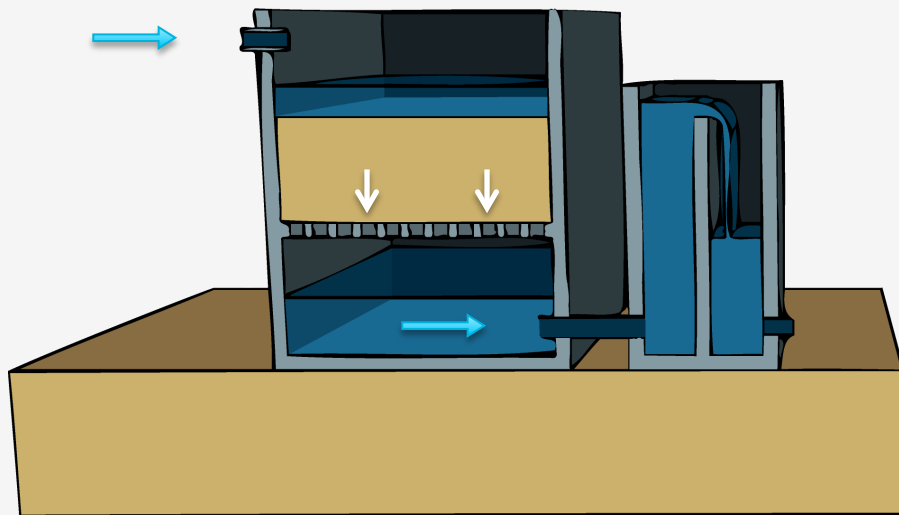


Filtration

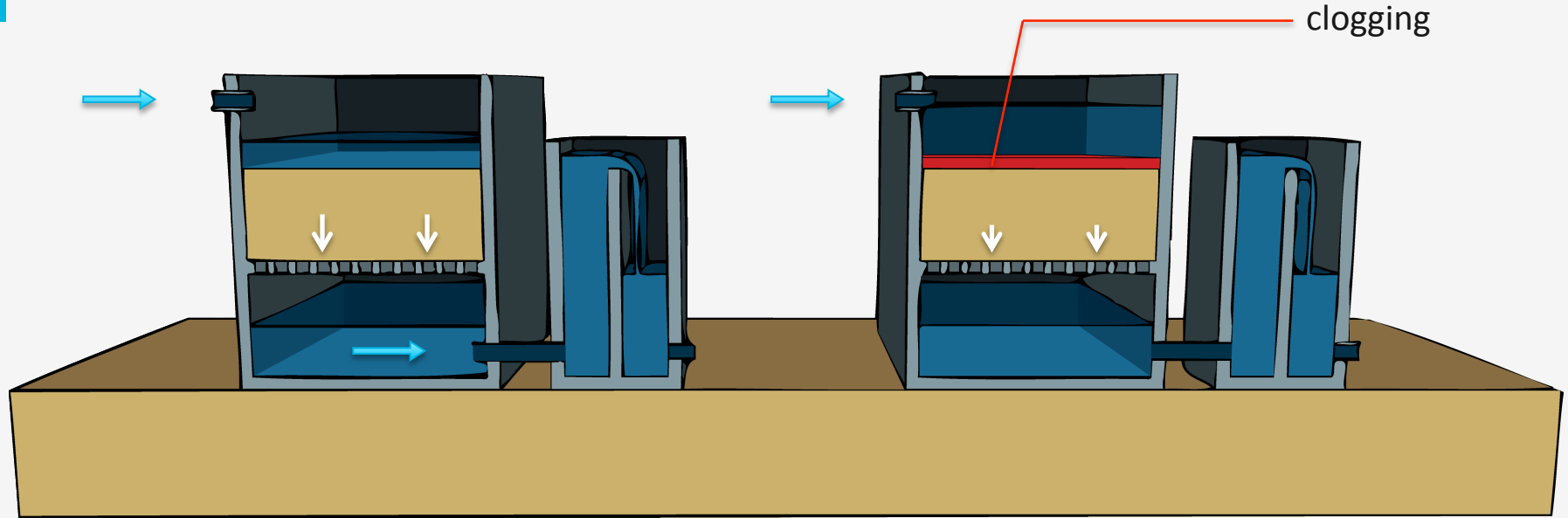
CTB3365x Introduction to water treatment

Prof.dr.ir. Luuk Rietveld

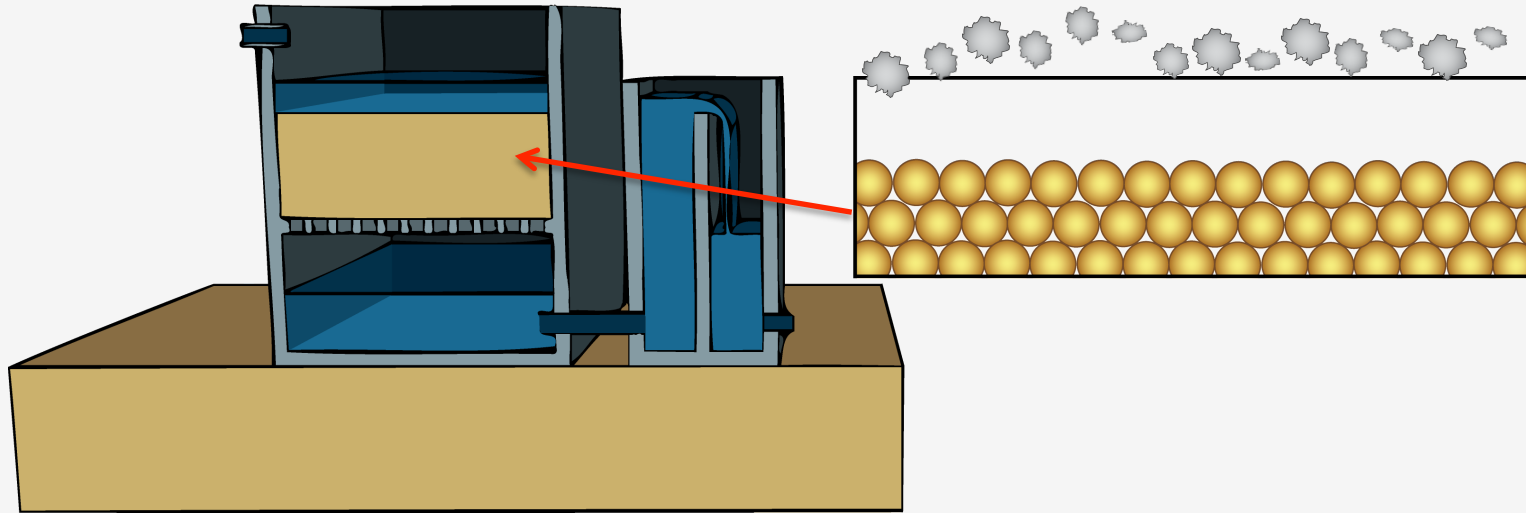
Rapid sand filtration



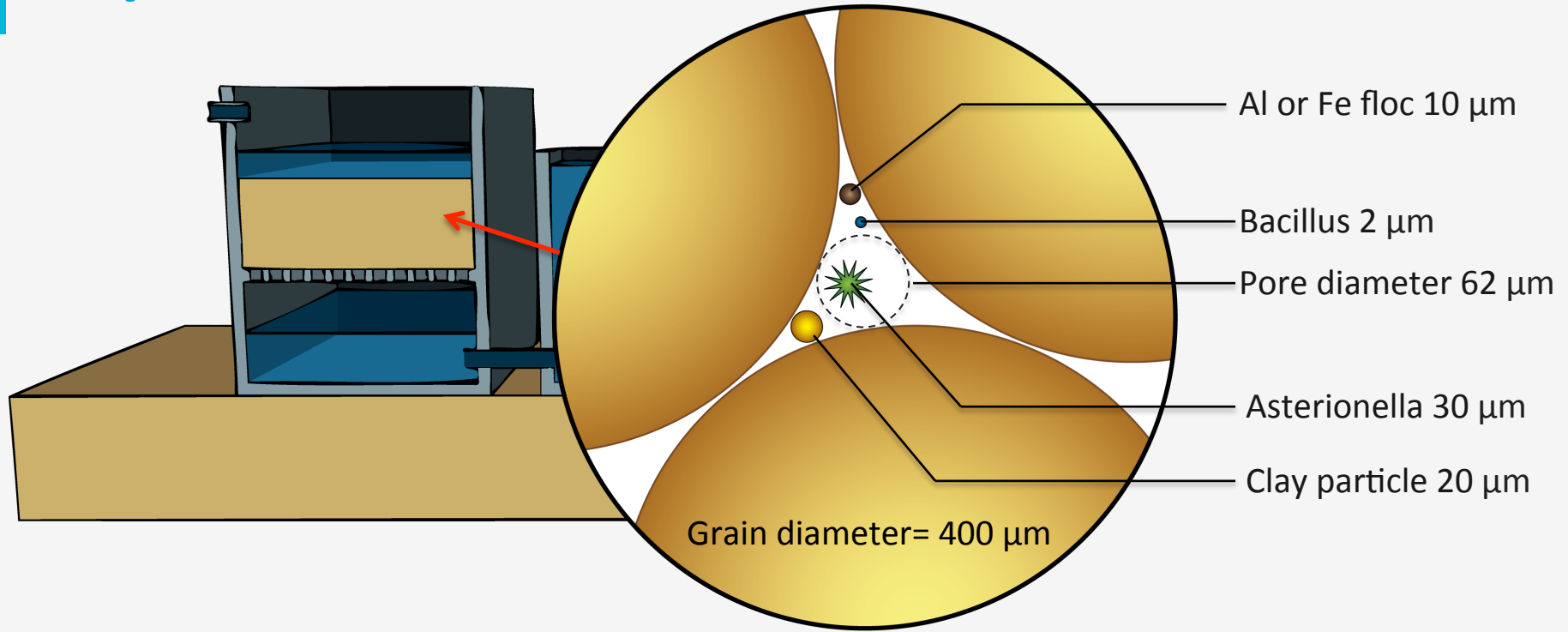
Rapid sand filtration



Rapid sand filtration



Rapid sand filtration



Chemical transformations

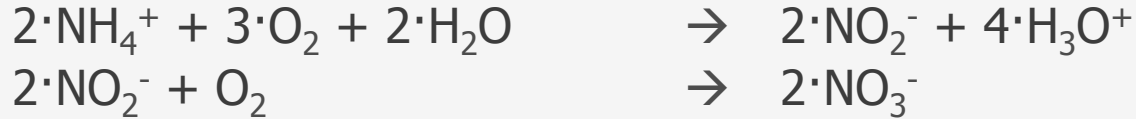


Results in clogging of the filter

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

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

Biological transformations



Nitrosomonas and nitrobacter

1 mg NH_4^+ uses 3.55 mg/l O_2

Biodegradable organic matter



1 mg/l CH_4 uses 4 mg/l O_2

Bacteria production:

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

Design filtration proces

Define the filtration velocity

Total surface area required for filtration

Filter bed height

Grain size filtering material

Filter column

A: Supernatant water
Large grains

B: Filter bed

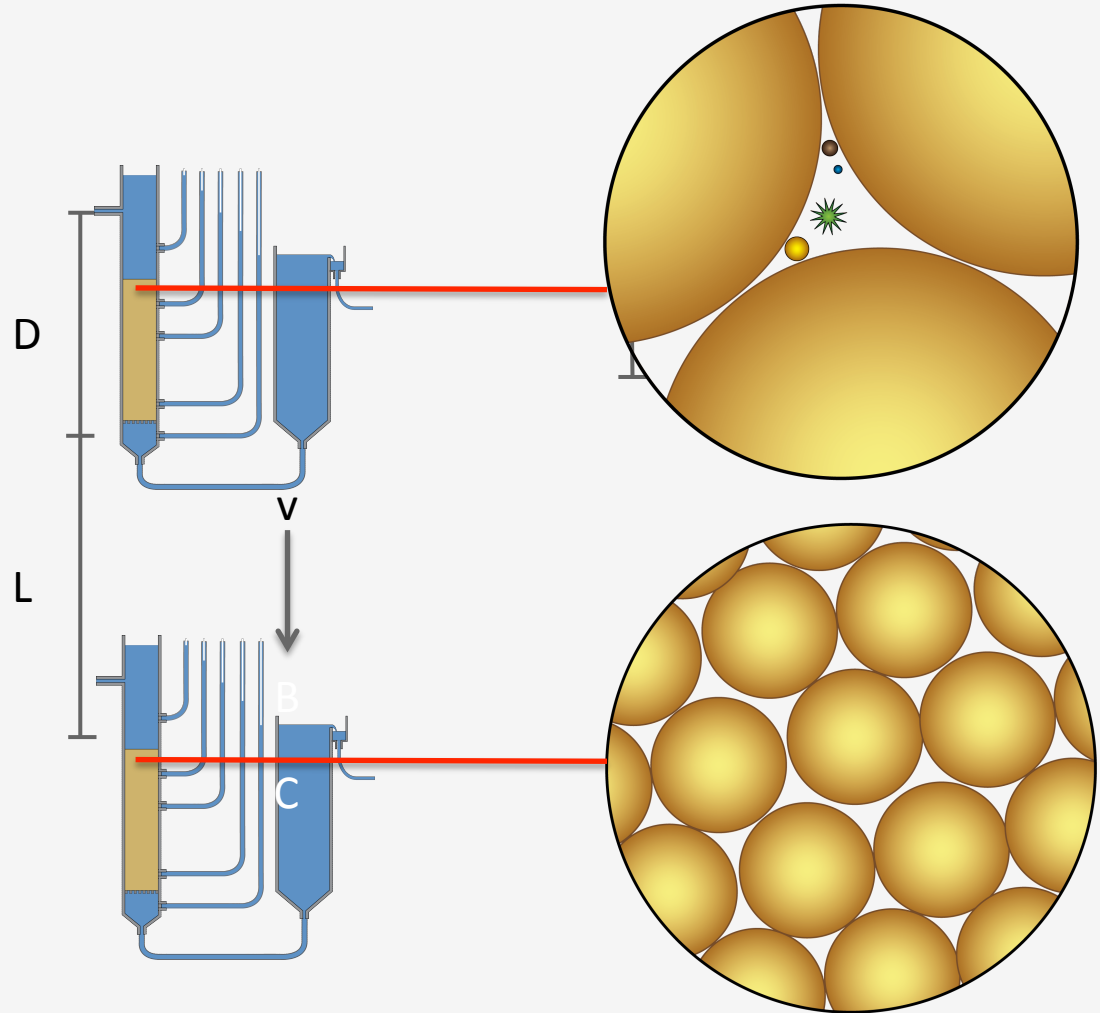
C: Filter bottom

$L = 1 \text{ m}$

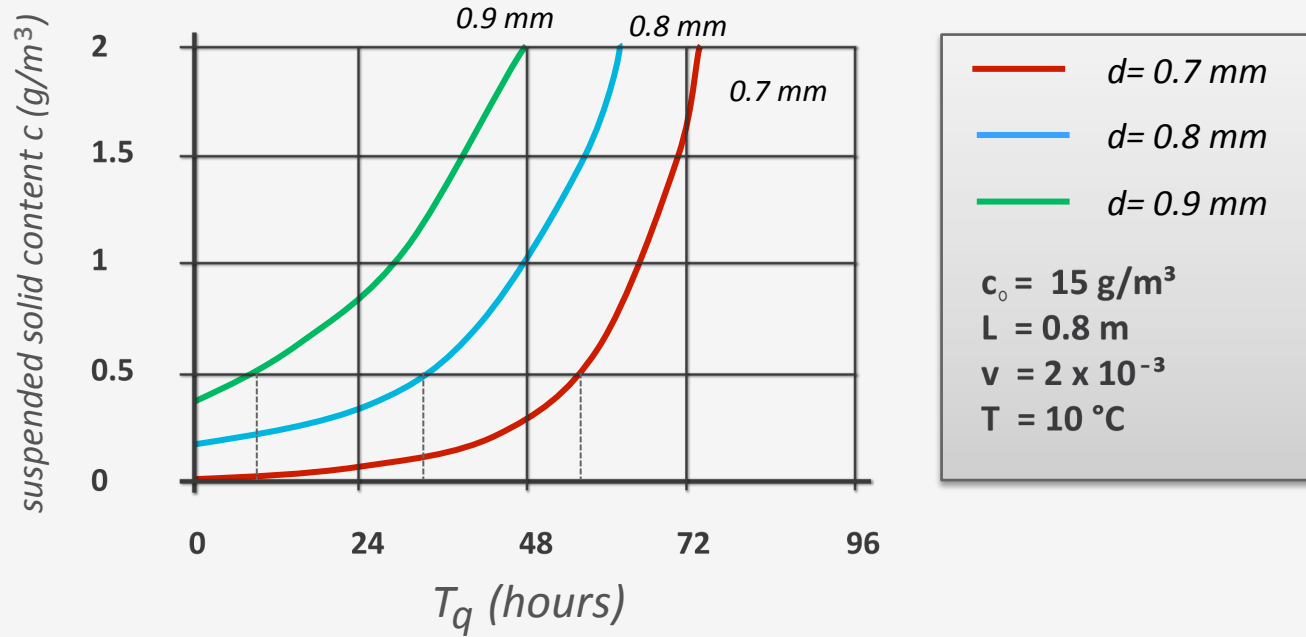
$H = 1.5 \text{ m}$

Small grains: $1.0 - 1.6 \text{ mm}$

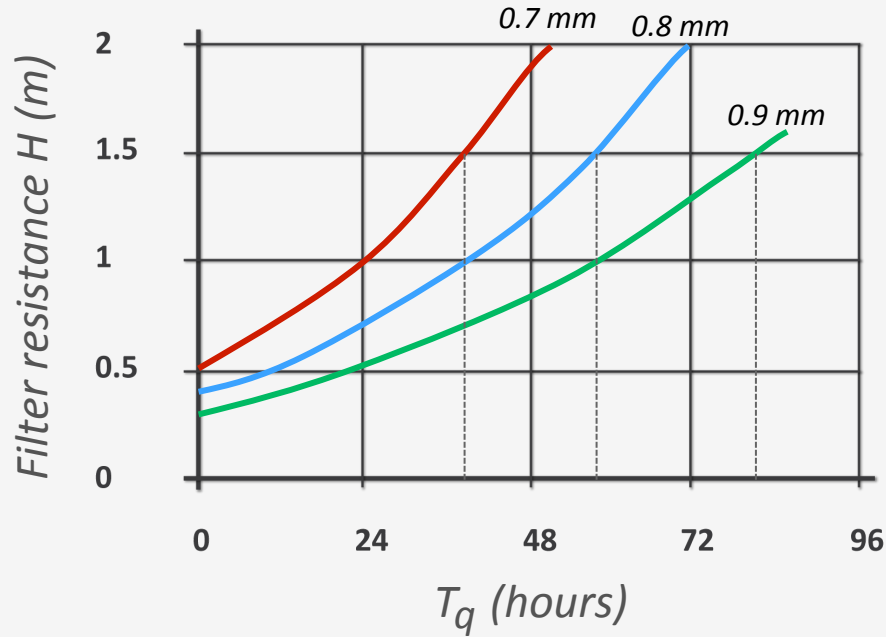
$v = 5 \text{ m/h}$



Filtration



Filter resistance



- $d = 0.7$ mm
- $d = 0.8$ mm
- $d = 0.9$ mm

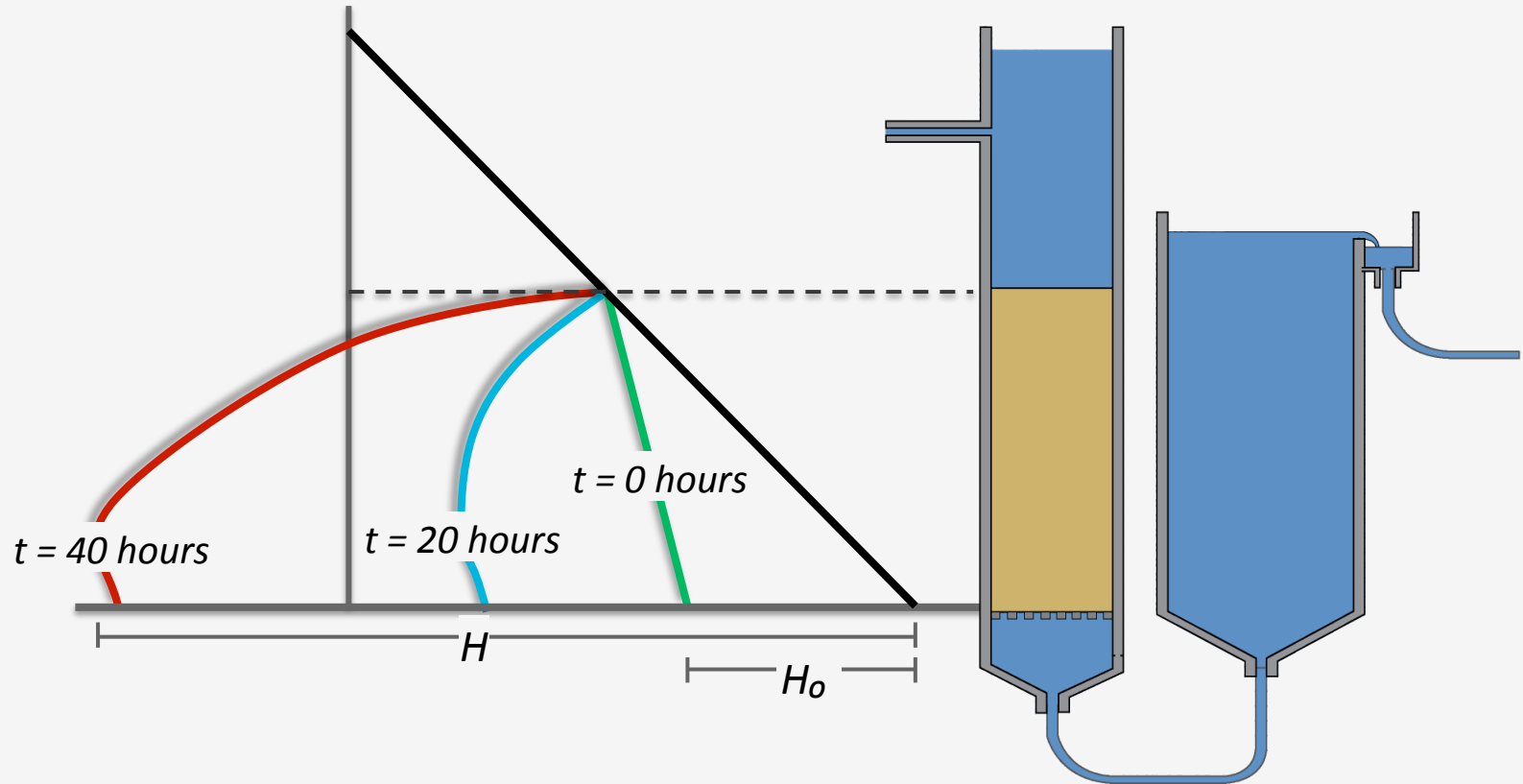
$$c_0 = 15 \text{ g/m}^3$$

$$L = 0.8 \text{ m}$$

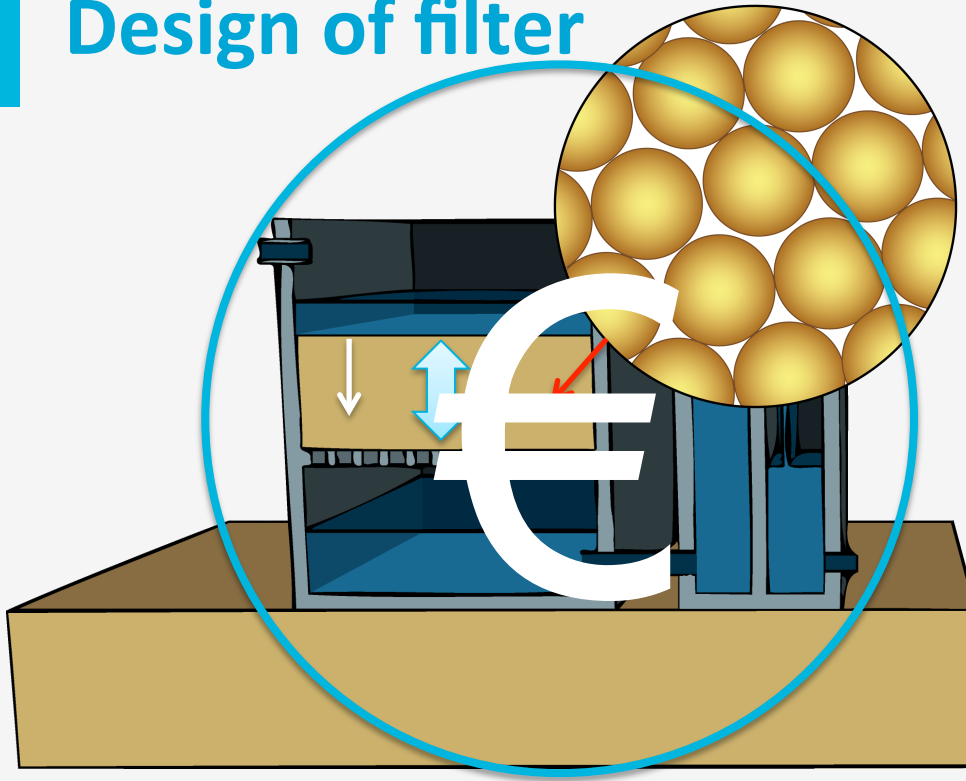
$$v = 2 \times 10^{-3}$$

$$T = 10^\circ \text{C}$$

Lindquist diagram



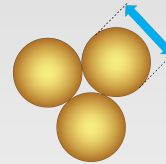
Design of filter



Filtration velocity



Filter bed height

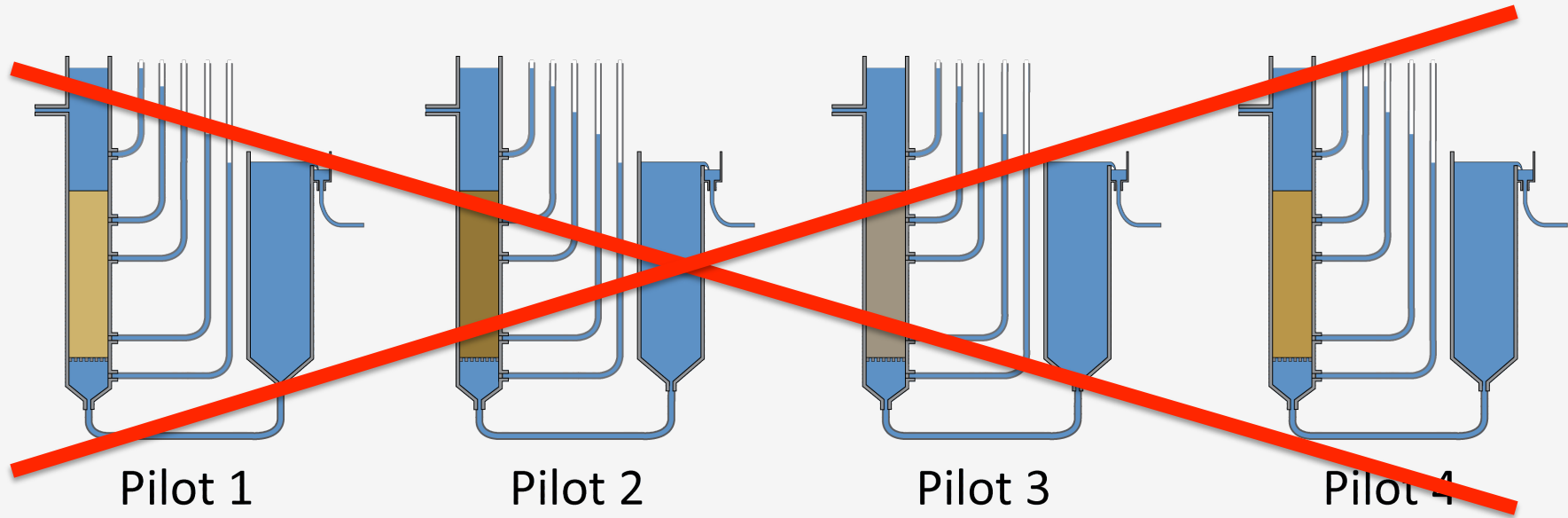


Grain size



Economic factors

Filtration theory - Kinetics



Filtration theory - Kinetics

$$-\frac{\partial c}{\partial y} = \lambda \cdot c \quad \lambda = \lambda_o \cdot \left(1 - \frac{\sigma_v}{(n \cdot p_o)}\right)$$

Lerk-Maroudas

$\sigma \downarrow v = \sigma / \rho \downarrow d$ = reduction in volume of pores

c = concentration suspended solids

y = depth of filterbed

λ = filtration coefficient [s^{-1}]

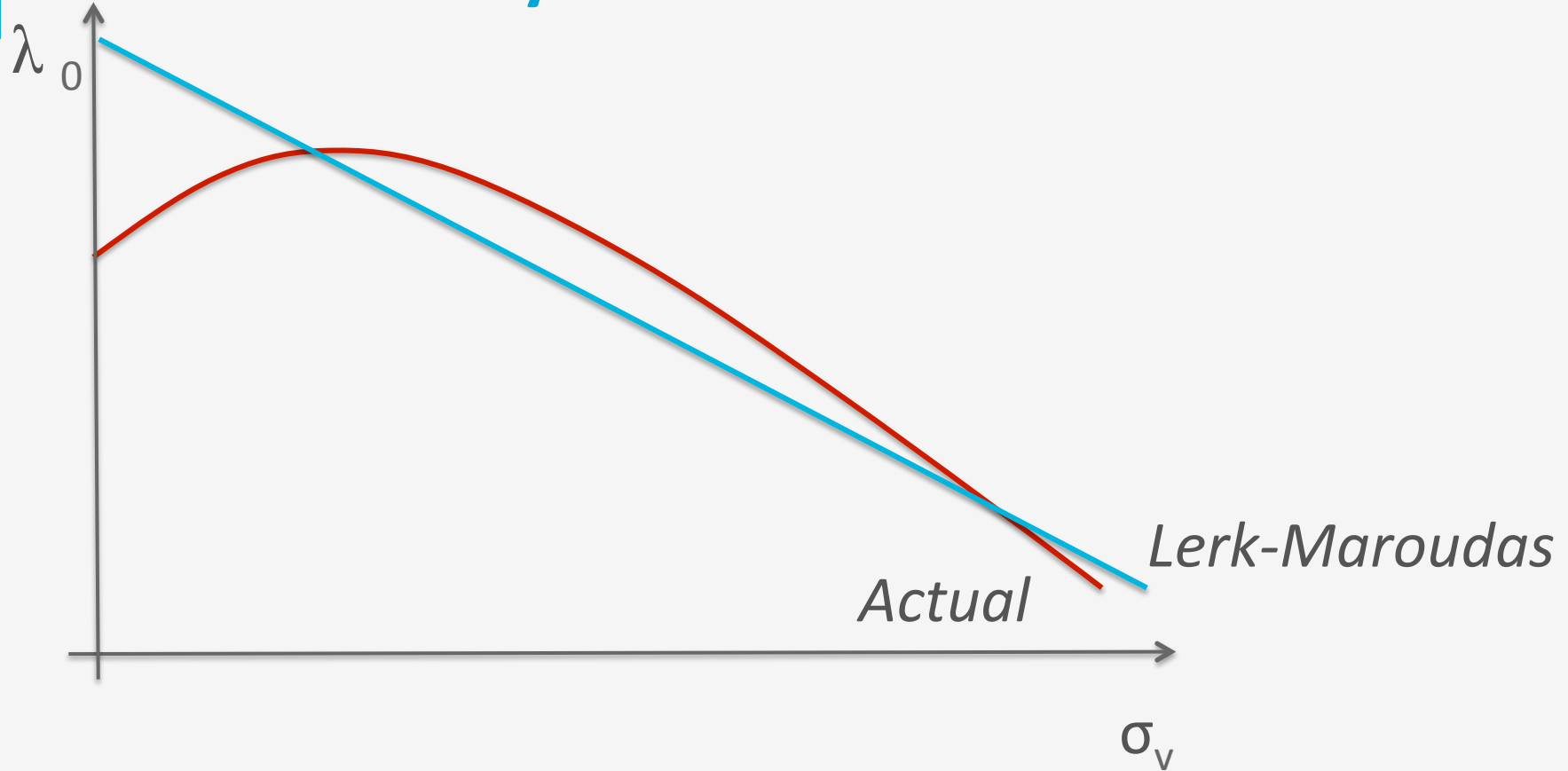
σ = deposits in pores [g/m^3]

p = porosity [-]

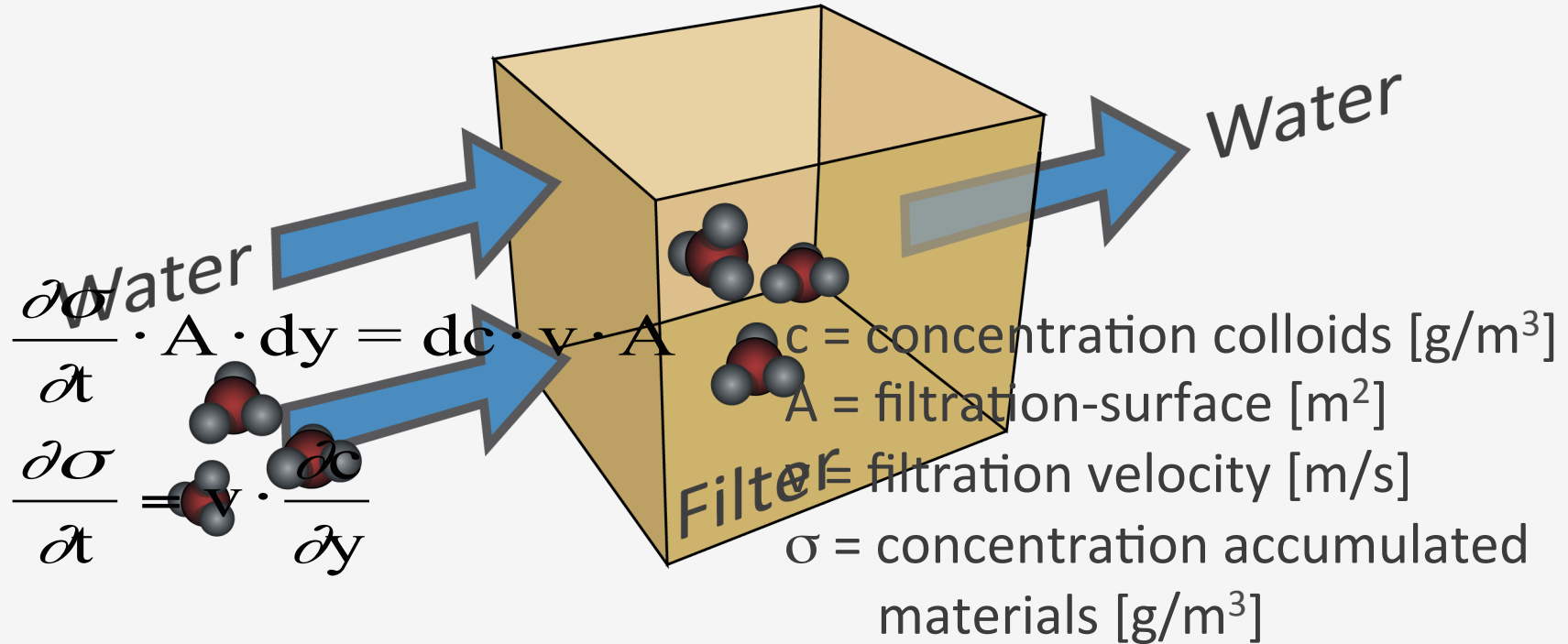
n = maximum filling of pores ($0 < n < 1$)

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

Filtration theory - Kinetics



Filtration theory – mass balance

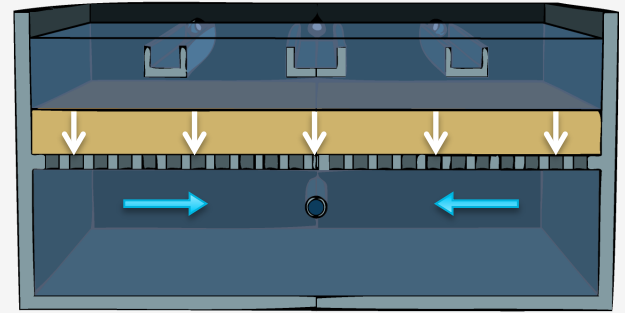
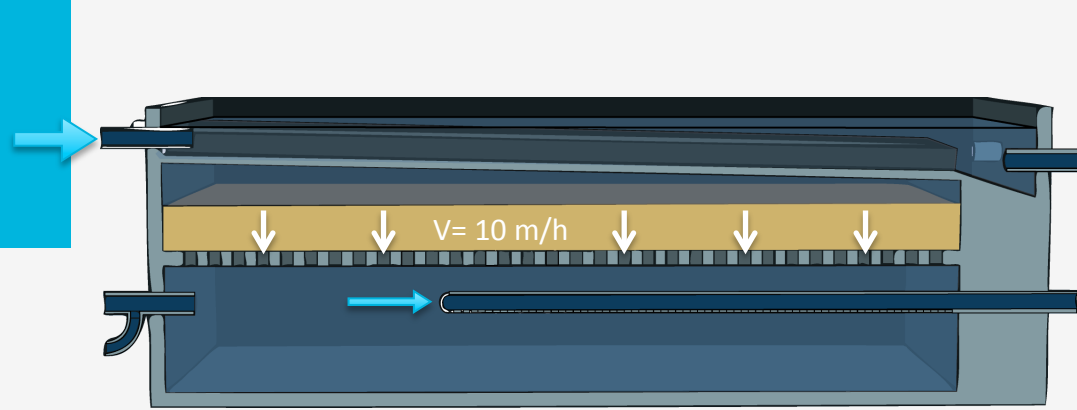


Carman-Kozeny equation

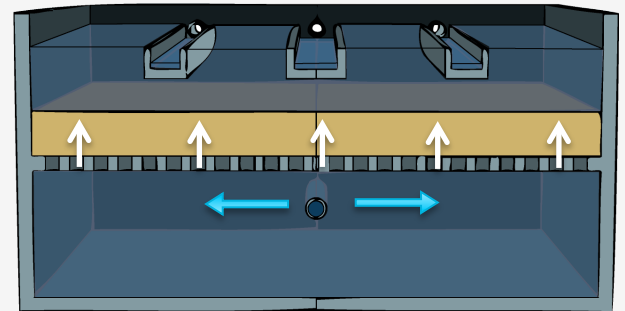
$$H = H_o \cdot \left(\frac{p_o}{p_o - \frac{\sigma}{\rho_d}} \right)^2 \quad H_o = \frac{180}{g} \cdot \nu \cdot \frac{(1 - p_o)^2}{p_o^3} \cdot \frac{v}{d^2} \cdot L$$

H = bed resistance [m]

H_o = clean bed resistance [m]



Backwash

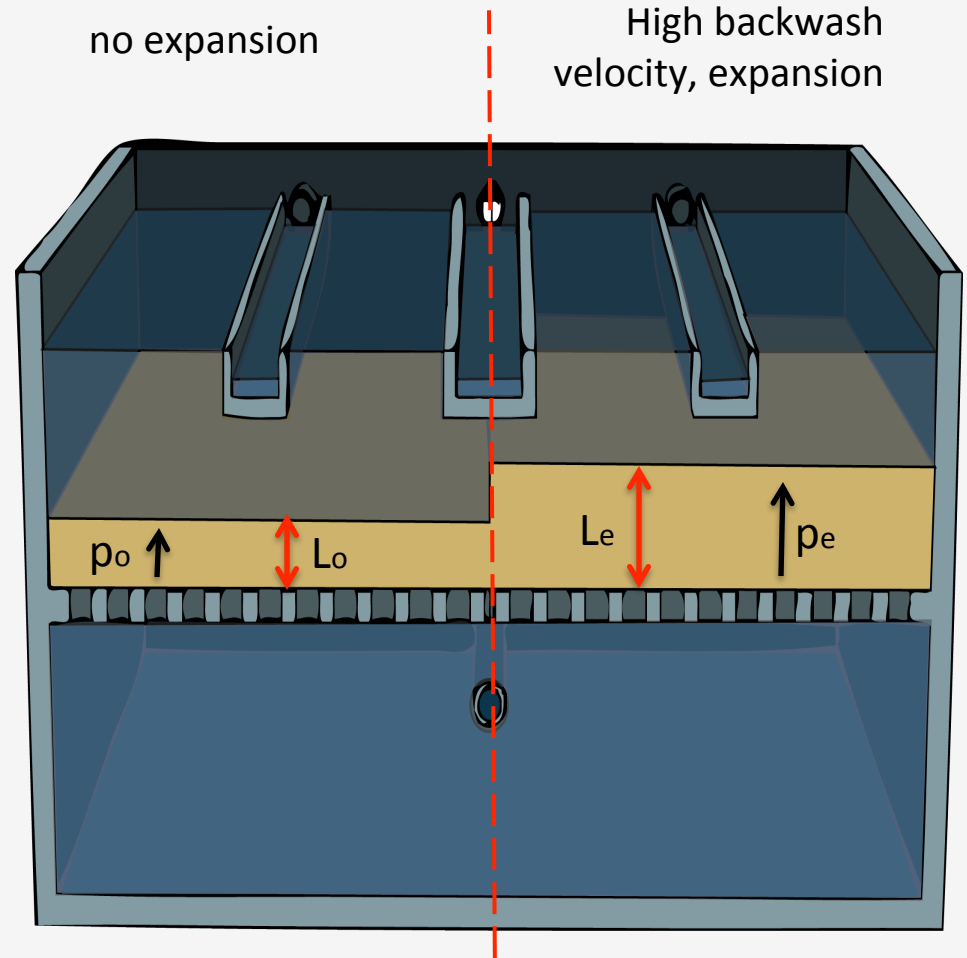


Backwash

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

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

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



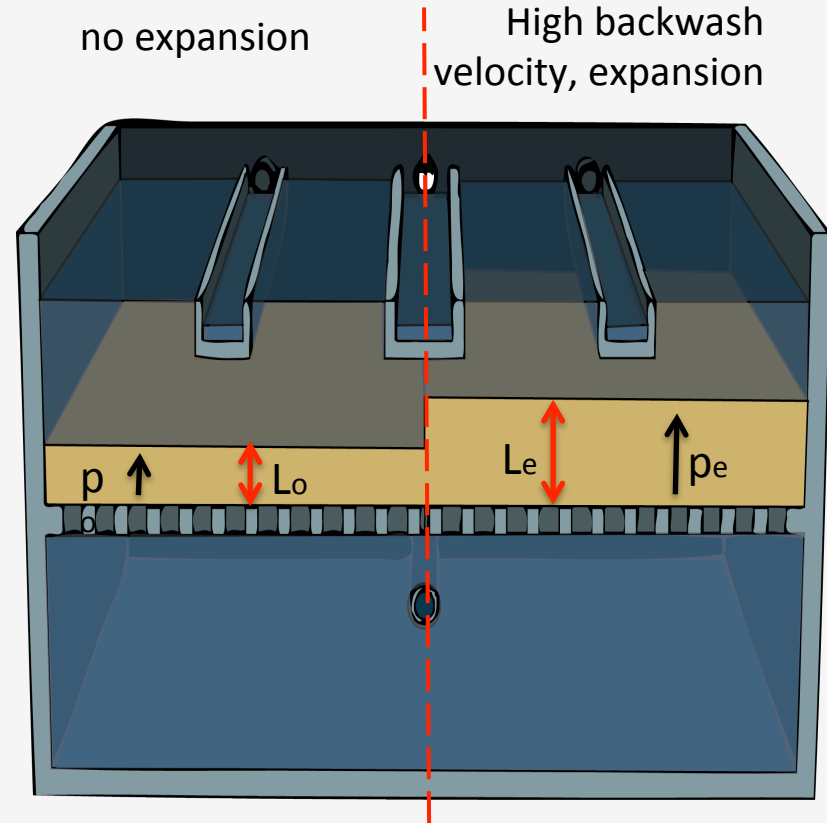
Backwash

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

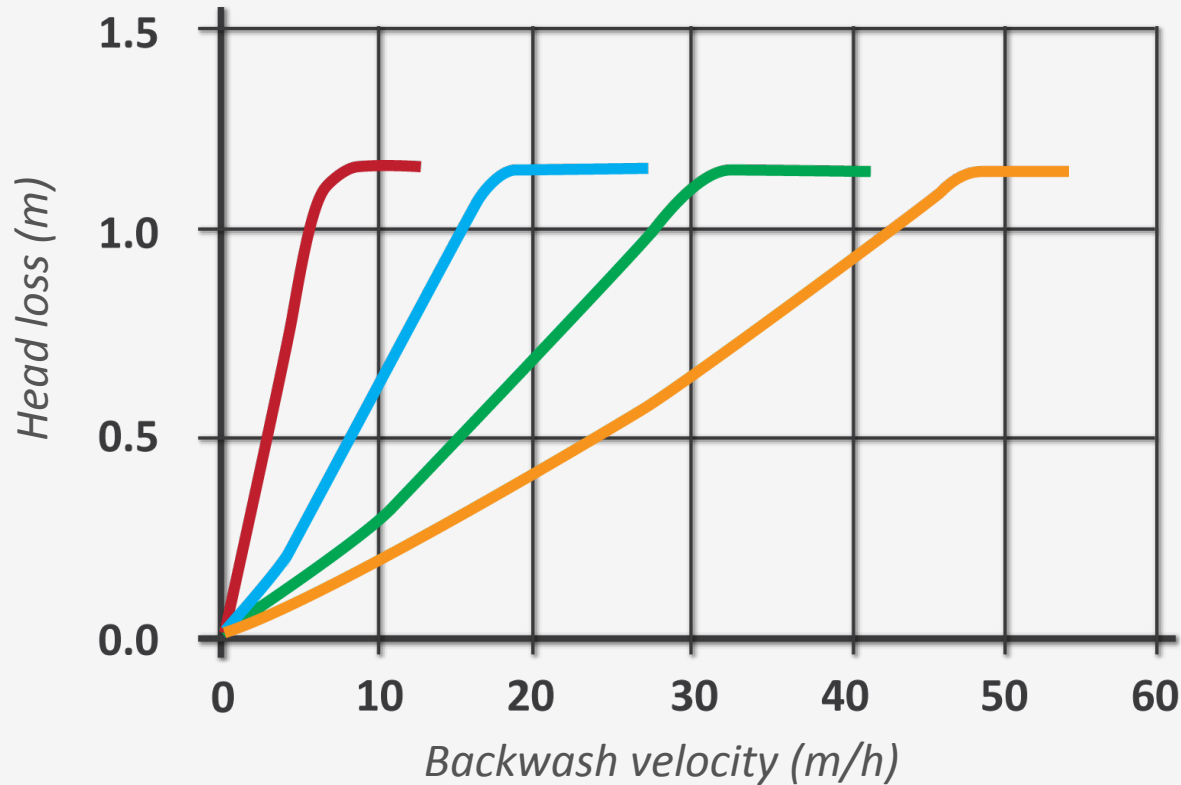
$$\rho_w \cdot g \cdot H_{\max} = (1-p_o) \cdot L_o \cdot (\rho_f - \rho_w) \cdot g$$

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

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



Backwash



- $d=0.4$ mm
- $d=0.8$ mm
- $d=1.2$ mm
- $d=1.6$ mm

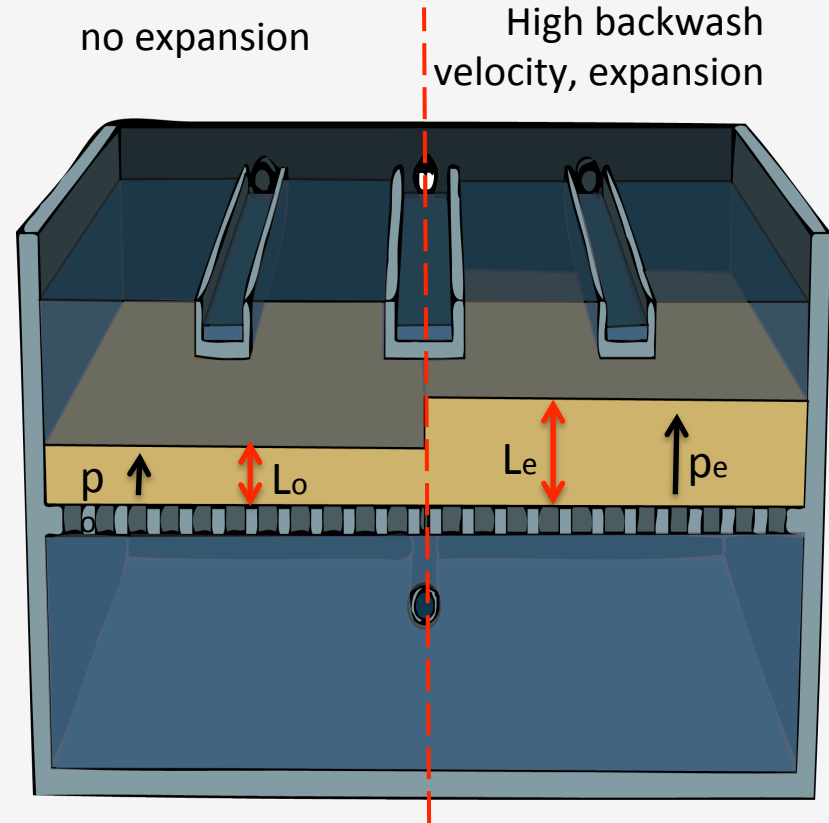
$L_o = 1.2$ m

$P_o = 0.4$

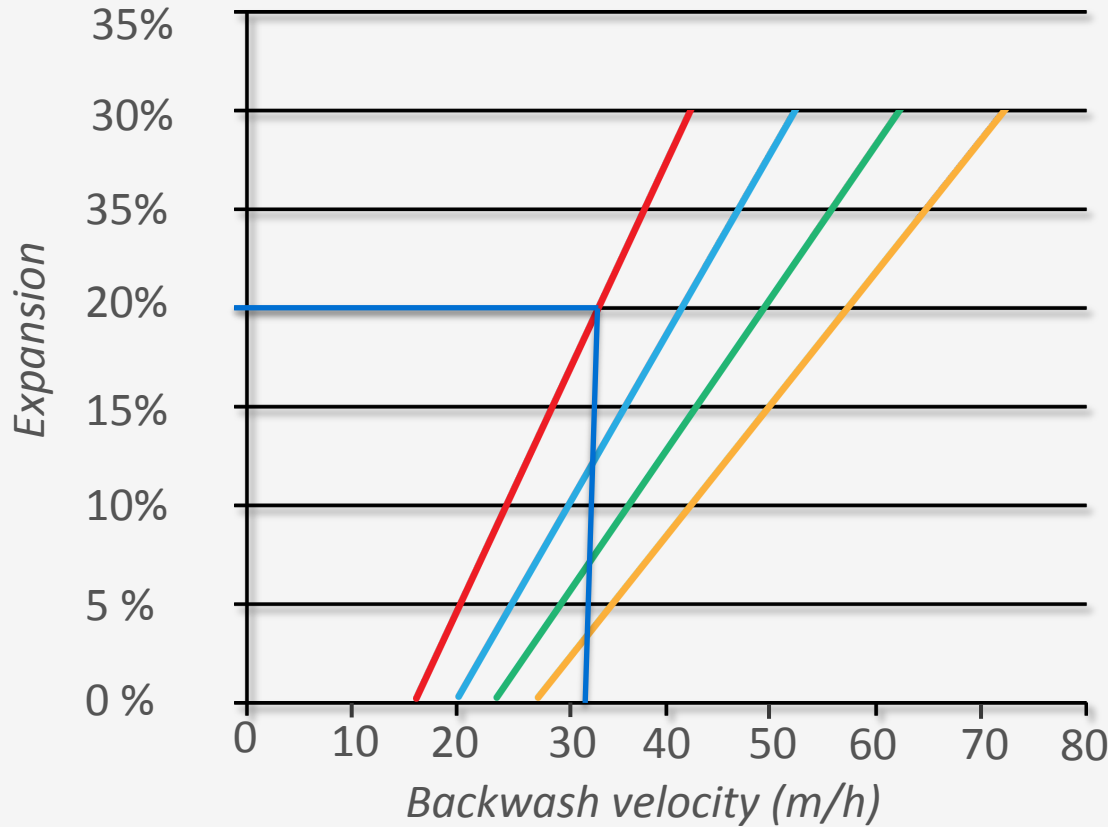
$r_f = 2650$ kg/m³

Backwash

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



Backwash



— 0 °C

— 10 °C

— 20 °C

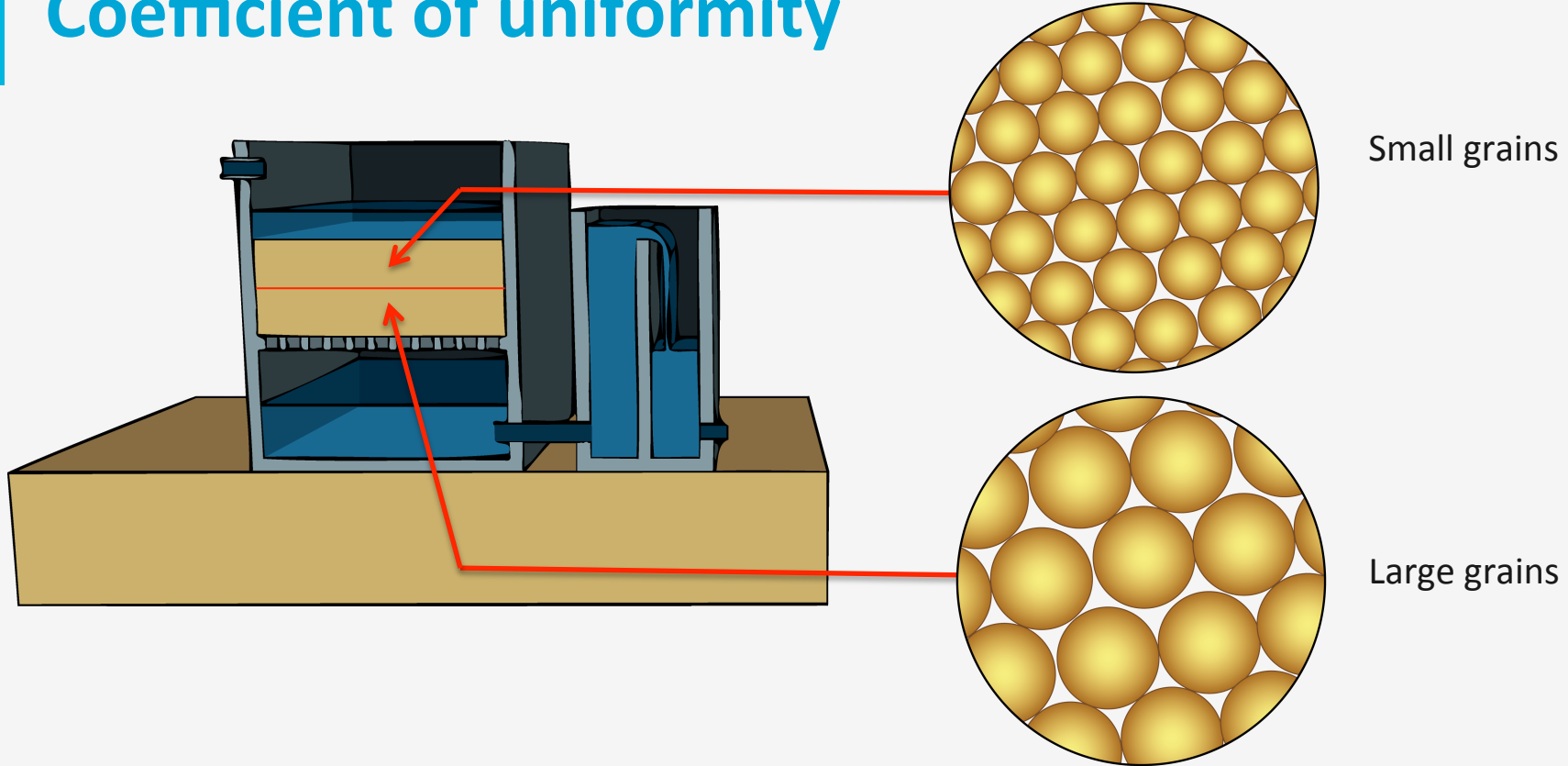
— 30 °C

$P = 0.38$

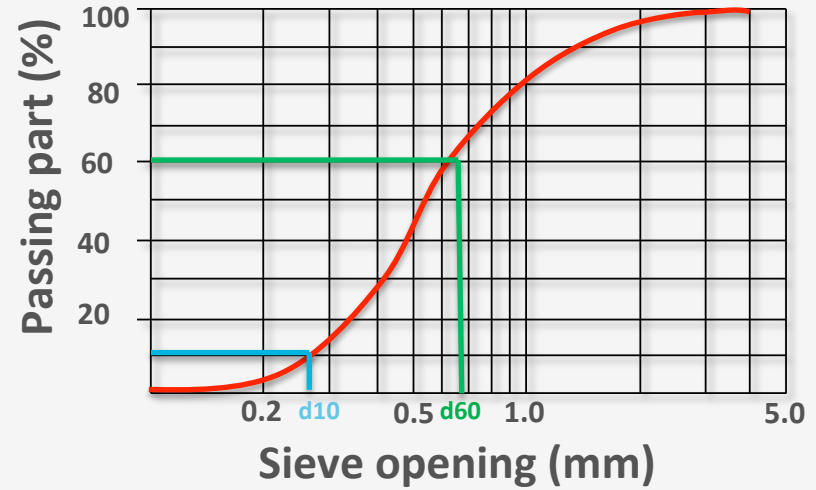
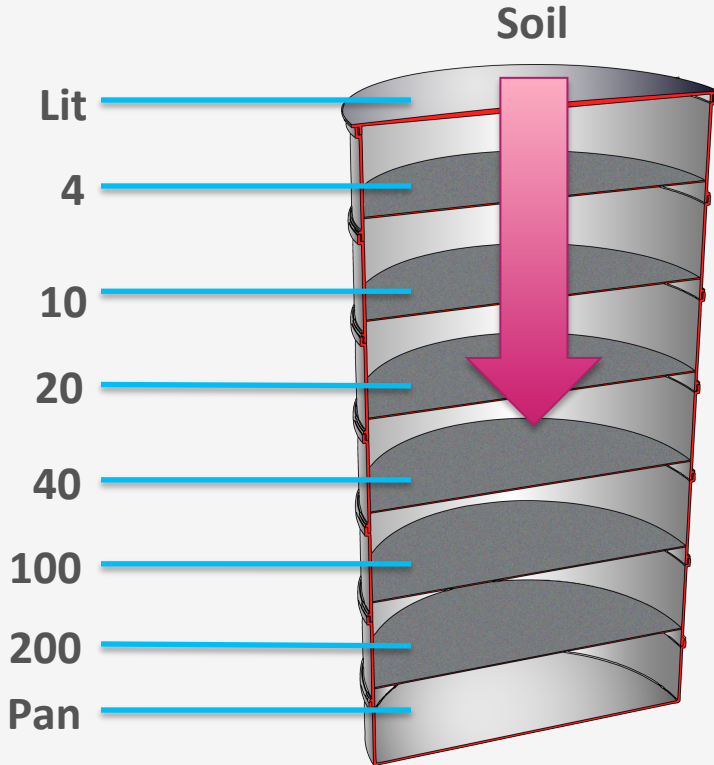
$D = 1.0 \text{ mm}$

$r_f = 2600 \text{ kg/m}^3$

Coefficient of uniformity



Coefficient of uniformity



$$U = \frac{d_{10}}{d_{60}}$$

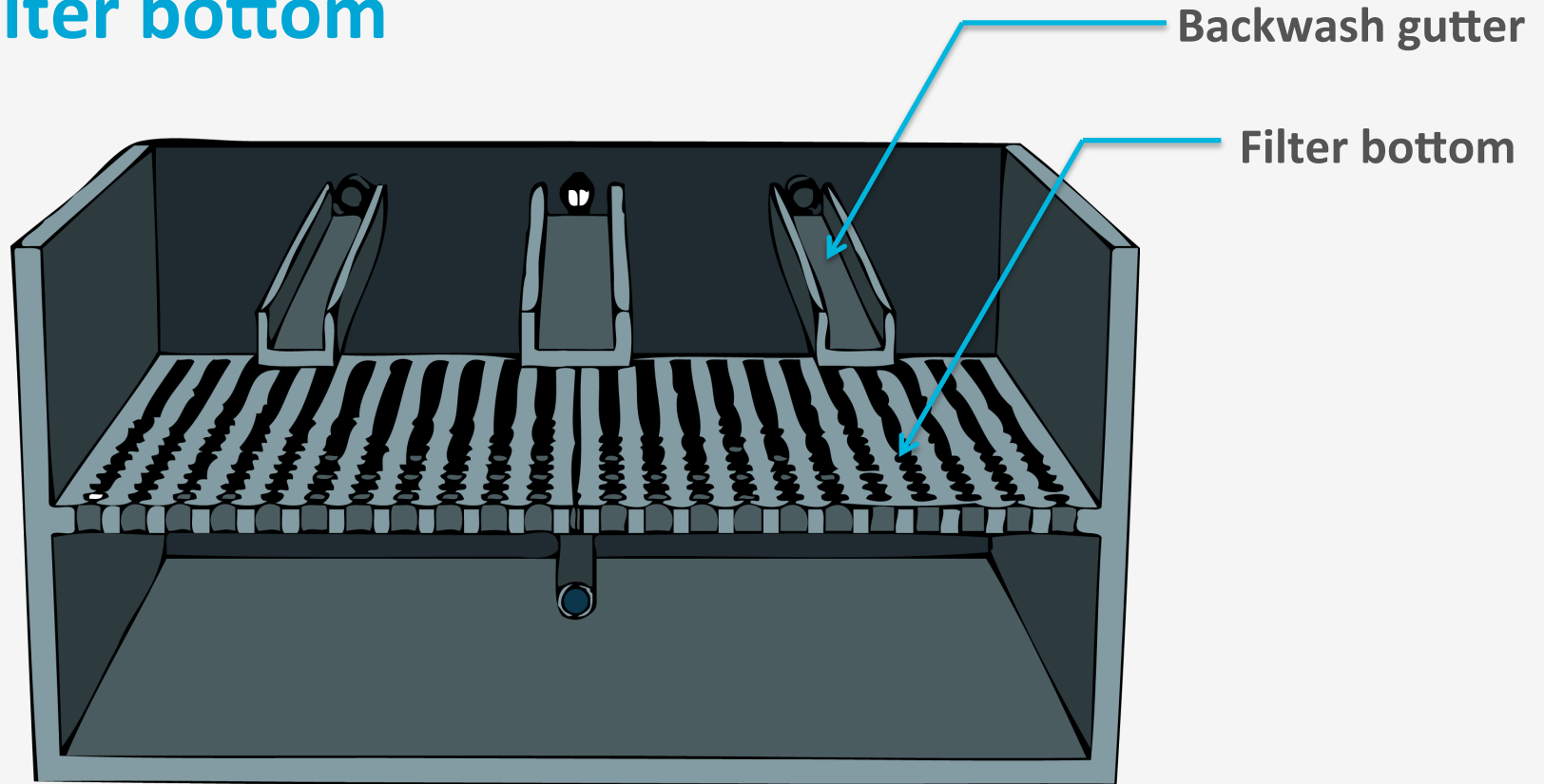
In which:

U = uniformity coefficient

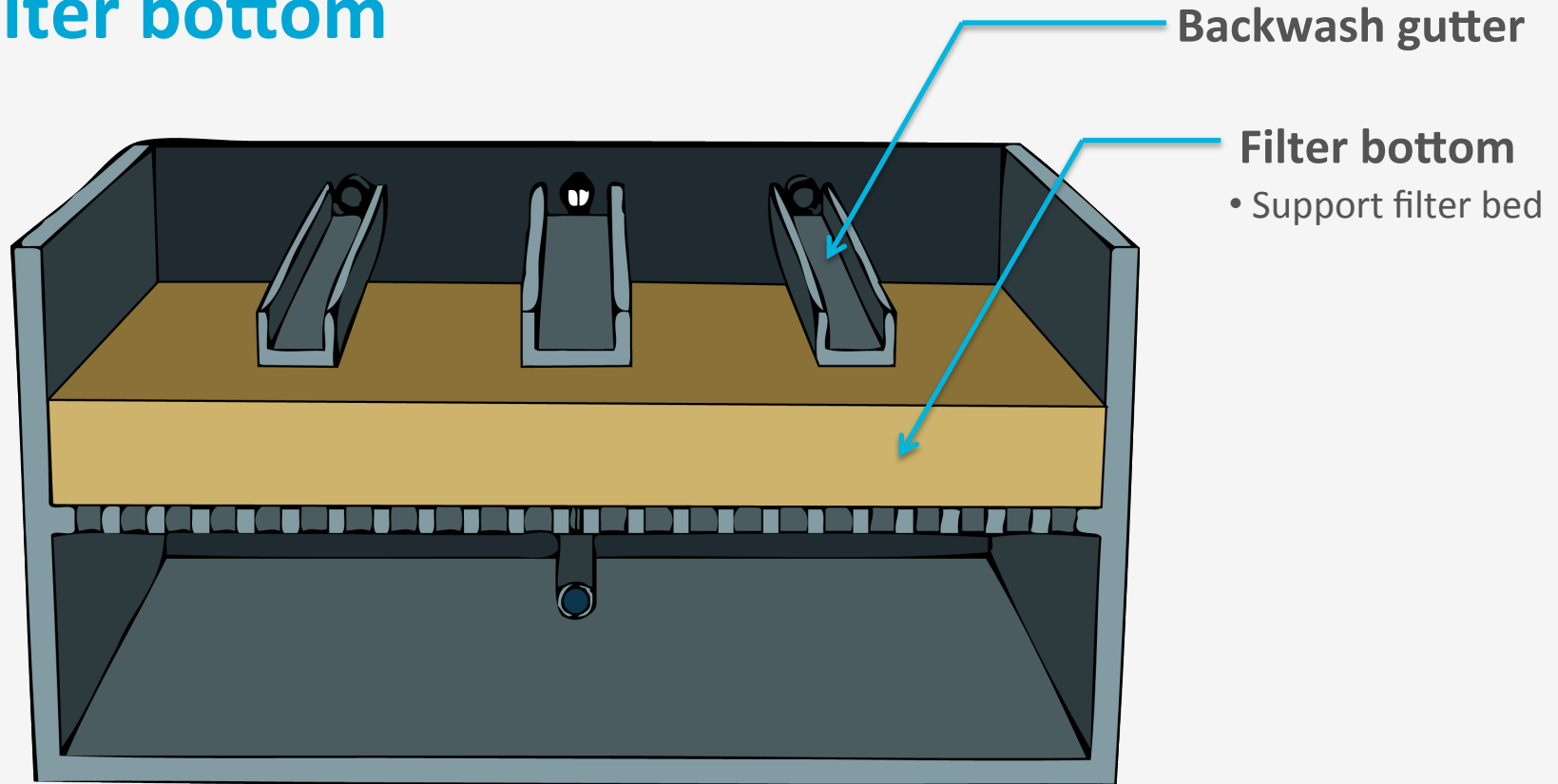
d_{10} = size of sieves that let pass 10% of the sand mixture (mm)

d_{60} = size of sieves that let pass 60% of the sand mixture (mm)

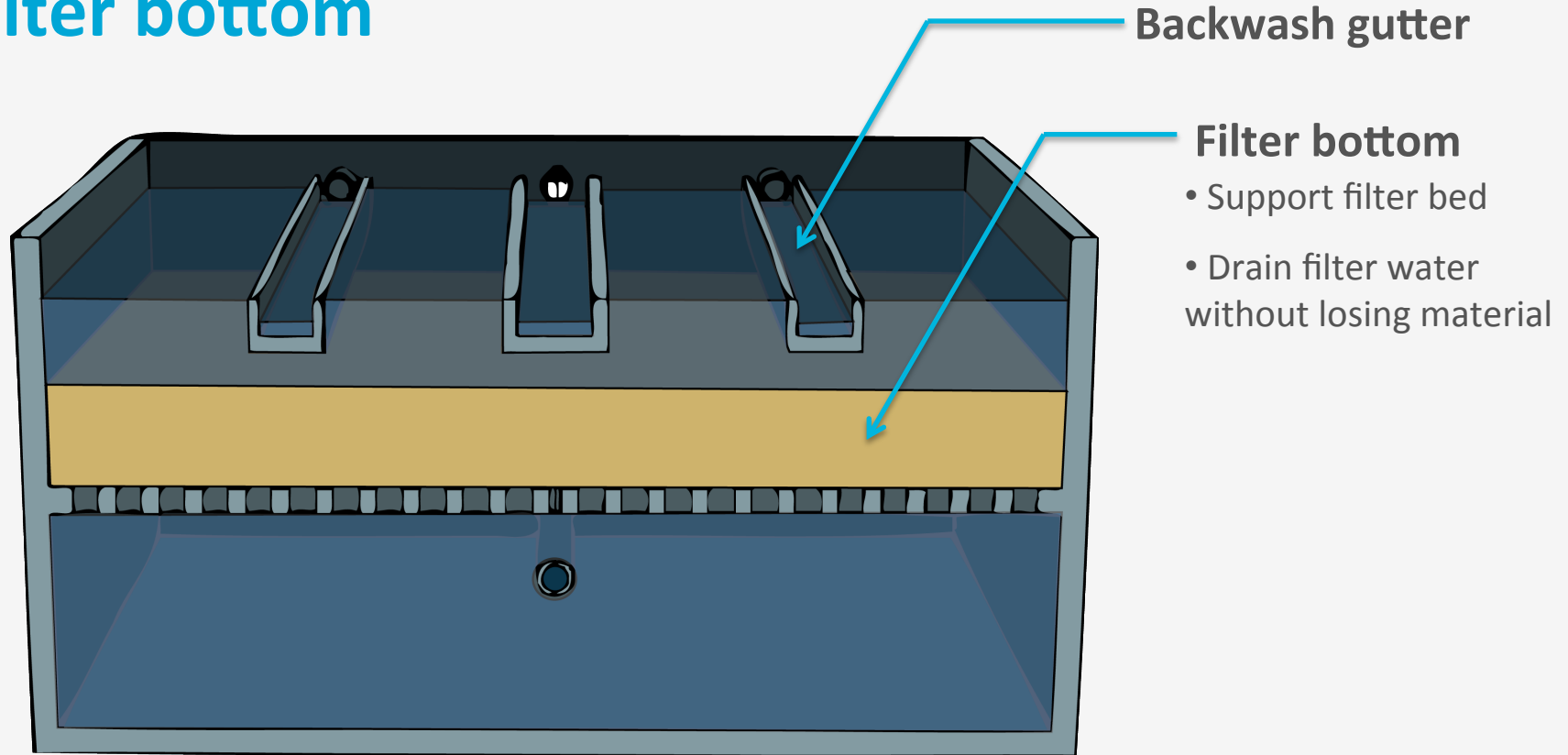
Filter bottom



Filter bottom



Filter bottom

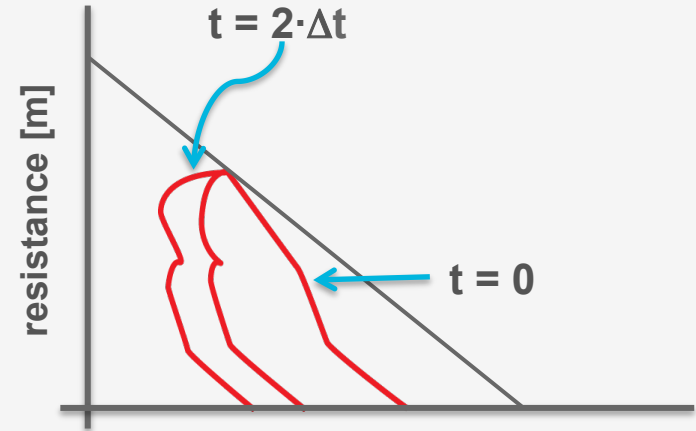
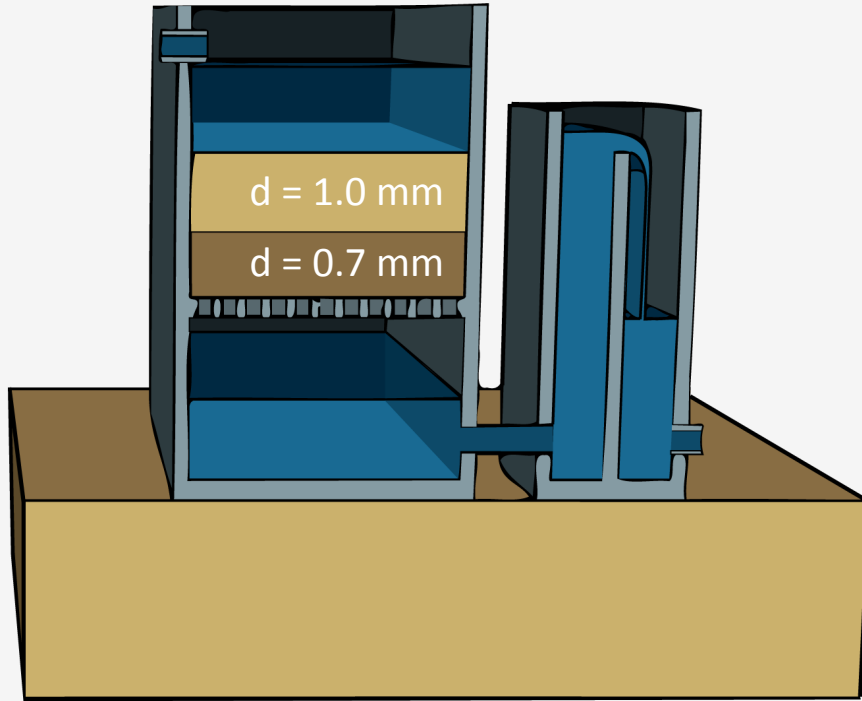


Filter trouble

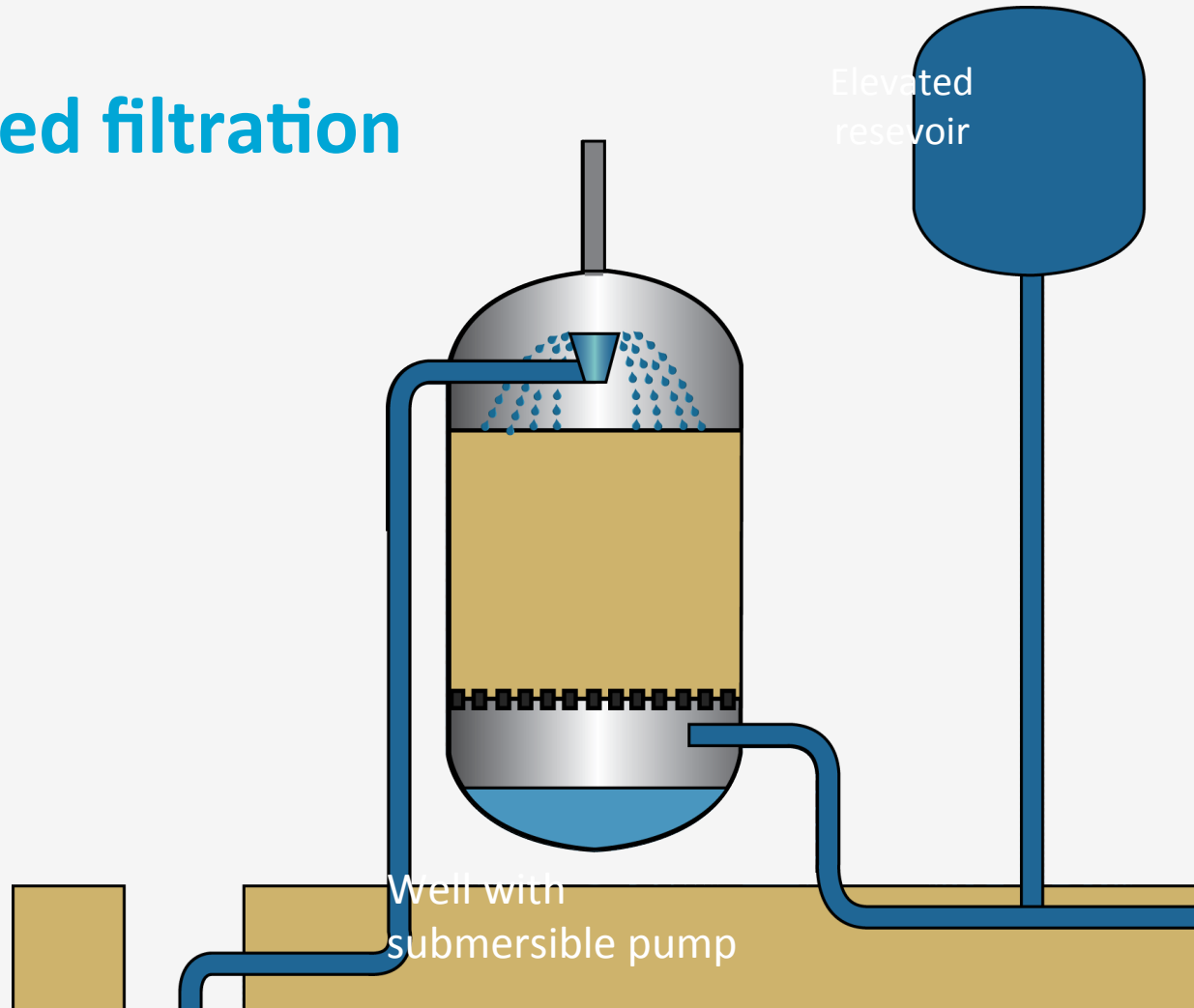
- Nozzle in the bottom breaks
- Filtering material can be lost



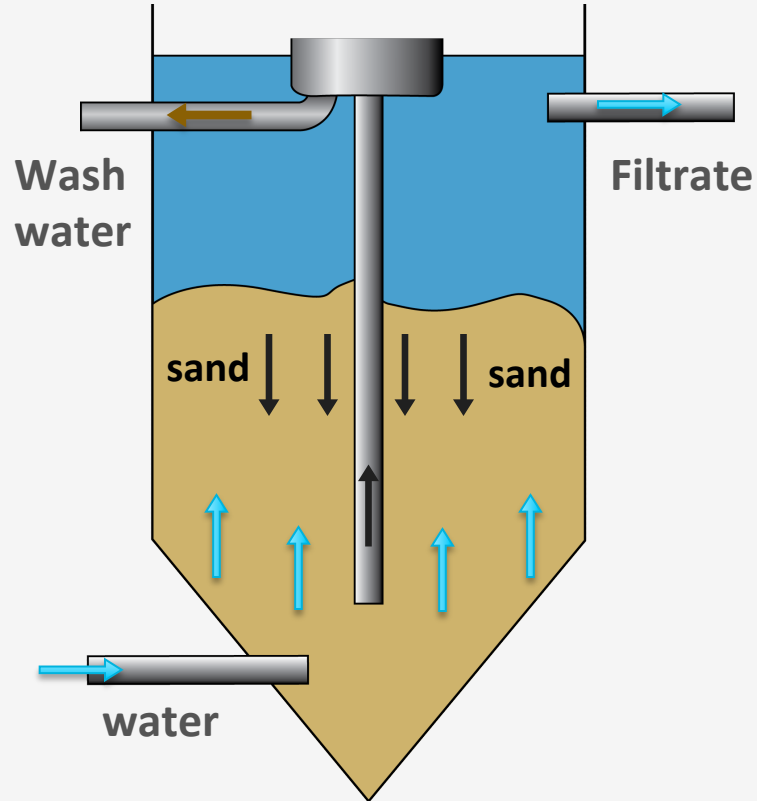
Double layered filtration



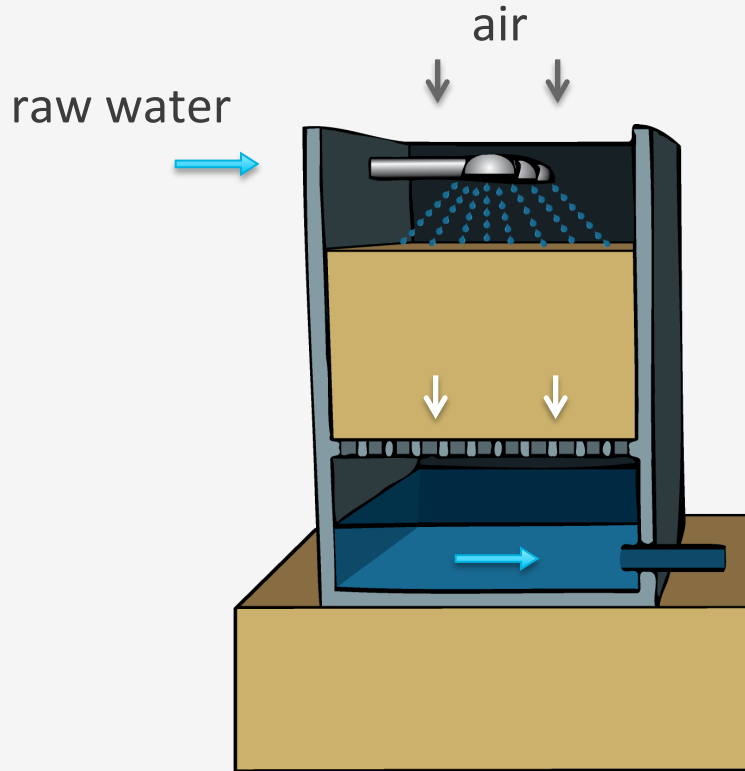
Pressured filtration



Continuous filtration



Dry filtration



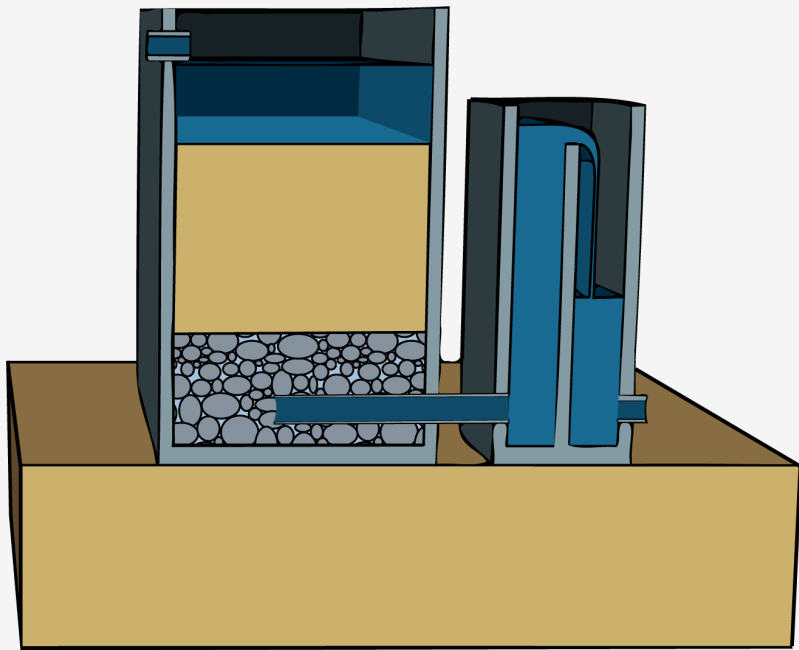
When

- High ammonia concentration

Advantages

- Supplement O_2 concentration
- High water velocity
- Stripping of CH_4 , H_2S and CO_2

Slow sand filtration





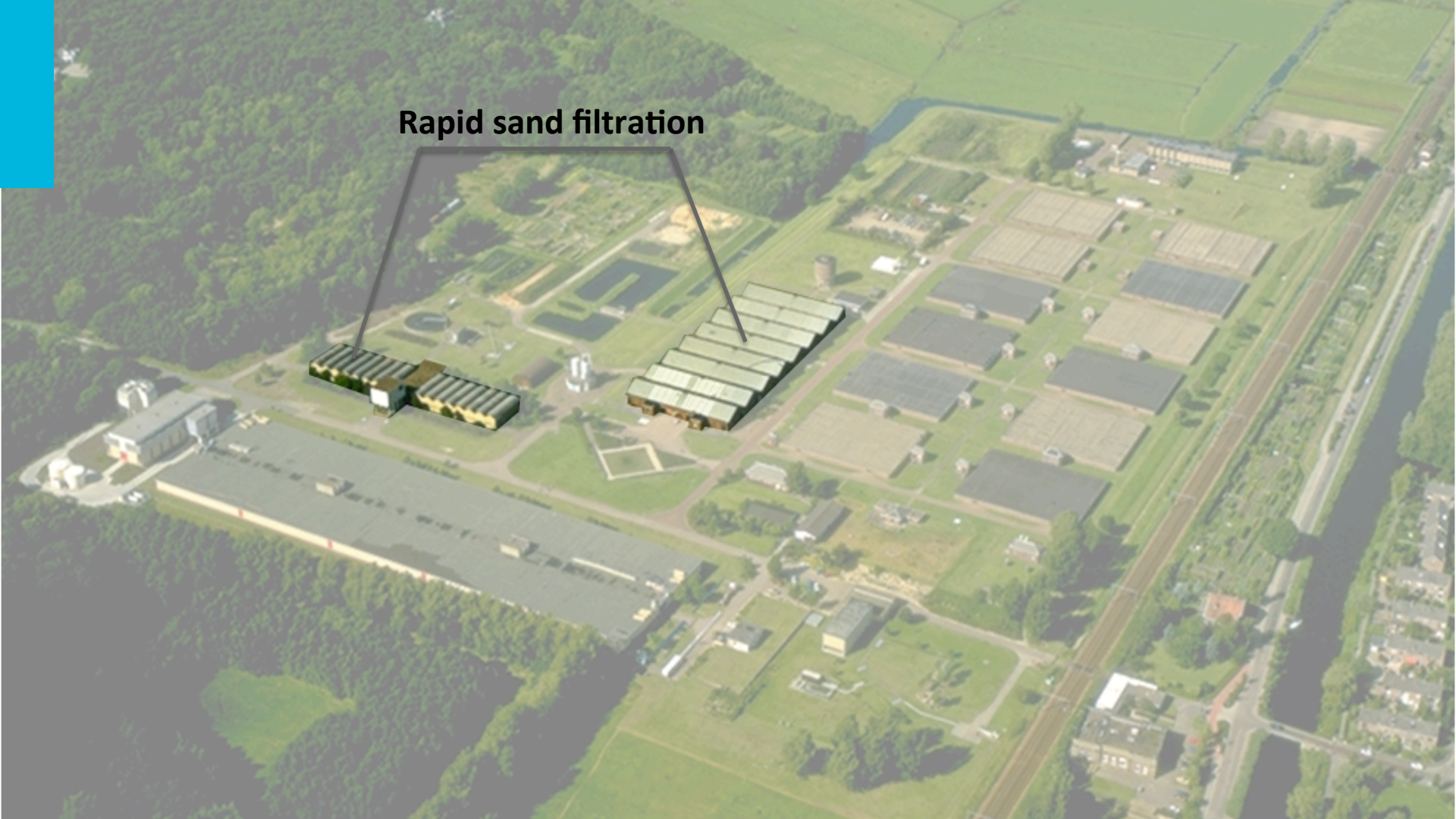
Slow sand filtration

%

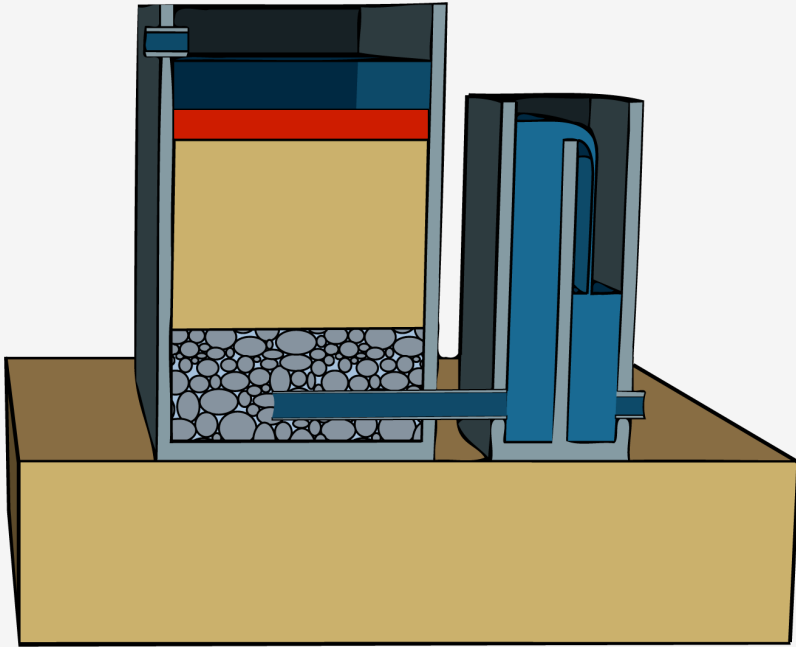
Slow sand filtration



Rapid sand filtration



Slow sand filtration



Filtration

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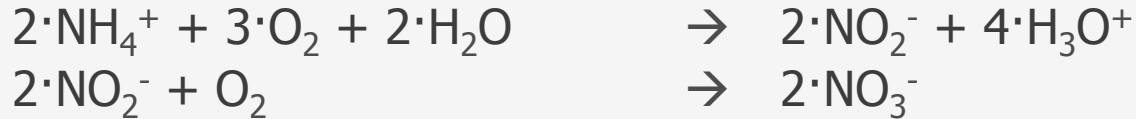
Prof.dr.ir. Luuk Rietveld

Filtration

CTB3365x Introduction to water treatment

Prof.dr.ir. Luuk Rietveld

Biological transformations



Nitrosomonas and nitrobacter

1 mg NH_4^+ uses 3.55 mg/l O_2

Biodegradable organic matter



1 mg/l CH_4 uses 4 mg/l O_2

Bacteria production:

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

Filtration theory - Kinetics

$$-\frac{\partial c}{\partial y} = \lambda \cdot c \quad \lambda = \lambda_0 \cdot \left(1 - \frac{\sigma_v}{(n \cdot p_0)}\right)$$

Lerk-Maroudas

$\sigma \downarrow v = \sigma / \rho \downarrow d$ = reduction in volume of pores

c = concentration suspended solids

y = depth of filterbed

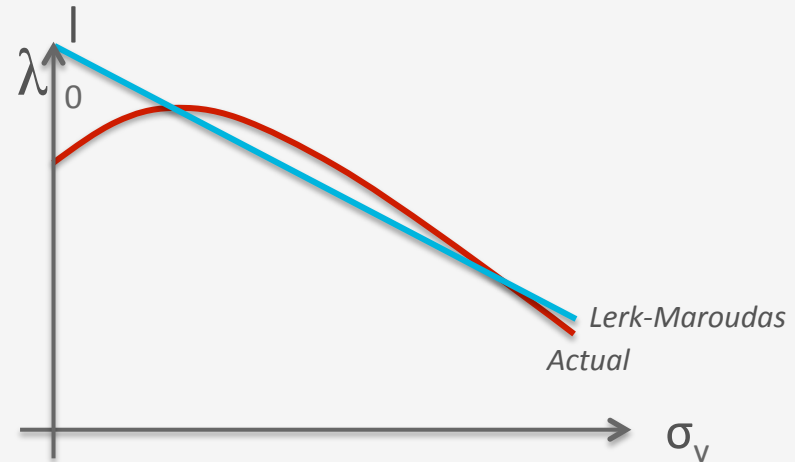
λ = filtration coefficient [s^{-1}]

σ = deposits in pores [g/m^3]

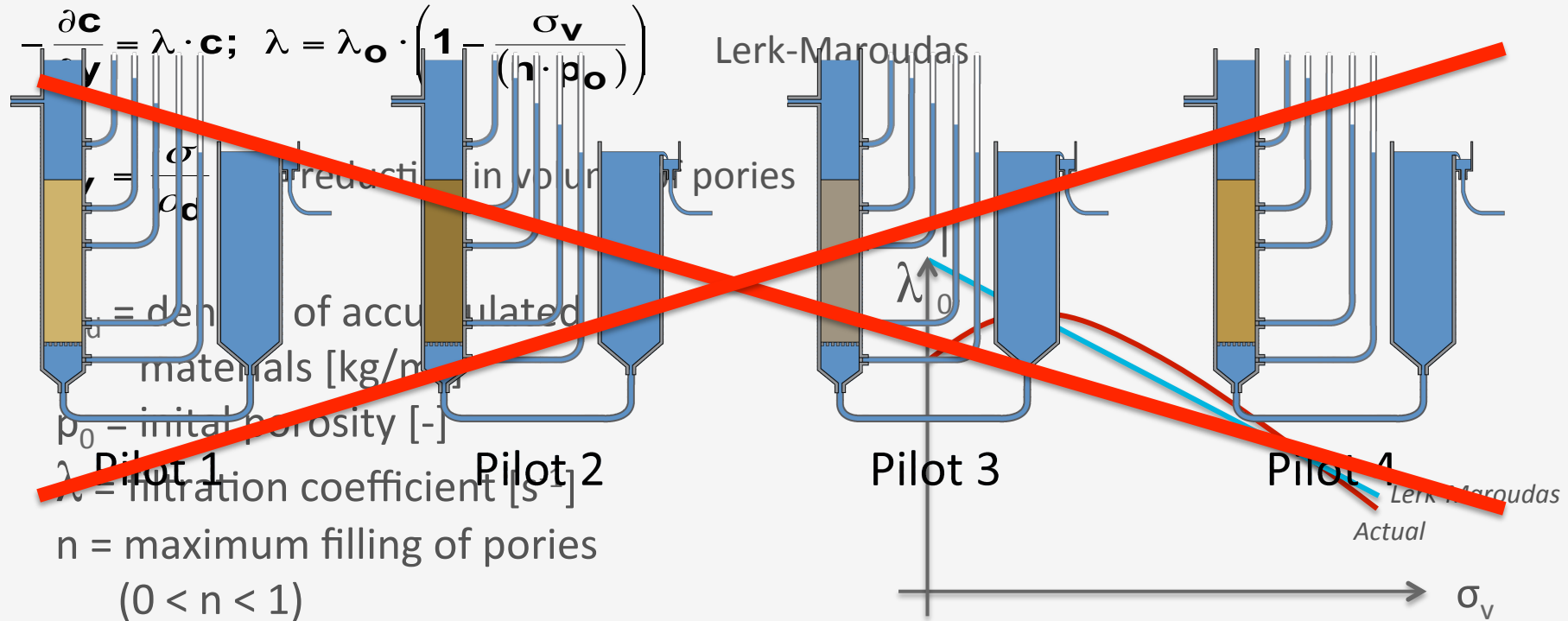
p = porosity [-]

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

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



Filtration theory - Kinetics



Carman-Kozeny equation

$$H = H_o \cdot \left(\frac{p_o}{p_o - \frac{\sigma}{\rho_d}} \right)^2$$

$$H_o = \frac{180}{g} \cdot v \cdot \frac{(1 - p_o)^2}{p_o^3} \cdot \frac{v}{d^2} \cdot L$$

H = foul bed resistance [m]

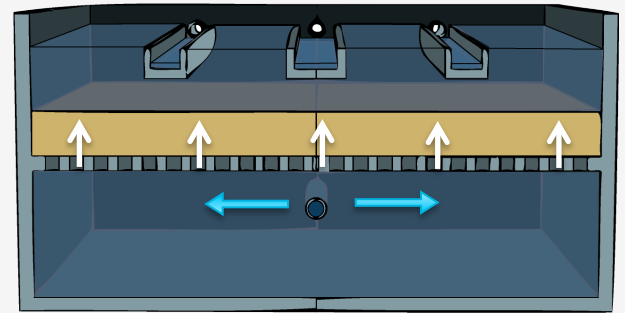
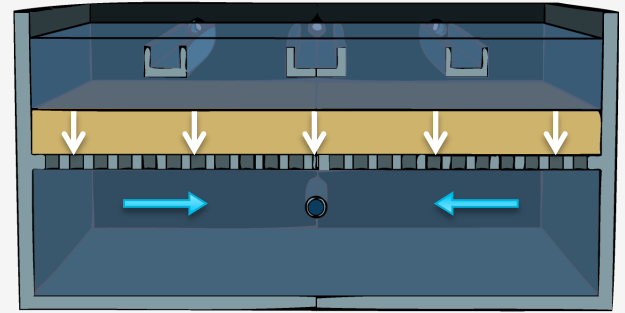
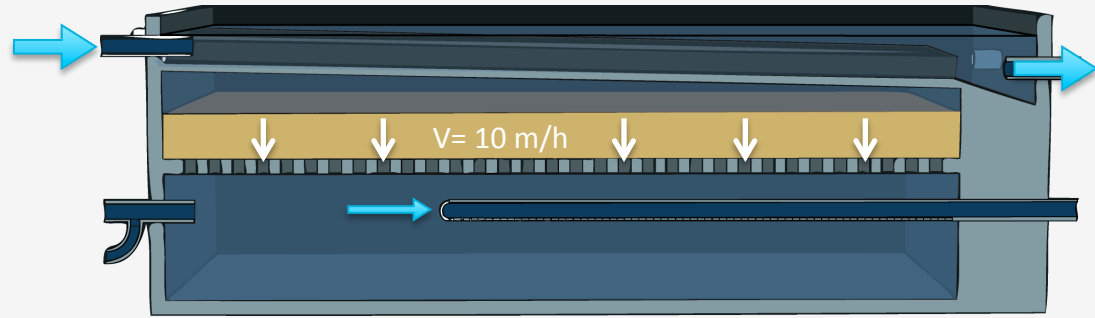
H_o = clean bed resistance [m]

H and c depend on:

design parameters: v, d, p_o, L

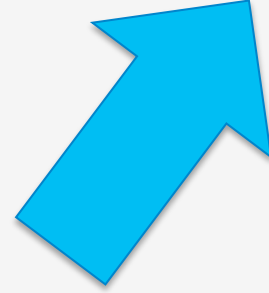
influent composition: c_o, ρ_d, n, T

Backwash

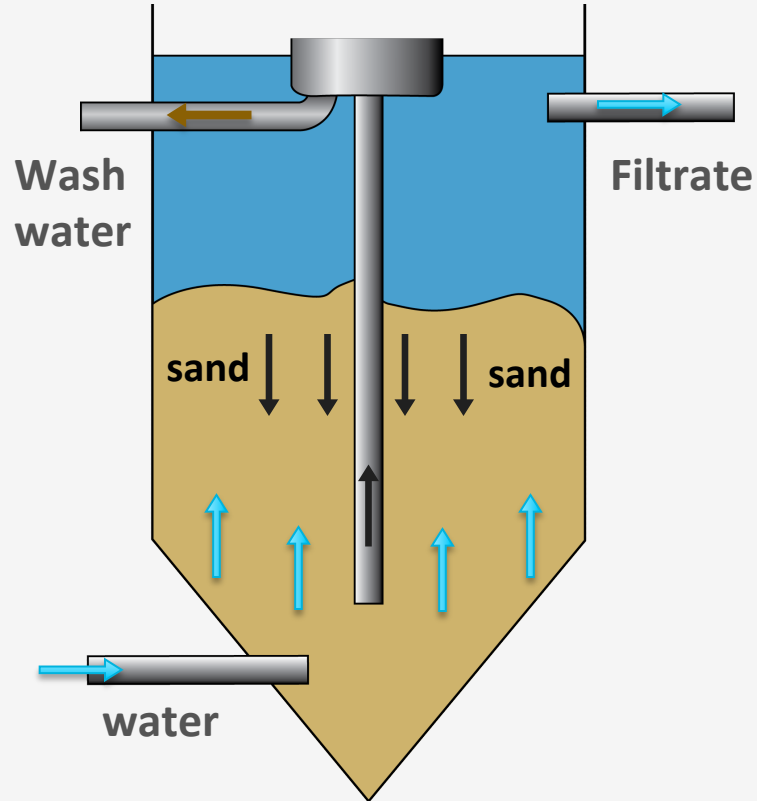


Filter trouble

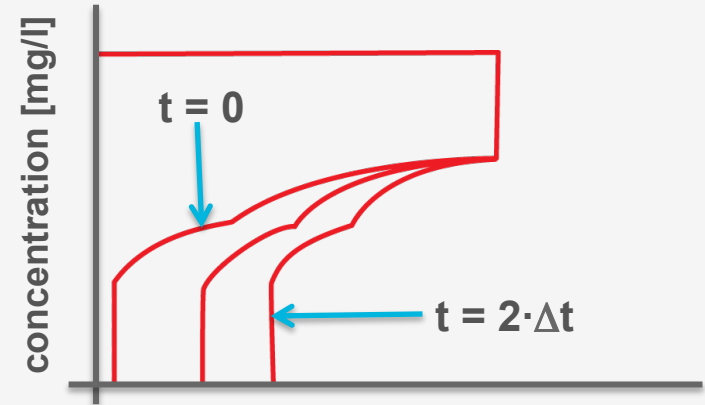
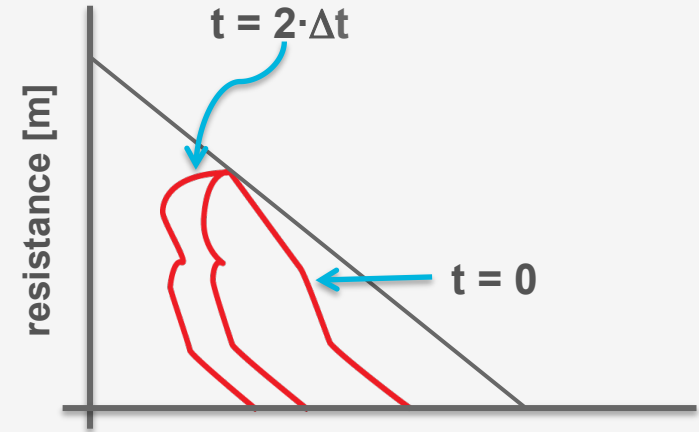
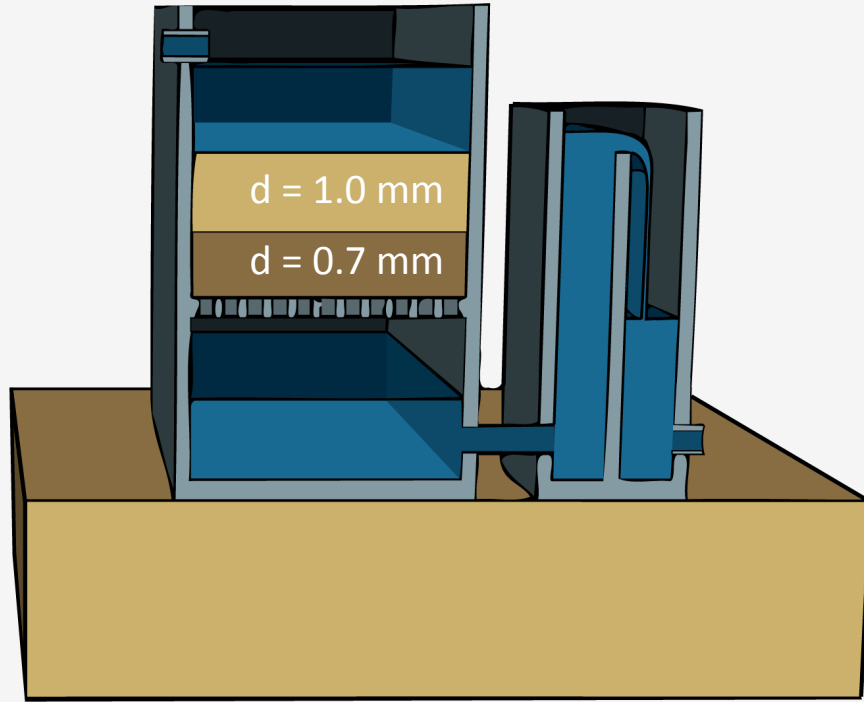
- Nozzle in the bottom breaks
- Filtering material can be lost



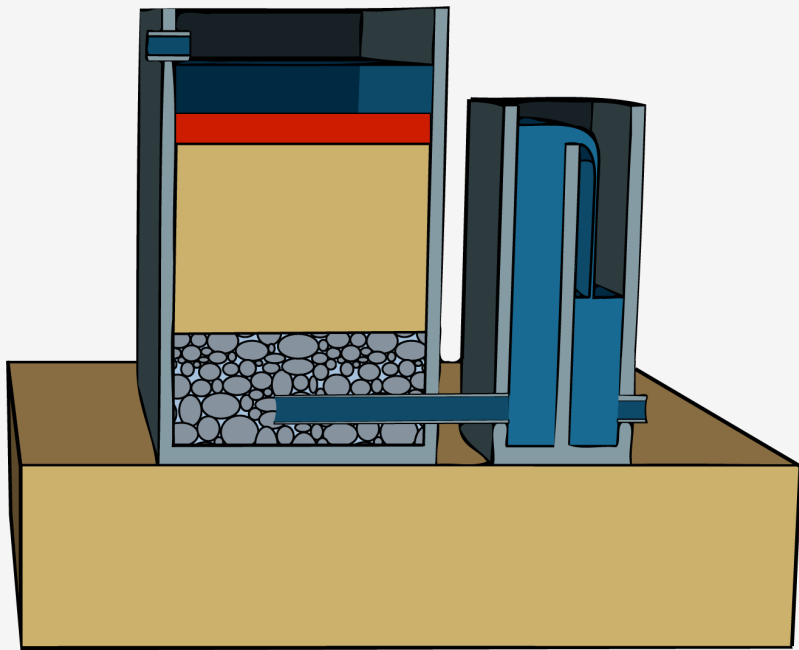
Continuous filtration



Double layered filtration



Slow sand filtration



Backwash

$$v = \frac{130 \cdot p_e^{1.2}}{(1 - p_e)^{10.8}} \cdot d^{1.8}$$

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

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

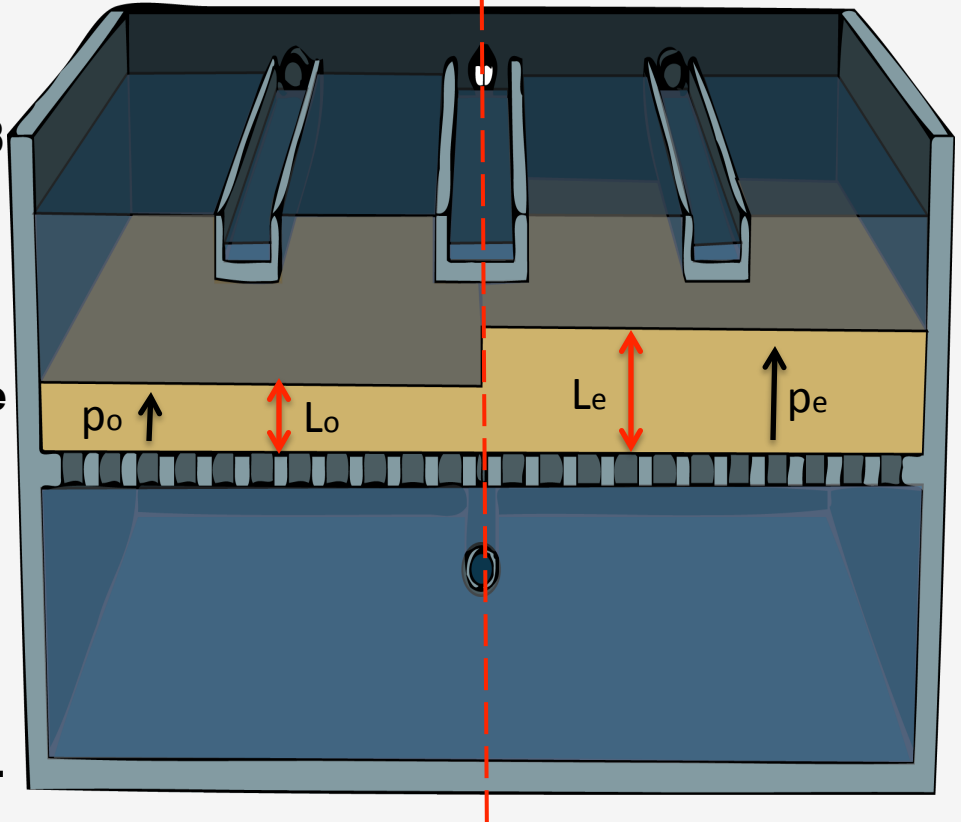
$$\rho_w \cdot g \cdot H_{\max} = (1 - p_o) \cdot L_o \cdot (\rho_f - \rho_w) \cdot g$$

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

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

Low backwash
velocity, no expansion

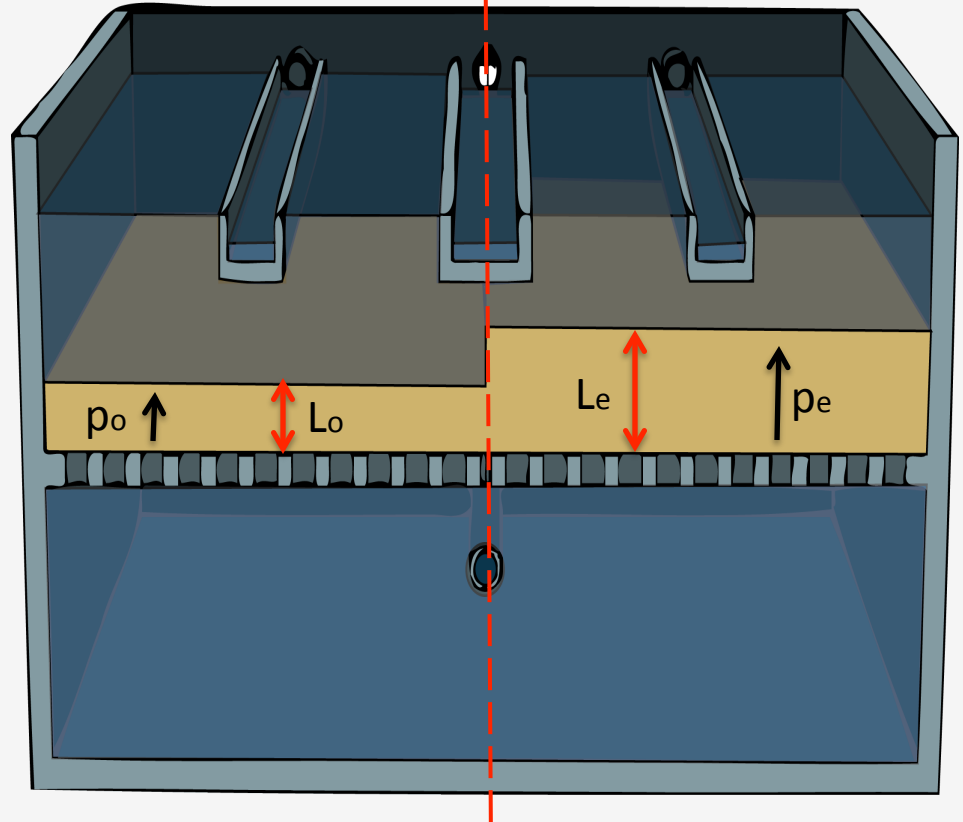
High backwash
velocity, expansion



Backwash

Low backwash
velocity, no expansion

High backwash
velocity, expansion



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

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

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

Backwash

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

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

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

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

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

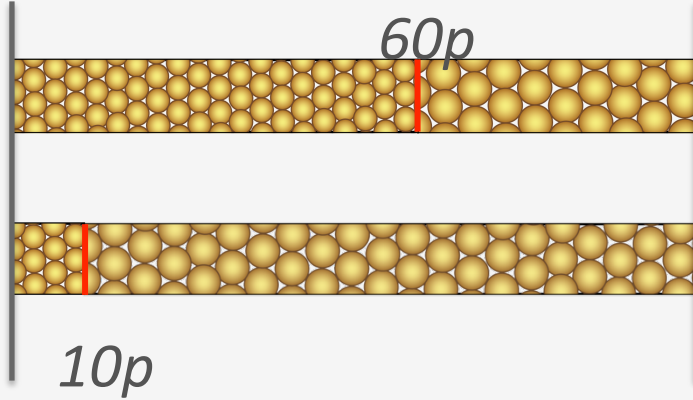
Carman-Kozeny equation

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

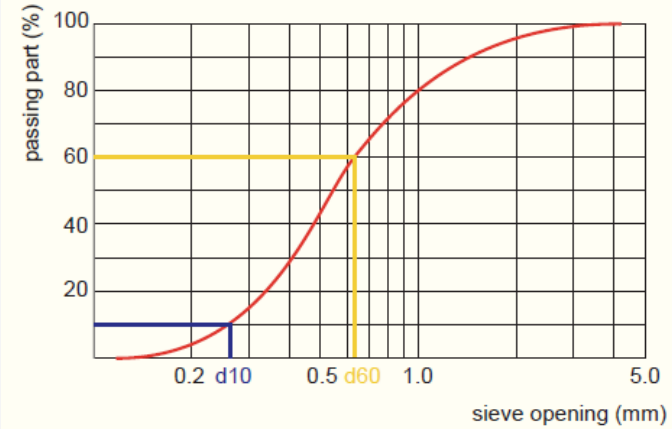
H = bed resistance [m]

H_o = clean bed resistance [m]

Coefficient of uniformity



% total grain by weight



Latter size

Effecti

$$U = \frac{d_{60}}{d_{10}}$$

in which:

U = uniformity coefficient (-)

d_{10} = size of sieves that let pass 10% of the sand mixture (mm)

d_{60} = size of sieves that let pass 60% of the sand mixture (mm)