WATER POLLUTION AND SANITATION

PRESENTED BY: Dr. S. Mahabali

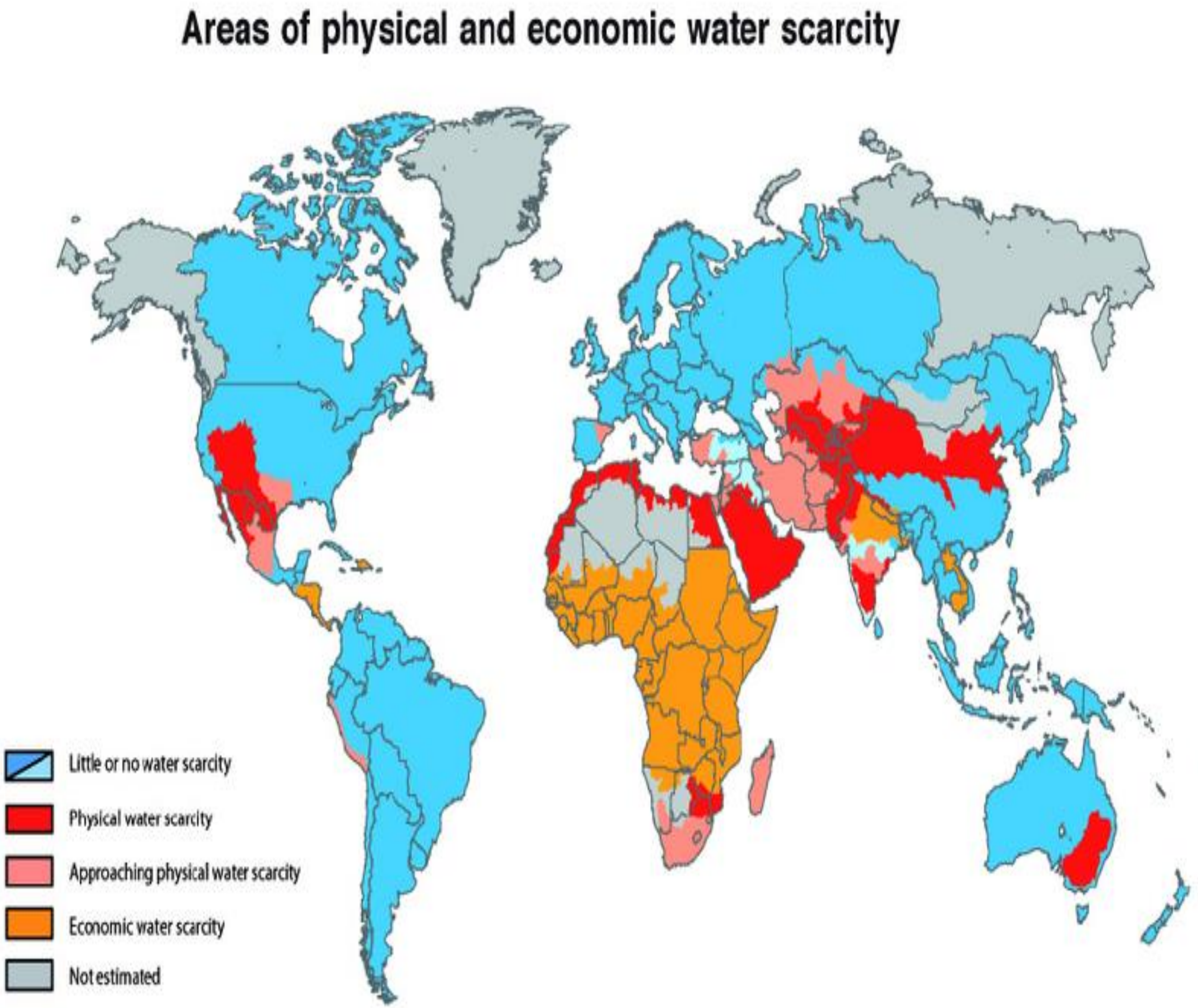
Major problem with water resources

Although water covers more than 70% of the earth's surface, only around 3% of it is freshwater.

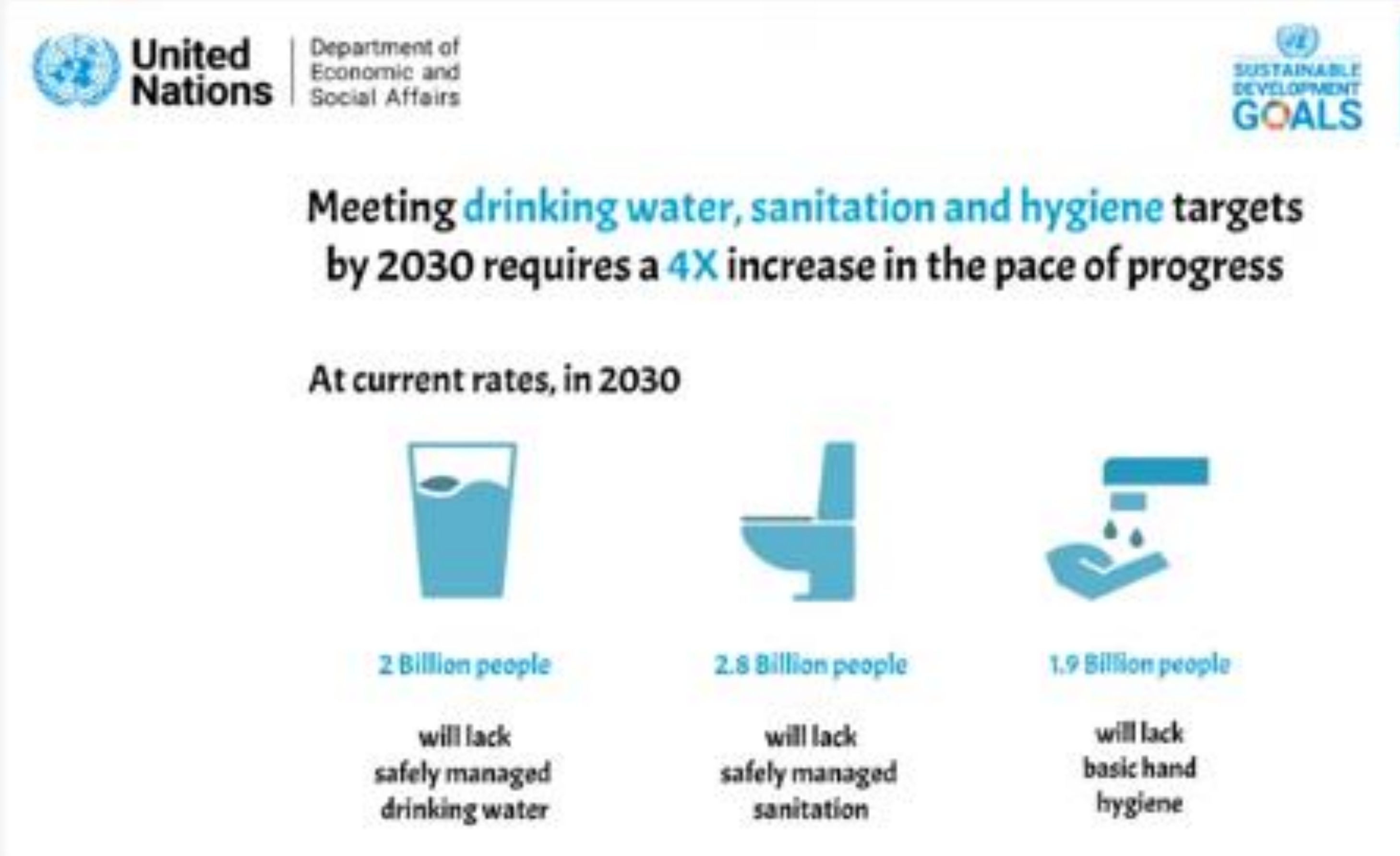
By 2030, the global demand for water will have exceeded the sustainable supply available by 40%.

(https://unstats.un.org/sdgs/report/2022/Goal-06/)

Increasing water scarcity



- More than a quarter of the world’s population live in water-stressed countries, according to the United Nations
- Climate change & Drought
- Physical vs economical water scarcity
- Existing freshwater solutions like desalination plants are costly and also damage the environment.



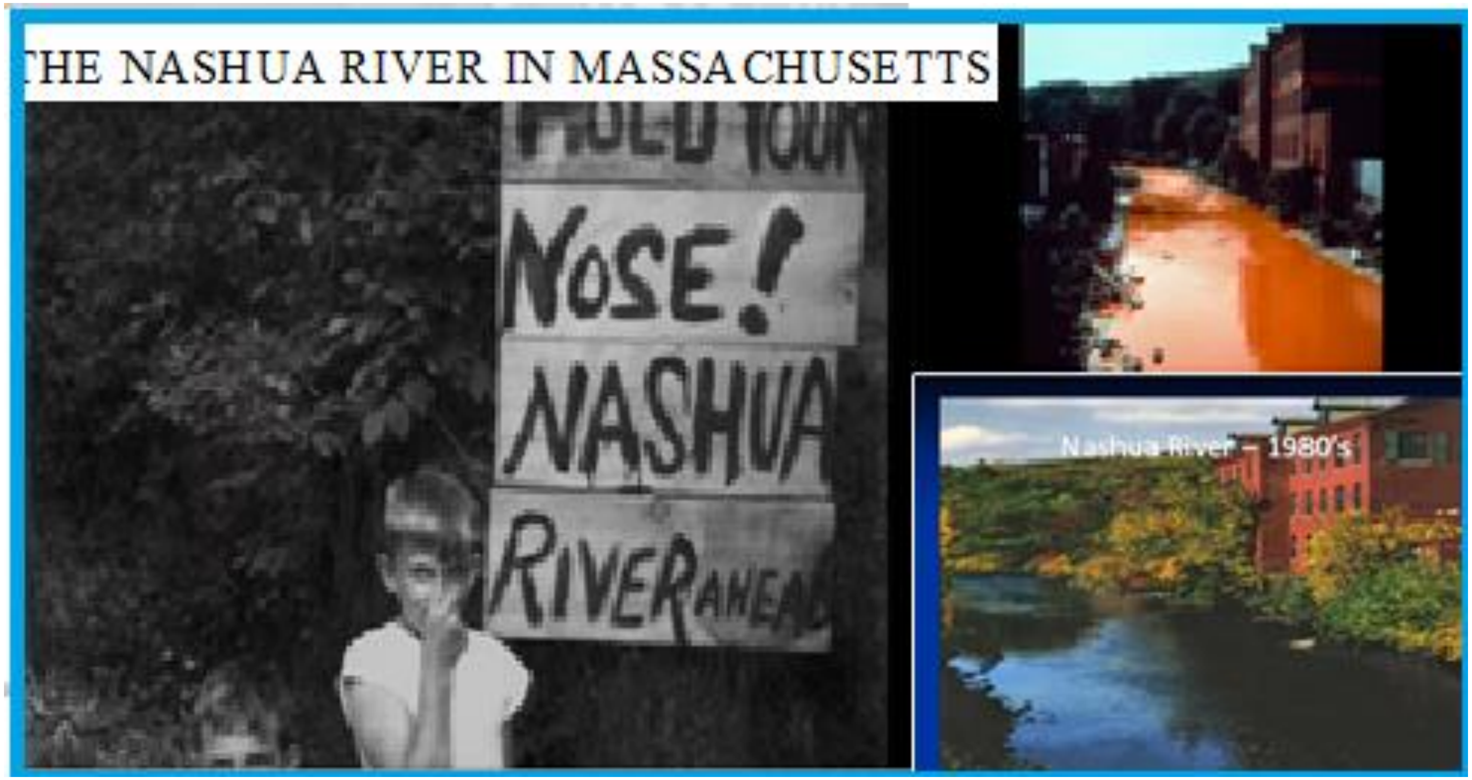
4x increase in the pace of progress: 829,000 lives saved annually = number currently die each year from diseases related to:

- unsafe water,
- inadequate sanitation
- poor hygiene practices.

History of water pollution (story of the US)

First: The Federal Water Pollution Control Act of 1948

1972: with amendments >>> Clean Water Act


THE NASHUA RIVER IN MASSACHUSETTS
NOSE!
NASHUA
RIVER
Nashua River – 1980's


Marking 50 years since the Cuyahoga River fire, which sparked US environmental action

SURINAME

2020: MILIEURAAMWET

NIMOS BESTAAT SEDERT 15 MAART 25 JAREN

Transitie naar

NMA UITVOERENDE ORGAAN

NOS Nieuws • Maandag 22 mei, 22:19

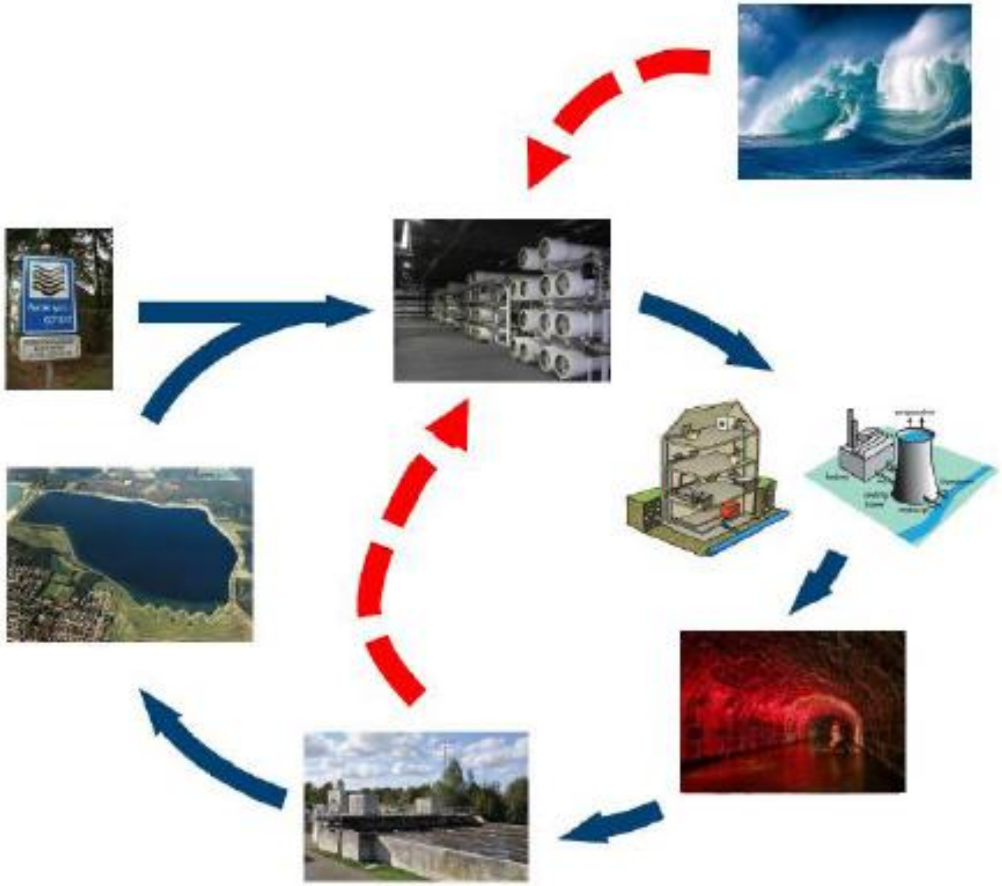
Onrust in Suriname na cyanide-lek, water grootste stuwmeer verontreinigd

https://www.starnieuws.com/index.php/welcome/index/nieuwsitem/75725

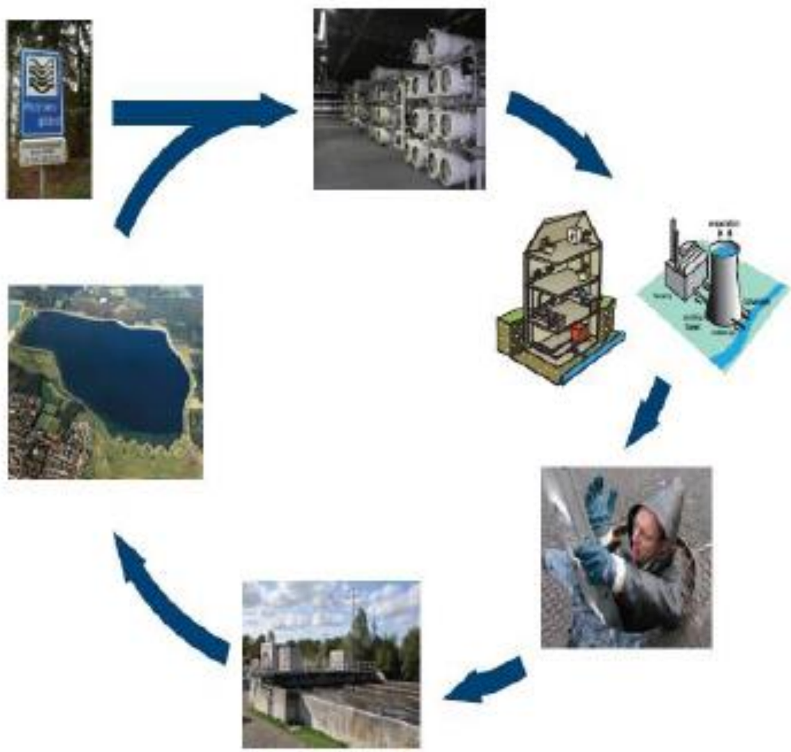
Na de berichten over vervuiling zijn drie samples getrokken waarvan twee de vervuiling met cyanide hebben bevestigd. Bij de eerste sample ging het om een cyanidewaarde van 334 mg en bij de tweede 421.42 mg cyanidewaarde. De derde sample was negatief.

Search for new water sources

- Traditionally:
  - Ground water
  - Surface water
- Increasing trend towards:
  - Seawater desalination
  - Wastewater reuse



Hydrological cycle



Water is continually being reused

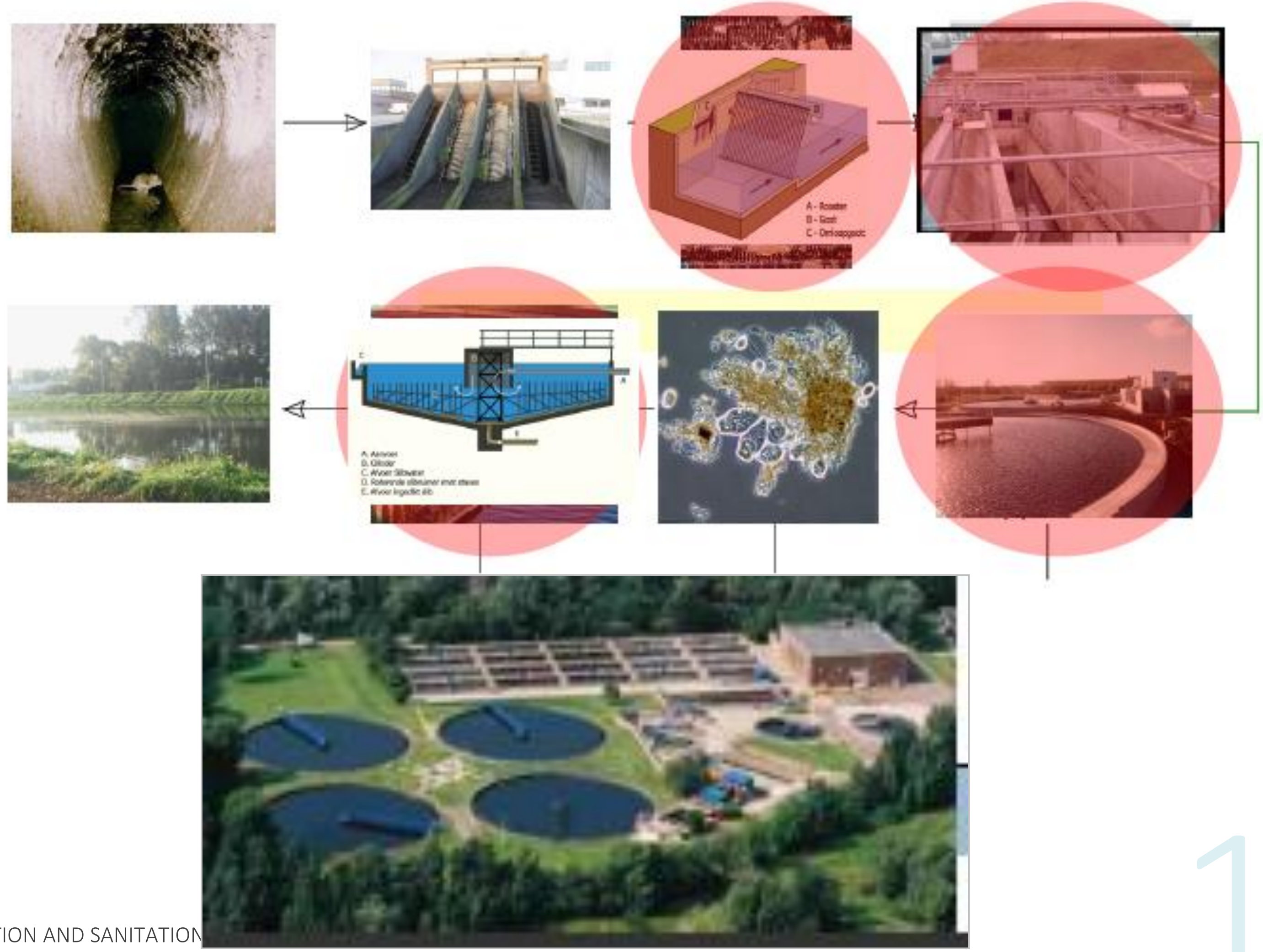
Water treatment is required

Physico-chemical treatment

- Physico: via physical methods:
  - Filtration/sedimentation/flotation
  - Mixing, aeration,…
  - Adsorption
  - Radiation (e.g., UV-light)
  - …
- Chemical: using chemicals:
  - Coagulation/flocculation (~ floc formation) by adding $FeCl_3$
  - Softening (calcium removal) by addition of $Ca(OH)_2$
  - Dosing of ozone (O_3), peroxide (H_2O_2), chlorine,…
  - …

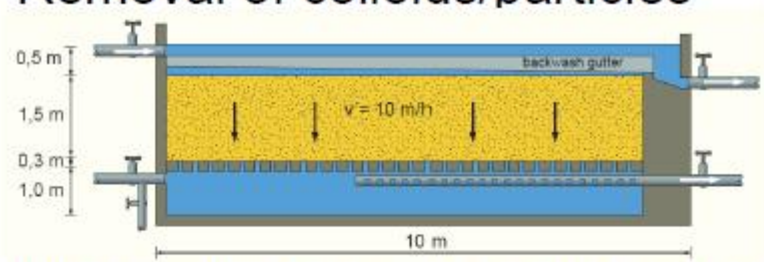
Physico-chemical WASTEwater treatment

- What does an average wastewater treament plant look like?

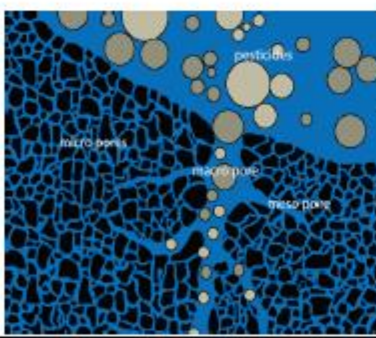


Physico-chemical wastewater treatment

- Sometimes further purification is required
- Removal of phosphorus (phosphate)
- Removal of colloids/particles



- Removal of organic pollutants (solvents, pharmaceuticals, pesticides,…)



Physico-chemical wastewater treatment

- Mechanical pretreatment is required to keep the installation running
- Sometimes it goes wrong…

Wastewater treatment

- Primary: mechanical = pretreatment
  - Main goal: to protect the installation
- Secondary: biological or physico-chemical
  - Main goal: removal of suspended and dissolved solids
- Tertiary = post-treatment / polishing
  - Main goal: removal of recalcitrant dissolved solids
- Sludge treatment

Primary treatment

- Grids/sieves
- Fat traps
- Sedimentation tanks/sand traps

GOAL:

- Removal of coarse suspended solids (e.g., TP)
- Reduction of pollutant load
- Protection of the installation (pumps,…)

Secondary treatment

- Biological

  → BOD broken down and transformed into micro-organisms (Cf. other part)

- Physico-chemical

  → Chemicals induce coagulation/flocculation

Membrane processes can be an alternative!!!

COD= Chemical Oxygen Demand

Secondary treatment

- Selection of type of secondary treatment depends on composition and concentration of the wastewater:

  → Physico-chemical treatment when water is:
    - Toxic
    - Diluted
    - Strongly varying in composition

- Physico-chemical treatment processes are easier to control and less sensitive

  → Biological treatment process might require long recovery periods after calamity; no living organisms in physico-chemical treatment processes

Tertiairy treatment

- Often as extra treatment/polishing
- Some examples:
  - Sand filters:
    - Removal of small particles
    - Removal of dissolved iron and manganese
  - Activated carbon filtration
    - Adsorption of organic pollutants (pesticides, pharmaceuticals,…)
  - Advanced oxidation processes (AOP):
    - (electro)chemical degradation of organic pollutants, but also bacteria:
      - UV, ozone, H_2O_2
      - Destruction of recalcitrant chemical
      - desinfection
  - Membranes

DRINKING WATER
QUALITY CRITERIA

Water must be free of organisms (microbial criteria) →

Most important criteria

Water must be free of chemical compounds or in concentrations which are not harmful to humans

Water must have a good taste, smell and color (organoleptic properties)

WHO 1958: international standards for drinking water

WATER POLLUTION
PARAMETERS (1)

QUANTIFICATION OF OXYGEN

1) BOD: BIOLOGICAL OXYGEN DEMAND

2) COD; CHEMICAL OXYGEN DEMAND

BOD^{20}_{5}: Amount oxygen used by micro-organisms for oxidation of the biological fraction

COD: Amount oxygen needed to chemically oxidize the biological and non-biological fraction

cBOD (oxidation of C-compounds) and

nBOD (oxidation of N-compounds): $NH_4^+ \rightarrow NO_3^-$

WATER POLLUTION
PARAMETERS (2)

Municipal waste water

COD : 600-1100 mg/l
BOD: 300-500 mg/l

Relationship BOD and COD:

$BOD_5^{20} = 0.65.fb.COD$

fb = fraction of biodegradable organic matter

*: 1 g COD gives 0.4 g biomassa
1 g sugar equals 1 g COD equals 1 g bCOD = 0.65 g BOD
1 g synthetic material = 1 g COD = 0 g bCOD = 0 g BOD

WATER POLLUTION
PARAMETERS (3)

3) SS: Suspended solids: particles which can be separated by means of centrifugation and filtration

4) Total N: (Kj-N + nitrate & nitrite)

N can occur as organic N, ammonium-N (Kjeldahl-N) and Nitrate & Nitrite-N

Municipal wastewater:

NH_4^+ -N: 40 – 65 mg/l

Org.-N: 30 – 50 mg/l

NO_3^- -N & NO_2^- -N: < 2 mg/l

WATER POLLUTION
PARAMETERS (3)

5) **Phosphorus, P : inorganic forms, orthophosphate and phosphite**

municipal wastewater: 15 – 30 mg/l

euthrophication: start already at low levels of P: 0.01-0.02 mg/l

6) **Metals: As, Cr, Cu, Pb, Ni, Ag, Zn, Hg, Cd**

As:

Major sources: erosion of natural deposits; runoff from orchards; and runoff from glass & electronics production wastes

Health effects: skin damage and increase risks of getting cancer

Cr:

Sources: erosion of chromium deposits found in rocks and soils. Chromium-6 is produced by industrial processes and manufacturing activities including discharges from steel and pulp mills

WATER POLLUTION
PARAMETERS (4)

Cr continued:

Health effects: Cr^{6+} : very toxic: carcinogenic

Cu:

Sources: Corrosion of household plumbing systems; erosion of natural deposits

Short term: gastrointestinal distress

Long term: liver or kidney damage,

Bad taste to water

Pb: household plumbing materials or in water service lines

children: delays in their physical or mental development

adults: long term: development of kidney problems or high blood pressure

WATER POLLUTION
PARAMETERS (5)

Ni: found in many ores as sulfides, arsenides, oxides or silicates;

Chronic: decreased body weight; heart and liver damage; dermatitis

Carcinogenic: ?

Ag: intoxication causes discoloration of skin and eyes

Zn: acceptable level is relatively high

Hg: erosion of natural deposits; discharge from refineries and factories; runoff from landfills and croplands.

Methylated Hg is of importance: bioaccumulation, biomagnification >> increased toxicity

Health effects: include sensory impairment (vision, hearing, speech), disturbed sensation and a lack of coordination

Unit of pollution: “vervuilingseenheid: V.E.” (1)

Up to end 1990: I.E. : measure of the amount of oxygen-binding compounds discharged on a daily basis per day per inhabitant

1 I.E. equals 180 liters wastewater per person with :

SS: 500 mg/l
BOD: 300 mg/l: 54 g BOD/I.E.dag
COD: 750 mg/l
Kj-N: 55 mg/l

Beginning of 1991: “V.E.”

formula expended with the terms Total N and P and Heavy Metals.

Dec. 1992: formula further adapted to take ecological effect of pollution into consideration

Unit of pollution: “vervuilingseenheid: V.E.” (2)

V.E.: N1 + N2 + N3 + Nc

N1: O2-binding compounds and SS

N2: Heavy metals

N3: Nutrients

Nc: Cooling water

Unit of pollution: “vervuilingseenheid: V.E.” (3)

“MILIEUHEFFING OP WATERVERONTREINING” = H

H = n V.E. x T

n= number of V.E.

T= tariff

Autopurification of water (1)

Organisch materiaal + O_2 → CO_2 + H_2O + celmateriaal + mineralen

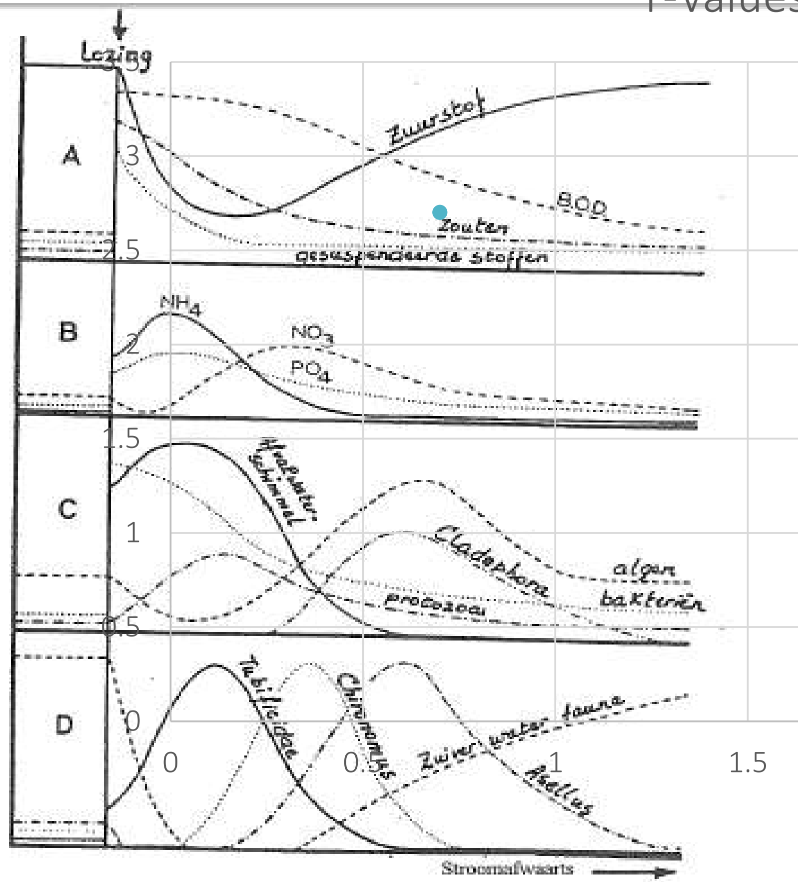


Fig. 10. Veranderingen in een waterloop ten gevolge van pollutie door huishoudelijk afvalwater

- Discharge of wastewater:

  •BOD increases → adaptation M.O.: evolution of different microbial populations → degradation O.M. (first order reaction).

  •O_2 used by M.O.; sometimes O_2 near zero: development of anaerobic M.O. + production of N2, H2S, CH4, H2 gas

Autopurification of water (2)

Streeter-Phelps equation: gives the relation between the DO concentration and the BOD over time and is a solution to the linear first order differential equation

$$\frac{\partial D}{\partial t} = k_1 L_t - k_2 D$$

This differential equation states that the total change in oxygen deficit (D) is equal to the difference between the two rates of deoxygenation and reaeration at any time.

The Streeter-Phelps equation, assuming a perfectly mixed stream at steady state is then

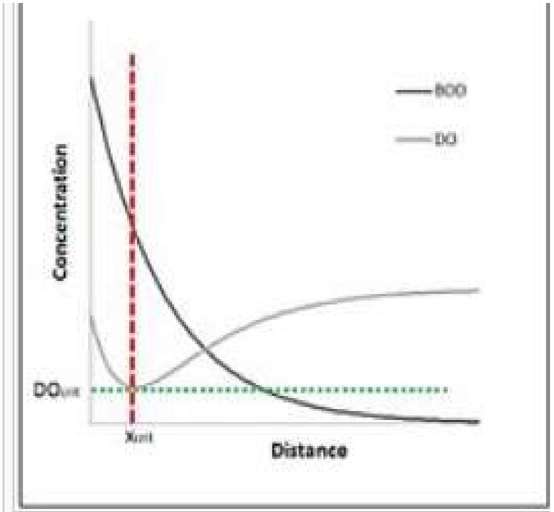
$$D = \frac{k_1 L_a}{k_2 - k_1}\left(e^{-k_1 t} - e^{-k_2 t}\right) + D_a e^{-k_2 t}$$

Autopurification of water (3)

Streeter-Phelps equation

$$D = \frac{k_1 L_a}{k_2 - k_1}\left(e^{-k_1 t} - e^{-k_2 t}\right) + D_a e^{-k_2 t}$$

- D is the saturation deficit, which can be derived from the dissolved oxygen concentration at saturation minus the actual dissolved oxygen concentration ($D = DO_{sat} - DO$). D has the dimensions $\frac{\mathrm{g}}{\mathrm{m}^3}$.
- k_1 is the deoxygenation rate, usually in d^{-1}.
- k_2 is the reaeration rate, usually in d^{-1}.
- L_a is the initial oxygen demand of organic matter in the water, also called the ultimate BOD (BOD at time t=infinity). The unit of L_a is $\frac{\mathrm{g}}{\mathrm{m}^3}$.
- L_t is the oxygen demand remaining at time t, $L_t = L_a e^{-k_1 t}$.
- D_a is the initial oxygen deficit $\left[\frac{\mathrm{g}}{\mathrm{m}^3}\right]$.
- t is the elapsed time, usually $[d]$.

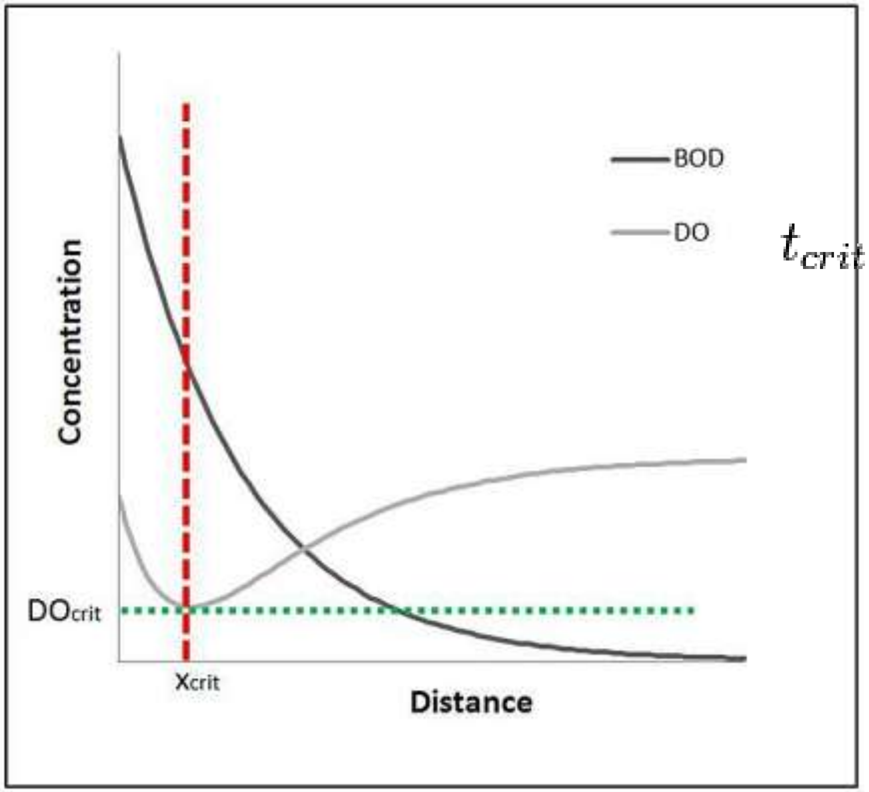


Streeter-Phelps DO sag curve and BOD development.

k_1 lies typically within the range 0.05-0.5 d^{-1} and k_2 lies typically within the range 0.4-1.5 d^{-1}.[2]
The Streeter-Phelps equation is also known as the DO sag equation. This is due to the shape of the graph of the DO over time.

Autopurification of water (4)

DO SAGcurve



Critical oxygen deficit

$$t_{crit} = \frac{1}{k_2 - k_1} \ln \left[\frac{k_2}{k_1} \left(1 - \frac{D_a(k_2 - k_1)}{L_a k_1} \right) \right]$$

To find the value of the critical oxygen deficit, , the Streeter-Phelps equation is combined with the equation above, for the critical time, . Then the minimum dissolved oxygen concentration is (note temperature corrections)

$$DO_{crit} = DO_{sat} - D_{crit}$$

Autopurification of water (5)
DO SAGcurve

The distance (x) travelled in a river from a given point or waste discharge downstream

to the DO_{crit} (which is the minimum DO) is found by

$$x_{crit} = v * t_{crit}$$

v = the flow velocity of the stream

WATER PURIFICATION (1)

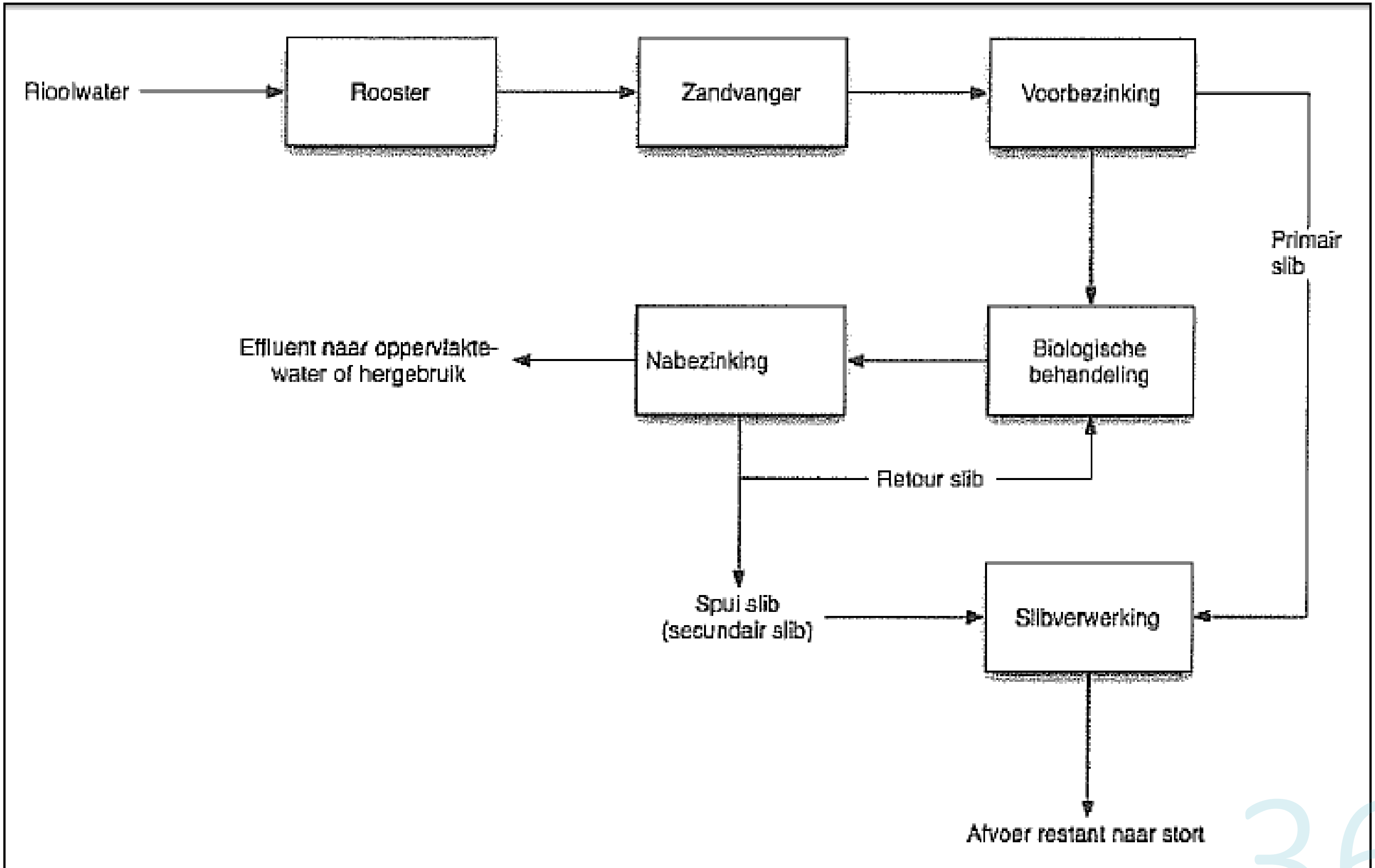
Type of pollution and purification techniques

Tabel 8. Indeling behandelingsmethoden in functie van de aard van de vervuiling

Aard van de vervuiling	Behandelingsmethode
Grove bezinkbare stoffen	Roosters, snijroosters, zeven
Fijne bezinkbare stoffen	Zandvangers
Olie, vetten & emulsies	Olie-afscheiders, flotatie, coalesceren
Drijvende bestanddelen	Flotatie
Fijne zwevende bestanddelen	Flotatie, bezinking, mechanische filtratie, microzeven
Zware metalen	Precipitatie, ionenwisseling
Extreme pH-waarden	Neutralisatie
Sulfiden	Precipitatie, stripping
Biodegradeerbare organische bestanddelen	Aëroob : actief slib, oxidatiesloten, biofilters Anaëroob : methaangisting

WATER PURIFICATION (2)

Schematic overview wastewater purification system



Groundwater treatment

- Groundwater is usually of better microbial quality
- Typical treatment scheme for groundwater

pumping → aeration → sand filtration → treated water → distribution

Groundwater treatment

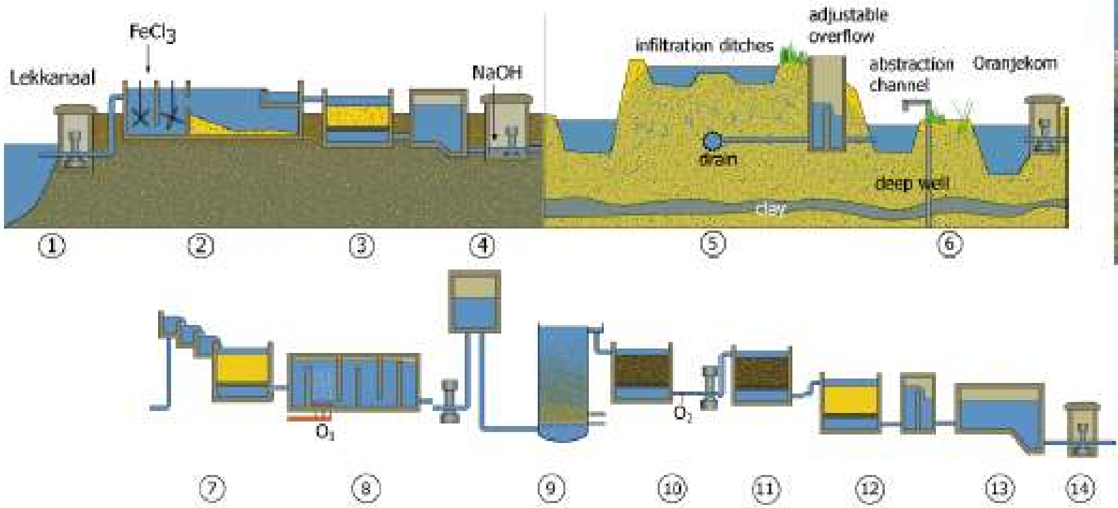
- Sometimes there's a "softening" step, when the water contains too much calcium

- Although relatively "simple", we still don't know everything about it (e.g., contribution of biological processes)

Surface water treatment

- Often much more extensive and more "complicated" due to the lesser quality of the water
- Many different treatment schemes, depending on the water quality and specific problems of the company
- Some examples:

Example: surface water treatment Amsterdam



- Use of ozone as desinfectant, and to degrade organic pollutants (e.g., pesticides) – often followed by adsorption

WATER PURIFICATION (3): INTRODUCTION TO DIFFERENT STEPS

GRIDS (1)

- Goal: removal of coarse pollutant that might clog the installation:
  - Gravel
  - Plastics
  - Toilet paper
  - ...
- Mesh size ~ 2 cm
- Place under a certain angle for ease of cleaning

GRIDS (2)

$$0,5 \text{ m/s} < v_h < 0,8 \text{ m/s}$$

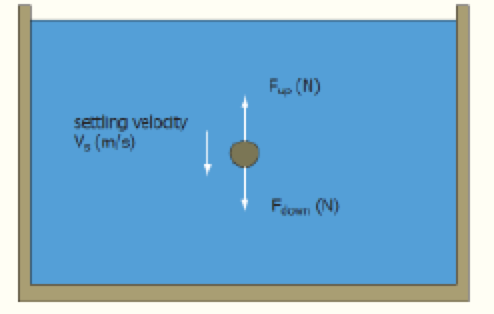
a) $v_h > 0.5$ m/s to avoid precipitation of sand

b) $v_h < 0.8$ m/s to reduce the drag force on the grid

(v_h = horizontal velocity)

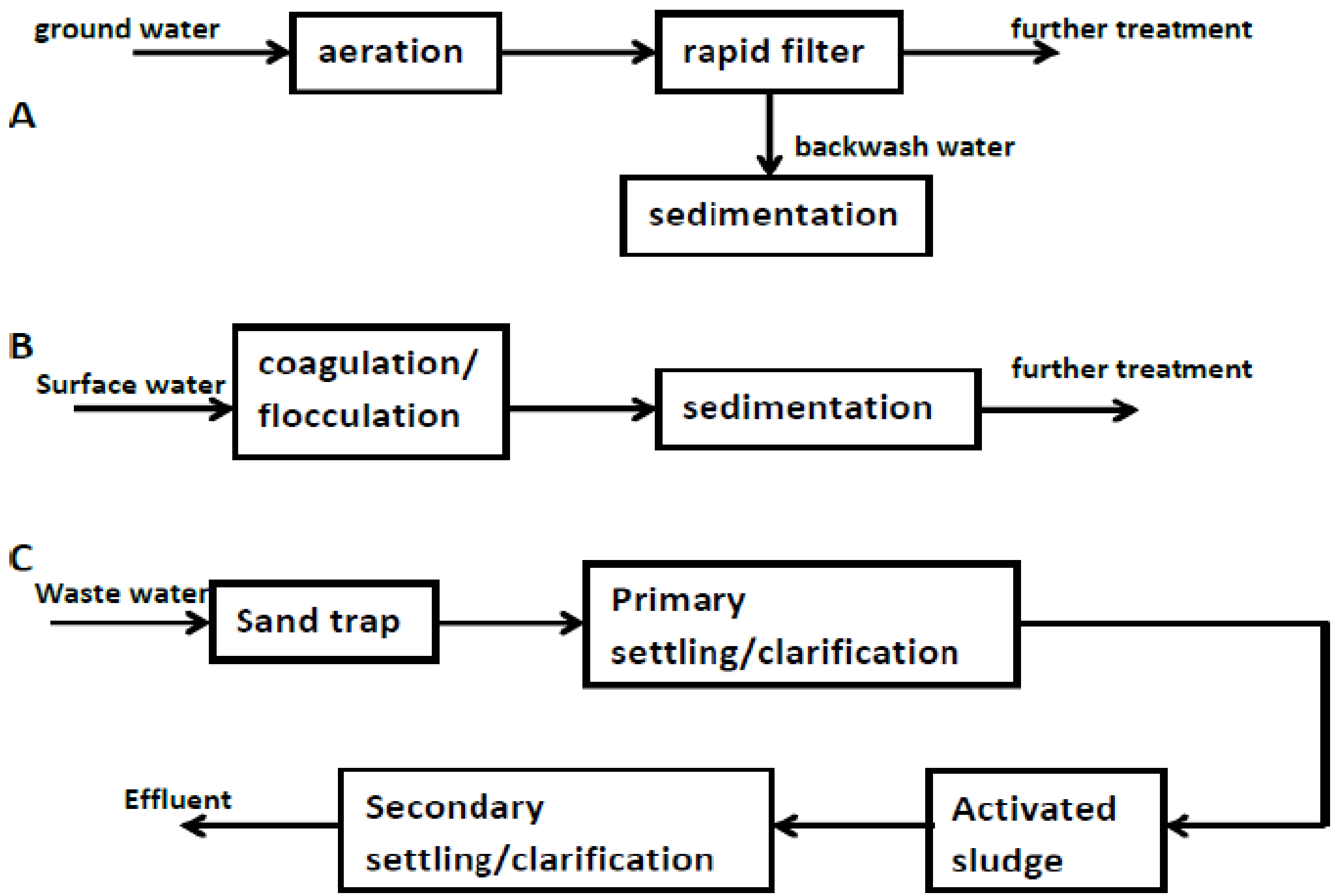
Sedimentation: introduction

- Settling of solid particles under the influence of gravity, in a liquid of lower density



- Settling velocity ~ density & (particle diameter)^2
- The larger and heavier the particles, the better the settling

Sedimentation in water treatment

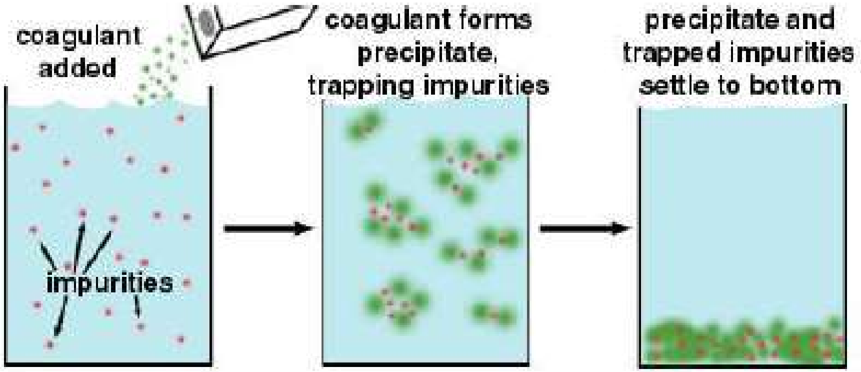


Filter backwash water

- Sand filters remove colloidal material and flocs
- When filters are clogged, they need to be cleaned by backwash
- Backwash water contains high amounts of settleable suspended solids
- Need to be removed before discharge

Coagulation/flocculation

- Surface water contains suspended solids and colloids
- These do not always settle easily because of size and density
- Coagulation/flocculation: turn them into larger aggregates/flocs
- Separation of these flocs: by sedimentation (or flotation)



Sand trap

Goal: mainly the removal of sand to prevent damage to pumps, etc. by abrasion and erosion. Also to prevent sand from sedimenting in the sludge basins

(longitudinal sedimentation basins are often used in drinking water treatment as well)

Primary sedimentation

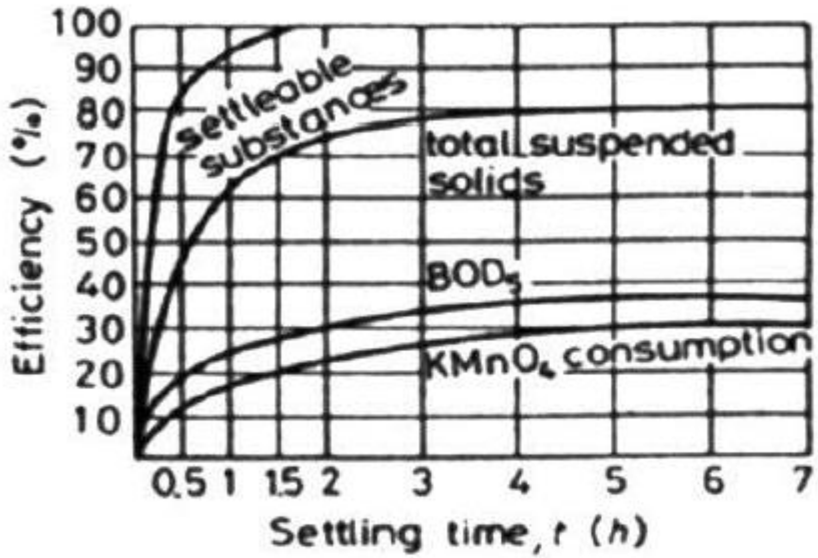
- Traditional activated sludge wastewater treatment:

wastewater → primary sedimentation → activated sludge → secondary clarifier → effluent

Primary sedimentation

- Reduction of SS by 50 – 80 %
- Reduction of BOD by 20 – 40 %
- Reduction of COD by 10 – 30 %

Efficiency can be further increased by coagulation/flocculation beforehand



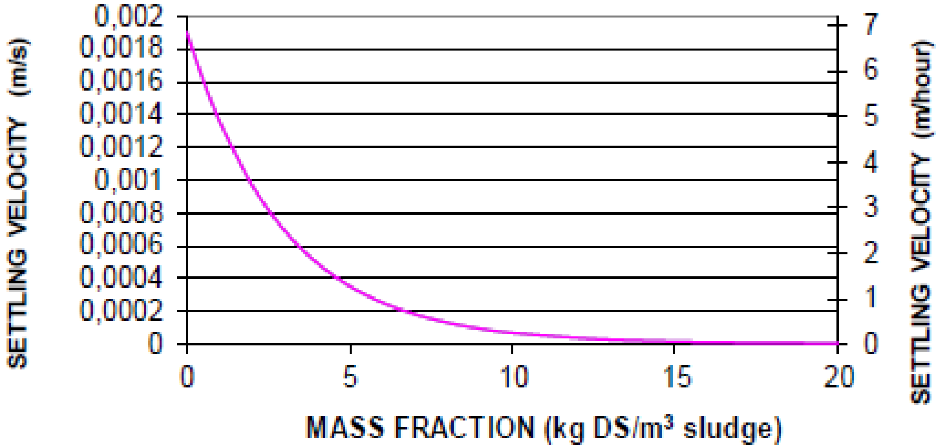
Secondary clarifiers

- To remove activated sludge
- Sedimentation velocity is dependent on activated sludge concentration
- Well-settling sludge in municipal wastewater (empirical equation):

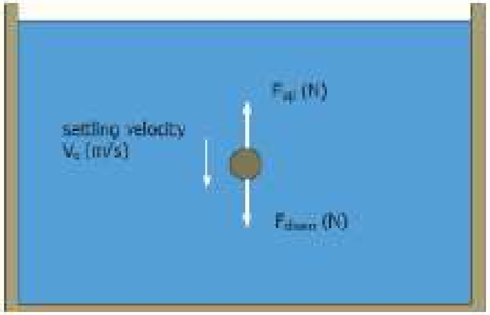
$$v = 0{,}0019 * \exp(-338 * c) \quad (m/s)$$

c = mass-fraction of dry solids (kg/kg)

- Settling velocity of activated sludge: varies between1 and 6 m/h



Theory of sedimentation: settling of discrete particles



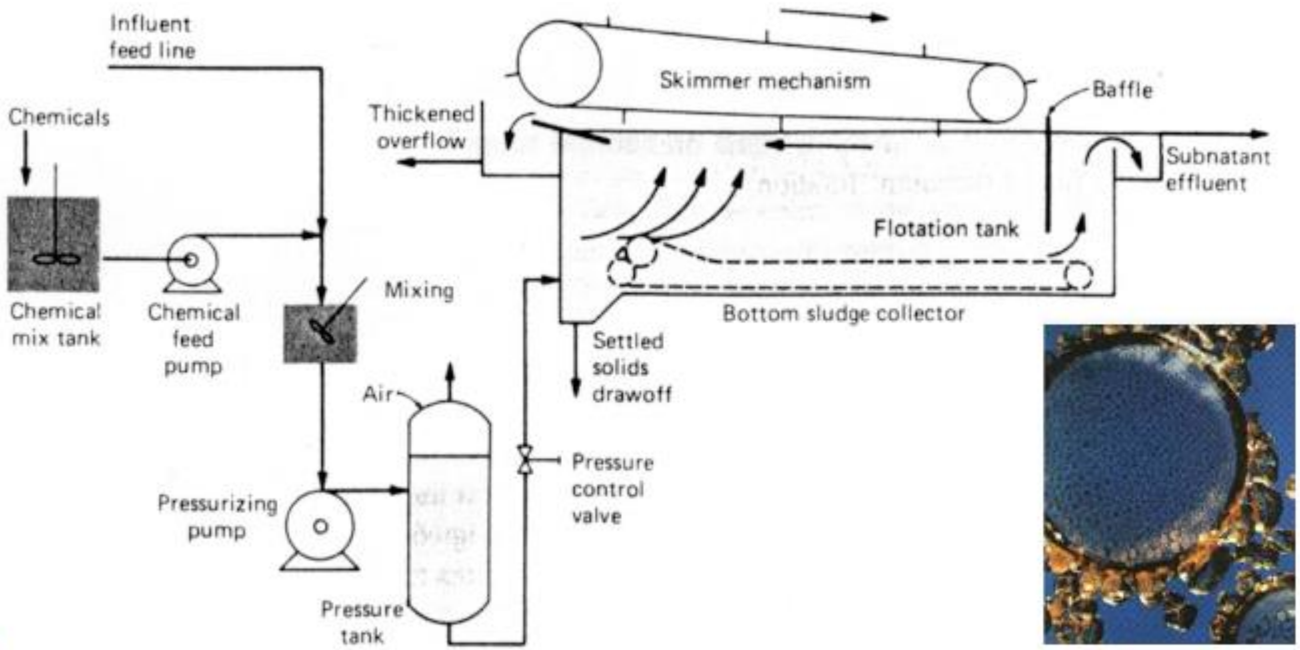
- downward force: <u>gravity:</u> $F_{down} = (\rho_s - \rho_W) \cdot g \cdot V$
- upward force: <u>friction/drag:</u> $F_{up} = C_D \cdot \frac{\rho_W}{2} \cdot v_s^2 \cdot A$

with:
- ρ_s: density of particles
- ρ_w: density of water
- V: particle volume
- A: particle projected surface area (=π.d²/4)
- C_D: drag coefficient
- v_s: settling velocity of particle

FLOTATION (1)

DAF: dissolved air flotation

- Water under pressure is supersaturated with dissolved air
- Upon relaxation, small bubbles are formed (solubility of gas in water is lower at lower pressure
- Air bubbles attach to the grease particles and take them to the surface



FLOTATION (2)

Size of the bubbles is important! (50 µm best) – requires 5 to 6 bar

Destabilisation & flocculation

STEP 1: Coagulation (destabilisation):

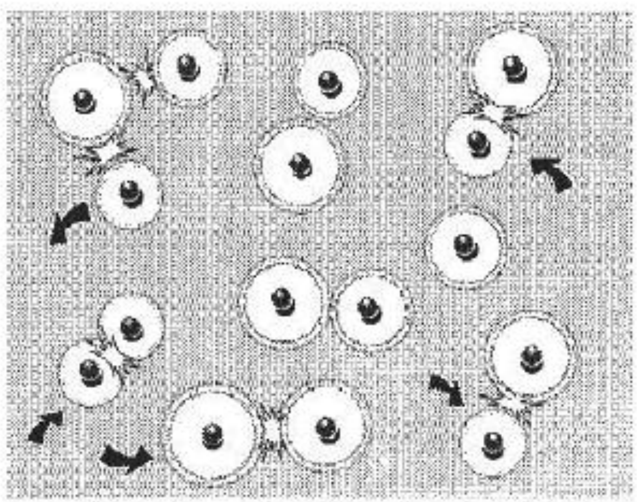
- Proces that initiates destabilisation
- Inhibition of stabilizing factors
- (can also be used to induce pure precipitation, e.g. $FePO_4$ for phosphate removal)

STEP 2: Flocculation (floc formation):

- Slow growth of destabilised particles to larger aggregates (flocs)
  - Spontaneous: perikinetic flocculation
  - Induced by turbulence: orthokinetic flocculation

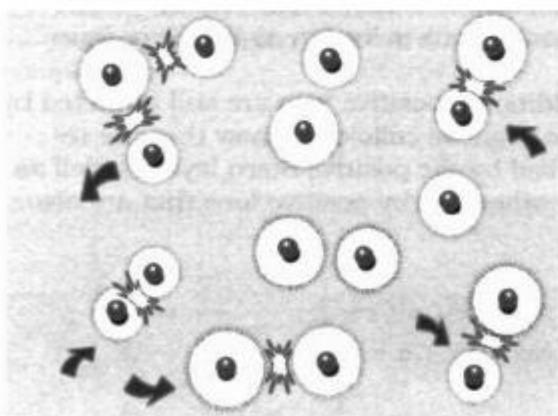
Coagulation = Destabilisation

- Stability as a result of electrostatic repulsion
- Most particles occuring in nature are negatively charged

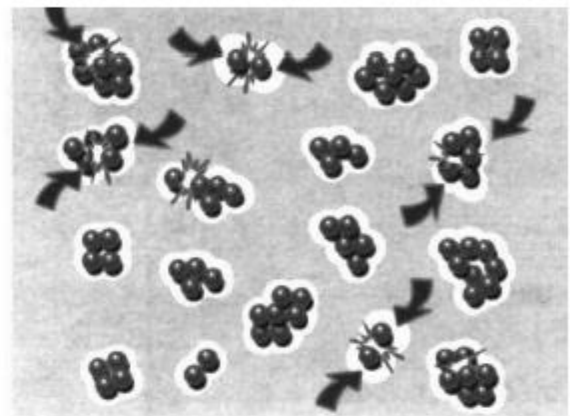


Destabilisation

1. Charged particles repel each other
2. Uncharged particles can collide and aggregate

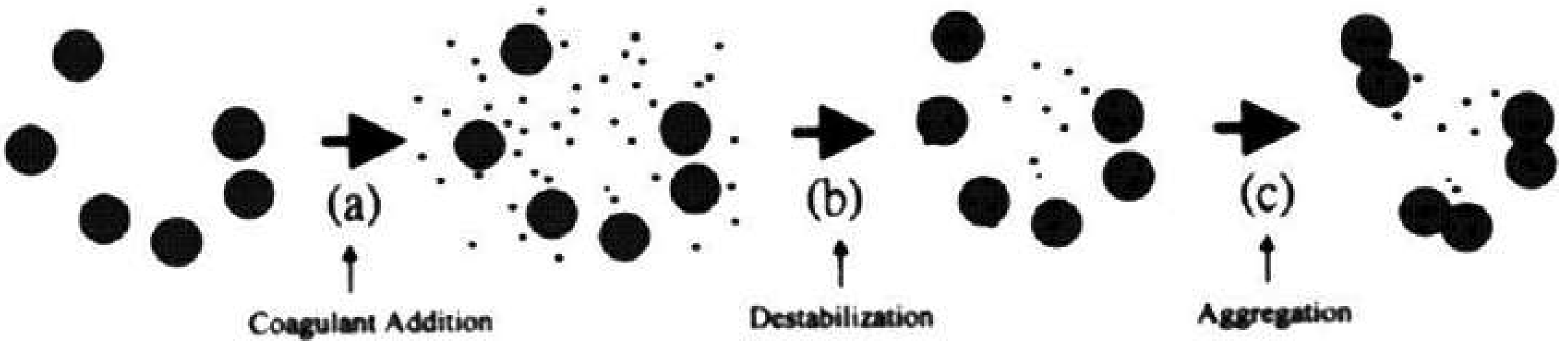


Charged Particles repel each other



Uncharged Particles are free to collide and aggregate.

Destabilization/floc formation



Coagulant:

removes stability

induces destabilization

Flocculant:

speeds up floc formation after destabilization

Physico-chemical treatment of municipal wastewater

- CEPS: *chemically enhanced primary sedimentation*
- Removal of:

after coagulation/flocculation		settling without chemical addition
50 to 80% of BOD	↔	25 to 40% of BOD
80 to 90% of SS	↔	50 to 70% of SS
Up to 90% phosphate	↔	no phosphate removal

Activated sludge removes 90 to 95% of BOD and 95% of SS !!

So: when possible: activated sludge, but not possible for all streams…

Chemicals

- Coagulants:

  Induce destabilization

- Flocculants = flocculation aids:

  Increase floc formation velocity and/or floc strength

- Conditioning of sludge:
  - Strengthens sludge flocs
  - Improves dewatering

Chemicals

Inorganic chemicals:

- For coagulation: mainly based on multivalent metal-cations

  → Al-sulphate, Fe(III)-chloride

- For pH-correction:
  - lime ($Ca(OH)_2$ in water)
  - Caustic soda (NaOH)
  - Sulphuric acid (H_2SO_4)

Chemicals

Inorganic coagulants mainly based on multivalent metal cations: mainly Fe^{3+}; Al^{3+}

Table 1 Commonly used inorganic coagulants and their chemical formulas

Chemical name	Chemical formula
Aluminum sulfate (alum)	$Al_2(SO_4)_3 \cdot 14H_2O$
Polyaluminum chloride (PACl)	$[Al_2(OH)_nCl_{6-n}]_m$
Polyaluminum sulfate (PAS)	$[Al_2(OH)_n(SO_4)_{3-n/2}]_m$
Ferric chloride	$FeCl_3$
Ferrous chloride	$FeCl_2$
Ferrous sulfate	$FeSO_4$
Polyferric sulfate (PFS)	$[Fe_2(OH)_nCl_{6-n}]_m$

Chemicals

Organic chemicals:

- For coagulation: mainly based on cationic hydrophilic polymers (polyelektrolytes)
- For flocculation: relatively uncharged to negatively charged polyelectrolytes as flocculation-aid
- For conditioning of sludge: mainly cationic polymers to increase dewaterability

Sand filtration

- Water flows through a granular medium (sand, antracite,…)
- Suspended solids are filtered out on top of and inside filter bed
  - Small particles
  - Colloidal material
  - Flocs after coagulation/flocculation
  - …
- Biological degradation:
  - Iron
  - Manganese
  - Ammonium
- Partial desinfection (dependent on flow velocity):
  - Bacteria, virusses and protozoa

Difference between RAPID and SLOW sand filtration

- Rapid sand filters (filter velocity 10 m/h or higher):
  - Drinking water:
    - Mainly applied for Fe and Mn removal, but also NH_4^+ (first oxidise Fe, Mn and NH_4^+ with air!)
    - Also for removal of small particles and turbidity
  - Waste water:
    - Mainly for removal of carry-over suspended solids/polishing
- Slow sand filters (< 1 m/h):

  Main application: water desinfection (die-off of pathogens and bacteria)

Difference between RAPID and SLOW sand filtration

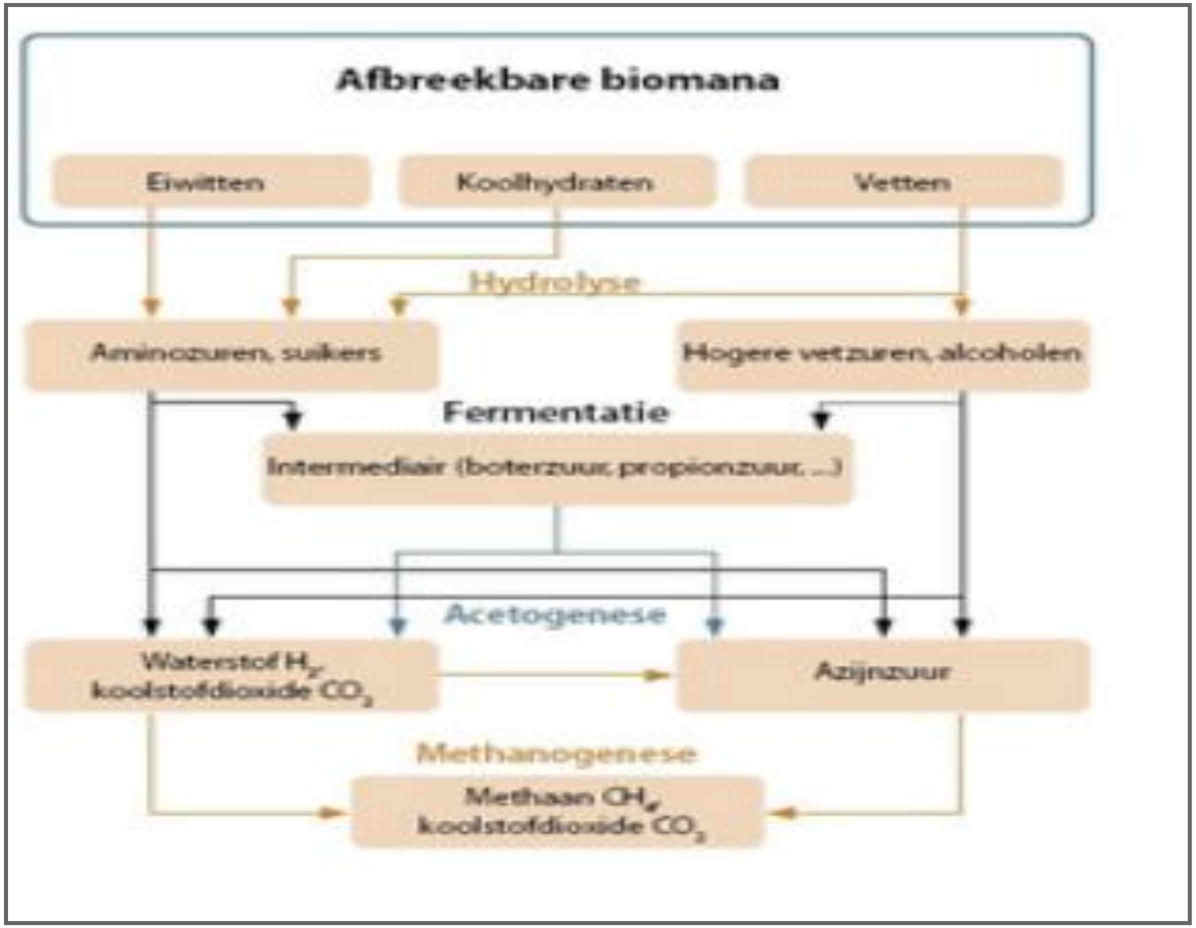
WATER PURIFICATION (3)

See presentations on grids, sand traps, primary sedimentation, biological treatment, secondary clarifier in separate presentations

WATER PURIFICATION (4)
“slibverwerking” or sludge treatment

SLUDGE TREATMENT: ANAEROBIC FERMENTATION → DEWATERING

ANAEROBIC FERMENTATION (SEE FIGURE)



4 Steps:
hydrolyse, fermentation (-acidogenese), acetogenes en methanogenesis. Last step>> production of biogas.

<u>COMPOSITION BIOGAS</u>

Volume-%

CH_4 50-75%

CO_2 25-50%

H_2O 2-7%

N_2 0-2% H_2 0-1% H_2S 0-2%

WATER PURIFICATION (5)
"slibverwerking" or sludge treatment

Dewatering of sludge: 20-40 % DS filter cakes (filter press)

Sometimes coagulants/flocculants added

Cakes go to landfill or incineration

Biotechnological methods of wastewater treatment (1)

AEROBIC (ACTIVATED SLUDGE SYSTEMS, BIOFILM REACTORS)

ANAEROBIC (ANAEROBIC FERMENTATION)

ALTERNATIVE PURIFICATION SYSTEMS; SEPTIC TANKS, EMSCHER TANKS, PERCOLATION FIELDS,

Biotechnological methods of wastewater treatment (2)

AEROBIC (ACTIVATED SLUDGE SYSTEMS, BIOFILM REACTORS)

ACTIVATED SLUDGE SYSTEMS

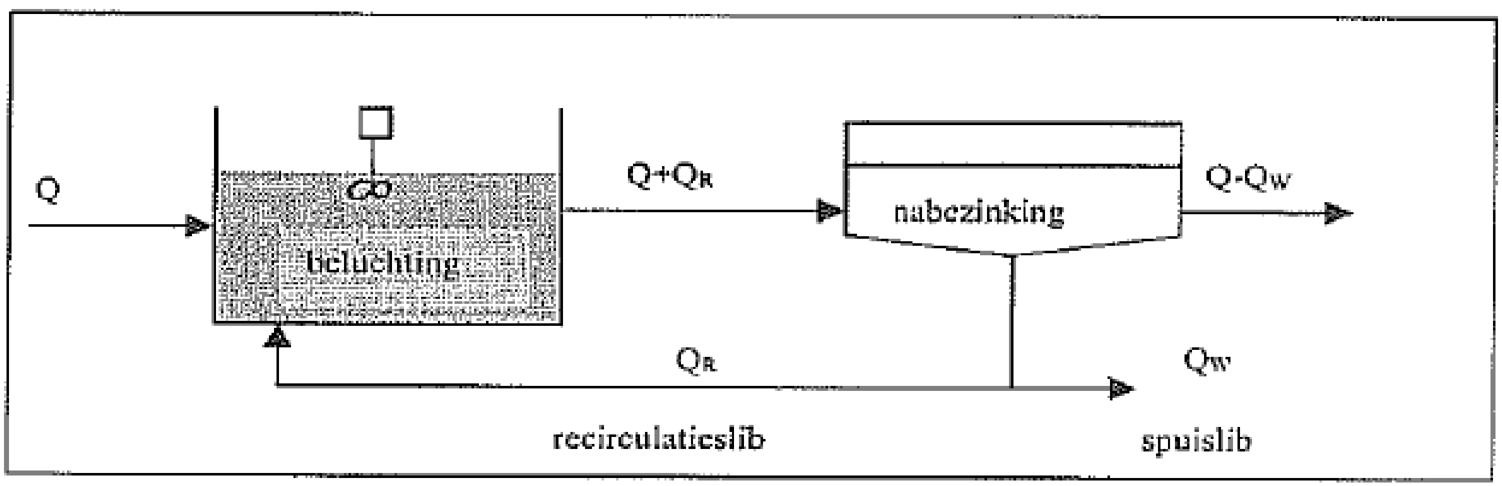


Fig. 16. Algemeen schema van een actief slibinstallatie

Biotechnological methods of wastewater treatment (3)
ACIVATED SLUDGE SYSTEM

WASTE WATER AERATED (OPEN OR CLOSED SYSTEM)

THEN SEDIMENTATION AND SLUDGE FORMATION

RETURN SLUDGE (Qr): USE TO INOCULATION OR ENRICH MO

SLUDGEPRODUCTION >>> TIME TO EJECT SOME OF IT! (Qw)

Biotechnological methods of wastewater treatment (4)
ACTIVATED SLUDGE SYSTEMS

LOADING THE SYSTEM

- hoog (meestal 2-trapssysteem, ook AB-systeem genoemd : hoogbelaste eerste trap, laagbelaste tweede trap)
- conventioneel
- laag : langdurige beluchting of 'extended aeration'

Enkele richtwaarden voor slibbelasting en volumebelasting zijn vermeld in Tabel 9.

Tabel 9. Classificatie actief slibprocessen op basis van belastingen

Type	B_x (kg bCZV/kg MLSS.d)	B_v (kg bCZV/m³.d)
Laag belast	< 0,2	< 0,8
Conventioneel	0,2 – 0,5 (default 0,25)	0,8 – 2,0 (default 1)
Hoog belast	> 0,5	> 2,0

Biotechnological methods of wastewater treatment (5)
ACTIVATED SLUDGE SYSTEMS

1. Gemengde vloeistof (mixed liquor) : mengsel van afvalwater en actief slib in het beluchtingsbekken.

2. Slibgehalte (MLSS = Mixed Liquor Suspended Solids) : hoeveelheid zwevende bestanddelen in de gemengde vloeistof. De MLVSS (MLSS na verassen) is een maat voor de hoeveelheid biomassa. Meestal bedraagt de MLVSS 65 tot 80% van de MLSS. Het slibgehalte in het äeratiebekken wordt meestal gestuurd rond 4 g/l.

3. Slibvolume-index (SVI) : het volume dat door 1 g MLSS wordt ingenomen na 30 minuten bezinktijd. Goed bezinkend slib heeft een SVI van 40 à 60 ml/g. Licht slib heeft een SVI van 200 ml/g en meer.

4. Volumebelasting (B_v) : het aantal kg binnenkomende bCZV per eenheid reactorvolume en per dag. De volumebelasting bedraagt meestal 1 kg bCZV/m³.d.

5. Slibbelasting (B_x) : het aantal kg inkomende bCZV per kg slib en per dag. De slibbelasting varieert van 0,05 tot 0,50 kg bCZV/kg MLSS.d. Meestal wordt gewerkt bij een waarde van 0,25. Deze parameter is van primordiaal belang ten aanzien van de bezinkingseigenschappen van het slib.

6. Zuurstoftoevoer : normaal wordt 1,5 à 2-maal de hoeveelheid zuurstof corresponderend met de bCZV-vracht voorzien (OC/load = 1,5 à 2 ; OC = oxygenation capacity).

Biotechnological methods of wastewater treatment (6)
ACTIVATED SLUDGE SYSTEMS

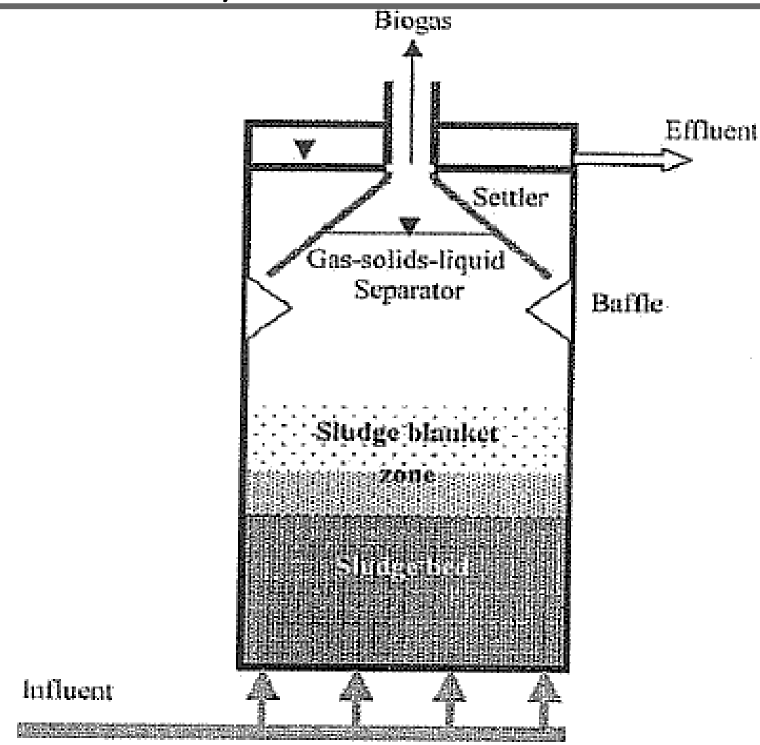
7. HYDRAULISCHE VERBLIJFTIJD (QH): 1 HOUR UP TO FEW DAYS

8. SLIBLEEFTIJD (Qx): 10 TO 20 DAYS: SLUDGE RESIDENCE TIME

9. SLIBPRODUKTIE (YIELD): 0.4 kg/kg degraded bCOD

Biotechnological methods of wastewater treatment (7)

UASB (UPSTREAM, ANAEROBIC SLUGDE BLANKET REACTOR)



Schema van de UASB opstroomreactor

<u>AIM</u>: decomposition of organic and inorganic matter in the absence of molecular oxygen.

- $V_{UPSTREAM}$: 1 m/hour
- MO: grow on granulates >> activated sludge forms 50-100 kg/m^3
- OM converted to CH4, CO2

•Advantages over aerobic systems

- less Energy
- reduced costs
- less nutrients (N.P)
- less space required

Biotechnological methods of wastewater treatment (8)

SEPTIC TANKS

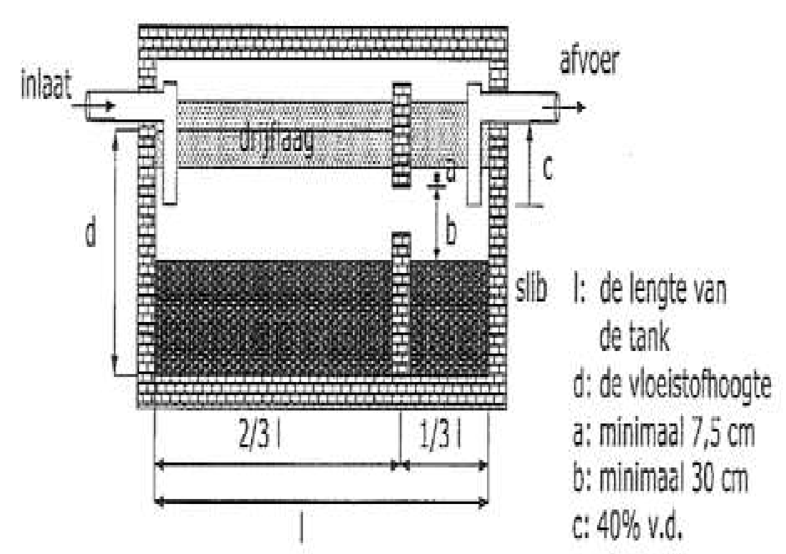
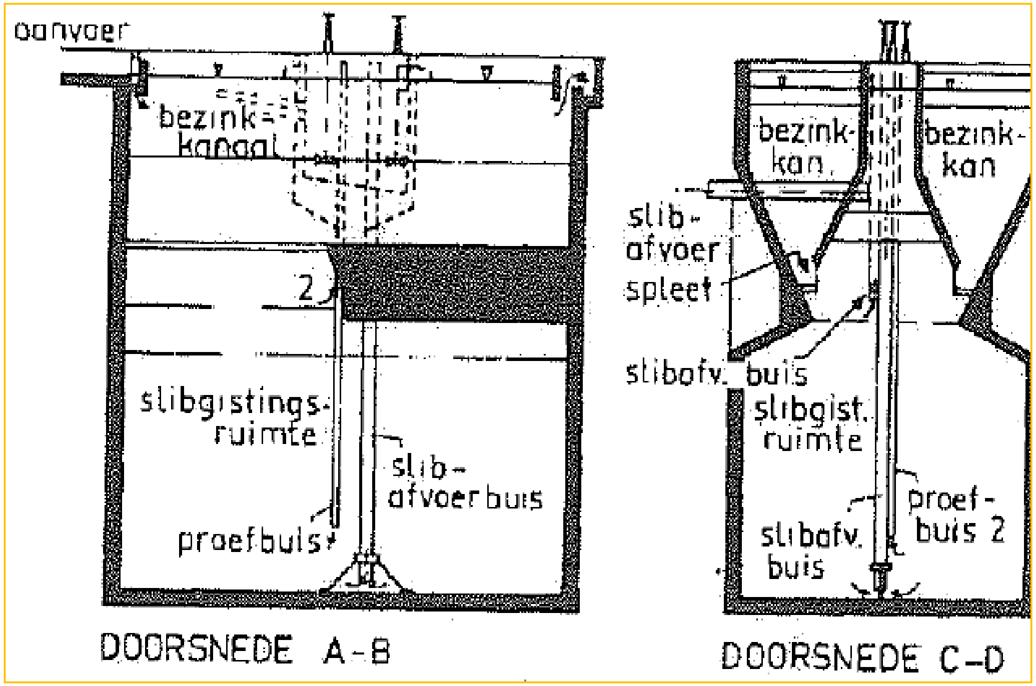


Fig. 25. Schema septische tank

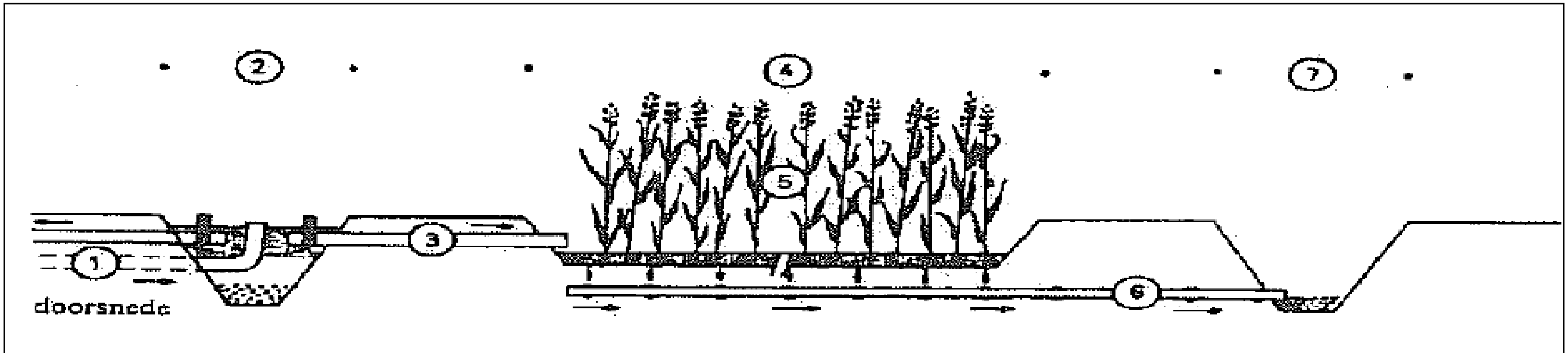
- 0.3 m^3 per IE
- sedimentation +fermentation in one chamber

EMSCHER OR IMHOFF TANKS



- 25 liters per IE (sedimentation tank)
  100 l per IE (fermentationtank)
- 2 chambers
- higher removal of SS; 50-70% compared to 20-70% (septic tank)

Biotechnological methods of wastewater treatment (9)
"PERCOLATIE VELDEN OF INFILTRATIEBEDDEN" or natural sandfilters



- Aim: clear (diluted) wastewater is percolated through soil and subsequently drained, with or without the aid of plants. (enhanced microbial degradation)
- Pollutants removed by physical- bio-chemical processes
- Advantage of plants (see course notes, part water, page 51)
- Removal efficiencies: high for BOD, COD, SS, Kj-N, NH4-N, somewhat lower for P (see page 52, course notes part water)

Biotechnological methods of wastewater treatment (10)

Water quality before discharge to surface water (VLAREM II)

MO

het te lozen afvalwater dat in zodanige hoeveelheden pathogene kiemen bevat dat het ontvangende water er gevaarlijk door kan worden besmet, moet ontsmet worden;

pH

de pH van het geloosde water mag niet meer dan 9 of niet minder dan 6,5 bedragen;

BOD

het biochemisch zuurstofverbruik in vijf dagen bij 20°C van het geloosde water mag volgende waarden niet overschrijden:

a) 25 milligram zuurstofverbruik per liter
b) 50 milligram zuurstofverbruik per liter voor de lozingen afkomstig van gebouwen die uitsluitend als woning gebruikt worden en waarin minder dan twintig personen wonen.

SS
HC

in het geloosde afvalwater mogen de volgende gehalten niet overschreden worden:

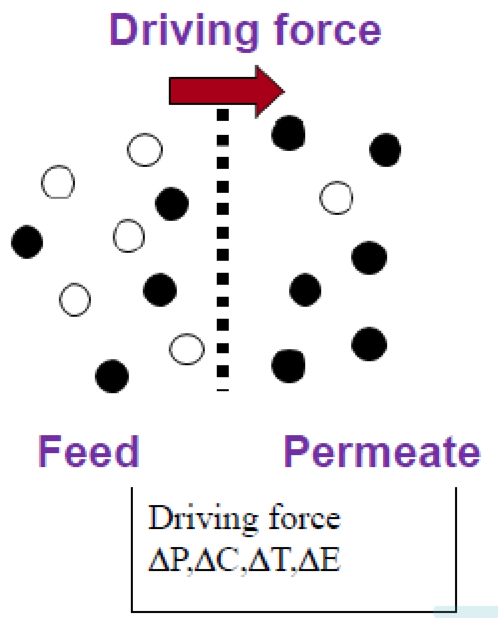
a) 0,5 milliliter per liter voor de bezinkbare stoffen (tijdens een statische bezinking van twee uur);
b) 60 milligram per liter voor de zwevende stoffen;
c) 3 milligram per liter voor de apolaire koolwaterstoffen extraheerbaar met tetrachloorkoolstof;

Oil and grease

een representatief monster van het geloosde afvalwater mag geen oliën, vetten of andere drijvende stoffen bevatten in zulke hoeveelheden dat een drijvende laag op ondubbelzinnige wijze kan vastgesteld worden; in geval van twijfel, kan dit vastgesteld worden door het monster over te gieten in een scheitrechter en door vervolgens na te gaan of twee fasen gescheiden kunnen worden. (Dit houdt in dat zonodig een vetvanger zal moeten geïnstalleerd worden)

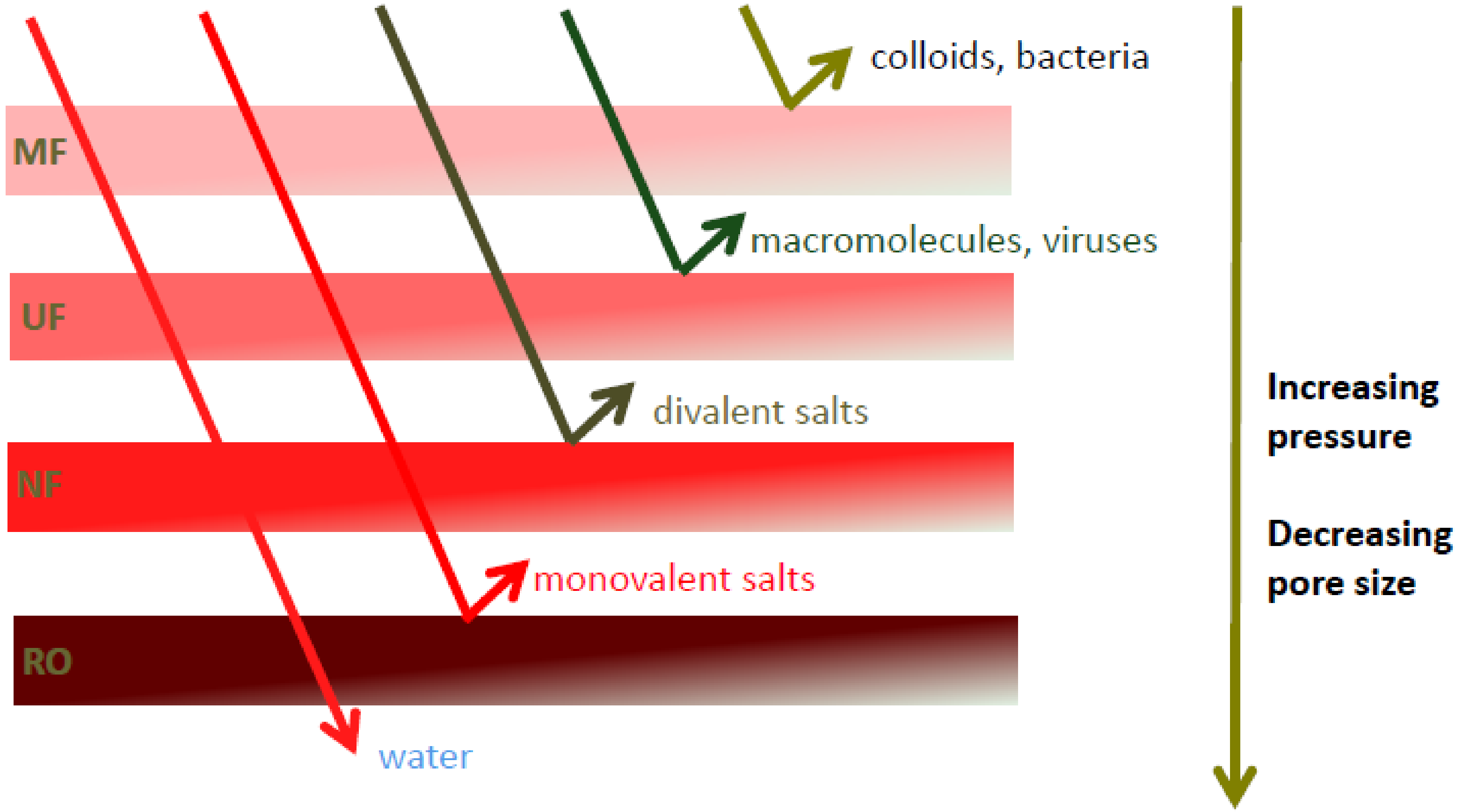
Membrane

- Membrane: semi-permeable barrier between two streams
- High permeability for water, low permeability for solutes (particles, ions,…)
- In practice:
  mostly pressure driven
- Different processes:
  - Microfiltration
  - Ultrafiltration
  - Nanofiltration
  - Reverse osmosis

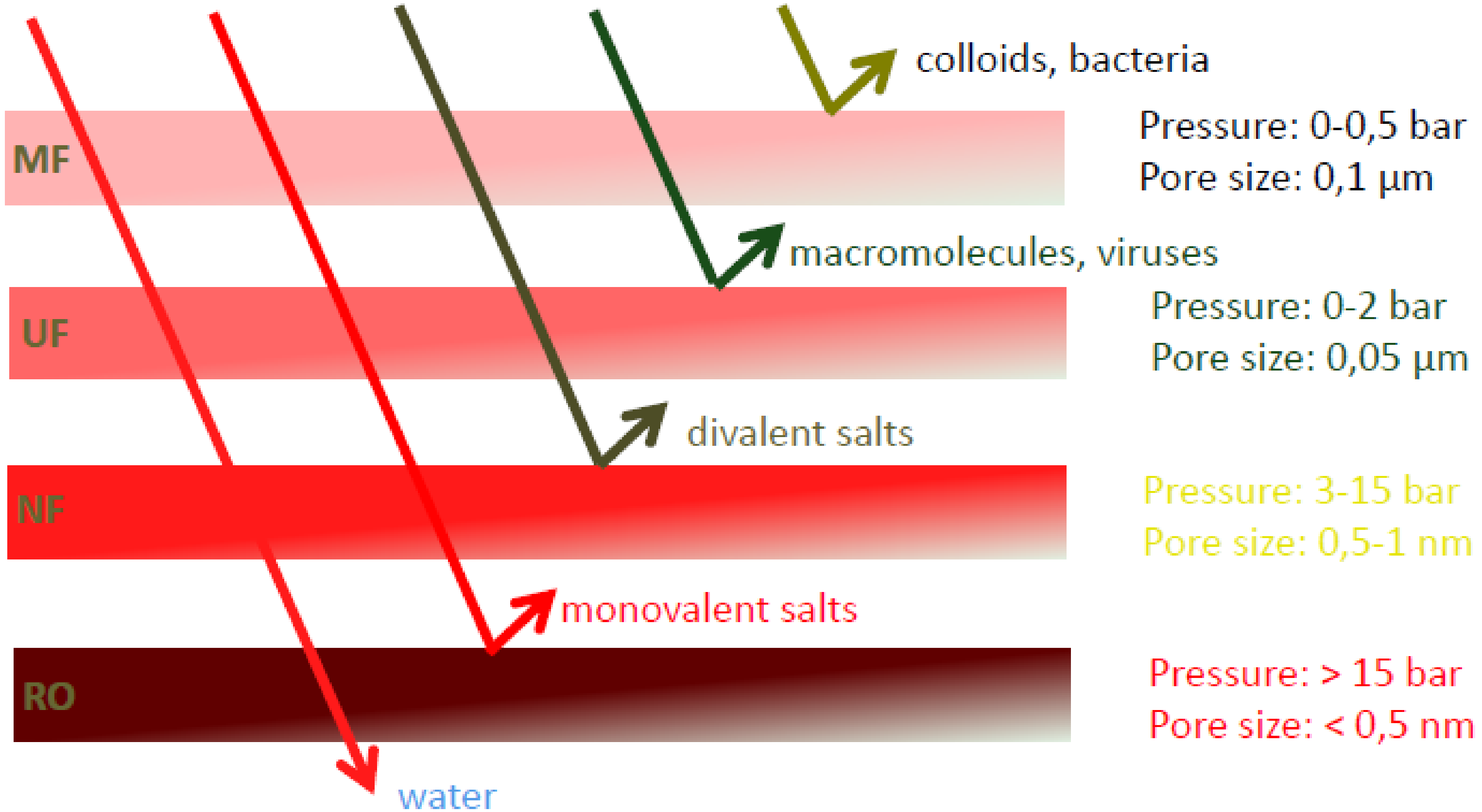


3 -

Difference between micro-, ultra- and nanofiltration and reverse osmosis



Difference between micro-, ultra- and nanofiltration and reverse osmosis



Membrane classification

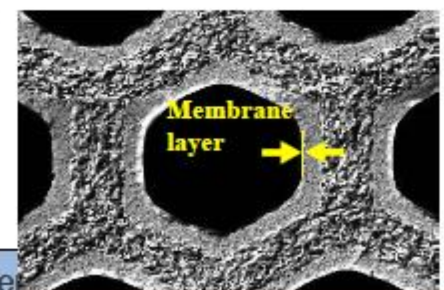
- According to porosity:
  - Porous (5 nm to µm)   (MF and UF)
  - Micro-porous (1 to 5 nm)   (~NF)
  - Non-porous (NF,RO)

Membrane classification

- According to porosity
- According to the transport mechanism:
  - Sieving ('*membrane filtration*'):
    - According to size
  - Electrostatic exclusion:
    - According to size + charge
  - Solution-diffusion: (convection-diffusion)
    - According to solubility and diffusivity

Membrane classification

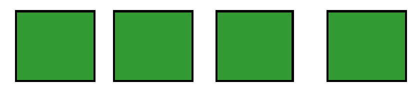
- According to porisity
- According to transport mechanism
- **According to composition:**
  - Organic = polymeric membranes
  - Inorganic = ceramic membranes
  - Organo-minerals = semi-ceramic membranes



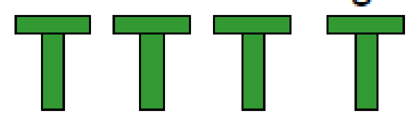
Environmental tech

Membrane classification

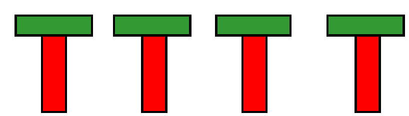
- According to structure:
  - Homogeneous = isotropic = symmetrical membranes:
    - Constant composition
    - Constant properties
    - But: flux <-> mechanical strength



  - Asymmetrical membranes:
    - * Thin top layer ('*skin layer*') results in selectivity and flux limitation
    - * Strong, porous, thick support layer gives mechanical strength
      - Constant composition
      - Varying properties



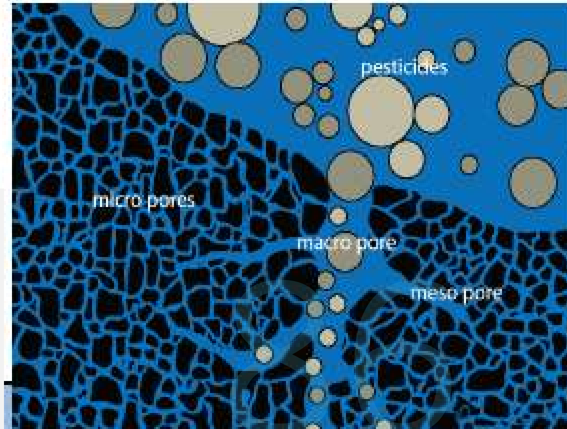
  - Composite membranes (TFC):
    - Varying composition and properties



Activated carbon

- Very porous, carbonaceous material
- Hydrophobic surface
- Peat, graphite, coconut,… is being activated at elevated temperatures (controlled pyrolysis ~ 800-1000°C)
- Creates a very high specific surface area (up to 4000 m² of adsorption area for 1 g of carbon !!!)
- Hundreds of different types of commercial carbon

- Mainly adsorption of C-type molecules (high affinity for carbon surface)
- Mainly adsorption of hydrophobic molecules



Activated carbon

- Applications:
  - Removal of odor and taste
  - Removal of pesticides, pharmaceuticals, trihalomethanes (desinfection by-products)
  - Removal of TOC/COD
  - Color removal
  - AOC removal after e.g., ozonation: biologically activate carbon
  - Dechlorination

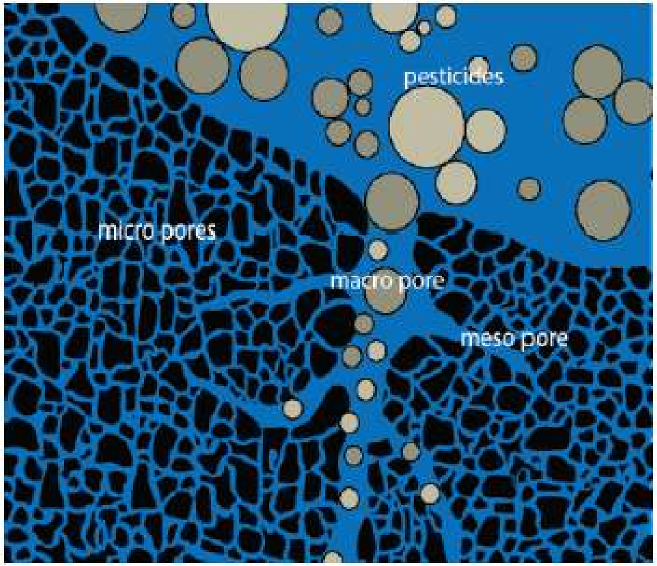
often polishing for recalcitrant components

- Removal by adsorption or biology (biologically activate carbon)

Colums: granular material (0.5-5 mm)

Dosing of powdered activated carbon (1-150 µm)

Activated carbon: principle of adsorption

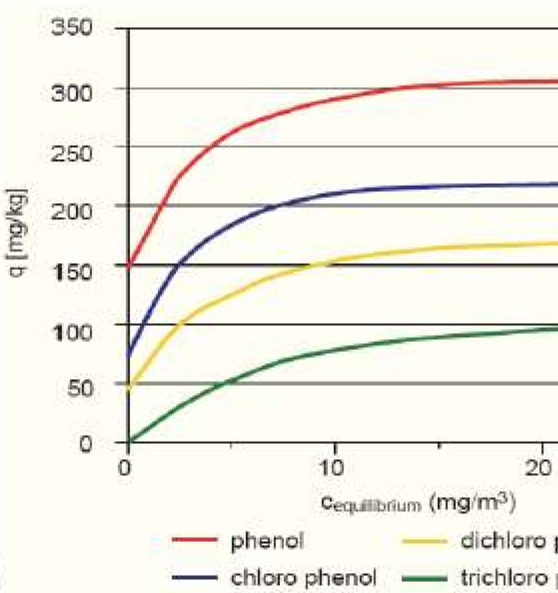


- Adsorption dependent on:
  - Polarity (hydrophobicity) and size of molecules
  - Pore size (distribution) of carbon
  - Specific surface area of carbon
  - Competion of molecules with bulk organic matter (NOM) for adsorption sites
  - Pore-blocking by larger molecules; pre-loading of carbon by other molecules

- But also on:
  - Solute bulk concentration
  - Temperature

Adsorption: Freundlich-isotherm

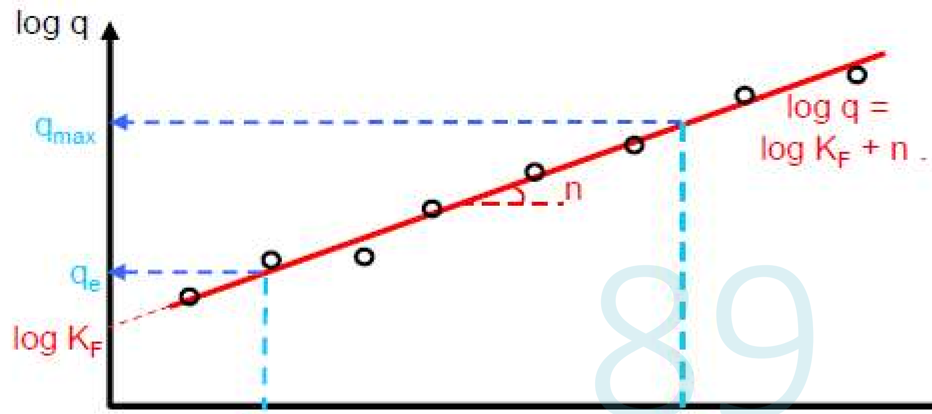
- Adsorption-isotherm: relationship between adsorbed amount of a solute and the remaining (equilibrium) concentration in the bulk



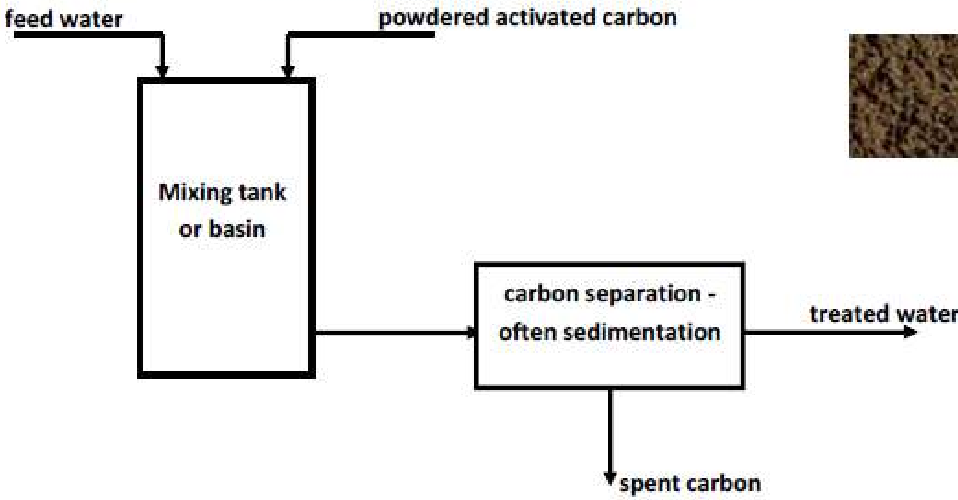
- $$q_e = \frac{X_e}{m} = K_F \cdot C_e^n$$
  - q_e = equilibrium loading (g_{solute}/g_{carbon})
  - X_e = adsorbed amount of solute (g)
  - m = carbon mass (g)
  - C_e = solute equilibrium concentration in bulk (g/m³)
  - K_F ((g/kg).(m³/g)^n) and n (-) = Freundlich-constants

  (dependent on pH, temperature, feed water matrix, carbon- and solute properties)

- High q_e → good removal
- Low q_e → inefficient removal



Powdered activated carbon



- Dosing of carbon with water stream
- Sorption until equilibrium
- Is the adsorbent fit for the removal of the solute?
  - q_{max} >10% → OK
  - q_{max} 5 à 10%→ additional tests required
  - q_{max} <5% → NOT OK

MASS TRANSFER ZONE AND BREAKTHROUGH POINT

Figure 6.11 illustrates the concept of the Mass Transfer Zone (MTZ). There is a zone in which adsorption still takes place, and a zone where the carbon is completely saturated. Over time, more of the carbon will become saturated and the zone where adsorption is still taking place will be situated deeper in the packed bed. At a certain moment, there will be insufficient unsaturated carbon left for complete solute removal, and solute concentrations will increase in the effluent of the packed bed column. This is phenomenon is called "breakthrough", and when the ratio of the effluent concentration over the influent concentration is plotted as a function of time, the phenomena explained above lead to the typical S-shaped concentration profile seen in Figure 6.12. At the beginning, the effluent concentration is 0, but as soon as the carbon starts to become saturated, the effluent concentration will increase until the point where all the carbon is saturated and $C_{effluent} = C_0$. However, in practice, the carbon is regenerated when $C_{effluent}$ reaches a certain limit value.

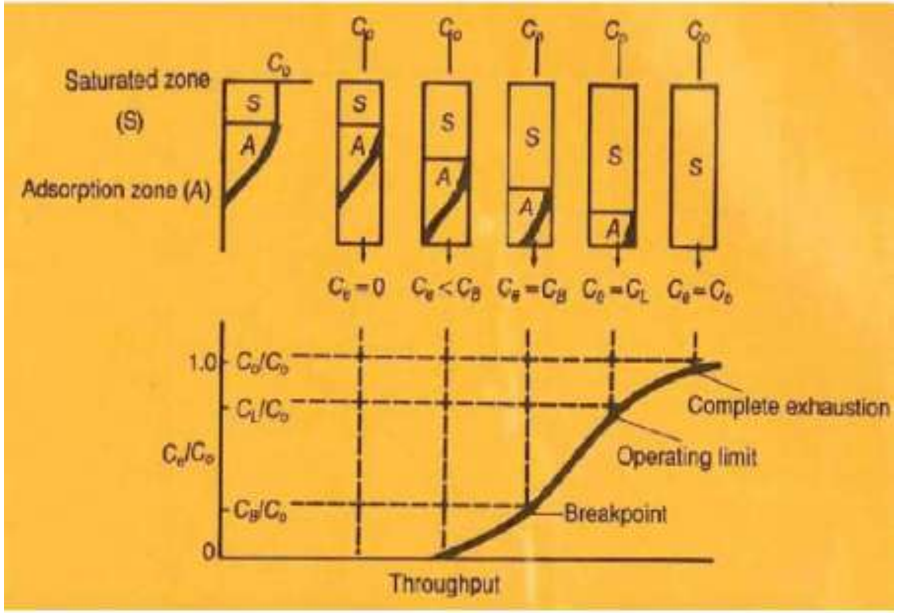
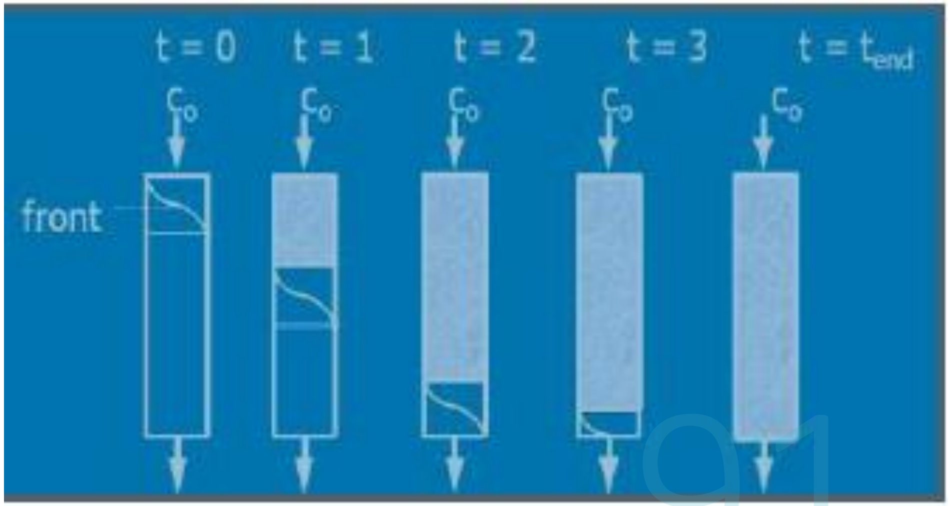


Figure 6.11 – Mass Transfer Zone in a packed bed column

Figure 6.12 is on the next slide



Granular activated carbon: breakthrough curve

- Activated carbon mostly used in colums: constant process, total removal (no equilibrium removal)
- Typical occurrence of mass transfer zone (MTZ), where actual adsorption/exchange is occurring
- Modelling as “layers” of PAC

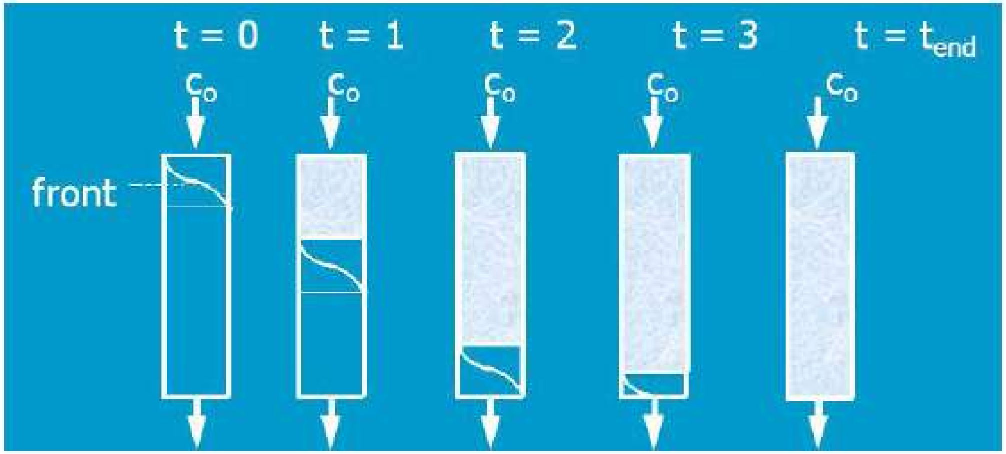
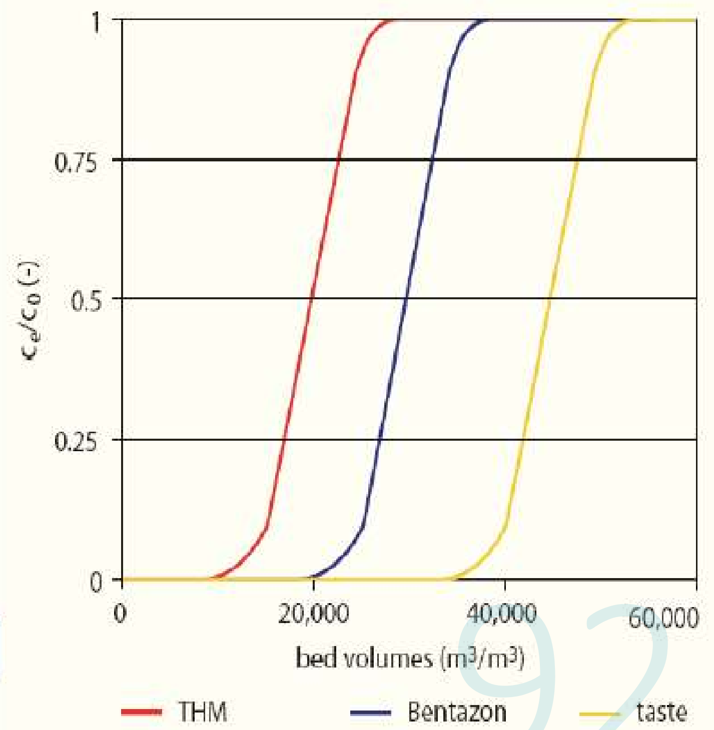


FIGURE 6.12



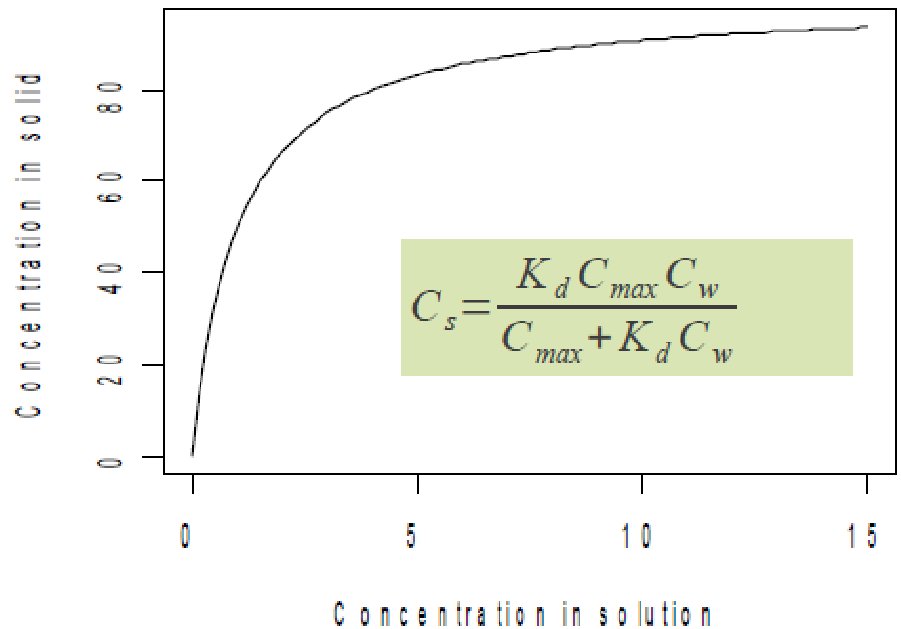
Sorptieisothermen

- Lineaire sorptie

$$C_s = K_d C_w$$

- Niet lineaire sorptie
  - Freundlich $$C_s = K_d C_w^n$$
  - Langmuir $$C_s = \frac{K_d C_{max} C_w}{C_{max} + K_d C_w}$$
  - ...
  - Empirische vergelijkingen: zeggen niets over achterliggend sorptiemechanisme

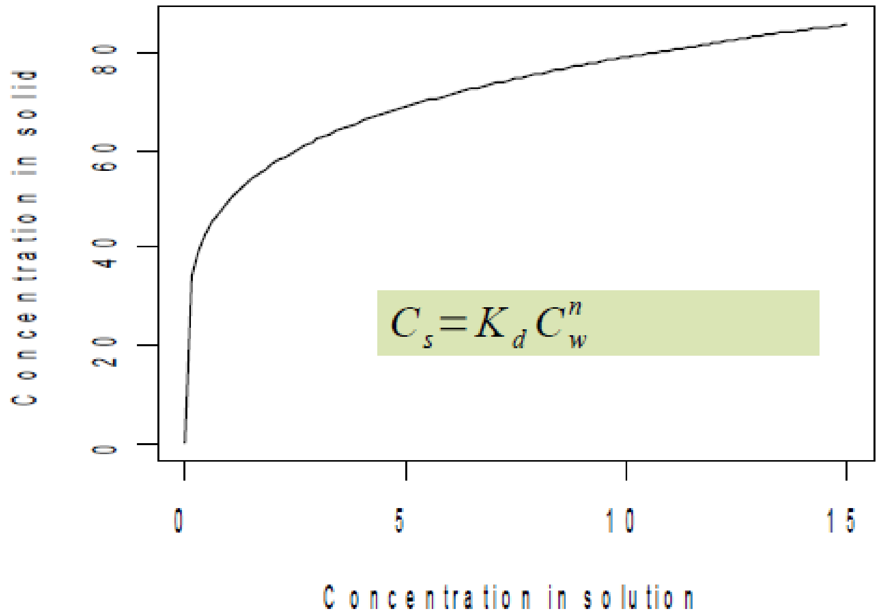
Langmuir



$$C_s = \frac{K_d C_{max} C_w}{C_{max} + K_d C_w}$$

- Hyperbolish model
- C_w <<: lineaire sorptie
- C_w >>: sorptiemaximum

Freundlich



- exponential model
- C_w >>: C_s >>

Example

Sorption by phosphate in a tropical agricultural soil Cameroon was studied. One gram soil samples were equilibrated during 24 hours with 50 mL of 0.01 *M* KCl containing carying amounts of P as KH_2PO_4. Following data were found

P added mg/g	Beker	C_w mg/L	C_s mg/g
0.5	1	0.49	0.48
1	2	3.1	0.85
2	3	15	1.25
4	4	44	1.80
6	5	79	2.05
8	6	111	2.45

Voorbeeld: Sorptie van fosfaat aan een tropische landbouwgrond van Cameroon werd bestudeerd door middel van het schudden van verschillende hoeveelheden fosfor (P) opgelost in 50 ml 0.01 M KCl oplossing (in total 6 bekers). In elke oplossing zit 1 g bodem of soil. Bereken steeds de Cs concentratie in mg P/ g bodem. De Cs voor beker 1 wordt 0.48 mg/g soil. Die voor beker 6 is 2.45 mg/g.

P sorbed:

For example 0.5 mg/g:

$$0.5\ (\text{mg/g}) \times 1\ (\text{g}) / 0.050\ (\text{L}) = 10\ \text{mg/L}$$

$$(10\ \text{mg/L} - 0.49\ \text{mg/L}) \times 0.050\ \text{L}/1\ \text{g} = 0.48\ \text{mg/g}$$

Freundlich

$$C_s = K_d C_w^n$$

lineaire vorm

$$\log C_s = \log K_d + n \log C_w$$

$$y \quad = \quad a \quad + \quad b \quad x$$

Langmuir

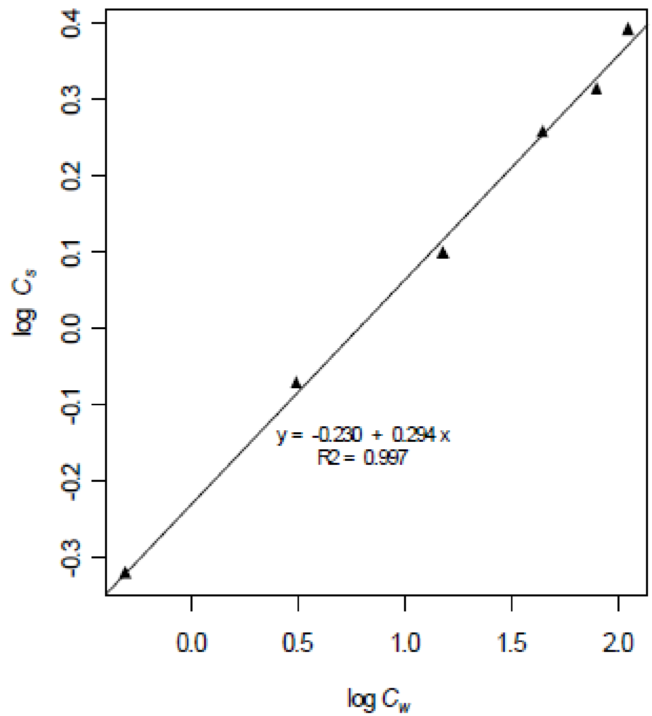
$$C_s = \frac{K_d C_{max} C_w}{C_{max} + K_d C_w}$$

lineaire vorm

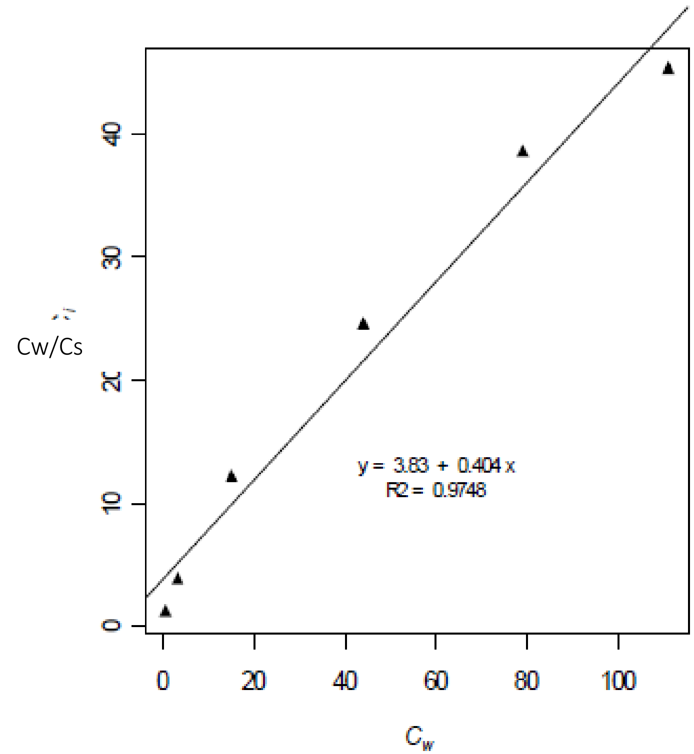
$$\frac{1}{C_s} = \frac{1}{K_d C_w} + \frac{1}{C_{max}} \qquad \text{of} \qquad \frac{C_w}{C_s} = \frac{1}{K_d} + \frac{C_w}{C_{max}}$$

$$y \quad = \quad bx \quad + \quad a \qquad\qquad y \quad = \quad a \quad + \quad b \quad x$$

Freundlich-fit

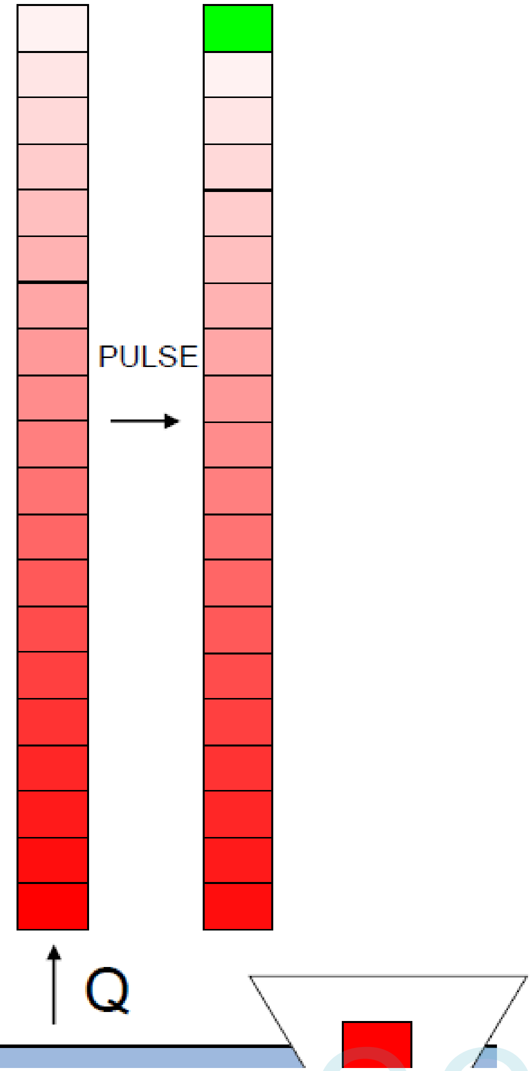


Langmuir-fit



Granular activated carbon (GAC)

- In practice: columns mostly placed in series to prevent breakthrough to effluent
- Mode of operation: saturated column at front is replaced by new column at the back
- Advantage: optimal use of carbon material, since only the (nearly) saturated carbon is being replaced
- Expanded case= pulsed bed: 1/20th of bed is replaced on pulse, rest moves down
- Maximum loading: $q_{max} = K_F.C_0^n$
- Minimal carbon usage $\approx (C_o-C_f)*Q/q_{max}$



Powdered vs granular carbon

- Advantages powdered carbon:
  - Minimal investment cost (combination with coagulation/sedimentation)
  - Smaller carbon particles: less pore blocking; always fresh carbon: no preloading; faster kinetics
- Disadvantages powdered carbon:
  - Effluent concentration = equilibrium ; so carbon used less efficiently
  - No regeneration possible ; not robust against peak loads

- Advantages granular carbon (column filters)
  - Effluent concentration = 0 (until breakthrough occurs)
  - Regeneration is possible
  - Biological AOC-removal is possible; robustness against peak loads
- Disadvantages granular carbon (column filters)
  - High investment costs
  - Pore blocking; preloading