Membranes for water treatment

Urs von Gunten

Membranes: properties and advantages

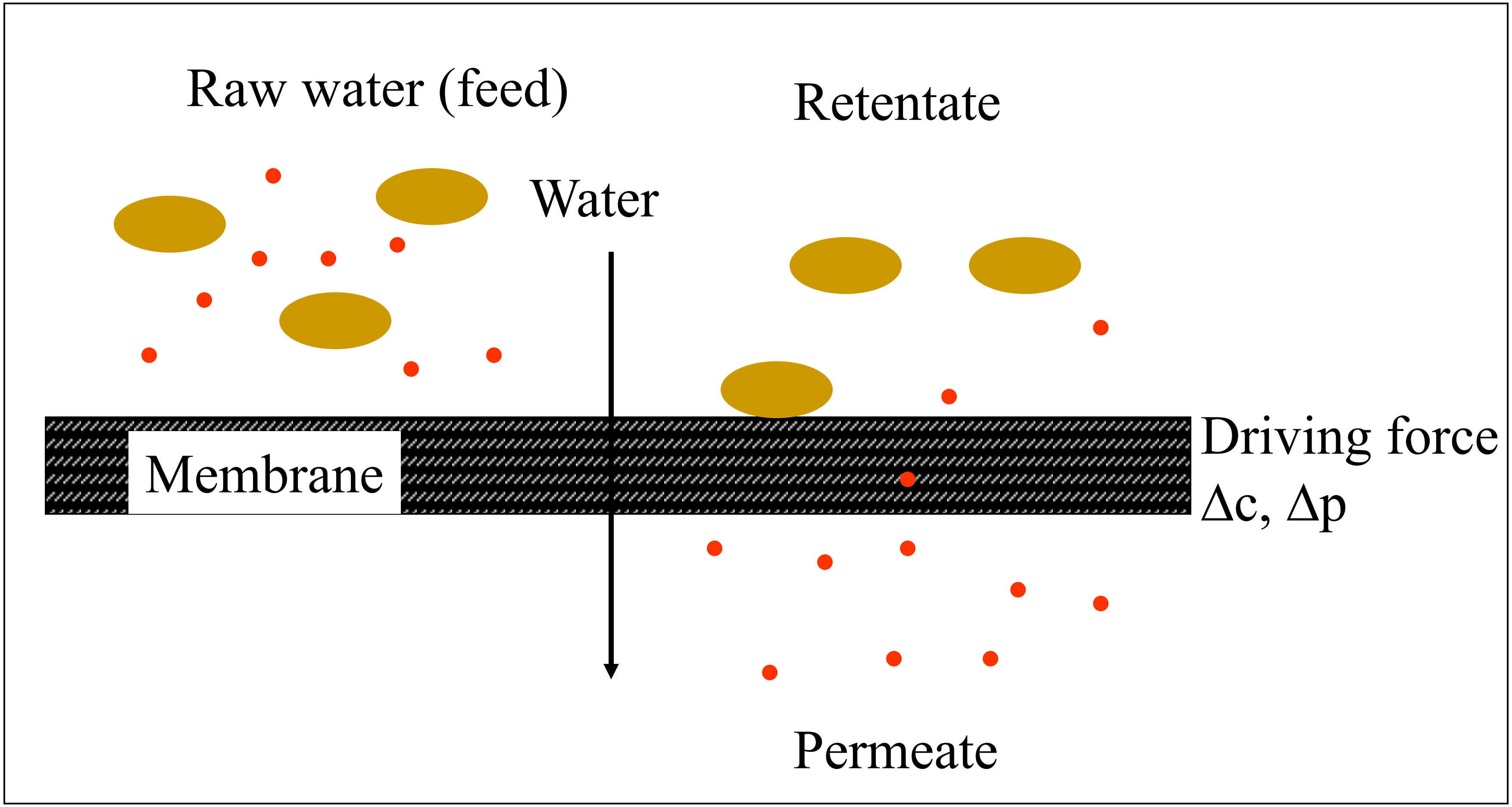
- A membrane is an absolute barrier
- Membrane type and process can be chosen according to the treatment requirements
- Removal of microorganisms/micropollutants can be performed "without" chemicals
- Compact units: less space than conventional filtration processes
- Modular design:
  - small-large sizes
  - cost advantage
- Developments:
  - lower energy requirements
  - increased fluxes
  - new materials: e.g. nanotechnology

Membranes: limitations

Membrane fouling/scaling
- depending on feed composition
- optimization of membrane and operation
- cleaning

Membrane stability
- depends on membrane material
- e.g. chemical resistance against cleaning agents

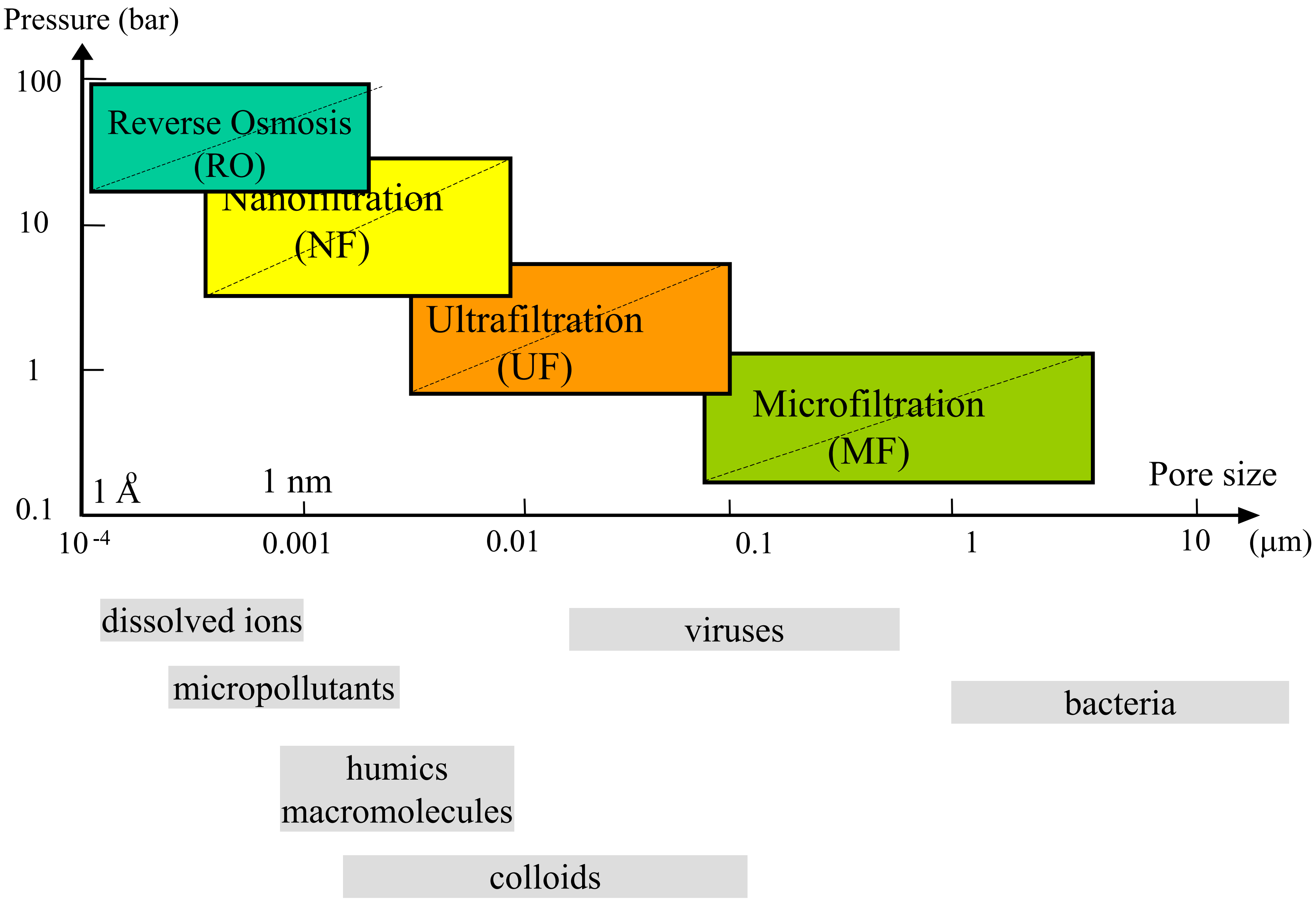
Membrane filtration processes



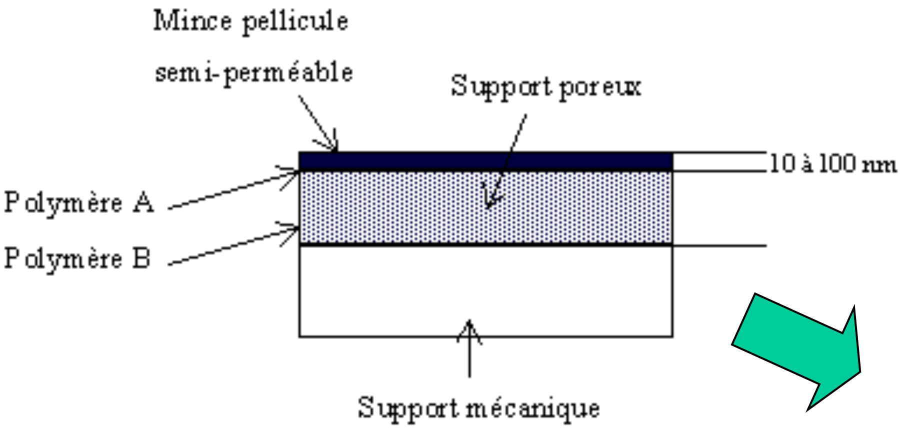
Porous membranes: pressure difference

Density solution-diffusion-membranes: electrochemical potential

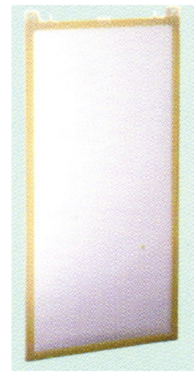
Membrane filtration processes



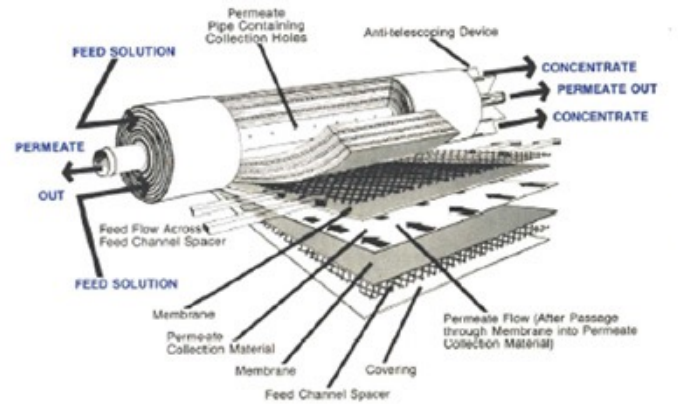
Polymers and membranes



Polymers



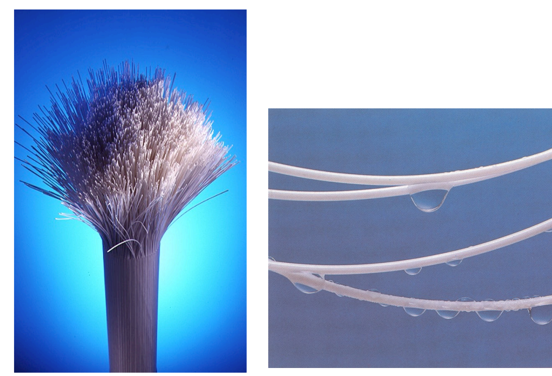
Planes



Spiral

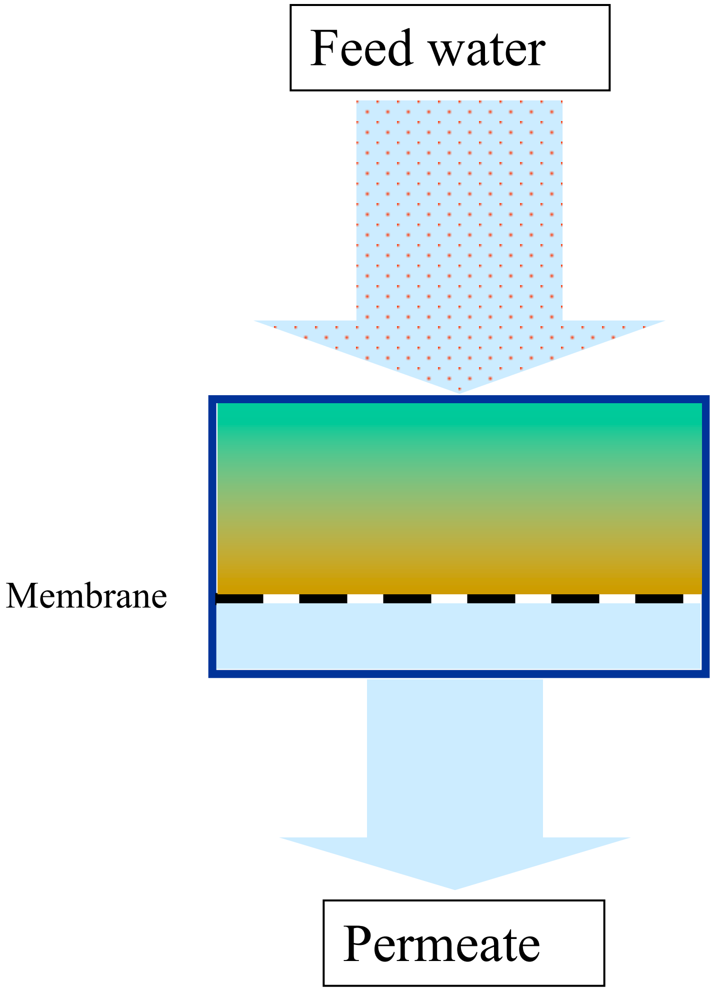
Tubes

Fibers



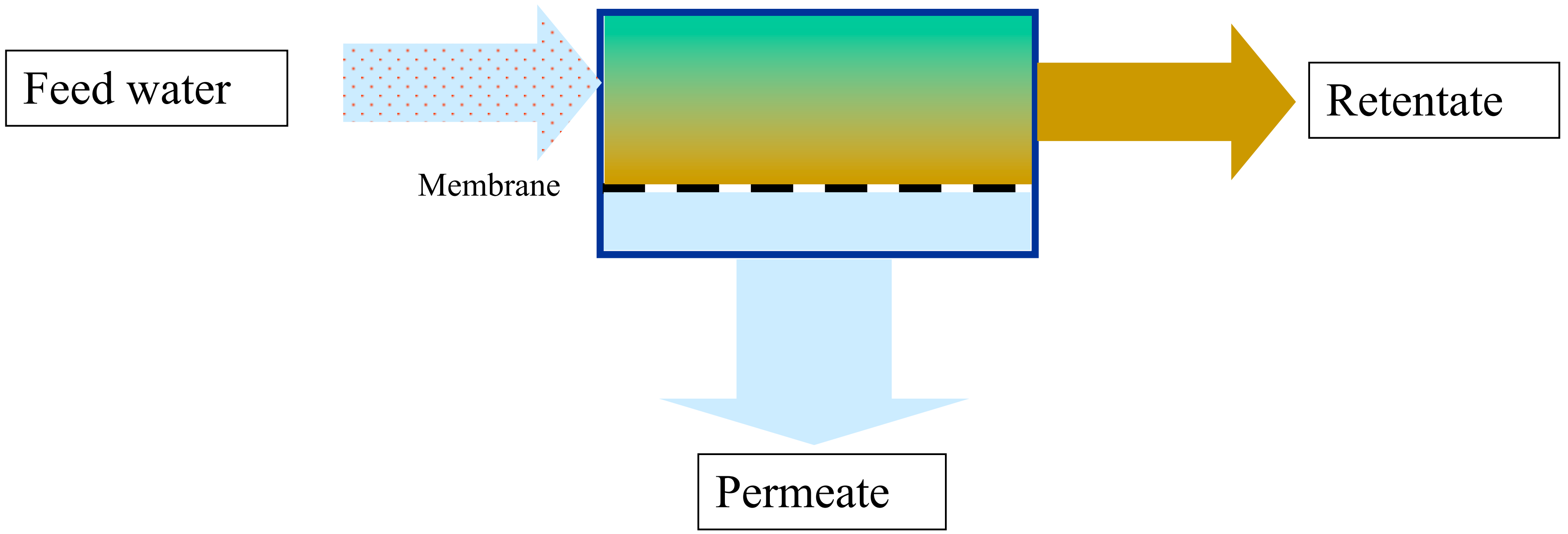
Membrane operation

„Dead-end“ operation



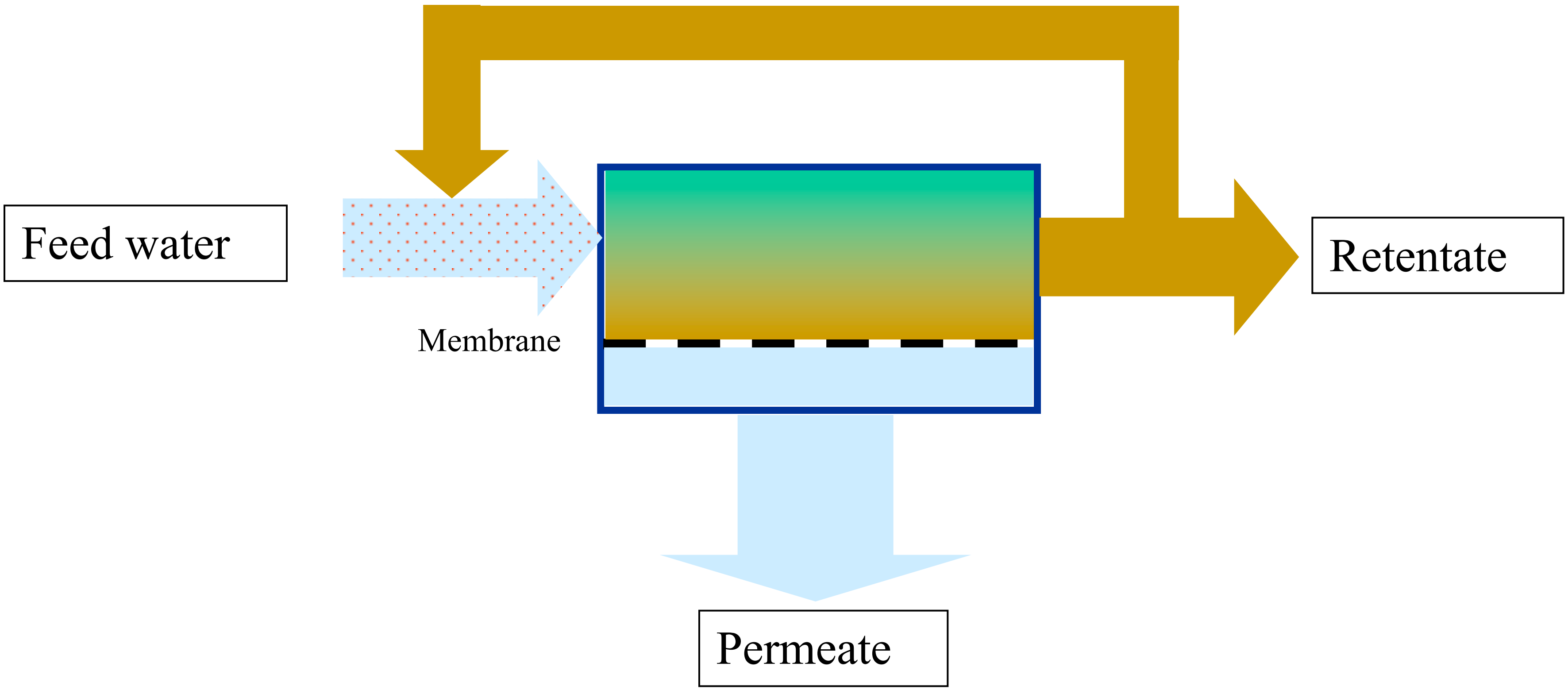
Membrane operation

„Cross-flow“ operation



Membrane operation

„Cross-flow“ operation with recirculation



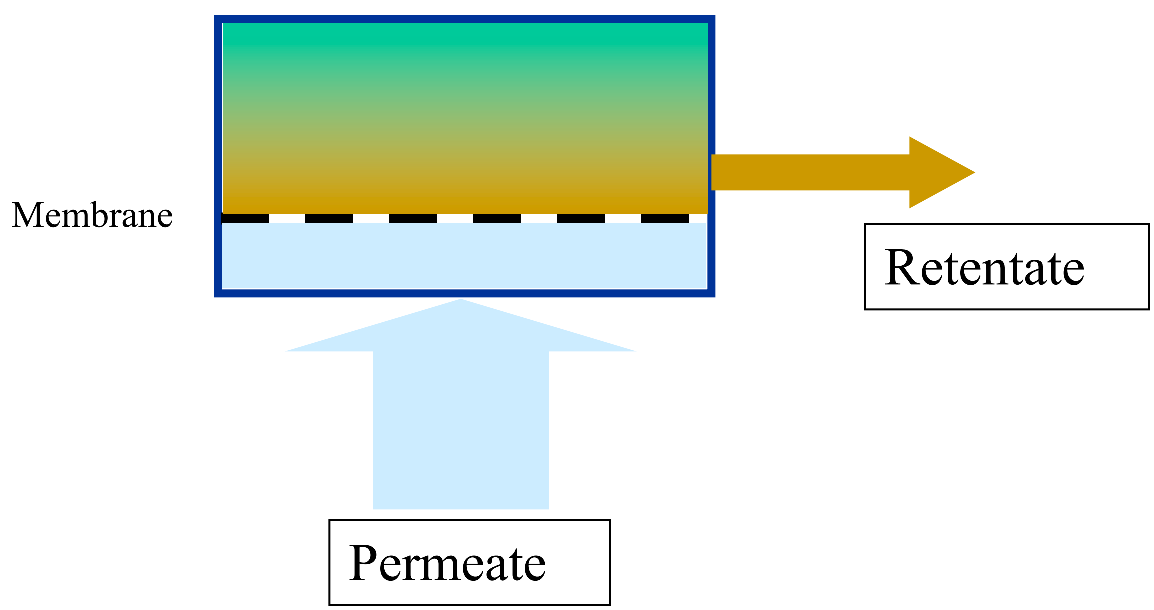
Turbulent conditions: - Reduce Fouling

- Reduce concentration polarization

Re > 2000 (> 2 m/s in spiral wound modules)

Membrane operation

Dead-end combined with intermittant backflushing



Membrane operation: Cross-flow or dead-end?

Cross flow:

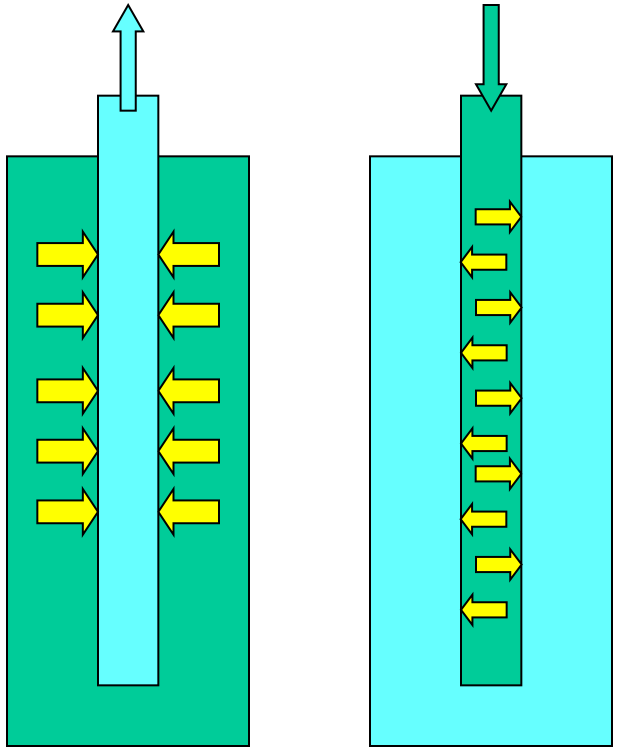
+ Decrease membrane fouling
+ Decrease concentration polarization

But:

- Increased energy consumption
- Higher investments (pumps, tubing etc.)

Today: mostly dead end filtration with back flushing

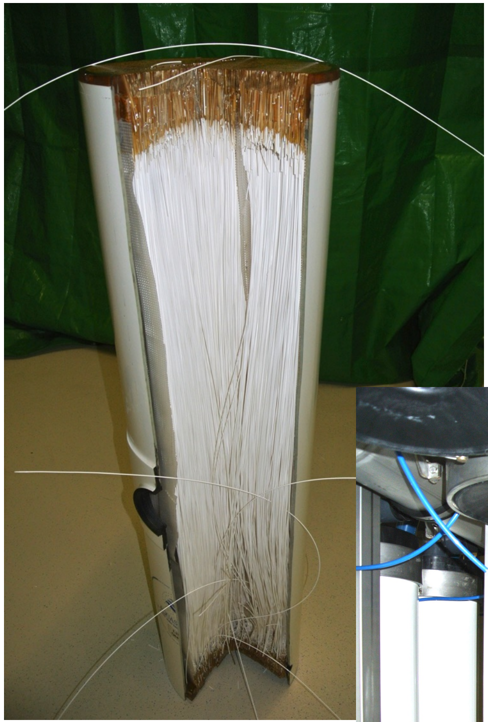
Submerged membranes



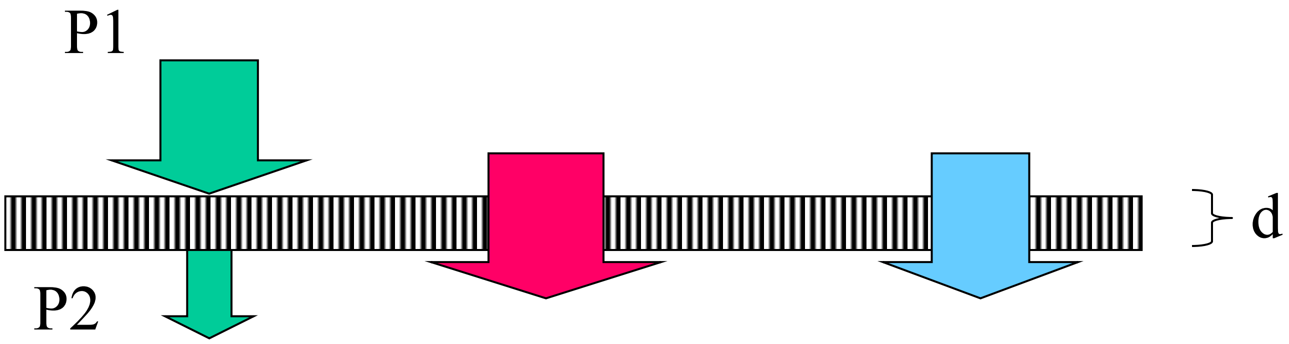
Outside-in   Inside-out

ZENON GmbH, Nikolaus-Otto-Str. 4, D-40721 Hilden,
Tel. +49/2103/5703-0, Fax. +49/2103/989850

Drinking water treatment plant Lausanne, Lutry



Definitions



Transmembrane pressure
TMP=P1-P2
[bar]

Flux

J=dV/dt/A

[l/h/m^2]

Permeability
Q = J/(TMP)
[l/m^2/h/bar]

Permeance = ratio between permeability and membrane thickness
P = Q/d [l/m^3/h/bar]

Definitions: Retention / Rejection

Retention / Rejection:

$$R_i = 1 - \frac{c_{i,p}}{c_{i,f}}$$

- R_i : Rejection of component [-]
- $c_{i,p}$: Concentration in permeate [mol/L]
- $c_{i,f}$: Concentration in feed [mol/L]

Bacteria / viruses: „Log removal (LR)“

$$LR = -\log \frac{c_{i,p}}{c_{i,f}}$$

Ultrafiltration / Microfiltration: Flux through membranes

$$J = \frac{\Delta P}{\mu \times R_m}$$

J = flux (m^3/m^2s^{-1})
ΔP = differential pressure across membrane ($kg\ s^{-2}m^{-1}$)
μ = dynamic viscosity of water ($kg\ m^{-1}s^{-1}$)
R_m = membrane resistance (m^{-1})

Temperature dependence:

$$J_{T1} = J_{T2}(1.03)^{T1-T2}$$

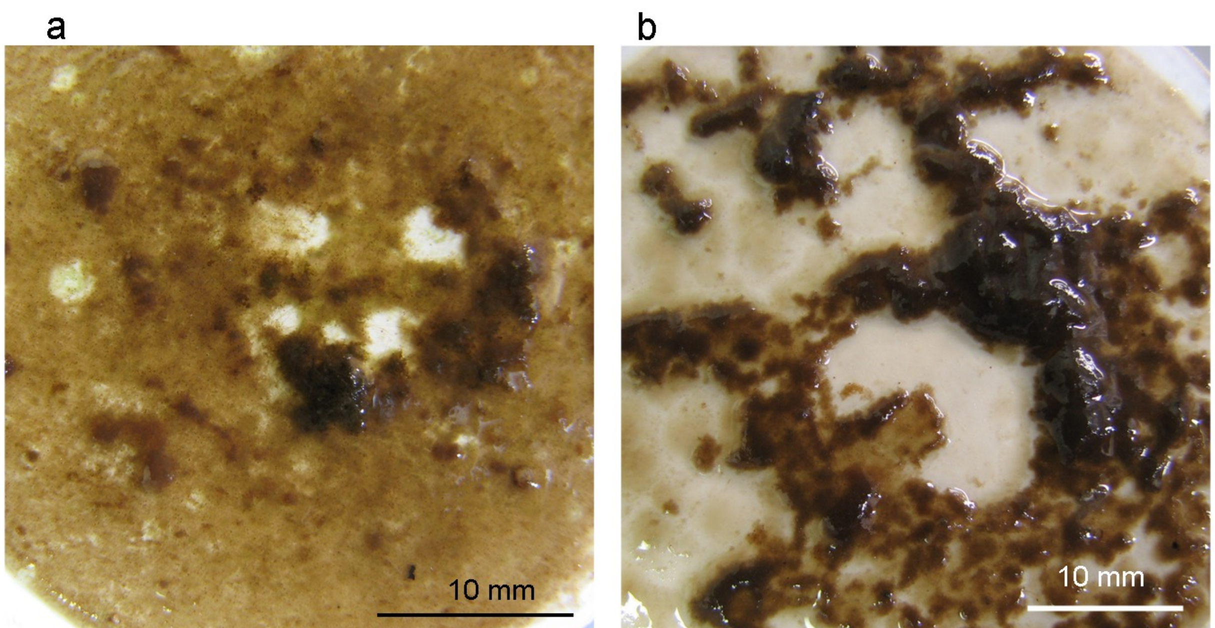
Increased flux at higher T

Membrane fouling and scaling

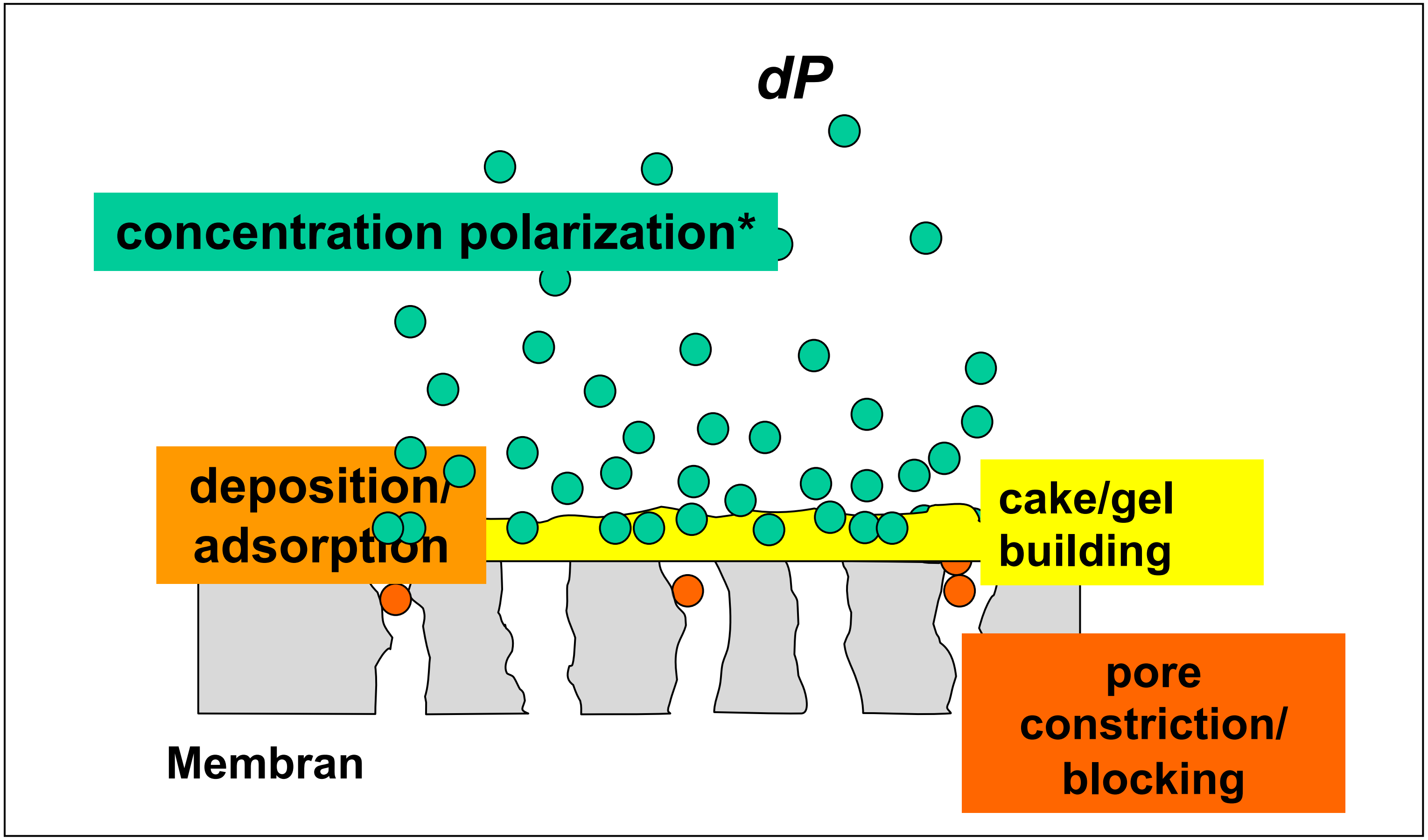
Fouling and scaling are the major limitations of membrane operation

Leads to higher pressures / lower flux:
- decreasing capacity per m^2
- increasing energy consumption

Caused by organic (fouling) and inorganic components (scaling) in the water, both by dissolved and particulate compounds



Membrane fouling



characteristic features: flux decline, reversibility, retention
*concentration gradient close to the membrane surface

Membrane scaling and fouling

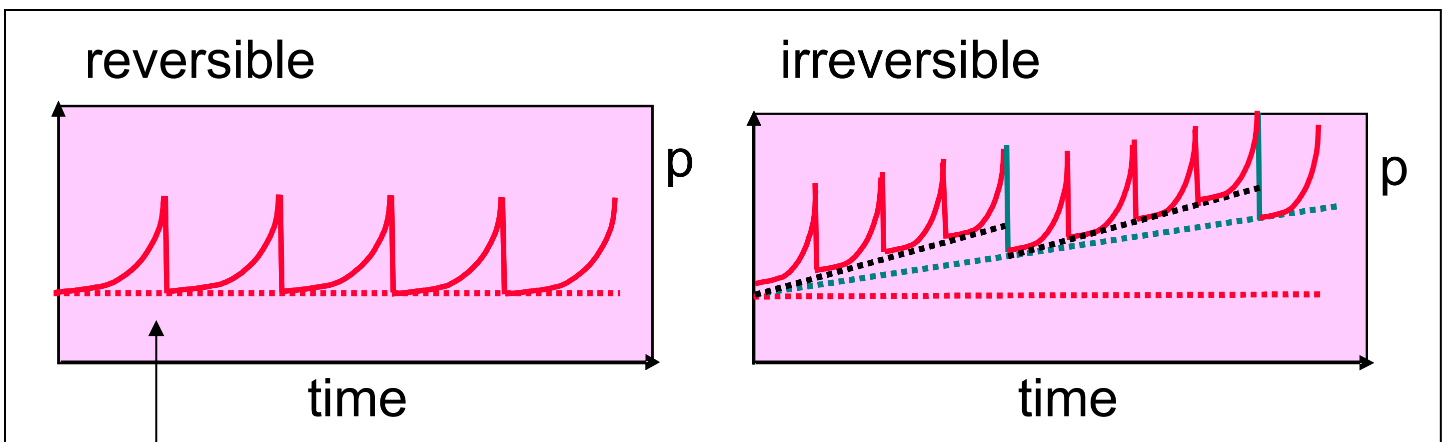
Scaling: precipitation of $CaCO_3$, $CaSO_4$

Fouling: deposition of NOM, biofilm formation

Permeability ↓; pressure & energy use ↑

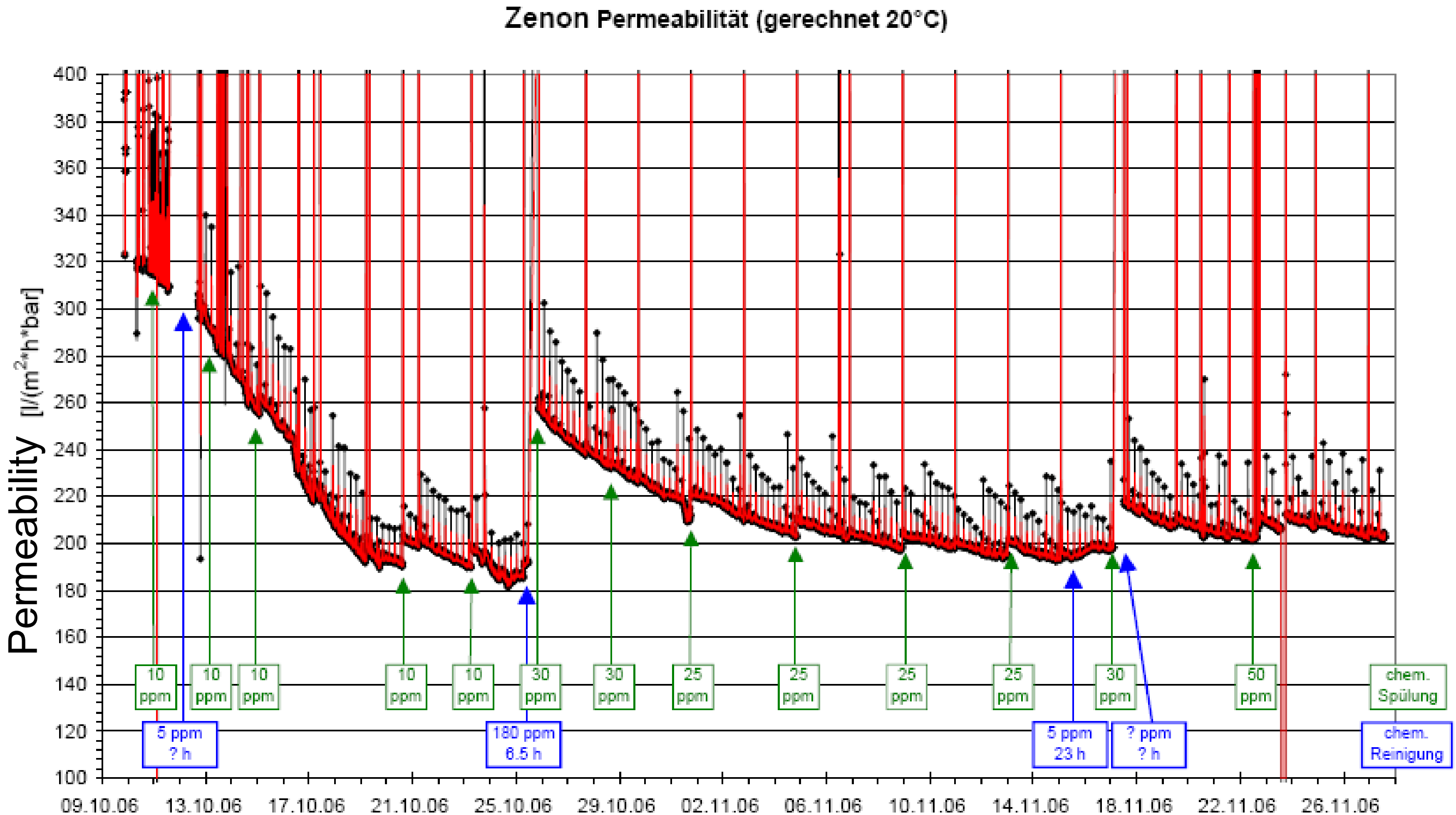
Backflushing and chemical cleaning (chlorine, acid/base, surfactants)

13.12



Cleaning step

Membrane fouling and cleaning in pilot-scale plant Lake Zurich water (O_3-GAC-UF)



Chemical flushing and cleaninng with chlorine

Membrane fouling: resistances in series

$$J = \frac{\Delta P}{\mu \times (R_m + R_C + R_A + R_{pr})}$$

R_m = membrane resistance
R_C = cake layer resistance
R_A = resistance due to adsorption
R_{pr} = resistance due to pore restriction

R_C: can be described by Carman Kozeny equation

(flow through granular media, compare headloss Forchheimer)

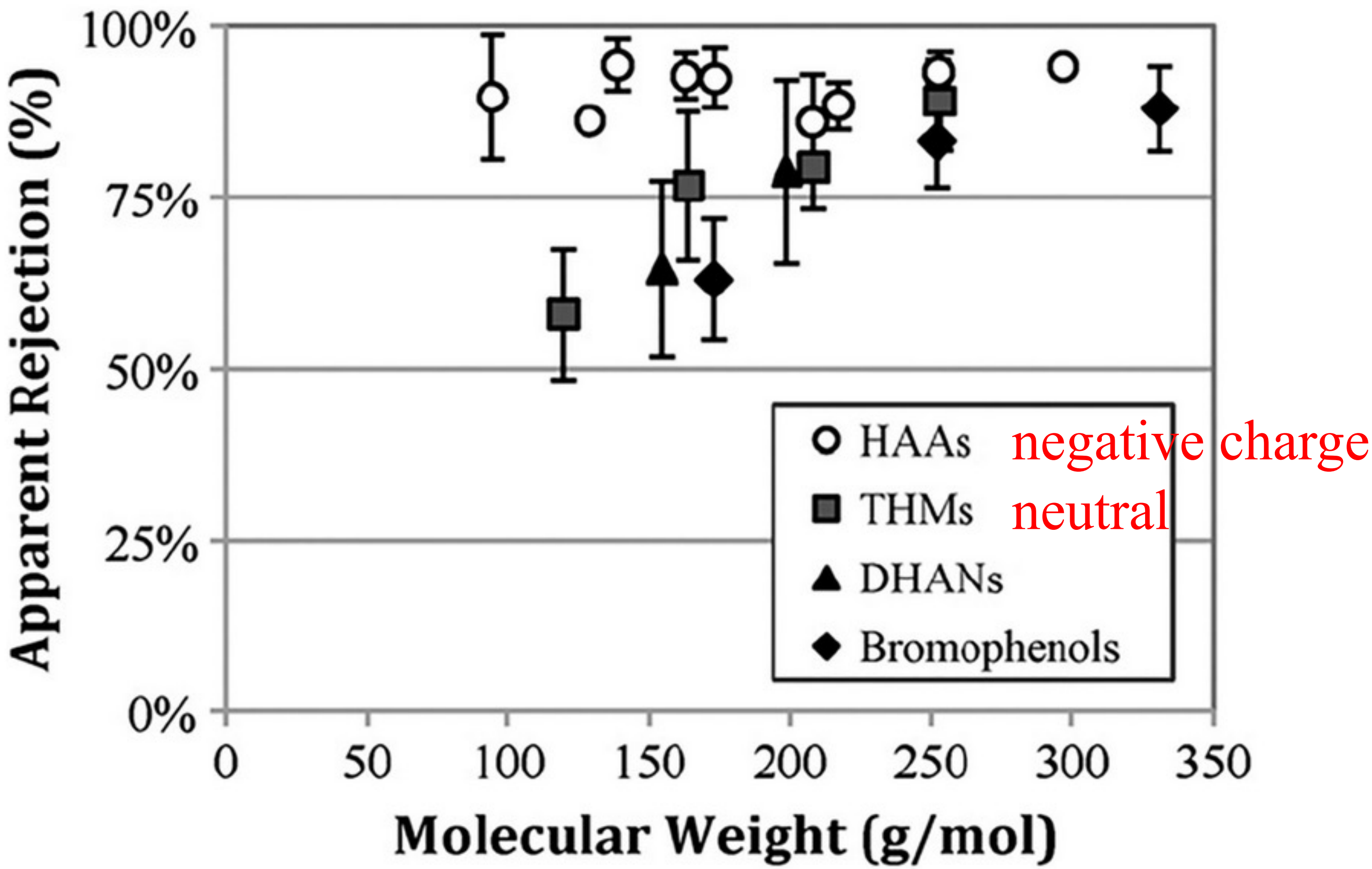
$$R_c = \frac{36 \times k_k (1-\varepsilon)^2 \delta_c}{\varepsilon^3 d_p{}^2}$$

k_k = Kozeny coefficient (-)
depending on particle geometry
(typically 5 for spherical particles)
ε = porosity (-)
δ_c = thickness of the fouling layer (m)
d_p = diameter of particles (m)

Important factors for the elimination of micropollutants by membranes

- Porous membranes only suited in combination with PAC (see lecture AC)
- Nanofiltration and reverse osmosis
- Molecular weight
- Charge
- Chemical interactions between molecules and membrane surface

Rejection of contaminants by reverse osmosis



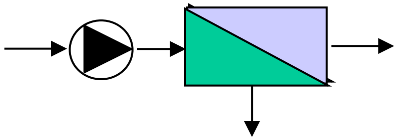
Marron et al. (2019) Accounts of Chemical Research ***52****(3): 615-622.*

Ultrafiltration

- Most commonly used membrane process in CH
- Mostly hollow fiber membranes
- MWCO ~ 100‘000 g/mole; Pore size ~ 10 nm
- Removal of viruses, bacteria and protozoa
- Clean water permeability: ca. 200 – 500 L/m^2/h/bar
- Mostly operated at low TMP (ca. 0.5 bar)
- No cross-flow (only dead-end)
- Many applications for drinking water and waste water treatment

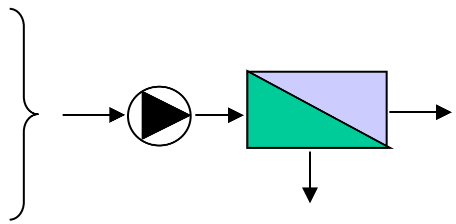
Membrane technology in drinking water treatment

1-step treatment



2-step treatment

PAC
Flocculation

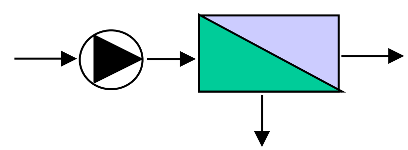


Disinfection

Multi-step treatment

Flocculation
Ozonation

Activated
Carbon
Filtration



Disinfection

Alternative treatment: Membrane as first treatment step (UF-O_3-AC-UV)

Conclusions

- Membranes are suitable treatment options for water treatment
  - Absolute barrier
  - Particle removal
  - Removal of microorganisms (viruses, bacteria, protozoa)
- Membrane fouling and scaling
  - Dissolved organic matter
  - Precipitation of minerals
  - Reduction of permeability
  - Cleaning required (back flushing, chemical cleaning)