Drinking Water 1

Activated carbon filtration

Dr.ir. S.G.J. Heijman

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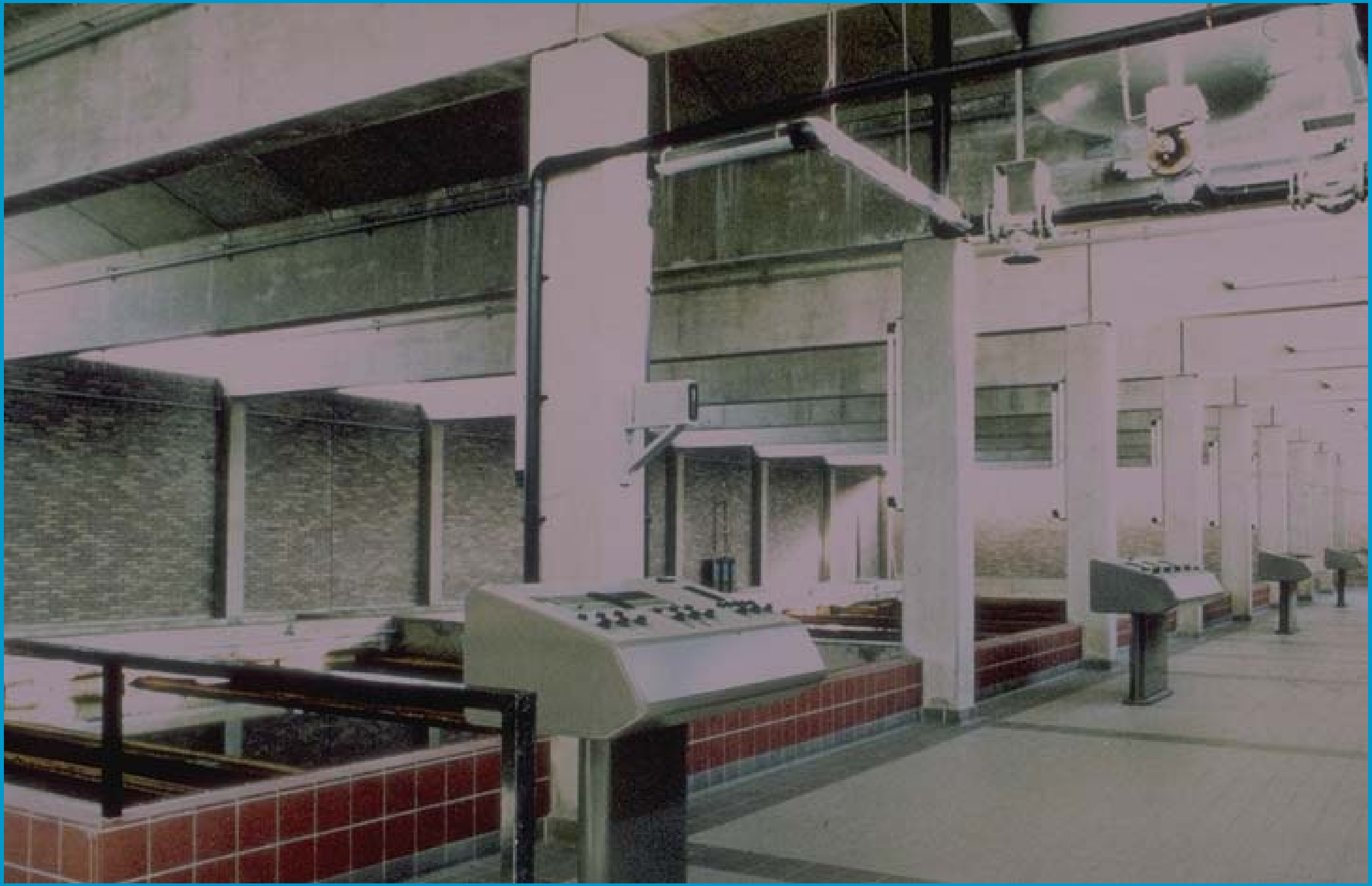
TU Delft
Delft University of Technology

Activated carbon filtration



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Contents

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Introduction

Granular Activated Carbon (GAC)

Powdered Activated Carbon (PAC)

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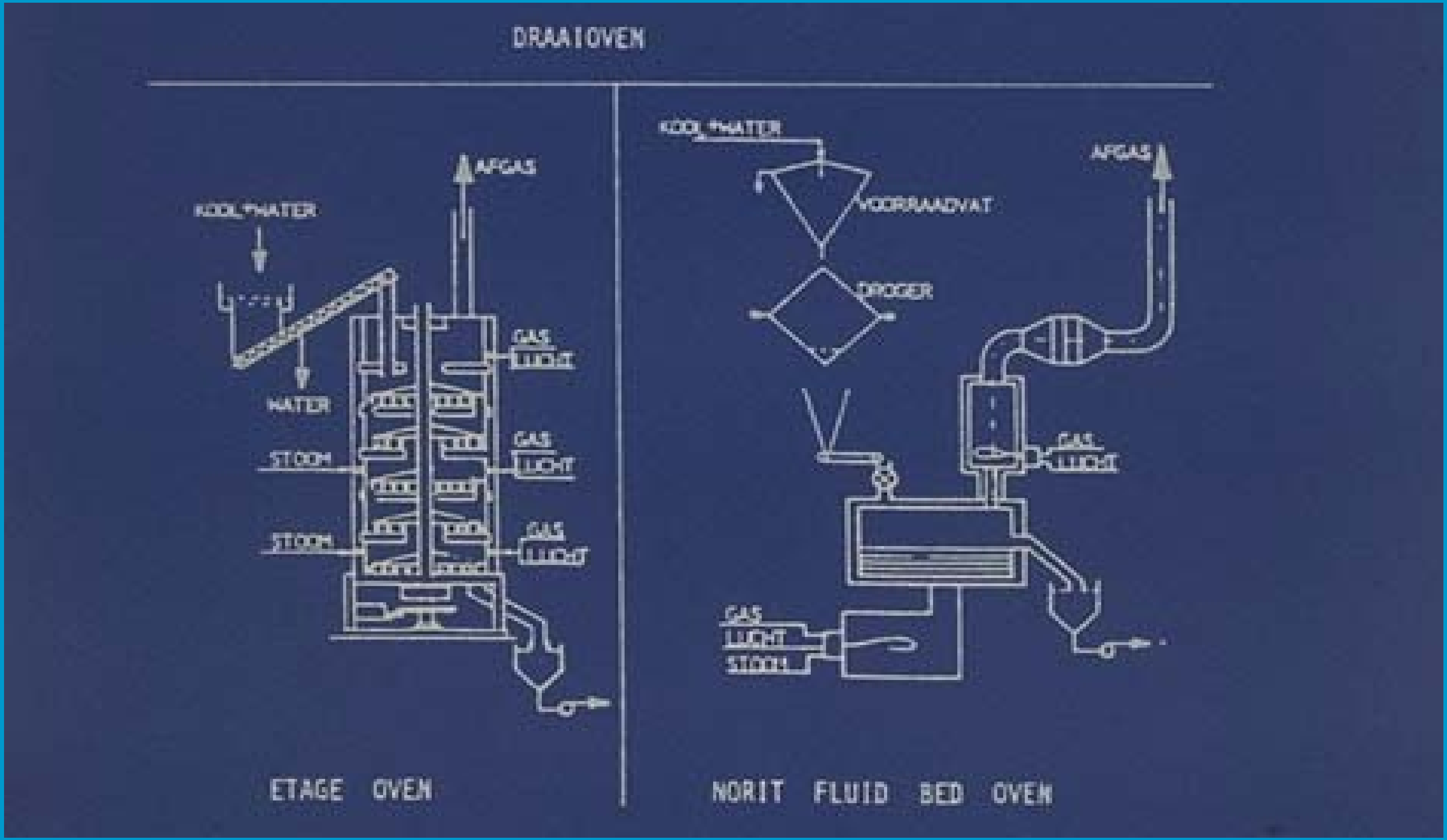
Introduction
Production and regeneration



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Introduction

Which substances?

- Odour and taste
- Pesticides
- Trihalomethanes
- DOC/TOC
- Colour
- AOX

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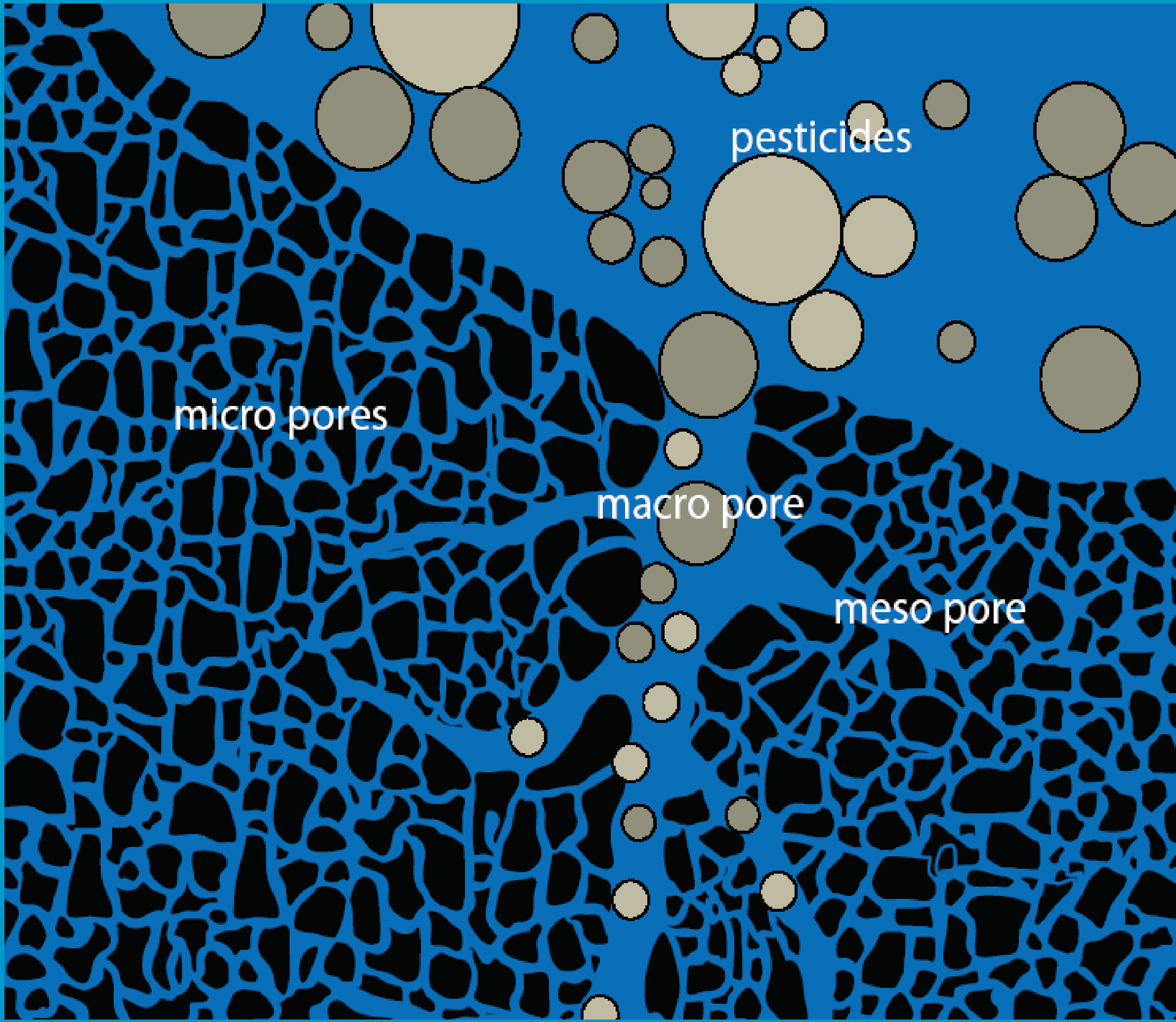
Introduction

Principle of adsorption



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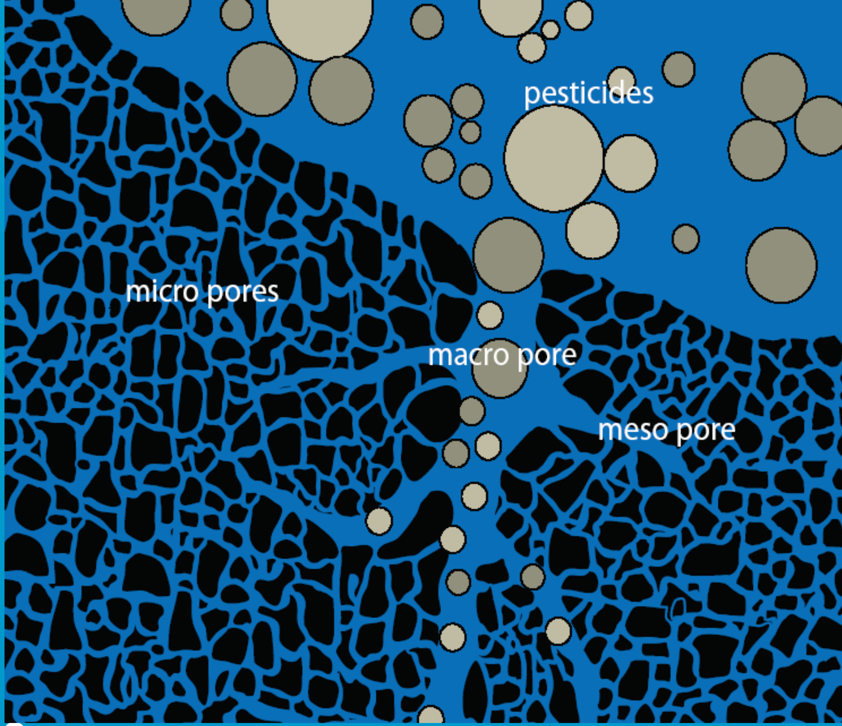
Introduction

Principle of adsorption



- Polarity of the molecule
- Size of the molecule
- Size of the pore
- Surface area adsorbent
- Competition of other organic molecules
- Pore blocking of larger molecules
- Pre-loading of the adsorbens with other organic molecules

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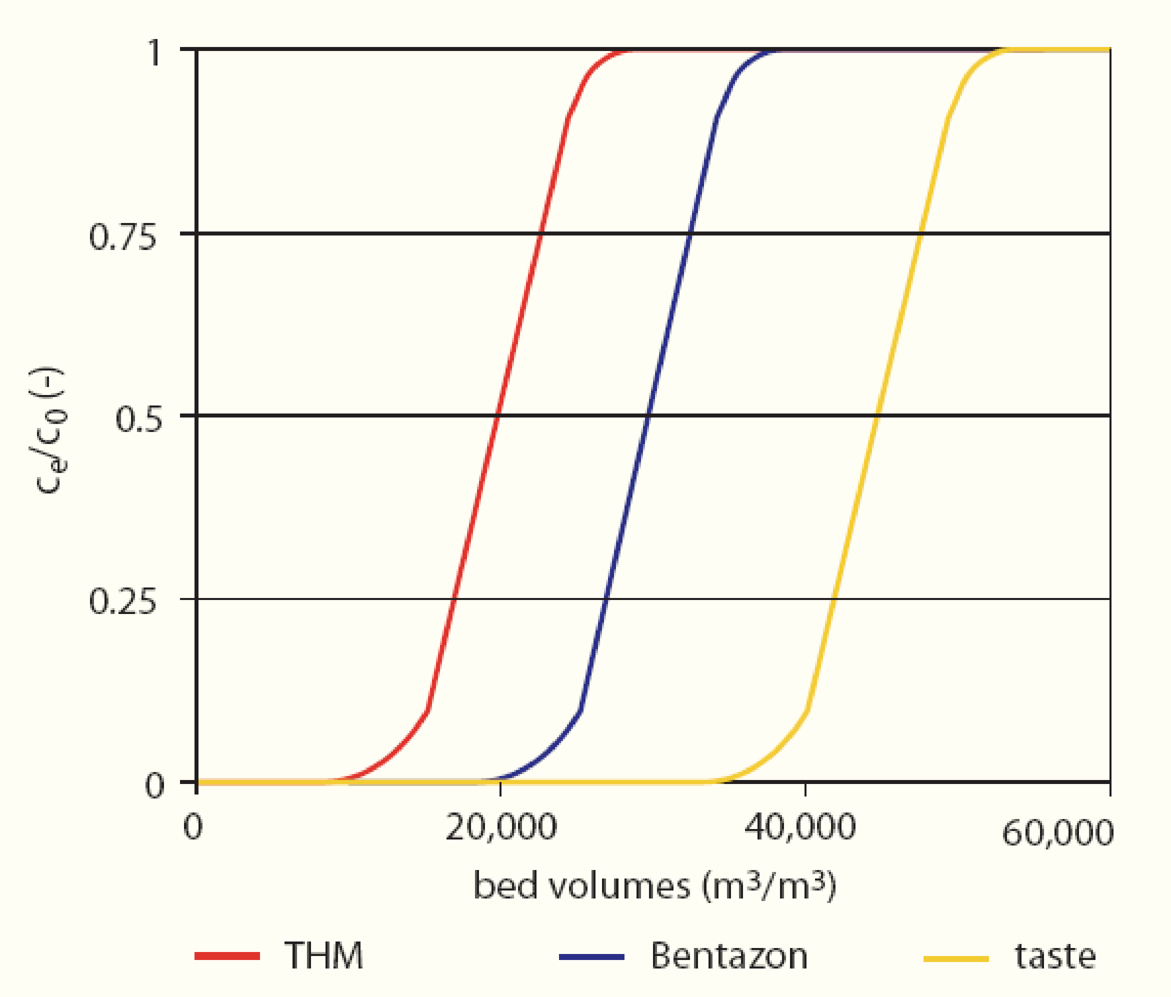
Introduction



Introduction

Operation of activated carbon

Odour, taste	50.000 BV	(1 €ct/m3)
Bentazon, atrazine	25.000 BV	(2 €ct/m3)
THM, AOX	15.000 BV	(3 €ct/m3)
EDTA, colour	2.500 BV	(20 €ct/m3)

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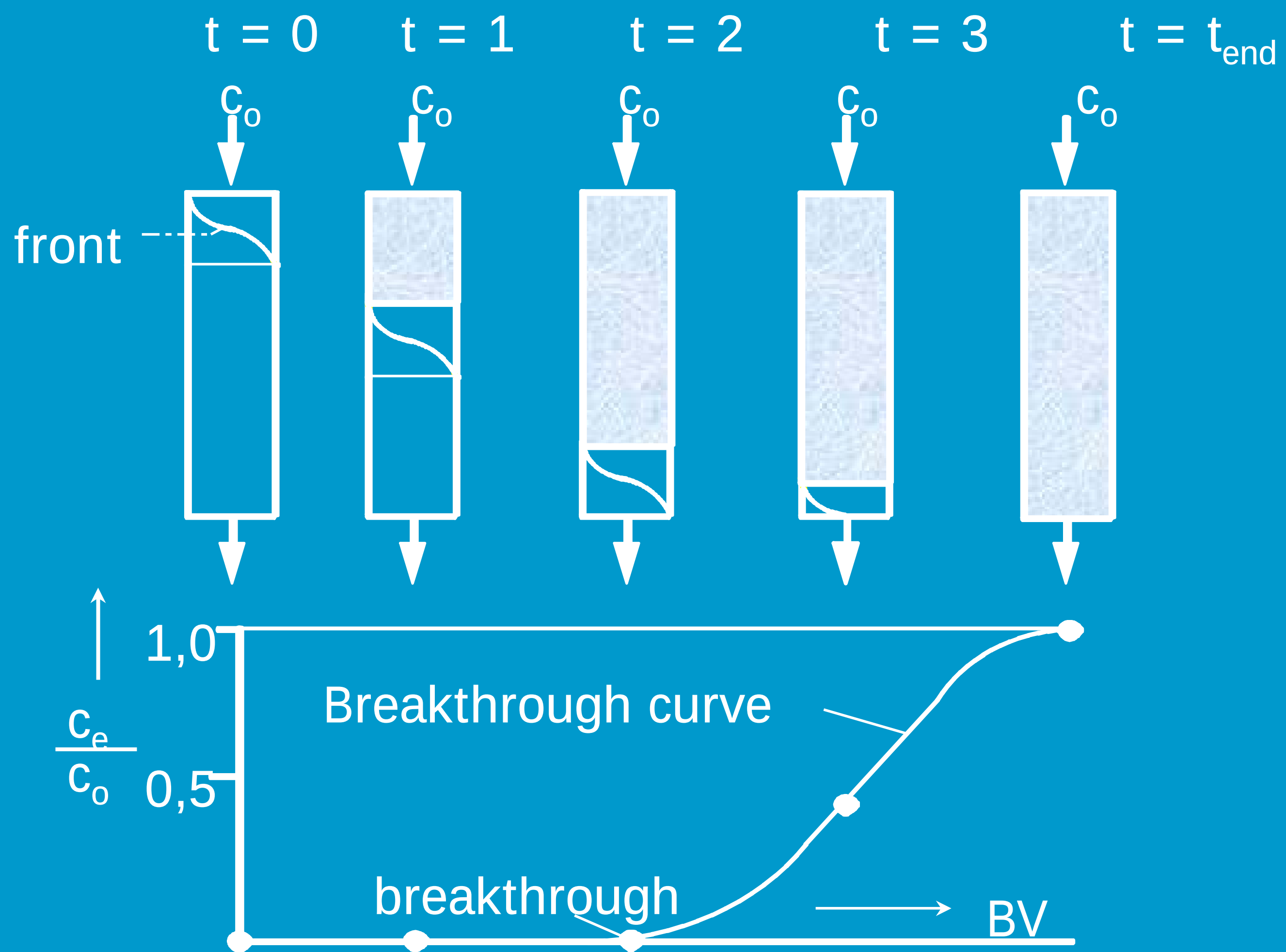
Introduction

Breakthrough curve



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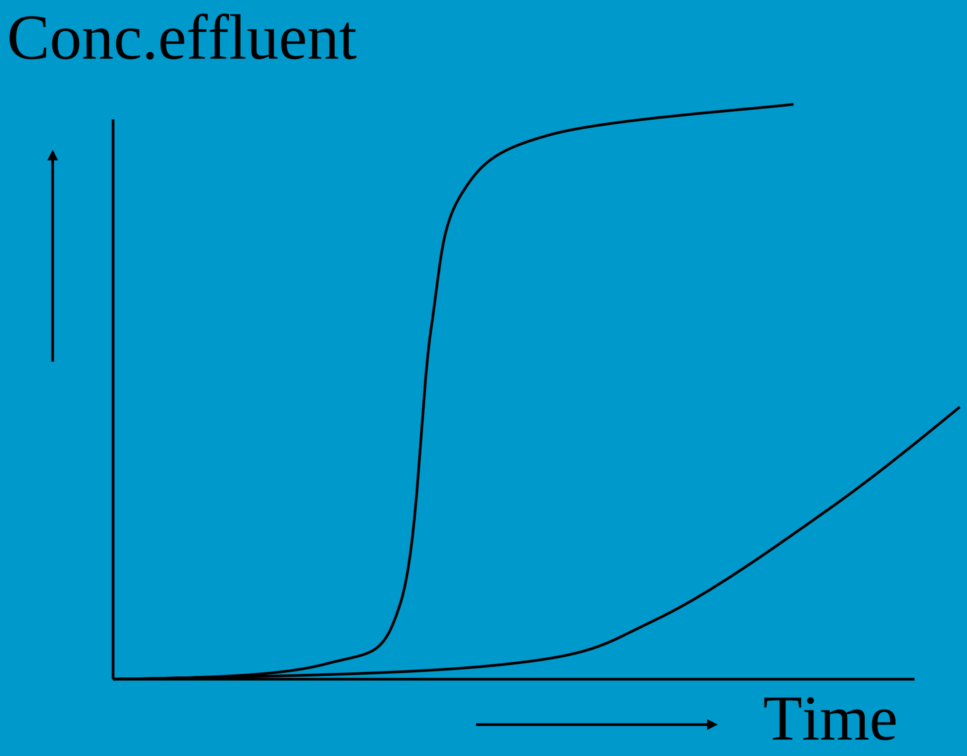

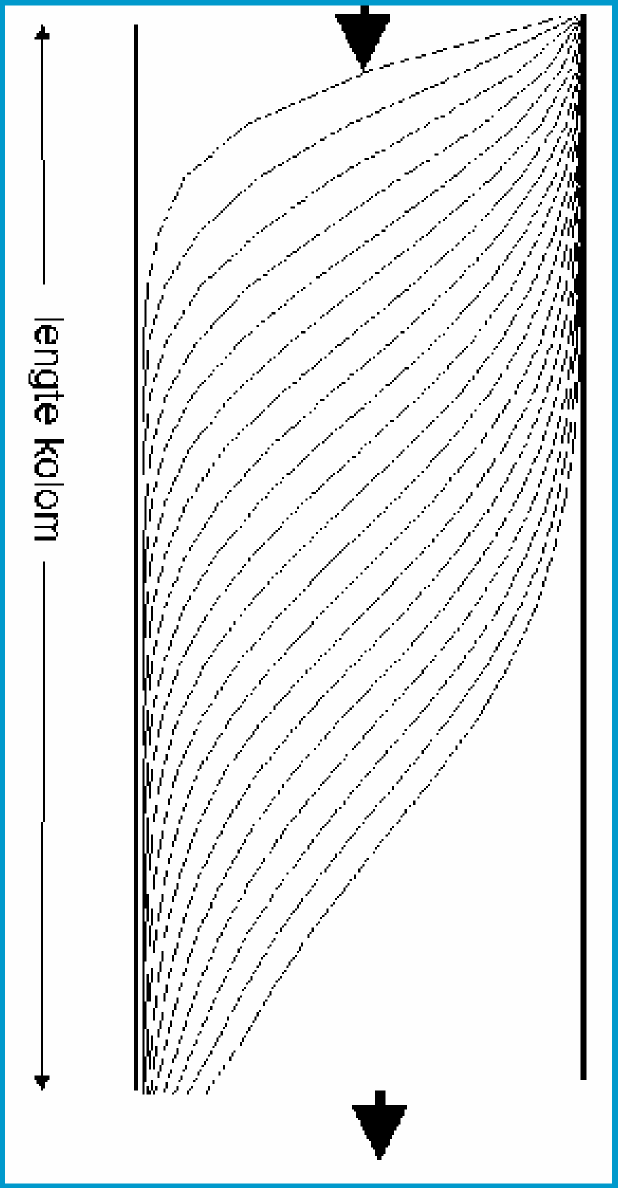

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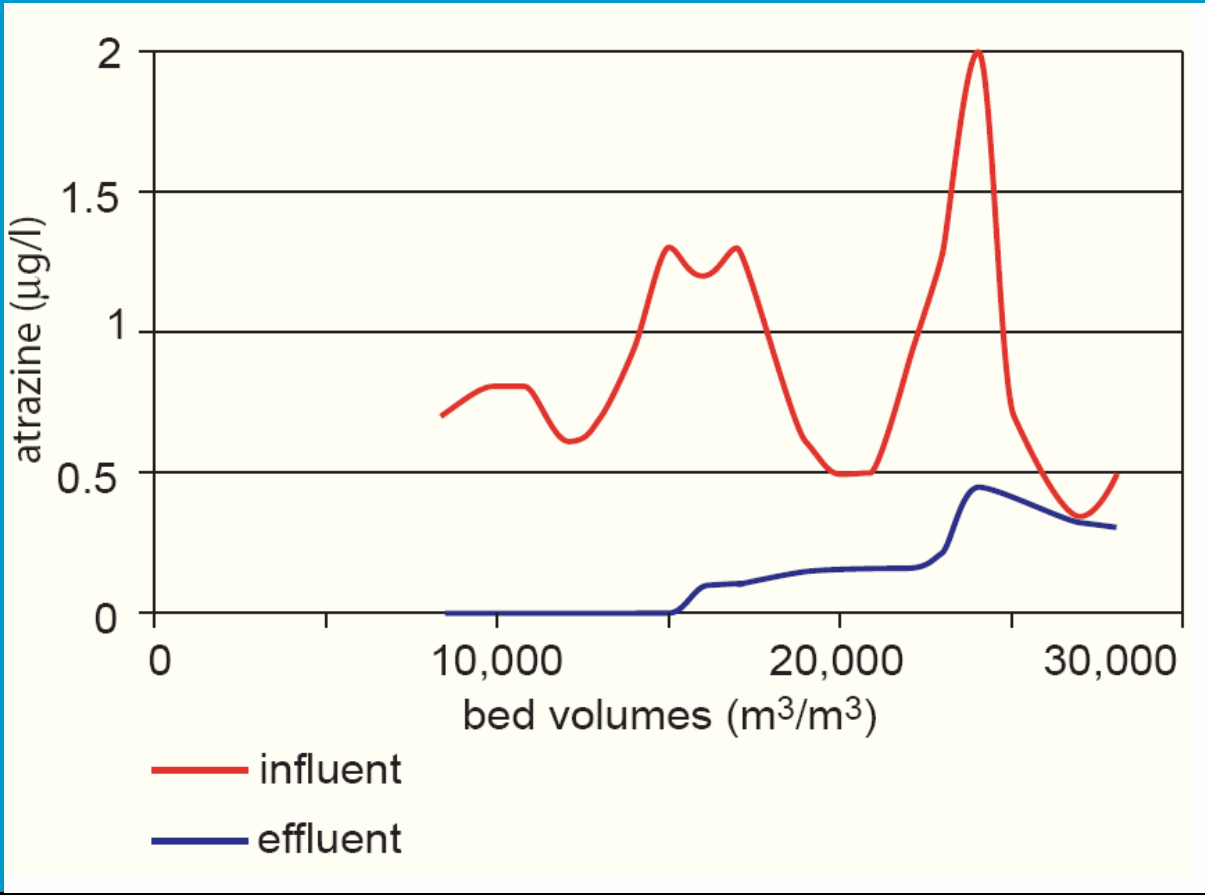
Introduction

Removal of Atrazine



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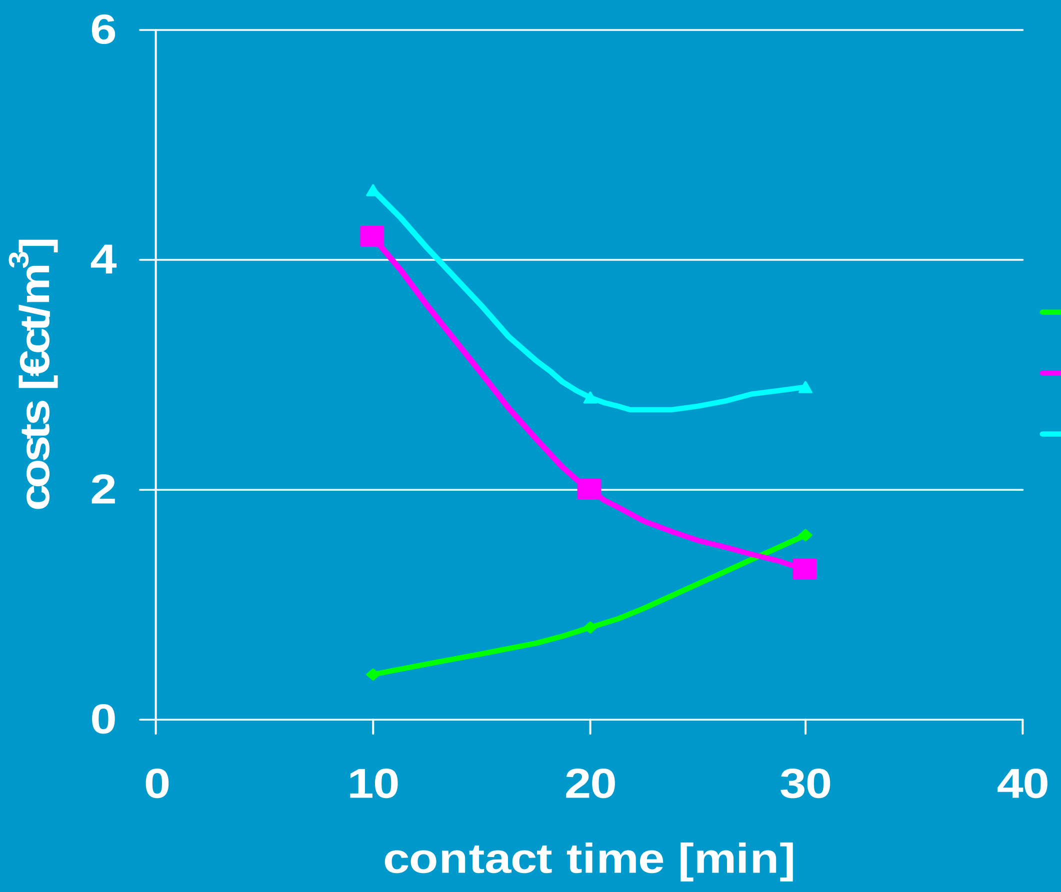
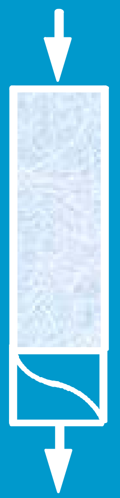
Introduction

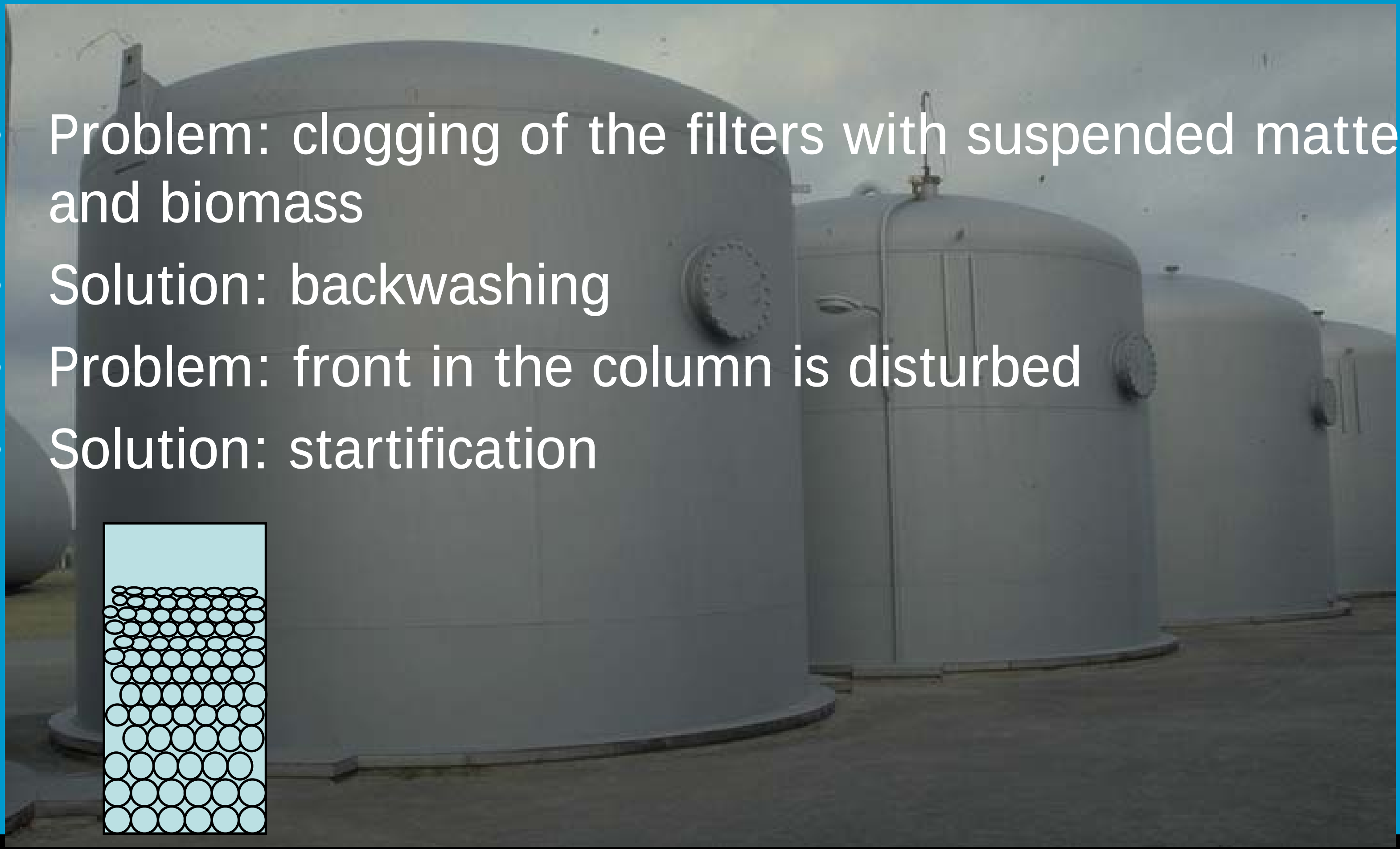
Costs of activated carbon filtration





Introduction

Activated carbon filtration Kralingen



- Problem: clogging of the filters with suspended matter and biomass
- Solution: backwashing
- Problem: front in the column is disturbed
- Solution: startification

Possible experiments
Powdered activated carbon

- Jar test predicts effluent concentration as a function of dose and contact time

- Time of the experiment about one hour

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Possible experiments

Adsorption isotherm

- Mix water and adsorbens continuously
- Wait for equilibrium
- Measure remaining pesticide
- Time of the experiment: one day to two weeks

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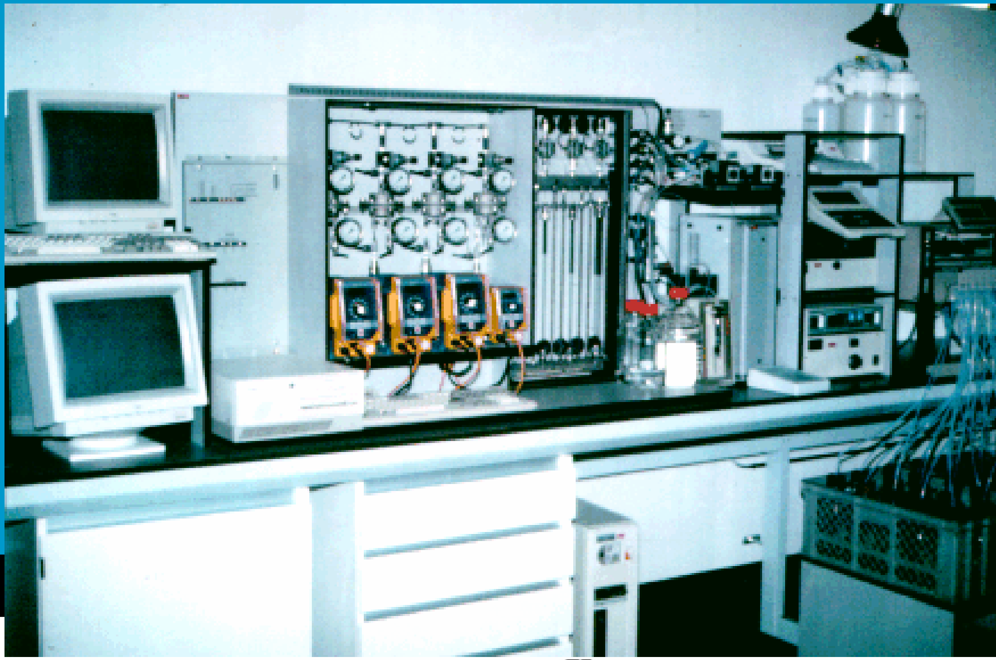
Possible experiments

Rapid small scale column tests

- Small column with small grains 0.1 mm
- Measure breaktrough curve
- 1 weak to 2 month



Possible experiments
Pilot plant test

- Measure breakthrough at real scale with real activated carbon
- Experiment takes several month to two years.

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Freundlich isotherm

Adsorption isotherm

Adsorption isotherm = relation between the adsorbed amount of a compound and the amount that remains in the bulk liquid at equilibrium

Freundlich-isotherm $q_{max} = \frac{x}{m} = K \cdot c^n$

qmax =	loading capacity (g/kg)
c =	concentration (g/m3)
x =	adsorbed mass of substance (g)
m =	mass activated carbon (kg)
K =	Freundlich constant (g/kg)*(m3/g)^n
n =	Freundlich constant (-)

!! Mind units !!

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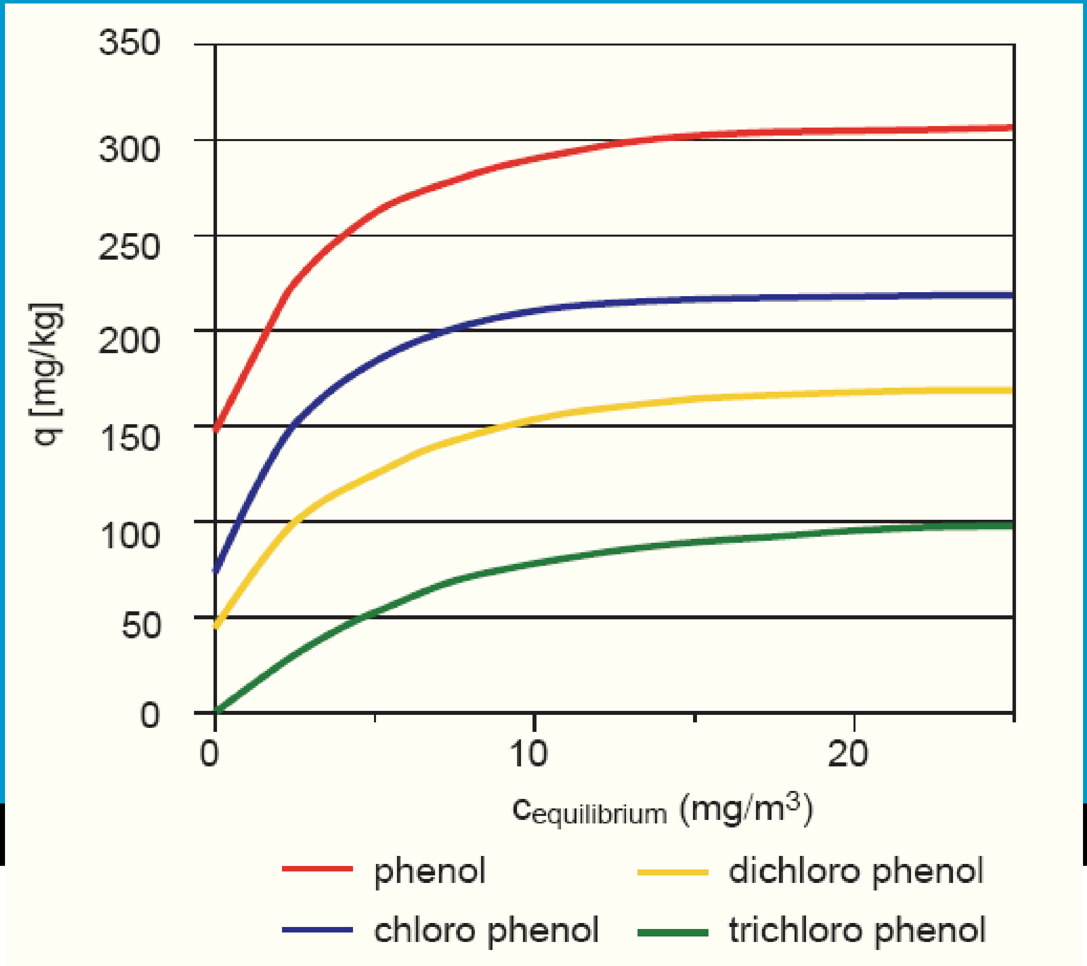
Freundlich isotherm

Adsorption isotherm



high q: easy to remove

low q : difficult to remove

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Freundlich isotherm

Freundlich constants K and n

K and n are constants, but depend on:
- type of carbon
- pH
- characteristics of the compound to be adsorbed
- presence of natural organic matter
- temperature

Degree of adsorption to be determined with
Structural Activity Relationship (SAR)

Freundlich isotherm

S.A.R.

	K	n
Alkanes		
CH3Cl	6.2	0.80
CHCl3 (chloroform)	95.5	0.67
CH2Cl - CH2Cl (DCEA)	129	0.53
CH2Cl - CHCl - CH3 (1,2 DCP)	313	0.59
Alkenes (compounds with double bounds are easier to remove)		
CCl2 = CHCl (TCE)	2000	0.48
Pesticides		
dieldrin (organochlorine)	17884	0.51
atrazine (organonitrogen)	38700	0.29
dinoseb (fenolderivate)	30400	0.28
2,4,5 TP (fenoxycarbonicacid)	15392	0.38
Aromates		
C6H6 (benzene)	1260	0.53
C6H5CH3 (toluene)	5010	0.43
C6H5OH (phenol)	503	0.54

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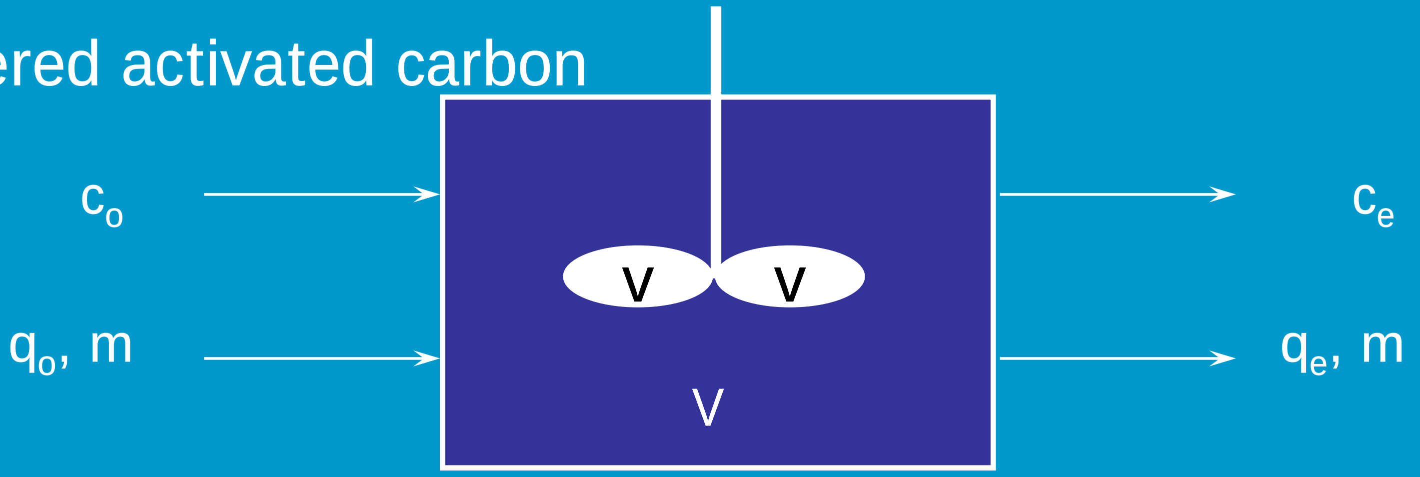
Batch versus column

Powdered activated carbon



Mass balance

$c_o \cdot V + q_o \cdot m = c_e \cdot V + q_e \cdot m$

$q_o = 0$ --> $W = \frac{m}{V} = \frac{c_o - c_e}{q_e}$

m = amount of carbon [g]
V = volume [m^3]
W = dosing of carbon [g/m^3]

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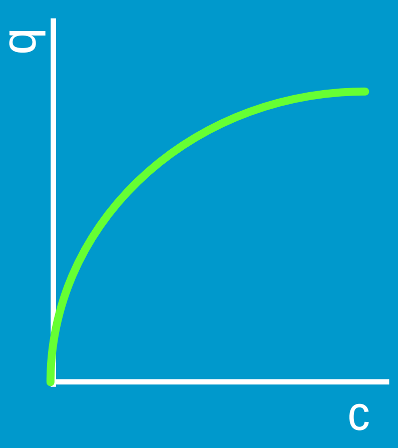
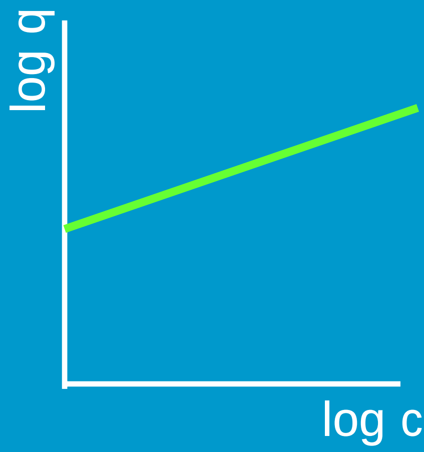
Batch versus column

PAC Scheveningen

Batch versus column

Powdered activated carbon





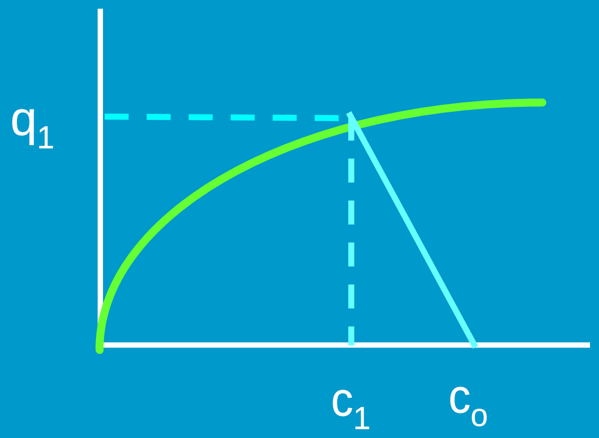
n = 0,1 - 0,5

K = 2 - 200

Freundlich $q = K \cdot c^n$

Ideal mixer

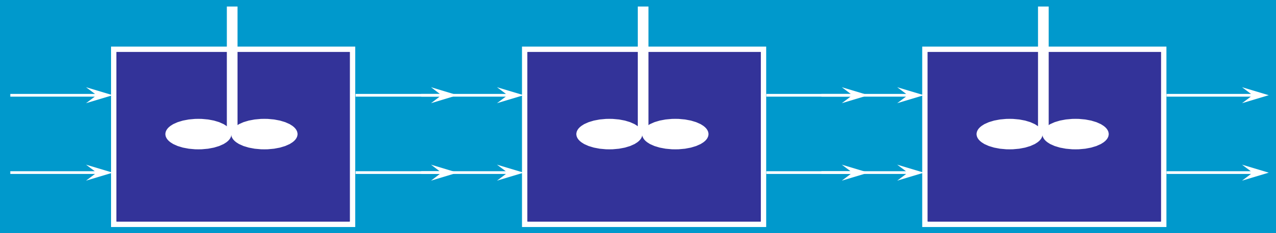
1 - step



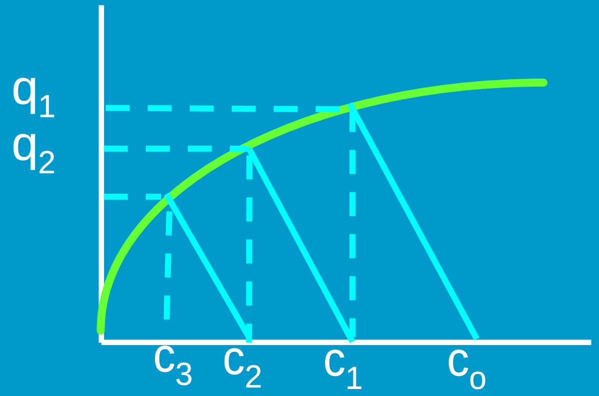
$c_1 - c_o = -W \cdot q_1$ (mass balance)

Batch versus column

Column= multiple batch proces



3 - steps



$$c_2 - c_o = -W_1 \cdot q_1 - W_2 \cdot q_2$$

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Batch versus column

- Advantages PAC:
  - Minimal investment costs (if combined with coagulation/sedimentation)
  - Small particles less pore blocking
- Disadvantages PAC:
  - Effluent concentration= equilibrium concentration
  - No regeneration possible

Batch versus column

- Advantages GAC:
    - Effluent concentration= zero (until breaktrough)
    - Regeneration possible
    - Robust againt peak concentrations
    - Also AOC-removal by microorganism
- Disadvantages GAC:
    - High investment costs
    - Pore blocking/ blocking of the inner part of the grain

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2. Possible experiments
3. Freundlich-isotherm
4. Batch versus column
5. **Activated carbon filtration**
6. **Alternative configurations**

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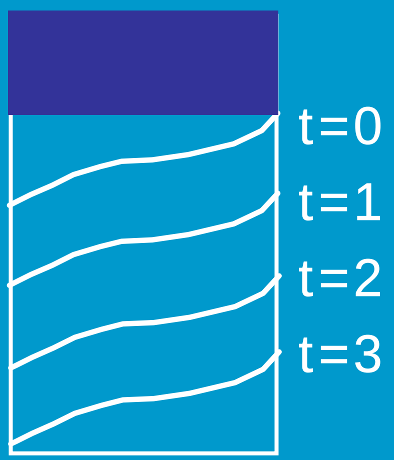
Activated carbon filtration

Principle



Equilibrium $q = K \cdot c^n$

Kinetics $\frac{dc}{dt} = k_2 \cdot (c_o - c_e)$

Mass balance $\frac{dq}{dt} = -v \frac{dc}{dy}$

c_o = 5 μg/l,
c_e = 0.1 μg/l

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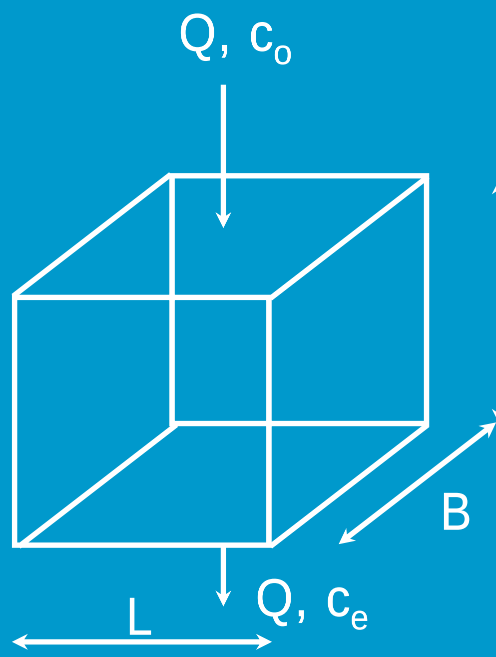
Activated carbon filtration

Definition of terms



$$v = \frac{Q}{B \cdot L}$$

$$EBCT = \frac{V}{Q} = \frac{H}{v}$$

$$BV = \frac{Q \cdot T}{V} = \frac{T}{EBCT}, \quad \text{therefor } T = BV \cdot EBCT$$

Q	= flow [m^3/h]
B	= width [m]
L	= length [m]
H	= height [m]
V	= volume [m^3]
c_o	= influent concentration [g/m^3]
c_e	= effluent concentration [g/m^3]
T	= operating time [h]
BV	= bed volume [m^3/m^3]
$EBCT$	= contact time [h]
v	= velocity [m/h]

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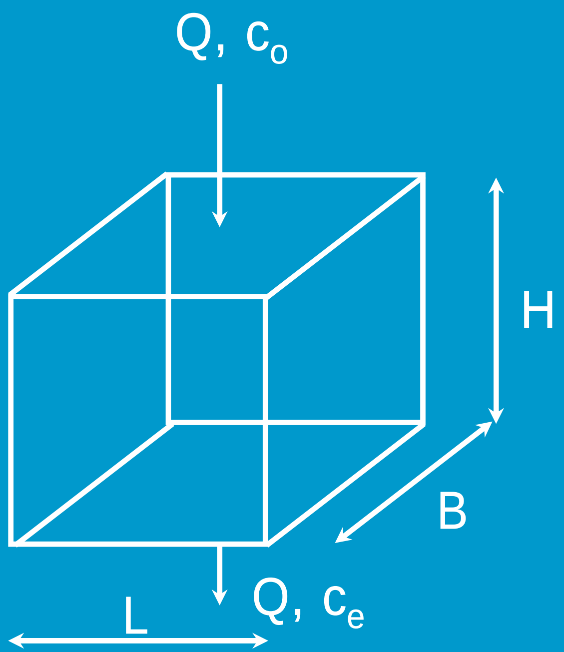
Activated carbon filtration

Basic equations



Q	= flow [m^3/h]
V	= volume [m^3]
c_o	= influent concentration [g/m^3]
c_e	= effluent concentration [g/m^3]
T	= operating time [h]
BV	= bed volume [m^3/m^3]
q	= loading [g/kg]
r	= density of carbon [kg/m^3]
W	= carbon usage [g/m^3]

$$q = \frac{Q \cdot T \cdot c_o}{V \cdot \rho} = \frac{BV \cdot c_o}{\rho}, \text{ therefor } BV = \frac{q \cdot \rho}{c_o} = \frac{K \cdot {c_o}^n \cdot \rho}{c_o}$$

$$W = \frac{\rho \cdot 1000}{BV}$$

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Activated carbon filtration

Example (1)

EBCT [min]	10			40		
BV [m^3/m^3]	5000	15000	30000	5000	15000	30000
T [h]	833	2500	5000	3300	10000	20000
r [kg/m^3]			500			500
W [g/m^3]	100	33	17	100	33	17
q [g/kg]	0.01	0.03	0.06	0.01	0.03	0.06
c_o = 0.001 g/m^3						
q [g/kg]	10	30	60	10	30	60
c_o = 1 g/m^3						

Activated carbon filtration

Example (2)

Freundlich

Effluent standard	c_e = 0.0001 g/m^3	n = 0.2		
		K = 2	20	200
		q = 0.3		3
30 g/kg				
	c_e = 0.1 g/m^3	n = 0.2		
		K = 2	20	200
		q = 1.3	13	130 g/kg
	c_e = 10 g/m^3	n = 0.2		
		K = 2	20	200
		q = 3	30	300 g/kg

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Activated carbon filtration

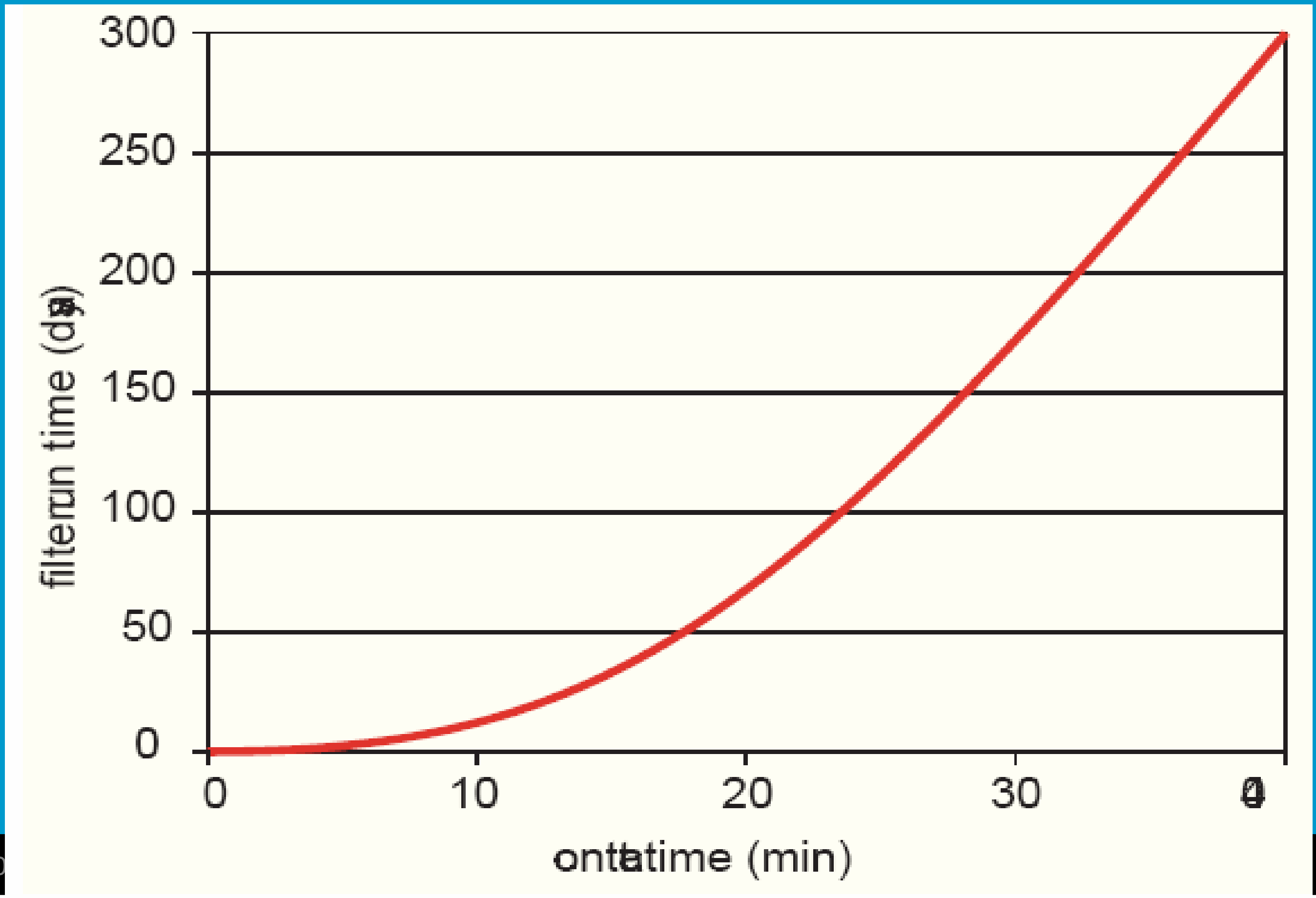
Example (3)

Suppose		$q =$	0.1	1	10 g/kg
$c_e = 0.001\ g/m^3$					
	$BV =$	5000	50000	500000	m^3/m^3
	$W =$	10	1	0.1	g/m^3
$c_e = 0.001\ g/m^3$					
	$BV =$	50	500	5000	m^3/m^3
	$W =$	10000	1000	100	g/m^3

Activated carbon filtration

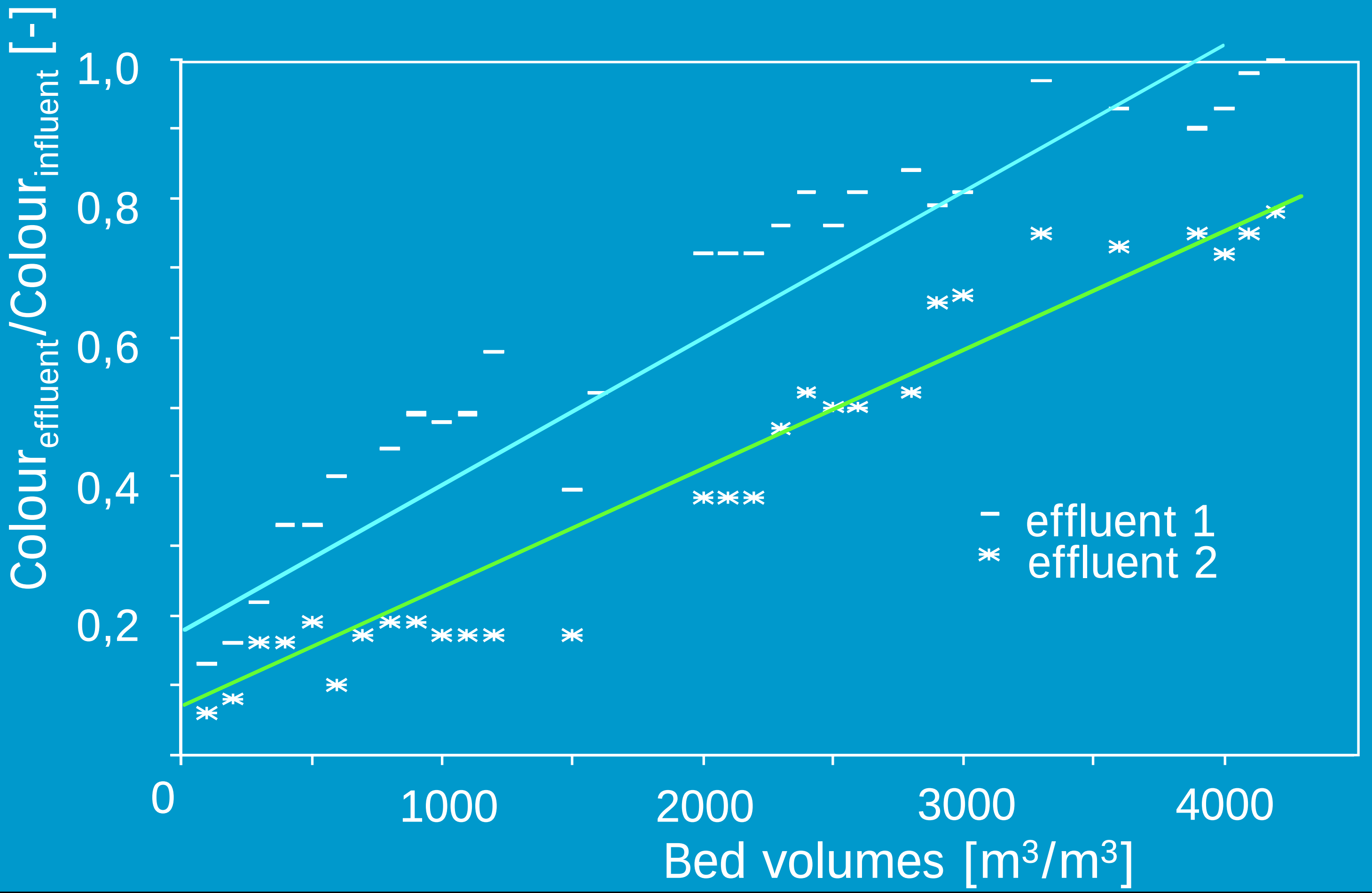
Contact time versus operating time

criterion = TOC-reduction of 50%



Activated carbon filtration

Removal of colour



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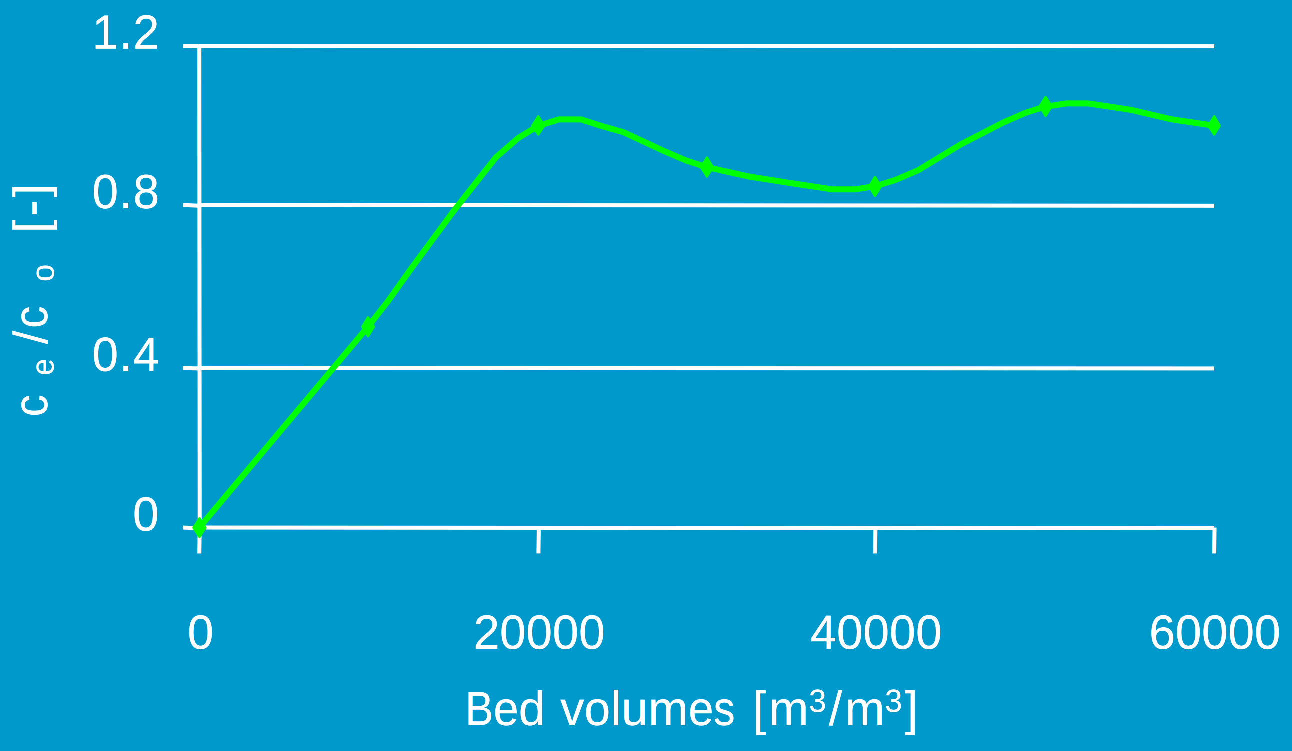
Activated carbon filtration

Example (1)

Breakthrough curve THM PS Berenplaat (c_o = 7 - 20 mg/l)



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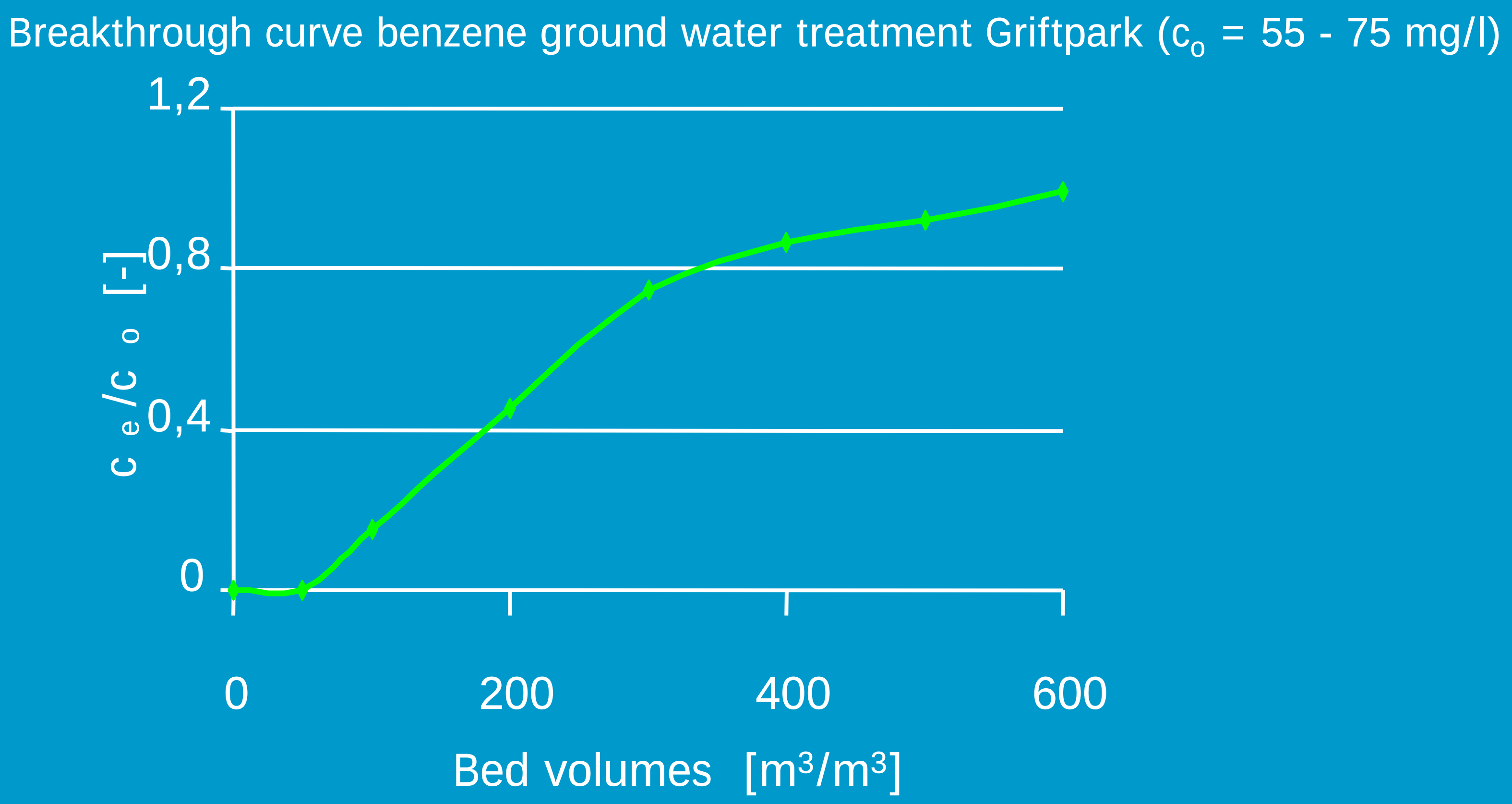
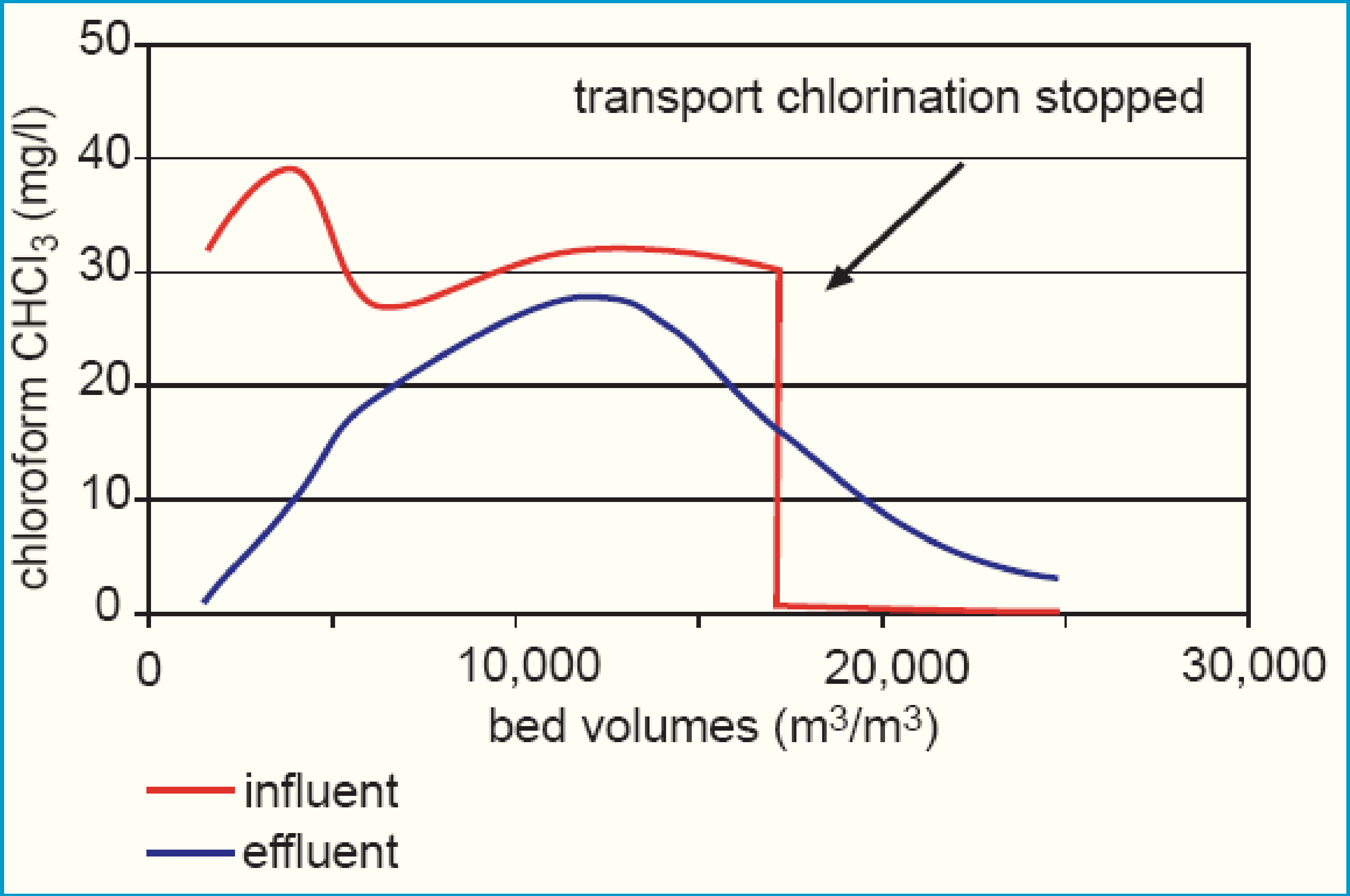
Activated carbon filtration

Example(2)



Activated carbon filtration



Activated carbon filtration

Practice (1)

Company	Location	Contact time (min)	Velocity (m/h)	Run time (months)	Bed volume (m^3/m^3)
WBE	Berenplaat	12	20	15	55000
PWN	Andijk	2 x 17.5	10.3	11 - 12	14000
WNWB	Zevenbergen	37	3,4	12	15000
DeltaN	Ouddorp	10.7 – 54.5	1.1 – 5.6	?	?
WMN	Zeist	2 x 12	7.5	10	21000 - 38000
GWA	Weesperkaspel	17 - 20	3.8 – 4.4	12	31000
WMO		12	11.1	24	50000

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Activated carbon filtration

Practice (2)

Company	Location	regeneration criteria	wash criteria	wash frequency
WBE	Berenplaat	Odor/Taste	time	1 x per week
PWN	Andijk	THM < 70 mg/l	resistance	5 x per run time
WNWB	Zevenbergen	-	resistance	not
DeltaN	Ouddorp	-	time	1 x per week
WMN	Zeist	TCE < 0.2 - 1 mg/l	resistance	not
GWA	Weesperkaspel	TCE 1 mg/l	resistance	not
WMO			resistance	not

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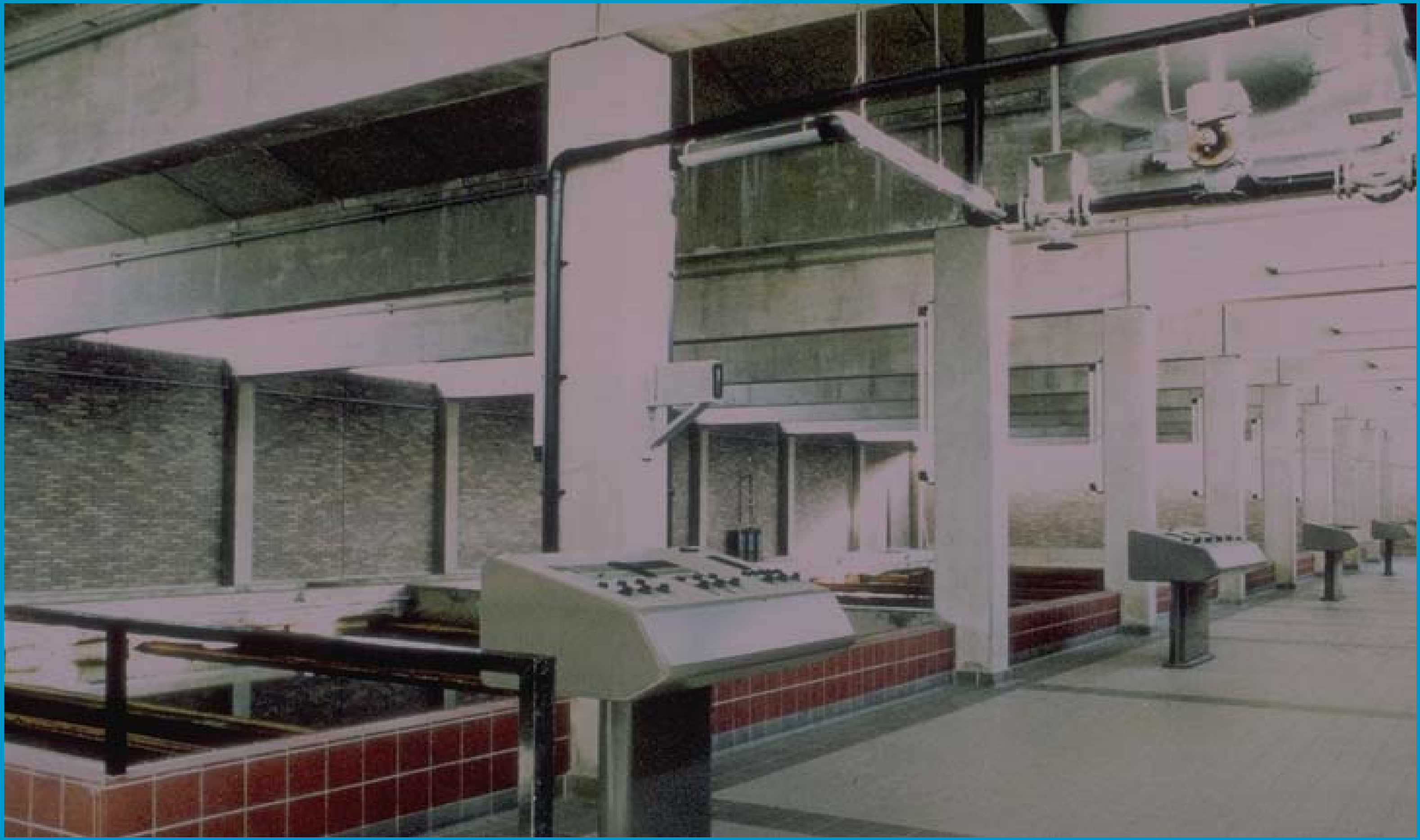
Activated carbon filtration

GAC Andijk



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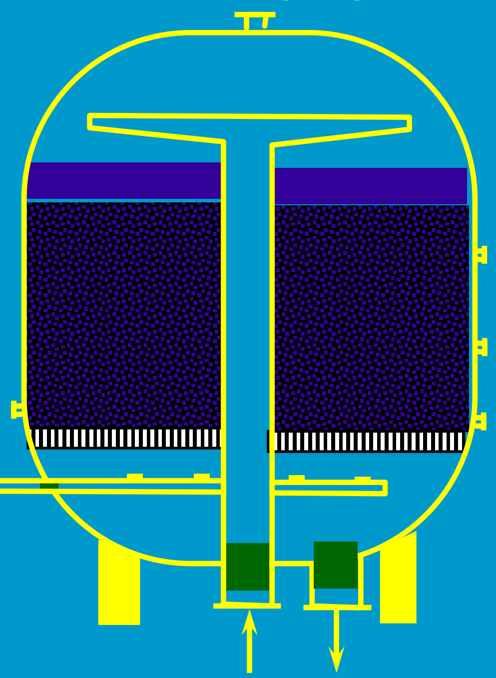
Activated carbon filtration

GAC Andijk

Parameter	before carbon	after carbon
colour (mg Pt/l)	4	1
UV extinction	5.1	1.1
TOC (mg C/l)	6.0	2.6
KMnO4 nº (mg/l)	10.3	2.5
$CHCl_3$ (mg/l)	21	15
$CHBrCl_2$ (mg/l)	24	7
$CHBr_2Cl$ (mg/l)	17	1
$CHBr_3$ (mg/l)	3	<1
TTHM (mg/l)	65	<24
AOCl (mg/l)	80	10
EOCl (mg/l)	10	1.5
Turbitity (FTU)	0.2	0.1

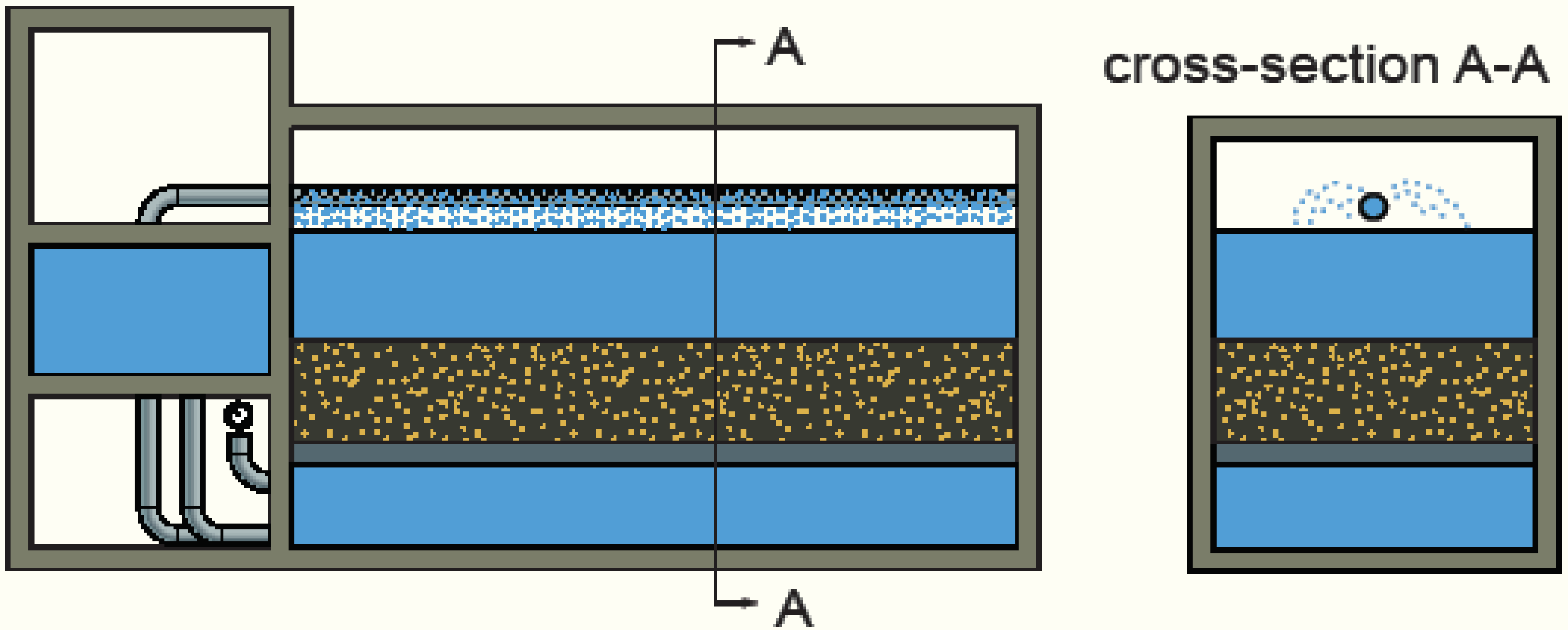
Activated carbon filtration

GAC Hendrik Ido Ambacht



Activated carbon filtration

Schematical representation of carbon filter



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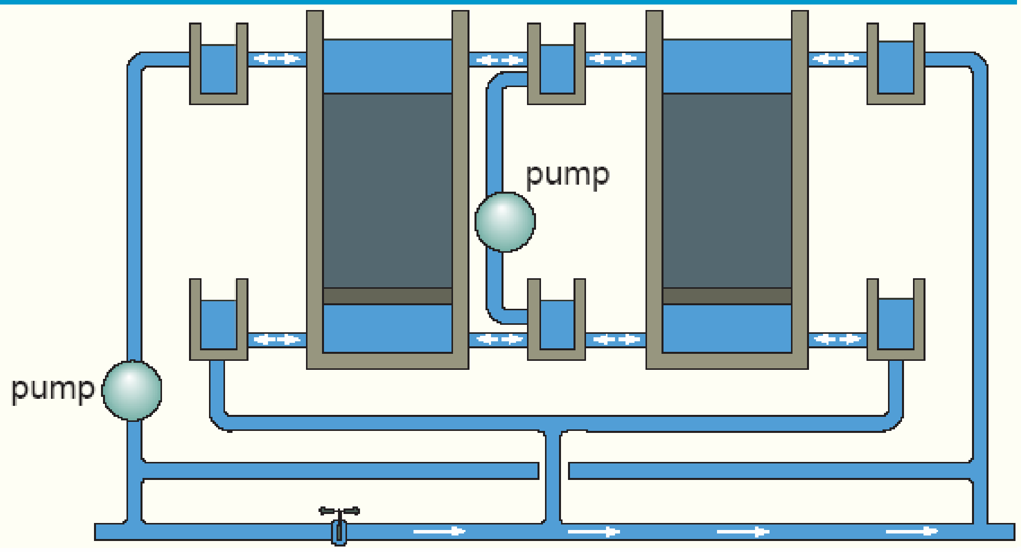
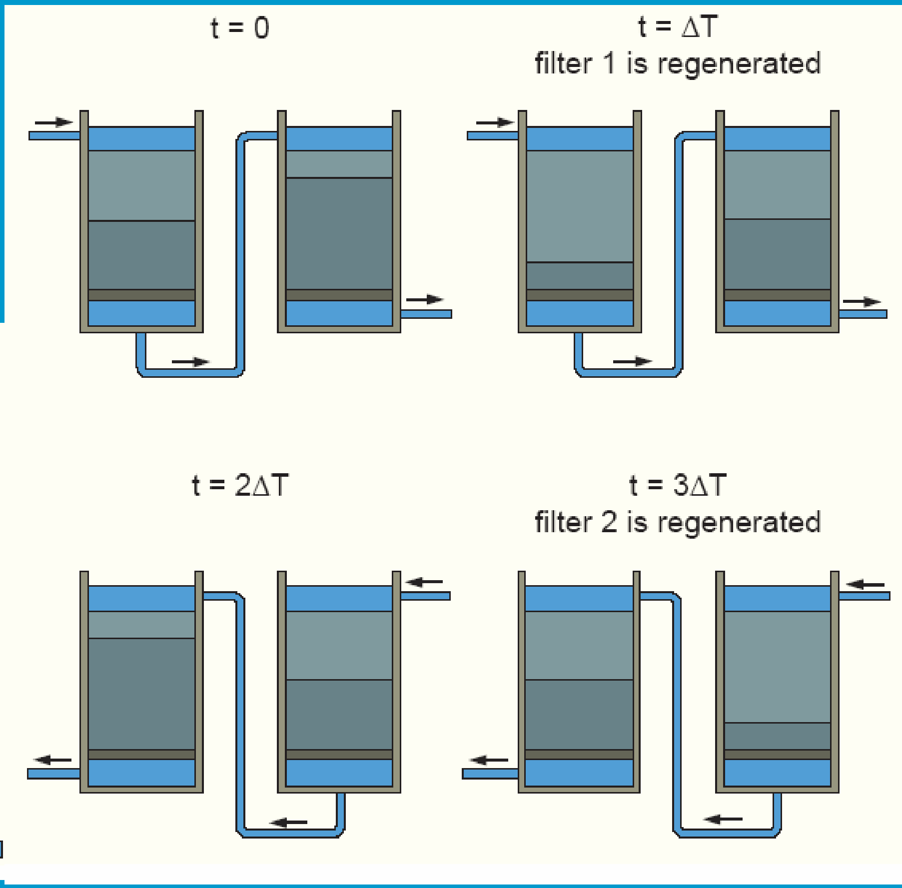
Alternative configurations

Pseudo moving bed





Alternative configurations

Biological activated carbon filtration

ozonation followed by activated carbon filtration

ozone --> oxidation organic compounds -->
increase of AOC -->
increase of bacteria -->
increase of degradation of adsorbed substances -->
adsorption new substance

disadvantage: higher AOC concentrations and increase of bacteria -->
regrowth bacteria in distribution system-->
post-disinfection

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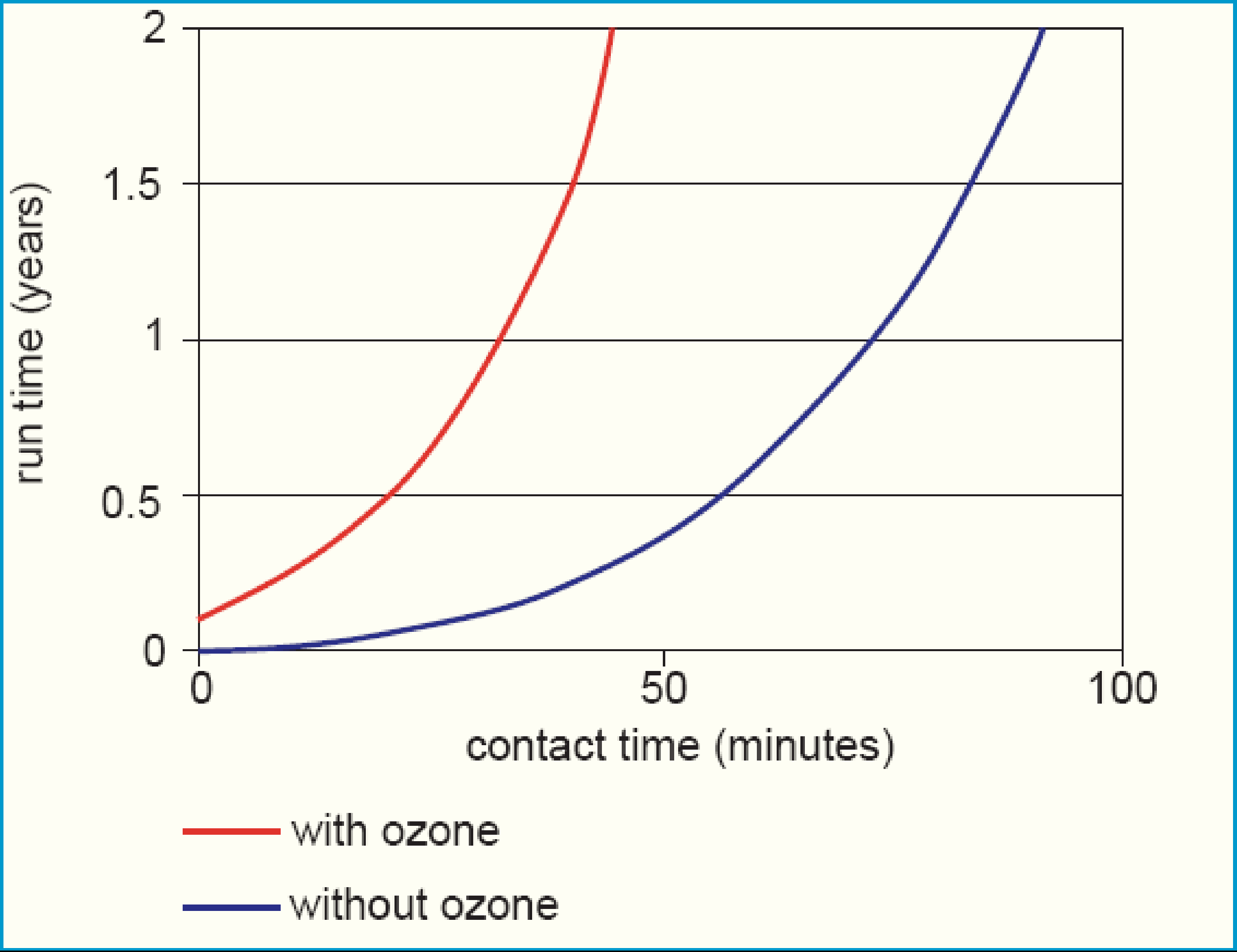
Alternative configurations



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