Drinking Water 1

Filtration

Room: 2.99

Prof. ir. Hans van Dijk

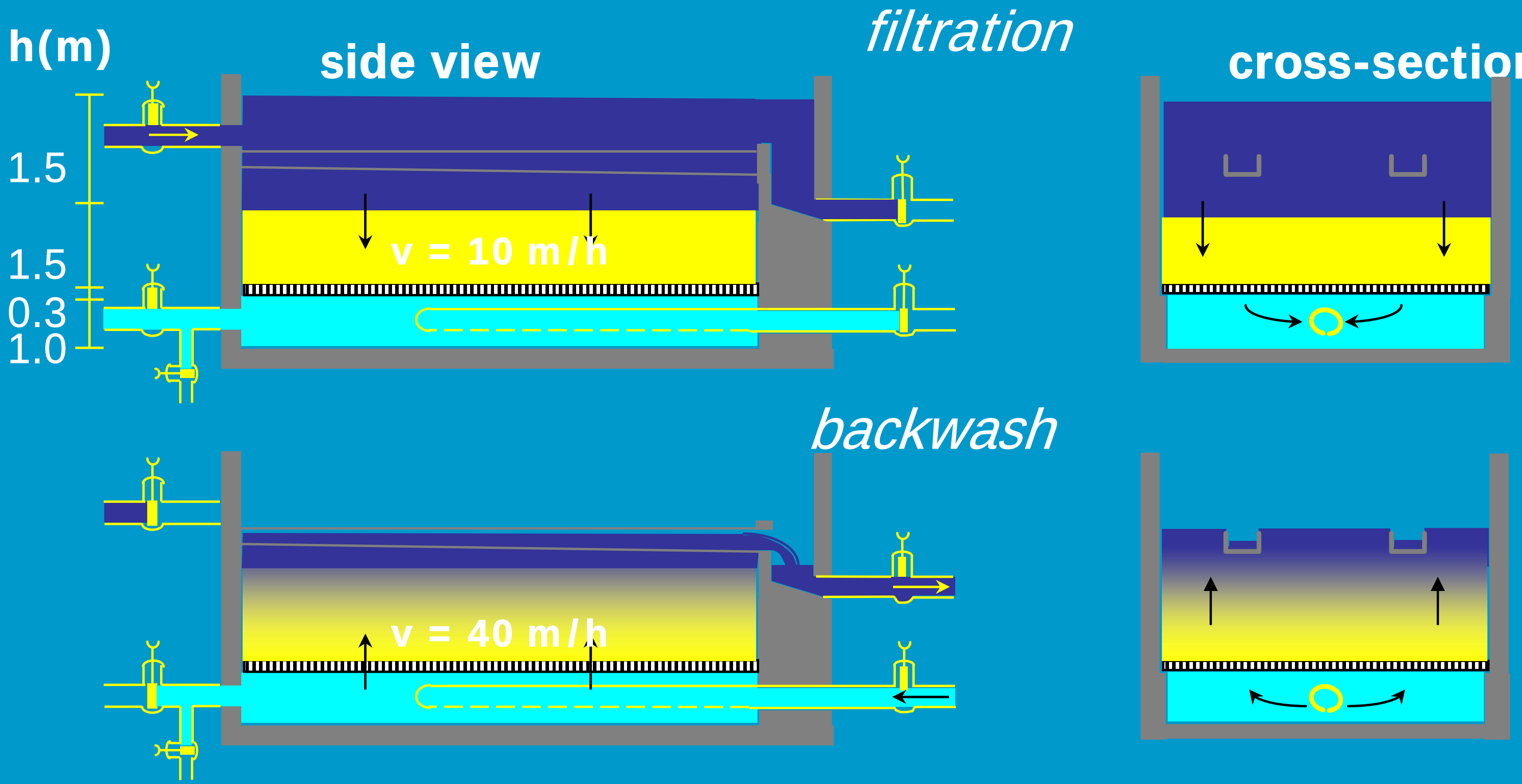
Delft University of Technology

Filtration

Contents

Introduction

Principle filtration



Rough size filterbed 10m x 5m

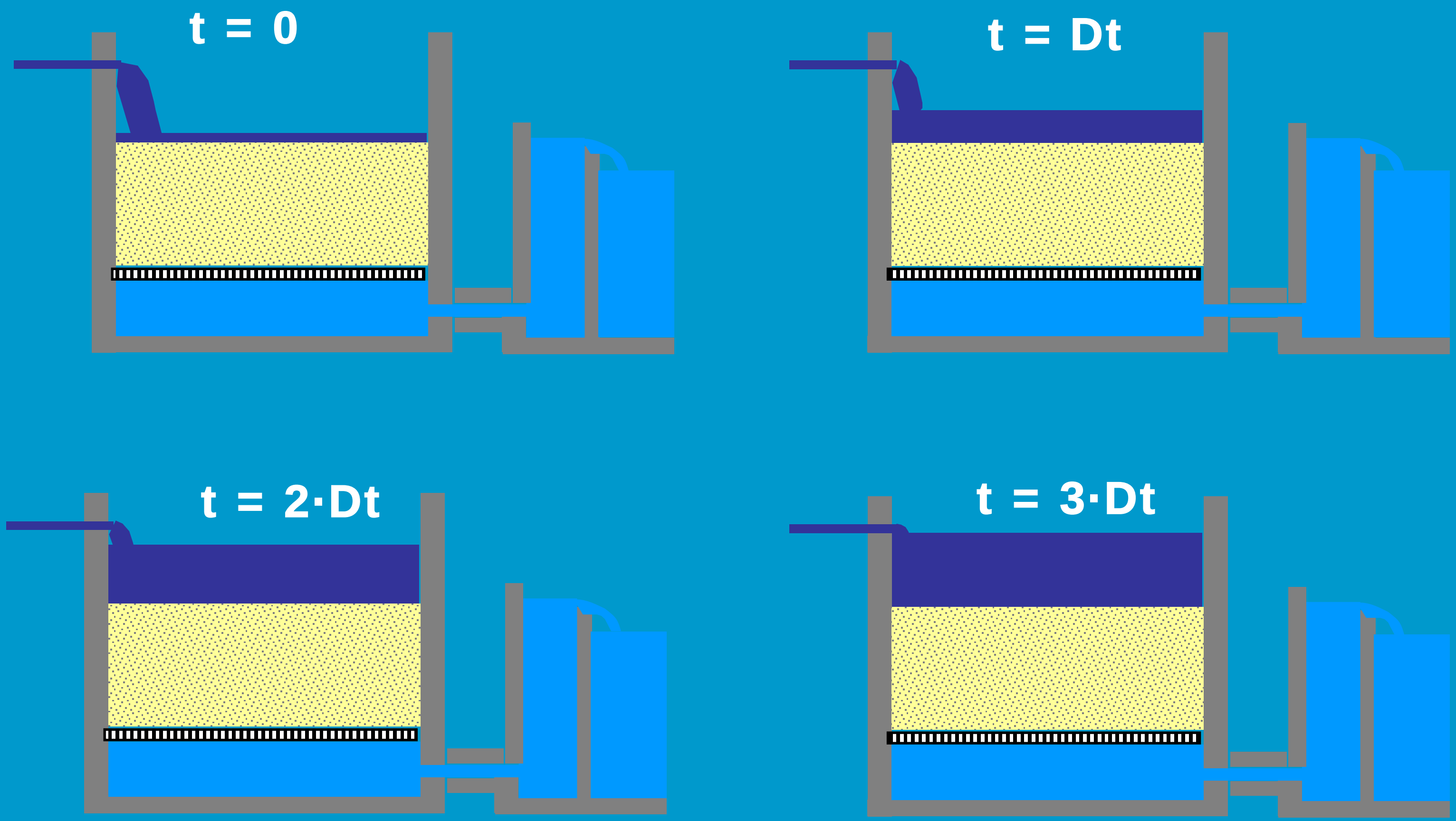
Introduction

Filtration

Introduction

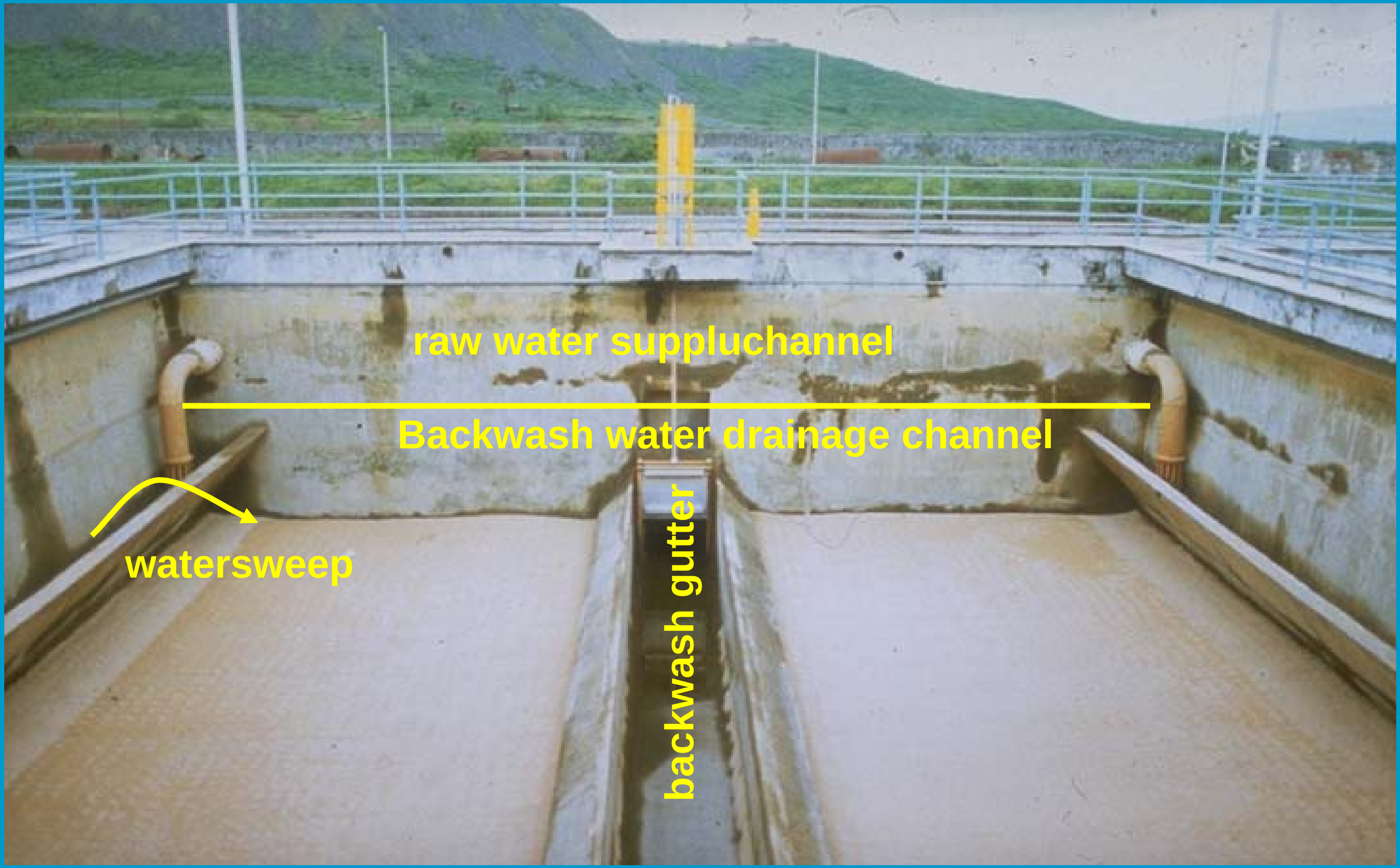
Filtration

Increase of resistance in time



Introduction

Filtration installation Bombay

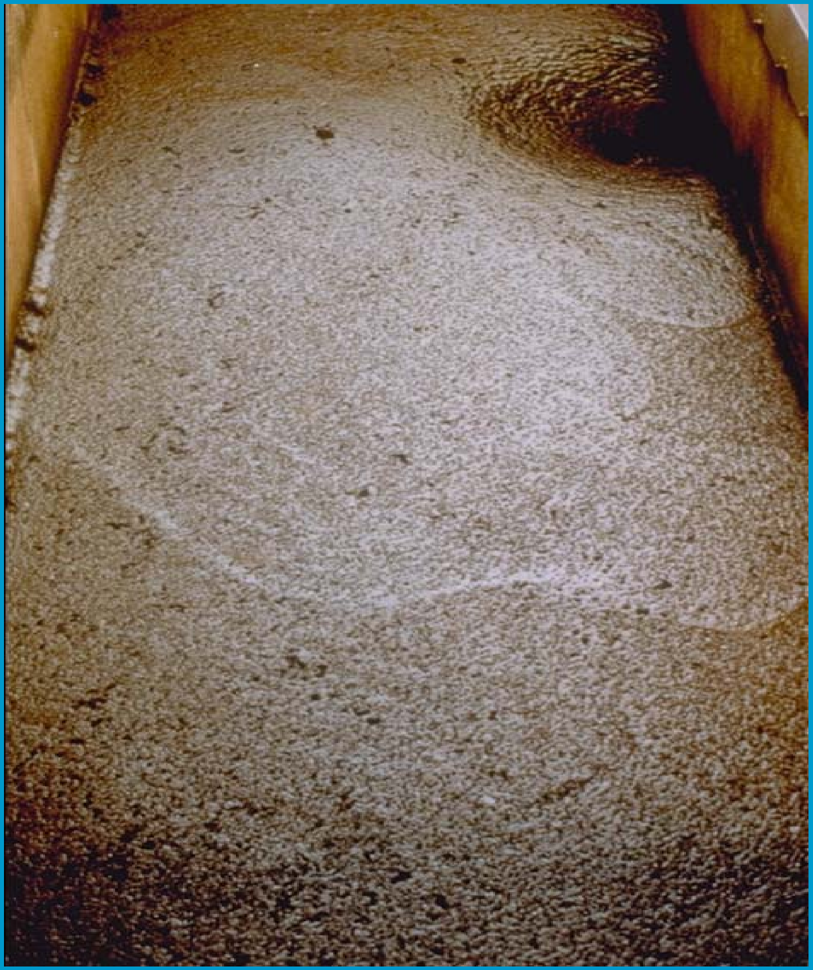


Introduction

Backwash

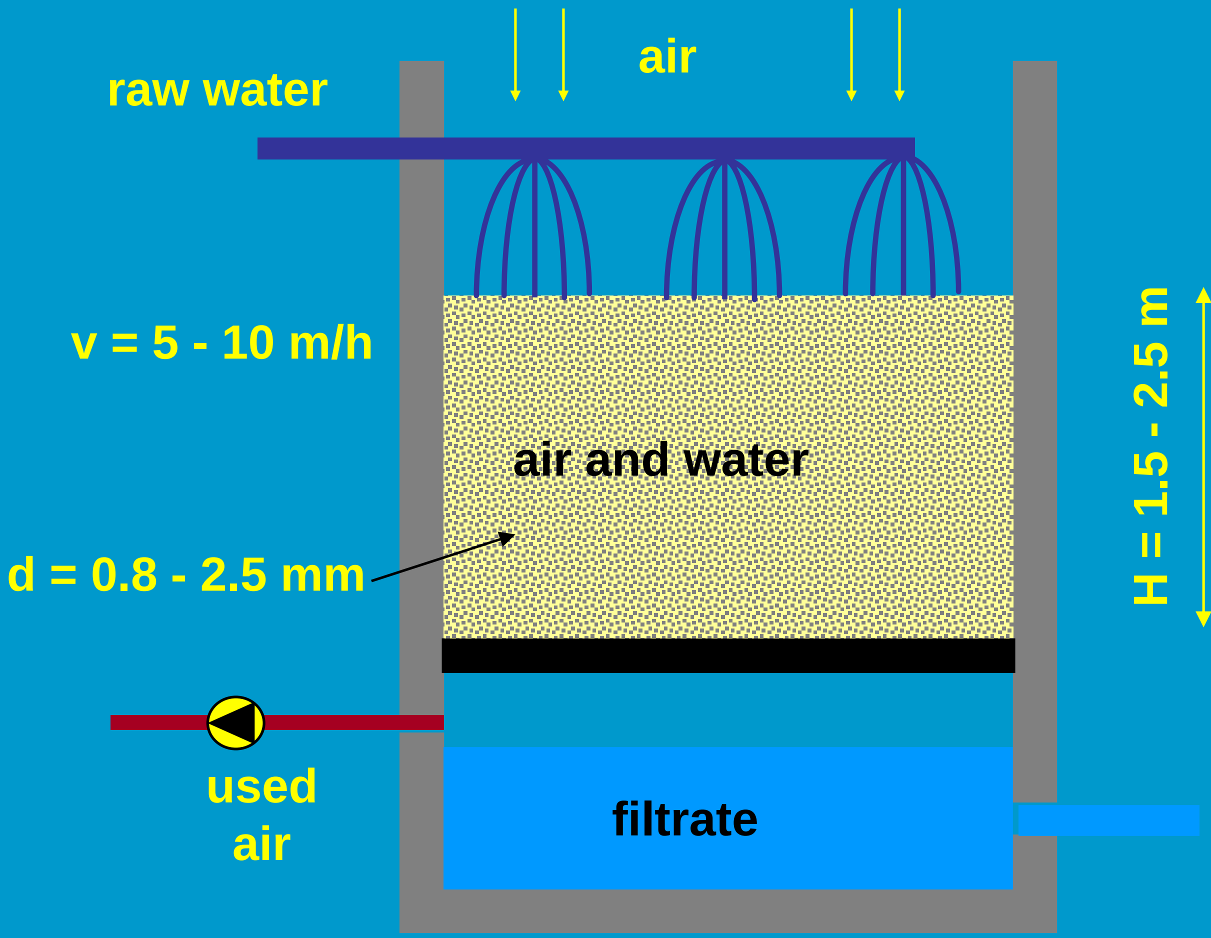
Introduction

Oops



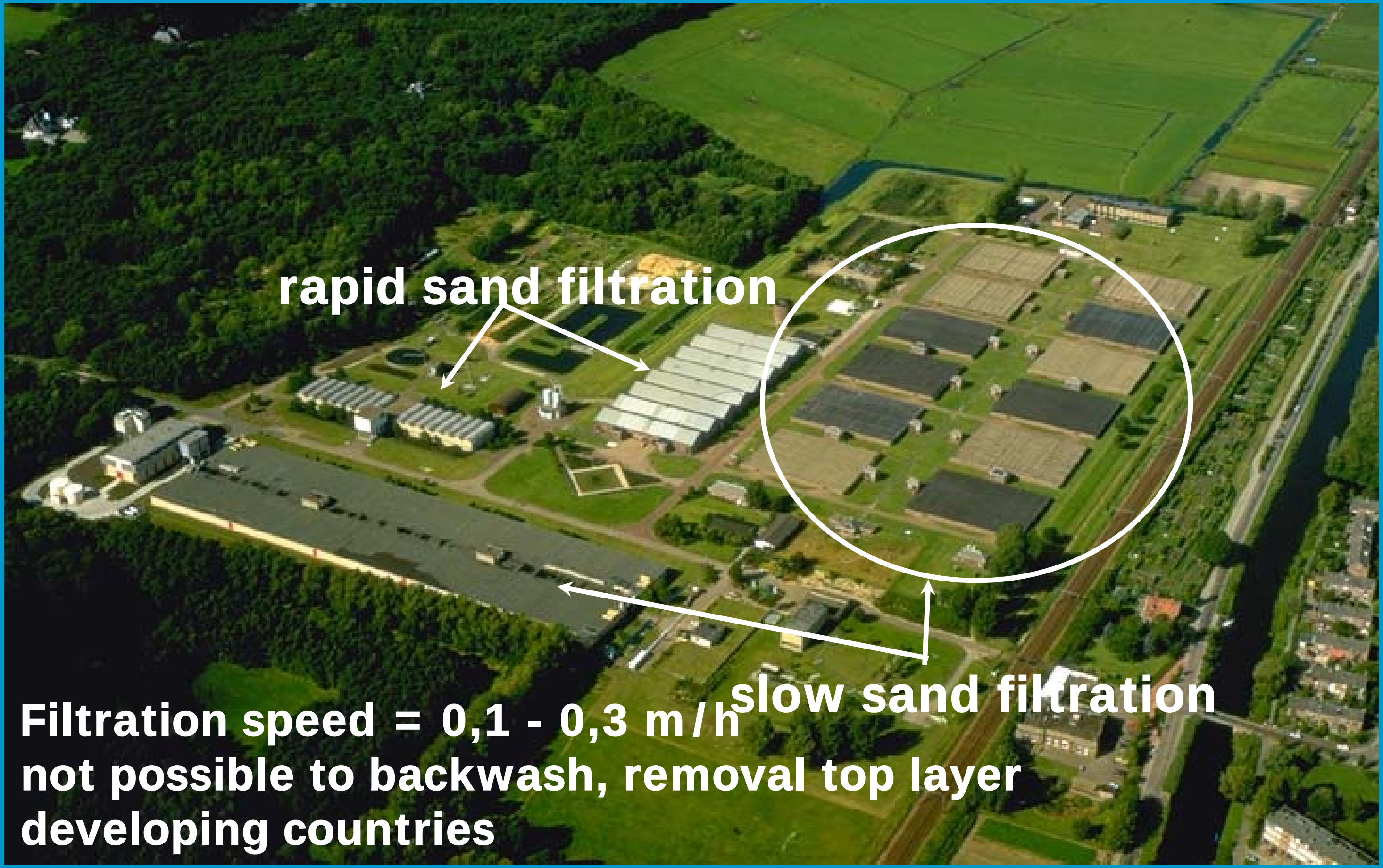
Introduction

Dry filtration



Introduction

Slow sand filtration



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Filtration mechanisms

On top of filter bed

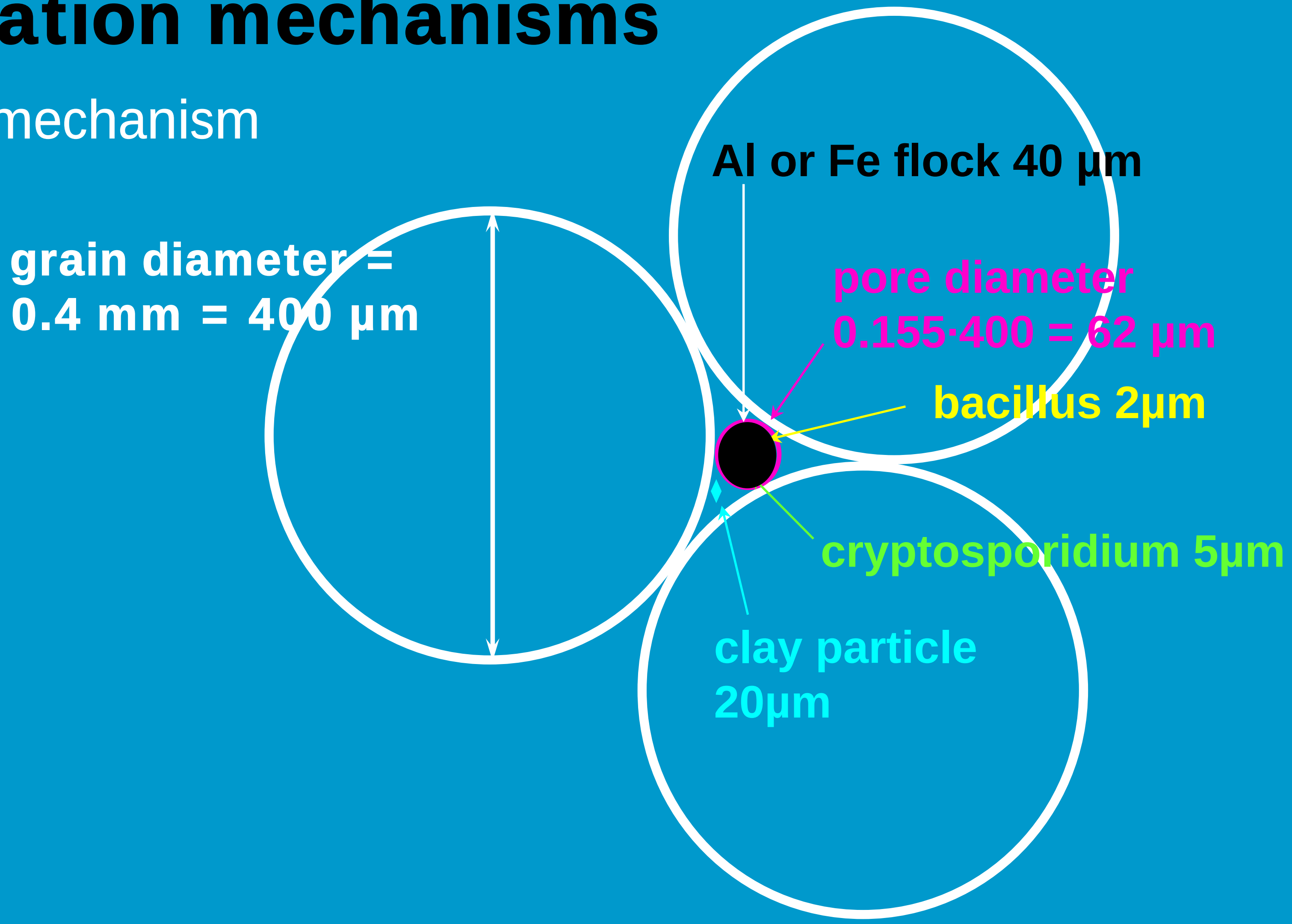
1. Sieve mechanism on top of the filterbed

In filter bed

2. transport of particles to grains and attachment to grains
3. chemical and biological transformations

Filtration mechanisms

Sieve mechanism



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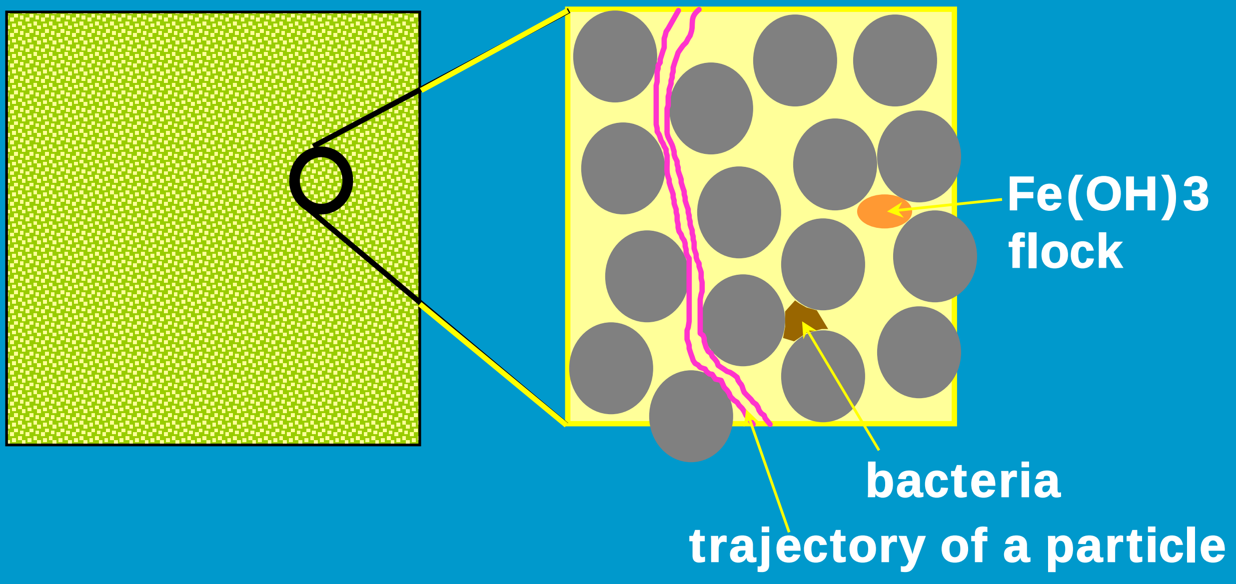
Filtration mechanisms

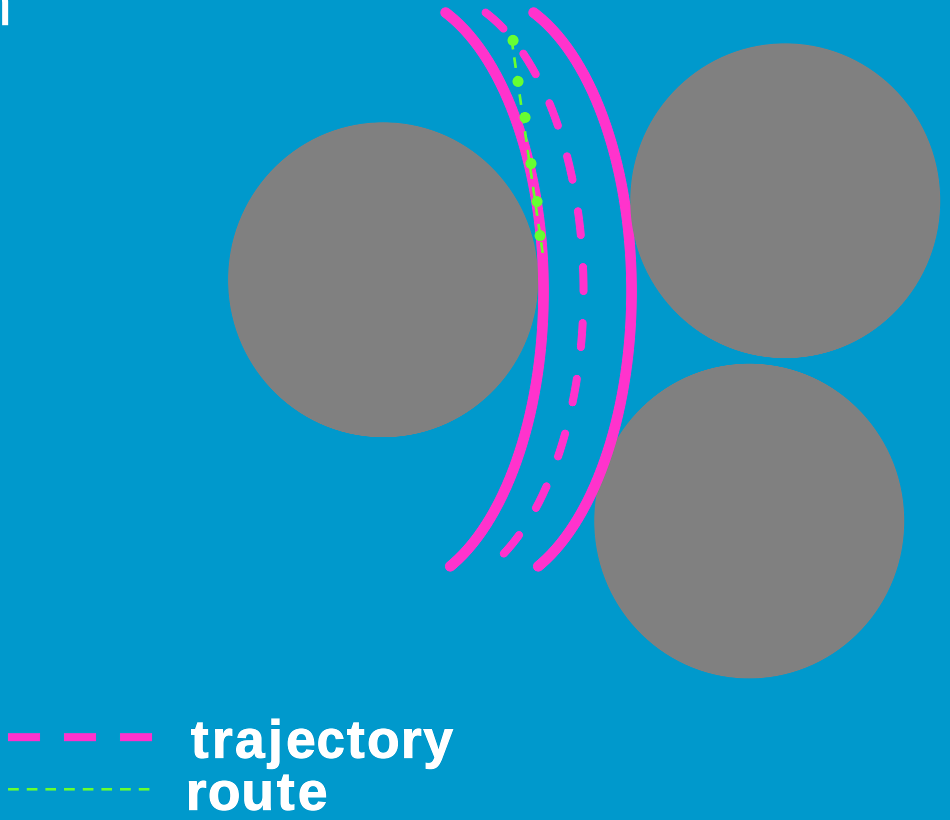
Transport and attachment



1. sedimentation
2. interception
3. diffusion
4. inertia
5. turbulance

Filtration mechanisms

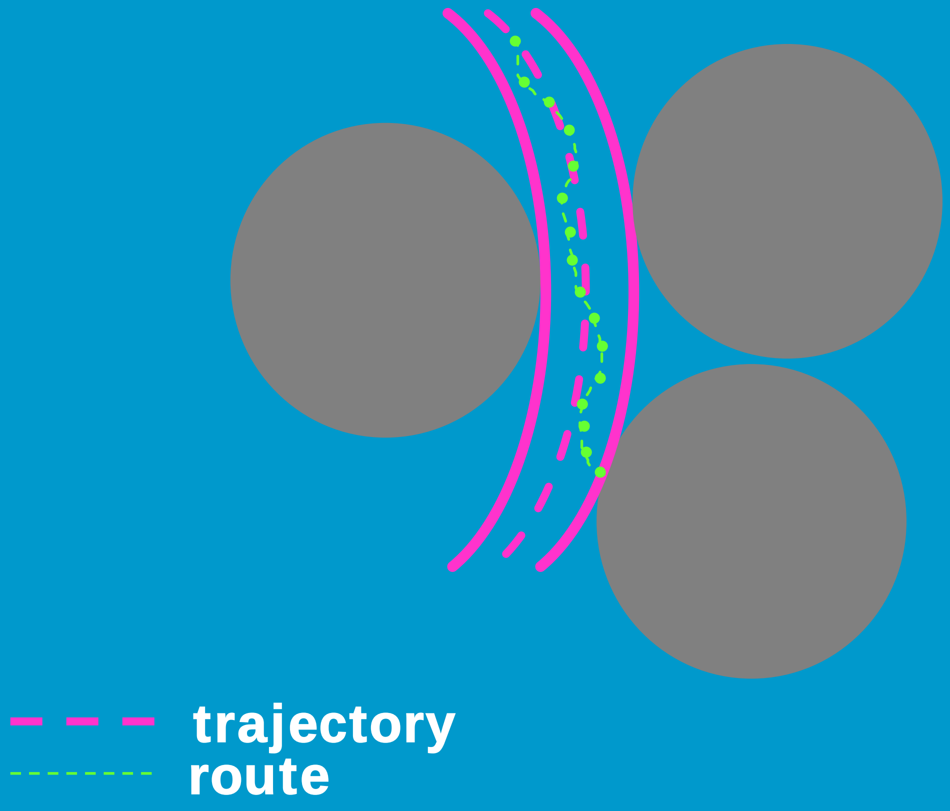
Sedimentation



Filtration mechanisms

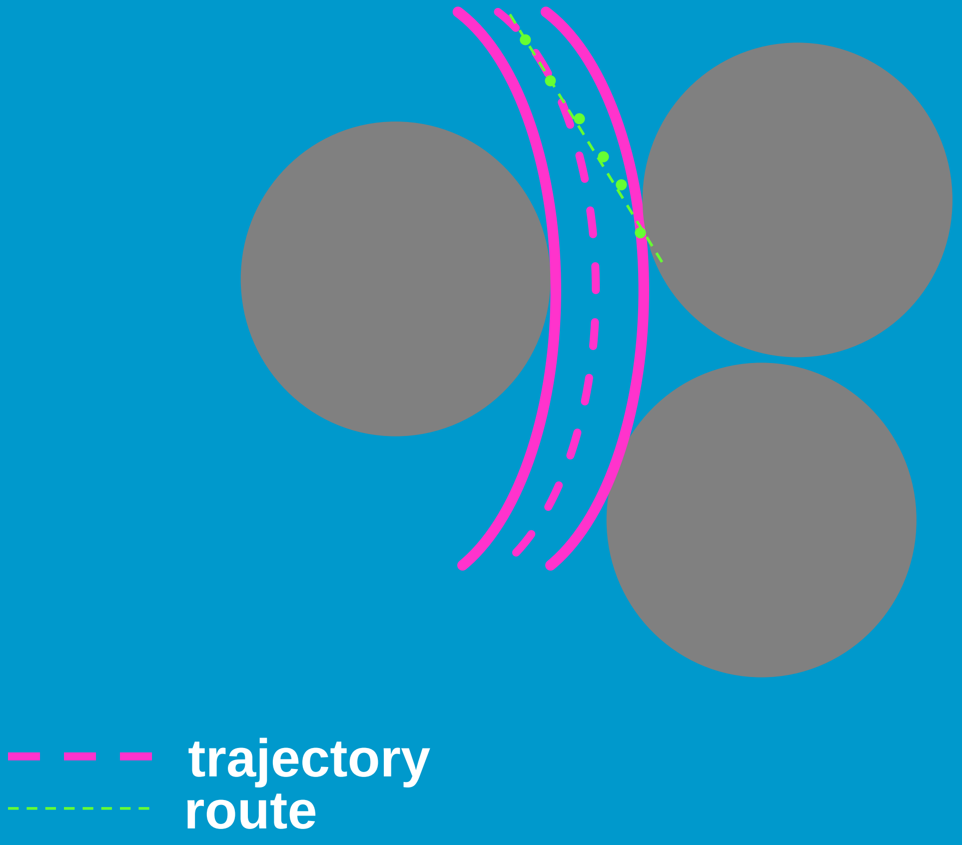
Diffusion

Mostly small parts



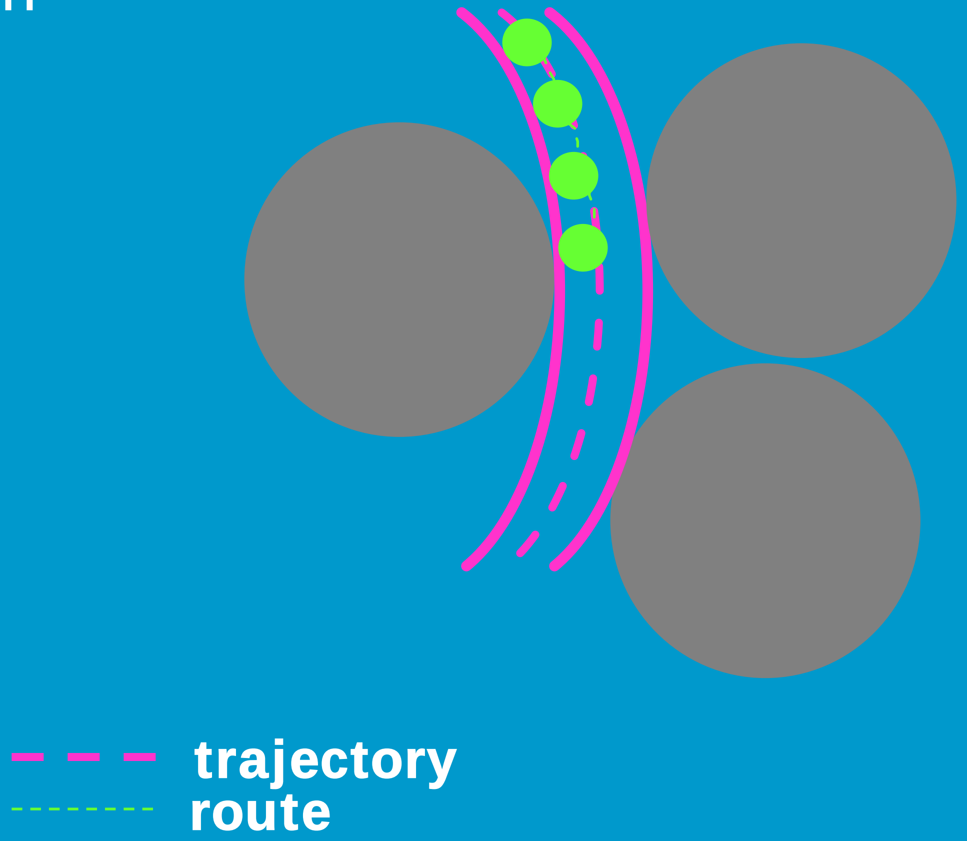
Filtration mechanisms

Inertia



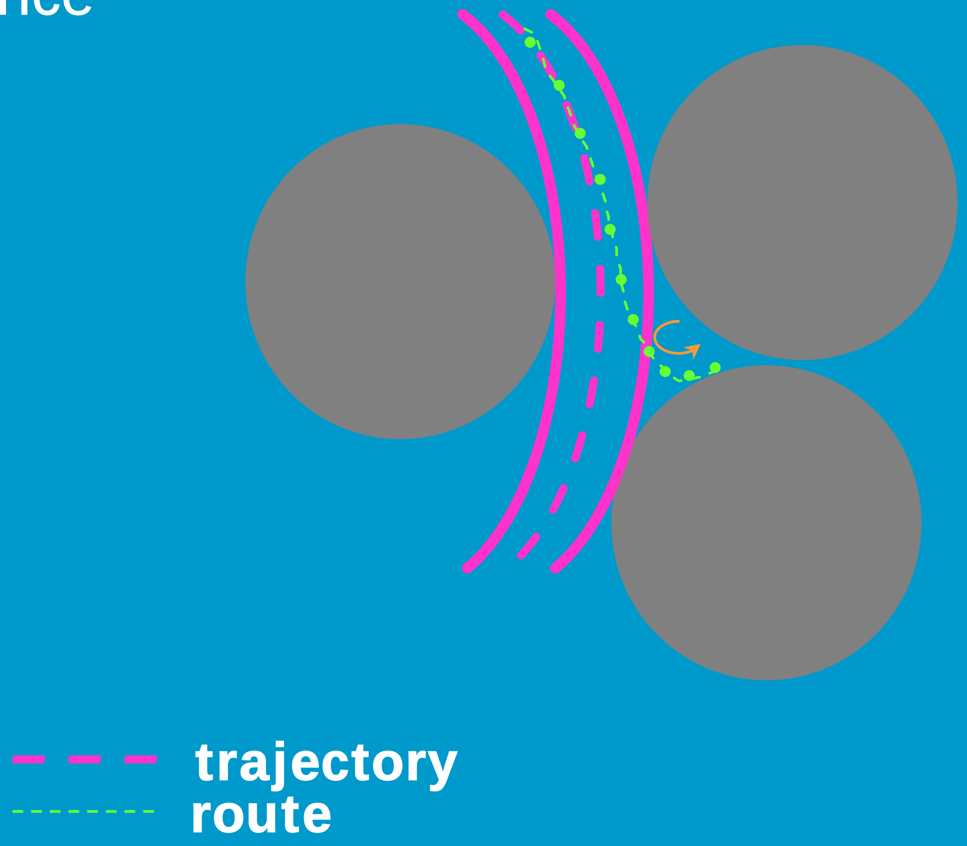
Filtration mechanisms

Interception



Filtration mechanisms

Turbulance



Filtration mechanisms

Chemical transformations

$4 \cdot Fe^{2+} + O_2 + 8 \cdot HCO_3^- \rightarrow 4 \cdot Fe(OH)_3 \downarrow + 8 \cdot H_3O^+$

$2 \cdot Mn^{2+} + O_2 + 6 \cdot H_2O \rightarrow 2 \cdot MnO_2 \downarrow + 4 \cdot H_3O^+$

Results in clogging of the filter

1 mg Fe^{2+} uses 0.14 mg/l O_2

1 mg Mn^{2+} uses 0.29 mg/l O_2

Filtration mechanisms

Biological transformations

$2\cdot NH_4^+ + 3\cdot O_2 + 2\cdot H_2O \rightarrow 2\cdot NO_2^- + 4\cdot H_3O^+$

$2\cdot NO_2^- + O_2 \rightarrow 2\cdot NO_3^-$

Nitrosomonas and nitrobacter

1 mg NH_4^+ uses 3.55 mg/l O_2

AOC, organic material

$CH_2O + O_2 \rightarrow CO_2 + H_2O$

Bacteria production:

nitrosomonas	0.15 g bacteria/ g ammonia
nitrobacter	0.06 g bacteria/ g nitrite
methane	0.10 g bacteria/ g methane

$CH_4 + 2\cdot O_2 \rightarrow 2\cdot H_2O + CO_2$

1 mg/l CH_4 uses 4 mg/l O_2

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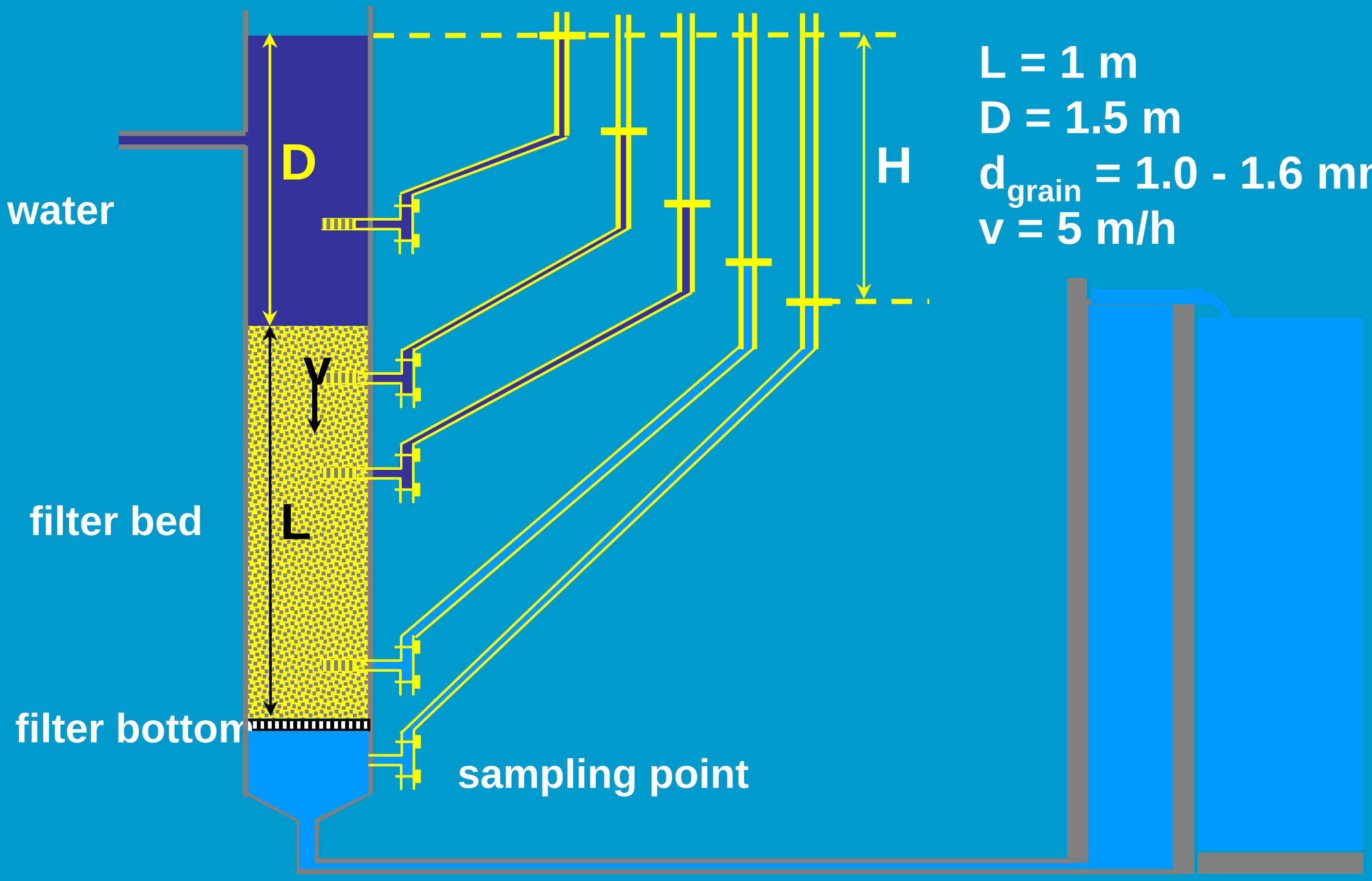
Filtration

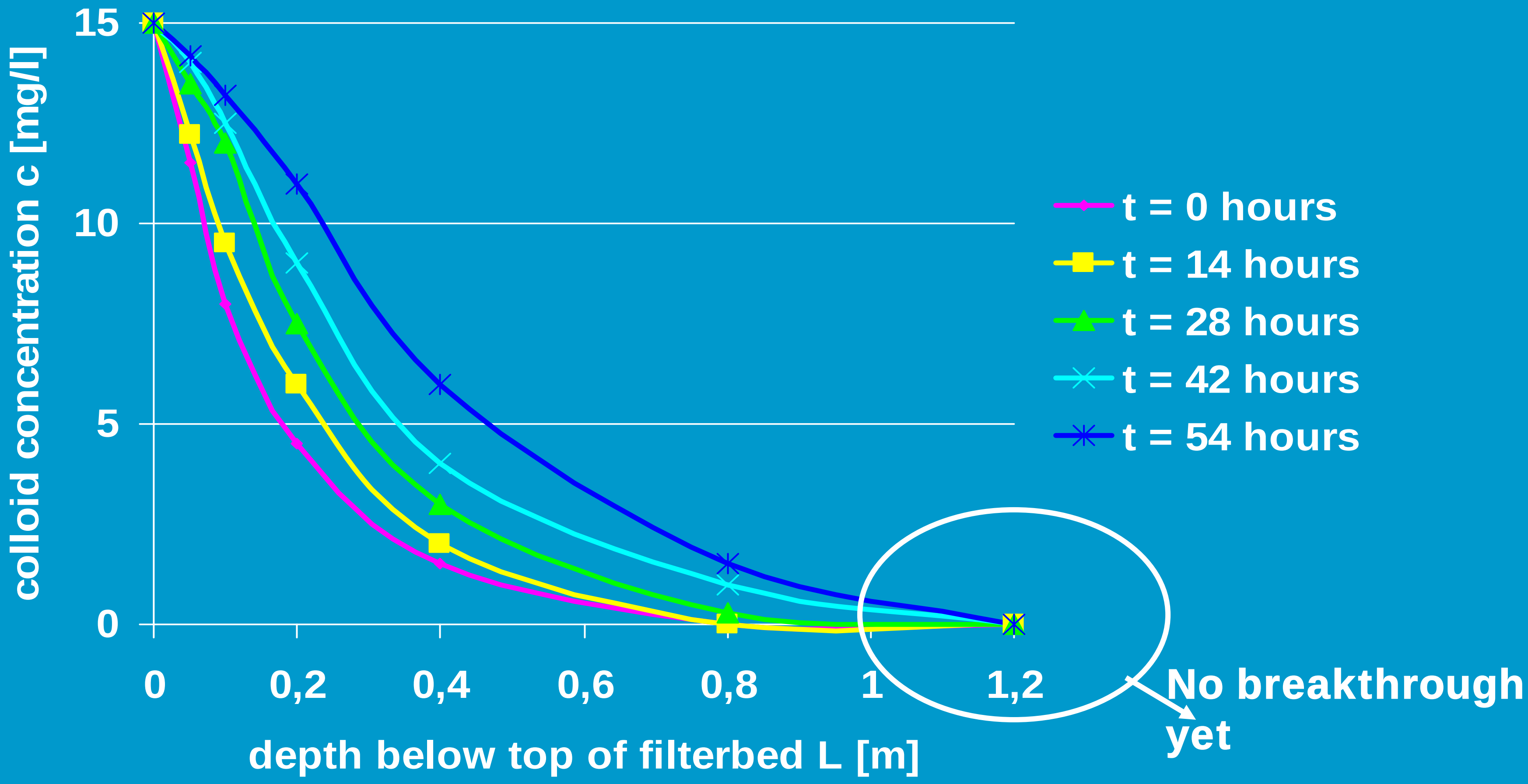
Filtration column



L = 1 m
D = 1.5 m
d_{grain} = 1.0 - 1.6 mm
v = 5 m/h

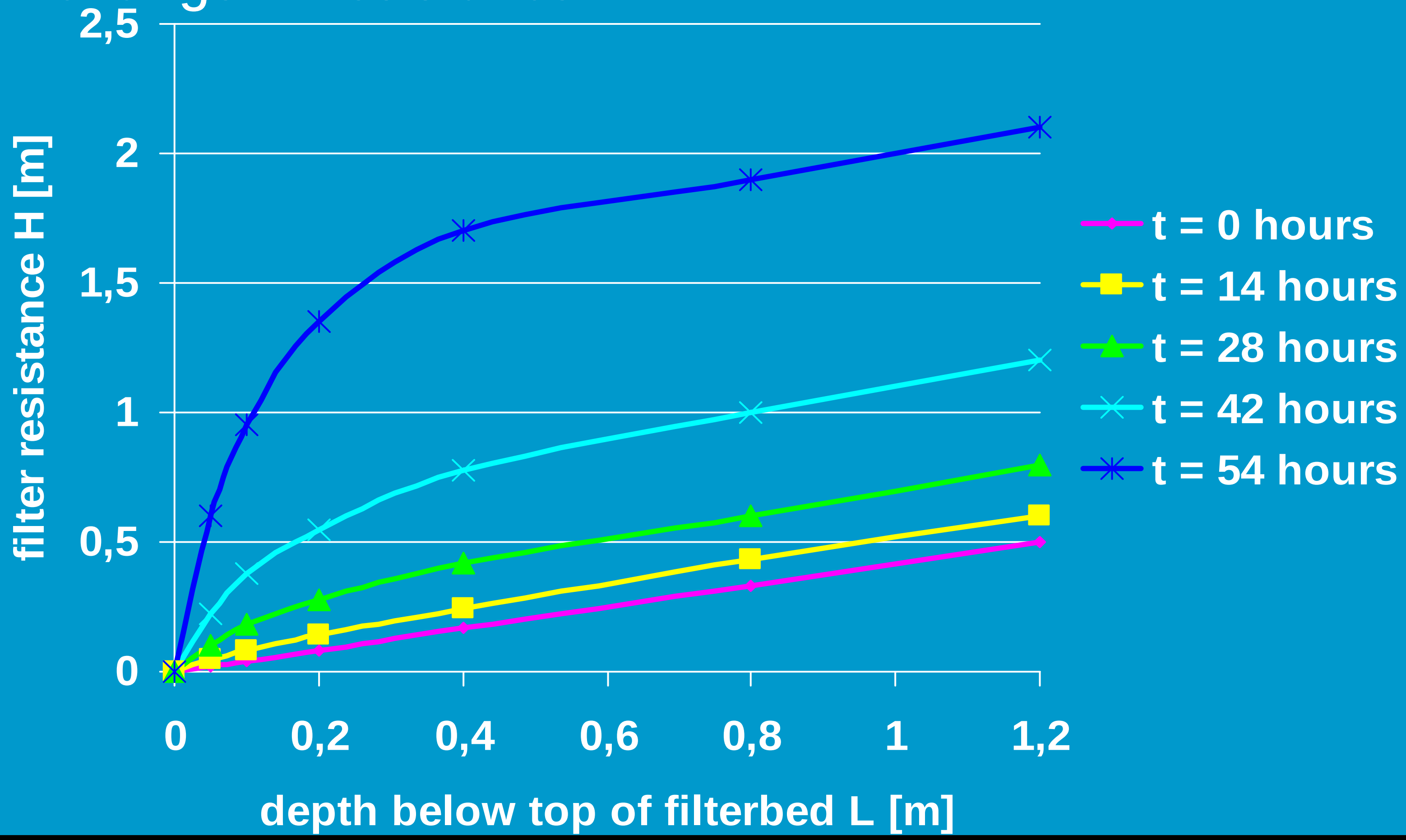
Filtration

Change in qualitiy



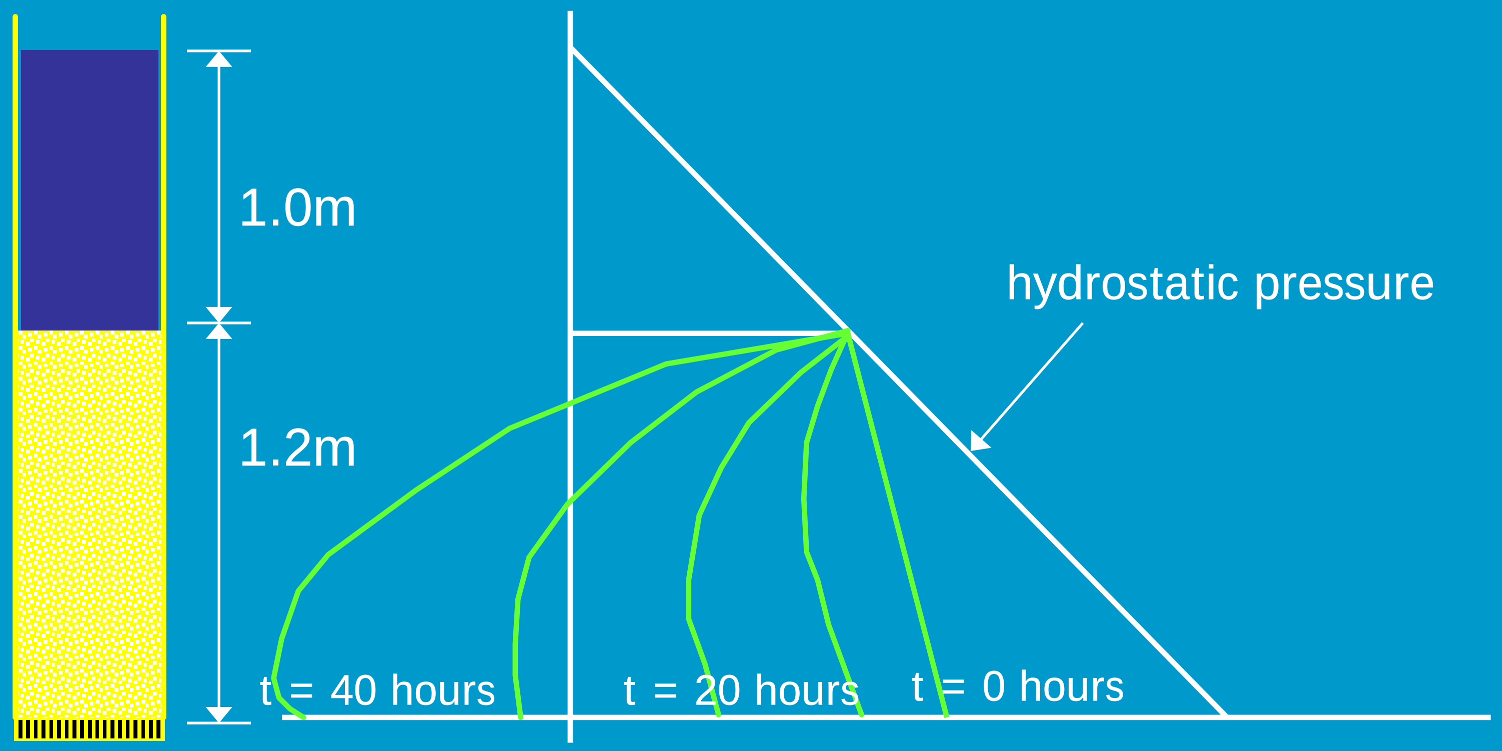
Filtration

Change in resistance



Filtration

Lindquist diagram



Filtration

Filter run time

Filter runtime depends on:

- influent = Tq (= run time quality)

    chemical, physical and bacteriological composition of the water

-design parameters = Tr (= run time resistance)

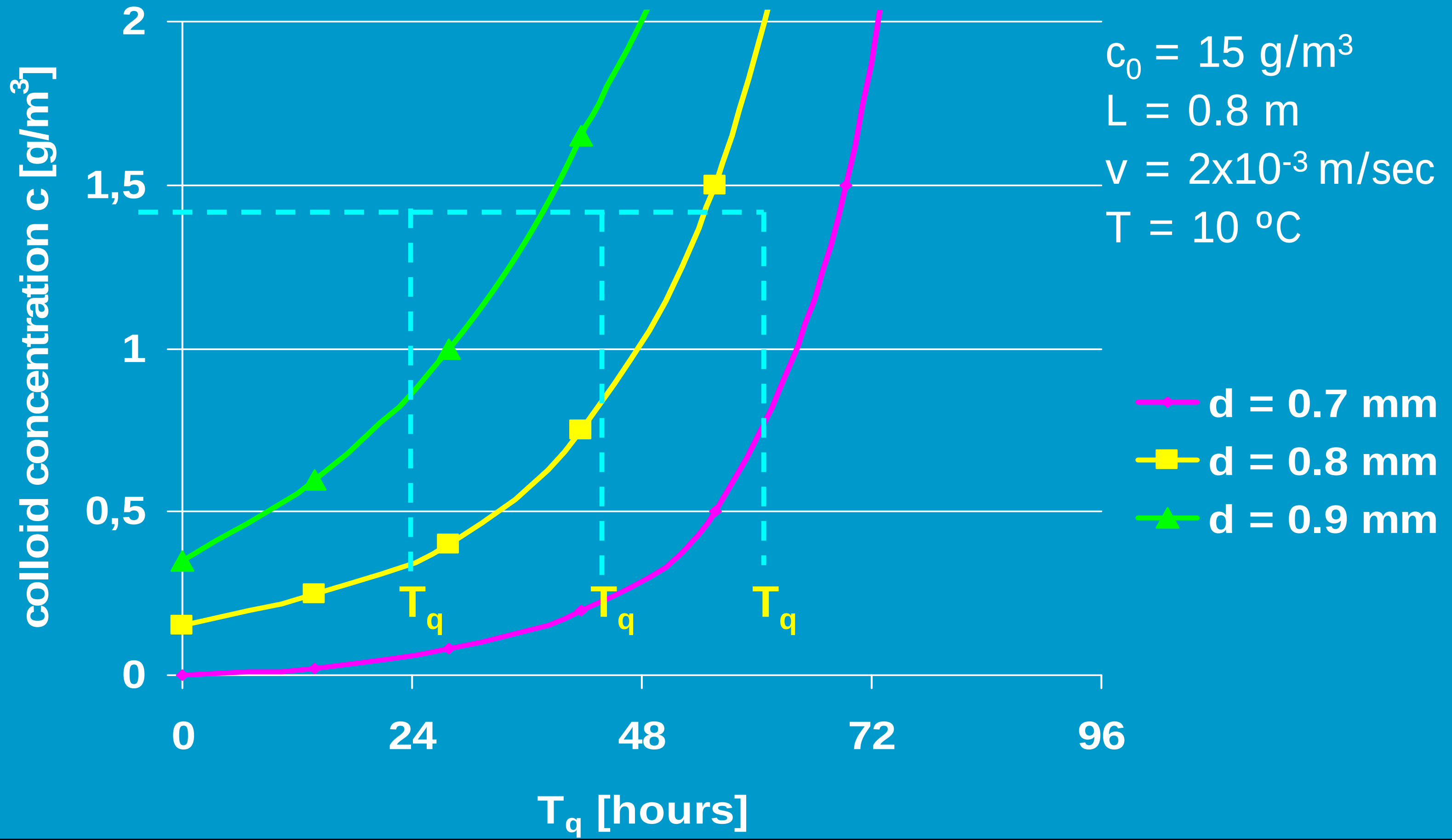
    filtration speed, filter bed thickness, grain size, water level on top, grain size distribution, kind of filter material

conditions:

- Tq > Tr
- Tq, Tr > 1 day

Filtration

Grain diameter (T_q)



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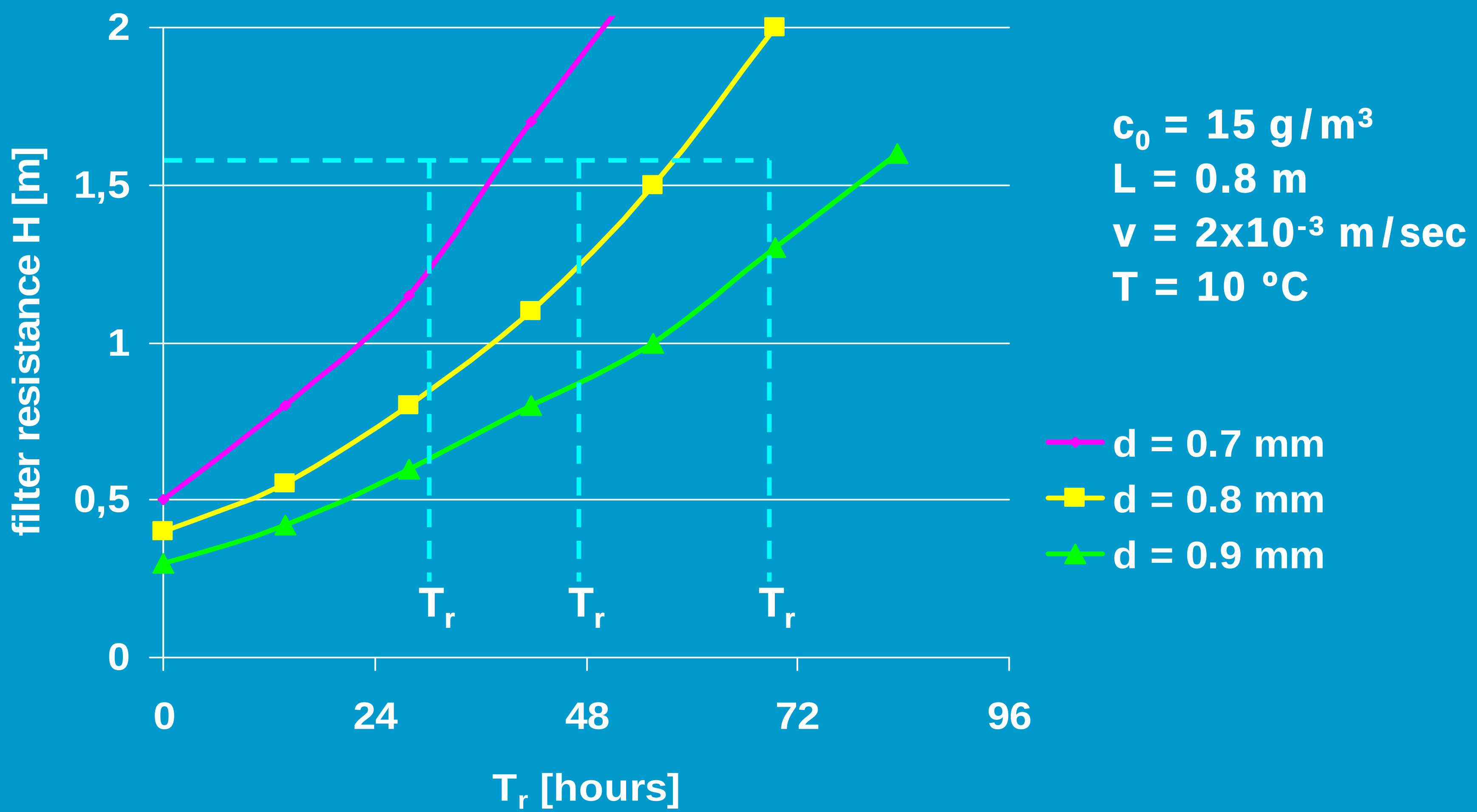
Filtration

Grain diameter (T_r)



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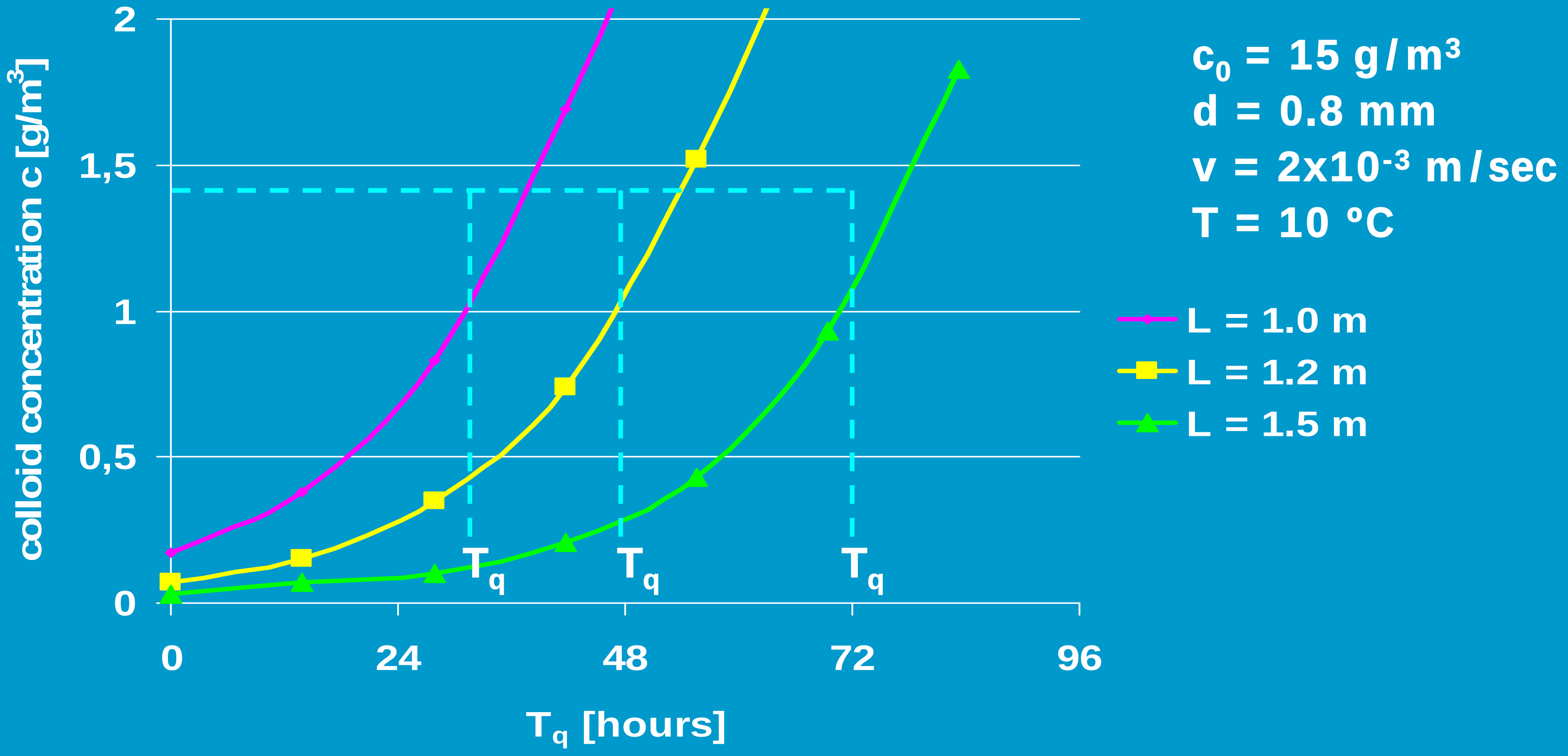
Filtration

Filter bed thickness (T_q)



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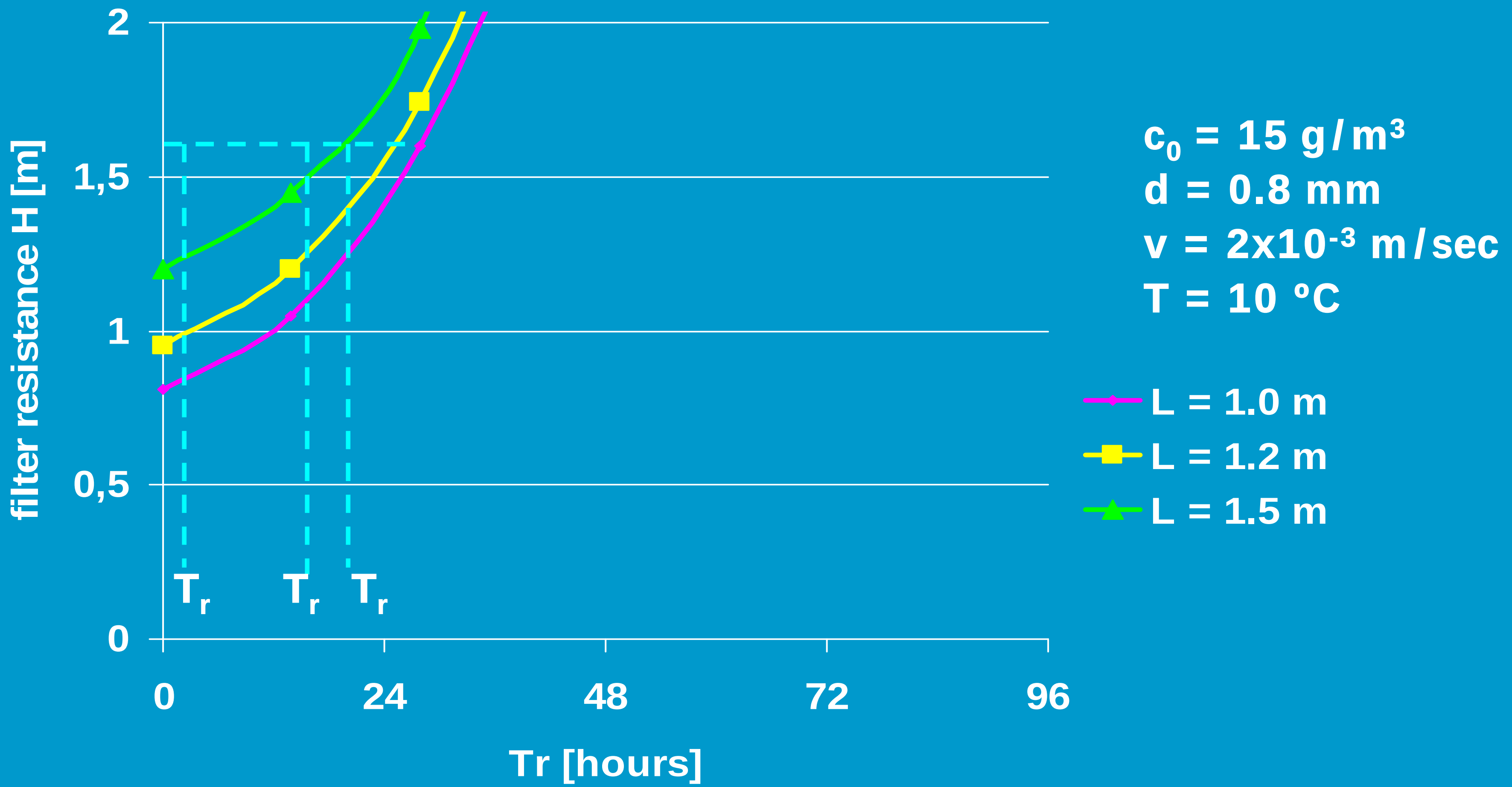
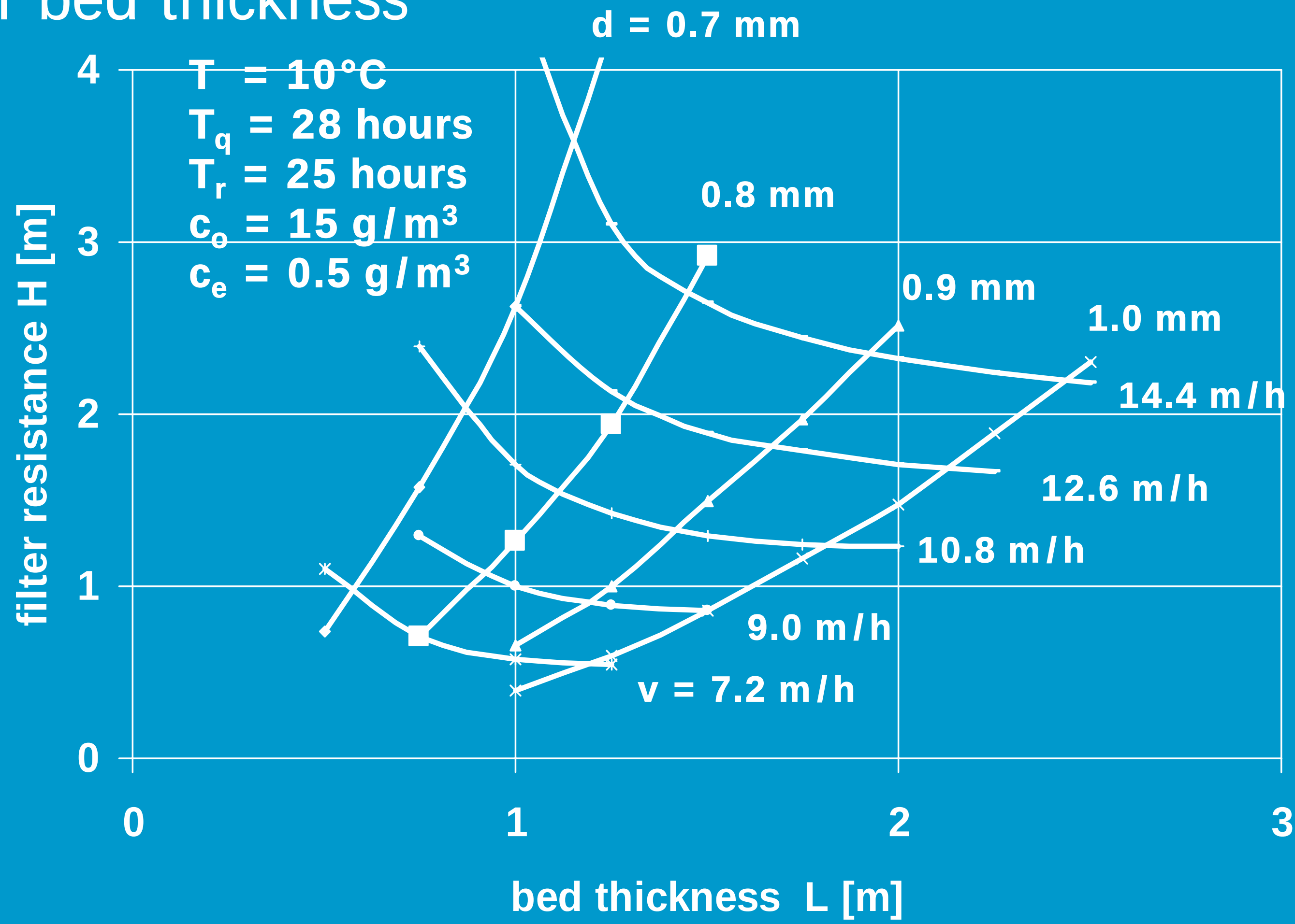
Filtration

Filter bed thickness (T_r)



Filtration

Filter bed thickness



Filtration

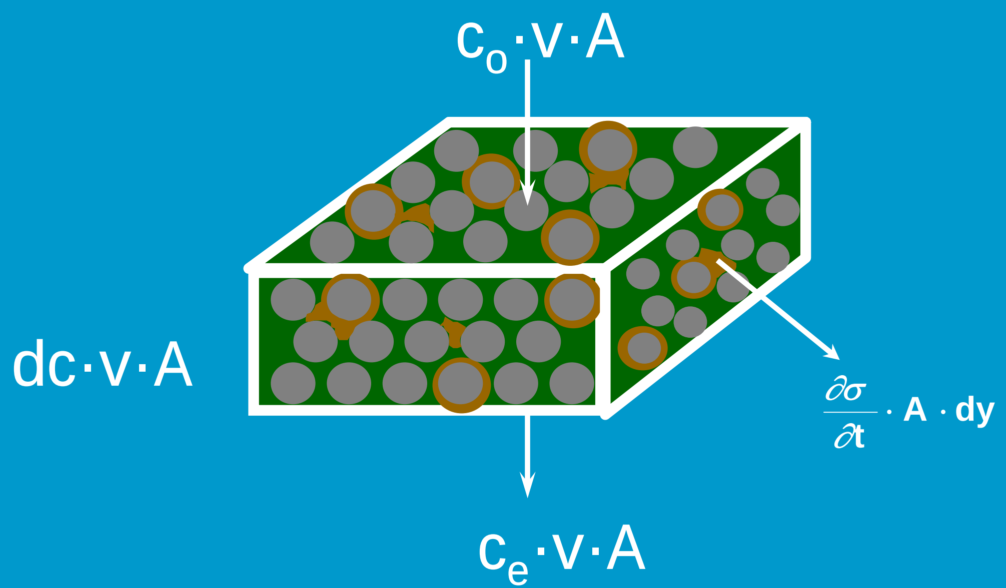
Influence of parameters

Influence parameters on T_q and T_r

	T_q	T_r
higher velocity v	shorter	shorter
larger bed thicknes L	longer	shorter
larger grain diameter d	shorter	longer

Filtration

Filtration theory



$$\frac{\partial \sigma}{\partial t} \cdot A \cdot dy = dc \cdot v \cdot A$$

$$\frac{\partial \sigma}{\partial t} = v \cdot \frac{\partial c}{\partial y}$$

c = concentration colloids [g/m^3]
A = filtration-surface [m^2]
v = filtration velocity [m/s]
σ = concentration accumulated materials [g/m^3]

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Filtration

Filtration theory

1. Kinetic equation (quality)

$$-\frac{\partial \mathbf{c}}{\partial \mathbf{y}} = \lambda \cdot \mathbf{c}; \quad \lambda = \lambda_{\mathbf{o}} \cdot \left(\mathbf{1} - \frac{\sigma_{\mathbf{v}}}{(\mathbf{n} \cdot \mathbf{p_o})}\right)$$ Lerk-Maroudas

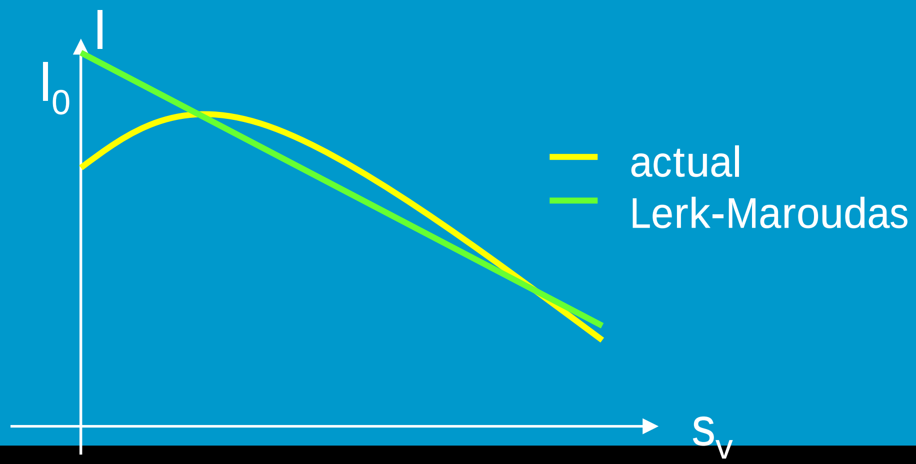
$$\sigma_{\mathbf{v}} = \frac{\sigma}{\rho_{\mathbf{d}}}$$ = reduction in volume of pores

r_d = density of accumulated materials [kg/m^3]

p_0 = inital porosity [-]

l = filtration coefficient [s^{-1}]

n = maximum filling of pores (0 < n < 1)



Filtration

Filtration theory

2. Mass balance (pore clogging)

$$Dc = f(Ds)$$

3. Pressure drop

$$\mathbf{H} = \mathbf{H_o} \cdot \left(\frac{\mathbf{p_o}}{\mathbf{p_o} - \sigma_\mathbf{v}} \right)^{\mathbf{2}}$$

H = drop in resistance [m]

H_o = clean bed resistance [m]

Filtration

Equation kinetics and mass balance

simplified equation: constant feed quality

$$c = c_o \cdot \frac{e^{\alpha \cdot t}}{e^{\lambda_o \cdot y} + e^{\alpha \cdot t} - 1}$$

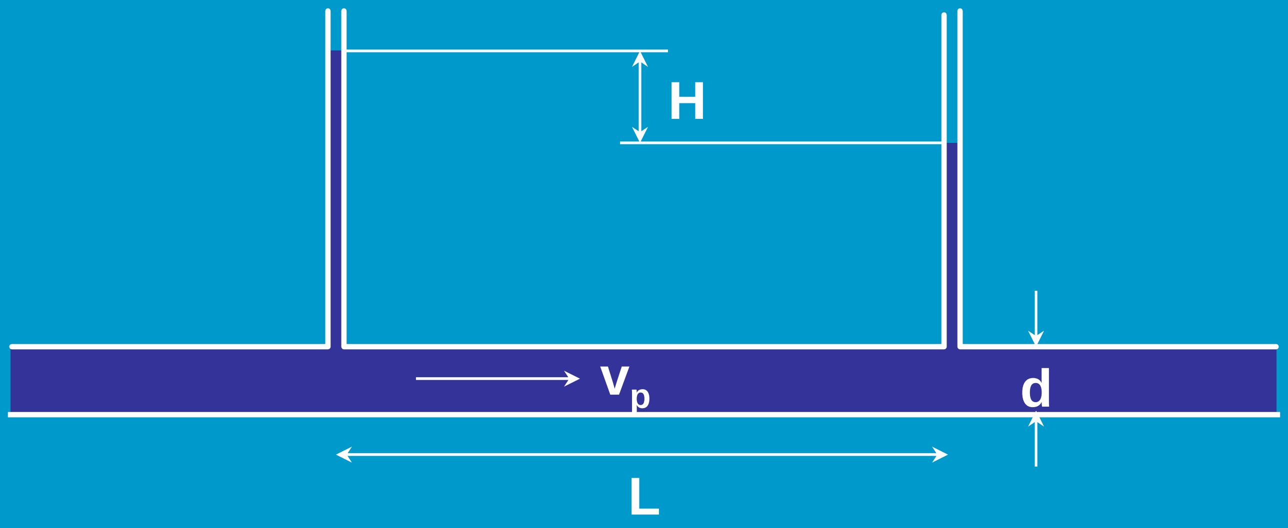
$$\alpha = \frac{v \cdot c_o \cdot \lambda_o}{n \cdot p_o \cdot \rho_d} \qquad \lambda_o = \frac{9 \cdot 10^{-18}}{\nu \cdot v \cdot d_o^{\,3}}$$

larger grain diameter --> l smaller --> less removal

higher filtration speed --> l smaller --> less removal

Filtration

Filter resistance



$$I_o = \frac{H}{L} = 180 \cdot \frac{\nu}{g} \cdot \frac{(1-p_o)^2}{p_o^{\,3}} \cdot \frac{v}{d_o^{\,2}}$$

Clean bed resistance = $H_o = I_o \cdot L$

Filtration

Equation of pressure drop

$$H = H_o \cdot \left(\frac{p_o}{p_o - \frac{\sigma}{\rho_d}} \right)^2 \longrightarrow H_o = \frac{180}{g} \cdot \nu \cdot \frac{(1 - p_o)^2}{p_0{}^3} \cdot \frac{v}{d^2} \cdot L$$

H and c depend on

design parameters: v, d, p_o, L

influent composition: c_o, r, n, T

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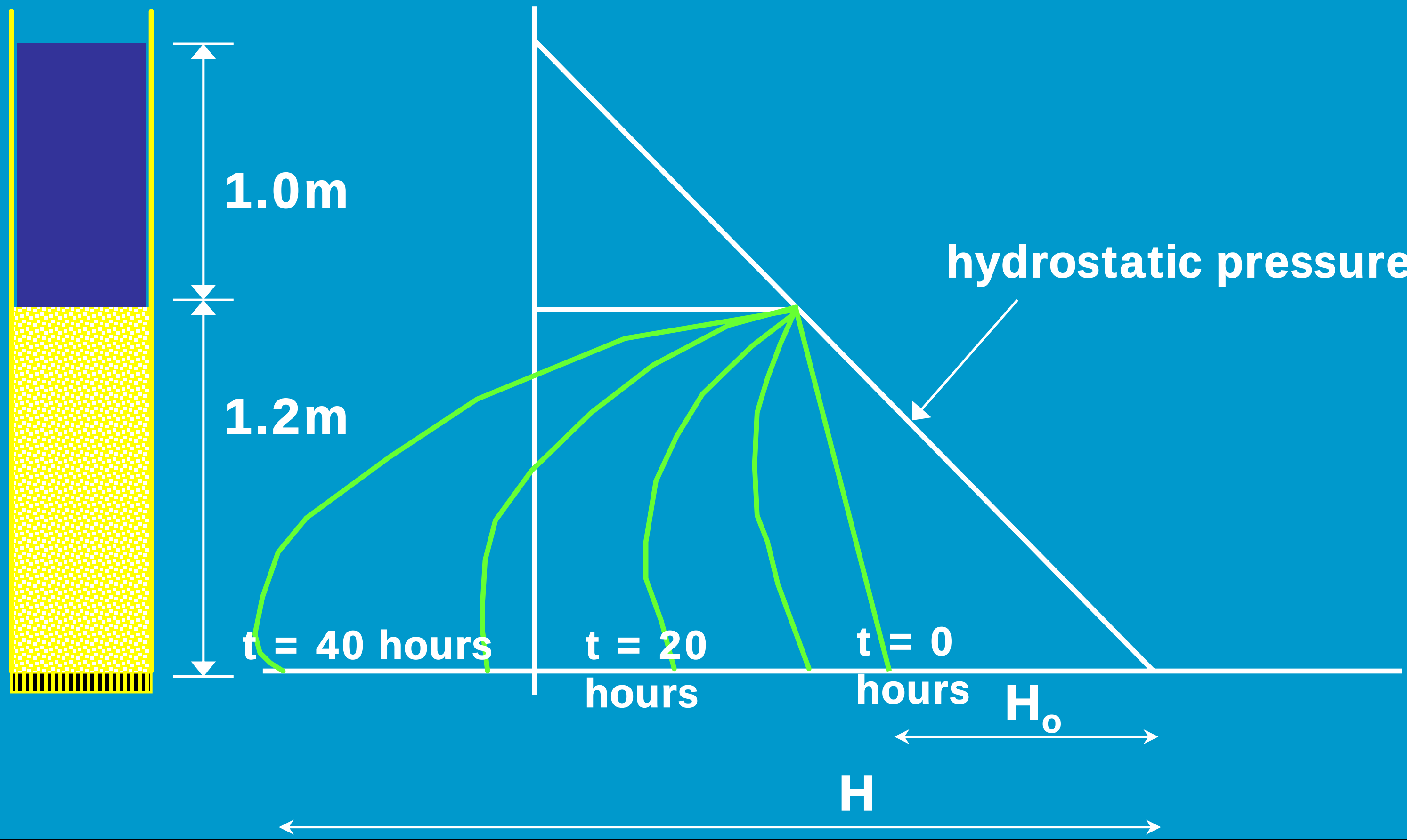
Filtration

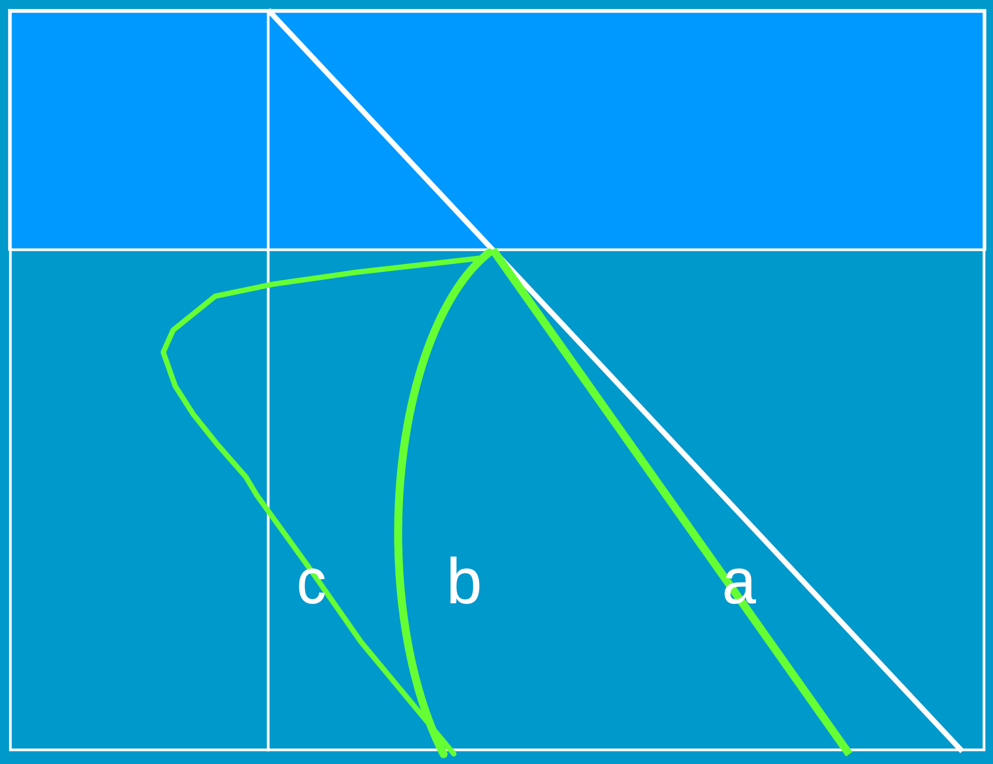
Filter resistance



Filtration

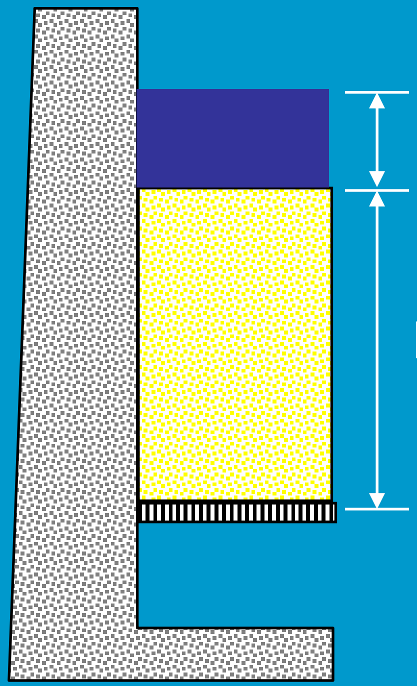
Resistance development

a clean bed resistance
b deep fouling
= deep bed filtration
c shallow fouling
= cake filtration

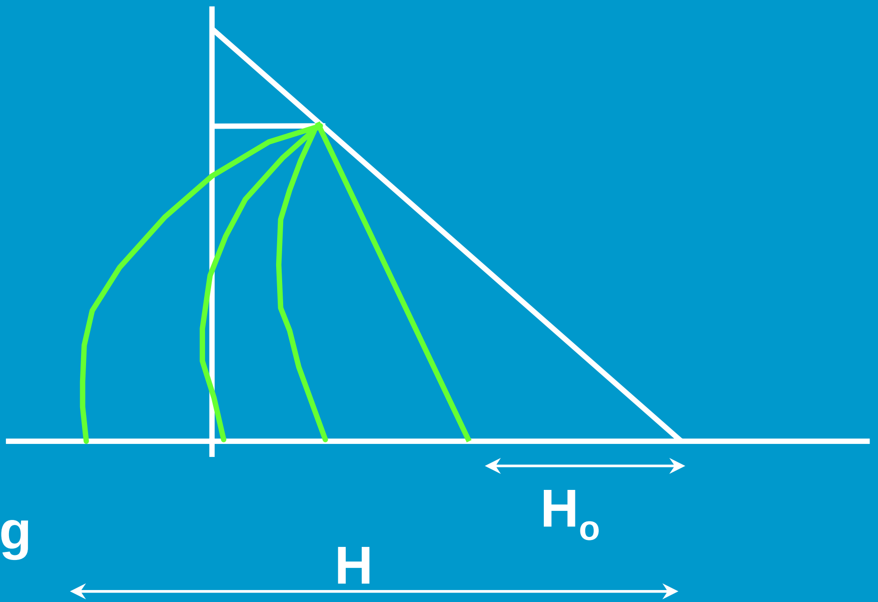


Filtration

Negative pressure



result: degassifying

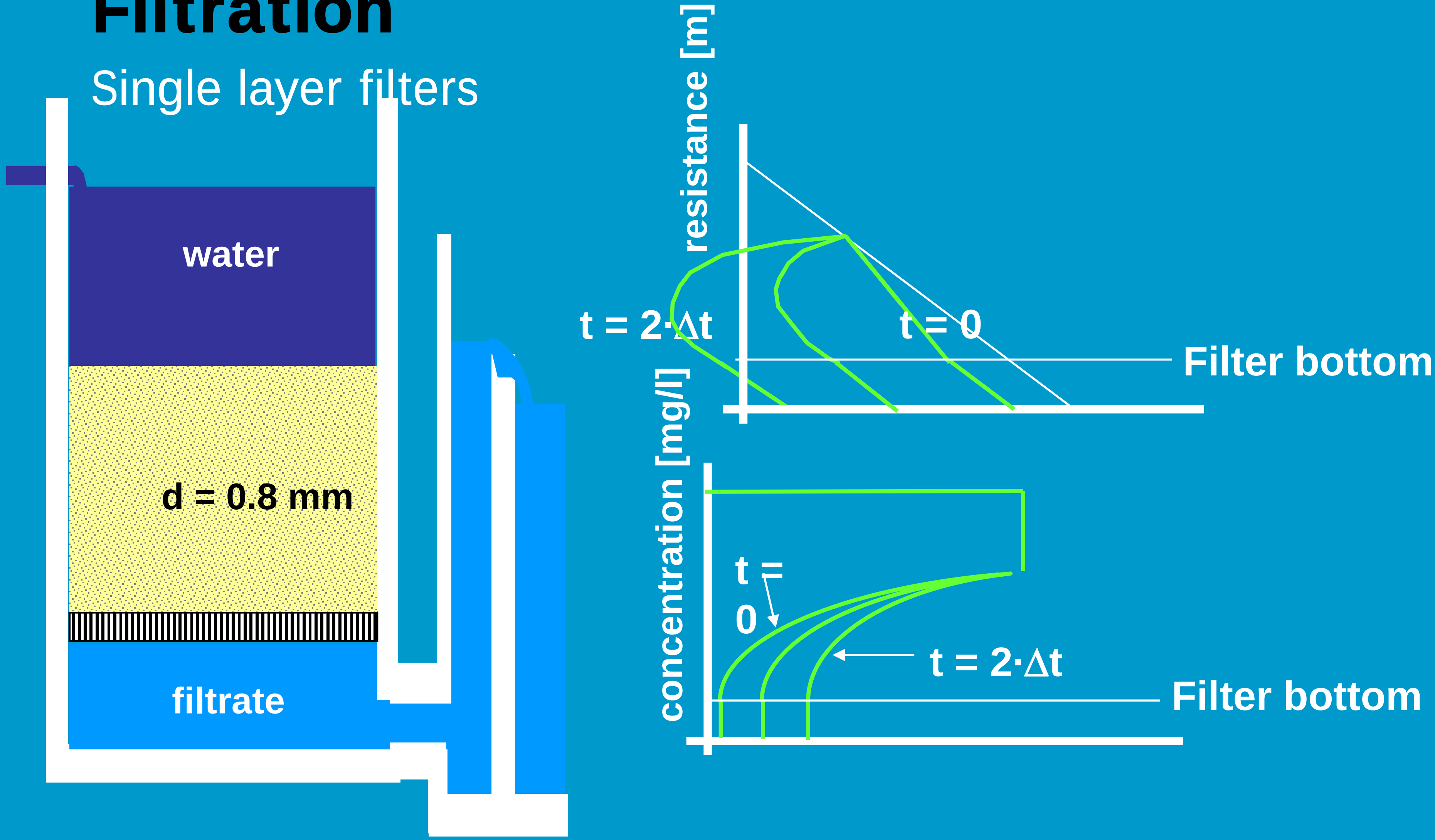


Prevention of negative pressure:

- D > H - L with deep bed filtration
- D > H with cake filtration

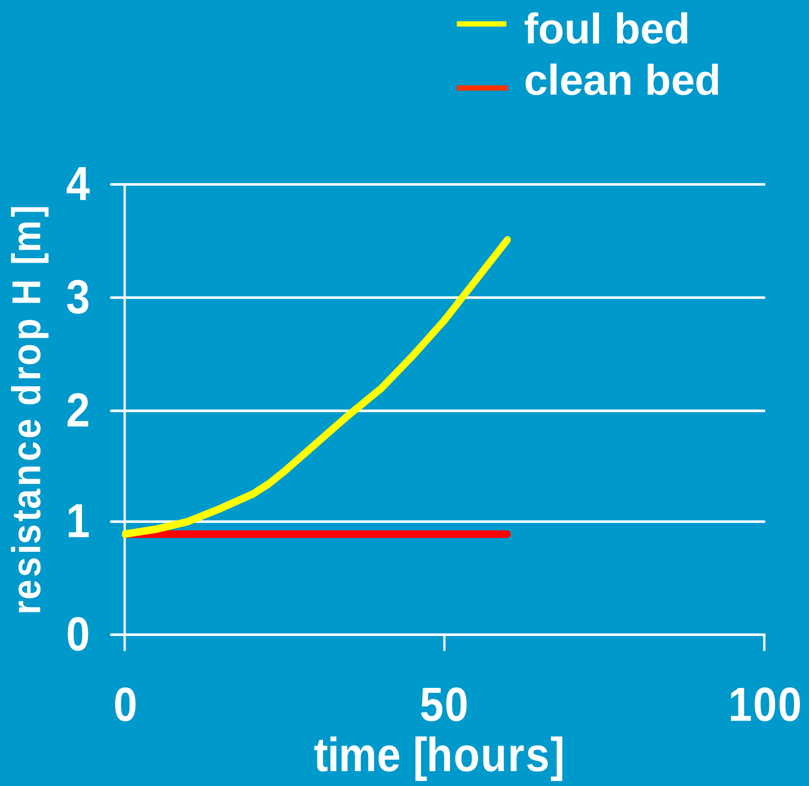
Filtration

Single layer filters



Filtration

Single layer filters



Single layer

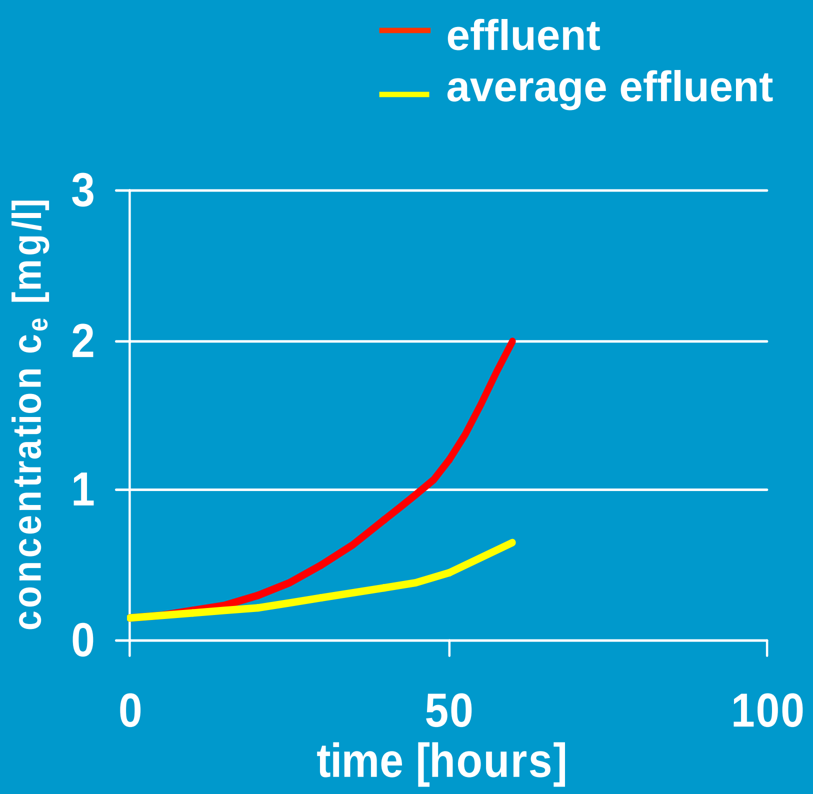
c_o = 15 g/m^3; ρ = 50 kg/m^3
n = 0.61; T = 10°C
v = 10.8 m/h

sand
d = 0.8 mm
p_o = 0.38
L = 1.1 m

T_q = 27 h

Filtration

Single layer filters



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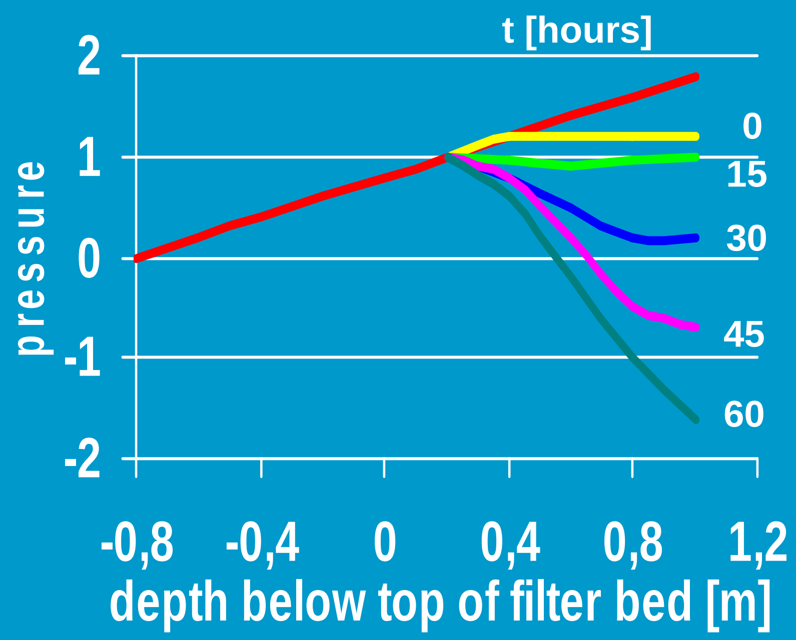

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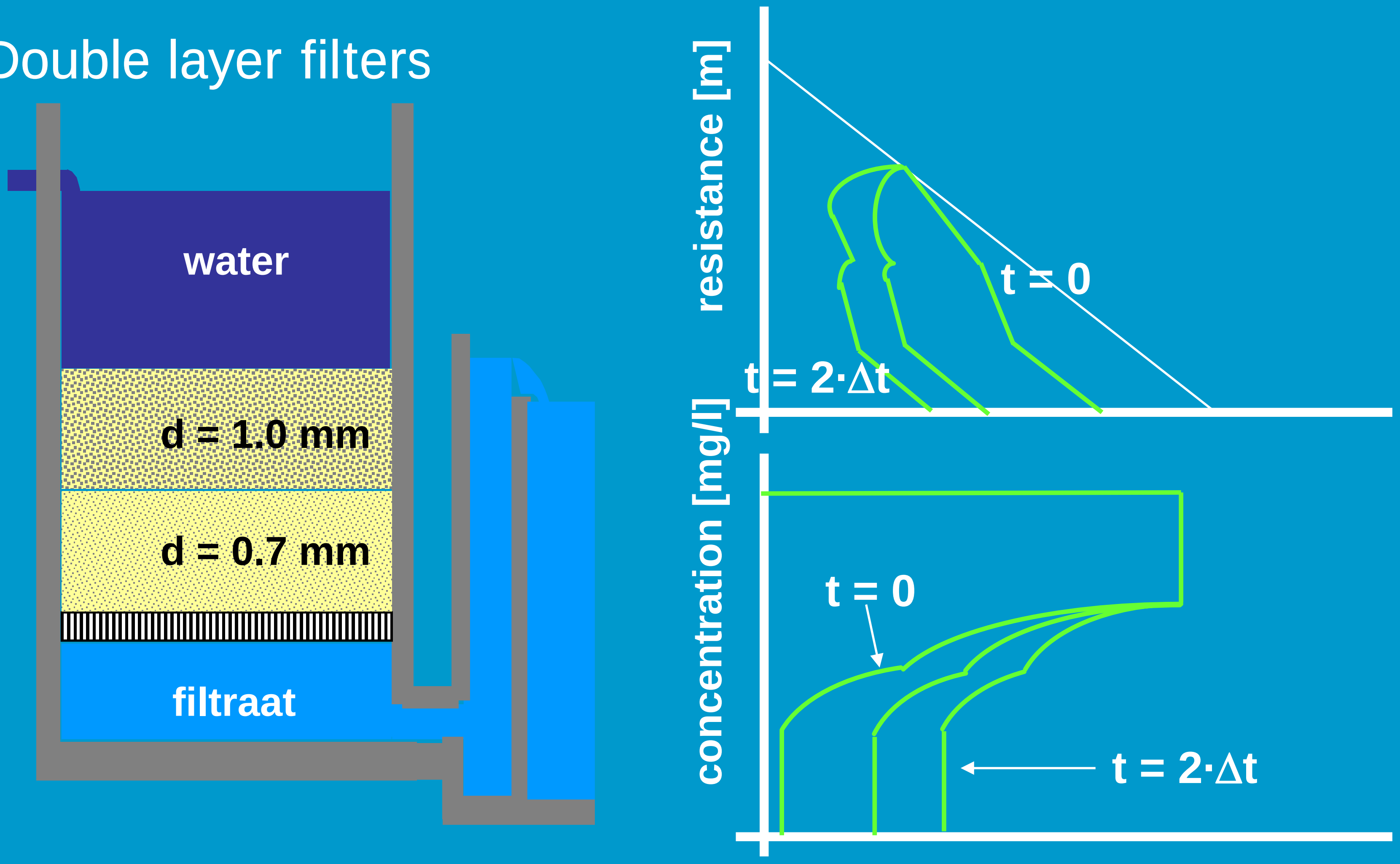

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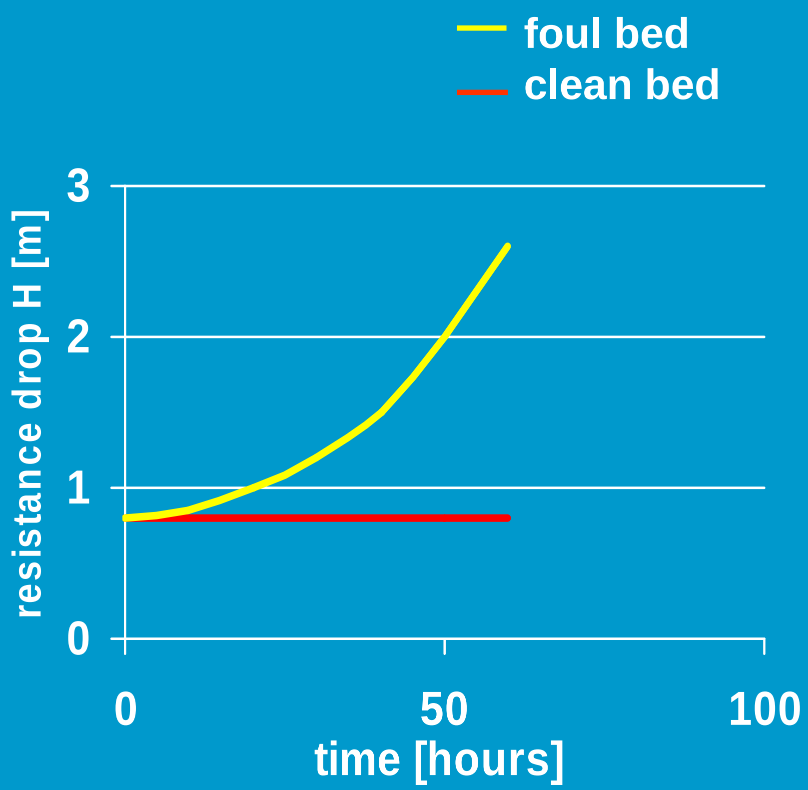
Filtration

Double layer filters



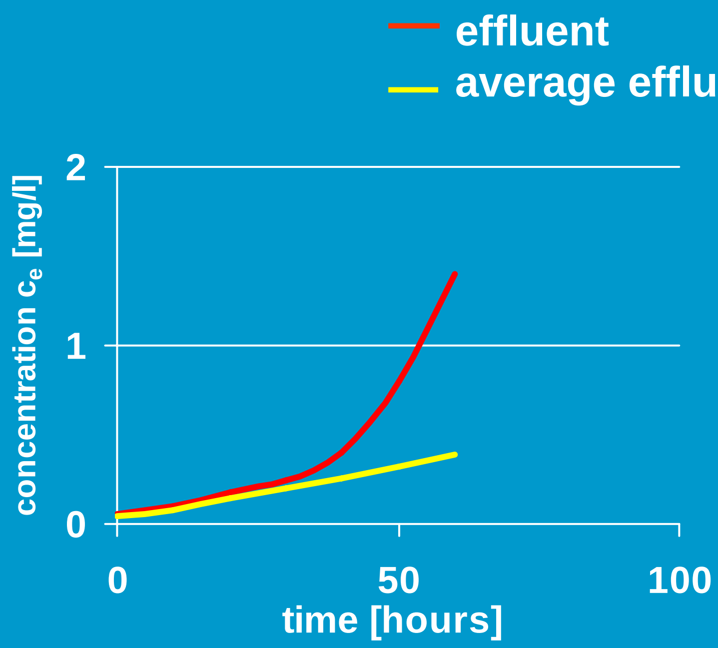
Double layer

c_o = 15 g/m^3;	ρ = 50 kg/m^3
n = 0.61;	T = 10°C
v = 10.8 m/h	
anthracite	sand
d = 1.0 mm	d = 0.7 mm
p_o = 0.5	p_o = 0.38
L = 0.4 m	L = 0.7 m

T_q = 41 h

Filtration

Double layer filters



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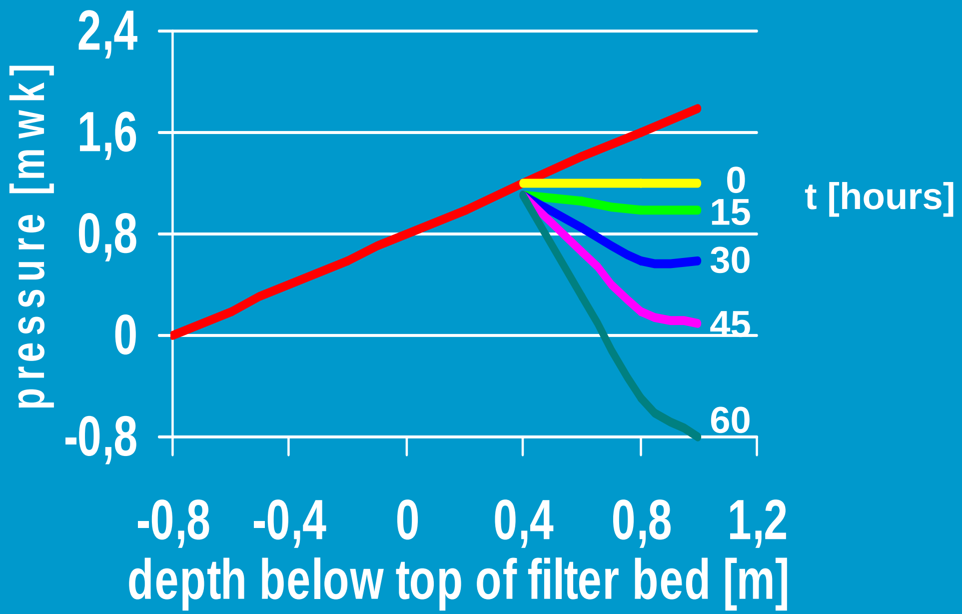
Filtration

Double layer filters



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anthracite	sand
d = 1.0 mm	d = 0.7 mm
p_o = 0.5	p_o = 0.38
L = 0.4 m	L = 0.7 m

T_q = 41 h

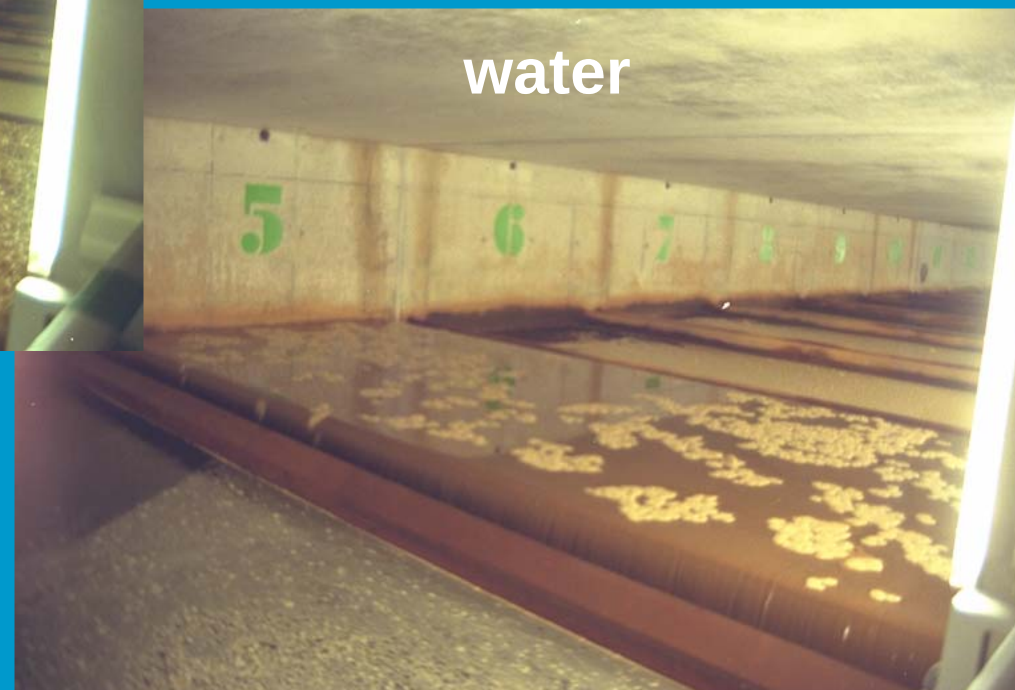
Backwash

Backwash criteria: T_q, T_r

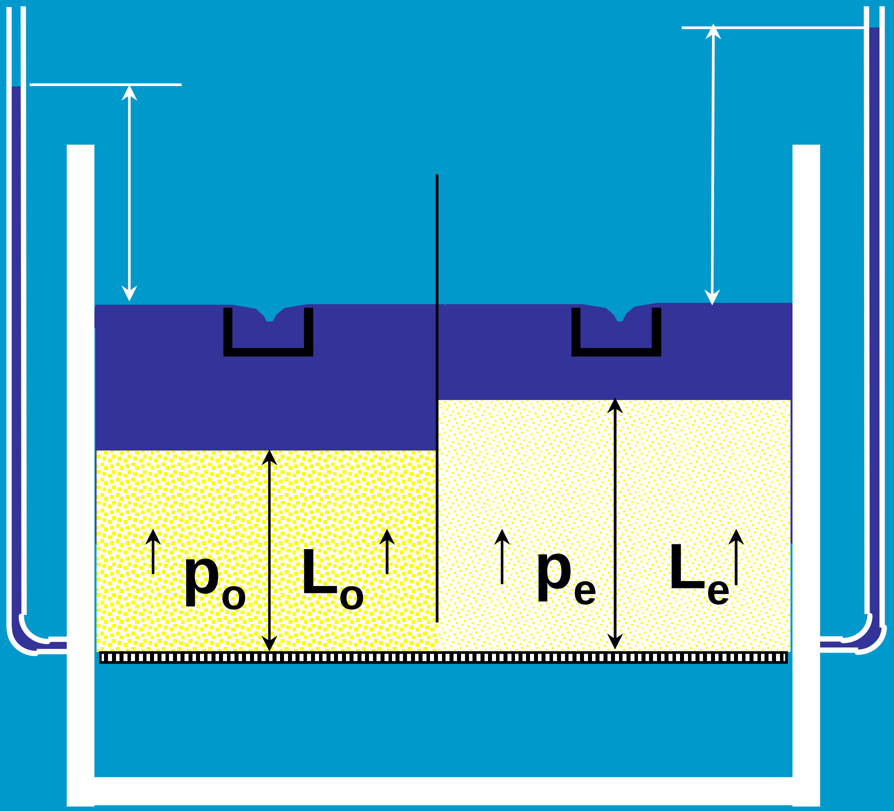
Goal: removal of sludge, bacteria, increase of porosity

Means: water, water and air

Backwash



Backwash



low
backwash velocity:
no expansion

high
backwash velocity:
expansion

$$E = \frac{L_e - L_o}{L_o}$$

ϕ = 0.8 mm -> E = 15 - 20%
ϕ = 1.2 mm -> E = 10%

$$(1 - p_o) \cdot L_o = (1 - p_e) \cdot L_e$$

$$p_e = \frac{p_o + E}{1 + E}$$

Backwash

$$H = 130 \cdot \frac{\nu^{0.8}}{g} \cdot \frac{(1-p_e)^{1.8}}{p_e^{3}} \cdot \frac{v^{1.2}}{d^{1.8}} \cdot L_e$$

$$\rho_w \cdot g \cdot H_{max} = (1-p_o) \cdot L_o \cdot (\rho_f - \rho_w) \cdot g$$

$$H_{max} = (1-p_o) \cdot L_o \cdot \frac{\rho_f - \rho_w}{\rho_w}$$

with $p_o = 0.4$ en $\rho_f = 2600$ kg/m^3 then $H \approx L$

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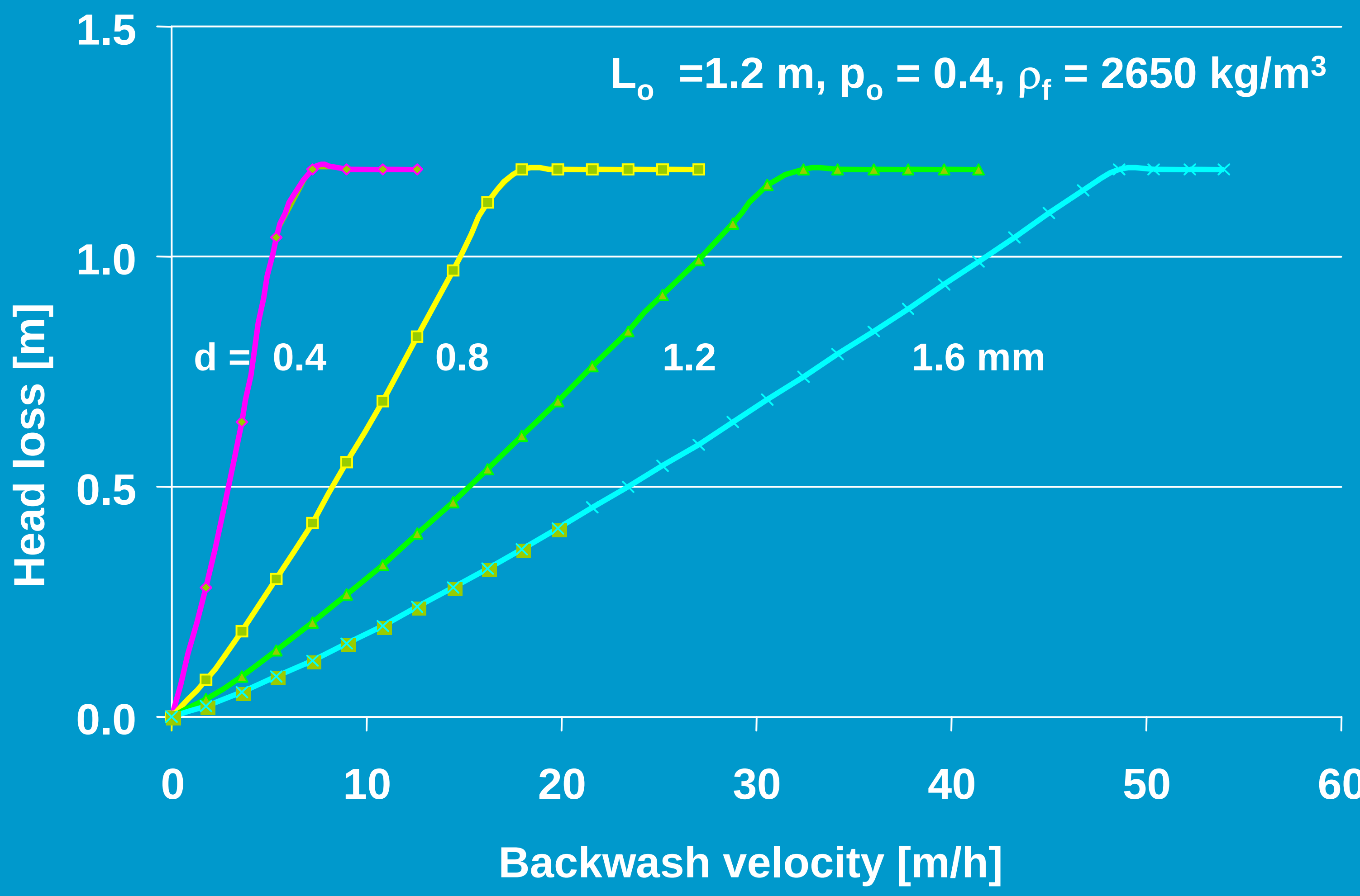
Backwash



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Backwash

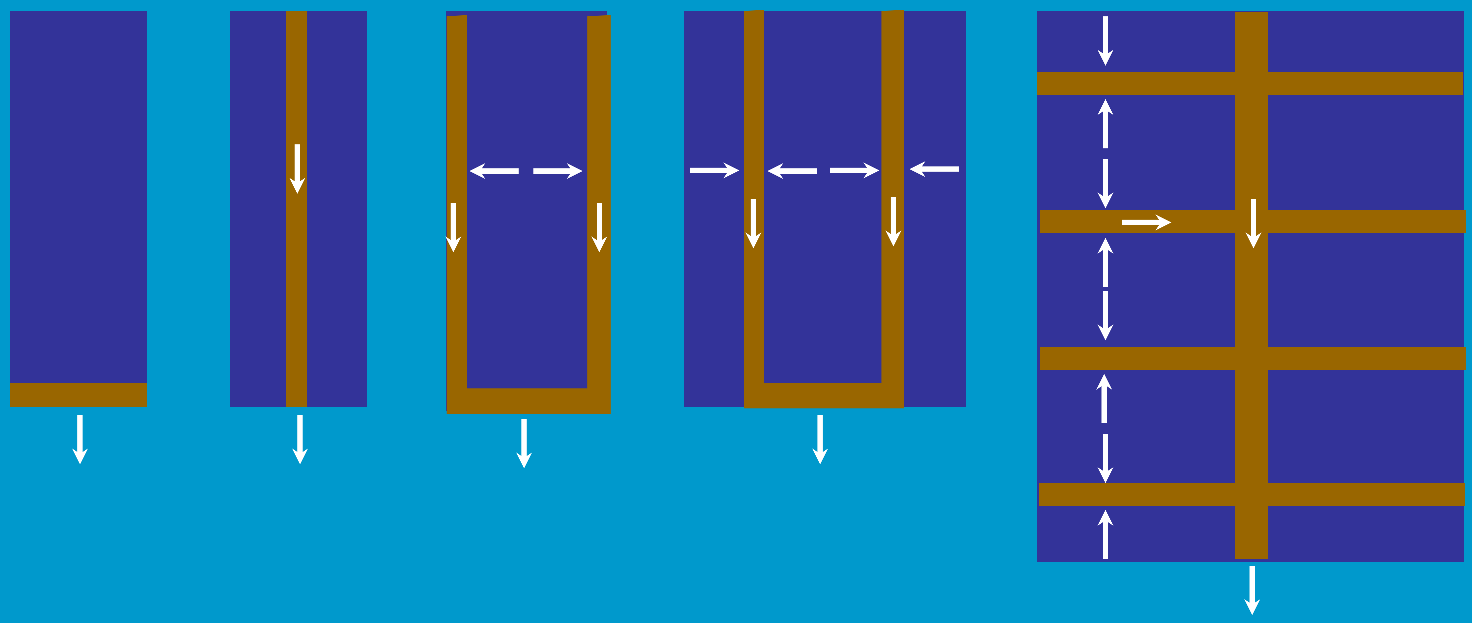
$$v^{1.2} = \frac{g}{130 \cdot \nu^{0.8}} \cdot \frac{\rho_f - \rho_w}{\rho_w} \cdot \frac{p_e^{\ 3}}{(1-p_e)^{0.8}} \cdot d^{1.8}$$

ρ_f/ρ_w = 2.65, d = 1.0 mm, p = 0.38

v [m/h]	E = 0	E = 10	E = 20	E = 30%
T = 0°C	16.2	24.5	33.4	42.9
= 10°C	20.2	30.2	41.4	52.9
= 20°C	23.8	36.0	49.0	63.0
= 30°C	27.7	41.8	56.9	73.1

Backwash

Design of backwash gutter



Backwash

Backwash

Backwash

Pipeworks

Backwash

Rules of thumb for backwashing

velocities:

water:	7 - 30 m/h
air:	30 - 90 m/h

time laps:

preliminary water flush:	2 - 5 min
water and air flush:	5 - 10 min
final water flush:	5 - 10 min

backwashvolume = 1 - 3% of produced water volume

Materials, bottoms and operation

Filter materials

Synthetic grains	1050 - 1300	kg/m^3	→ Double layer (synthetic grains, pumice stone, anthracite)
pumice stone	1200	kg/m^3	
anthracite	1400 - 1600	kg/m^3	
sand	2600	kg/m^3	→ upward (sand, garnet)
garnet	3500 - 4300	kg/m^3	
magnatite	4900 - 5200	kg/m^3	

Materials, bottoms and operation

Filter materials

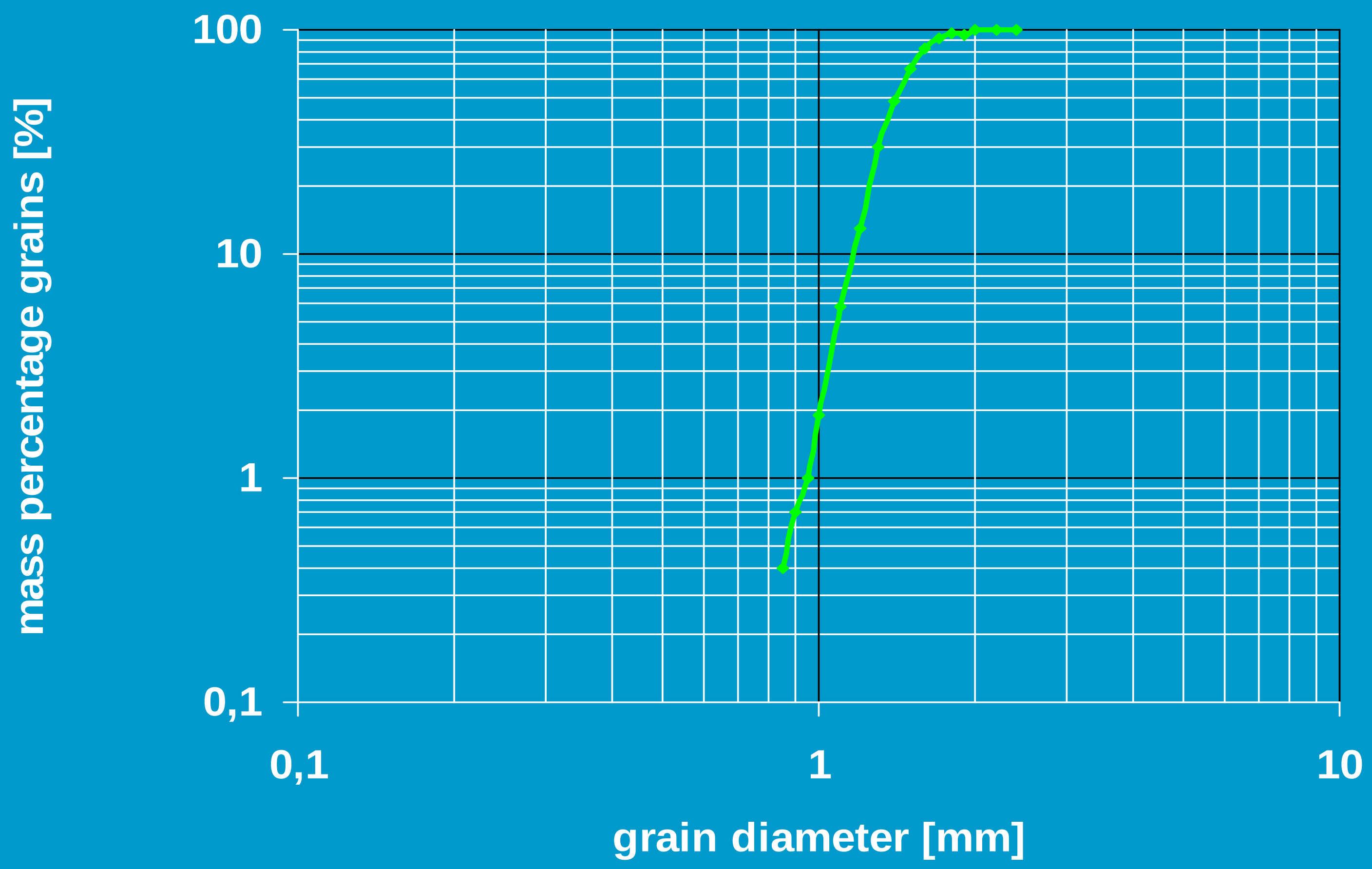
sufficiently resistance to wear
grain diameter within narrow limits
no contaminations

heated and sieved river sand
broken filter materials

sieve curve

Materials, bottoms and operation

Filter materials



Materials, bottoms and operation

Filter materials

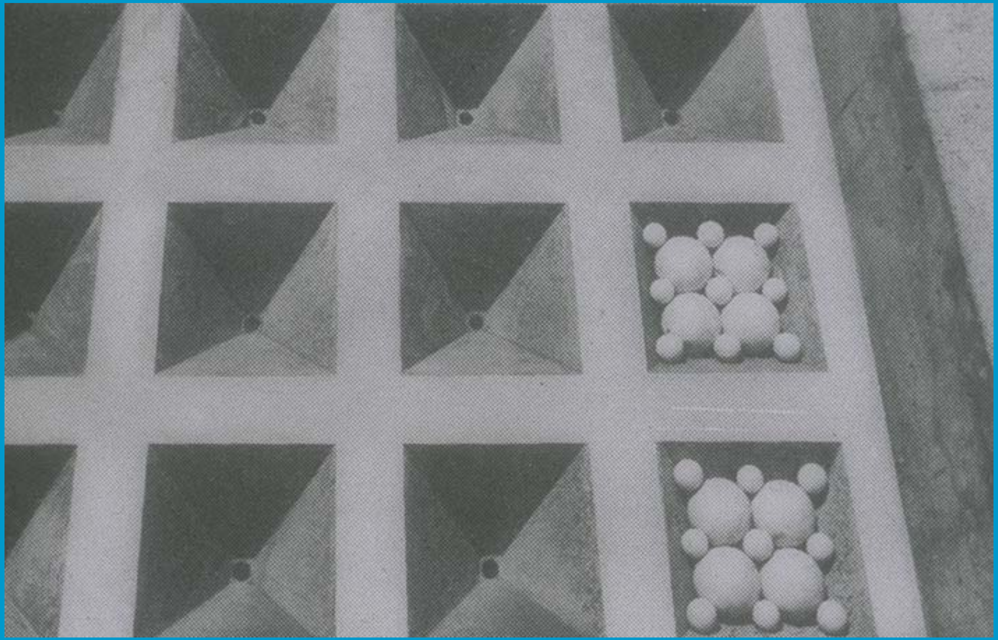
d_{10}: grain diameter for which 10% of the sand composition is smaller than that value

d_{60}: grain diameter for which 60% of the sand composition is smaller than that value

UC: uniformity coefficient = d_{60}/d_{10} = 1.3 - 1.5

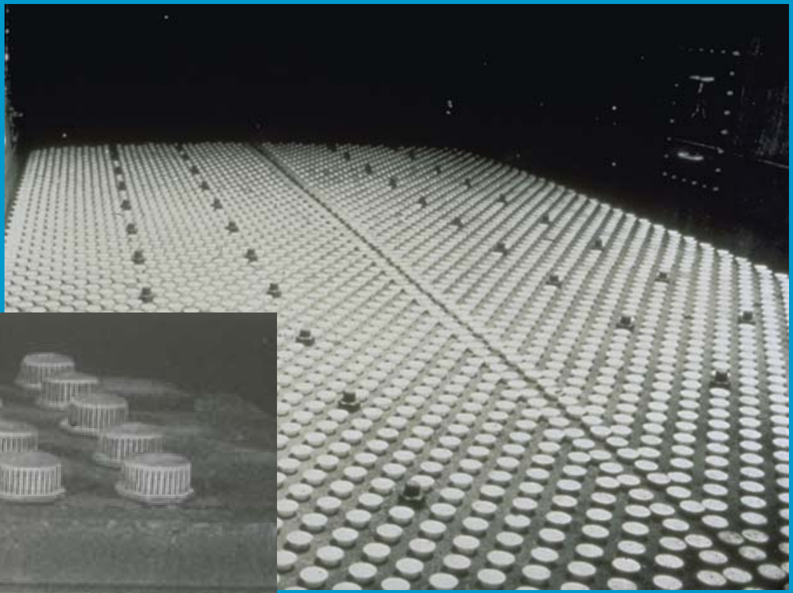
Materials, bottoms and regulation

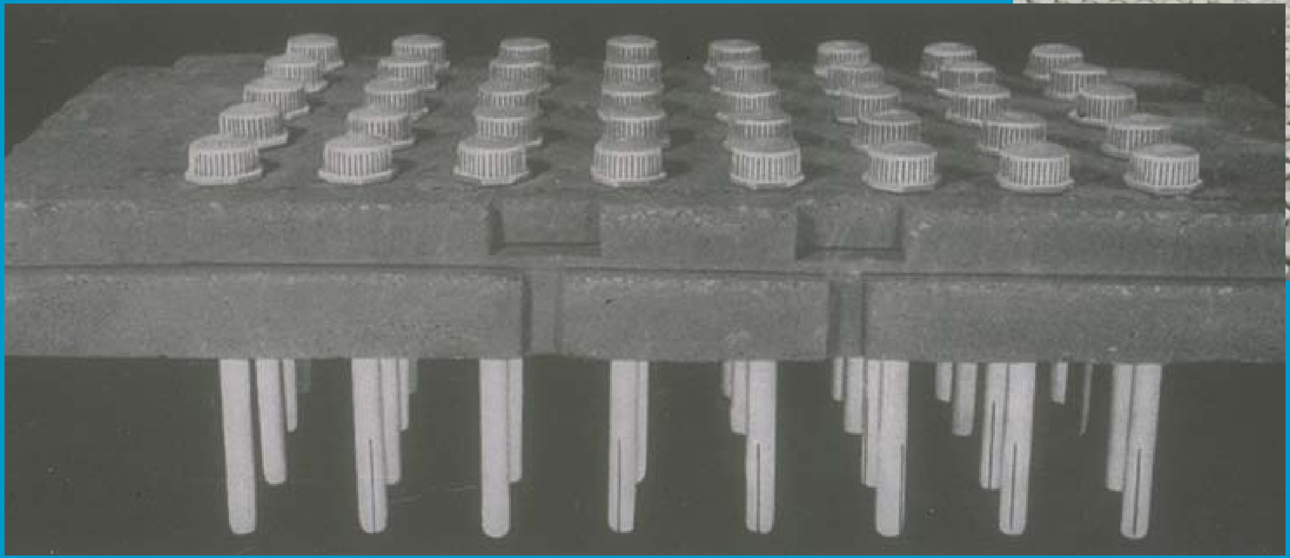
Filter bottoms



Materials, bottoms and regulation

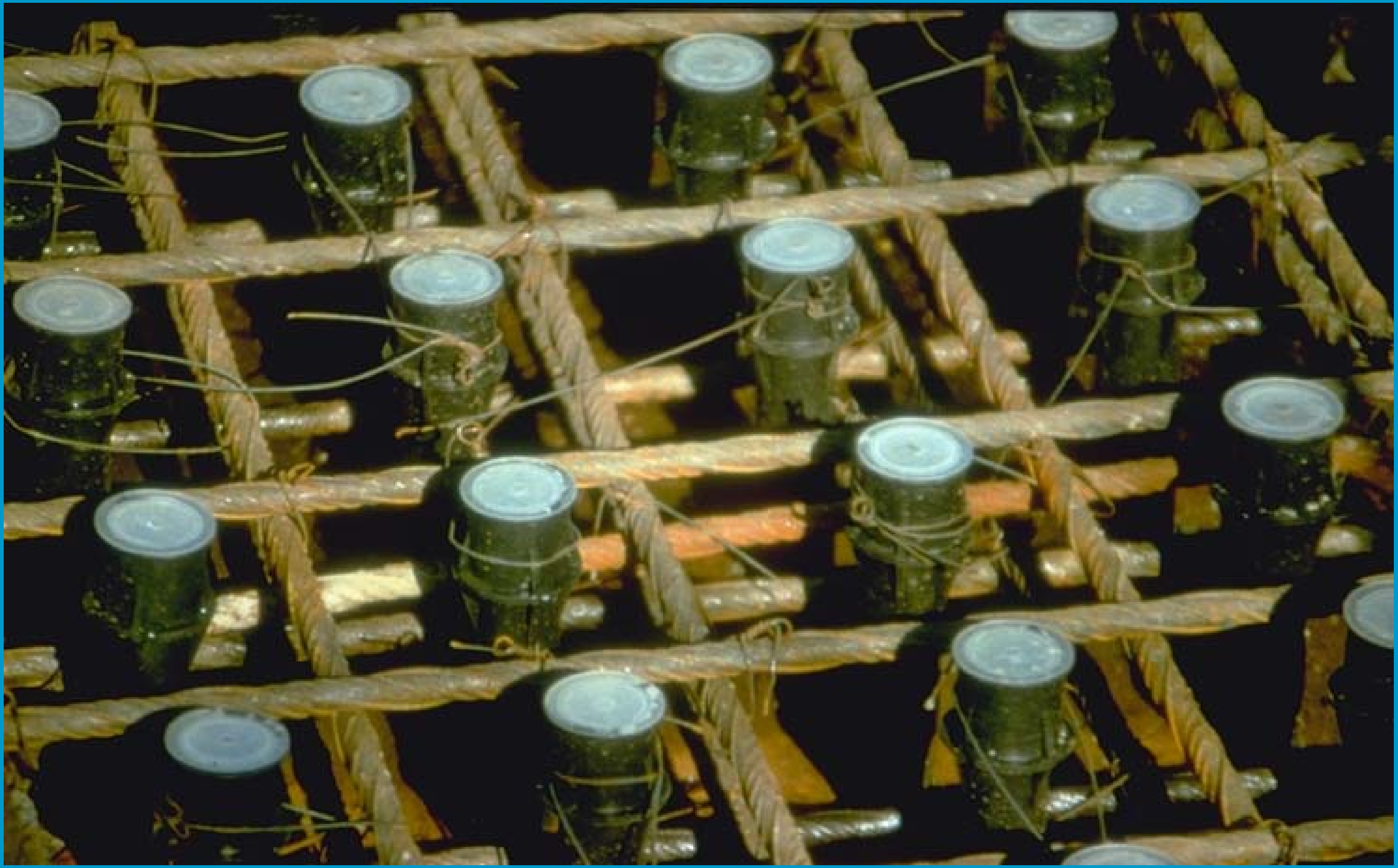
Filter bottoms





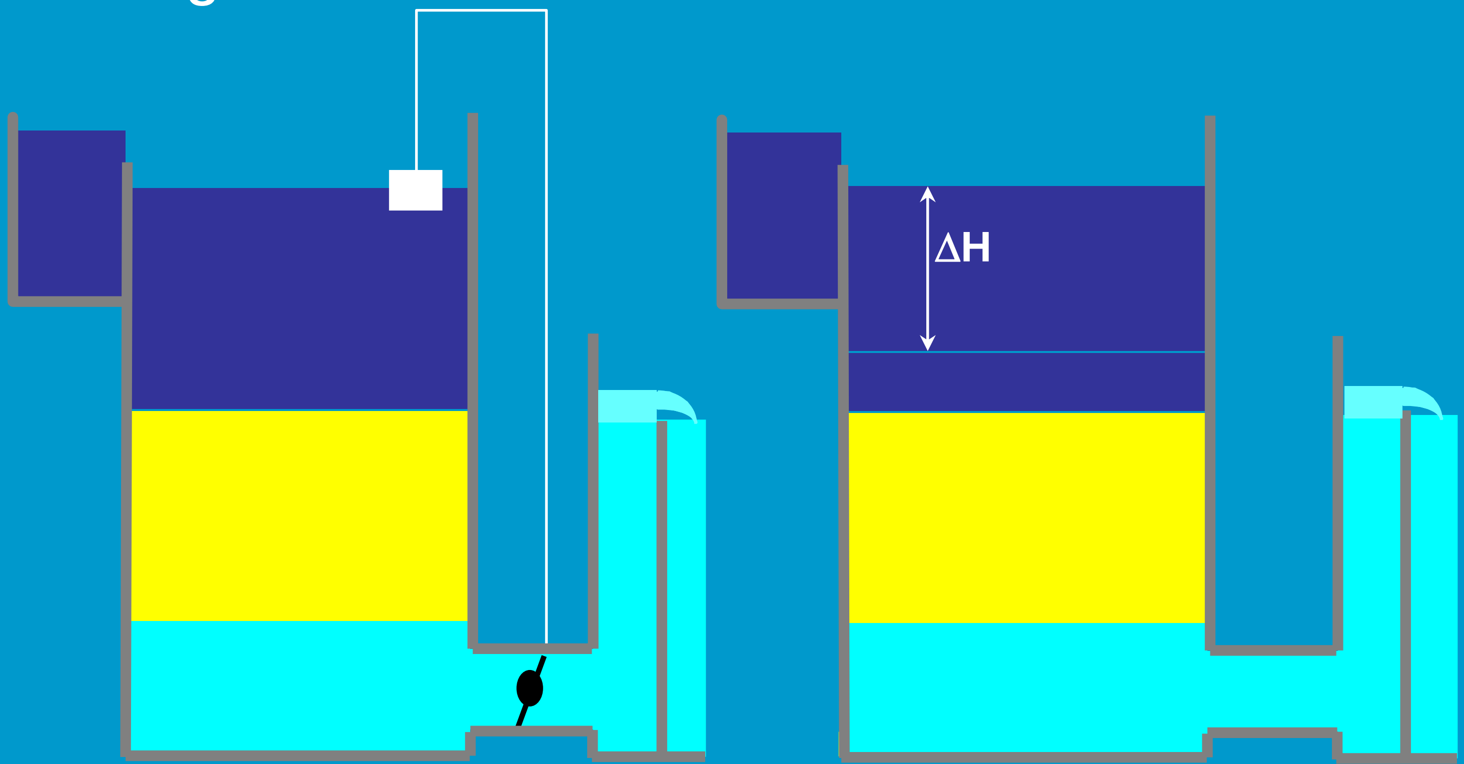
Materials, bottoms and regulation

Filter bottoms



Materials, bottoms and operation

Filter regulation

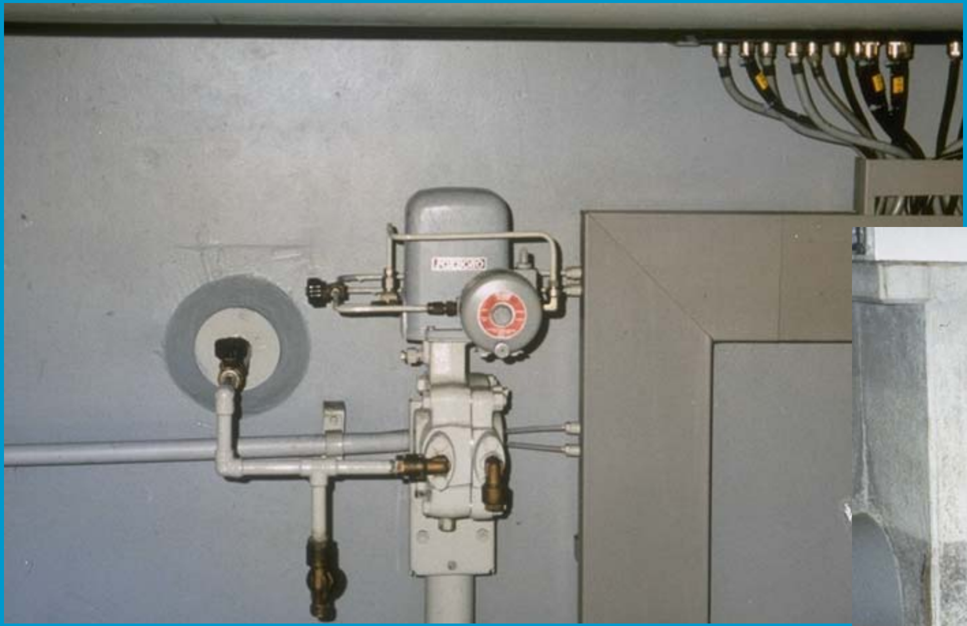


fixed filtration speed ,
fixed top water level

fixed filtration speed,
variable top water level

Materials, bottoms and regulation

Filter regulation

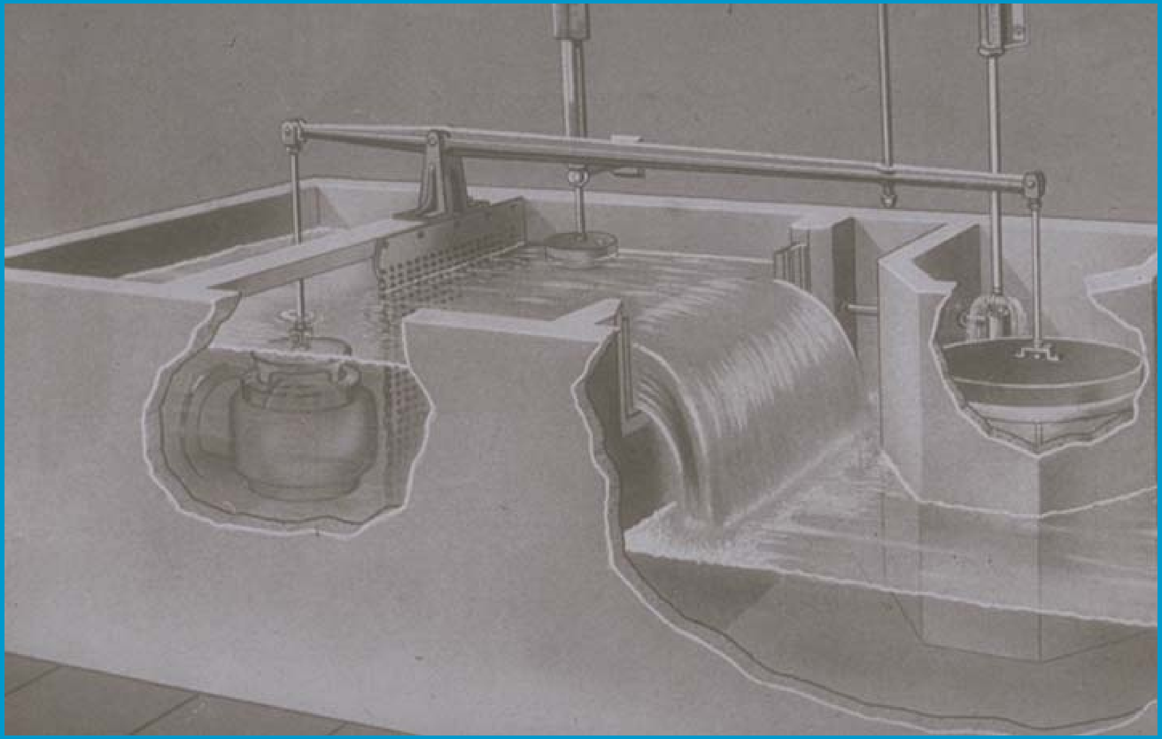


Materials, bottoms and regulation

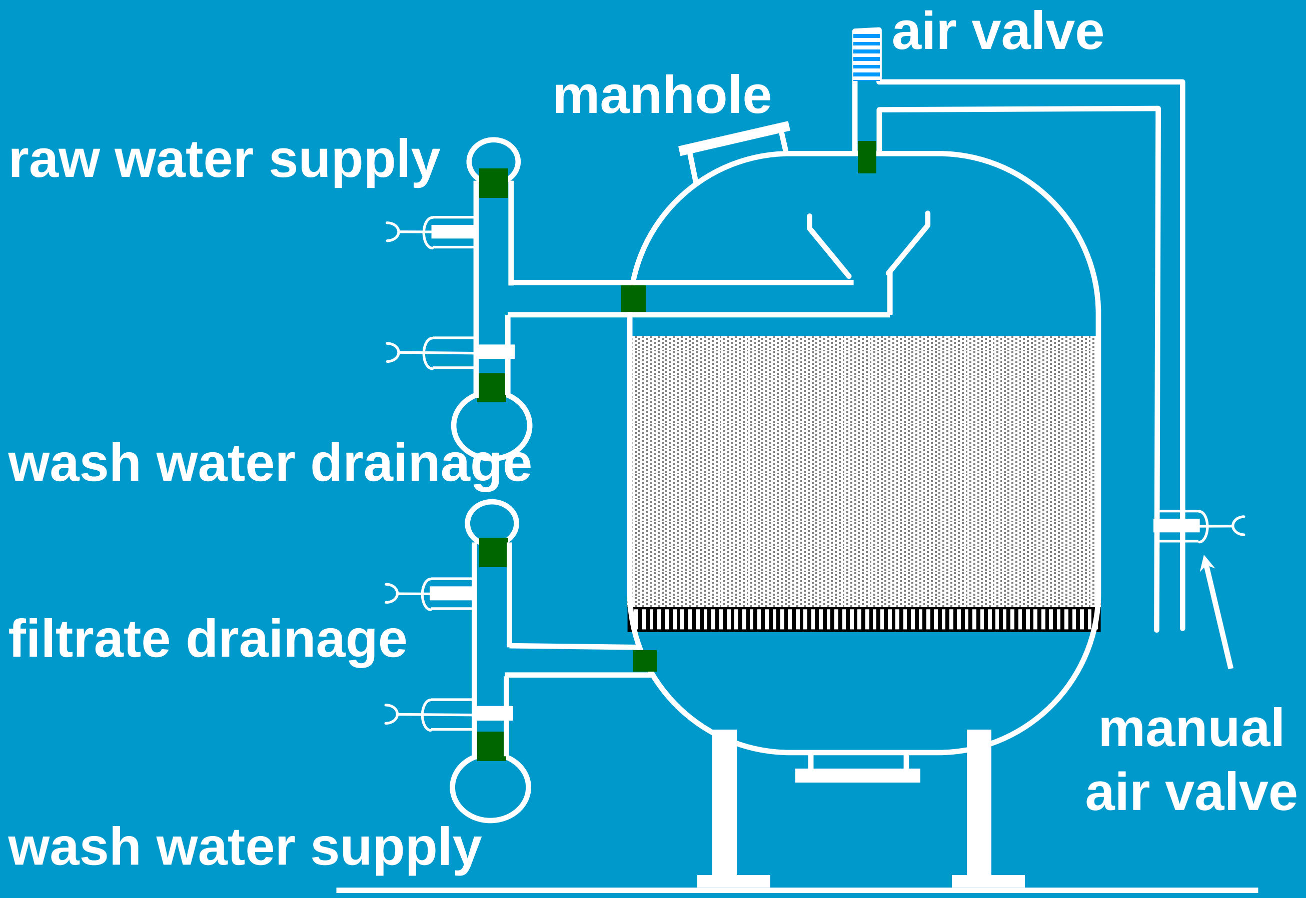
Filter regulation

Materials, bottoms and regulation

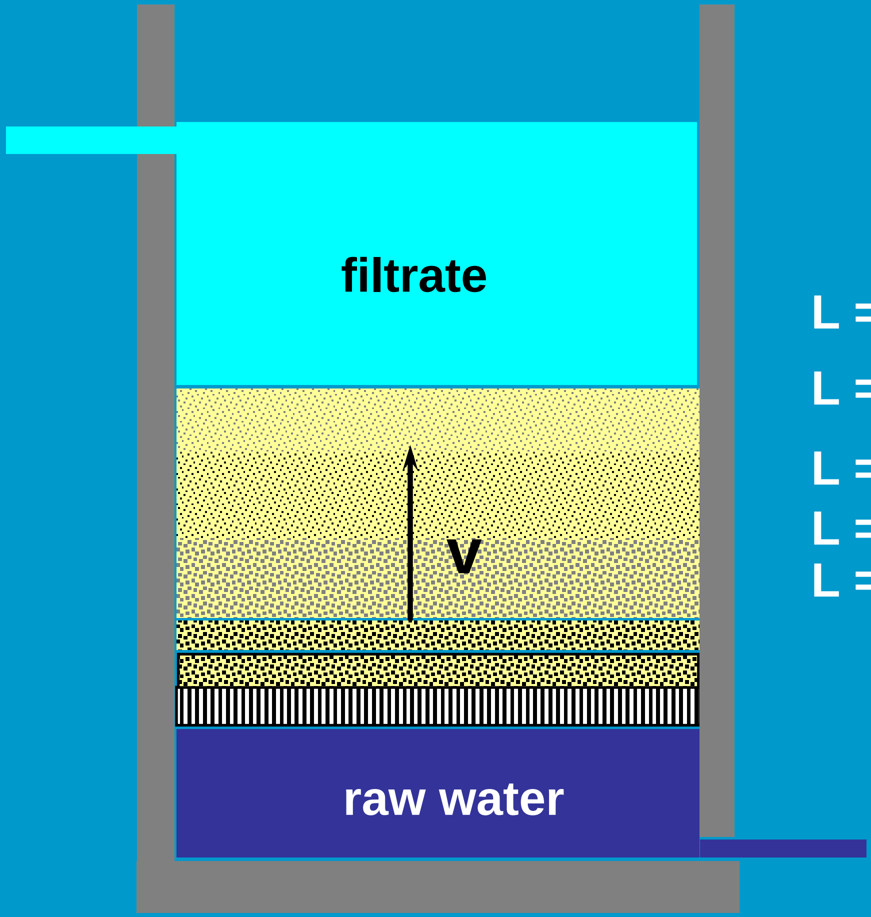
Filter regulation



Pressure filtration



Upward filtration



L = 0.50 m; d = 1.0 - 1.4 mm

L = 0.75 m; d = 1.4 - 2.0 mm

L = 0.75 m; d = 2.0 - 2.8 mm

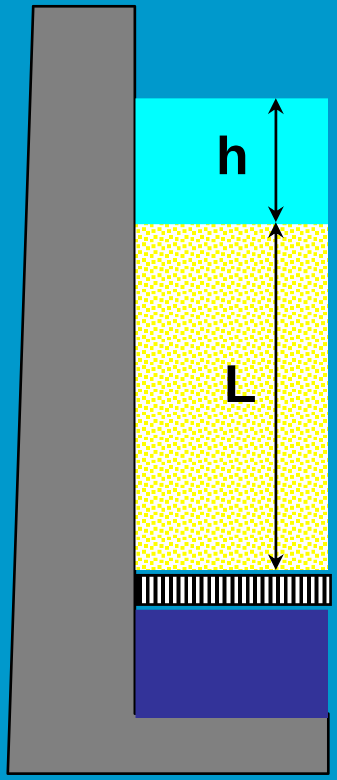
L = 0.30 m; d = 8 - 11 mm

L = 0.15 m; d = 32 - 45 mm

TU Delft

Upward filtration

Upward filtration



$$H_{max} = \frac{\rho_f - \rho_w}{\rho_w} \cdot (1 - p_o) \cdot L_o$$

filter material = sand

ρ_f = 2600 kg/m^3

ρ_w = 1000 kg/m^3 **H = 0.96·L**

p = 0.40

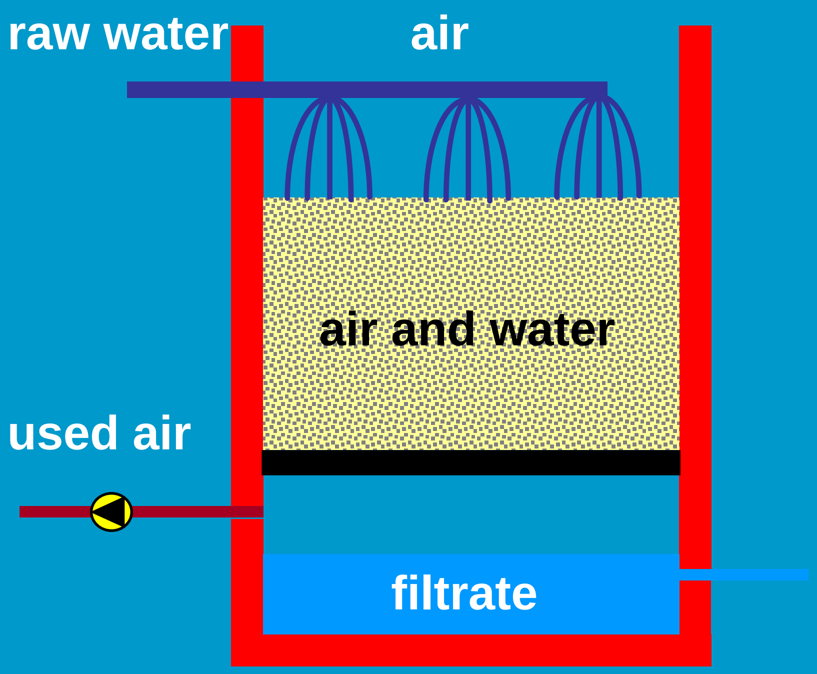
filter material = magnetite

ρ_f =4900 kg/m^3

ρ_w = 1000 kg/m^3 **H = 2.15·L**

p = 0.45

Dry filtration

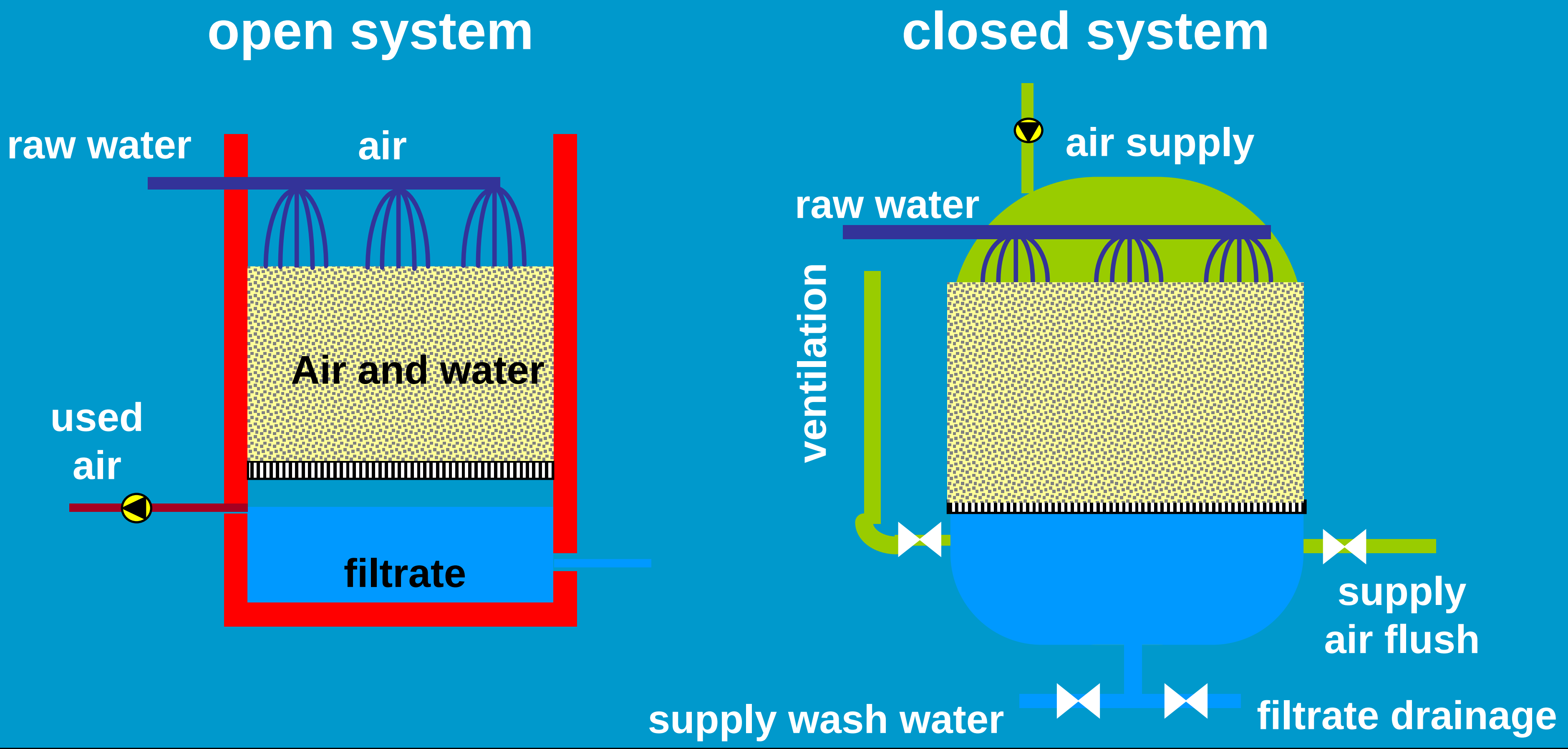


when?
- high ammonia concentration

advantages:
- supplement O_2 concentration
- high water speed
- stripping of CH_4, H_2S and CO_2

Dry filtration

Construction dry filtration



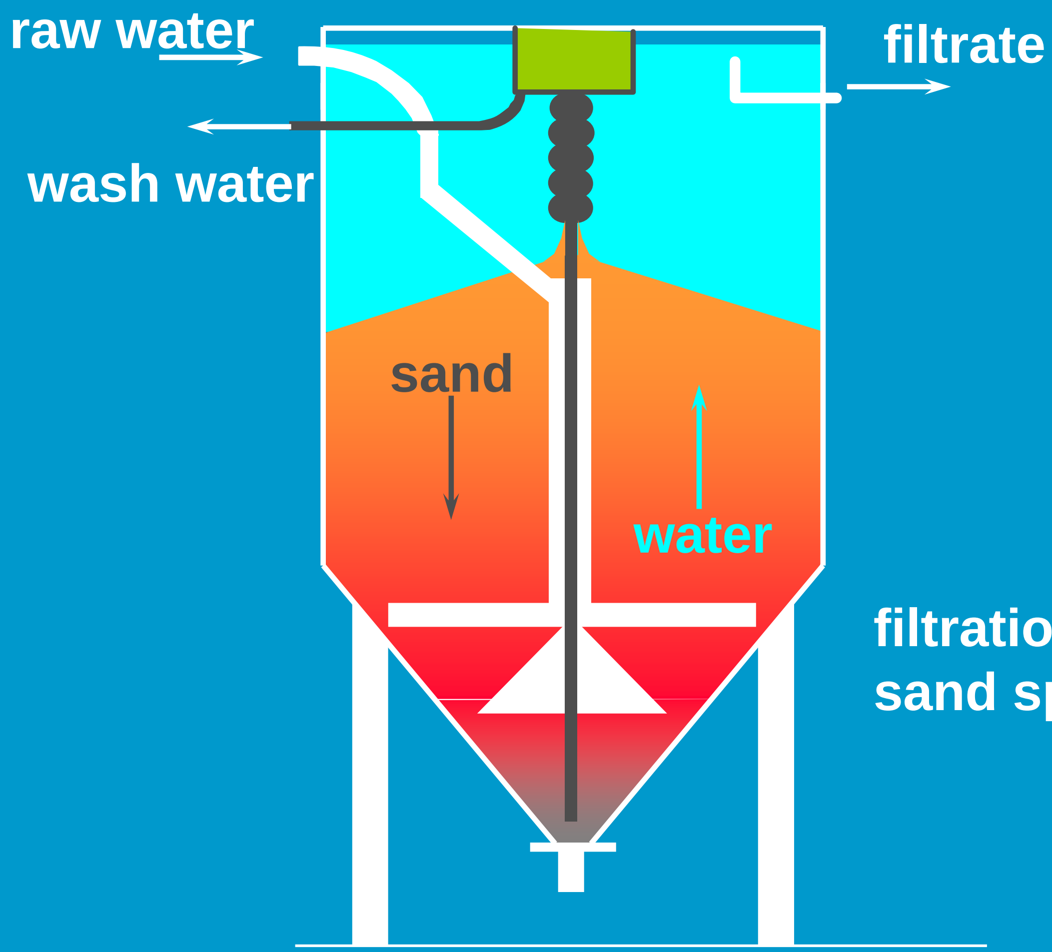
TU Delft

Dry-filtration

Construction dry-filtration

open system:	
filter height:	1.8 - 2.5 m
grain diameter:	0.8 - 2.5 mm
filtration speed:	7 m/h
closed system:	
filter height:	1.8 - 2.5 m
grain diameter:	0.8 - 2.5 mm
filtration speed:	10 - 18 m/h

Continuous filtration



filtration speed: 14 - 18 m/h
sand speed: 2 - 20 mm/s

Slow sand filtration

goal: to make hygienically safe water
polishing filtration (colloids, turbidity)

mechanisms:
- biological ;
- mechanical sieving of colloids;
- adsorption.

location: after rapid sand filtration
run time: few months to one year

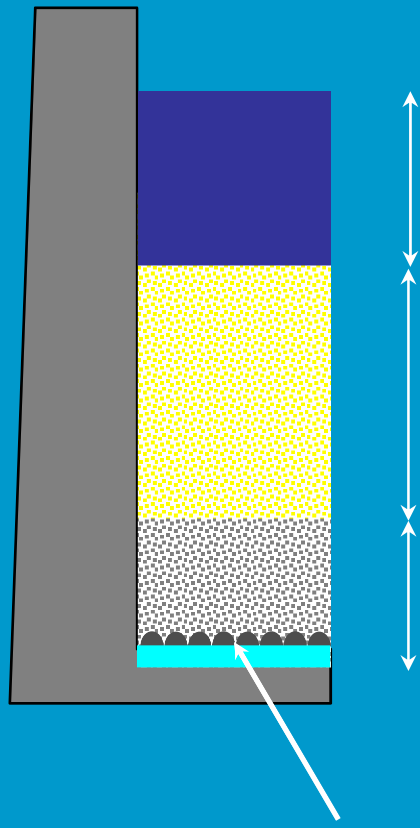
grain diameter: 0.1 - 0.3 mm
filtration speed: 0.1 - 0.3 m/h
results in high surface area requirements

Slow sand filtration

TU Delft

Slow sand filtration

Filter bed



water 0.95 m

sand 1.25 m

gravel 0.65 m

1.0 - 1.5 mm:	0.10 m
1.5 - 3.0 mm:	0.10 m
3.0 - 10 mm:	0.15 m
10 - 30 mm:	0.15 m
30 - 60 mm:	0.15 m

Girders to prevent congestion of bottom

Slow sand filtration