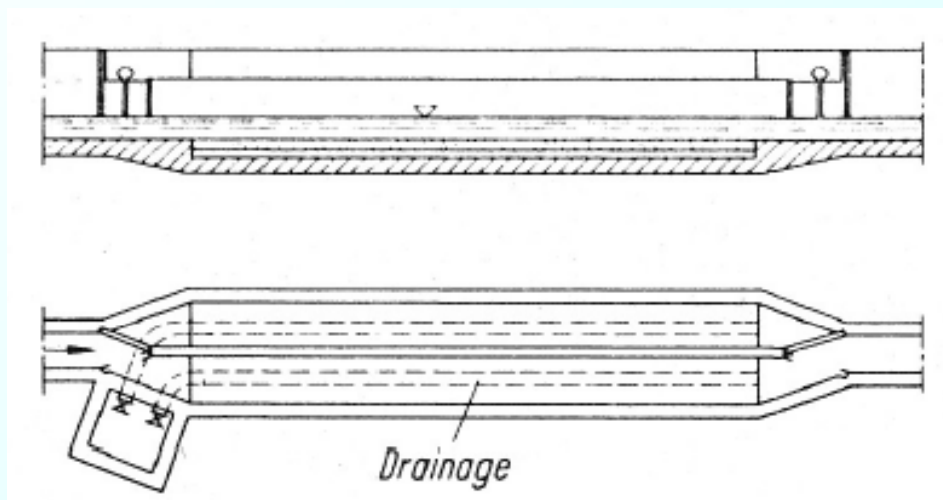


Grit and Grease separators

- separate particles of a size of **0.1 to 2 mm**.
- Organic matter should not be settled together with inorganic matter

These requirements are met at a **flow velocity of > 0.2 m/s**.

- Separation of organic matter is prevented by artificial turbulences (paddles, aeration)
- Aerated grit chambers can be combined with grease separator.



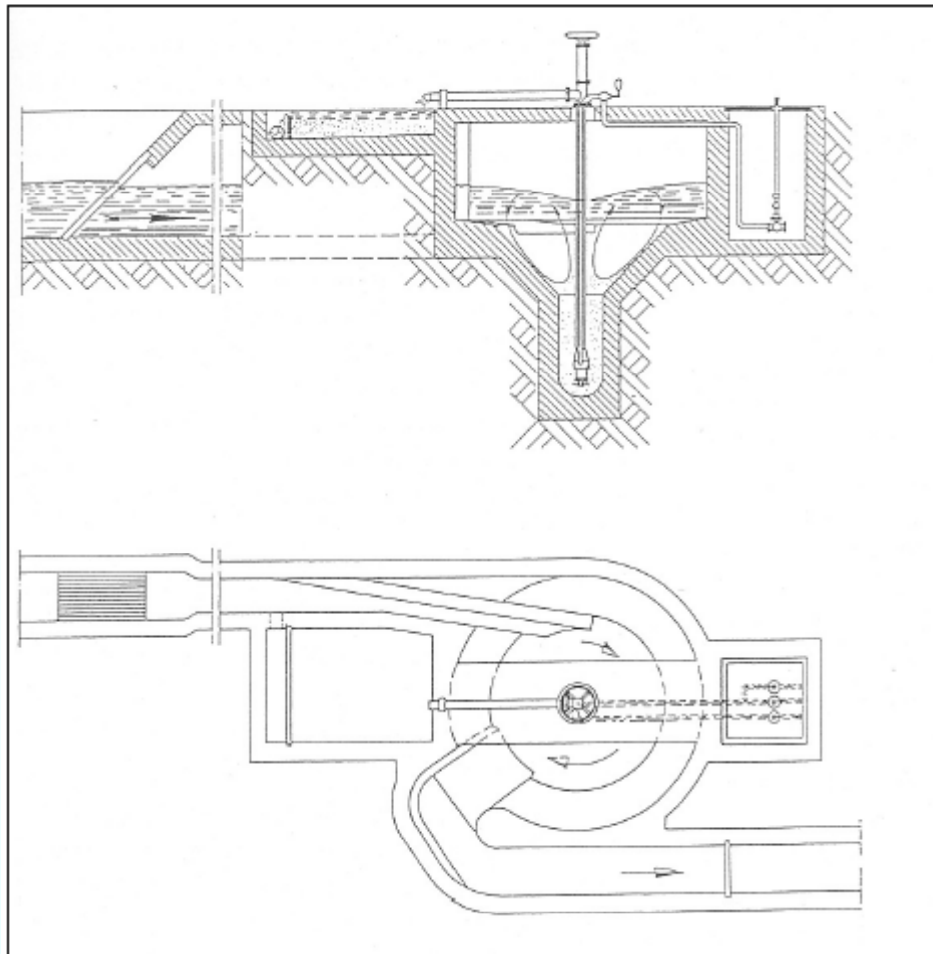
Longitudinal grit chamber

Grit and Grease separators



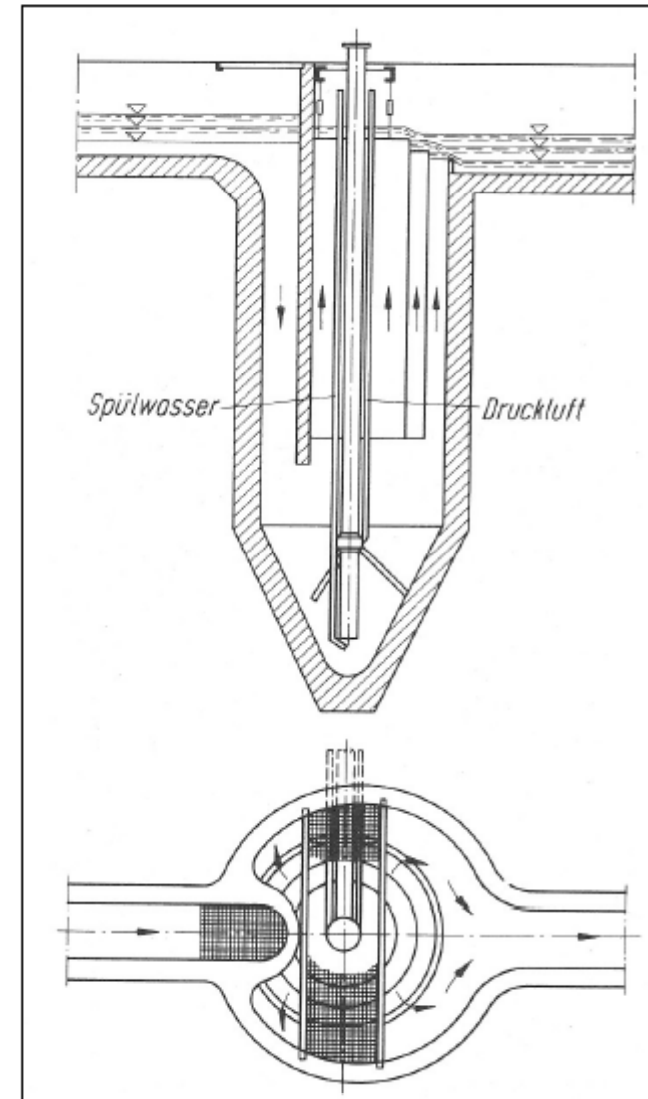
Longitudinal grit chamber

Grit and Grease separators

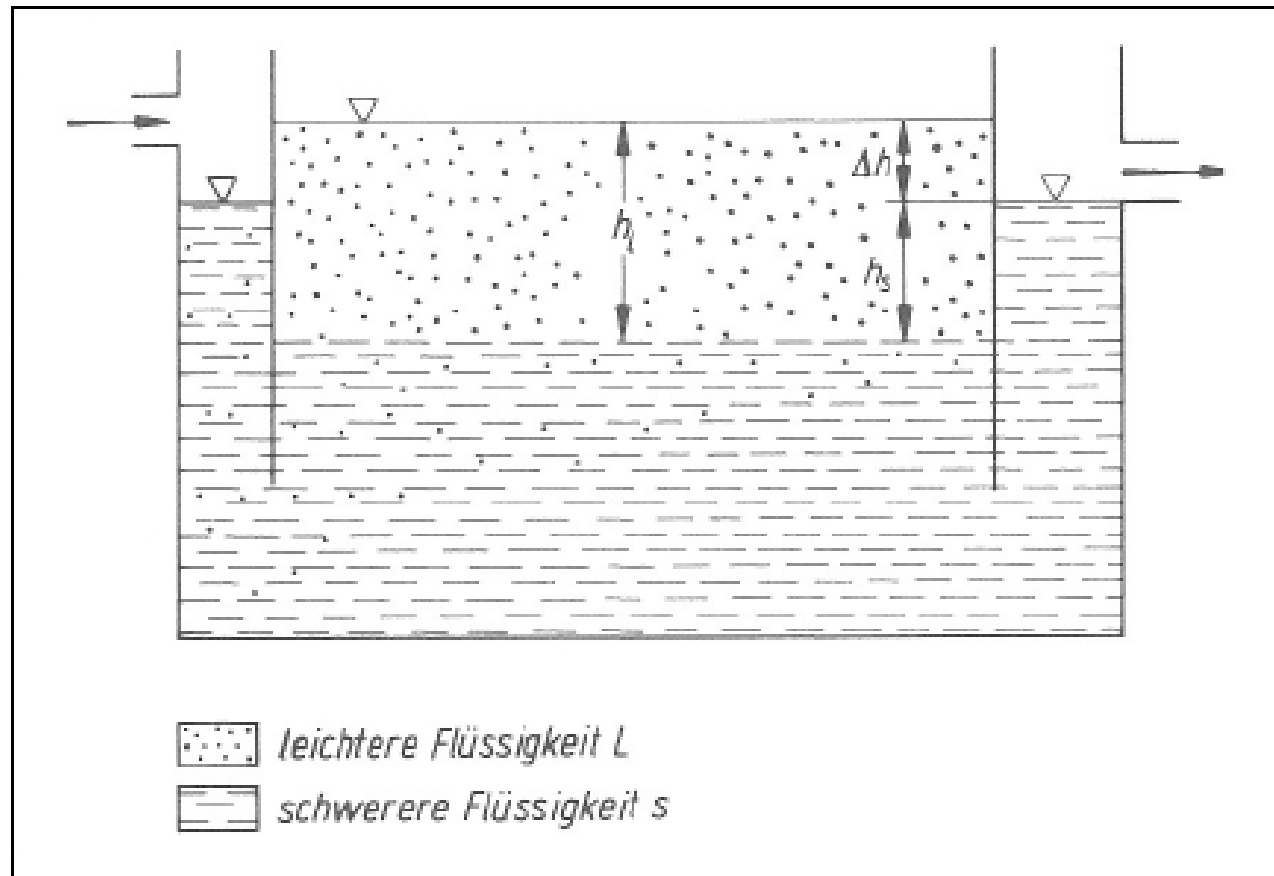


Circular grit chamber ^^^

Deep grit chamber >>>

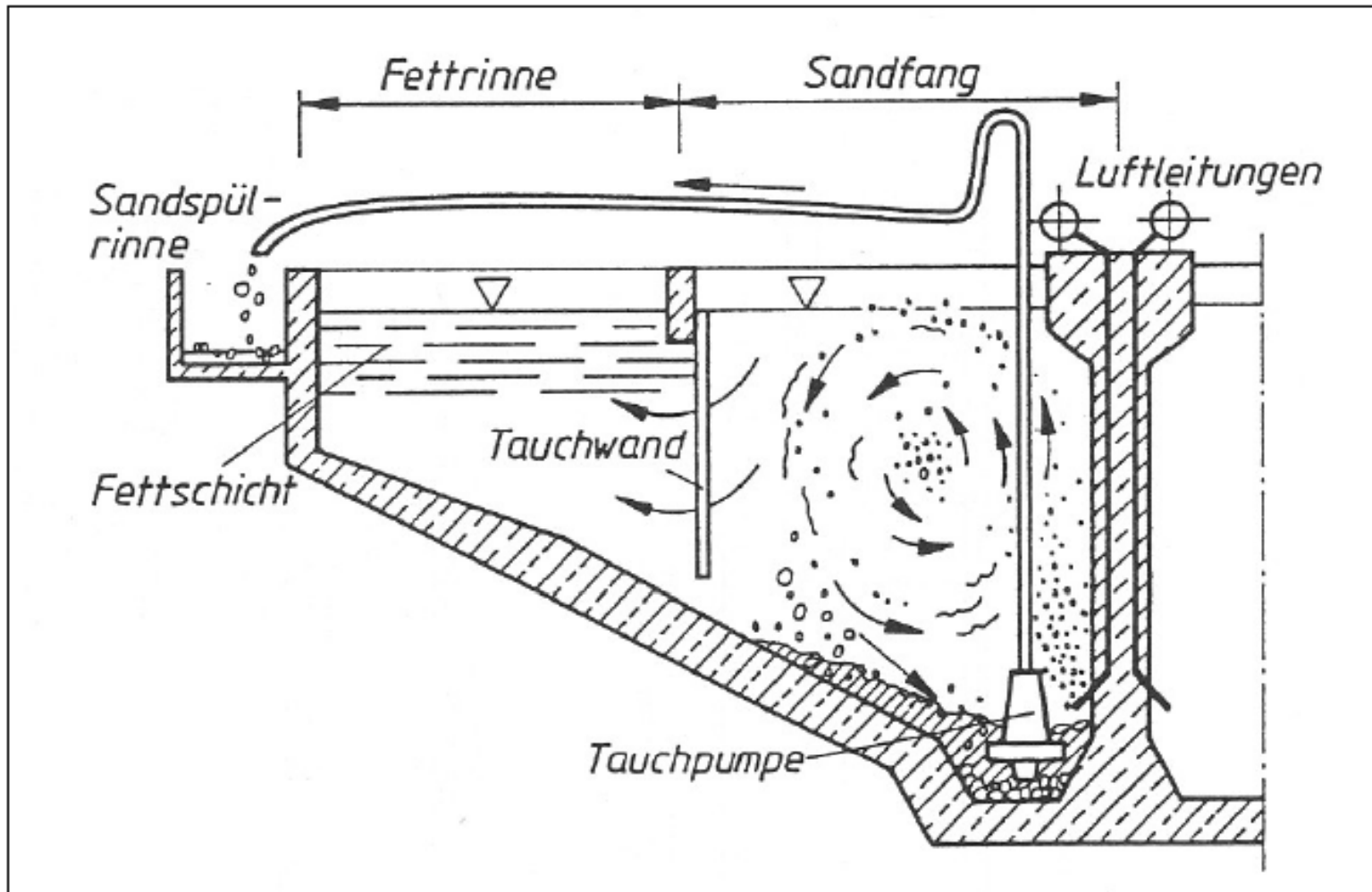


Grit and Grease separators



Principal of light liquid separation

Grit and Grease separators



Cross-section of an aerated grit chamber and combined grease separator

Settled substances (sand) are removed by a pump (e.g. jet pump or mammoth pump)

Grease is retained at a scum board

Primary clarifier (settlement)

Reduction of flow velocity enables settleable matter to sink to the bottom.

- Settlement is granted when the **sinking time** of a certain particle is **shorter than the flow time** through the clarifier.

Primary Clarifier has to remove particle sizes larger than 0.1 mm.

Sinking velocity of Sand, Coal, SS (domestic wastewater); m/h for different diameters

Stoff	Dichte		Durchmesser mm						
			1,0	0,5	0,2	0,1	0,05	0,01	0,005
Sand	2,56 kg/l	m/h	502	258	82	24	6,1	0,3	0,06
Coal	1,50 kg/l	m/h	152	76	26	7,6	1,5	0,08	0,015
SS	1,20 kg/l	m/h	122	61	18	3	0,8	0,03	0,008



Primary clarifier (settlement)

Primary Clarifier has to remove particle sizes larger than 0.1 mm.

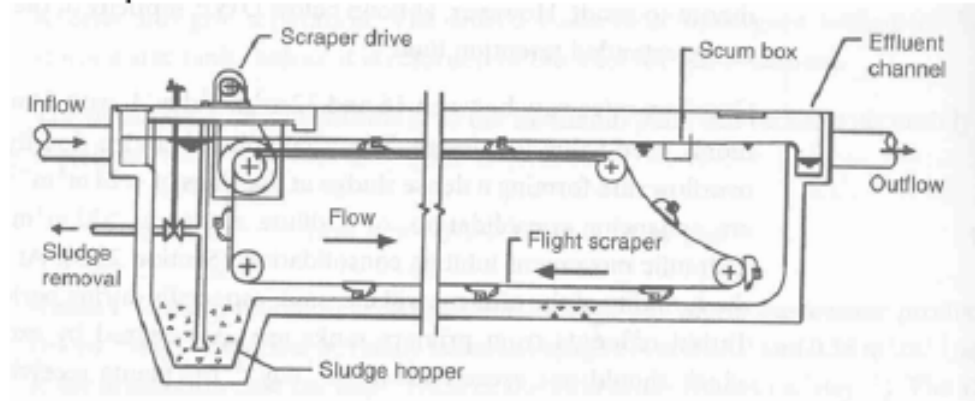
- Thus, the **hydraulic surface loading should be in the range of 2.5 to 4.0 m³ / m²*h**
- To prevent re-dispersion of settled particles, the maximum flow velocity should be **1 cm / s** in case of dry-weather-flow.

Design:

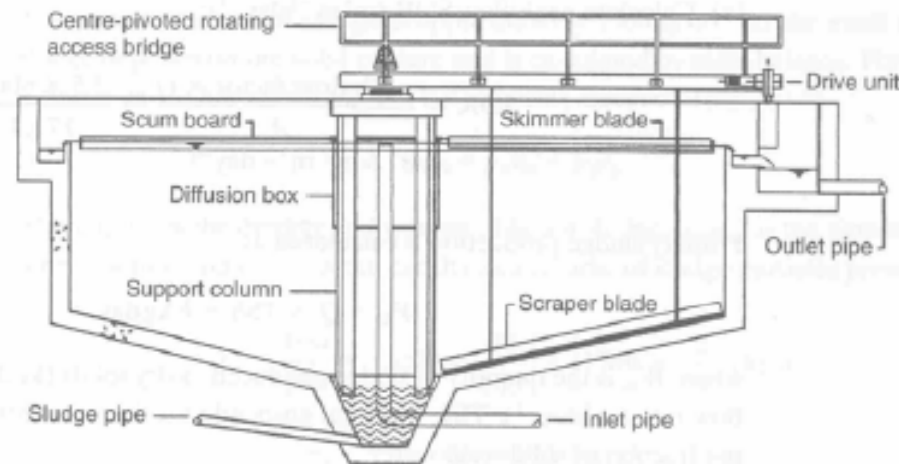
- Depth usually 2 to 3 m.
- Settled particles removed by a scraper installation.
- floating matter is removed from the surface

Primary clarifier (settlement)

Examples



Horizontal flow, rectangular tank with longitudinal scraper

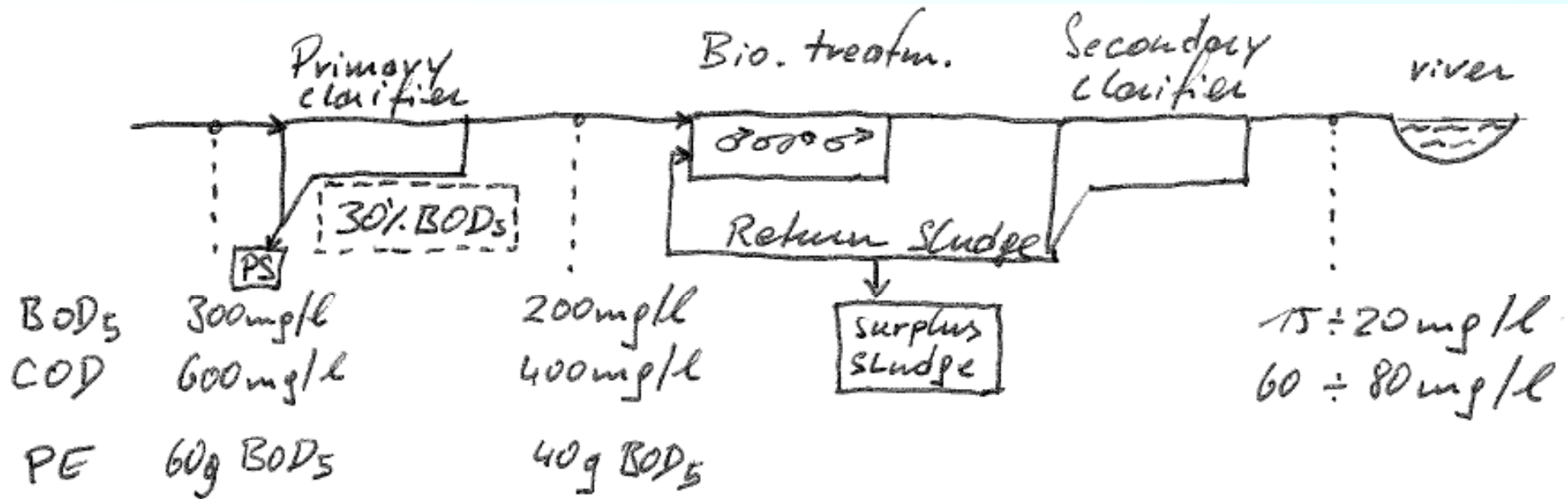


Horizontal flow, circular tank with circular scraper

Primary clarifier (settlement)



Wastewater treatment - balance



$$BOD_{TOT} \approx BOD_{20}$$

$$\Rightarrow BOD_5 \rightarrow \text{less}$$

$$\Rightarrow \frac{COD}{BOD_5} = 1,5$$

$$\frac{COD}{BOD_{TOT}} \approx 1$$

Biological Wastewater treatment

Principles of biological wastewater treatment are **self-cleaning processes** found in rivers and upper soil layers.

Self-cleaning processes are:

- **Adsorption** (the binding of molecules or particles to a surface)
- **Resorption** (uptake of substances by organism)
- **Dissimilation / Assimilation** (generate energy / accumulation of energy)

Natural self-cleaning processes run slowly because of

- Low nutrient concentration
- Low concentration of MO
- Limited by the available oxygen and mixture of MO and nutrients
- Natural self-cleaning processes need very large “reactors” like soil or rivers

Biological Wastewater treatment

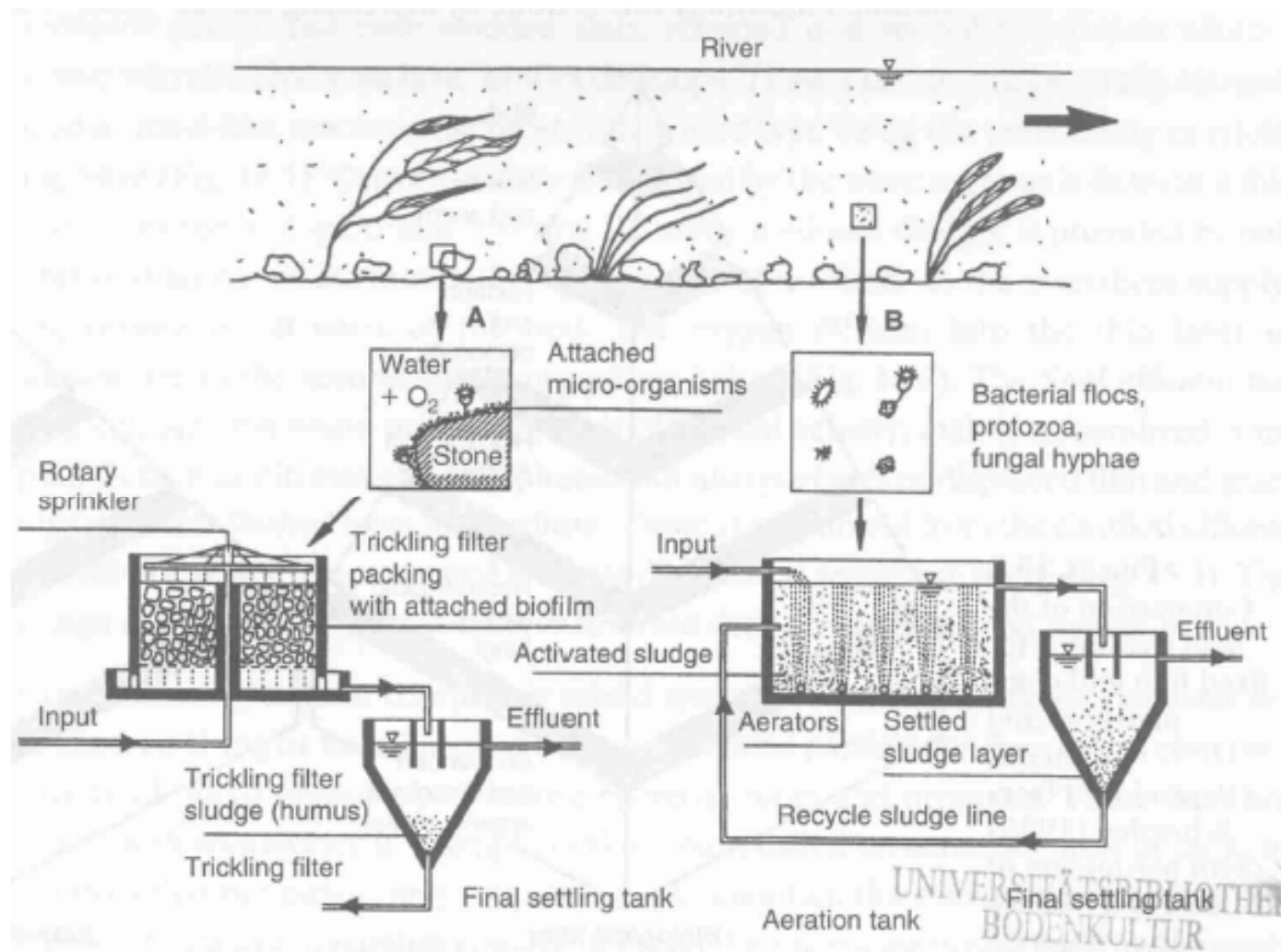


Figure 3 Transmission of natural self-cleaning processes from a river to WWTP

Sessile MO >>> **biofilm / fixed bed reactor** (e.g. trickling filter)

Floating MO >>> **aeration tank / activated sludge process**

Biological Wastewater treatment: Technical solution

The biological degradation of pollutants is carried out by the MO metabolism.

Intensifying the natural processes by:

- Concentration of nutrients (sewer)
- Concentrating the MO population (Bio-reactor)
- Sufficient oxygen supply (aeration)
- Better contact between MO and nutrients (mixing)

Requirements for a proper bio-degradation of pollutants:

- Sufficient available **oxygen** & sufficient **reaction time**
- Optimal composition of nutrients $C:N > 12$ and $C:P > 30$
 - No bacterial toxins or inhibitors
 - Good living conditions for MO (temp., pH, food supply)
 - Good dispersion of nutrients, oxygen and MO within the reactor

Biological Wastewater treatment: Technical solution

MO metabolism requires:

Energy source

- Sunlight (phototrophic) or
- **Oxidation of inorganic or organic substances (chemotrophic)**

Electron donor (hydrogen donor)

- Inorganic (lithotrophic)
- **Organic (organotrophic)**

Carbon source

- Carbon dioxide CO₂ (autotrophic)
- **Organic substances (heterotrophic)**

Biological Wastewater treatment: Technical solution

Influencing factors on the microbial activity:

Oxygen:

- **Oxygen saturation is the most important parameter.**
 - **Aerobic** processes: sufficient dissolved oxygen available (e.g. degradation of C + altering ammonia to nitrate → Nitrification)
 - **Anoxic** processes: no dissolved oxygen but oxygen in bonds (e.g. NO_3^-) available (e.g. Denitrification = degradation of NO_3^-)
 - **Anaerobic** processes: no dissolved oxygen and no oxygen in bonds available (e.g. digestion (=degradation of C))

Biological Wastewater treatment: Technical solution

Influencing factors on the microbial activity:

Nutrition:

- With increasing living conditions, the growth rate will increase.
- This increase is asymptotically approaching a maximum value.

Temperature:

- Activity of heterotrophic bacteria doubles with an increase of 10 °C.
- Autotrophic bacteria double their activity with an increase of 7 °C.
- Maximum activity is at 35 °C, above that the activity decreases again

pH value:

- Bacteria prefer a neutral pH (7 to 8).
- An acid range (pH lower than 4) is lethal

Nutrition conditions (anabolism uptake)

The biodegradation of carbon by heterotrophic MO needs

1 % phosphorus and **5 % nitrogen** per 100 % carbon equivalent

(carbon equivalent = BOD₅ (mg Oxygen required in 5 days / l wastewater))

➤ **BOD₅ : N : P = 100 : 5 : 1**

Domestic wastewater:

➤ **BOD₅ : N : P = 100 : 17 : 4**

Biological degradation of carbon

- Chemo-organo-heterotrophic MO use organic substances as an **energy source**, **electron donor** and **carbon source**.
- Aerobic respiration uses **oxygen as terminal electron acceptor**.
- Potential energy in hydrogen is made available to the MO by respiration, binding the substances to water (build H₂O from H and O).

Aerobic degradation of carbon happens in different ways:

- **Mineralisation** (gaining energy with oxidation of C to CO₂ and H₂O) = energy **metabolism**
- Synthesis of biomass (growth) = **anabolism**

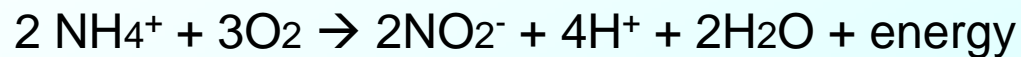
Biological degradation of nitrogen

Nitrogen cycle:

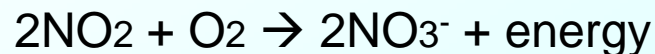
- **Ammonification:** Degradation of organic substance: **org. N** → **NH₄⁺**
NH₄⁺ Source = Urine

- **Nitrification:** **NH₄⁺** → **NO₂⁻** → **NO₃⁻**
by MO, oxygen required, aerobe conditions @ aeration tank

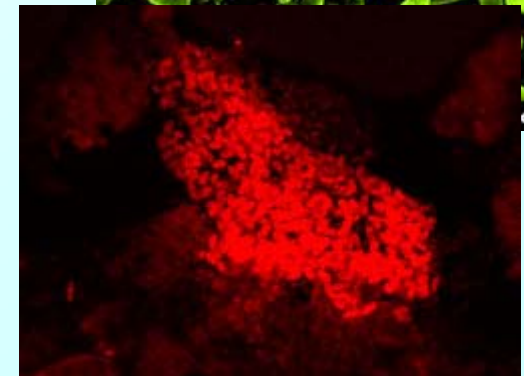
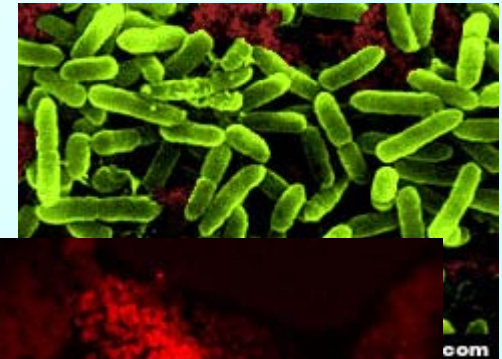
Nitrosomonas



Nitrobacter



- **Denitrification:** **NO₃⁻** → **N₂(gas)**
by MO, no dissolved oxygen → only in bonds (**NO₃⁻**), carbon source required, anoxic conditions @ upstream / downstream or simultaneously deni.tank



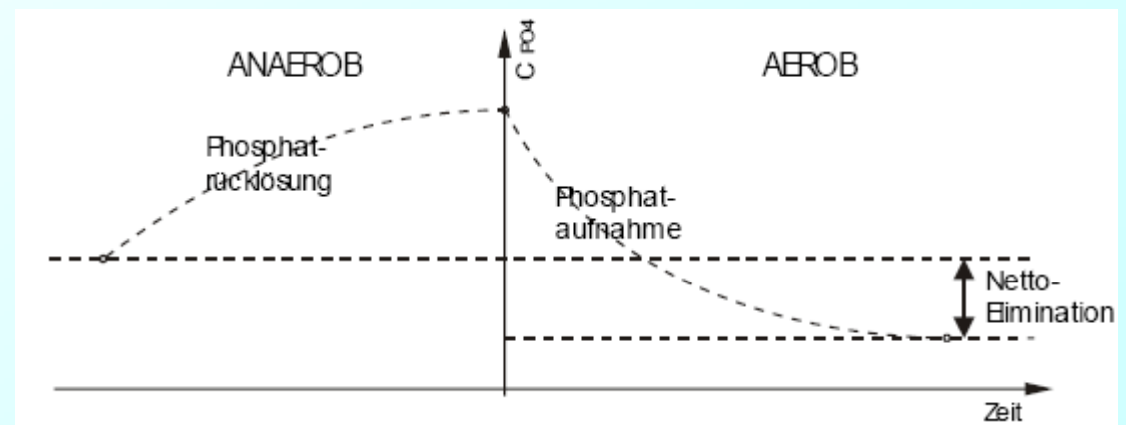
Removal of phosphorus

Biological degradation of phosphorus: (BIO-P):

- MO under specific conditions: growing biomass will have an increased phosphorus uptake (“**luxury uptake**”).
- Phosphorus bound in biomass can be removed with the surplus sludge.
- The required specific conditions are **alternating aerobic and anaerobic** conditions.
- The surplus sludge reaches phosphorus concentrations of about 3 %.

Chemical precipitation of phosphorus:

- By adding metallic cations
- phosphorus anions are caught in an insoluble bond and are precipitated.
- $\text{Me}^{3+} + \text{PO}_4^{3-}$
- $\rightarrow \text{MePO}_4 \downarrow$
- Common coagulants (flocculants) are **aluminum- and iron compounds**.



Biological Wastewater treatment: Overview

Aerobe intensive system

- **Biological film (fixed bed) reactors**
 - Trickling filter
 - Rotating biological contactor
 - Biofilter
- **Activated sludge process**
- **SBR**

Aerobe extensive system

- **Constructed wetlands**
 - Horizontal flow
 - Vertical flow
- **ponds**

Anaerobe system

Pretreatment for very high organic loads

- fixed bed reactors
- floating bed reactors

Trickling filter

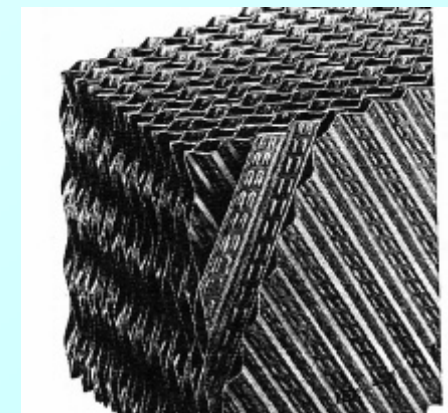
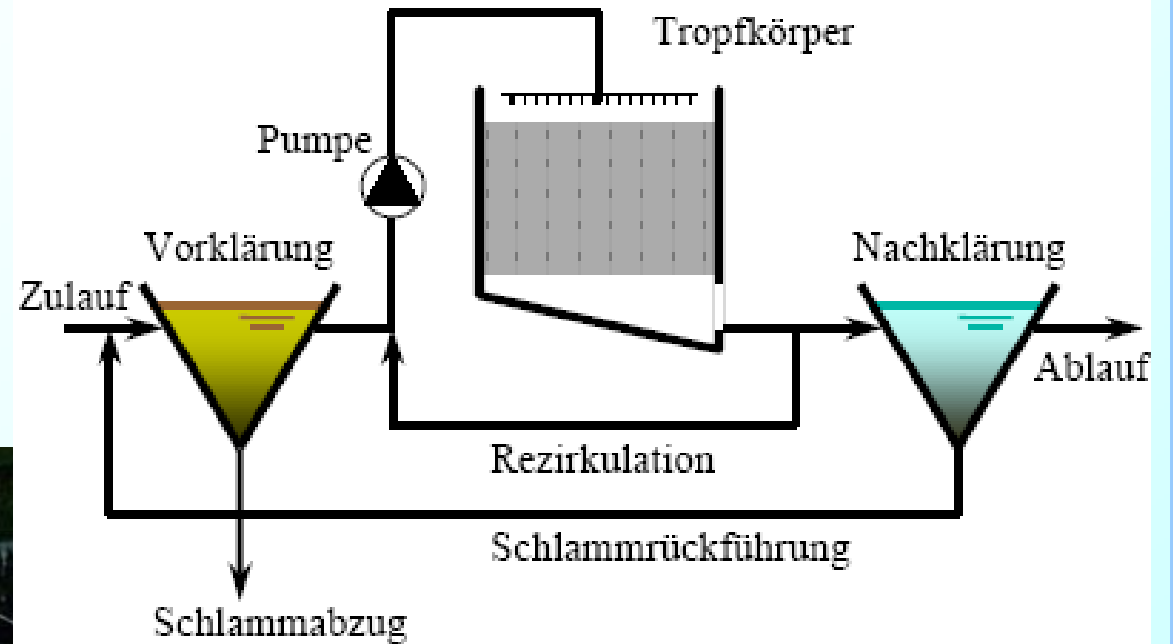
Common for all processes is that biomass and wastewater have to **get in contact** and that biomass must have a sufficient **oxygen supply**.

Advantages of fixed bed processes are:

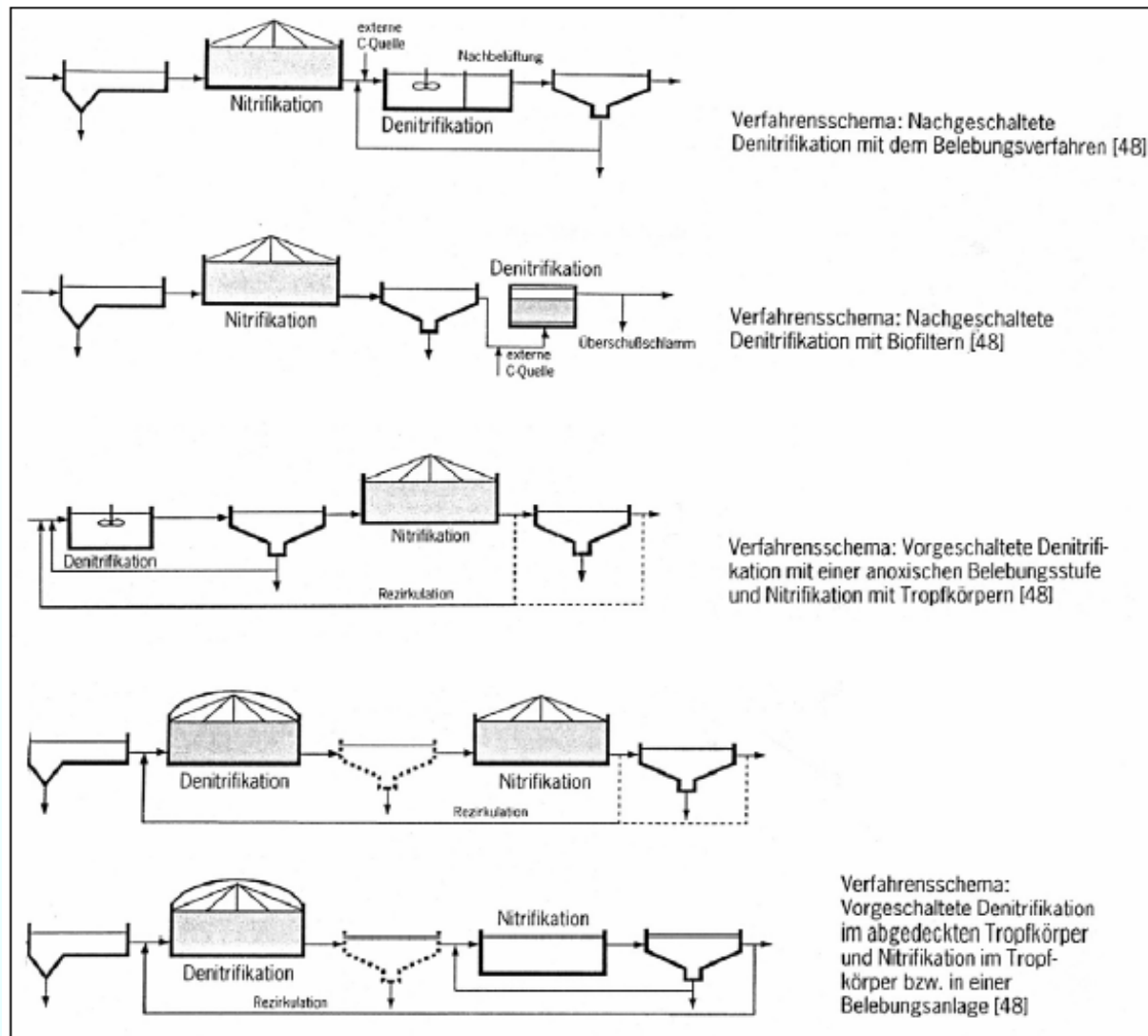
- They are easily to run and show a high **stability**
- **No return sludge** is necessary; Secondary Clarifier can be optimized separately
- Fixed bed reactors enable the growth of MO populations with long generation times (accommodation of MO towards specific substances!)
- With such MO colonies it is possible to treat also hard degradable bonds.
- Energy consumption of fixed bed processes is usually low.

Trickling filter

- biofilm growth on stones or artificial support media



Trickling filter



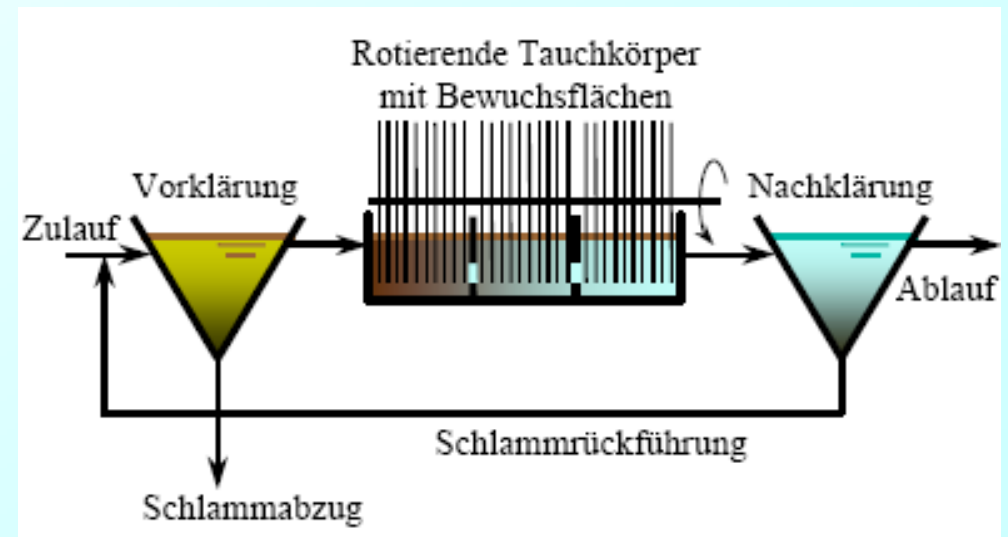
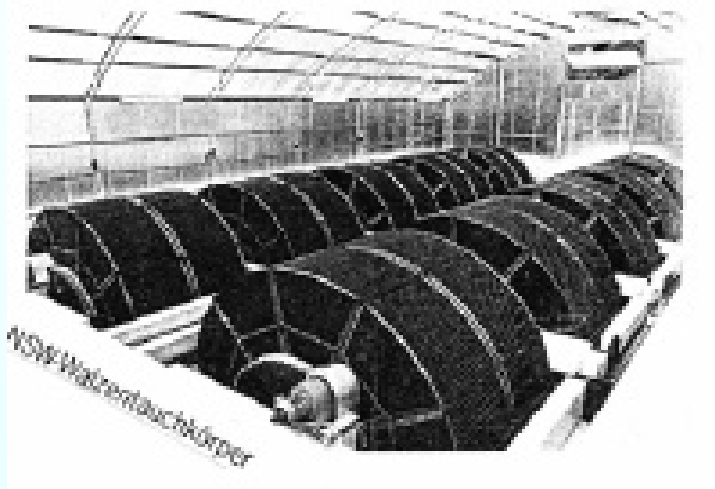
Different operation modes for denitrification with trickling filters

- Downstream denitrification with activated sludge process
- Downstream denitrification with Biofilter
- Upstream denitrification with activated sludge process and nitrification within the Trickling filter + return flow
- Upstream denitrification with covered Trickling filter and nitrification within a Trickling filter or aeration tank

Rotating biological contactor

The rotating contactor is half submerged in basins filled with wastewater.

- Rotation of the supporting media will bring the biofilm to the air to take up oxygen and
- afterwards to the wastewater again to take up nutrients.
- **Low energy consumption!**



Activated sludge process

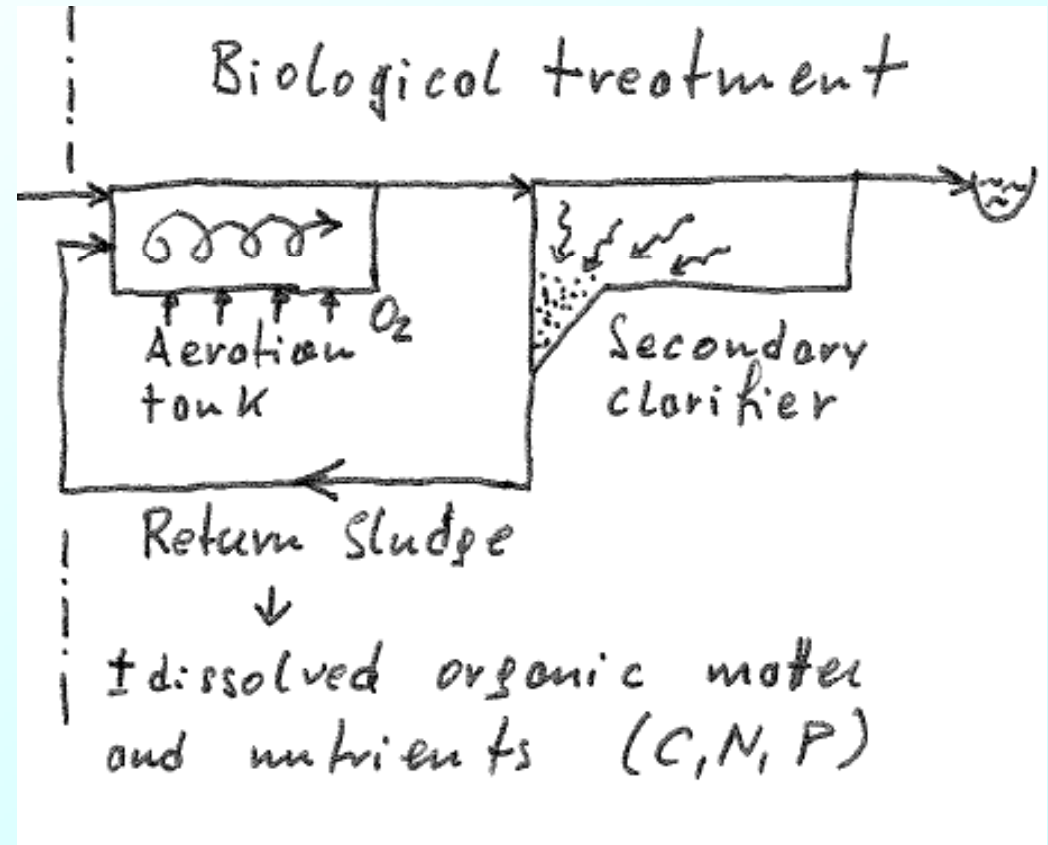
...most common treatment process for domestic wastewater

Requirements:

- sufficient **number of MO**
- Sufficient **oxygen supply**
- Proper **mixing**

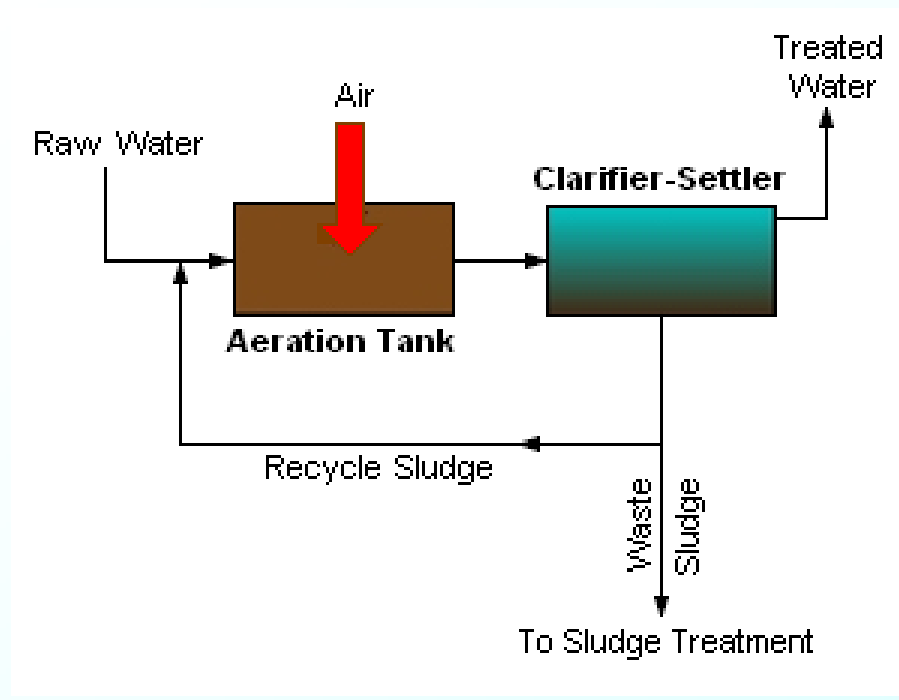
Fulfillment with technical measures:

- Recirculation of biomass (**return sludge**)
- Artificial **aeration** covers the oxygen demand of the MO
- **Mixing** device



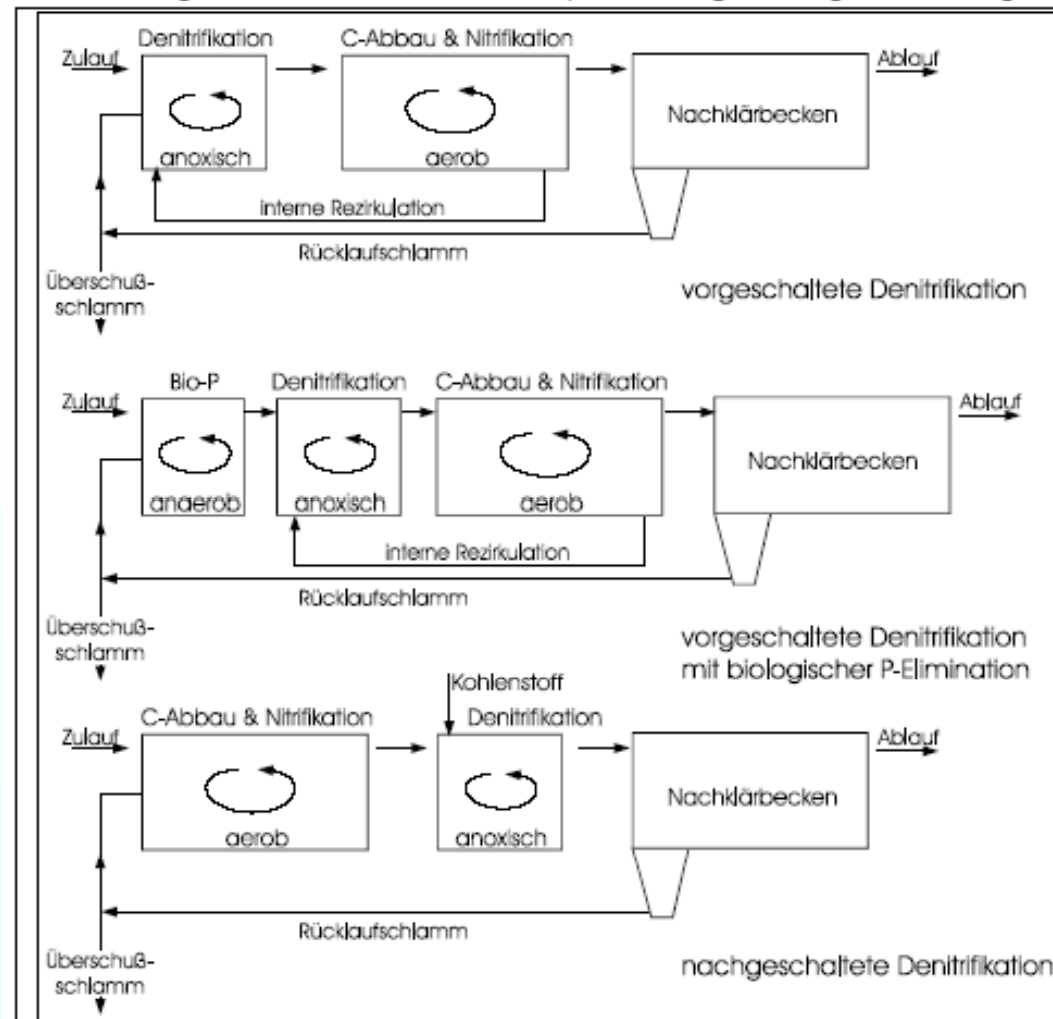
The activated sludge process is easier to adapt for different inflow quantities and qualities (return sludge control, aeration control)

Activated sludge process – principle



Operation modes of activated sludge plants:

➤ Biodegradation of nutrients (including biological nitrogen and phosphorus removal) requires different conditions during the process

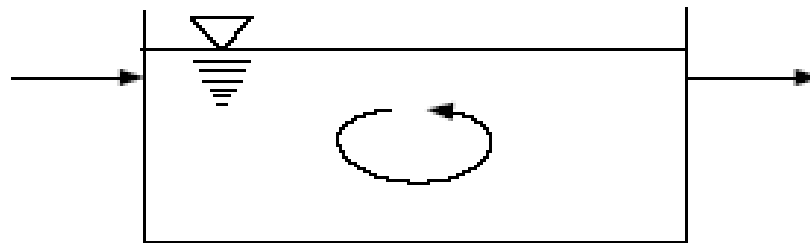


➤ Mainly an interplay of aerobic and anoxic conditions in combination with recirculation (return flow)

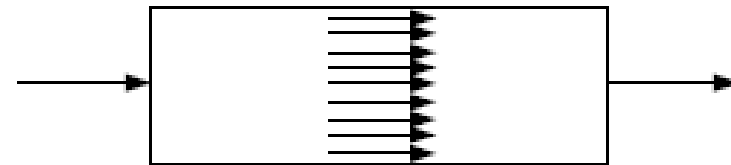
- **Upstream denitrification** with internal return flow (70 %) to provide Nitrate for the denitrification
- **Upstream denitrification** with internal return flow and upstream **Bio-P** (MO are stressed with anaerobic conditions to take up more P)
- **Downstream denitrification** with an additional carbon source

Activated sludge process – Different designs of aeration tanks

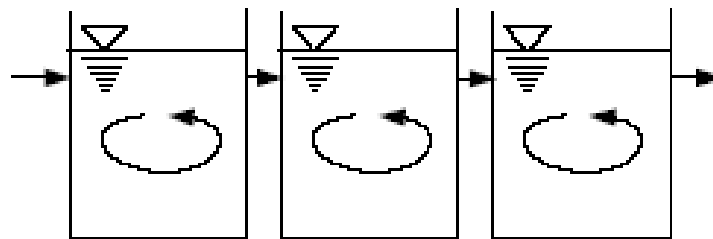
- **Totally mixed tank, Plug-flow systems (cascade)**
- **Totally mixed tank cascade**
- **Circulating flow activated sludge tank (oxidation ditch)**



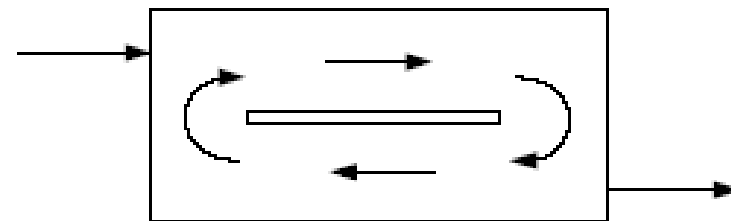
Totales Mischbecken



Pfropfenförmig durchströmtes
Becken



Mischbeckenkaskade



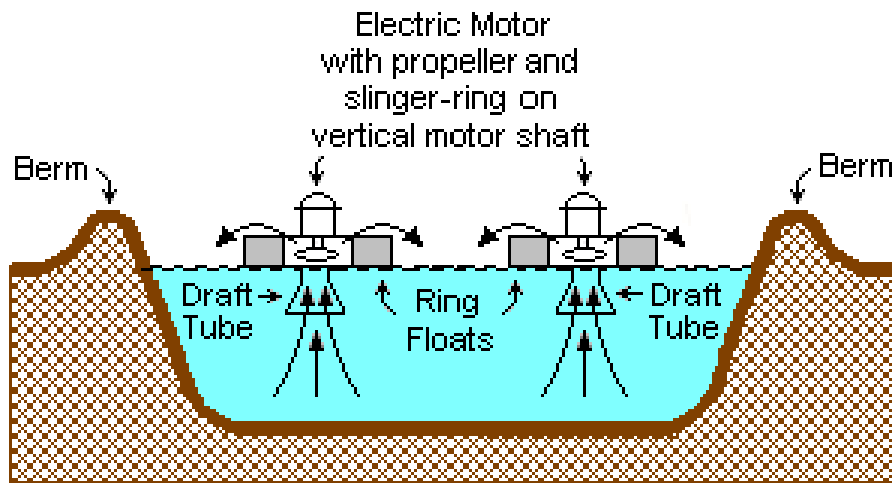
Umlaufbecken

Activated sludge process – Different designs of aeration tanks

Totally mixed tank



Activated sludge process – Aeration



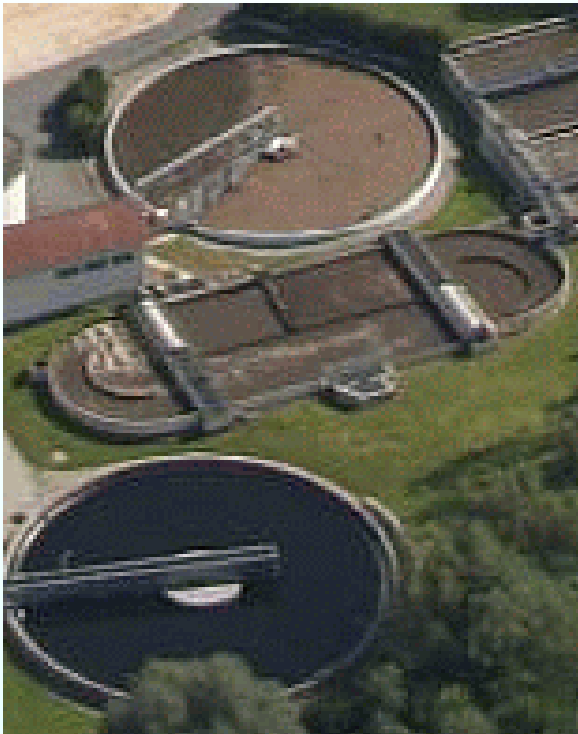
A TYPICAL SURFACE – AERATED BASIN



Fine bubble membrane diffusers in an aeration tank

Activated sludge process – Different designs of aeration tanks

Circulating flow activated sludge tank



Activated sludge process – Simultaneously denitrification:

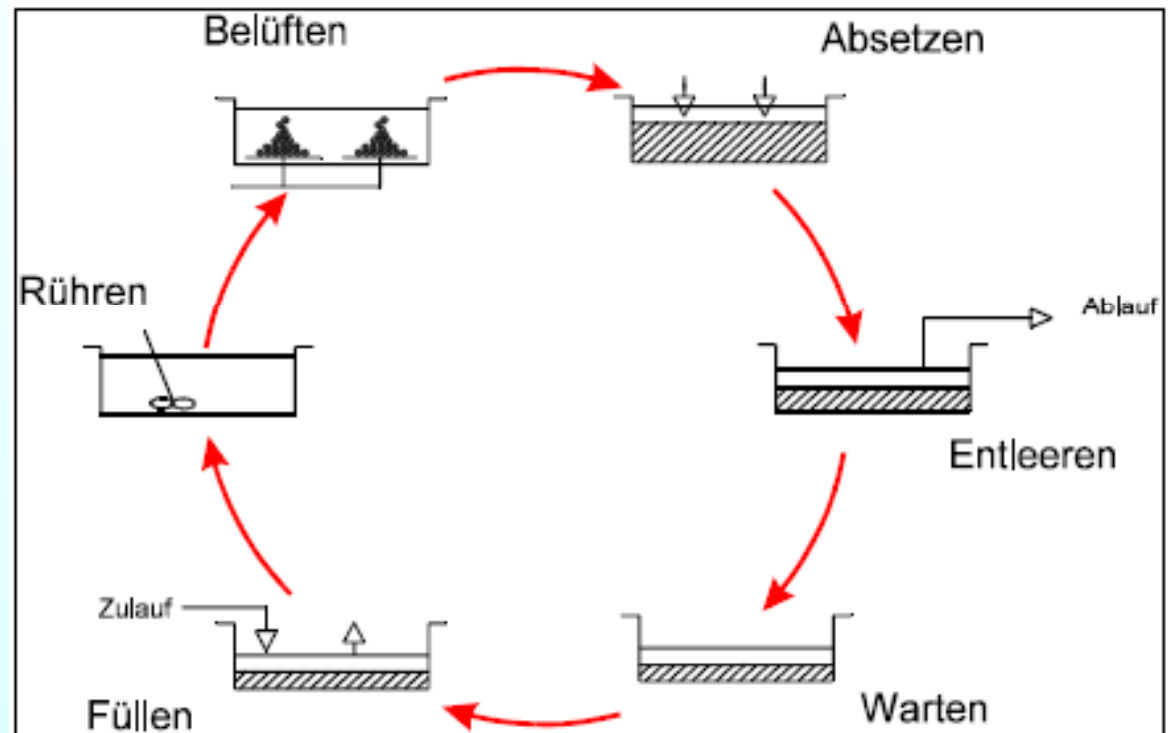
Circulating flow activated sludge tanks can be operated in a way that provides

- **aerobic and anoxic conditions**
- at different regions within the tank



Activated sludge process – SBR (Sequencing Batch Reactor)

- Temporary **aeration tank and sedimentation tank**.
- aeration cycle, bio degradation takes place.
- sedimentation time, MO settle down
- clarified supernatant is drained of.
- remaining biomass mixed with a new batch of wastewater
- To keep up a continuous flow at least two parallel SBR or
- SBR with an additional storage tank.



The SBR process provides

- **aerobic and anoxic conditions at different times** during a treatment cycle.

Design parameter of the activated sludge process:

Oxygen

required by the MO for the **degradation of**

- **organic compounds** and for the
- **nitrification**

- Oxygen concentration and aeration time are the major influencing factors to the treatment performance

O₂ concentrations are required:

- Carbon degradation: 0.5 to 1.0 mg / l
- Nitrification: 2 mg / l

Design parameter of the activated sludge process:

Oxygen

Aerators:

- Pressurised air aeration at the bottom (diffuser with fine / medium / coarse bubbles)
- Surface aerators

Efficiency of aeration:

- Depth of the air introduction (**diffuser depth**)
- **Depth of the tank** (surface aerators)
- Bubble size (exchange surface)
- Turbulence (mixing and retention time of the air in the liquid)



Design parameter of the activated sludge process:

Organic pollutant load:

specific sludge loading =

$(\text{Influx } Q * \text{BOD}_5) / (\text{aeration tank volume} * \text{SSAT (dry solids)})$

[kg BOD₅ / kg SS and day] ... typically: 0,08 und 0,22 kg BOD₅ / kg SS

Nutrients

Nutrition demand related to the degraded BOD₅:

BOD₅: N : P = 100 : 5 : 1

- Lower concentrations of N and P will result in a decreasing biodegradation of C
- Higher concentrations (**domestic wastewater!**) have to be removed with additional measures:
 - N: Nitrification + Denitrification
 - P: chemical Precipitation (by flocculants) or Bio-Phosphorus removal (Bio-P)



Activated Sludge

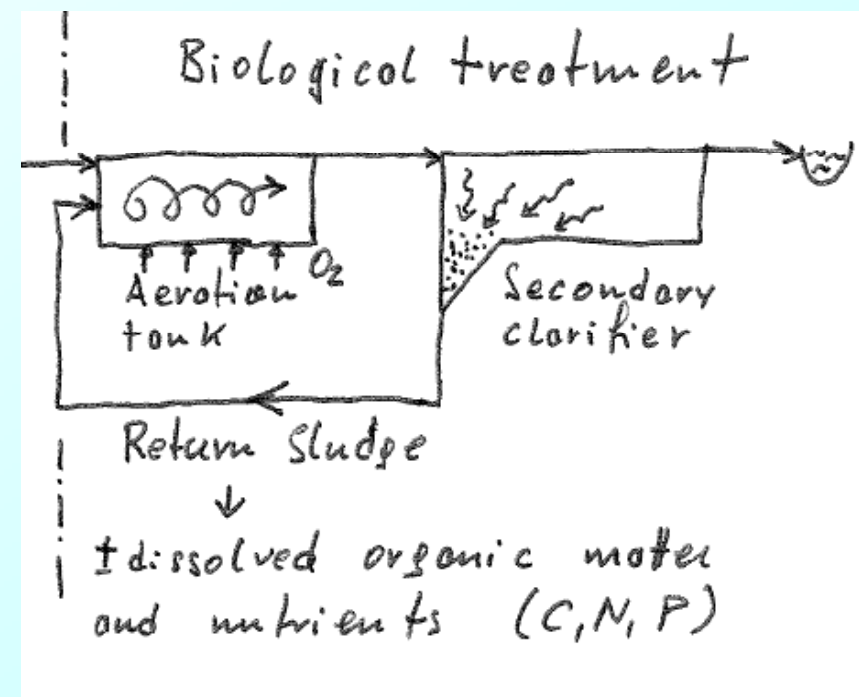
... is responsible for the treatment (degradation) performance

- **Bacteria (MO) live on organic carbon and other nutrients in the wastewater**
- **Primary consumers are filtering bacteria out the wastewater**
- **Higher organisms live on the primary consumer (predacious)**

- **Dry Solids (SS) concentration [g/l];**
- **typical values: SS_{AT} 3.5 g/l, SS_{Ret} 7 g/l**

Parameter:

Settled sludge volume & sludge volume index (**SVI**)



Activated Sludge - Parameter:

Sedimentation performance is characterized by two parameters:

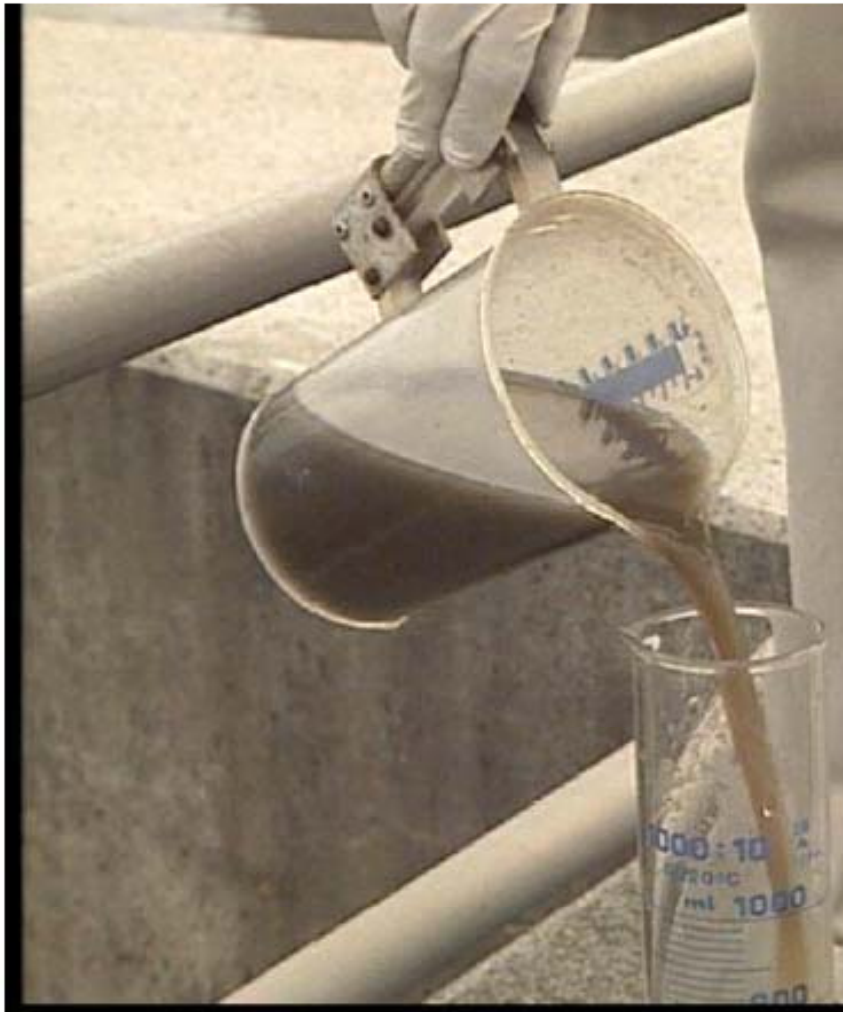
- **Sludge volume** =
specific volume of settled sludge after 30 min. sedimentation time [ml / l]
- **Sludge volume index (SVI)** =
Volume of 1 g settled sludge after 30 min. sedimentation [ml / g]
- **SVI = Sludge volume [ml / l] / SS concentration [g/l]**

Activated Sludge process

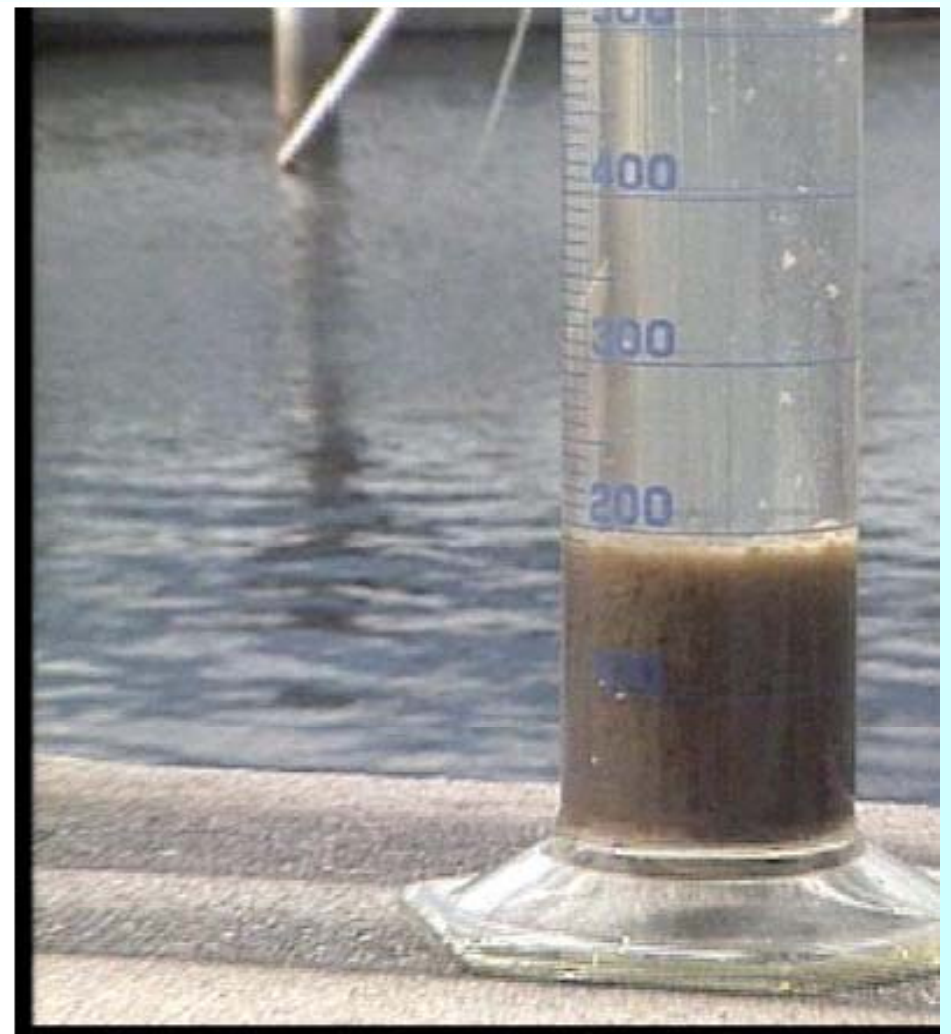


Activated sludge tank with covered cylinder aerator

Activated Sludge process

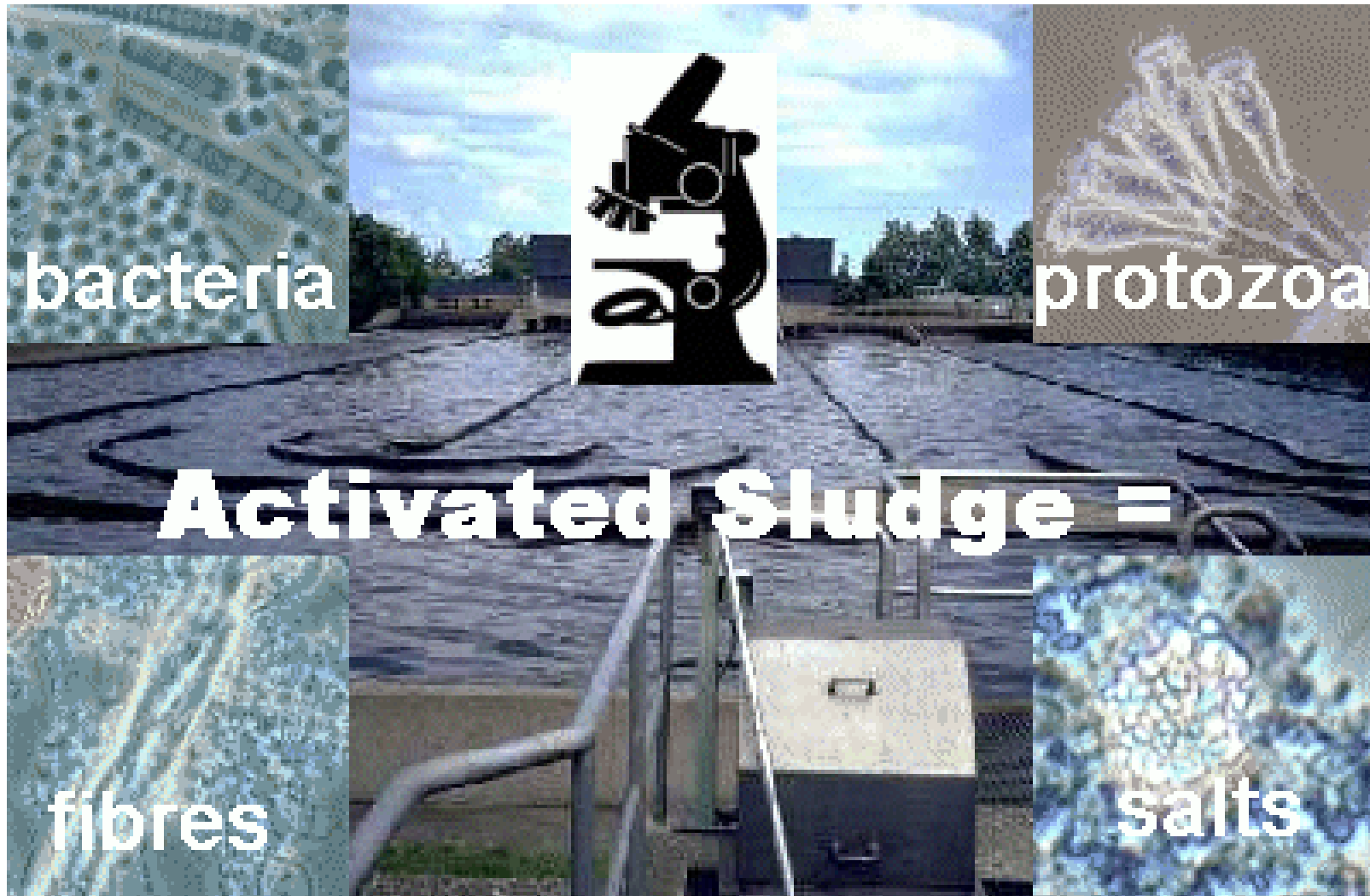


Activated sludge



Settled sludge and supernatant = clarified water

Activated Sludge process

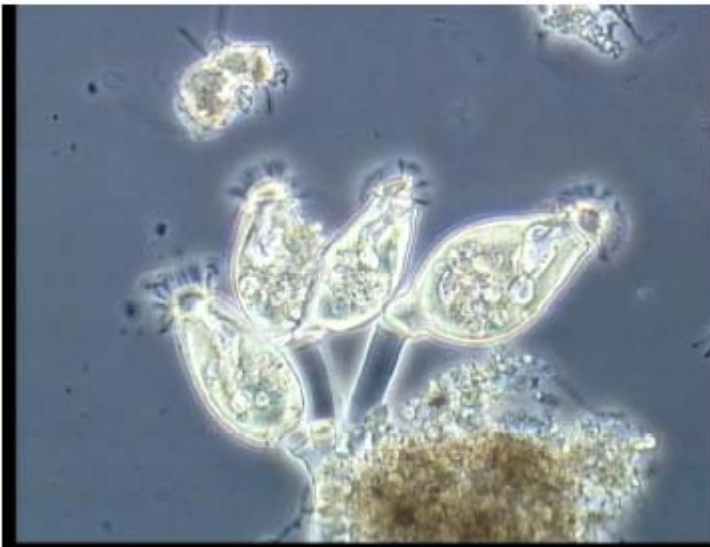


Activated Sludge process



Micro
organism
found in
activated
sludge

Activated Sludge process



Vorticella
(left)



Flagellates
(left)

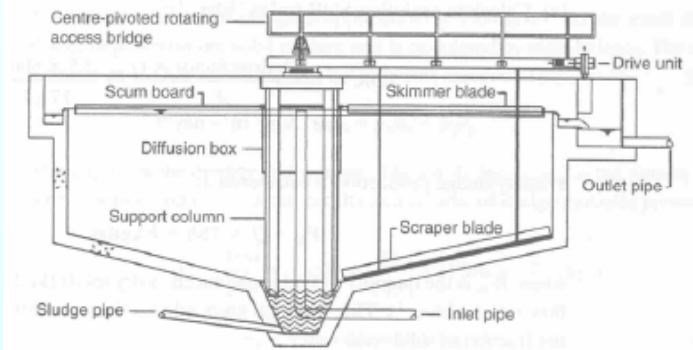
Ciliates
(right)

Final step of WWT process: **secondary clarifier**

Sedimentation of sludge flocks
(MO, primary + secondary consumer, EPS, fibers)

Built like primary clarifier but bigger
(slow sinking velocity of sludge)

- Drain supernatant (clarified water)
- Return activated sludge to the bioreactor
- Discharge surplus sludge



Small scale treatment plants

Properties of small scale treatment plants:

- Plants for solitary objects (households, restaurants, creamery, industry,...)
- Plants for detached houses or isolated areas of a community (up to 500 inhabitants)
 - **Non-permanently used objects**
 - **High variations in influx load**

Requirements:

- plant design – simple to run and low maintenance
- High stability and high buffering capacity (regarding hydraulic and chemical aspects)
- Low surplus sludge production