BioModel

Modellare necesse est, … !

B. Tolnai
Mechanical Engineer

"In practice, people are very reluctant to give up a theory in which they have invested a lot of time and effort."
- Stephen Hawking

Chapters from the topic of biological filtration

Re-Water Braunschweig
6.-7. November 2013.

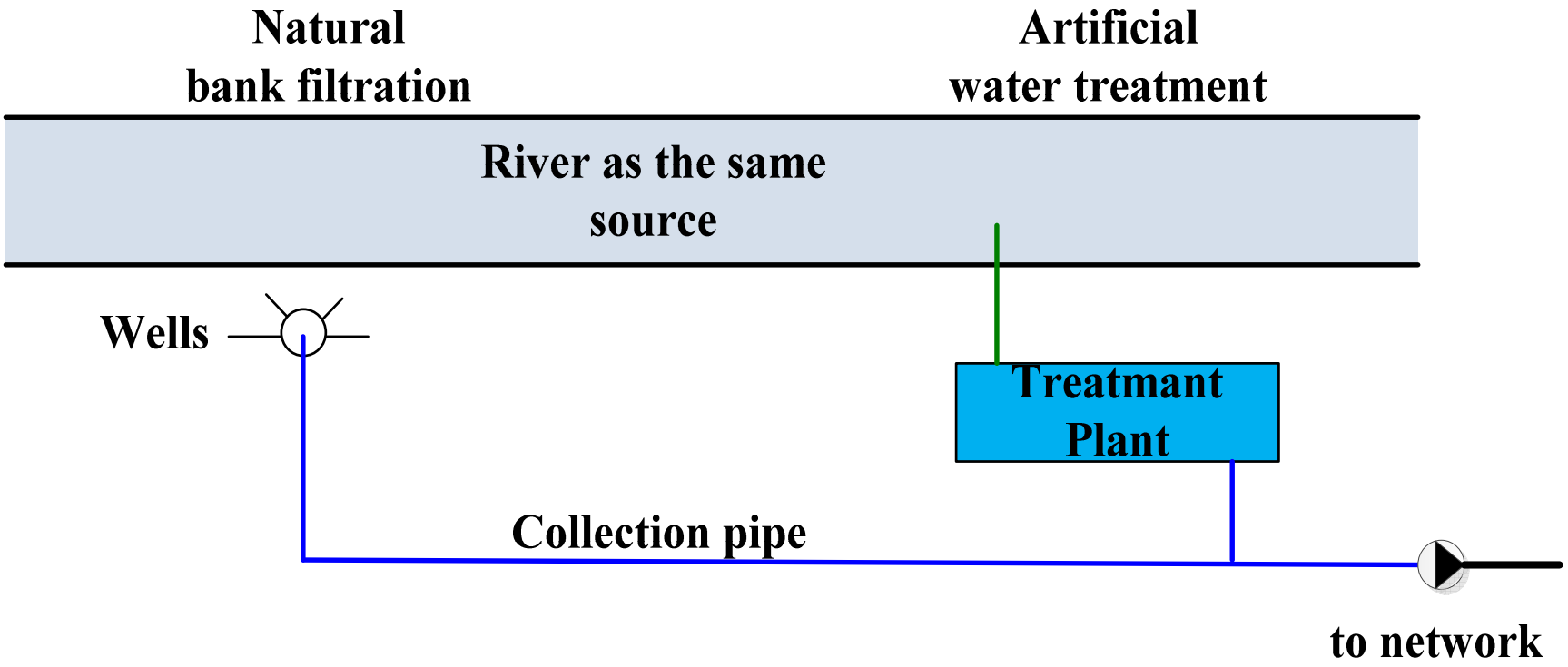
tolnaibela51@gmail.com

Instead of Contents

Who want to do a good biological drinking water treatment, he must arrive at the site of waste water treatment, because there gathered till now more experience.

But who want to create an economical and efficient waste water recycling, he must know the operation of bank filtration.

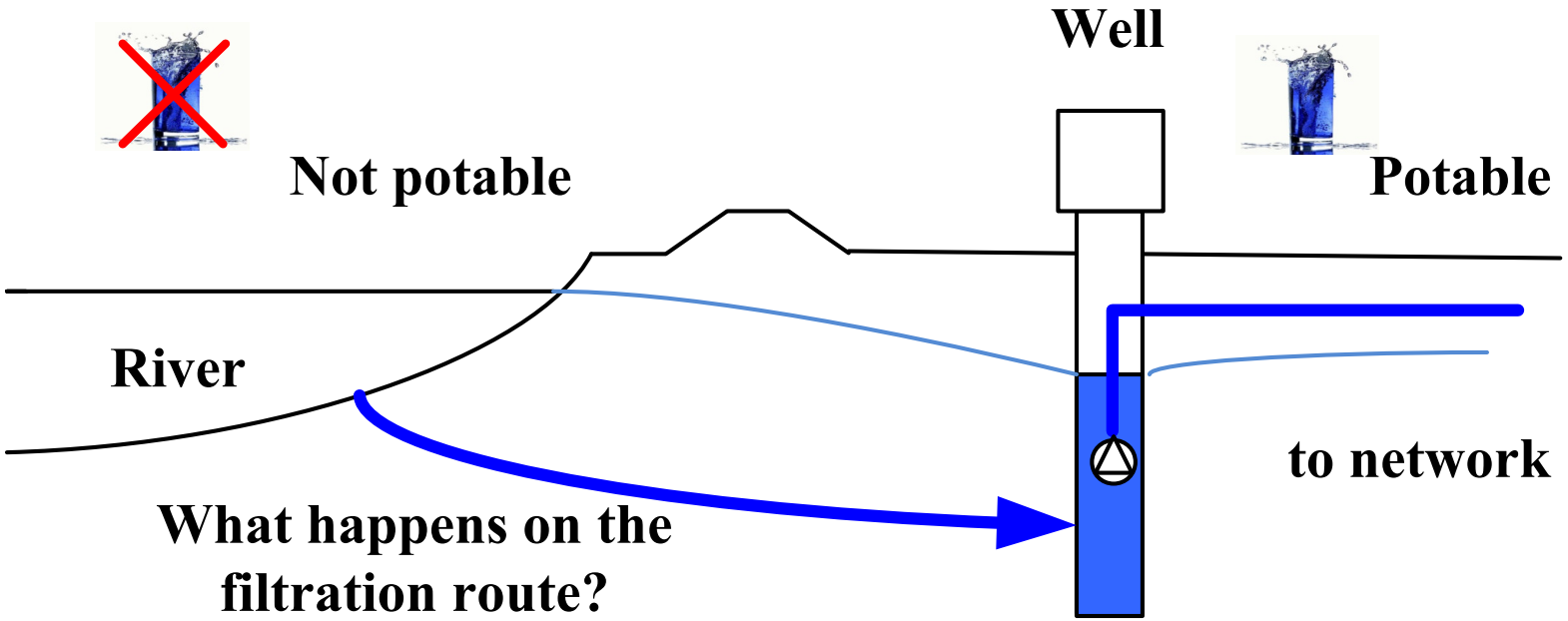
20 years for comparison



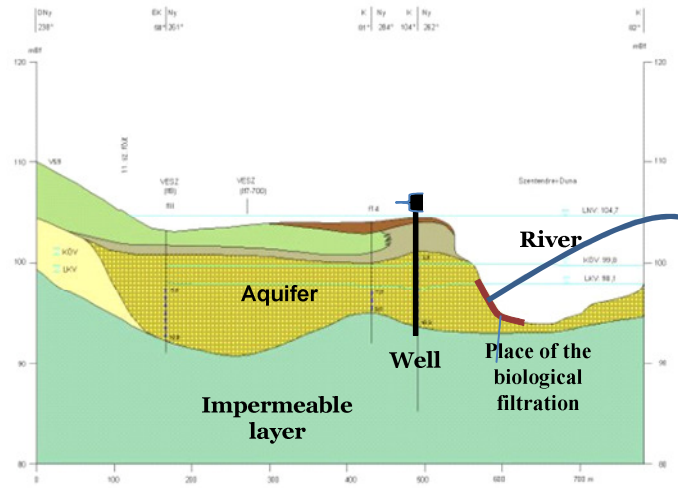
The water cleans
in one step

The water has cleaned
in many steps

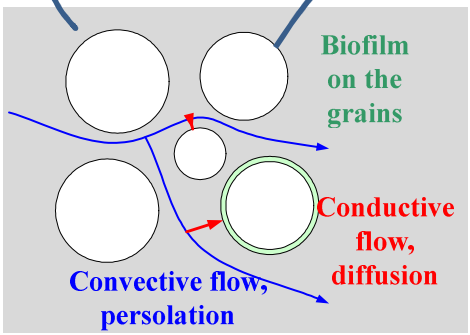
To drink or not to drink? – That is the question!



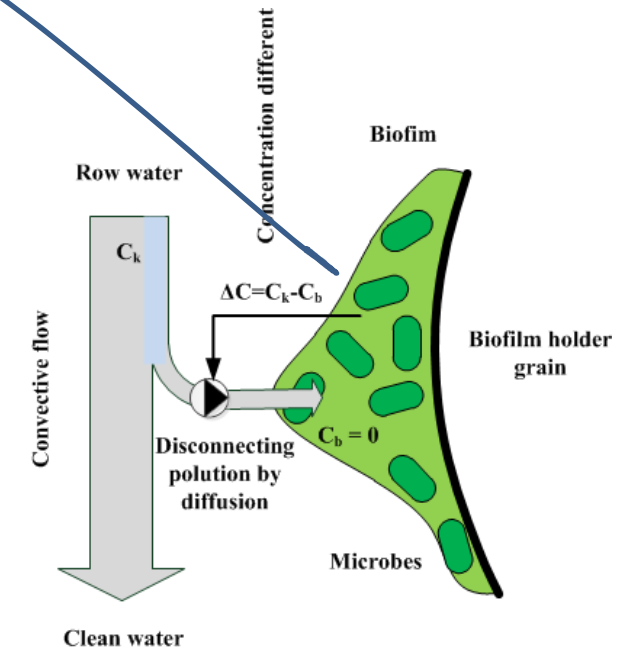
Quantity and quality by pumping



[m]



[mm]



[µm]

The bank filtration process

Partial Process	Driving force	Maintened by
Convective flow (persolation) **to the biofilm**	Pressure different	Pumping
Conductive flow (diffusion) **into the biofilm**	Concentration different	Work of bacteria
Bio-chemical degradation **inside the biofilm**	Redox envinronment	Life-drive of bacteria

Serial proceeding

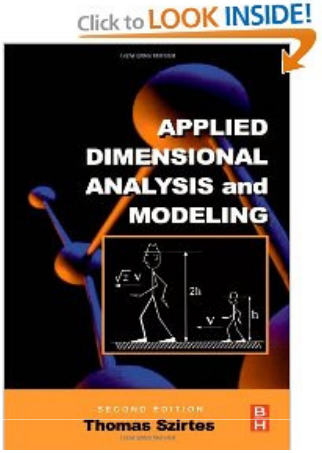
Feedback

Logistic terms

Climatic conditions

Listing the characteristical variables

Variable name	Sign	SI dimension
Nutrient degradation rate	ΔS	kg/m^3
Kinematic viscosity	ν	m^2/s
Velocity of filtration	w	m/s
Diffusion coefficient of oxygen	D_{O2}	m^2/s
Redoxpotentiall	E_h	$m^2kg/s^3/A$
Biologically active layer thickness	L	m
Faraday constant	F	As/mol
Absolute temperature	T	K
Molar gas constant	R	$m^2kg/s^2/K/mol$
Diffusion coefficient of substrate	D_S	m^2/s
Dissolved oxygen level	C_{O2}	kg/m^3
Size of standard particle	d_m	m



Dimension matrix

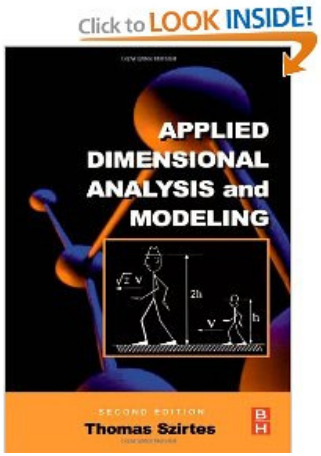
		ΔS	ν	w	D_{O2}	E_h	L	F	T	R	D_S	C_{O2}	d_m	
	m	-3	2	1	2	2	1	0	0	2	2	-3	1	
B	kg	1	0	0	0	1	0	0	0	1	0	1	0	A
	s	0	-1	-1	-1	-3	0	1	0	-2	-1	0	0	
	K	0	0	0	0	0	0	0	1	-1	0	0	0	
	A	0	0	0	0	-1	0	1	0	0	0	0	0	
	mol	0	0	0	0	0	0	-1	0	-1	0	0	0	

Reduction the number of variables

Dimension matrix

		ΔS	v	w	D_{O2}	E_h	L	F	T	R	D_S	C_{O2}	d	
	m	-3	2	1	2	2	1	0	0	2	2	-3	1	
B	kg	1	0	0	0	1	0	0	0	1	0	1	0	**A**
	s	0	-1	-1	-1	-3	0	1	0	-2	-1	0	0	
	K	0	0	0	0	0	0	0	1	-1	0	0	0	
	A	0	0	0	0	-1	0	1	0	0	0	0	0	
	mol	0	0	0	0	0	0	-1	0	-1	0	0	0	
	Π_1	1	0	0	0	0	0	0	0	0	0	-1	0	
	Π_2	0	1	0	0	0	0	0	0	0	-1	0	0	
D	Π_3	0	0	1	0	0	0	0	0	0	-1	0	1	**C = - $(A^{-1}B)^T$**
	Π_4	0	0	0	1	0	0	0	0	0	-1	0	0	
	Π_5	0	0	0	0	1	0	1	-1	-1	0	0	0	
	Π_6	0	0	0	0	0	1	0	0	0	0	0	-1	

Results matrix

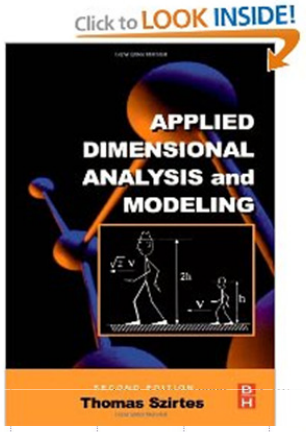


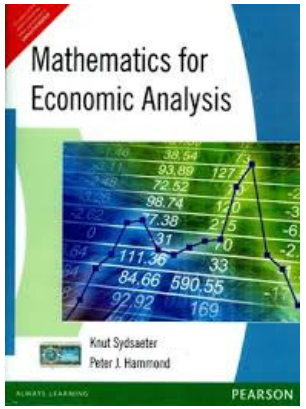
$\Pi_1 = \Delta S / C_{O2}$	Ratio of concentrations
$\Pi_2 = \nu / D_S$	Sc-number (Schmidt)
$\Pi_3 = w\ d / D_S$	**Pe-number (Peclet)**
$\Pi_4 = D_{O2} / D_S$	Ratio of diffusion coefficients
$\Pi_5 = E_h\ F / RT$	Ne-coefficient (Nernst)
$\Pi_6 = L / d$	**Geometric ratio**

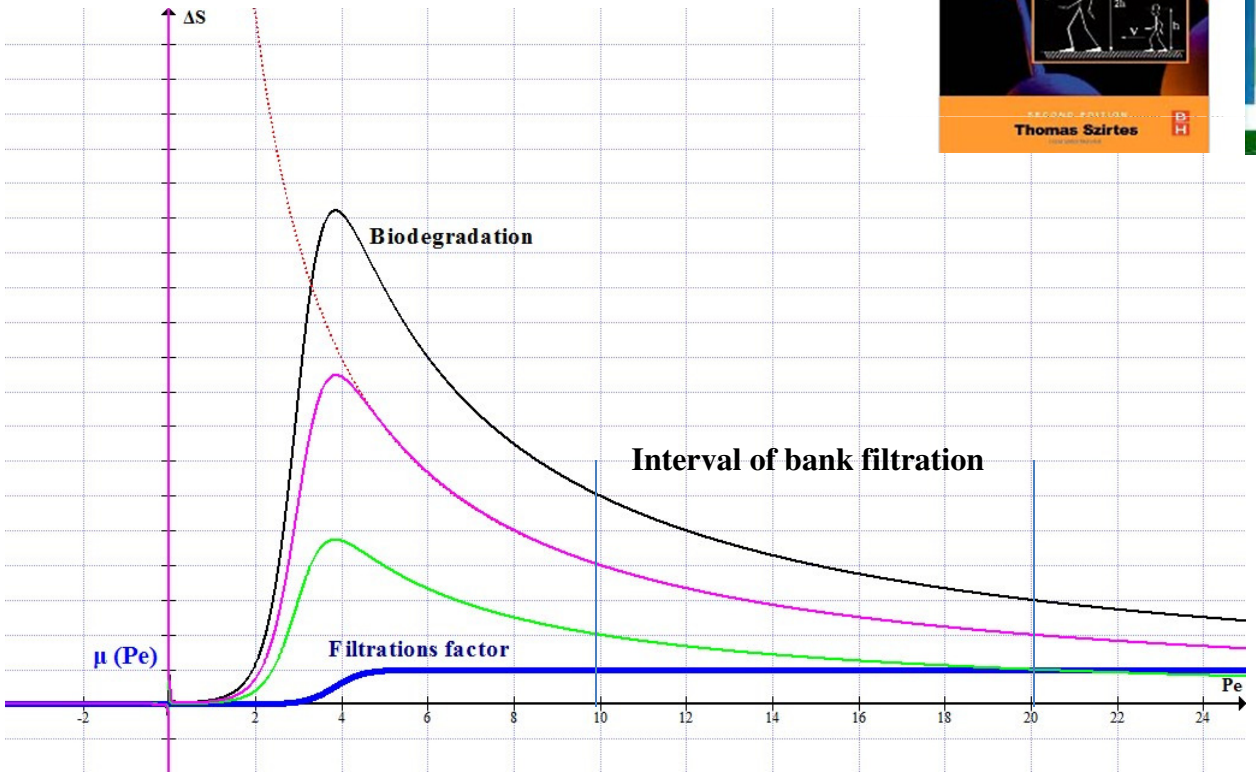
The formula through heuristic ideas

$$\Delta S = \mu(Pe)\, C_{O_2}\, \frac{1}{Pe}\, Sc\, rH\, \frac{L}{d}$$

where rH = rH (Ne, pH)
dimensionless redoxpotential







The similarity transformation

$$Pe_{\text{man-made filtration}} = \frac{w \uparrow \quad d_m \downarrow}{D_S \uparrow} := Pe_{\text{bank filtration}}$$

	Variable	Attribution	Change direction
w	speed of filtration	*Operating property*	Because investments reasons it should be increased, so the filter equipment will be smaller than the riverbank size.
d_m	standard grain diameter	*Filter media (biofilm holder) characteristic*	It can be reduced by replacing the filter media
D_S	diffusion coefficient of substrat	*Feature of the raw water*	Ozon dosage is crushing the great organic molecules, so the diffusion coefficient of substrate will be greater.

The extent of the possible change

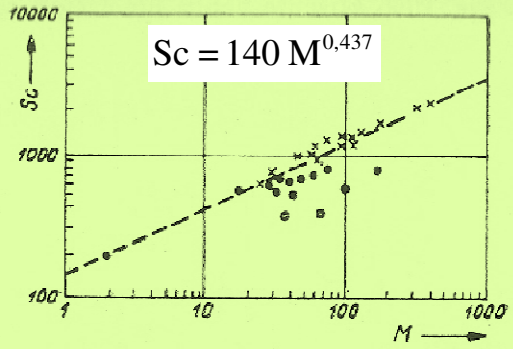
$$Pe = \frac{w \uparrow \quad d_m \downarrow}{D_S \uparrow}$$

		Bank filtration	Biological filtration with speed of rapid filters	Order of magnitude
w	m/d	0,1	100	3 ↑
	m/h		5	
d_m	m	1,3E-3	1,2E-5	2 ↓---
D_S	m^2/s	2E-10	10E-10	0,5 ↑
Pe	-	10	20	0,2

$$3 \approx 2 + 0,5 + 0,2$$

The diffusion coefficient

$$D_S = \frac{\sum_{i=1}^{n} D_i C_i}{\sum_{i=1}^{n} C_i} \qquad or \qquad D_S = \min D_i$$

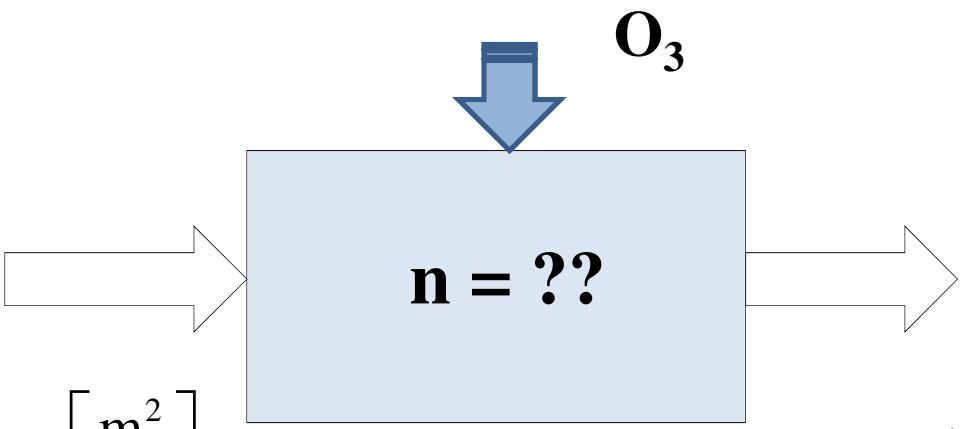


The **Schmidt-number** in aqueous solutions

$D_S = 2...20 \times 10^{-10} \quad [m^2/s]$

			M	Sc	ν	D_S	D_S measured
				[-]	[m²/s]	[m²/s]	[m²/s]
Hydrogen	H_2	1*2	2	190	1,00E-06	5,28E-09	4,50E-09
Metan	CH_4	12+1*4	16	470	1,00E-06	2,13E-09	
Ammonium	NH_4	14+4*1	18	495	1,00E-06	2,02E-09	1,97E-09
Nitrogen	N_2	14*2	28	601	1,00E-06	1,67E-09	1,88E-09
Oxygen	O_2	16*2	32	637	1,00E-06	1,57E-09	2,00E-09
Metanol	CH_3OH	12+4*1+16	32	637	1,00E-06	1,57E-09	
Drug residues			200	1 418	1,00E-06	7,05E-10	
			400	1 920	1,00E-06	5,21E-10	
			700	2 452	1,00E-06	4,08E-10	
			800	2 599	1,00E-06	3,85E-10	
Typical molecule/ by von Gunten			3354	4 862	1,00E-06	2,06E-10	

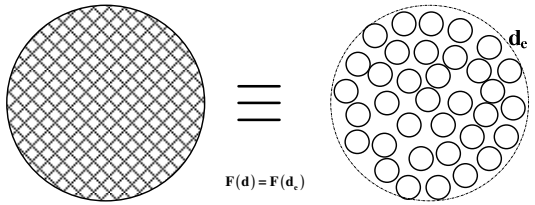
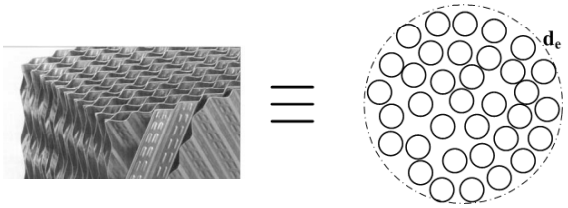
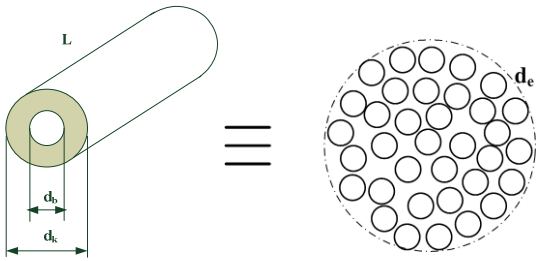
Increasing of diffusion coefficient



$$D_S = (2 \ldots 5) * 10^{-10} \left[\frac{m^2}{s} \right]$$

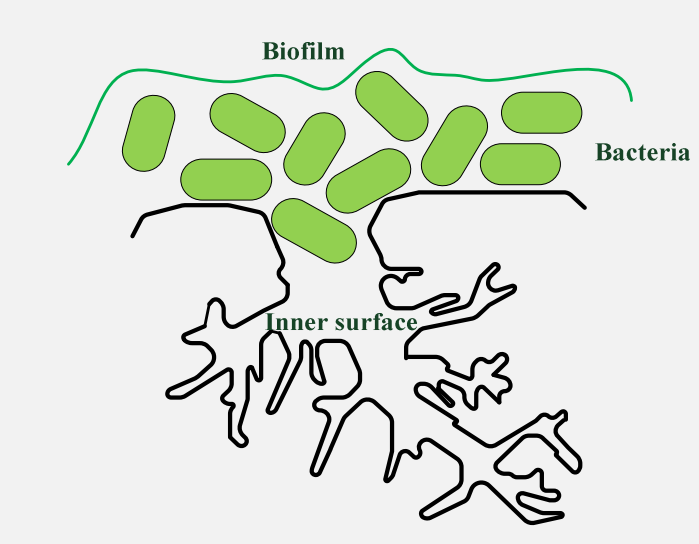
$$D_S = n * (2 \ldots 5) * 10^{-10} \left[\frac{m^2}{s} \right]$$

The equivalent grain diameter

Activated carbon or zeolite		**Specific surface:** a [m^2/g] **Size of granules:** d [mm] **Density:** ρ [kg/m^3]
Trickling filter media (plastic)		**Block surface:** a [m^2/m^3] **Block density:** ρ_t [kg/m^3] **Material density:** ρ [kg/m^3]
Membrane filter element, „the macaroni" under vacuum		**Fiber geomertry** $V = \frac{(d_k - d_b)^2 \pi}{4} L$ $F = d_k \pi L$

$$d_e = 6\frac{V}{F}$$

The liveable surface

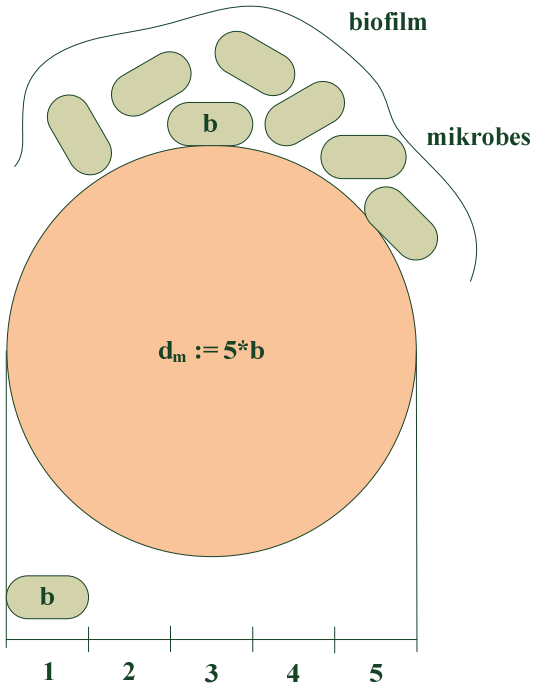


The standard grain diameter :

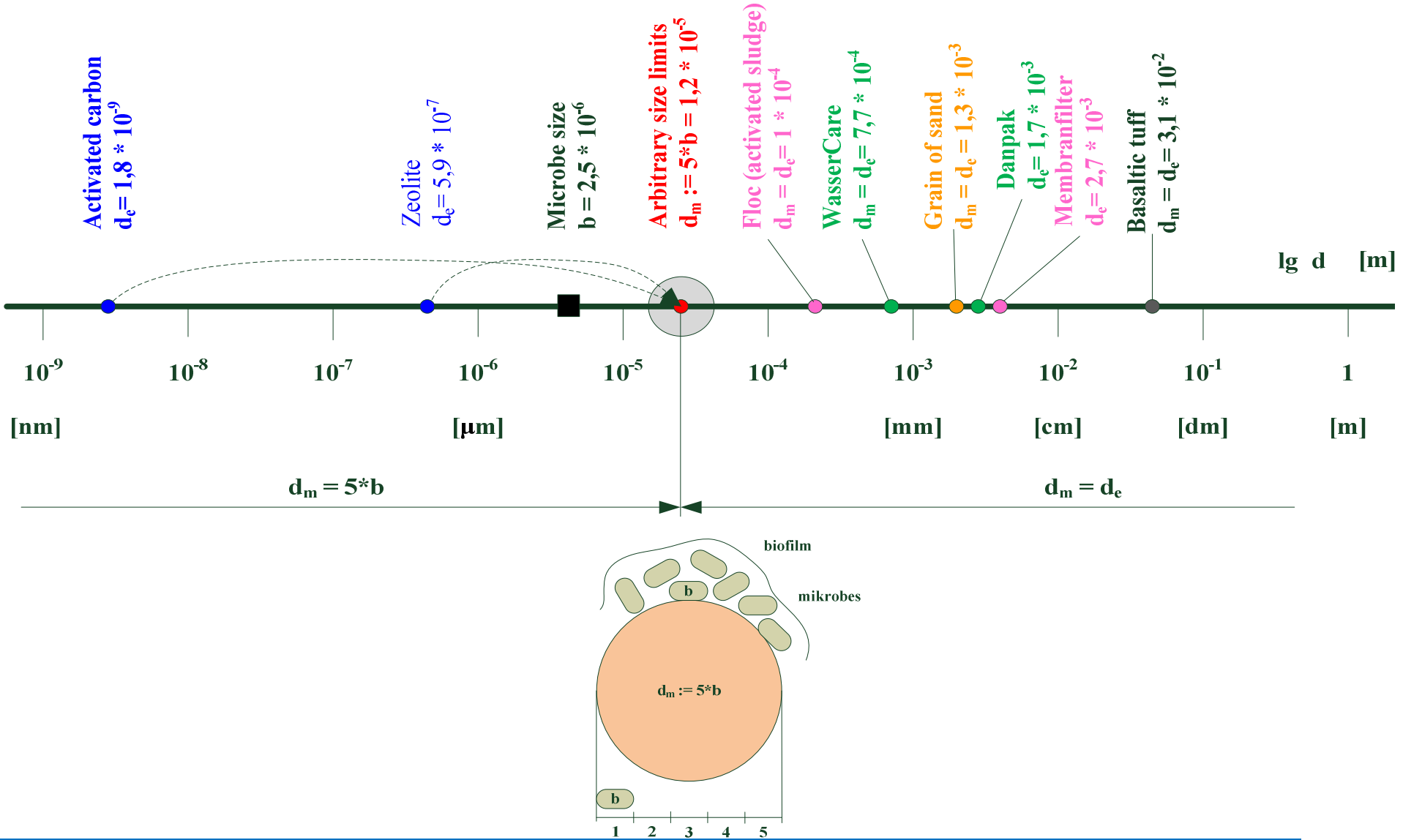
$d_m = d_e$ if $d_e > b$

$d_m = 5 * b$ if $d_e < b$

where b = the size of bacteria



The standard grain diameter

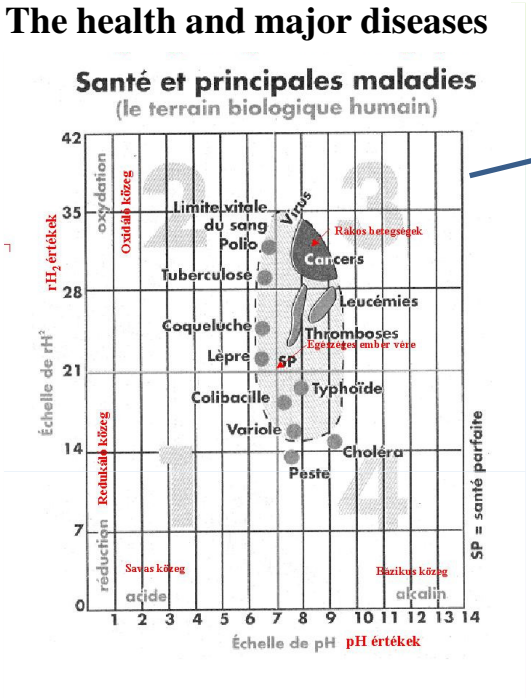


Compare of biological filtrations

N	Biological filtration	D_S [m^2/s]	d_e [m]	d_m [m]	w [m/s]	w [m/h]	Pe [-]	Comment
1	Bank filtration	1,5e-10		1,5e-3	1,2e-6		10	Produces drinking water quality
2	Bank filtration at low water level	1,5e-10		1,5e-3	2,4e-6		20	Is moderately effective
3	Ammonia removal on rapid filter	19,4e-10		1,5e-3	8,8e-4	3,16	670	Filtermedia is sand Can not operate effectively under rapid filtration conditions?!
4	Activated carbon filtration	5,0e-10	1,8e-9	1,2e-5	3,5e-3	12,6	34	Sometimes worms, protozoa appear
5	Aktivated sludge wwt	1,5e-10	0,1e-3	0,1e-3	???		???	Inefficient?! 18x reactor dimensions arise
6	Trickling filter wwt 240 m^2/m^3	1,5e-10	7,7e-4	7,7e-4	2,8e-4	1	1440	In spite of the optimal air intake is not effective?
7	Trickling filter wwt with ozon dosage	5,0e-10	7,7e-4	7,7e-4	2,8e-4	1	432	More effective ?!
8	Wwt on zeolite bed filter	5,0e-10	5,9e-7	1,2e-5	4,2e-4	1,5	10	10-15 microns of biofilmholder porosity would be sufficient !
9	Membran filtration	1,5e-10	2,7e-3	2,7e-3	1,0e-5		187	Do not develop meaningful biology

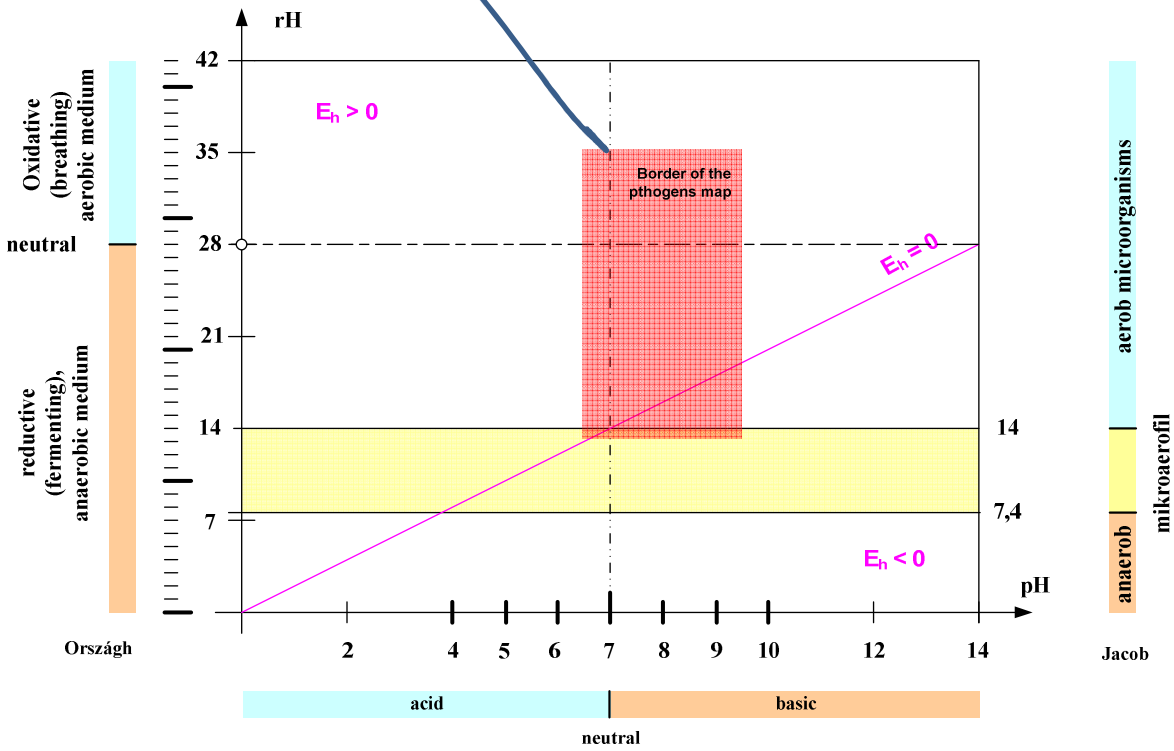
Vincent chart: the map of pathogens

The health and major diseases



„ Withdraw the disease its breeding ground and the disease dies.”
Louis-Claude Vincent

And vice versa !!



$$rH = \frac{2\,F\,E_h}{RT\,\ln 10} + 2\,pH$$

$$pH = -\log(H^+)$$

Országh, J.: http://www.eautarcie.com/

Biodegradation (inside the biofilm !!!)

Mechanism:

dissolved O_2 + organic substance → [microorganisms] → CO_2 + biological growth

Chemical interpretation (von Gunten):

$$(CH_2O)_{106}(NH_3)_{16}(H_3PO_4) + 138\,O_2 =$$

typical mulecule *oxygen*

$$106CO_2 + 122H_2O + 16NO_3^- + HPO_4^{2-} + 18H^+$$

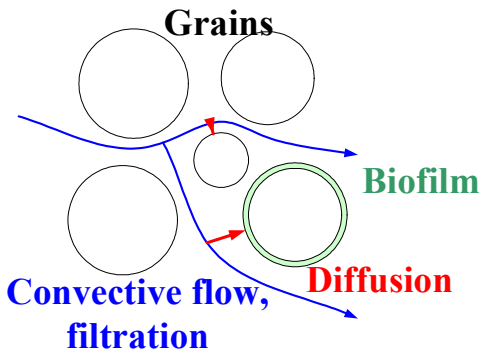
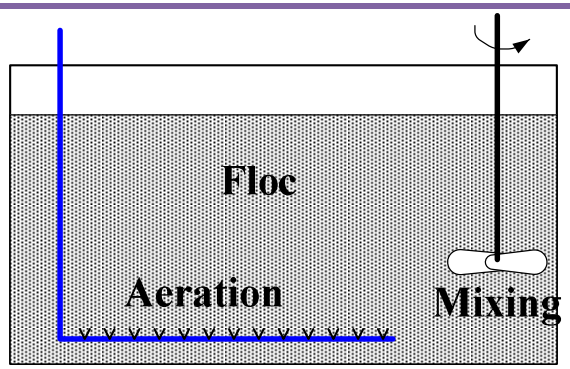
carbon dioxide *water* *harmless substances*

Conclusion:

The degradation needs a lot of oxygen

Mostly carbon dioxide and water is produced,
and a small amount of waste material which will be mechanically filtered out.

Standing and moving biofilm

Bank filtration	Actived sludge waste water treatment
 Biofilms adherence on the grains A biofilm is standing. The moving fluid transports nutrients. The movement created by pumping The filtration speed (convection) is well-defined, it's a low value. The diffusion efficiency is very good.	 Biofilm adherence on sludge flakes A biofilm is moving. The moving fluid transports nutrients. The movement created by mixing and air insufflation. The relative speed between fluid and biofilm is only statistically meaningful, it's a large value. The effectiveness of the diffusion is questionary.

Residence time and sludge age

w = 0,1 m/d

If not pumped w = 0,
so bank filtration is without work
Residence time in the layer have a characteristic?

Filtering with variable speed

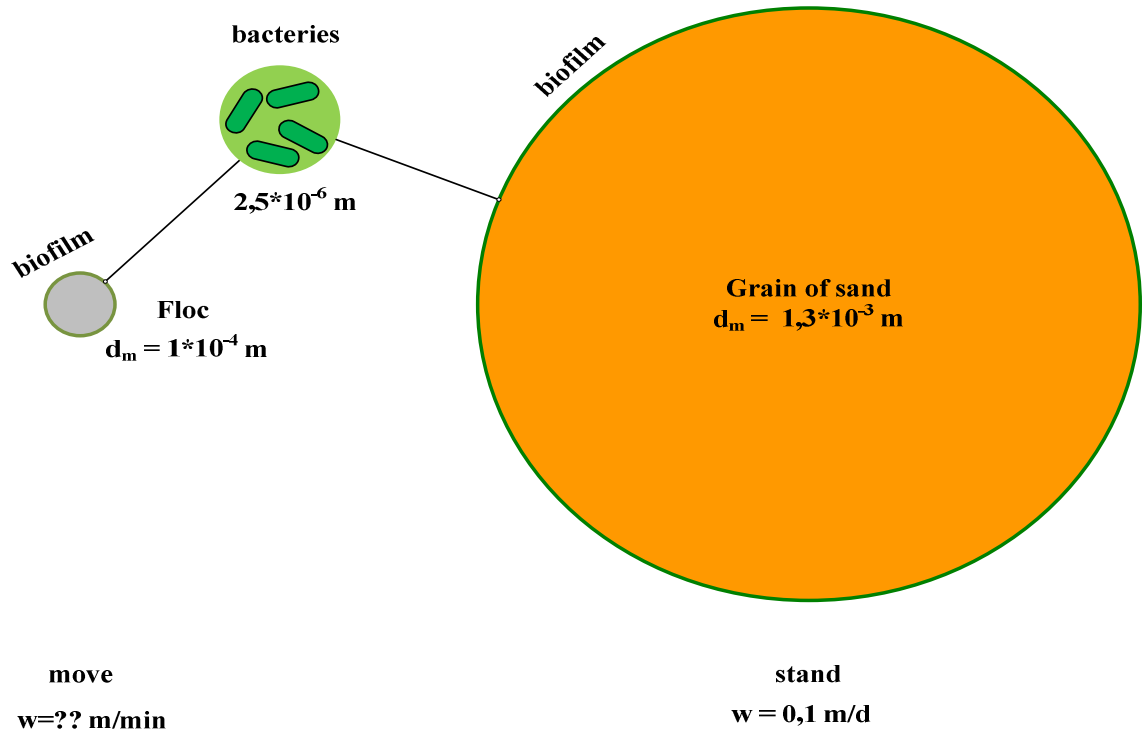
w >> 0,1 m/d

If mixing and air intake is stopped
so sludge will be dead.
The oxic/anoxic difference
can be as more higher/lower
relative velocity interpreted)
Sludge age is really a feature in the pool?

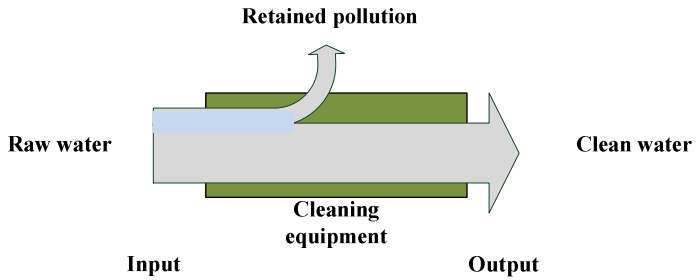
Conclusion: the residence time and sludge age is not a direct feature!!

With the floc moving and on grain standing biofilm

Activated sludge waste water treatment	Bank filtration

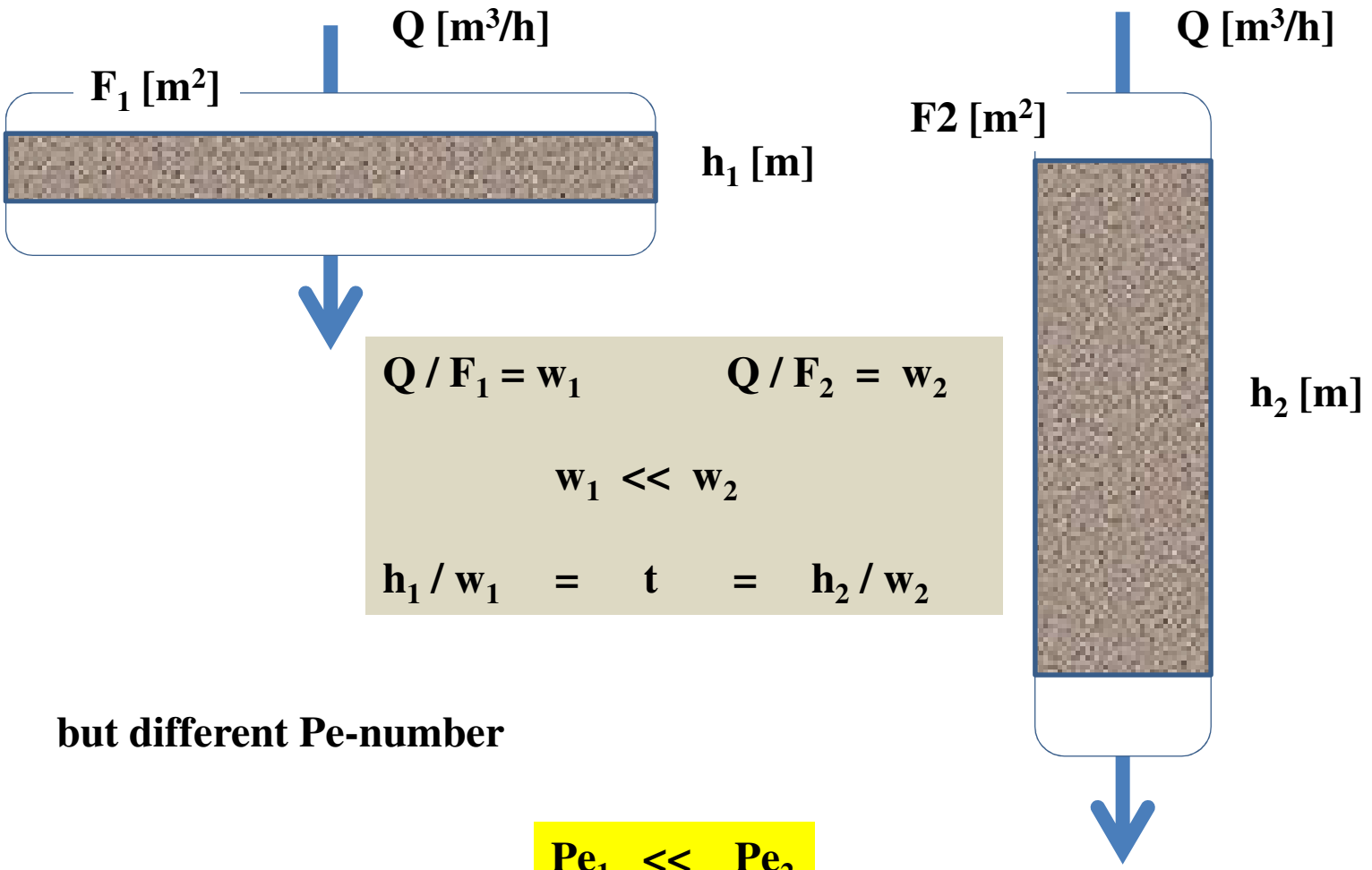


Watershed: "burning" rather than retention



Process	Method of operation	Accessories	Comment
Drum filter	Mechanical retention		Needs cleaning
Rapid sandfilter	Mechanical retention	Reagent dosage	Flushing
Clarification	Gravity separation	Flocculant dosage	
Adsorption	Surface conclusion		exhausted, expensive
Membran filter	Mechanical retention		Needs cleaning, expensive
Bank filtration Filterbed filtration	Biodegradation	Ventilator	Only a handful of "roughage" arises
Actived sludge wwt	Biodegradation	Blower and Mixer	Too much space of bioreactor is needed, because of diffusion can't become effective
Trickling filter wwt	Biodegradation	Ventilator	Small surface area because of inadequate dimensioning

The same contact time



$Q / F_1 = w_1$ $\quad$ $Q / F_2 = w_2$

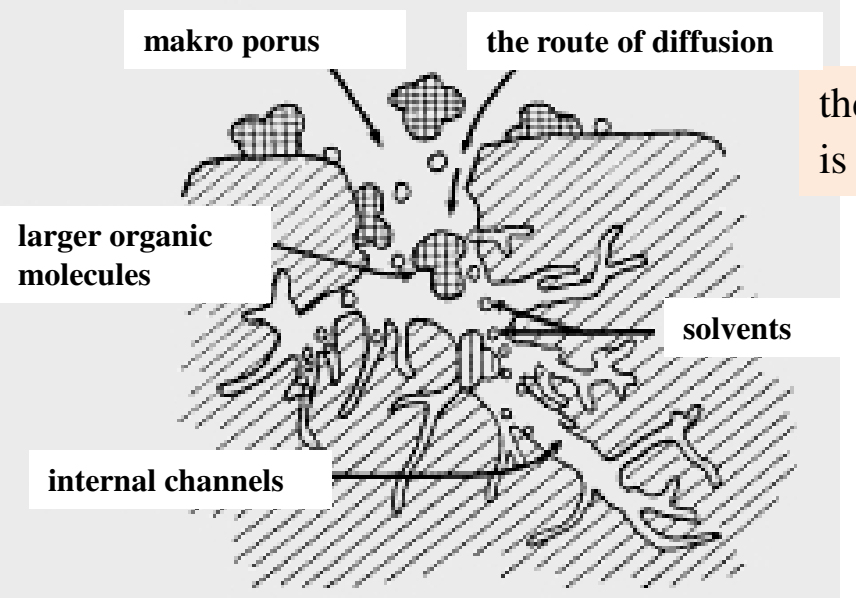
$w_1 << w_2$

$h_1 / w_1 = t = h_2 / w_2$

but different Pe-number

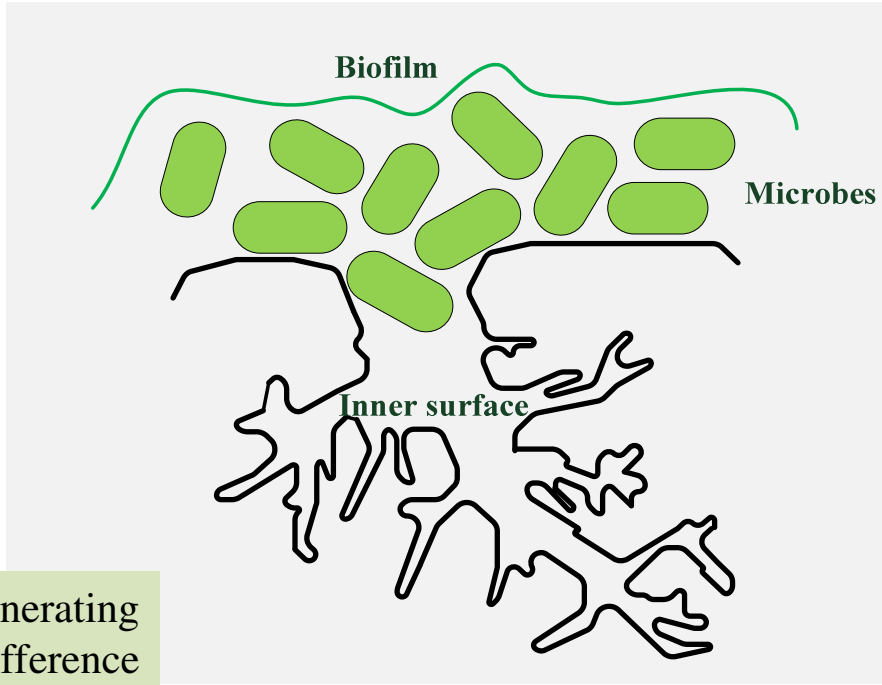
$Pe_1 << Pe_2$

Adsorption and biological filtration



http://www.vilaglex.hu/Lexikon/Html/Adszorp.htm

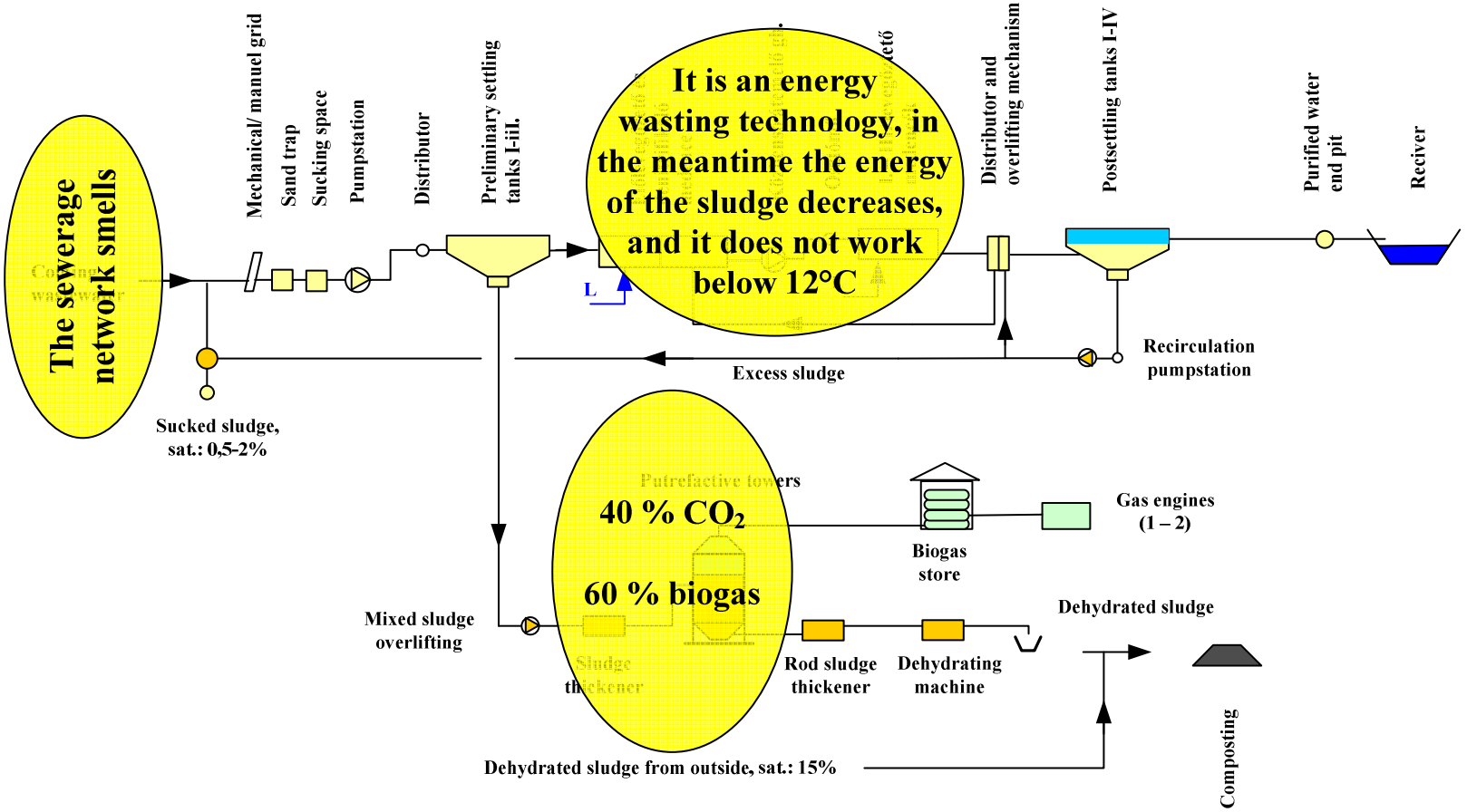
the concentration equalization is continued till fullness is indicated by the iodine number.



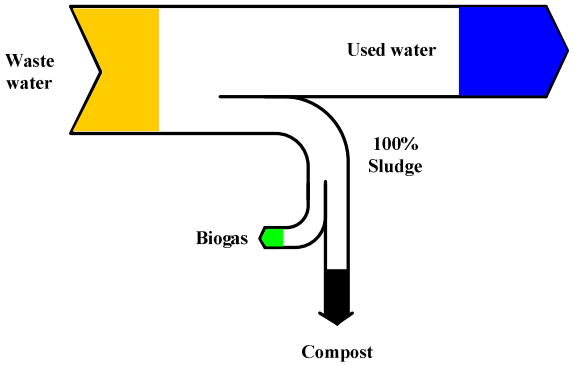
continuously regenerating concentration difference

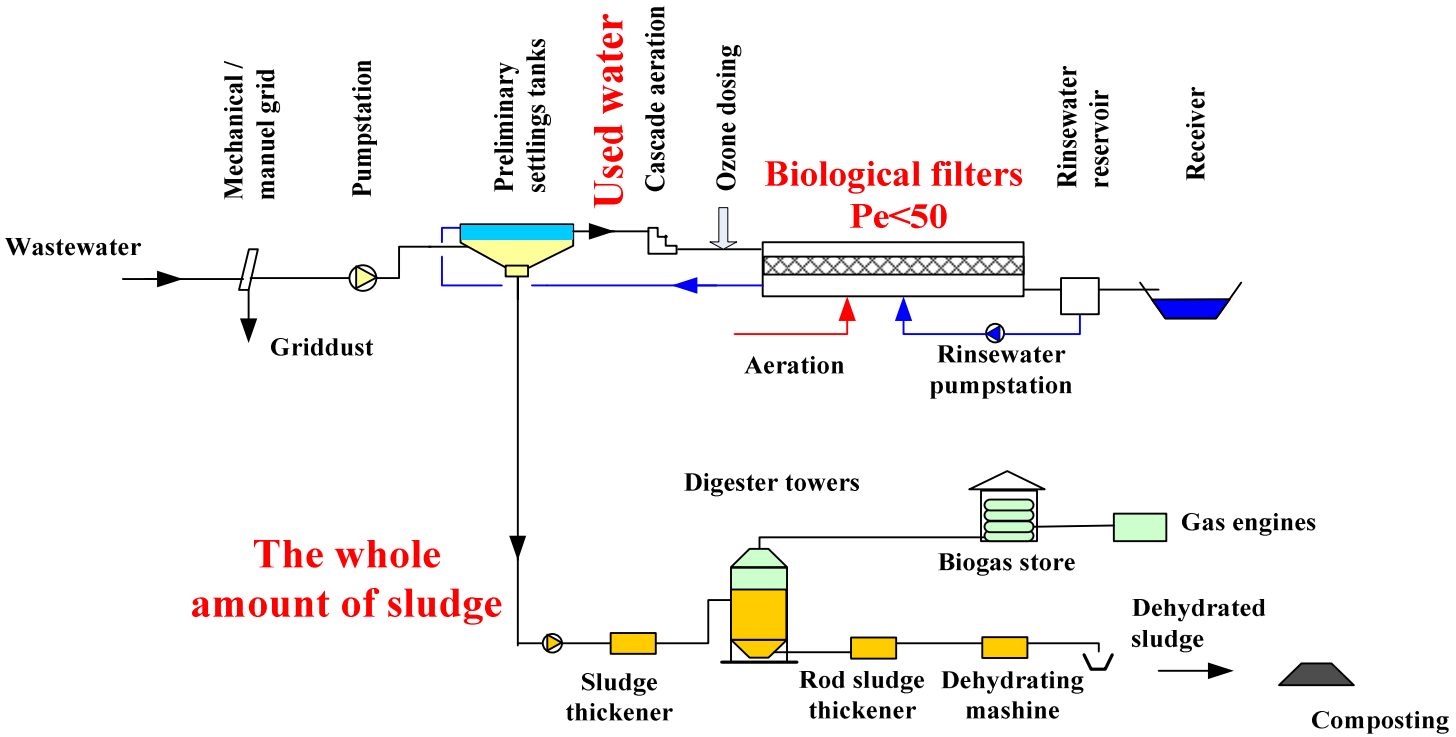
The need for a paradigm shift

Traditional technology



Cleaning only the used water





Consequences of the paradigm shift

The sewage network smells bad.

The network works as a biologigal reactor, the waste water has to reach the plant as soon as possible!

The dear customer is not a polluter, rather a raw material supplyer

We can not wake remorse just because if someone is using the toilet.

The environmental penalty from water fee should be removed!

The compost comes out of the land!

A sewerage inlet and the compost must be controlled !!

The mix of biogas is 40% CO_2 and only 60% metan

In order to usability, the cleanig of biogas is necessary.

It's better the total amount of sludge to compost!

Only the used water should be cleaned

We need an inexpensive technologie „without sludge" !

See it before.

Designing in two steps

The results of the dimensional analysis

$$\Delta S = \mu\, C_{O_2}\ \frac{D_S}{w\, d}\ \frac{\nu}{D_{O_2}}\ rH\ \frac{L}{d_m}$$

$$\Delta S = \mu(Pe)\ C_{O_2}\ \frac{1}{Pe}\ \frac{\nu}{D_{O_2}}\ rH\ \frac{L}{d_m}$$

Determination the cross section of the filter

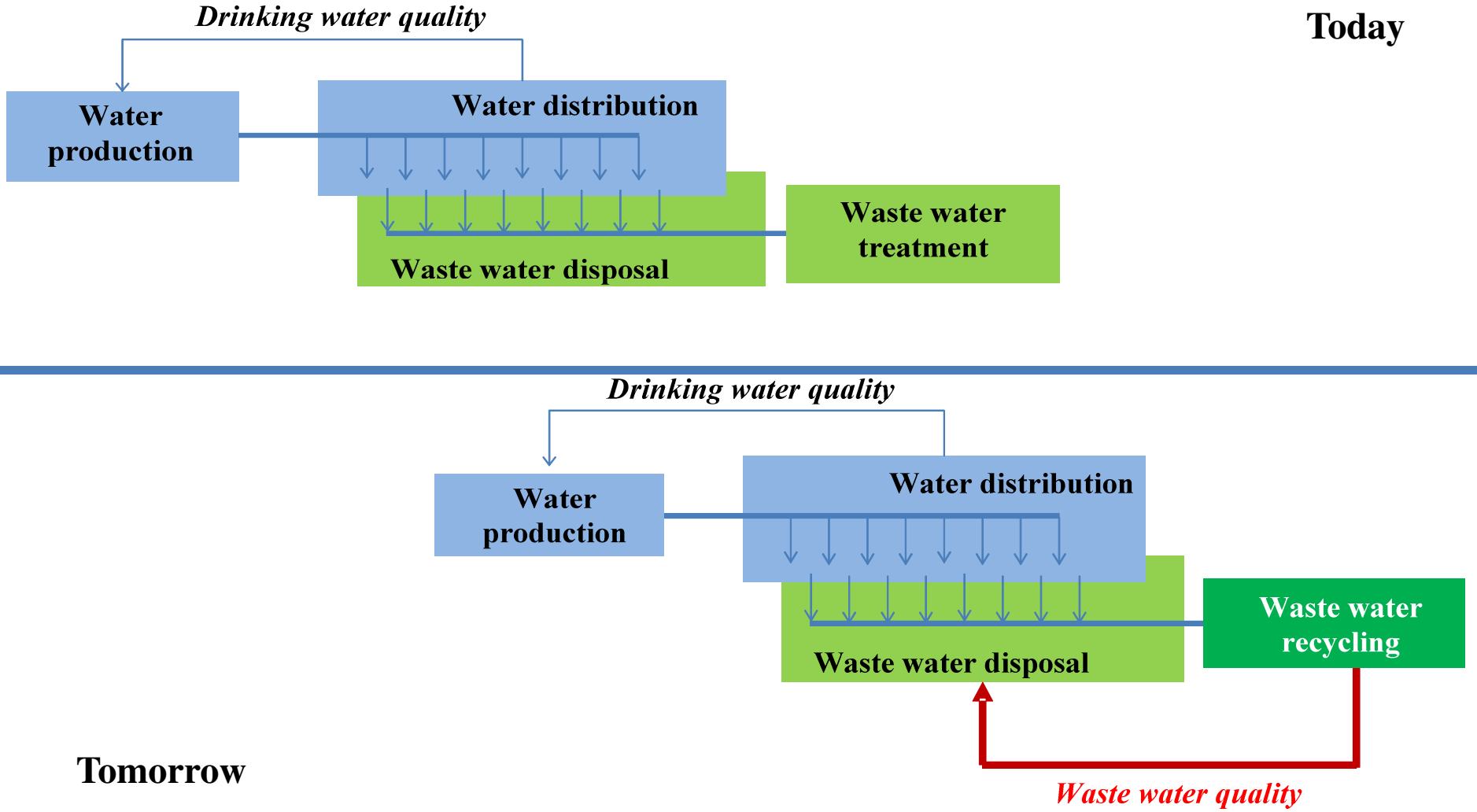
$$Pe = \frac{w\, d_m}{D_S} := 10...20 \qquad w = \frac{(10...20)\, D_{S,\,cleaned\ water}}{d_{m,\,man-made\ filtration}} \qquad Q = Aw \quad A = \frac{Q}{w}$$

Determination the thickness of the filter layer

$$\frac{L_{bank\ filtration}}{d_{m,\,bank\ filtration}} = \frac{L_{man-made\ filtration}}{d_{m,\,man-made\ filtration}} \qquad L_{man-made\ filtration} = d_{m,\,man-made\ filtration}\ \frac{L_{bank\ filtration}}{d_{m,\,bank\ filtration}}$$

$$h = L_{man-made\ filtration}\ \frac{BOD_{celaned\ water}}{BOD_{river\ water}}$$

Terminology in water services



"In practice, people are very reluctant to give up a theory in which they have invested a lot of time and effort."
- Stephen Hawking

Béla TOLNAI
worked in watersupply
at the Waterworks of Budapest

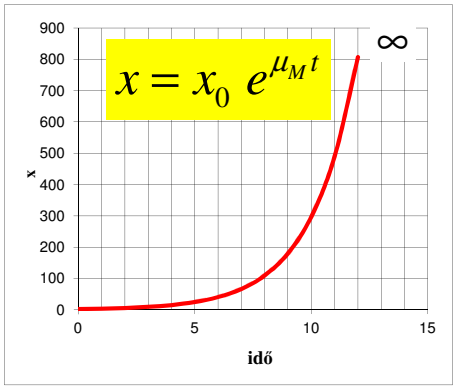
Thank you for attention!

The context of microbial growth

Monod kinetics

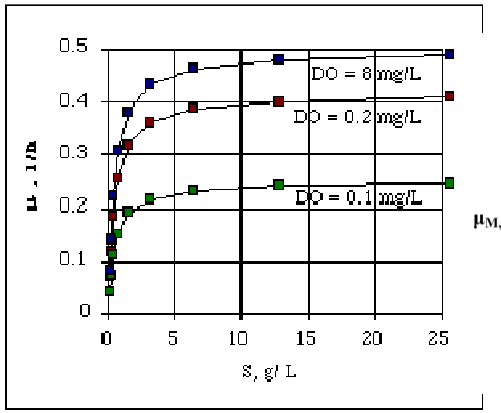
$$\frac{dx}{dt} = \mu_M \; x$$

Process with relative constant growth



$$\mu_M = \mu_{M,\max} \frac{S}{K_S + S}$$

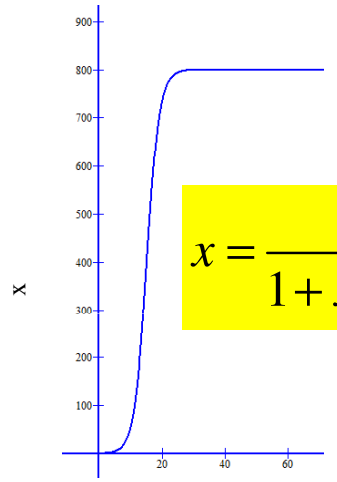
$K_s = K_s$ (type of bacteria).



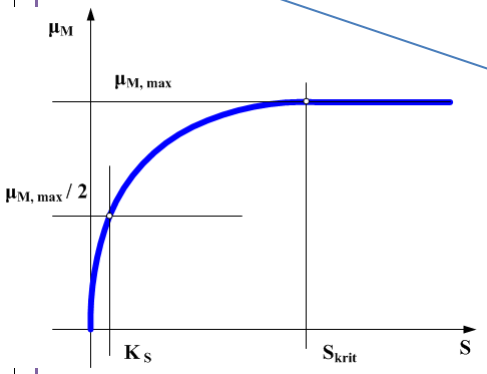
Logistic functions

$$\frac{dx}{dt} = \mu_M \; x\left(1 - \frac{x}{K}\right)$$

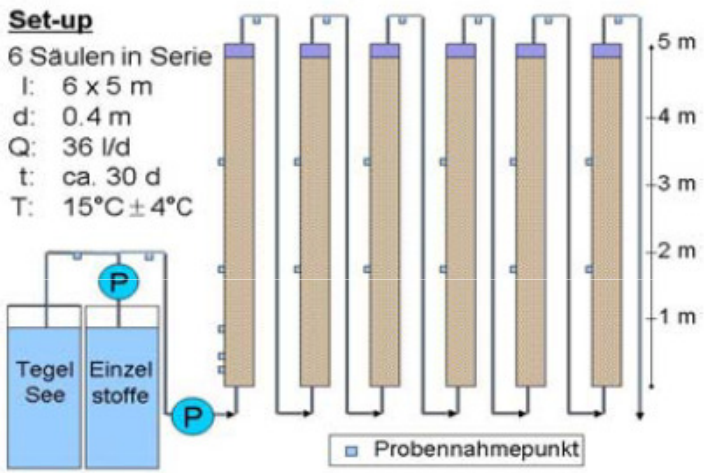
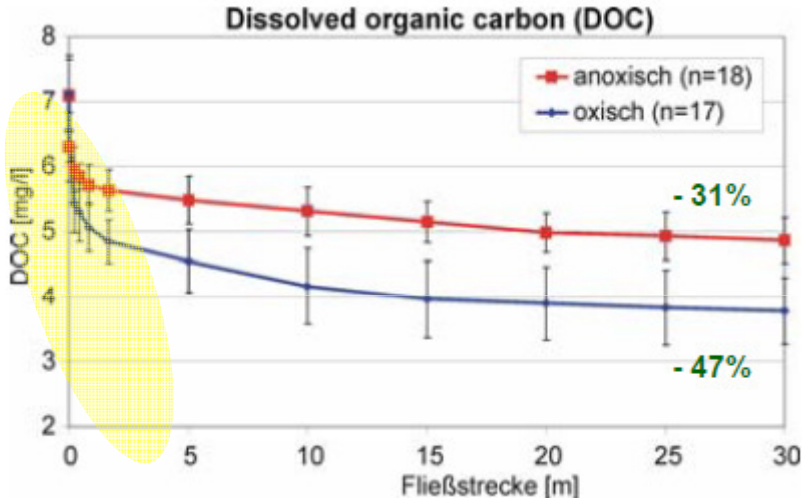
x: live cell mass



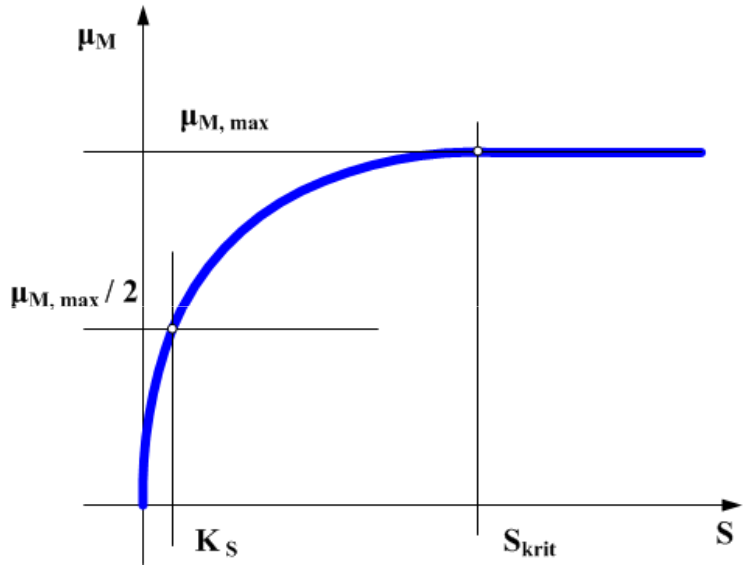
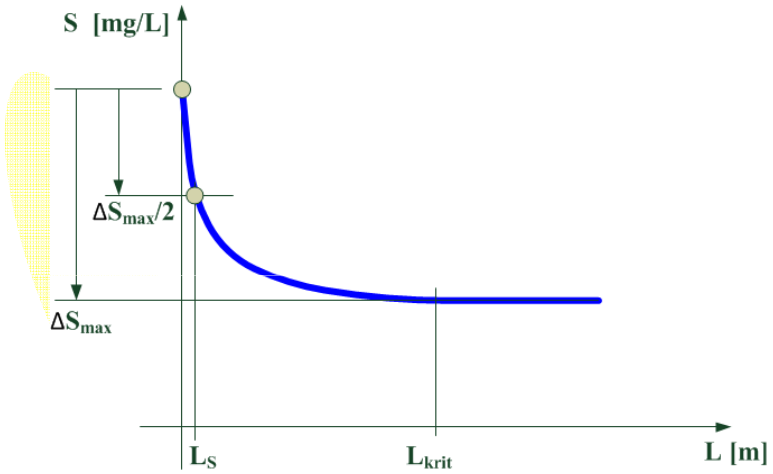
$$x = \frac{K}{1 + x_0 e^{-\mu_M t}}$$



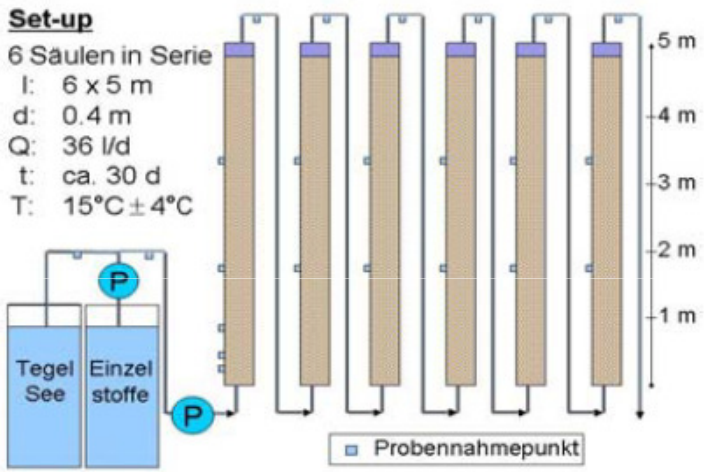
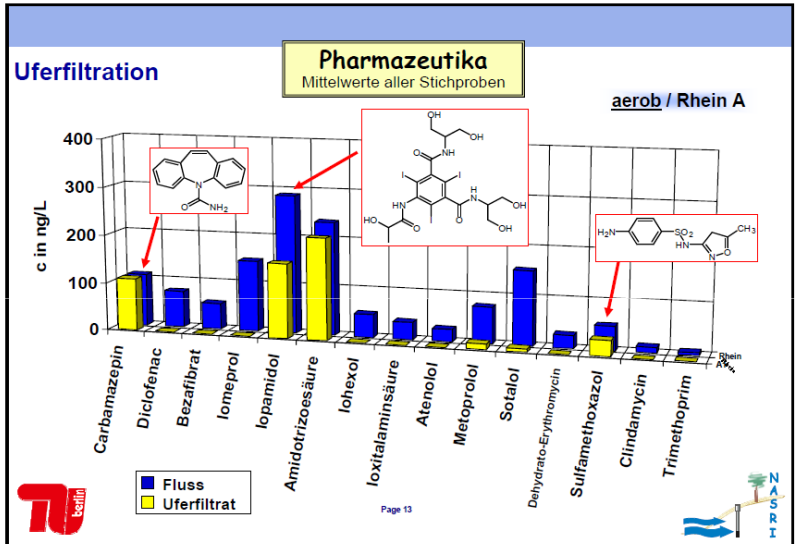
Degradation along the filter route

Jekel experiment	Experimental results
	
w= 0,28 m/d (~bank filtration)	Parameter: oxic / anoxic Biologically active layer thickness: L ~ 1,5-5 m, depends on the type of microbes (?) and does not depend on the amount of oxygen!

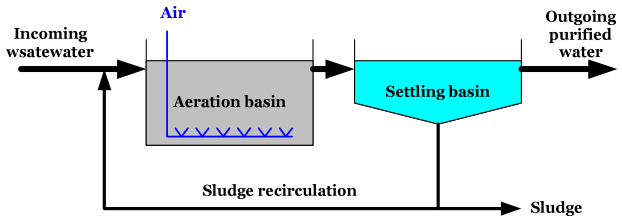
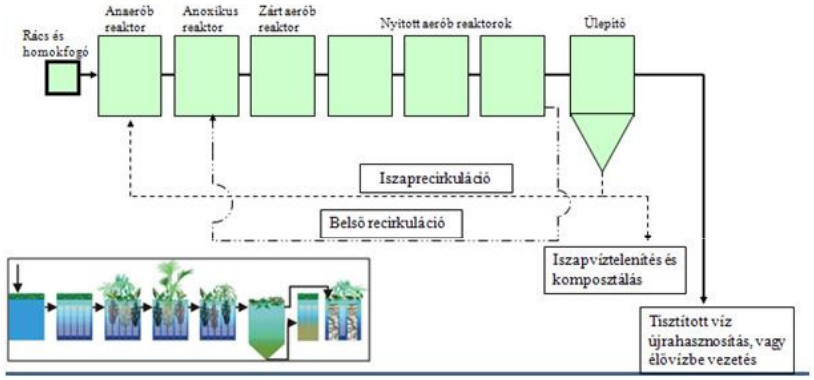
The character of degration

Monod kinetics	Degradation along the filter route
	
$\mu_M = \mu_{M,\max} \frac{S}{K_S + S}$	$\Delta S = \Delta S_{max} \frac{L}{L_S + L}$

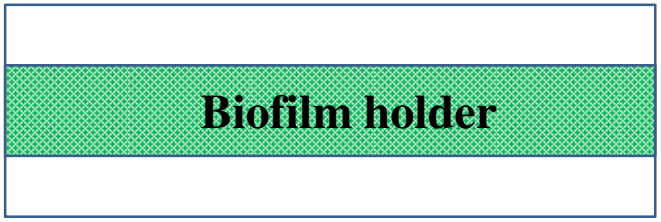
Easily and very persistent substances

Jekel experiment	Experimental results
	
w= 0,28 m/d (~bank filtration)	
Dosing of known contamination	easy and difficulty diffusing substances

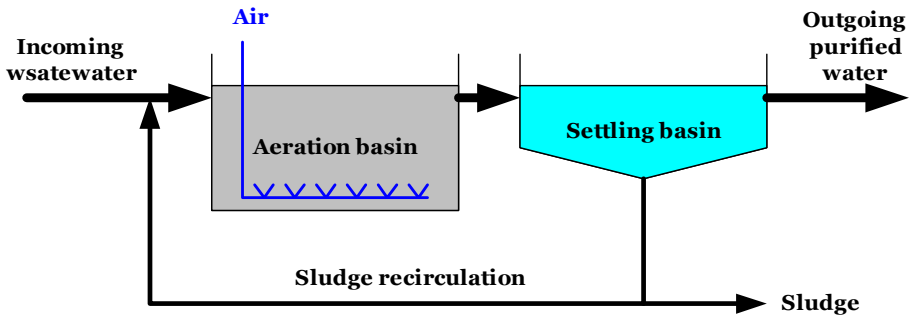
What's the different ?

Activated sludge waste water treatment	Living mashine waste water treatment
 The living sludge technology	
The bioreactor has no extra biofilmholder, the sludge itself. **Recirculation be due to continued operation.**	**It is an activated sludge technology** **Carrying the vegetation root role in biofilmholder, increases the surface where the settling can happen.**

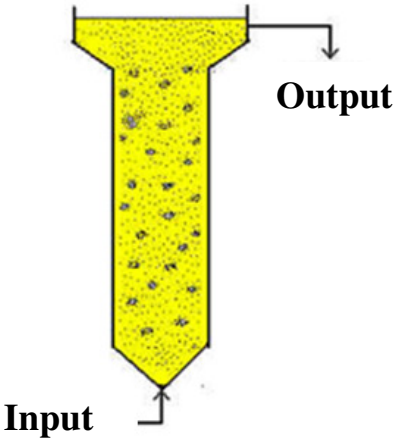
Comparison of screening

Mechanical filtering	Biological filtration
Filtration = retention (input – output)	
	
Retention through mechanical way Rinse the filter is needed Specific: Mostly it is filtered out, what we put into it.	Retention with degradation water, CO2 and roughage is produced Specific: The resulting small amount of roughage

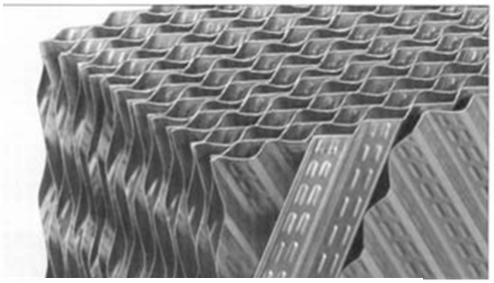
Intensification or accessory itself ?



The living sludge technology



Fluidized bed



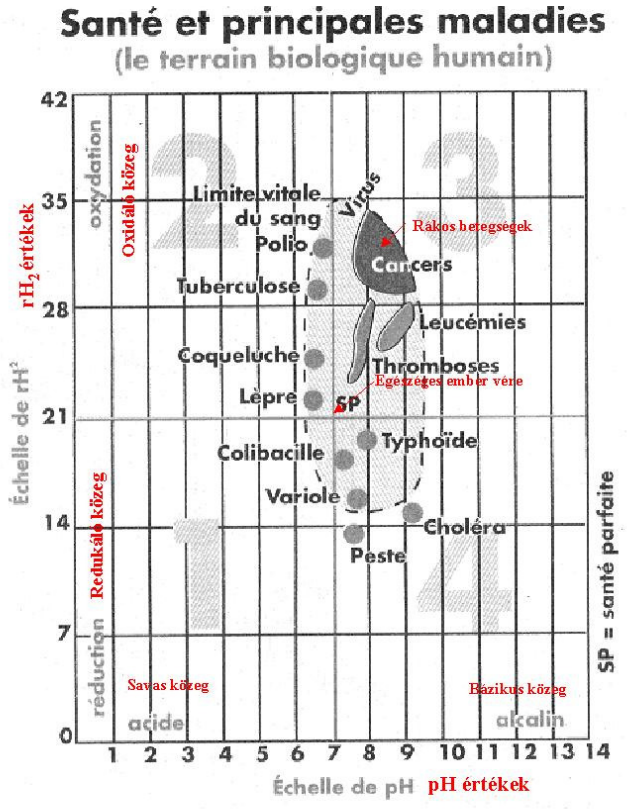
Trickling filter

- Supplement the biofilm holder area with activated carbon impregnated sponge pieces
- Supplement with a living machine wwt equipment (roorts of plants)
- Instead of deep airation, using oblique air supply pipe
- Avoid blind spots.
- Swapping aerobic and anaerobic roles of basins
- Mixing.

„The map” of the pathogens

Vincent-diagram: pH-rH

The health and major diseases



http://www.eautarcie.com/

„Entziehe der Krankheit ihren Nährboden
und die Krankheit stirbt ab.”

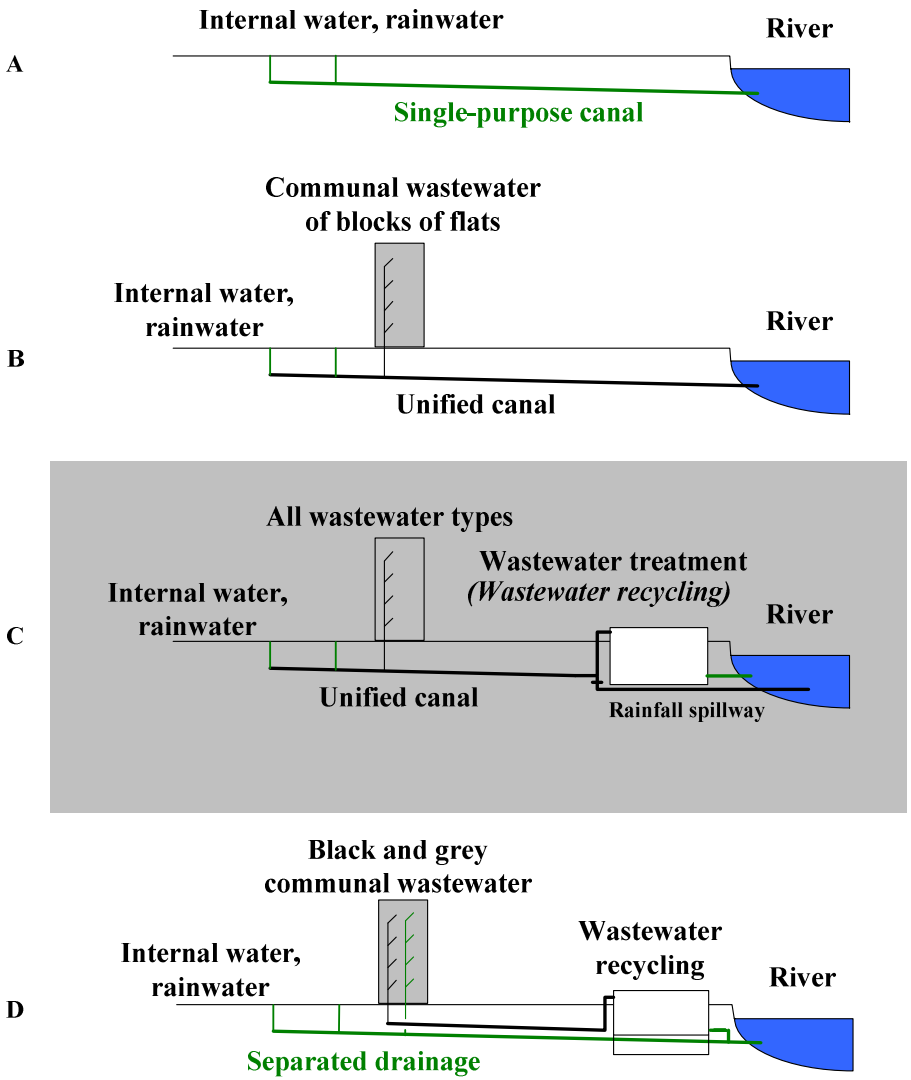
Louis-Claude Vincent

$$rH = \frac{2\,F\,E_h}{RT\ln 10} + 2\,pH$$

$$pH = -\log(H^+)$$

And vice versa !!

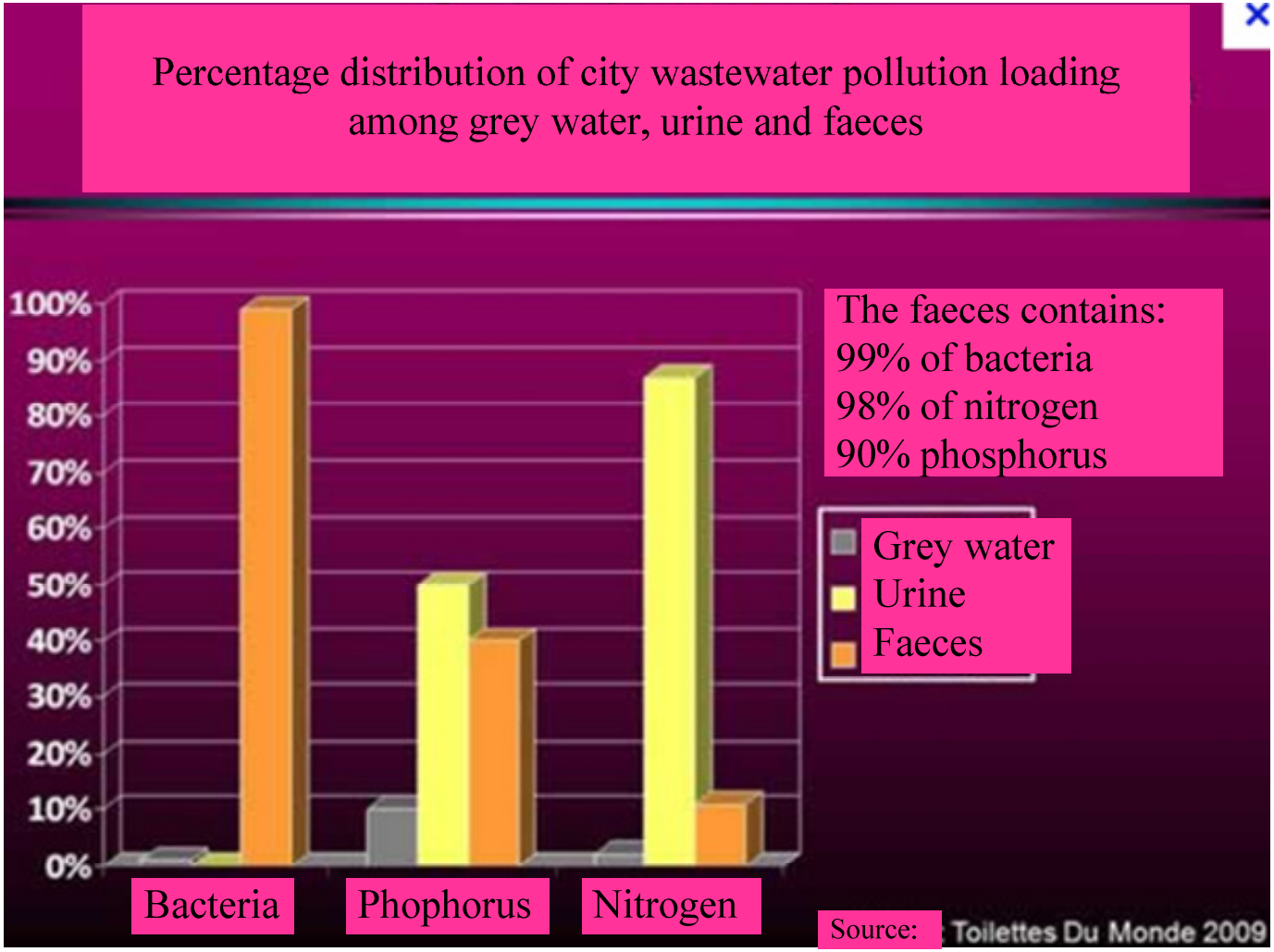
The development of ww disposal and ww treatment



What can happen with sludge?

	Sludge action	Comment	Product
1	Landfill disposal	not utilized	-
2	Incineration	polluting	-
3	Digestion and composting		Biogas and compost
4	Composting the total amount		Compost

Parameters of grey and black ww



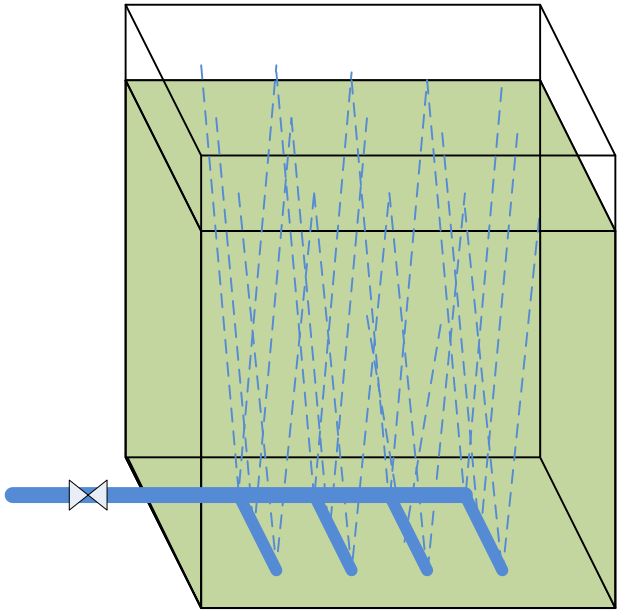
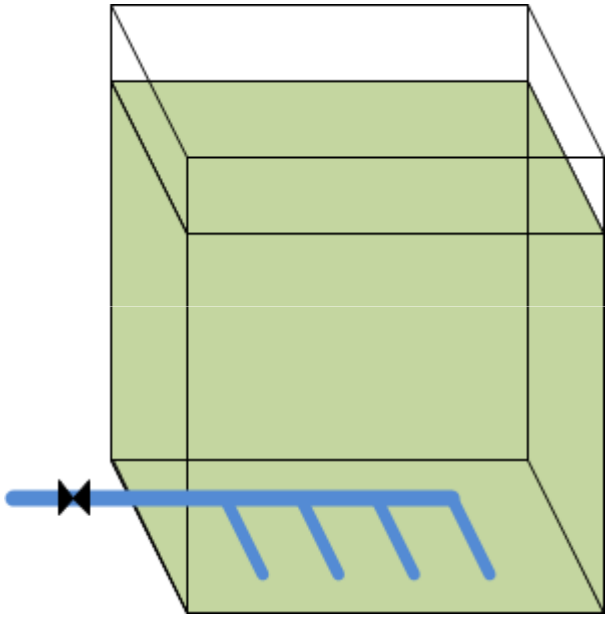
Comparison 1

	Filter bed technology	Activated sludge technology
Baseline	Wastewater recycling	Wastewater treatment
Biogas production	The whole sludge quantity may be gasified.	Biogas yield is significantly lower as in the process of water purification the sludge becomes exhausted.
Necessary biological reactor space	If rounded: 20-fold smaller reactor space is needed.	Greater investment cost.
Biofilm holder	It is needed and requires considerable additional costs.	The sludge itself performs this task.
Rinsing	Rinsing is needed, which involves the following: filters should be rinsed in the case of bank filtering twice yearly, here approximately every 2 days.	The task does not occur.
Mixing	It is not needed.	Mixing involves the use of electric energy.

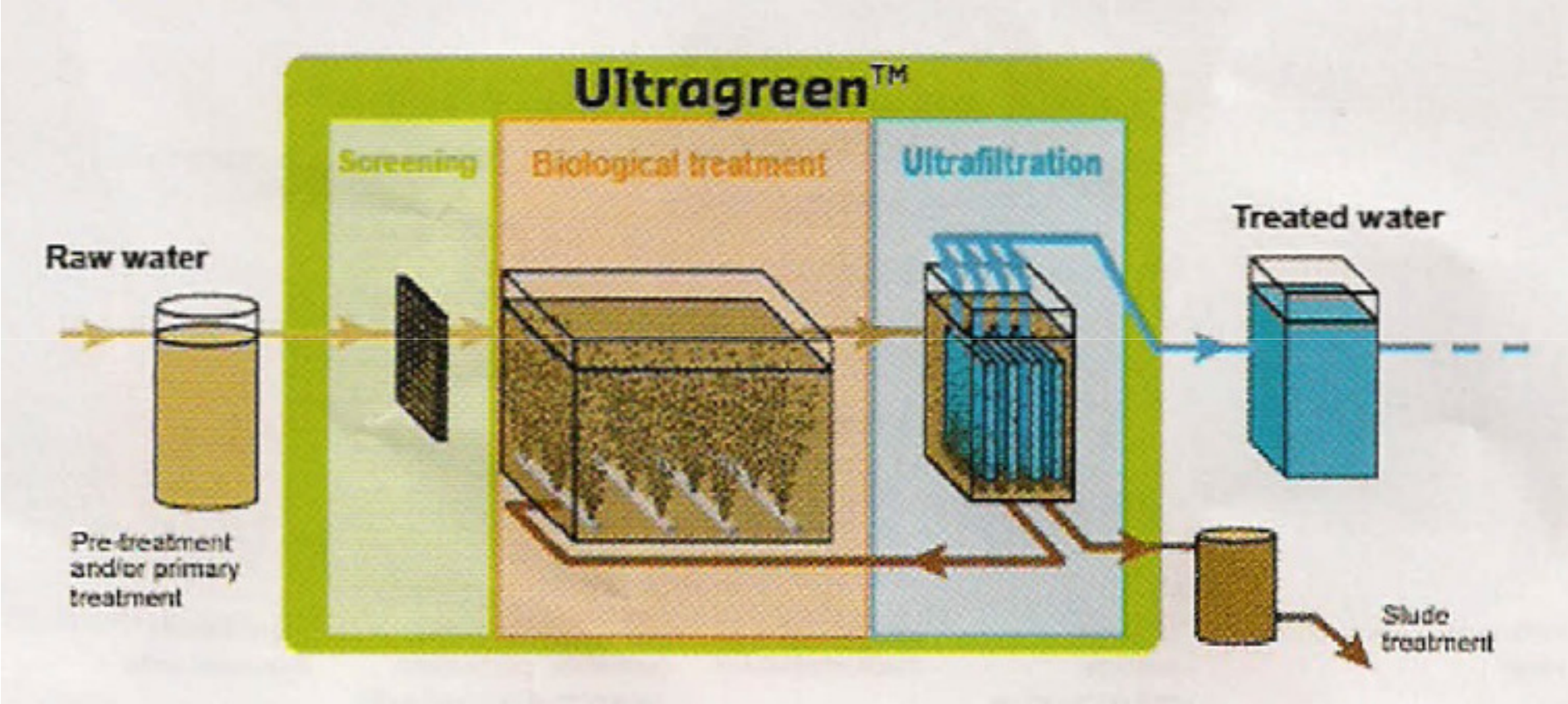
Comparisen 2

	Filter bed technology	Activated sludge technology
Depth of the reactor space	Thickness of filtering layer is 1.5 m.	The depth of the reactor space is great, 8 m.
Air feeding	From below, by low-power fan, through a 1.5 m thick filtering layer. Rinsing is air feeding as well.	The energy demand of blowers providing deep aeration is great.
Operation in winter	Bank filtering has a stable operation in winter as well, and filter bed technology also does so.	Below 12°C nutrient degradation practically stops.
Operation	It needs a totally different thinking. Attention actually has to be paid to the rinsing of filters.	Flowing through is continuous, the task of operation consists of interchanging oxic-anoxic spaces.
Sending to technology by means of pumping	It has to happen in the case of both technologies. Going through the technology is gravitational in both cases.	

Effect of the air supply

Oxic	Anoxic
	
The dosage of air is changing the flow conditions, which prevent the diffusion.	**The flow conditions only determined by the mixing, diffusion can occur more easily.**

The Ultragreen technology of Degremont



The quality and the load of the waste water

The waste water (or contaminated water) is a complex mixtures of pollutants and water. In most cases the molecular composition and structure is not possible or in any event are not required (not economical) determined.

The analytical control of water treatment options
Pulai Judit (VE) - Helmut Kroiss - Karl Svardal (TU Wien - Austria)

At the biological purification of water two things are important!

What we need to forget the water, called **water quality**. Knowledge of quality requires knowledge of the composition of the molecule with respect to size in any case. The above statement is therefore not satisfactory defined.

The mean much to remove the water **load**. The load averages respect - that of COD, BOD, BDOC, TOC parameters [mg / L] characterized as one of - the above statement is true.

The biodegradation as grating

The molecular quality means:

What is in the water, how can it be degradated?

crushing

rasping

cut

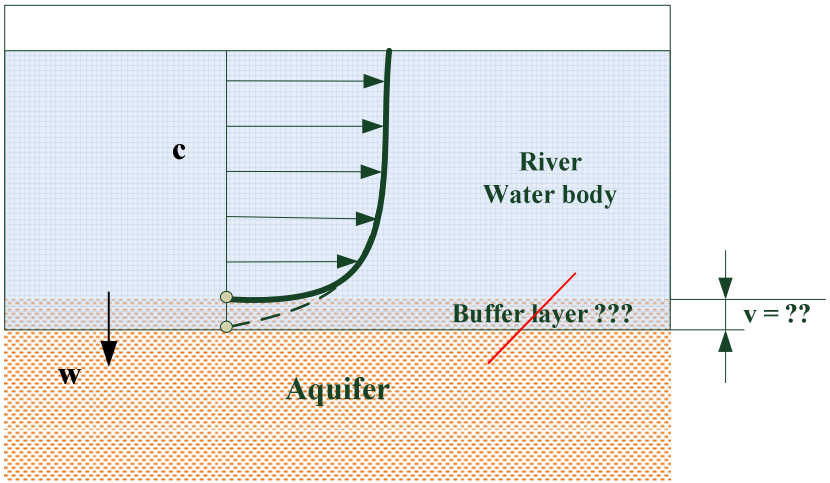
The load is defined by:

What number or size of equipment is needed?

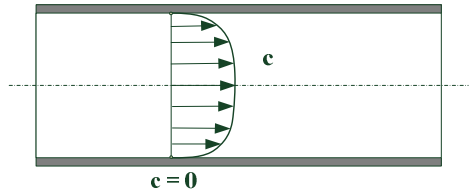
...

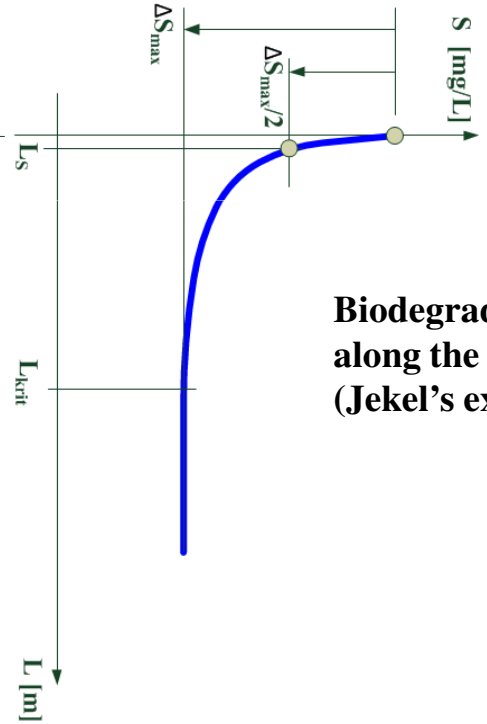
or

The amount of roughage



Flow in pipe





Biodegradation along the filter route (Jekel's experiment)

Cleaning of filter media:

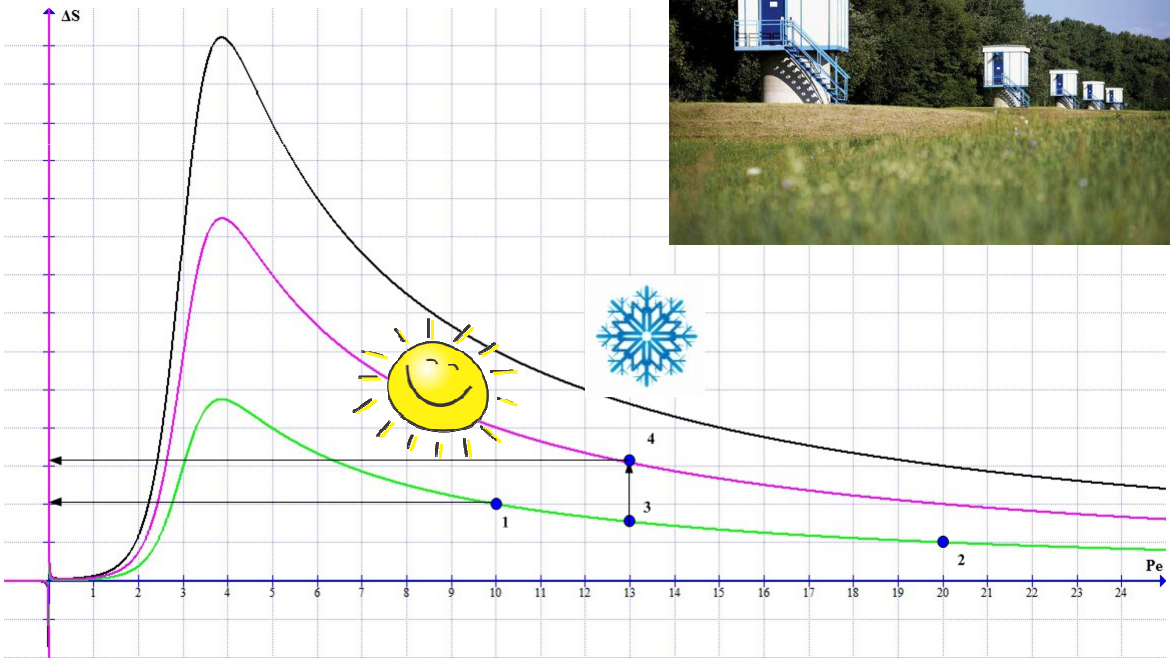
two times in a year during the flood

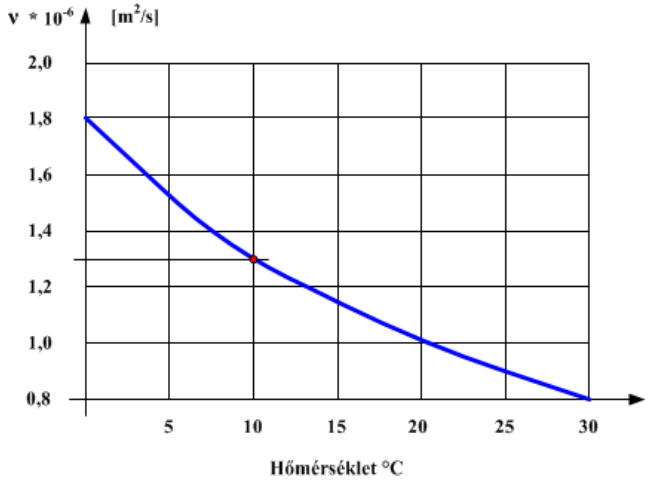
Danube water BOD~ 5 mg/L

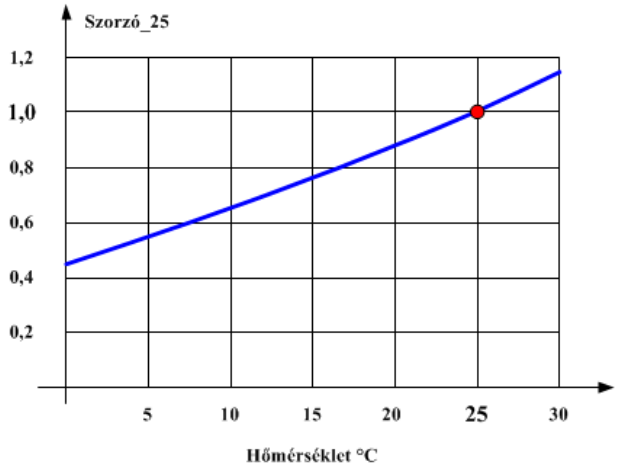
Temperature dependence of bank filtration

$$\Delta S = \mu(Pe)\ C_{O_2}\ \frac{1}{Pe}\ \frac{\nu}{D_{O_2}}\ rH\ \frac{L}{d_m}$$

$$Pe = \frac{w\ d_m}{D_S}$$



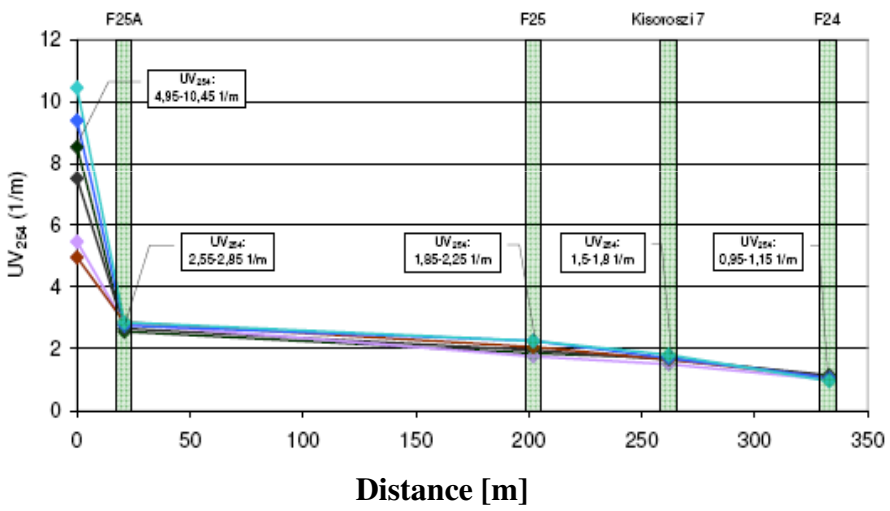




Facts by bank filtration

In winter

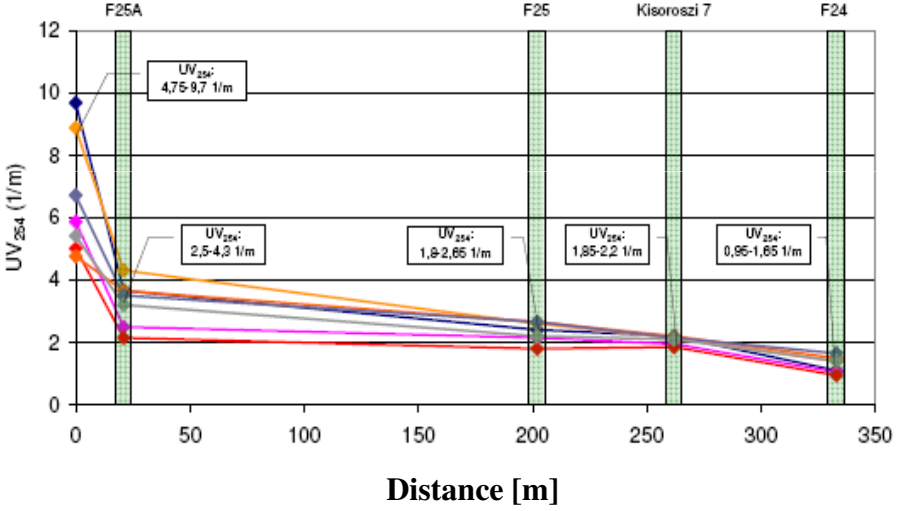
Kisoroszi / 7. well
(January-February-March)
Temperature of Danube: 1-3 °C



Danube | Monitoring well | Monitoring well | Well | Monitoring well

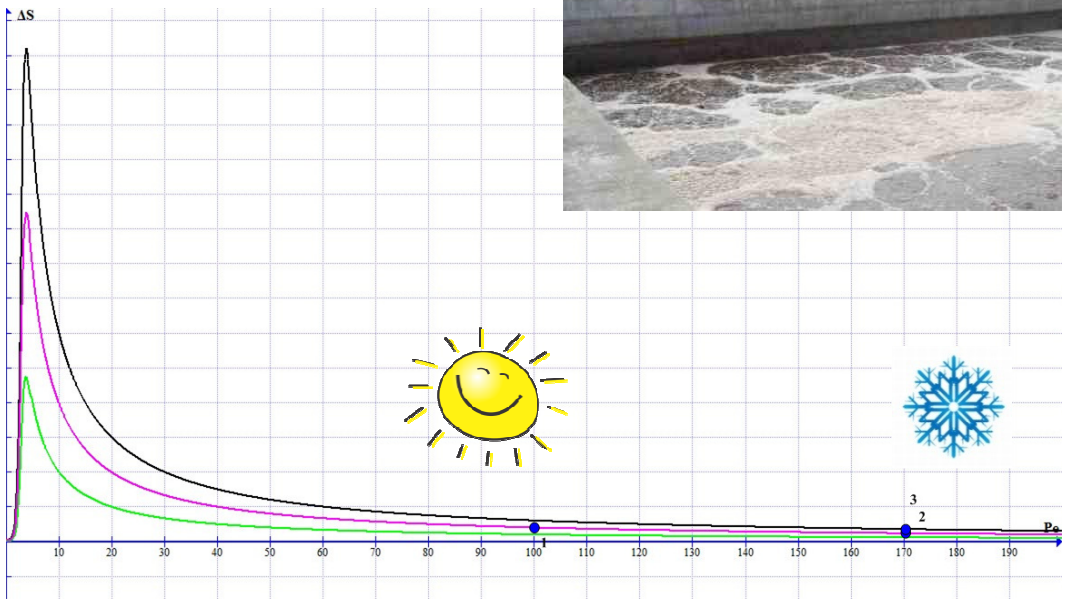
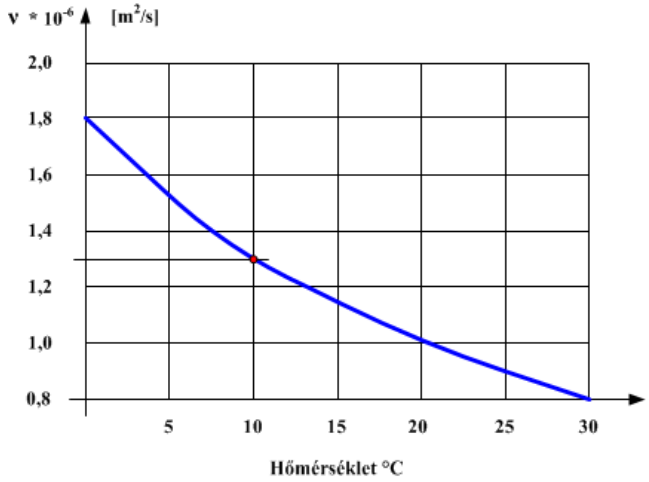
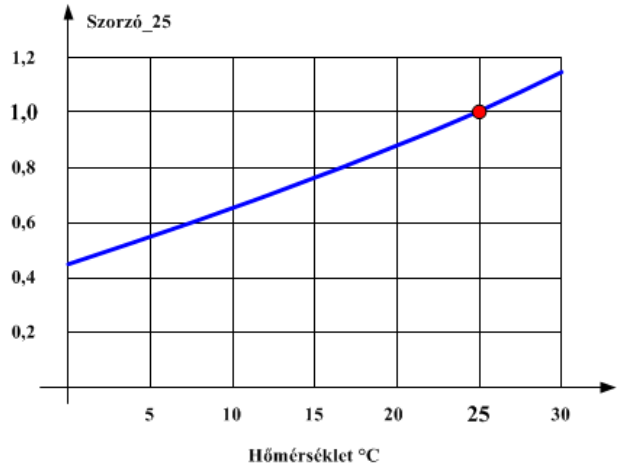
In summer

Kisoroszi / 7. well
June-July-August)
Temperature of Danube: 16-24 °C



Danube | Monitoring well | Monitoring well | Well | Monitoring well

Temperature dependence of wwt

$$\Delta S = \mu(Pe)\ C_{O_2}\ \frac{1}{Pe}\ \frac{\nu}{D_{O_2}}\ rH\ \frac{L}{d_m}$$

$$Pe = \frac{w\ d_m}{D_S}$$