Aalto University
School of Engineering

WAT-E2120 - Physical and Chemical Treatment of Water and Waste

Granular Media Filtration

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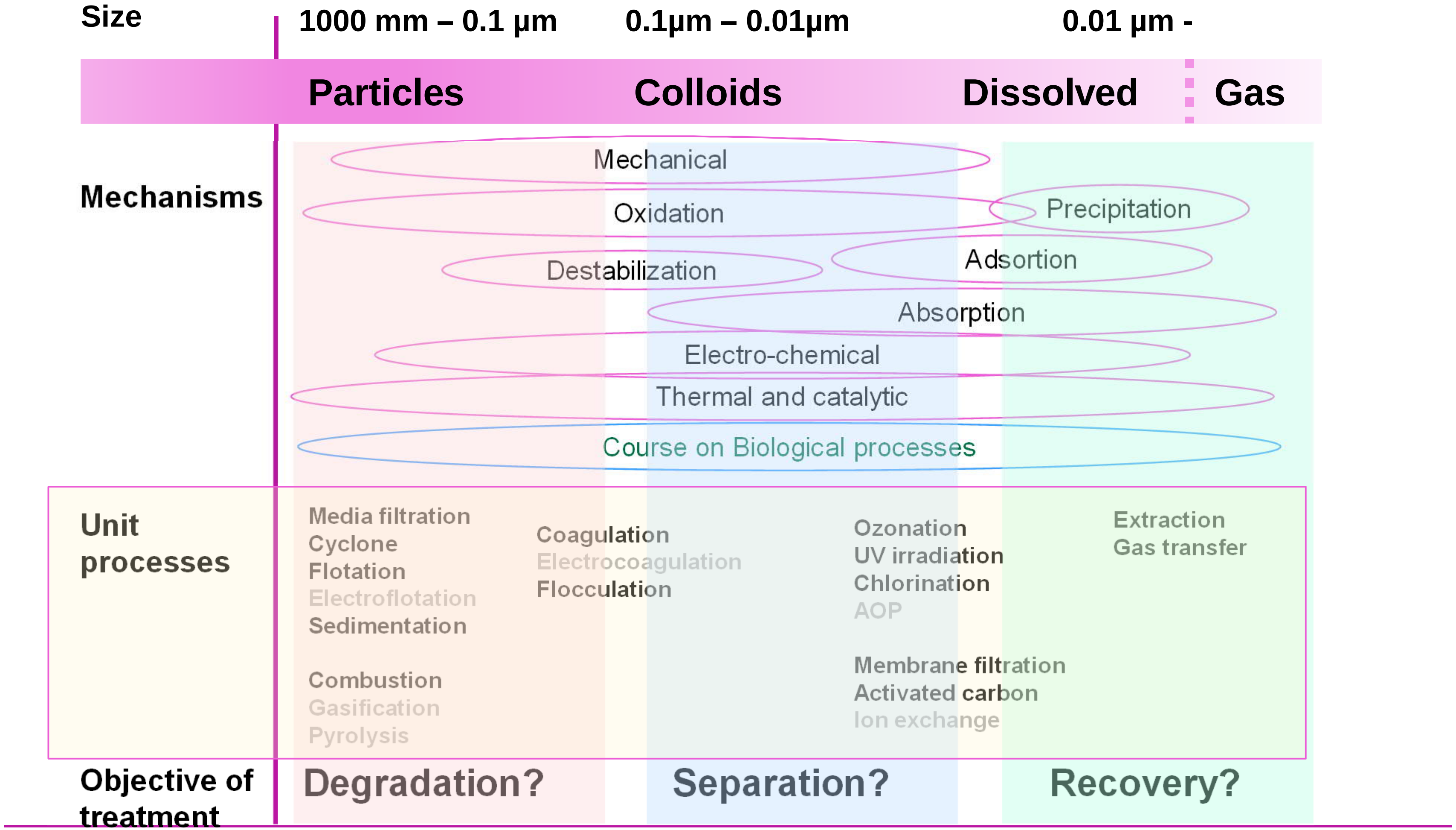
Content / Learning outcomes

- Filtration
  - Overview on media filtration
  - Removal and transport mechanisms in granular media filtration
  - Design and operating variables in granular media filtration
  - Cleaning of filters
  - Screening
- Excursion to Vanhakaupunki plant
- Group discussion: Objectives and focus of different treatment processes

- After the lesson you should
  - Know the principles of media filtration
  - Understand the variables affecting granular media filtration
  - Know what to ask in Vanhakaupunki



Size

1000 mm – 0.1 µm

0.1µm – 0.01µm

0.01 µm -

Particles

Colloids

Dissolved

Gas

Mechanisms

Mechanical

Oxidation

Precipitation

Destabilization

Adsortion

Absorption

Electro-chemical

Thermal and catalytic

Course on Biological processes

Unit processes

Media filtration
Cyclone
Flotation
Electroflotation
Sedimentation

Combustion
Gasification
Pyrolysis

Coagulation
Electrocoagulation
Flocculation

Ozonation
UV irradiation
Chlorination
AOP

Membrane filtration
Activated carbon
Ion exchange

Extraction
Gas transfer

Objective of treatment

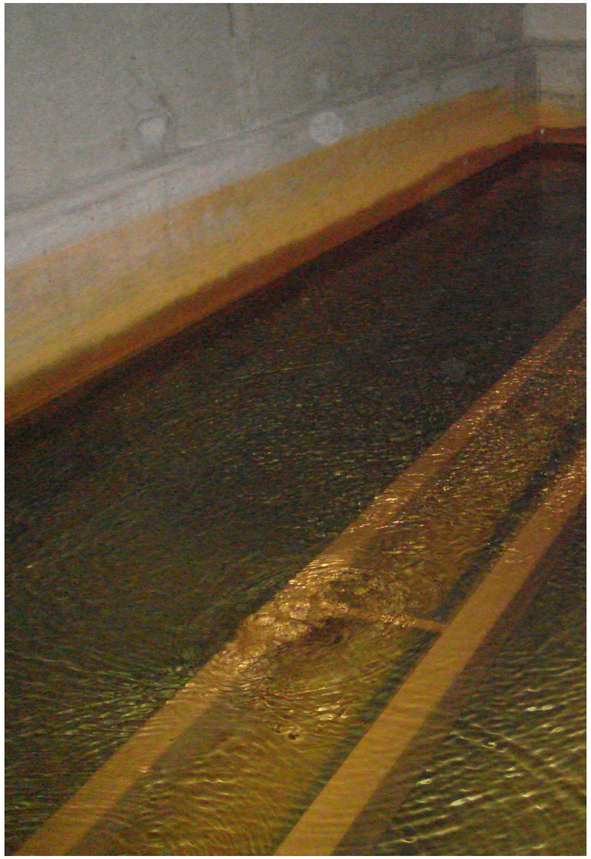
Degradation?

Separation?

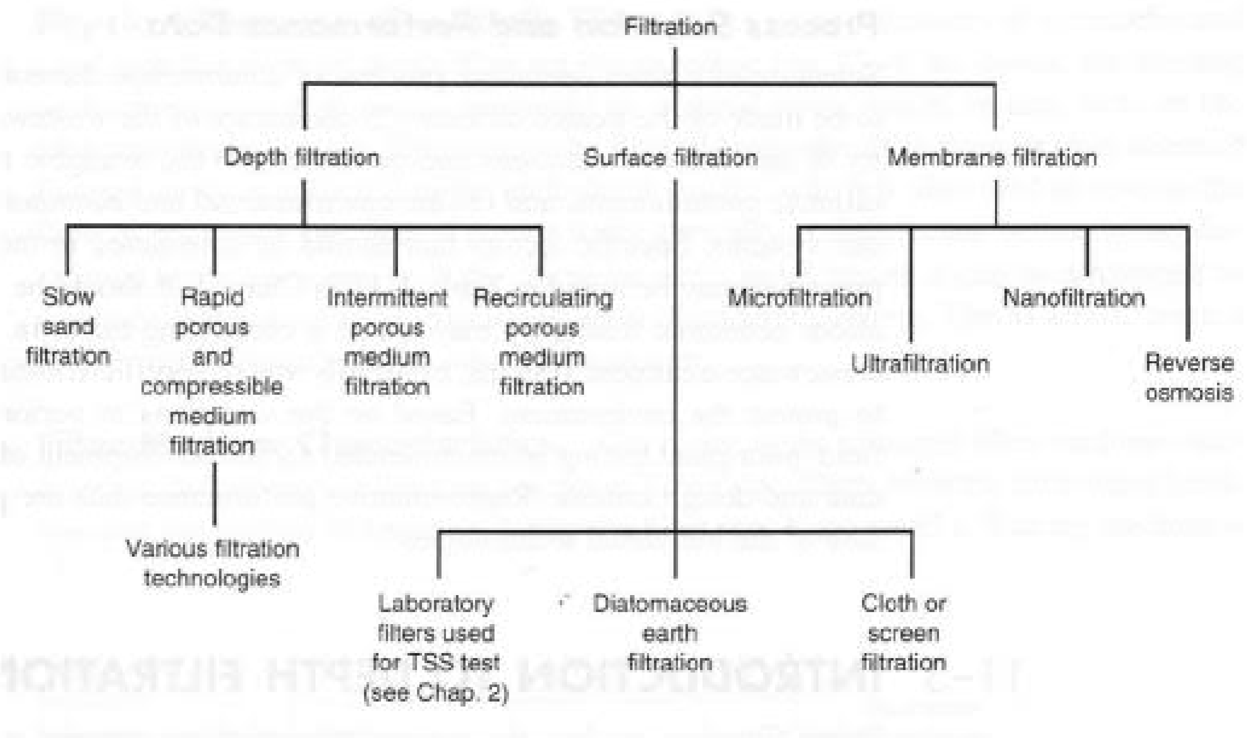
Recovery?

Filtration

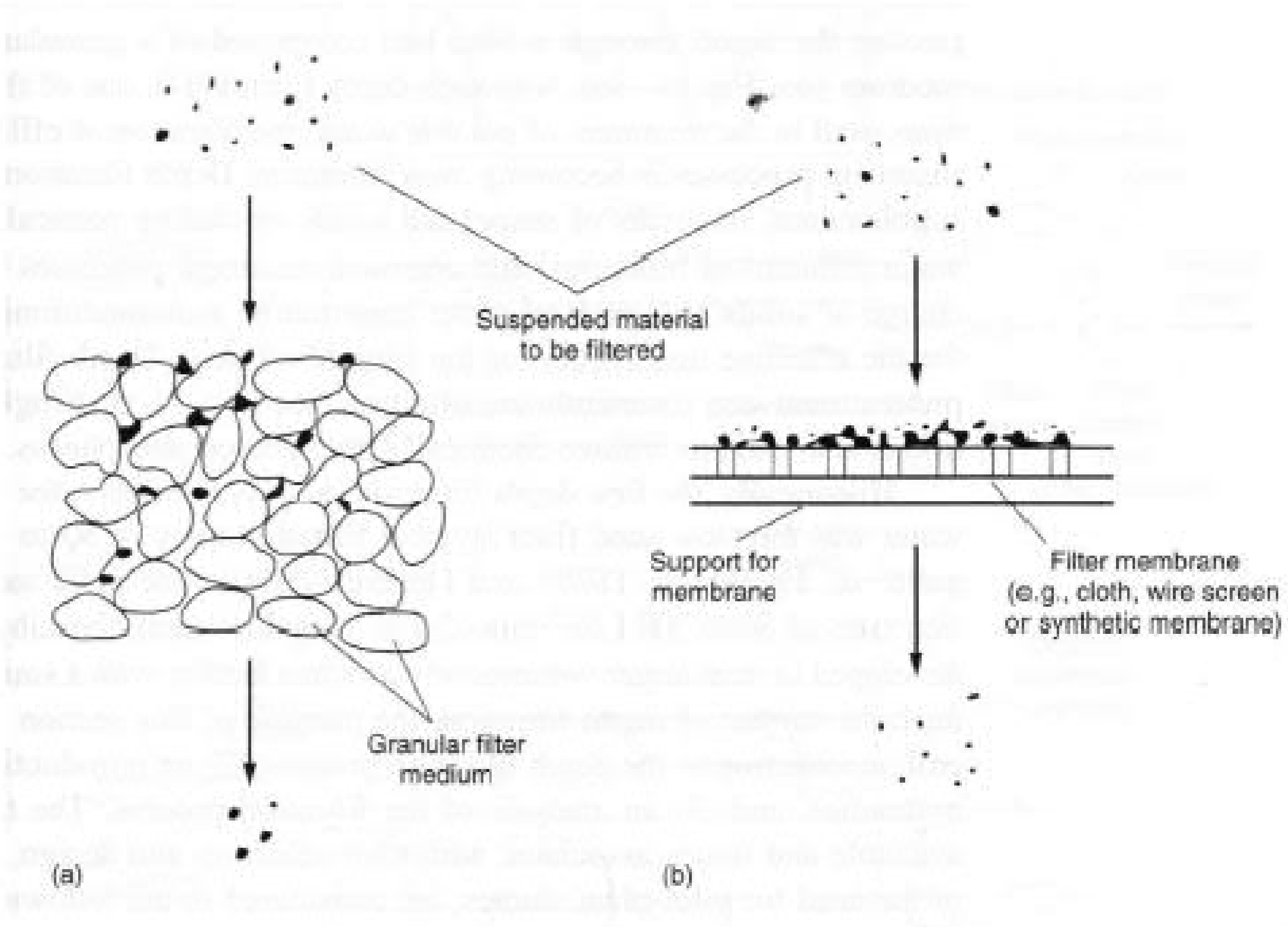
- **Filtration processes primarily remove particulate, colloidal and suspended matter by passing water through a layer or bed of a porous material.**
- **Typical applications for removal of clay, silt, microbes, colloidal organic particulates and precipitates:**
  - after sedimentation/flocculation or direct filtration after flocculation to remove remaining flocs and fine particles (rapid filtration),
  - as a polishing step for DW before final disinfection (slow sand filtration)
  - as a tertiary WW treatment step before discharge



Filtration theory



LÄHDE: Tchopanoglous Figure 11-2



LÄHDE: Tchopanoglous Figure 11-3

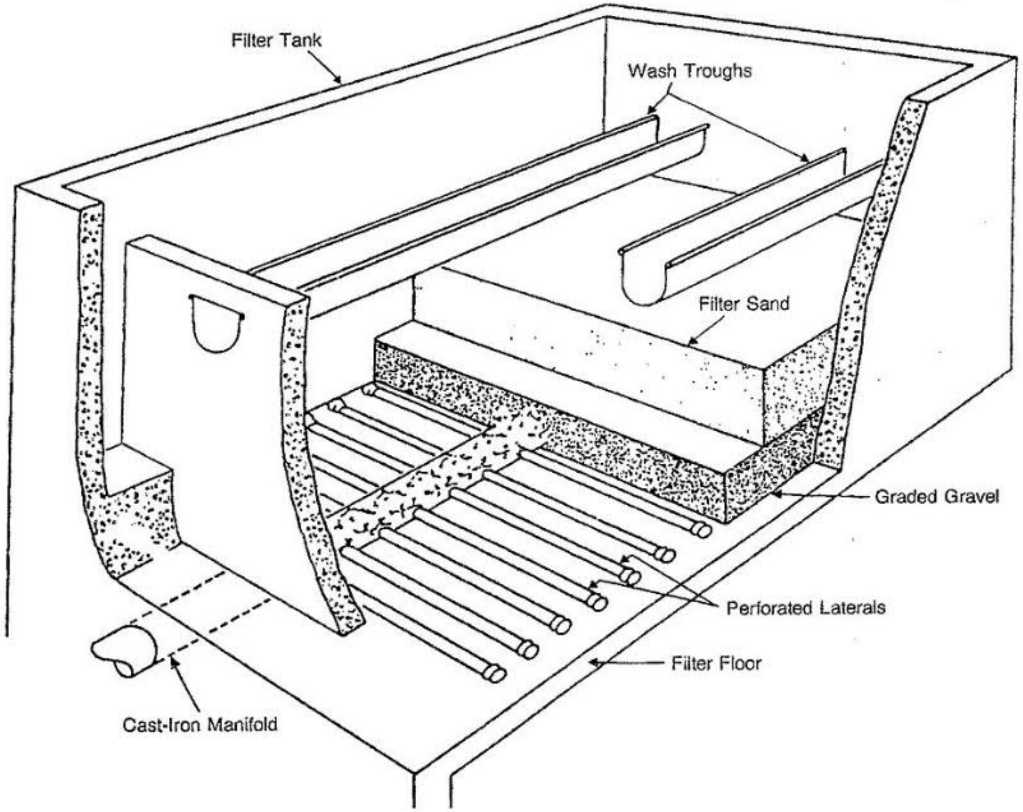
Classification of filters

Advantages of the dual or multi media filters?

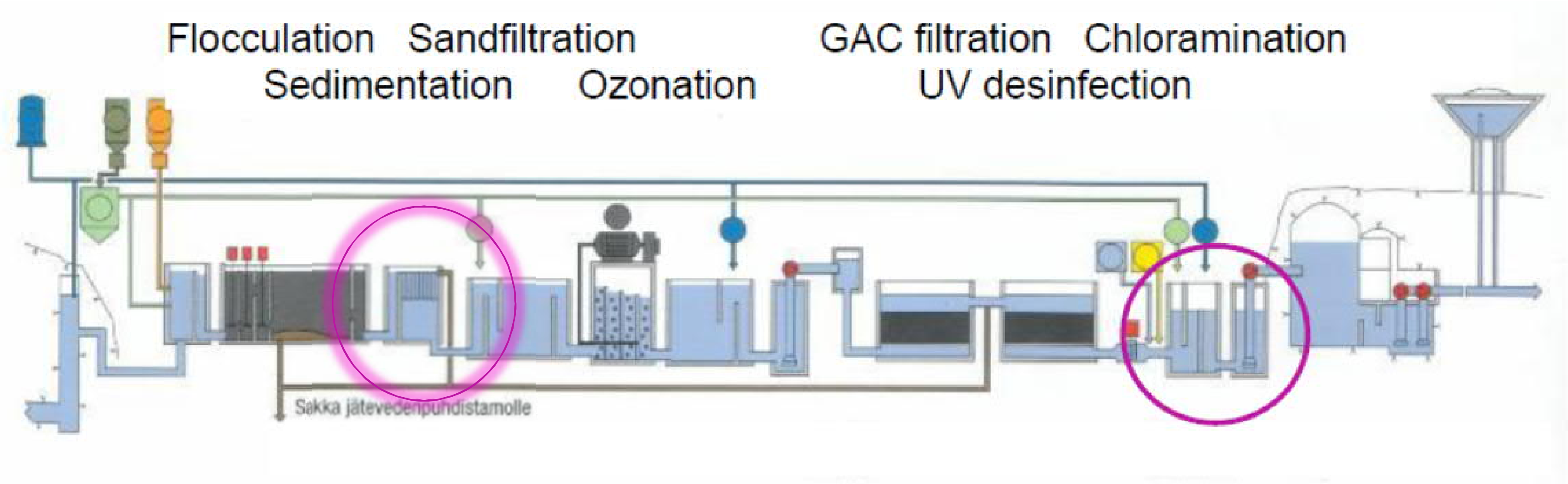
- **According to type of granular media used**
  - single medium (e.g. sand or anthracite)
  - dual media (e.g. anthracite and sand; sand and limestone)
  - multi media (e.g. anthracite, sand, garnet)
- **According to flow through medium**
  - Gravity filters are open to the atmosphere and flow through the medium is achieved by gravity
  - In pressure filters filter media is contained in pressure vessel and water is delivered to the vessel under pressure
  - Slow sand filtration usually involves biological removal

Gravity-driven granular media filter

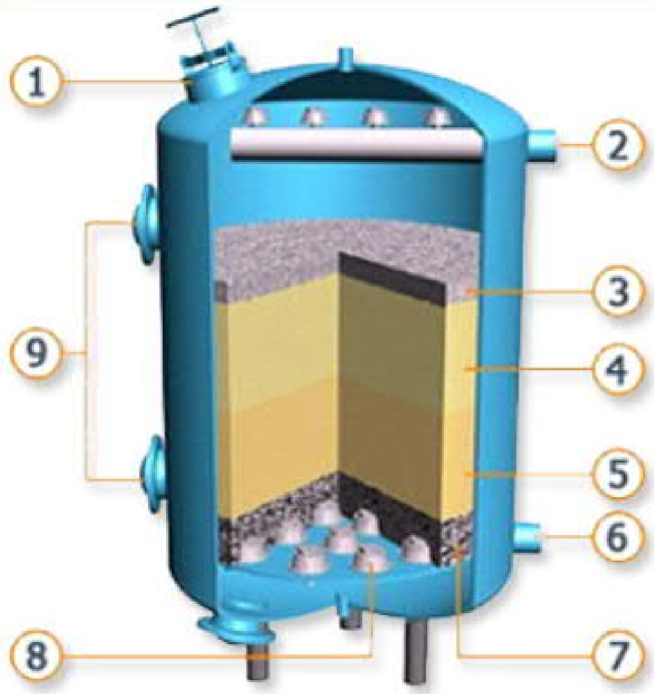
- **Rapid granular media filtration is the most common application in water treatment.**
- **Filtration rate (flow rate per cross-sectional surface area) typically 3-30 m/h in rapid filtration**
- **Two modes of operation**
  - Filtration
  - Backwash



Rapid sand filtration in HSY’s DW process



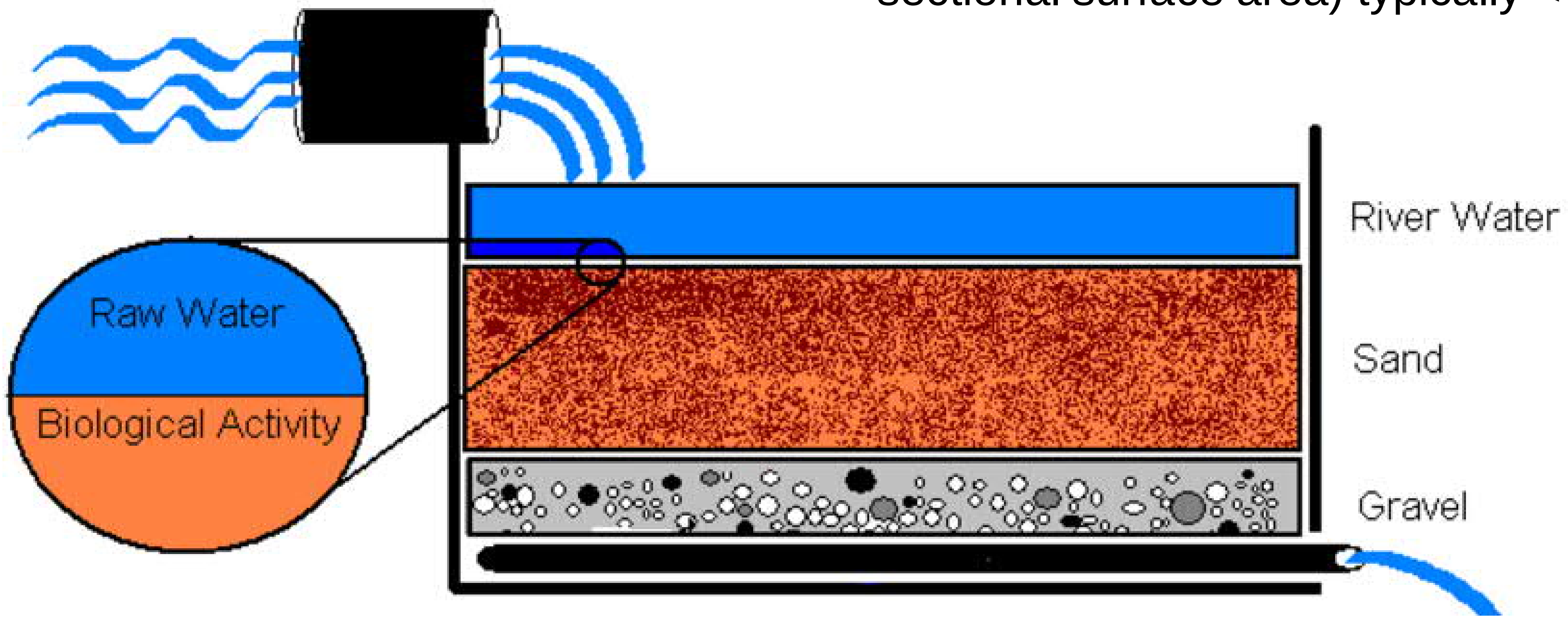
Pressure filter



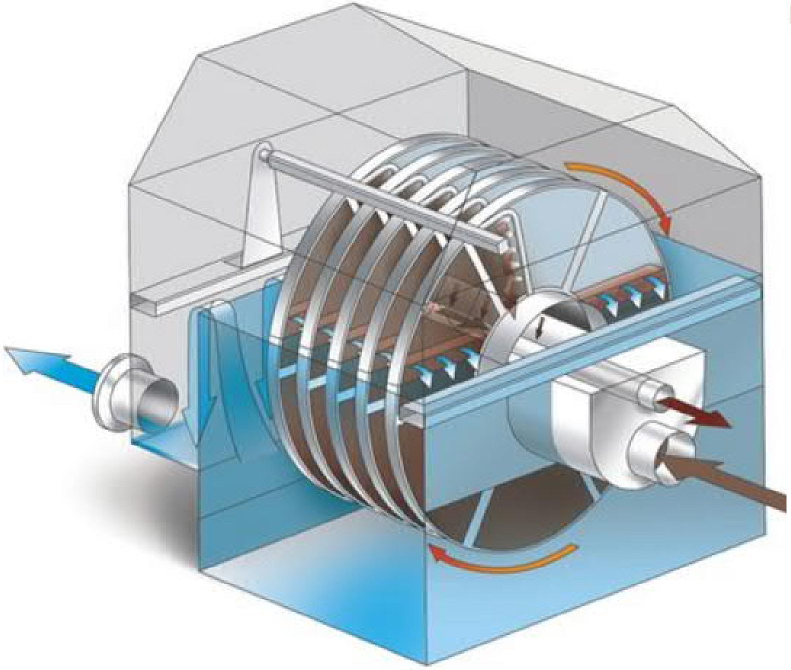
1. Upper Service Hole
2. Filter Inlet
3. Anthracite Layer
4. Fine Sand Layer
5. Coarse Sand Layer
6. Filter Outlet
7. Gravel Support Layer
8. Filter Element
9. Side Service Hole

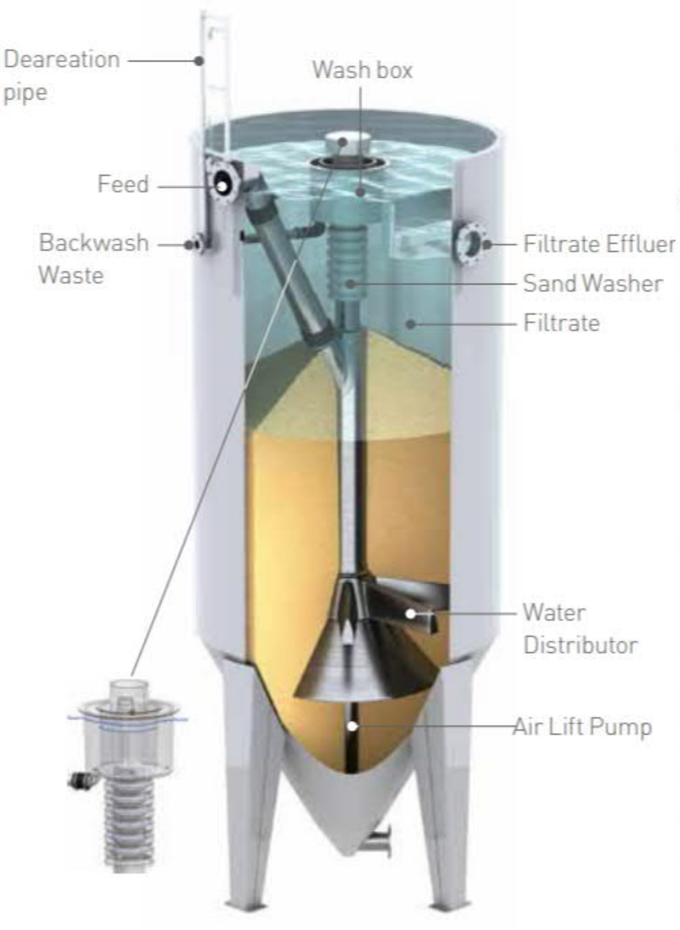
Slow sand filtration

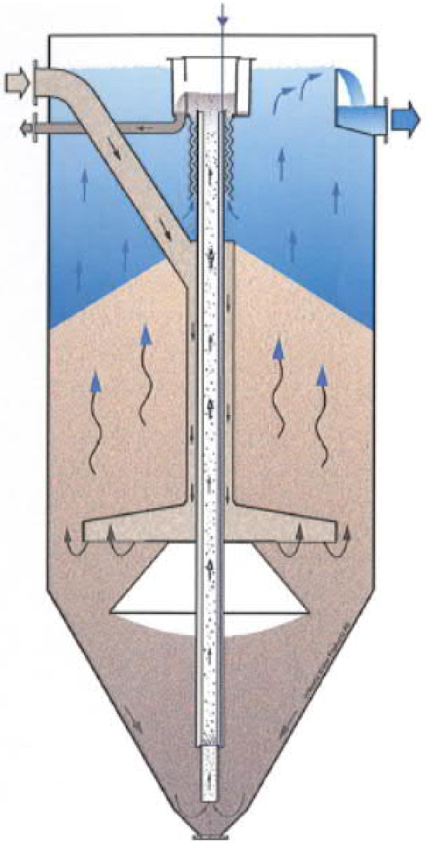
- Filtration rate (flow rate per cross-sectional surface area) typically < 2 m/h



Disc filter and continuous sand filter







Filter Media Properties

- **Size (effective size)**
  - Affects removal efficiency and headloss
- **Size distribution (uniformity)**
  - Affects utilisation of bed capacity and media stratification
- **Density**
  - Affects backwash flow velocity
- **Shape (sphericity)**
  - Affects removal efficiency, headloss, backwash flow velocity, fixed bed porosity
- **Porosity (fixed bed and loose bed)**
- **Depth**
- **Surface chemistry**

Filter media properties

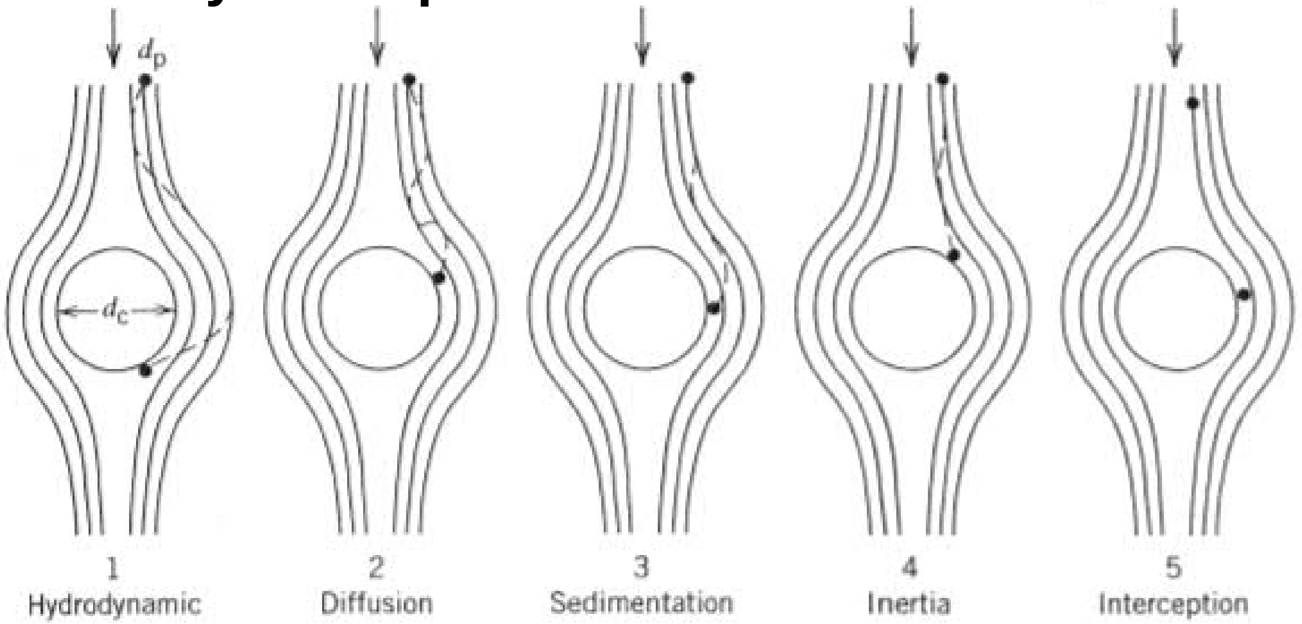
- **Effective size of the filter media d_{10}**
  - The effective size of the media is the diameter that 10% of the filter media is less than this size.
- **Uniformity coefficient of the filter media d_{60}/d_{10}**
  - d_{60} = sieve size that passes 60% by weight
  - d_{10} = sieve size that passes 10% by weight
- **Another important sieve size is d_{90} that is used to calculate the backwash velocity.**
- **d_{10} d_{60} and d_{90} are found by sieve analysis of the media to be used in the filter.**

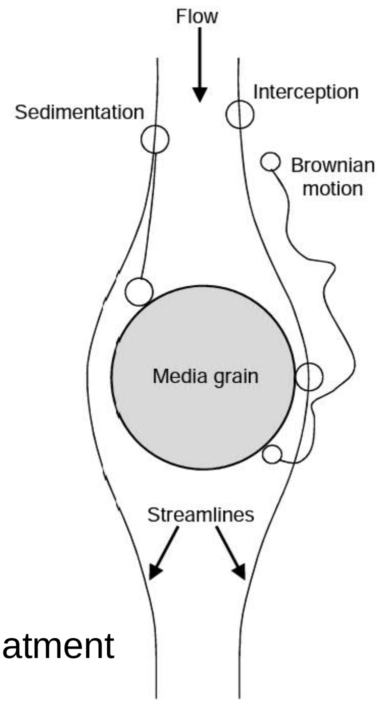
Removal Mechanisms in Filtration

- **The transport brings small particles from the bulk solution to the surface of the media by**
  - gravitational settling,
  - diffusion,
  - interception and
  - hydrodynamics.
- **At the surface of the filter media, an attachment mechanism is required to retain the particles**
  - electrostatic interactions
  - chemical bridging
  - adsorption
  - destabilisation of influent particles affects the attachment

Mechanism of Filtration

- **Transport is affected by physical characteristics such as size of the filter medium, filtration rate, fluid temperature, size and density of suspended solids.**

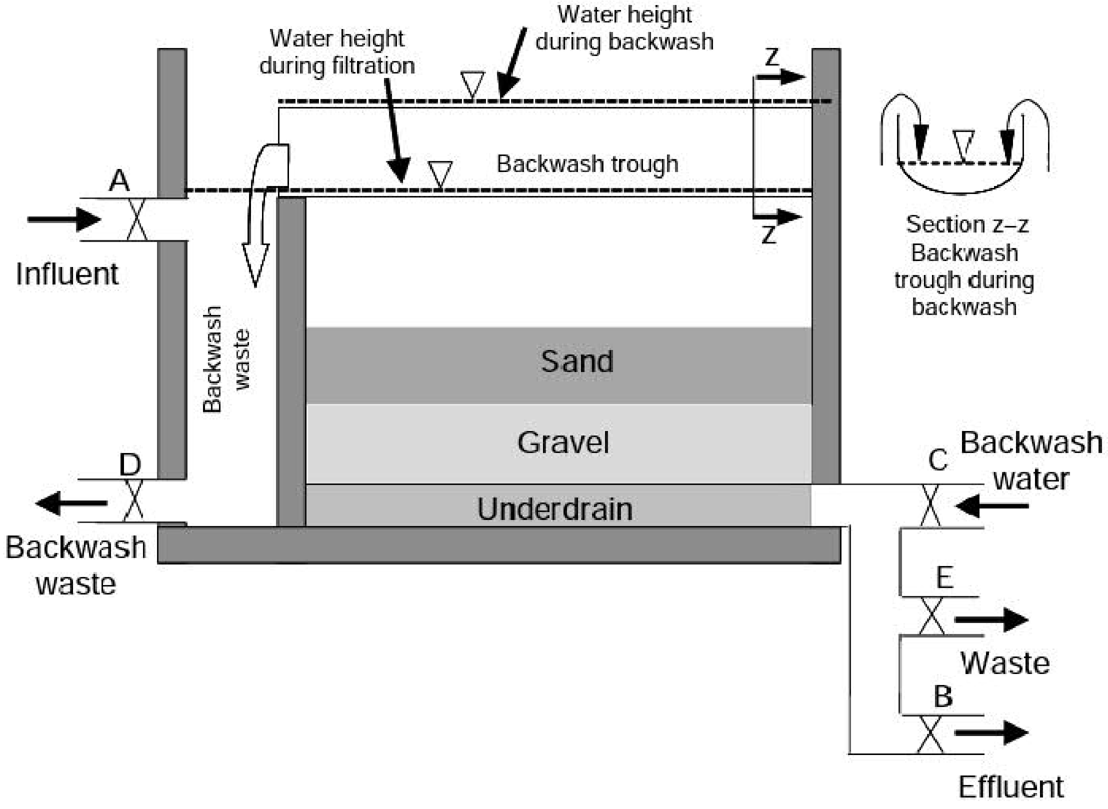




Main Removal Mechanisms in Filtration

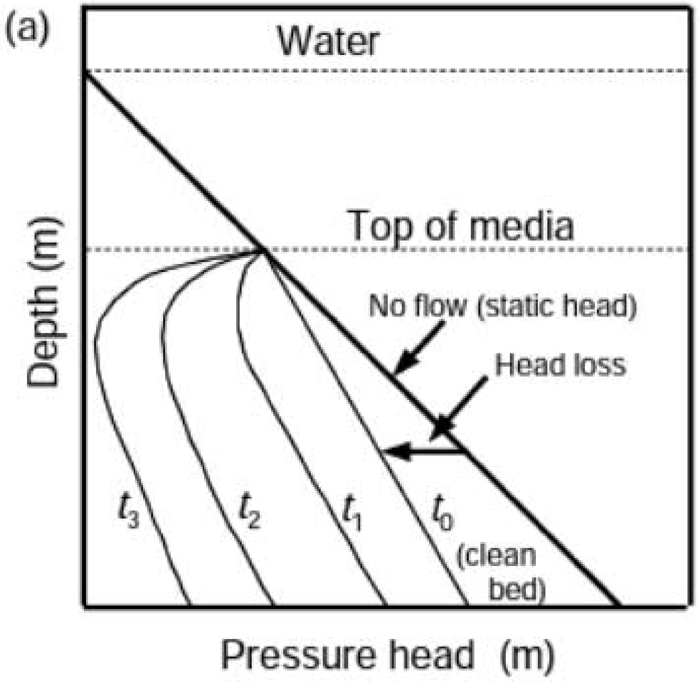
	Rapid sand filtration	Slow sand filtration
Straining at the surface		x
Sedimentation	x	
Interception	x	
Cake formation		x
Adhesion and adsorption to the grains	x	
Microbial activity		x

Gravity-driven granular media filter



- Operational monitoring
  - Water level
  - Effluent flow
  - Time between backwash
  - Filtrate turbidity

Head loss = potential energy lost as the water passes through the filter = the difference between the pressure heads under static and flow conditions at this depth = energy expended per unit volume of water to pass the water through the filter



- In a filter with no flow (static conditions), the pressure head increases linearly with depth.
- If the clean media bed has uniform characteristics, the change in pressure head through the clean bed is linear, but the slope is less than above the bed, because energy is expended to overcome the friction between the water and the grains.
- Captured particles increase the head loss because they provide additional surface and therefore increase the frictional resistance to water flow and because they reduce the available pore volume for the flow.

Calculation of headloss, h_L

The Carman–Kozeny equation is the fundamental equation describing the head loss in a clean filter bed as a function of properties of the fluid, properties of the media, and design and operating variables.

$$\frac{h_L}{Z} = k \frac{\mu}{\rho_L g} \frac{(1-\varepsilon)^2}{\varepsilon^3} S_0^2 v_0 \qquad (14\text{-}59)$$

where

Z	full length of the bed
k	empirical constant, generally 5
μ	viscosity of water
ε	porosity
ρ_L	density of water
g	gravitational constant
S_0	surface area per unit volume of bed = shape factor/grain diameter
v_0	superficial velocity, filtration rate = flow rate onto filter surface / surface area of filter

Example 1, Headloss calculation

Calculate the headloss for a dual media filter composed of 0,3 m anthracite (mean size of 1,5 mm) above a 0,6 m layer of sand (mean size of 0,5 mm) at a filtration rate of 10 m/h and a water temperature of 10 ^{o}C. Assume shape factor of 7,5 and a porosity of 0,40 for both media.

$$h_L = k \frac{\mu}{\rho_L g} \frac{(1-\varepsilon)^2}{\varepsilon^3} S_0^2 v_0 Z$$

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Calculate the head loss for a dual media filter composed of 0,3 m anthracite (mean size of 1,5 mm) above a 0,6 m layer of sand (mean size of 0,5 mm) at a filtration rate of 10 m/h and a water temperature of 10 °C. Assume shape factor of 7,5 and a porosity of 0,40 for both media.

Calculate the head loss separately for both media and sum up.

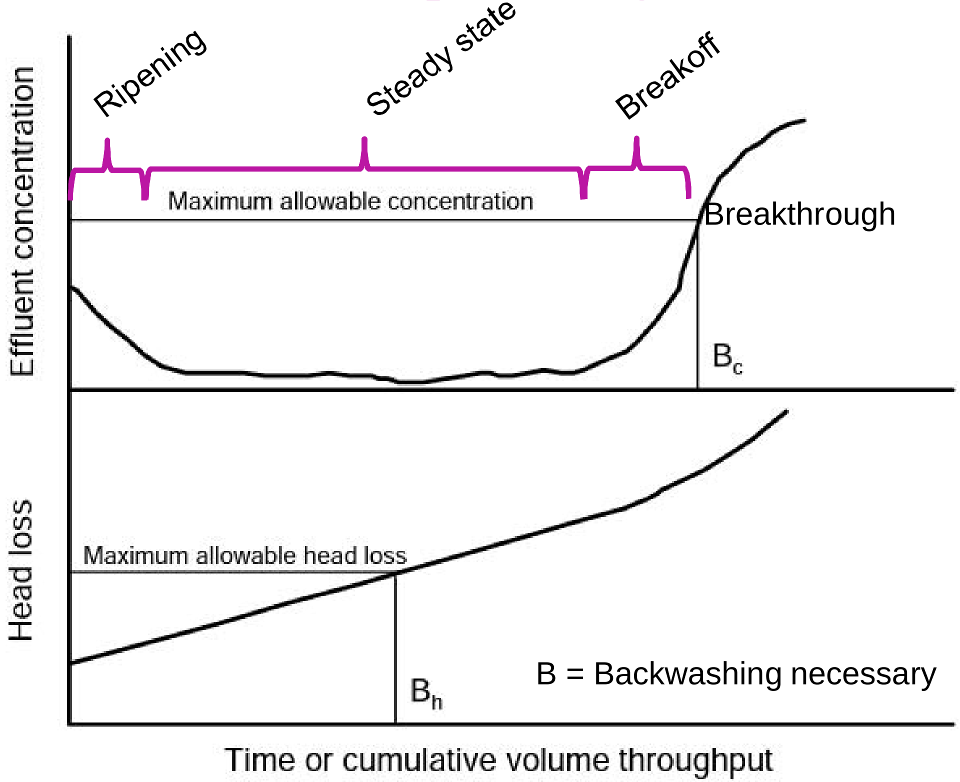
$$h_L = k \frac{\mu}{\rho_L g} \frac{(1-\varepsilon)^2}{\varepsilon^3} S_0^2 v_0 Z$$

k = 5
μ = 13,08 * 10^{-3} g/cm.s (at 10 °C)
ε = 0,40
ρ_L = 0,999 g/cm^3
g = 981 cm/s^2
S_0 = 7,5/0,15 cm; 7,5/0,05 cm
v_0 = 0,28 cm/s
Z = 30 cm; 60 cm

Homework 1

Filter run / filter performance – effluent quality and head loss

Operational monitoring of a filter?



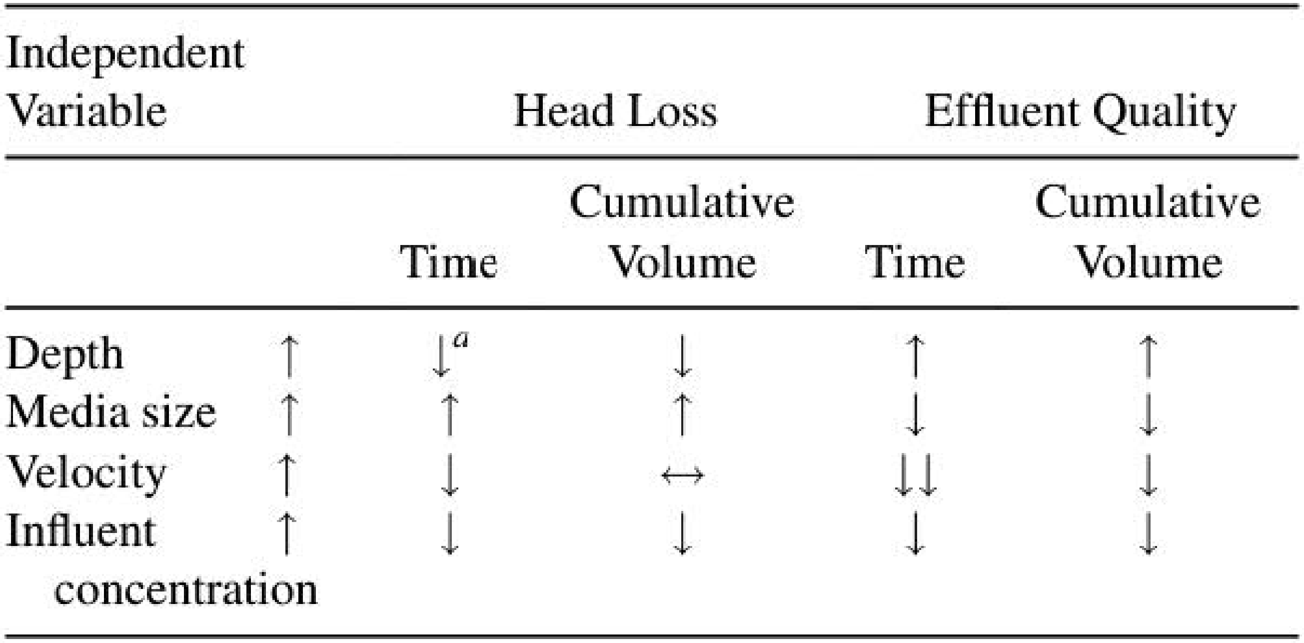
- Head loss should increase slowly enough that the filter can operate until a high normalized production is achieved
- Effluent should be of sufficient quality in the early part of a run that little or no water needs to be wasted or recycled before meeting the effluent guidelines.
- Effluent should meet water quality guidelines over a long time period and steadily.
- The head loss criterion should be met sooner than the water quality criterion in drinking water applications to guarantee required effluent quality.

Effects of Operating Variables on Length of Filter Run

depth, increased collection

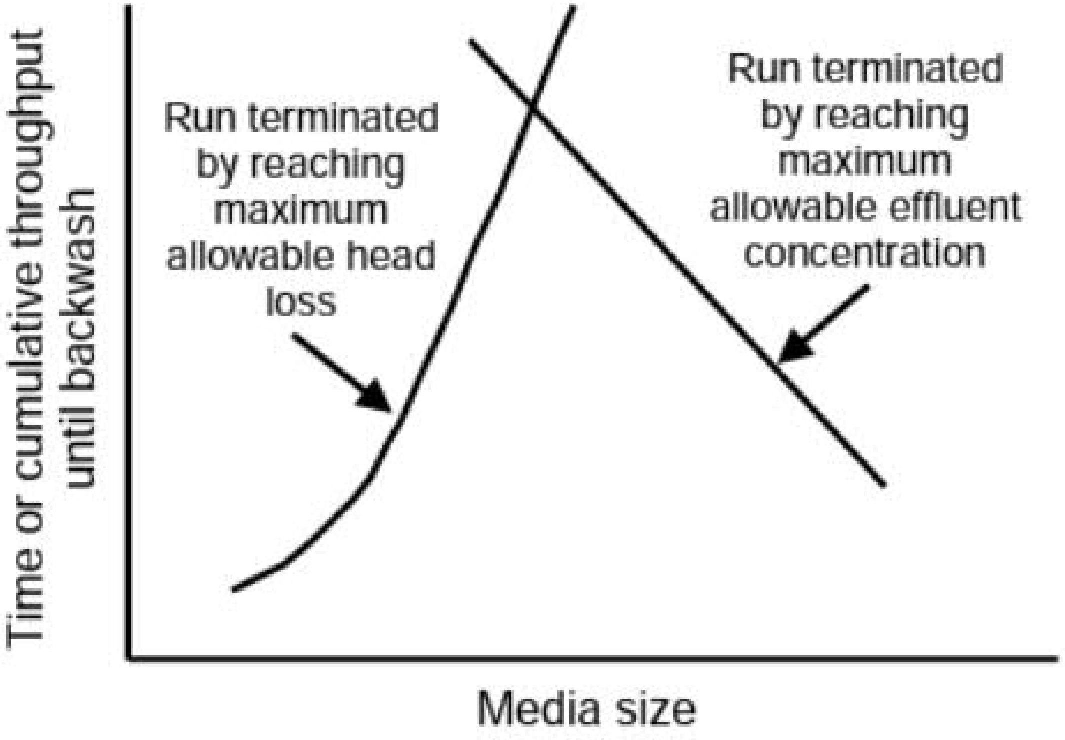
less friction, reduced collection

velocity, more particles enter, reduced collection, higher breakoff



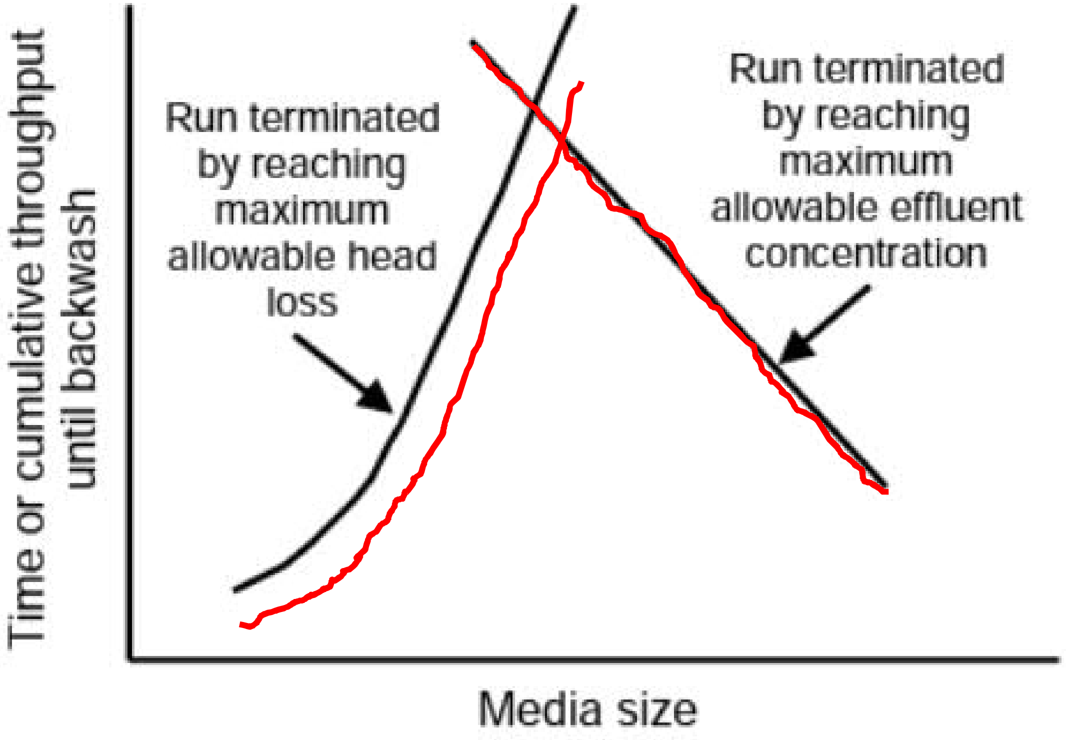
Independent Variable		Head Loss		Effluent Quality	
		Time	Cumulative Volume	Time	Cumulative Volume
Depth	↑	↓[a]	↓	↑	↑
Media size	↑	↑	↑	↓	↓
Velocity	↑	↓	↔	↓↓	↓
Influent concentration	↑	↓	↓	↓	↓

Example 2, operating variables

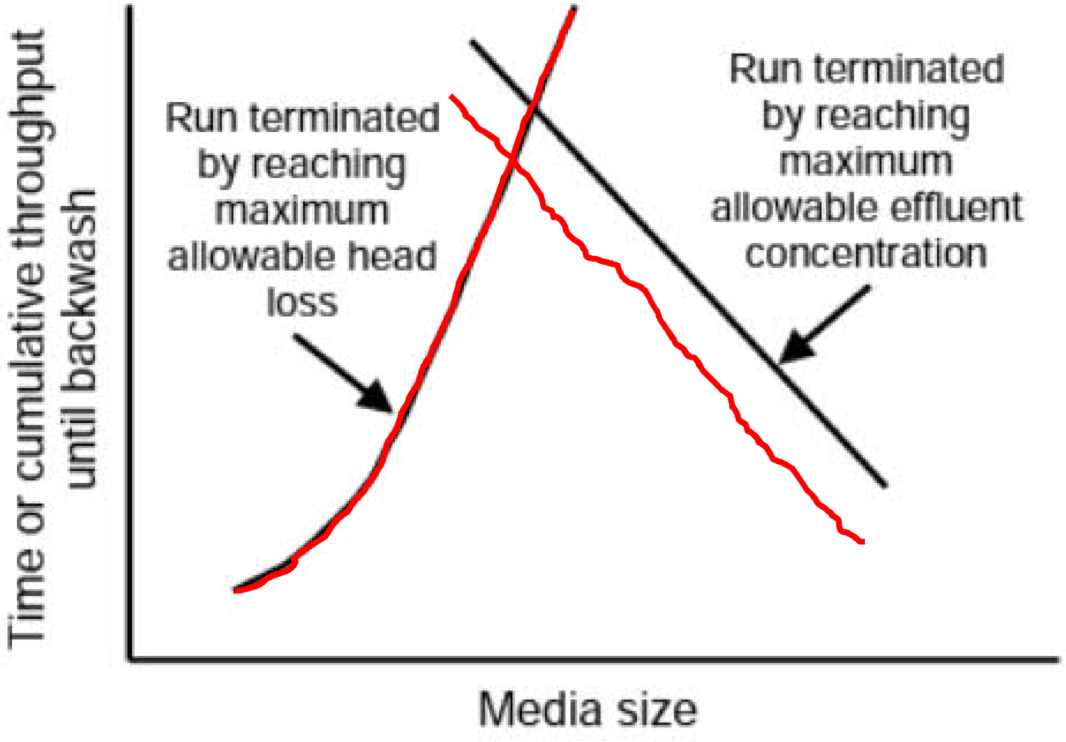


The locations of the two lines depend on all the other design and operational variables as well as on the values set for the two criteria. **How the two lines would move on different variables?**

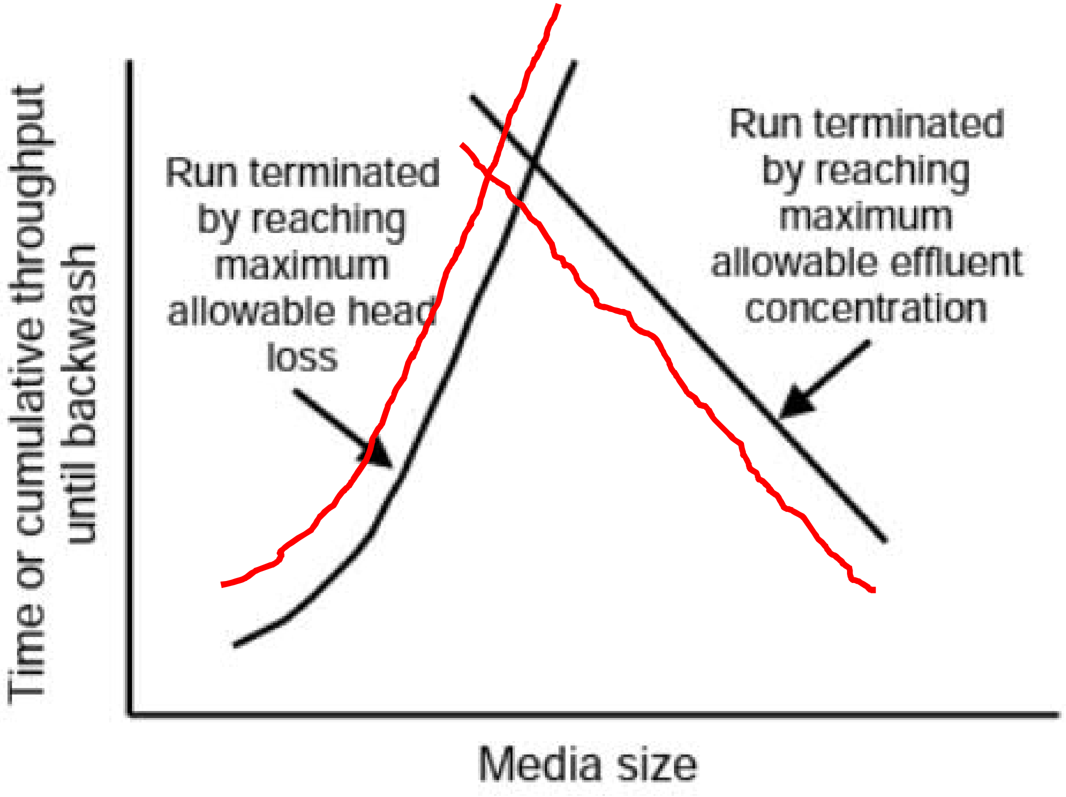
Example 2: Reduce the maximum allowable head loss.



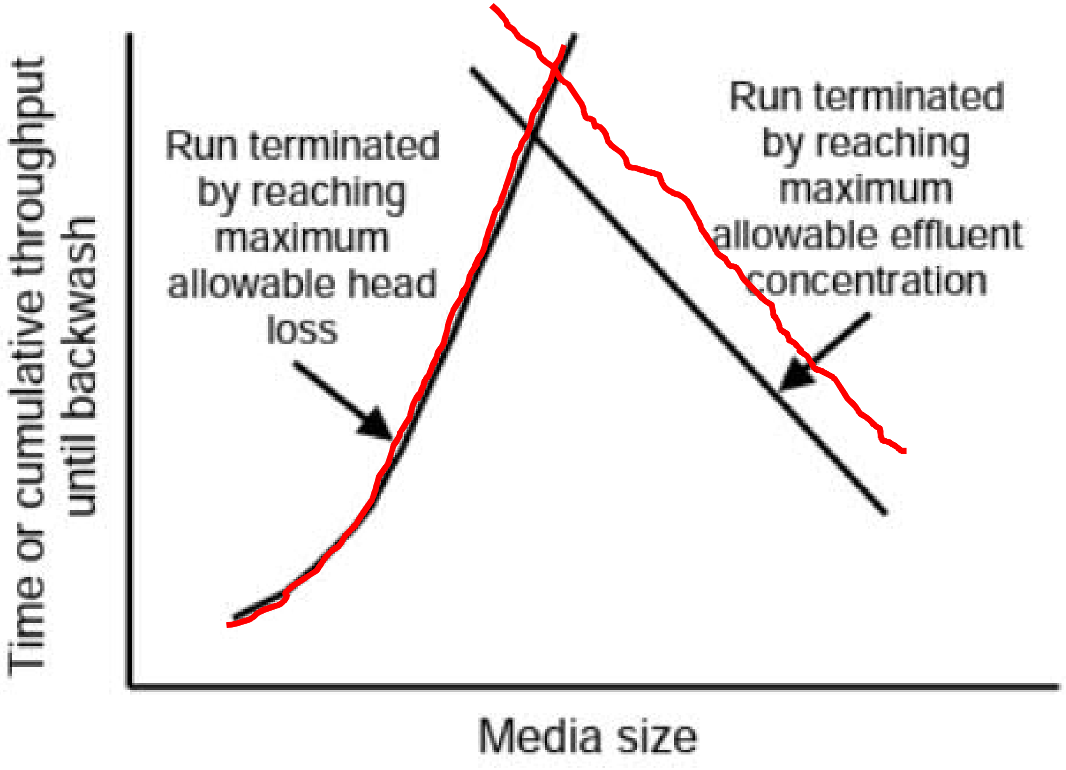
Example 2: Reduce the maximum allowable effluent concentration



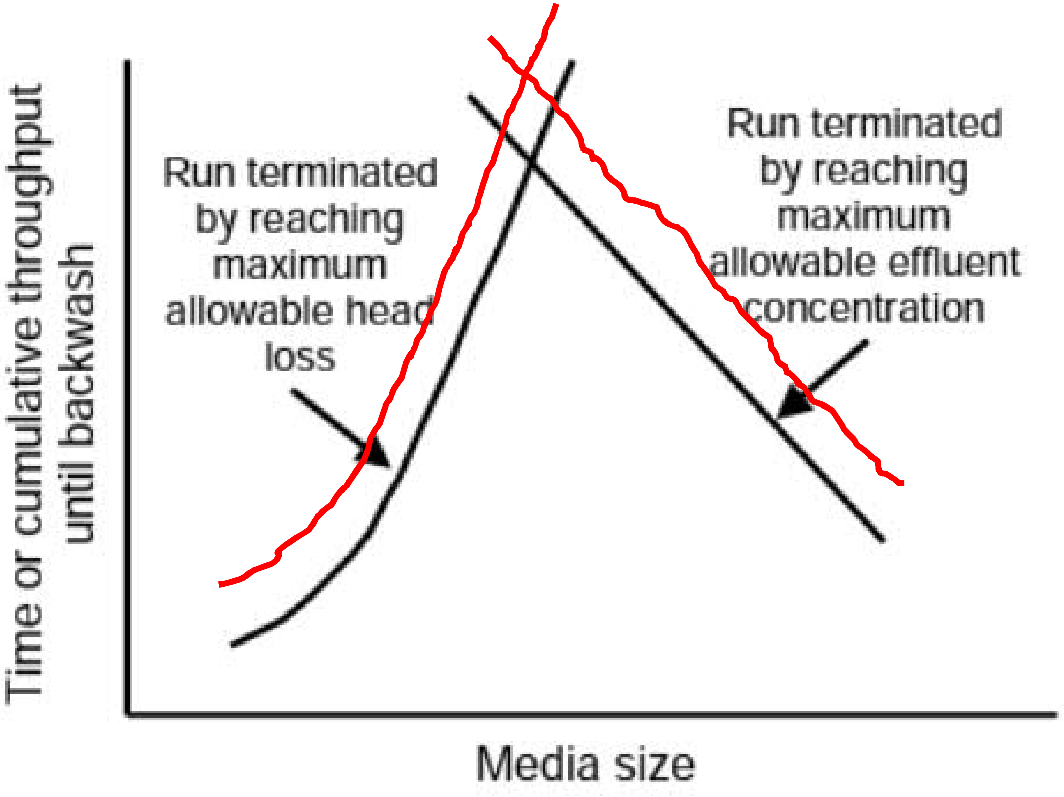
Example 2: Reduce the depth of the media



Example 2: Reduce the filtration rate



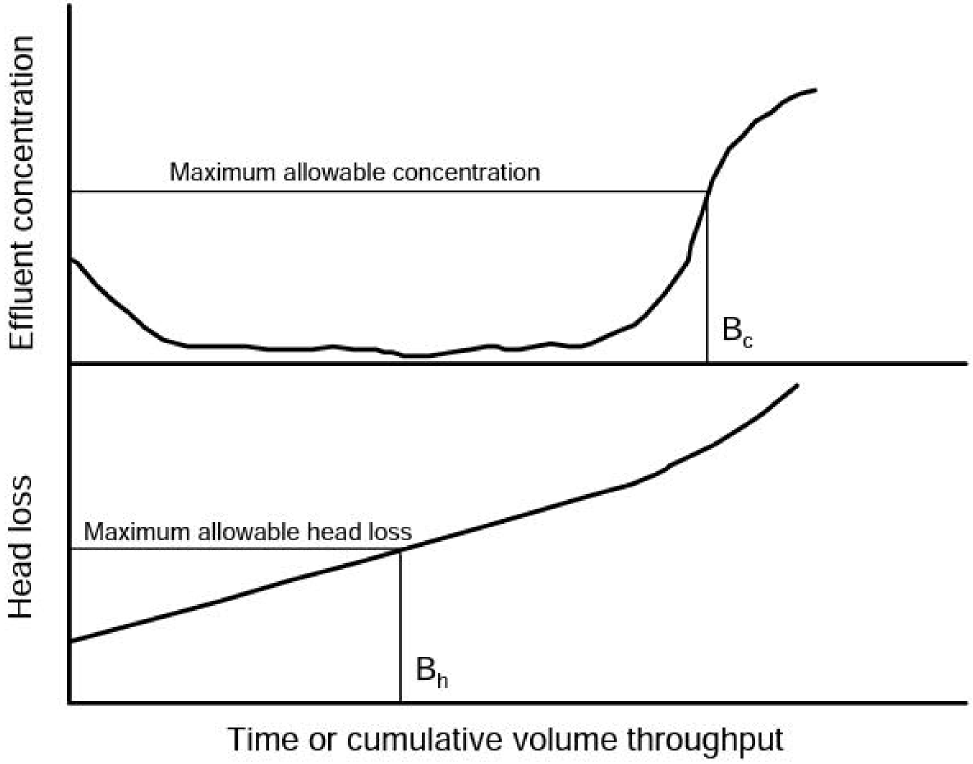
Example 2: Reduce the influent concentration



Homework 2

Filter cleaning

- **Need for backwash is indicated by one of the following criteria:**
  - Increase of head loss across the filter to the available limit or to a lower established limit
  - Deterioration of filtered water quality
  - Maximum time limit



Backwashing

What shouldn’t backwashing do to the multimedia filters?

- During backwashing the net downward force (gravity minus buoyancy) on the media is balanced by the upward drag force exerted by the moving fluid on a velocity by which, the packed media is fluidized (the filter grains no longer be supported by each other but by the force of the rising fluid).
- At velocities above the minimum required for fluidization (v_{mf}), the bed expands. Media washout should be avoided.
- The v_{mf} is a function of the porosity of the bed, the diameter and density of the grains, and the temperature. It is easily evaluated numerically for a specific situation using the d_{90} size of grains.
- Backwashing is often insufficient to clean the media by itself.

Surface wash

- To break up the cake on top of the filter, a high-velocity downward water flow is injected before the start of the vertically upward flow of the backwash.
- Surface wash systems only affect the top several centimeters of the bed

→ most effective for monomedia filters with relatively small media size

Air scour

- Air is supplied in a separate system from the backwash flow, through nozzles at the bottom of the media.
- The goal is to have the bubbles form, collapse, and reform a number of times as they rise; this condition has been called collapse-pulsing.
- Backwashing is most effective in systems with air scour if the water velocity is considerably below that required for fluidization of the bed.

Screening

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Working principle of screens

Many different screens

Solids are removed mecanically

Openings between 2 – 10 mm

Recent very fine screens (0,5 mm →)

Removes finer particles via filtration through the layer of screenings

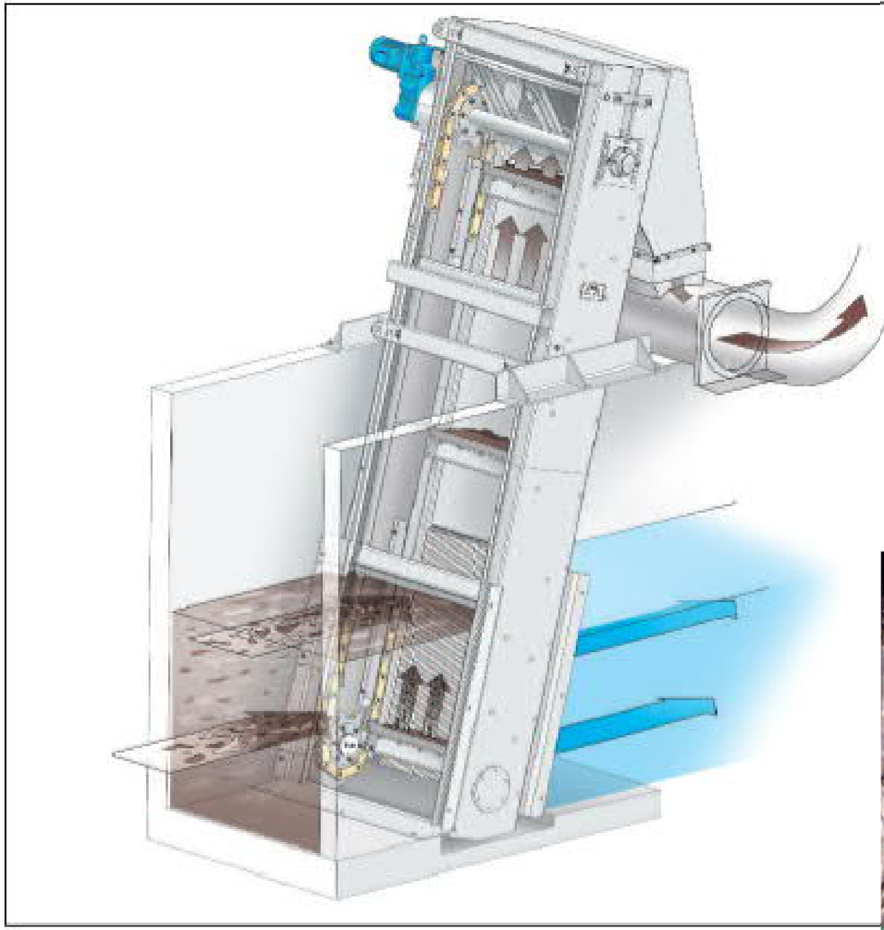
Applications:

Pretreatment of wastewater

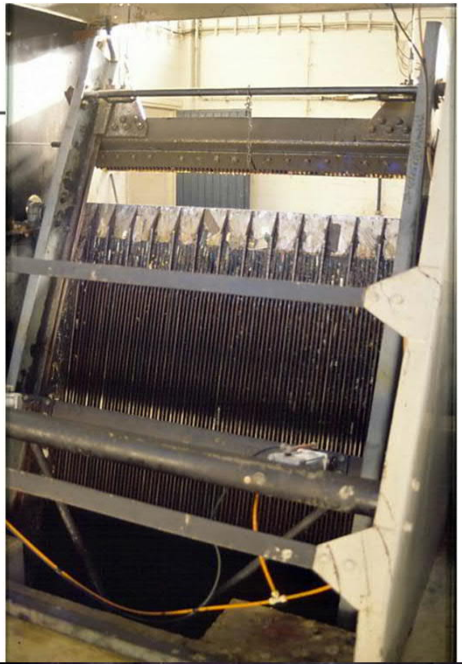
Pretreatment of ceptic tank sludges

Treament of storm water overflows (new)

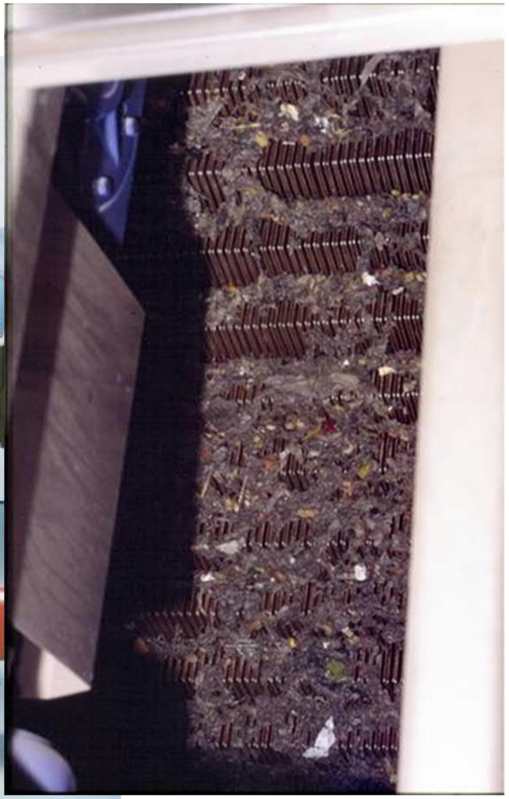
Bar screen



Schematic drawing of the HUBER RakeMax® Multi-Rake Bar Screen



Step screen

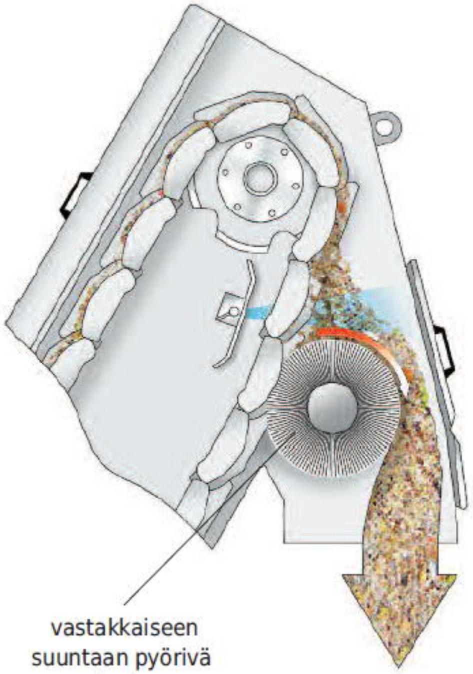


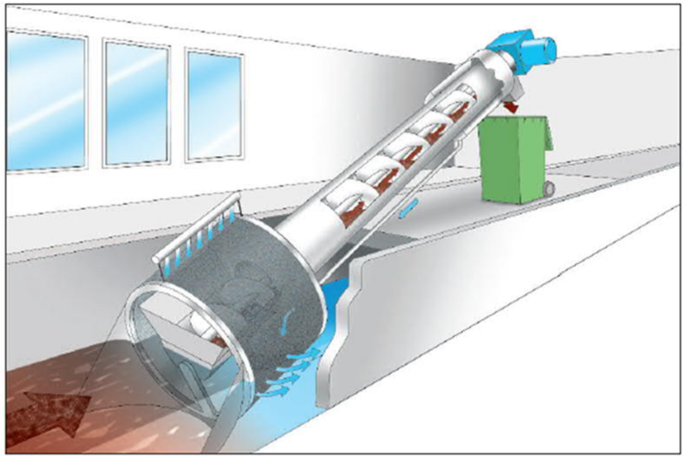
Mesh size 2-3 mm

Head loss <-> steps move up

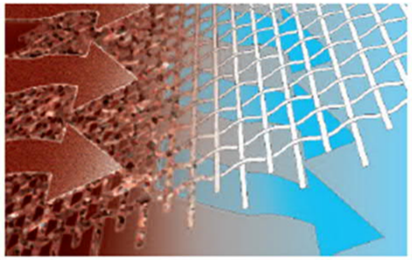
Removes finer particles all the time

Belt screen   Membrane screen Punched-hole screen





Flow diagram of the ROTAMAT® Membrane Screen RoMem



Maximum separation efficiency due to the square mesh that provides a defined separation size

Excursion to Vanhakaupunki plant next Wednesday 13.2.

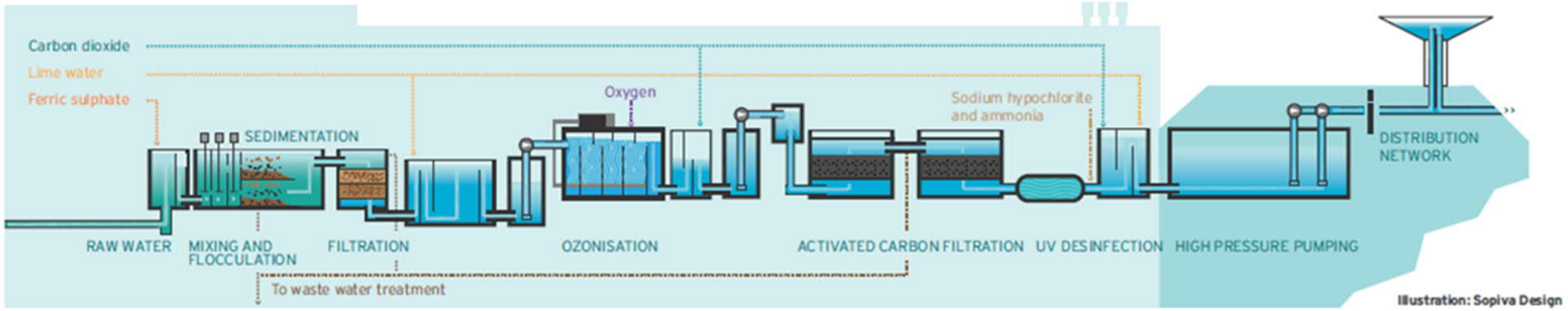


Illustration: Sopiva Design

See instructions for the transportation

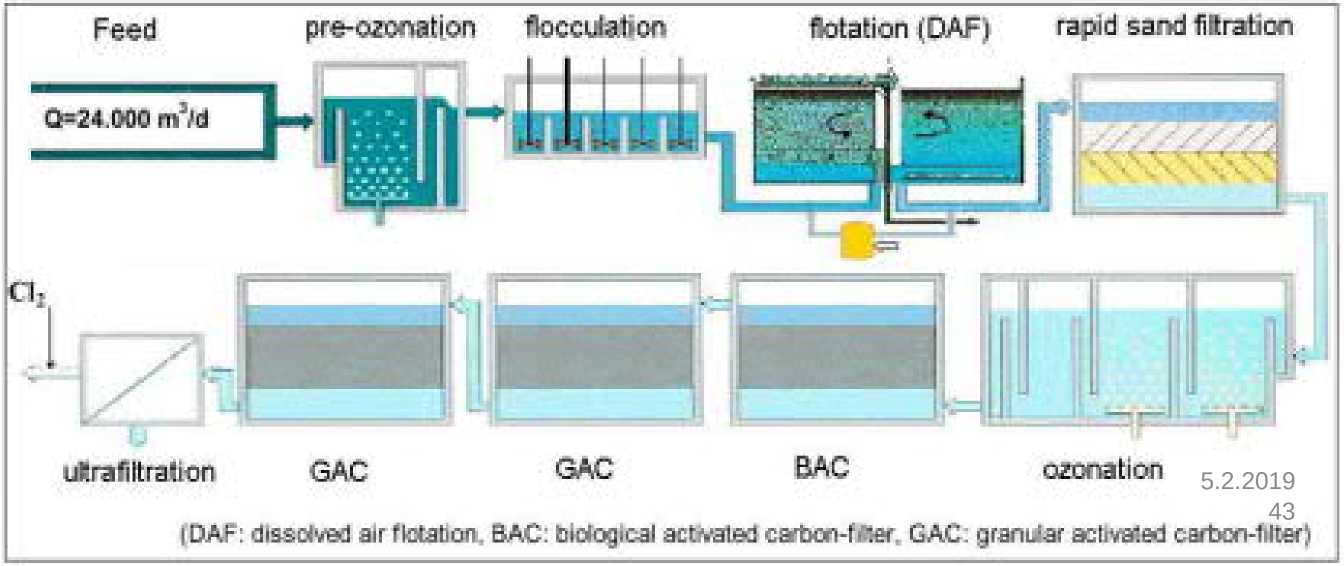
List of questions

Let’s make the best of this visit!!

Group discussion: What is the objective in different treatment steps in Windhoek? How have the processes been dimensioned? How about emerging pollutants?

Namibia, Windhoek

- From 1968



(DAF: dissolved air flotation, BAC: biological activated carbon-filter, GAC: granular activated carbon-filter)

Group discussion: What is the objective in different treatment steps in this case? How have the processes been dimensioned? How about resource recovery?