Ozonation and PAC addition schemes, results of pilot and full-scale operations

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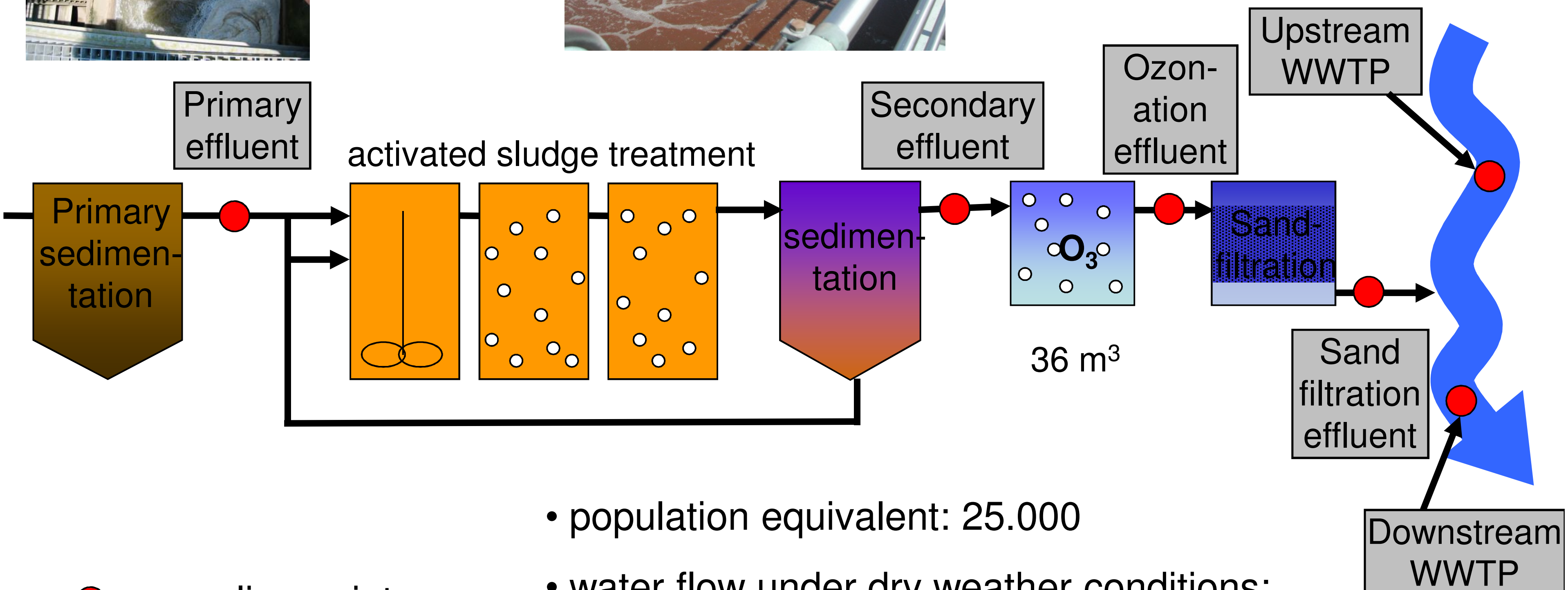
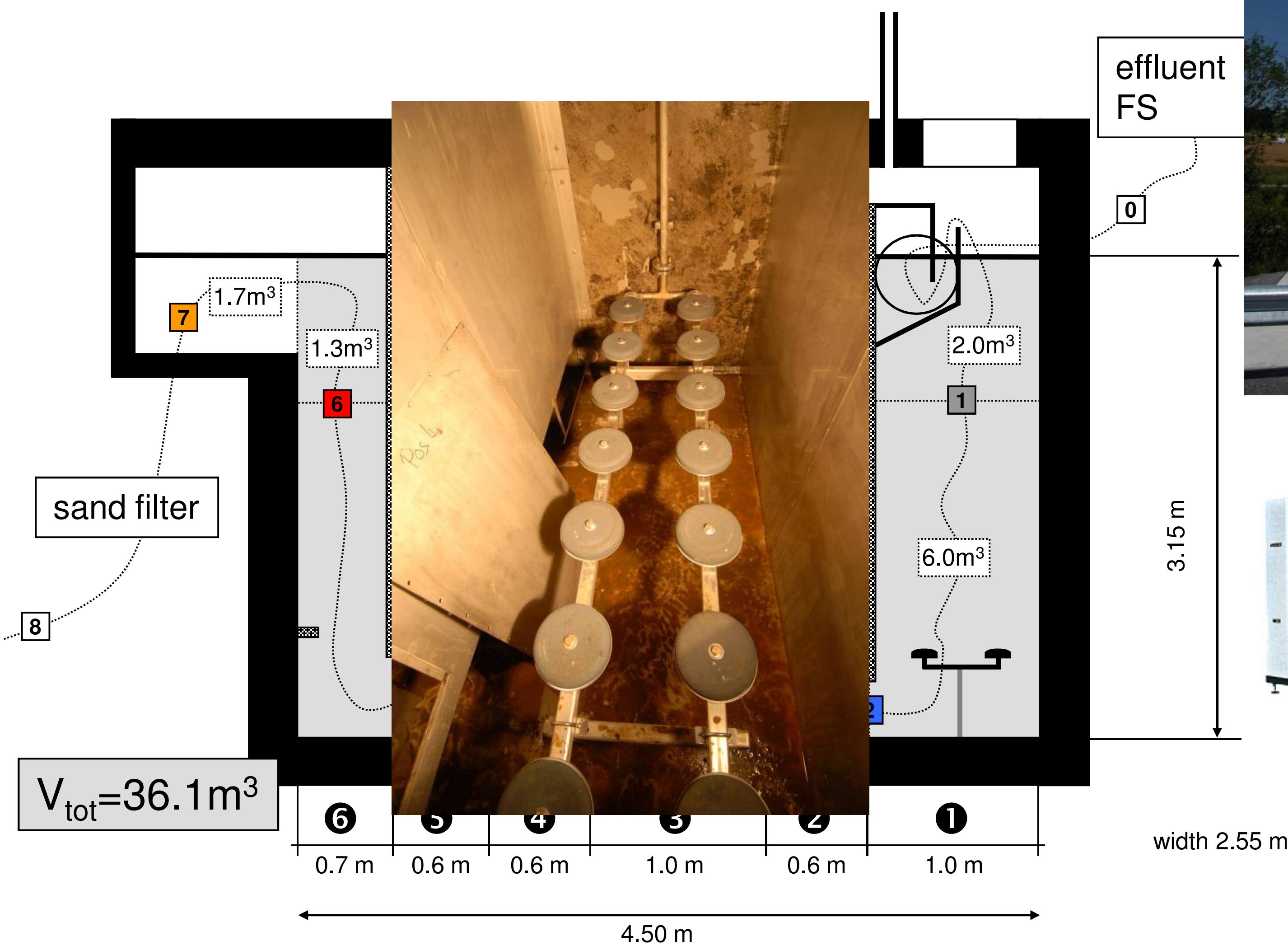
Full scale ozonation at WWTP Regensdorf



- population equivalent: 25.000
- water flow under dry weather conditions: 30-120 L/sec ~ 50 % water flow of creek

● sampling points

Ozonation



effluent
FS
0
1
2
6
7
8
sand filter
1.7m³
1.3m³
2.0m³
6.0m³
3.15 m
width 2.55 m
V_tot=36.1m³
❻
❶
0.7 m
0.6 m
0.6 m
1.0 m
0.6 m
1.0 m
4.50 m

Full-scale ozonation

Ozone dosage

- Online measurement of ozone and DOC (as UV absorption)
- Control of ozone concentration by DOC measurements
- Ozone concentration: 0 – 1200 g /kg DOC ≈ 0 – 6 mg/L Ozone

Sampling

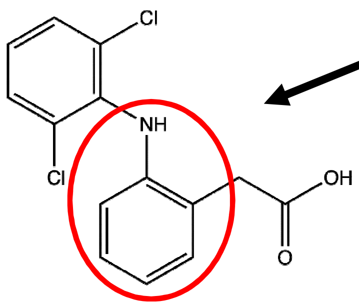
- 10 sampling compaigns
- 24h- or 48h-volume proportional composite samples
- Fitration on-site (0.7 µm glassfiber filters)

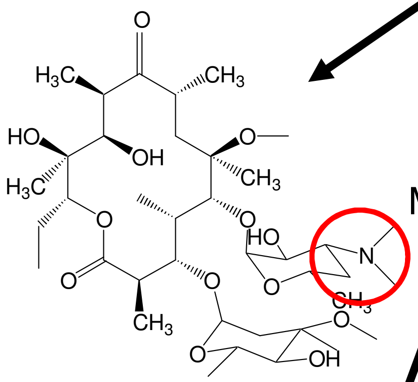
Analysis

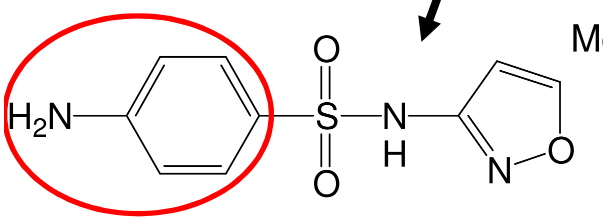
- Micropollutants
- Ecotoxicity
- Pathogens

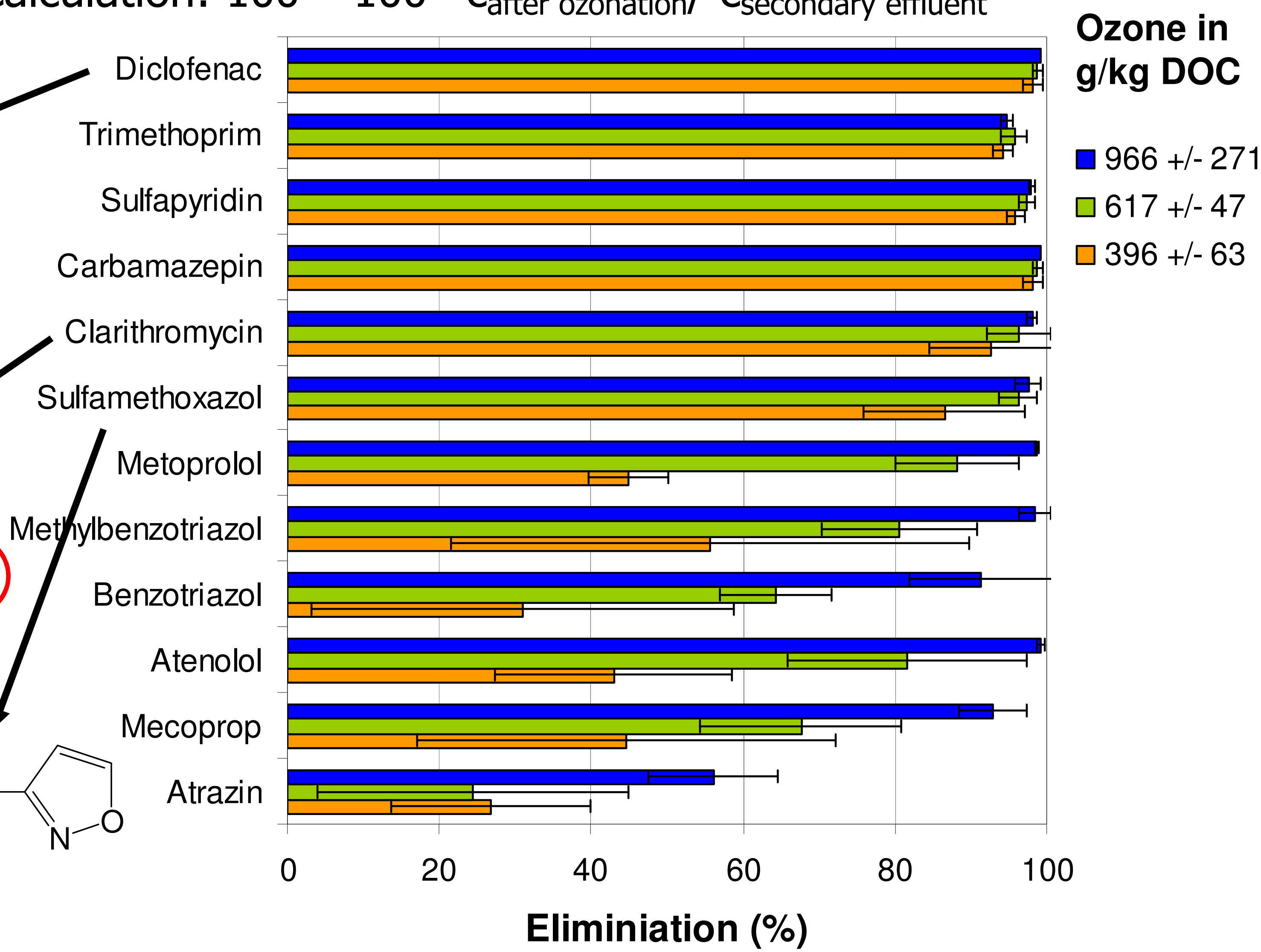
Effect of ozone concentration on elimination efficiency

Calculation: 100 – 100 *$c_{\text{after ozonation}}$/ $c_{\text{secondary effluent}}$









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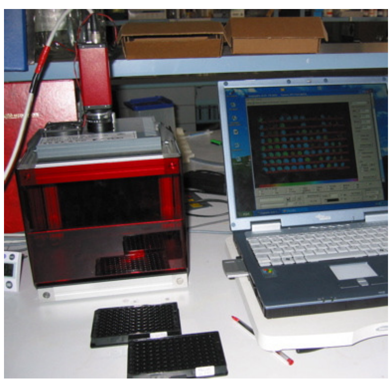
Elimination efficiency – micropollutants

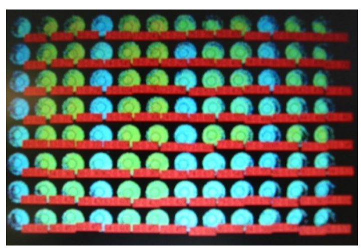
	Number	Secondary Effluent >15 ng/L	Ozonation effluent (634 g O3/kg DOC) > 15 ng/L	Ozonation effluent (634 g O3/kg DOC) > 100 ng/L
Pharmaceuticals	14	12	3	Atenolol
Antibiotics	10	8	0	
X-Ray contrast media	6	6	not determined	
Biocides/Pesticides	12	8	3	Mecoprop
Corrosion inhibitor	2	2	2	(Methyl)-Benzotriazol
Endorine disruptors	4	1	1	Bisphenol A
Metabolites	5	1	1	

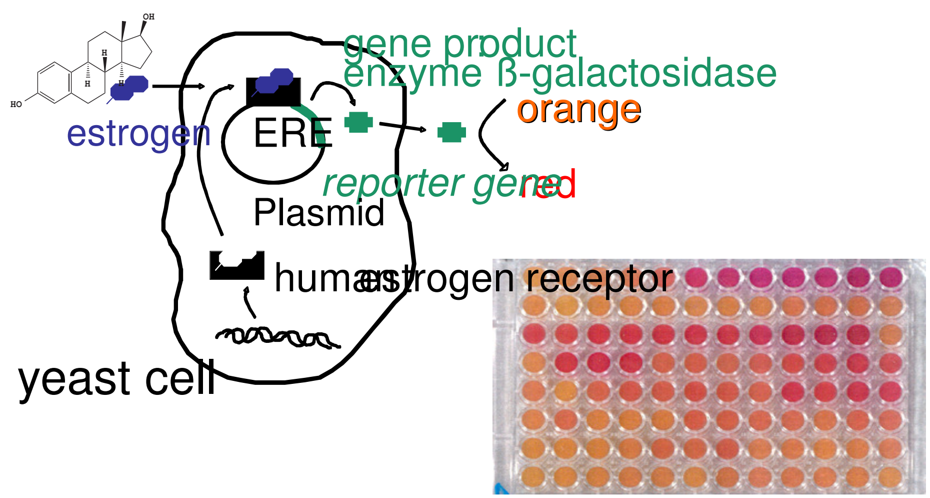
Elimination efficiency of toxic effects

Testbattery (in vitro)

➢Bioluminescence test	non-specific toxicity
➢Algae test	inhibition of photosynthesis
➢Acetylcholinesterase test	neurotoxicity
➢Yeast estrogen screen (YES)	endocrine disruption

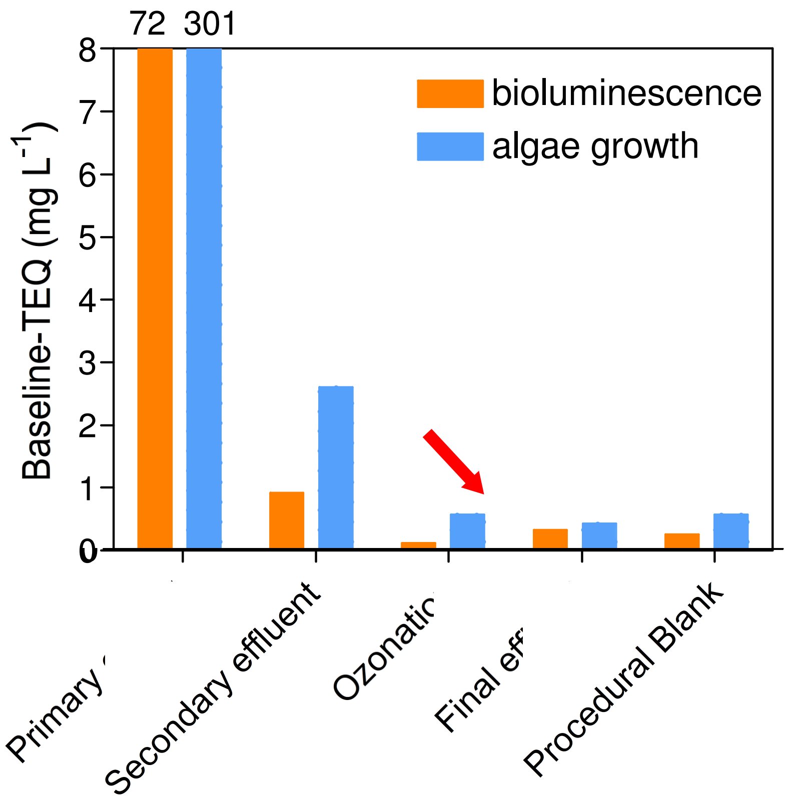




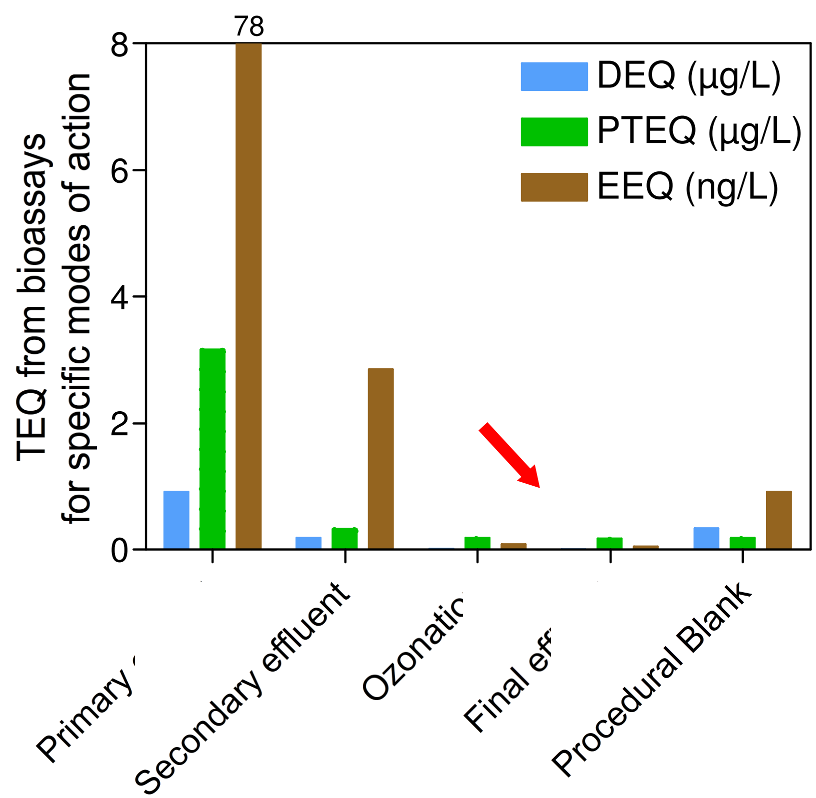


Elimination efficiency of toxic effects

non-specific toxicity



specific toxicity



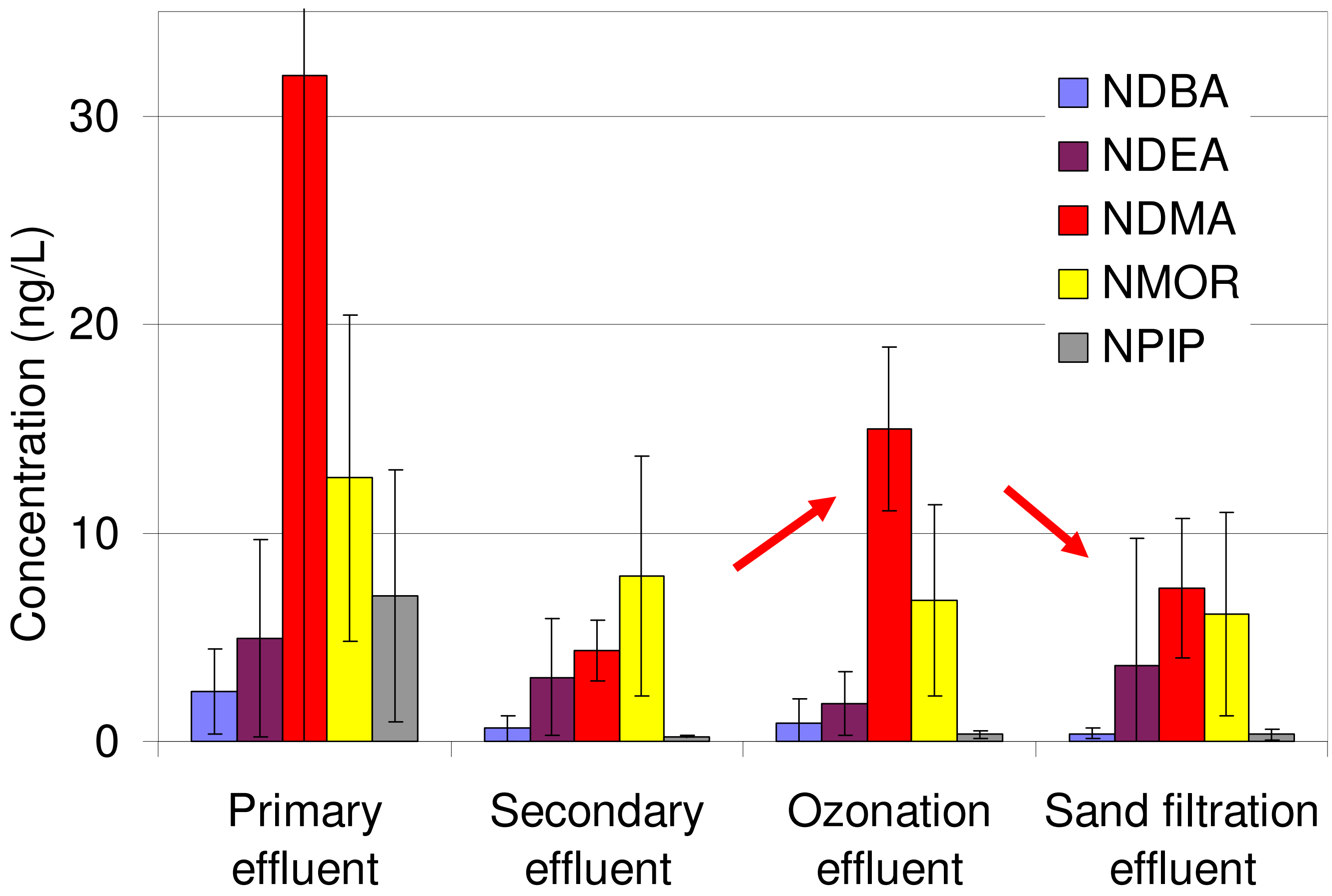
➔ Ozonation leads to a significant reduction of non-specific and specific toxicity

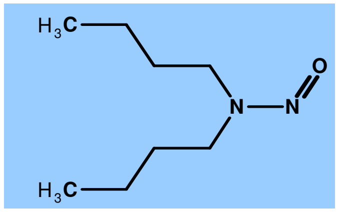
<u>Ozone dose</u>

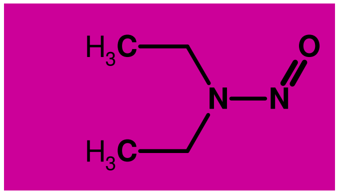
600 g O_3 / kg DOC

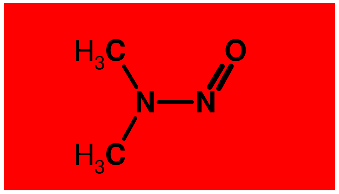
Cancerogenic nitrosamines - byproducts of ozonation?

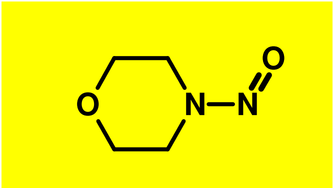
Mean values of 9 -11 sampling campaigns

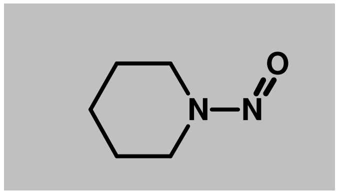




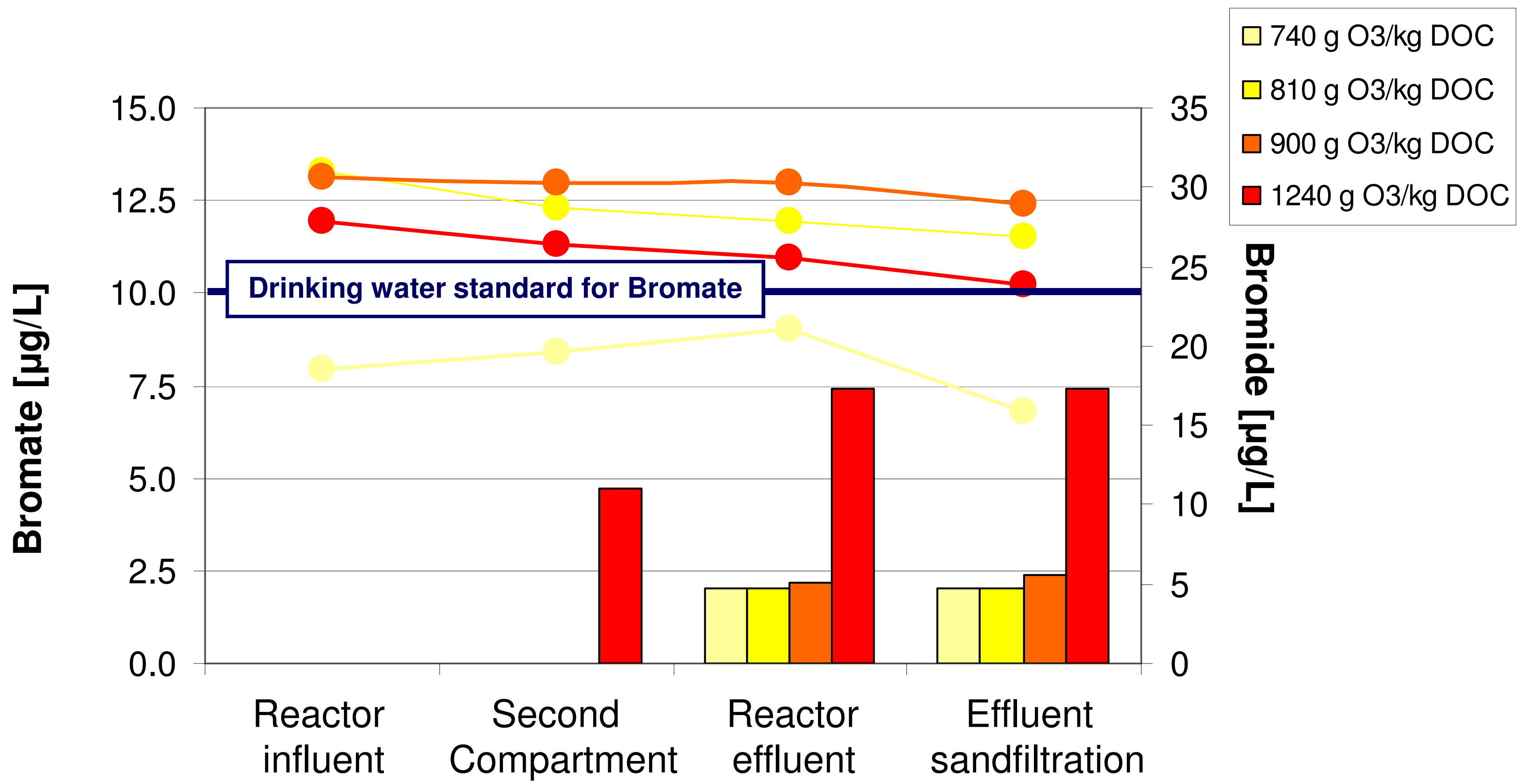






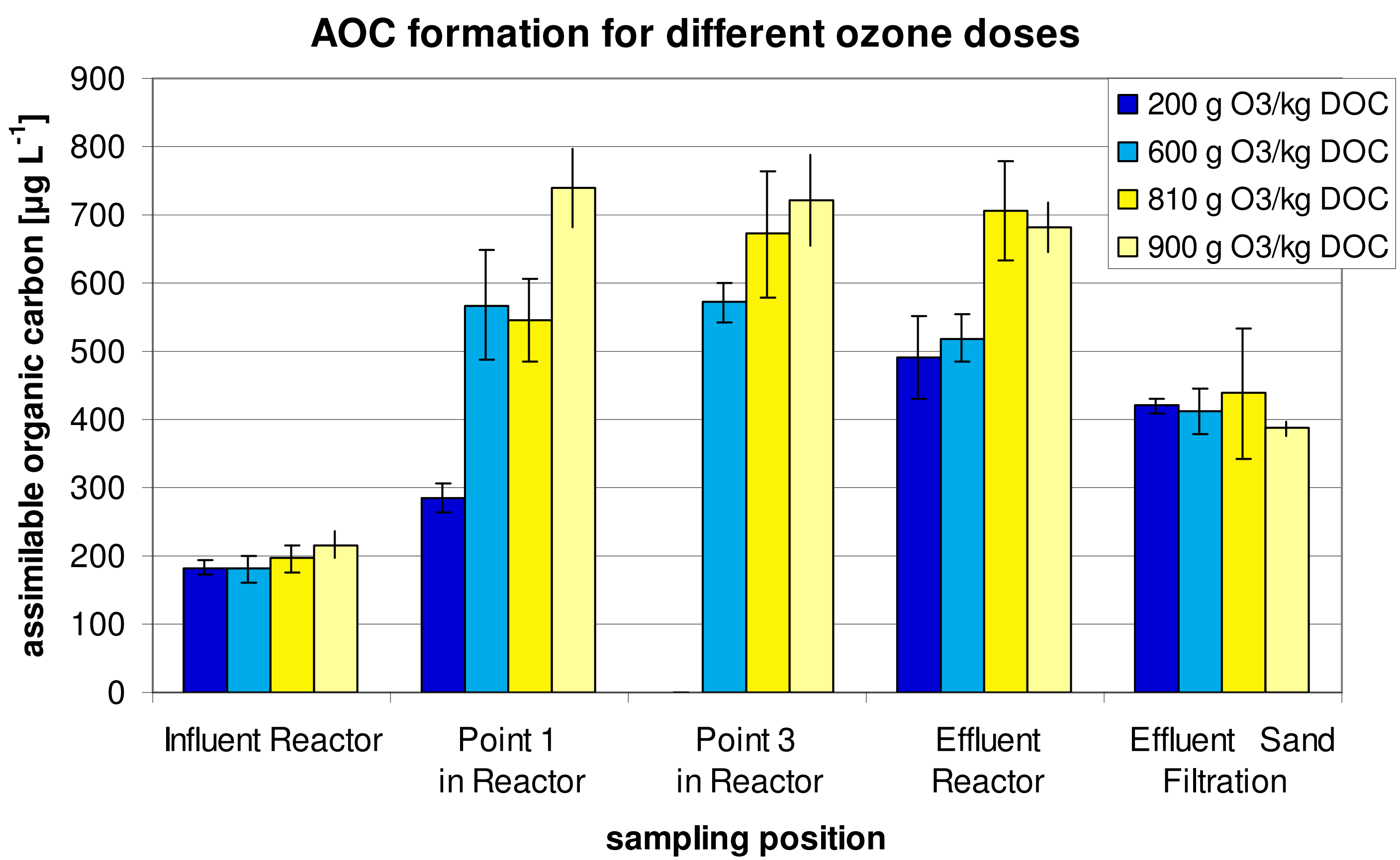


Bromate formation in ozone reactor



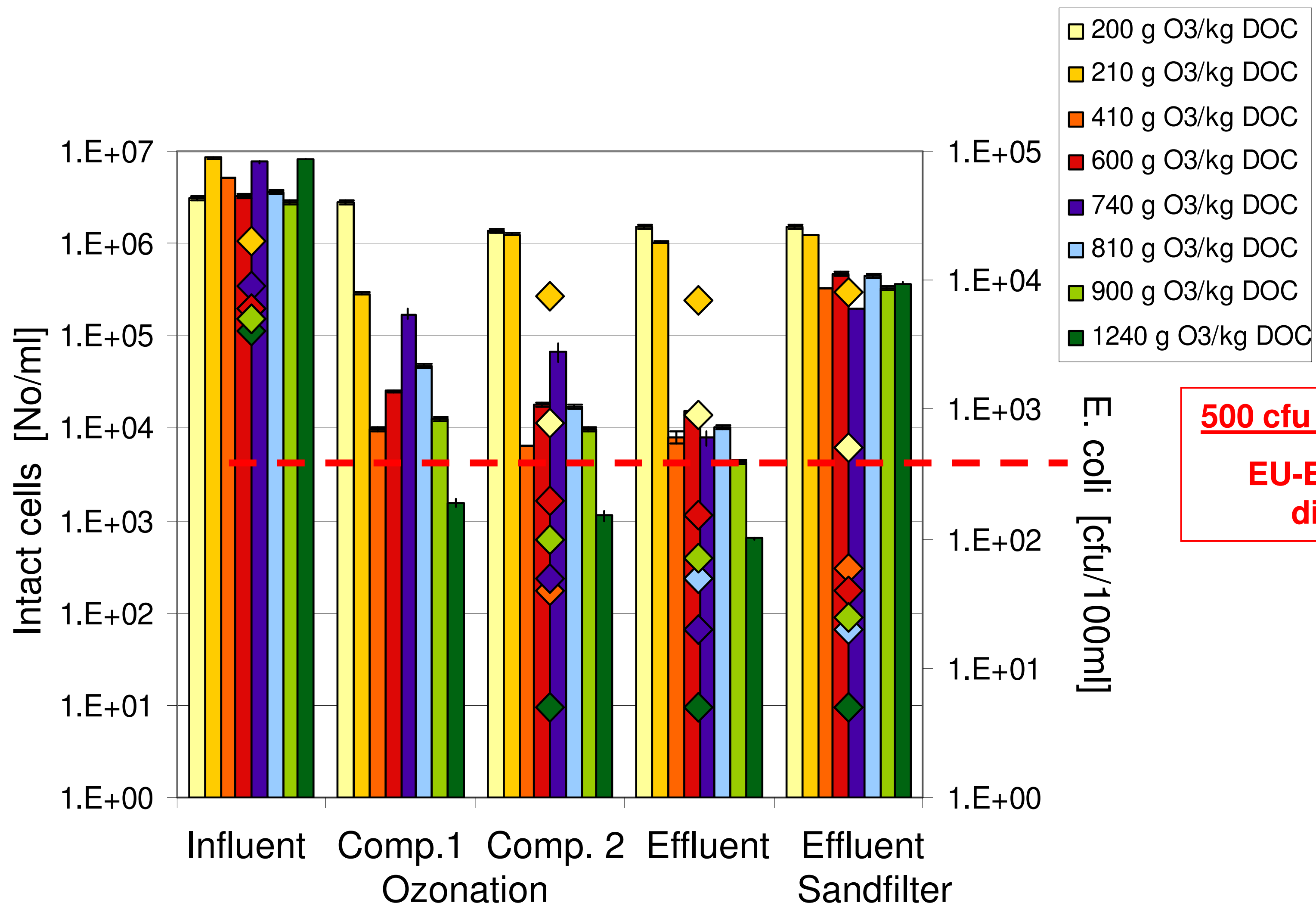
- **Bromate formation only for very high ozone dose (LOQ = 2 µg L^{-1})**
- **Concentration remains even below the drinking water standard!**

AOC formation in the ozonation reactor



- **ozonation increases the assimilable organic carbon up to a factor of 3.5**
- **sand filtration decreases it subsequently to twice the influent concentration**

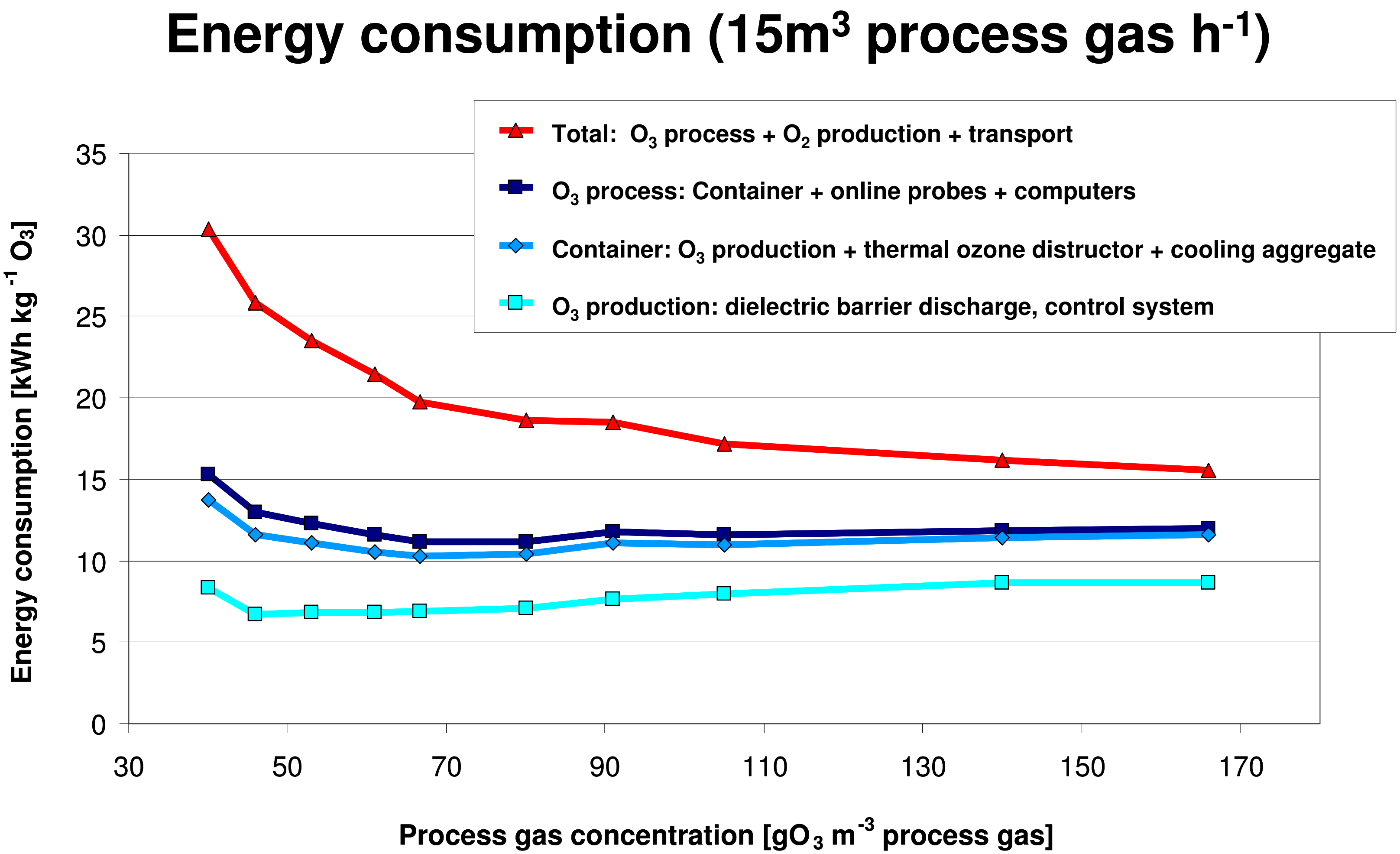
Desinfection efficiency of ozonation



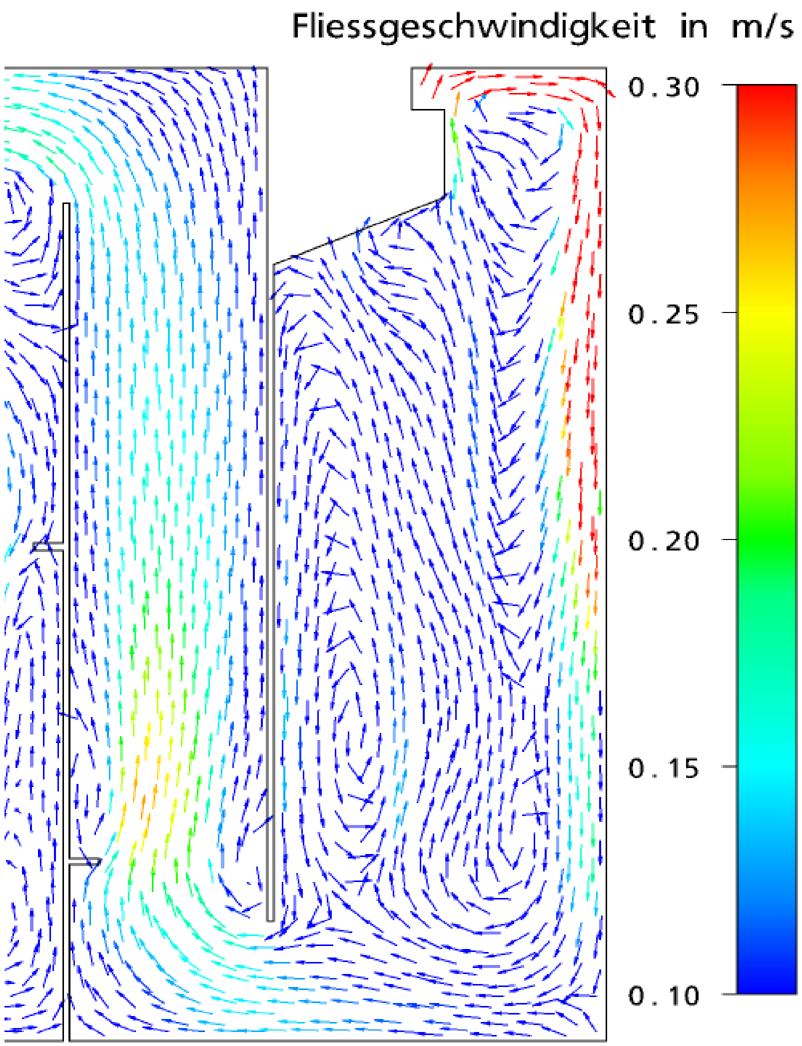
500 cfu E.coli/100 ml

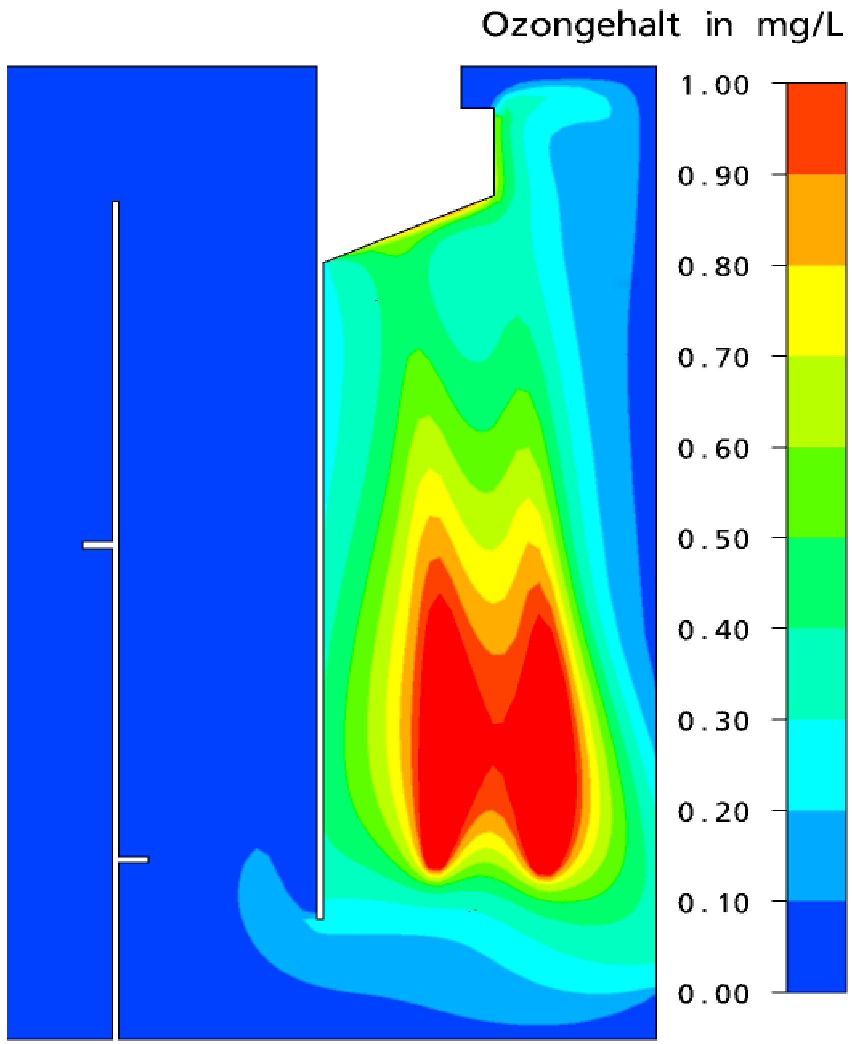
EU-Bath water directive

Electrical energy for ozon from air oxygen



Short-circuiting in ozonation reactor

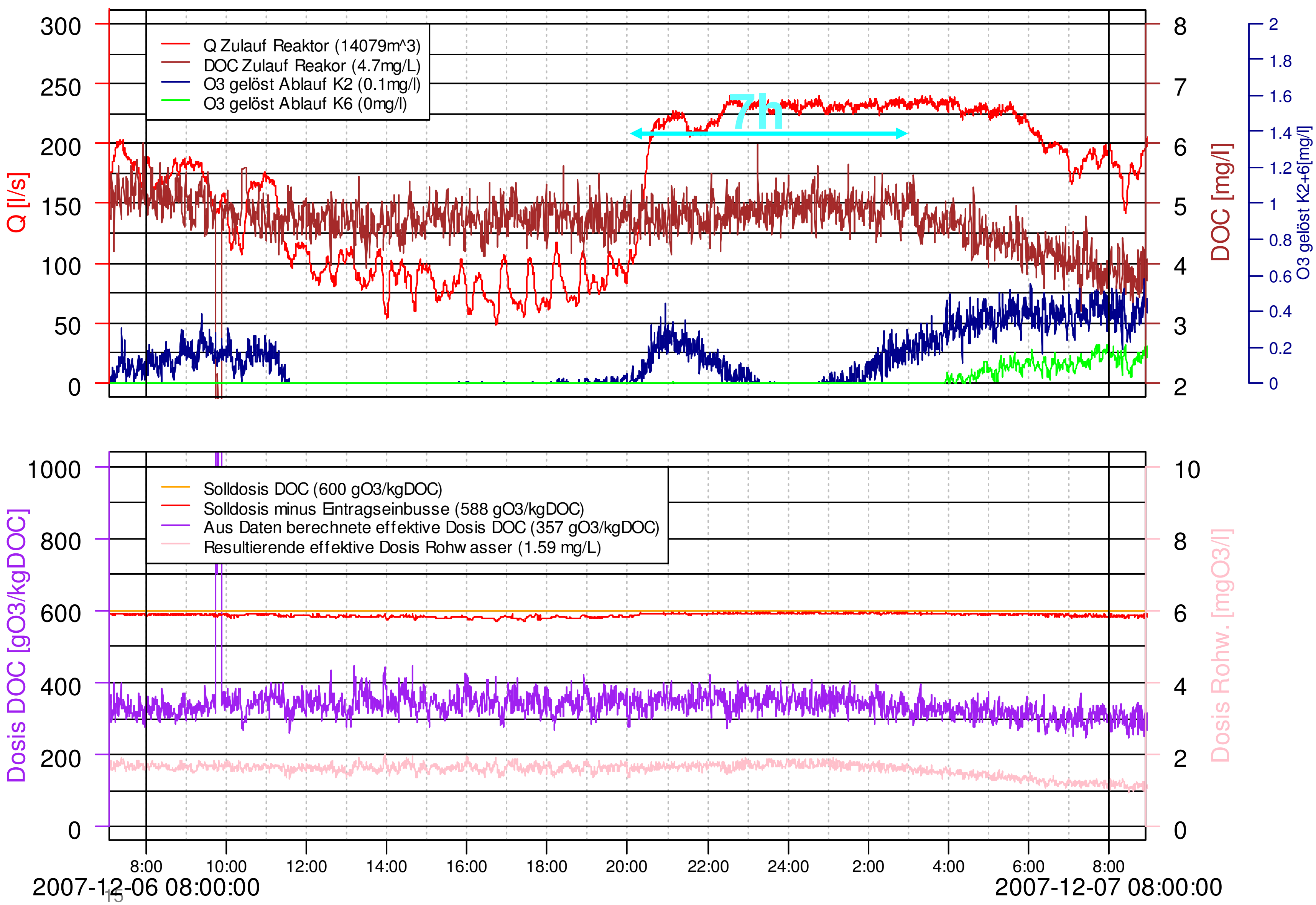




Three-dimensional CFD-simulation for Q = 0.15 m^3 sec^{-1}, and O_3-dosage = 5 g m^{-3}

Markus Gresch, Process Engineering, Eawag

Behavior during stormwater



Conclusions Ozonation

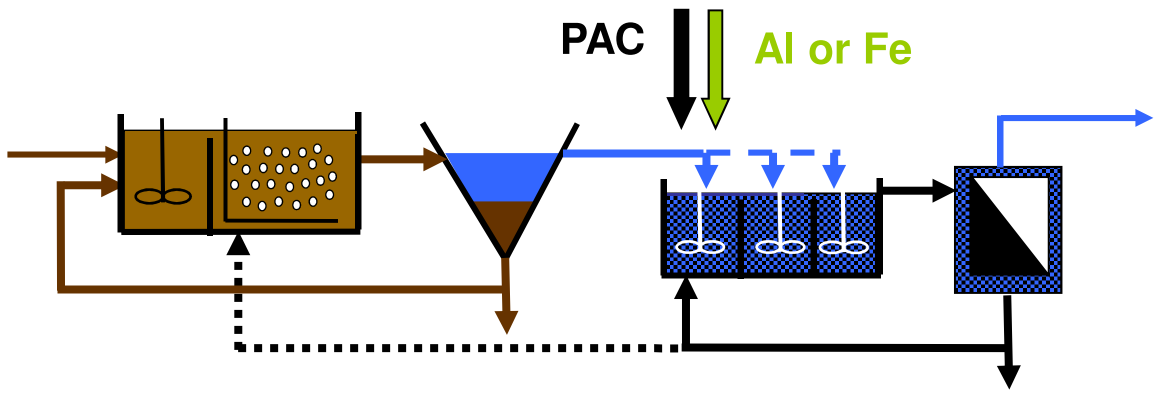
- Full scale reactor in Regensdorf proves ozonation to be an efficient technique for the elimination of micropollutants and disinfection
- 0.6-0.8 g Ozone/g DOC is sufficient to significantly reduce (80-100%) the selected micropollutants
- Ozonation reduces both specific and non-specific in vitro ecotoxicity
- Sandfiltration seems appropriate as an additional barrier for the elimina-tion of products formed during ozonation e.g. NDMA but especially AOC
- Bromate formation is not of concern in wastewater with such low bromide concentrations
- E.coli is reduced significantly and bathing water quality reached with 0.6 g_{O3}/g_{DOC}, 0.9 g_{O3}/g_{DOC} reaches the requested CT-value of 10 min·mg_{O3}/l
- HRT should be 15-20 minutes during dry weather to prevent ozone loss during stormwater (HRT about 5 minutes)
- Short circuiting in the ozonation chamber should be avoided
- Energy consumption for 1 kg ozone incl. pure oxygen production and transport to WWTP is about 15-17 kWh
- For 0.8 gO_3/gDOC and 5-10 gDOC m^{-3} wastewater electrical energy consumption is 0.06 - 0.13 kWh m^{-3} (20-40% of nutrient removal WWTP

PAC addition - Overview

- Introduction: potential flow schemes
- Effect of Background DOC on PAC dosage
- PAC-Application: Pilot- and full scale experiments
  - Contact SBR: Single- and two stage application
  - Flocculation/sandfiltration: Single stage application
- Modelling PAC addition with and without PAC recycling
- Conclusions

Introduction – potential flow schemes

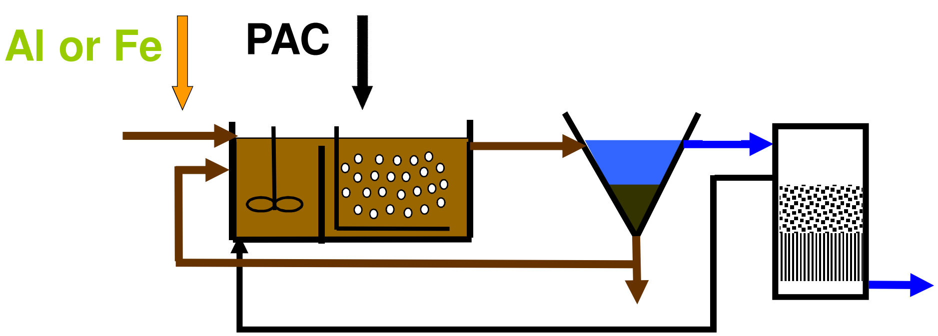
- PAC/flocculant addition to a contact/flocculation tank with additional sedimentation or membrane separation for PAC recycling
- After the sedimentation a filter is needed to reduce PAC loss



Sedimentation followed by filtration or membrane separation

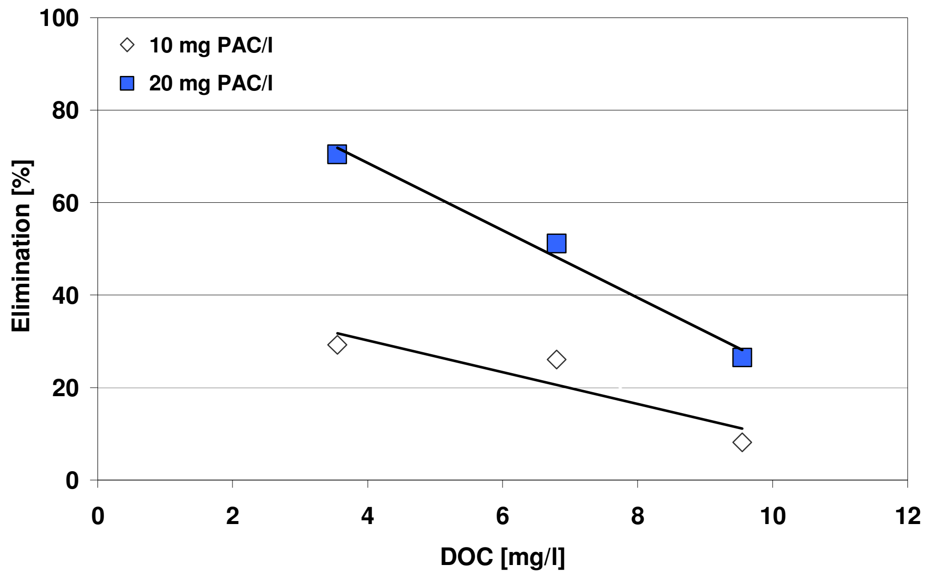
Alternatives:

- PAC addition to filtration
- PAC additon directly to activated sludge system

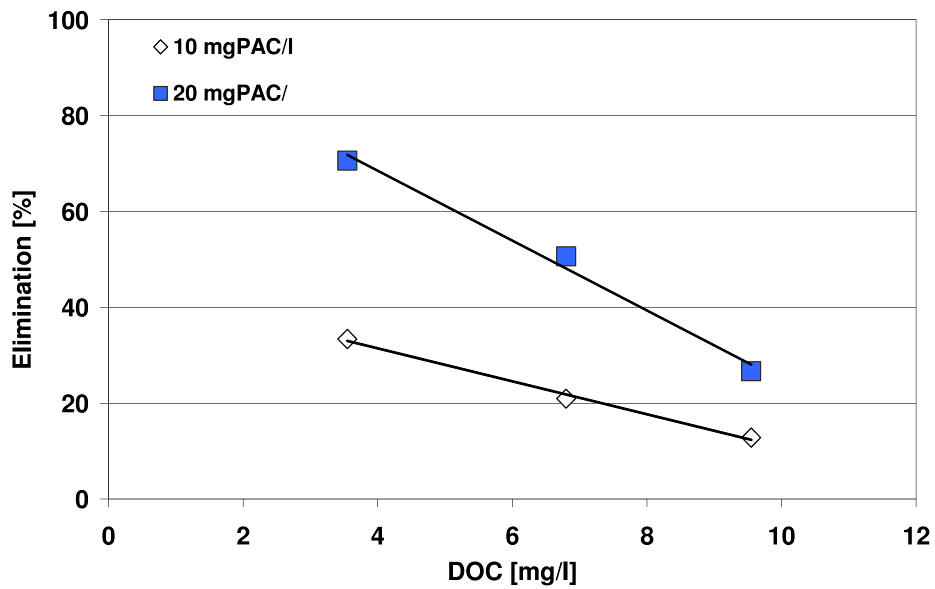


Effect of background DOC

Iopamidol



Sulfamethoxazole



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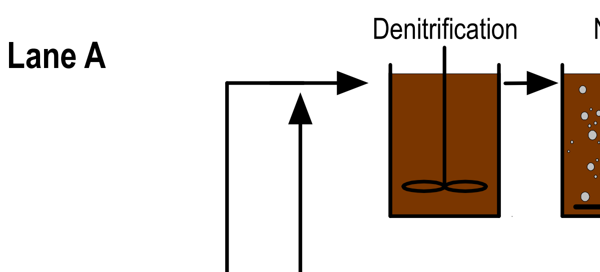
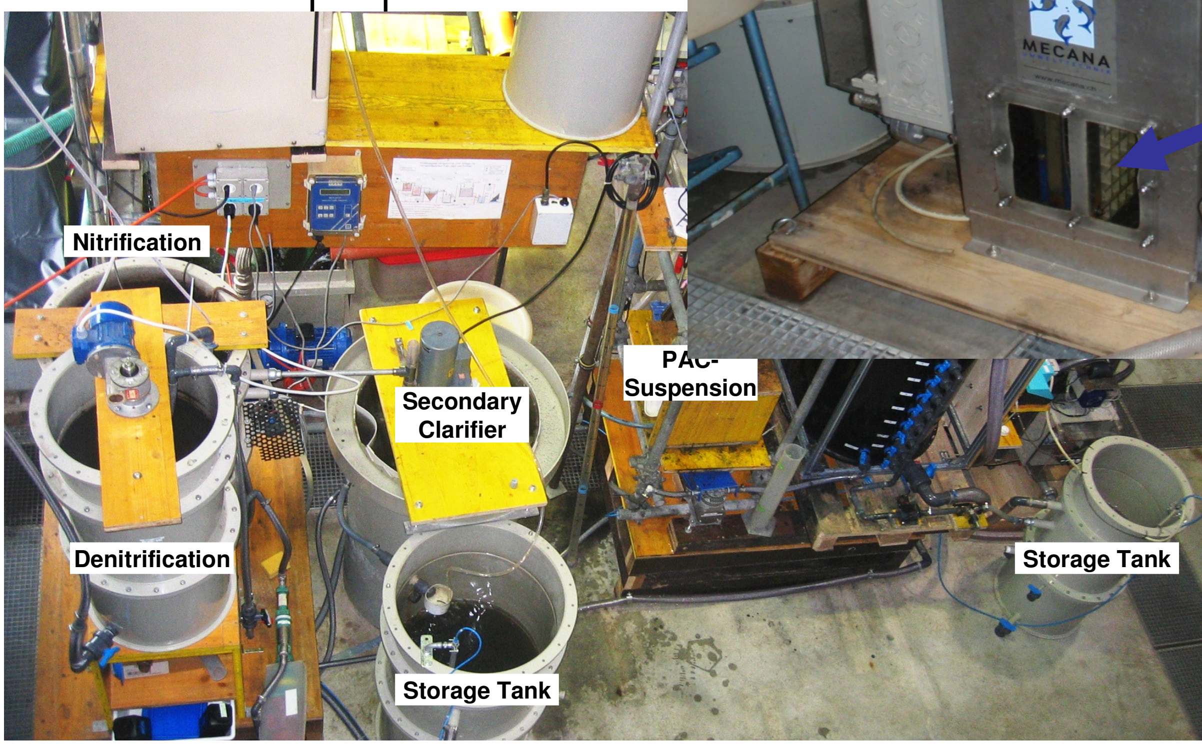
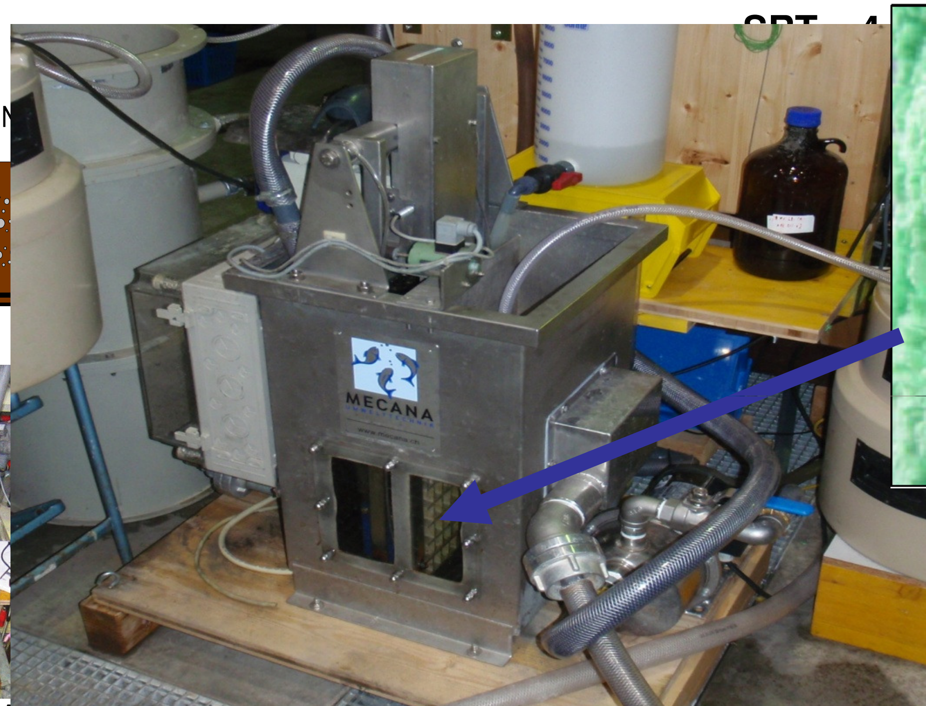
PAC addition to secondary effluent
(SBR, with and without PAC recycling)

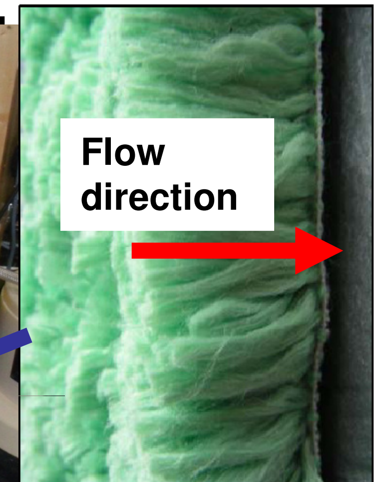
Pilot plant Eawag

SRT ~

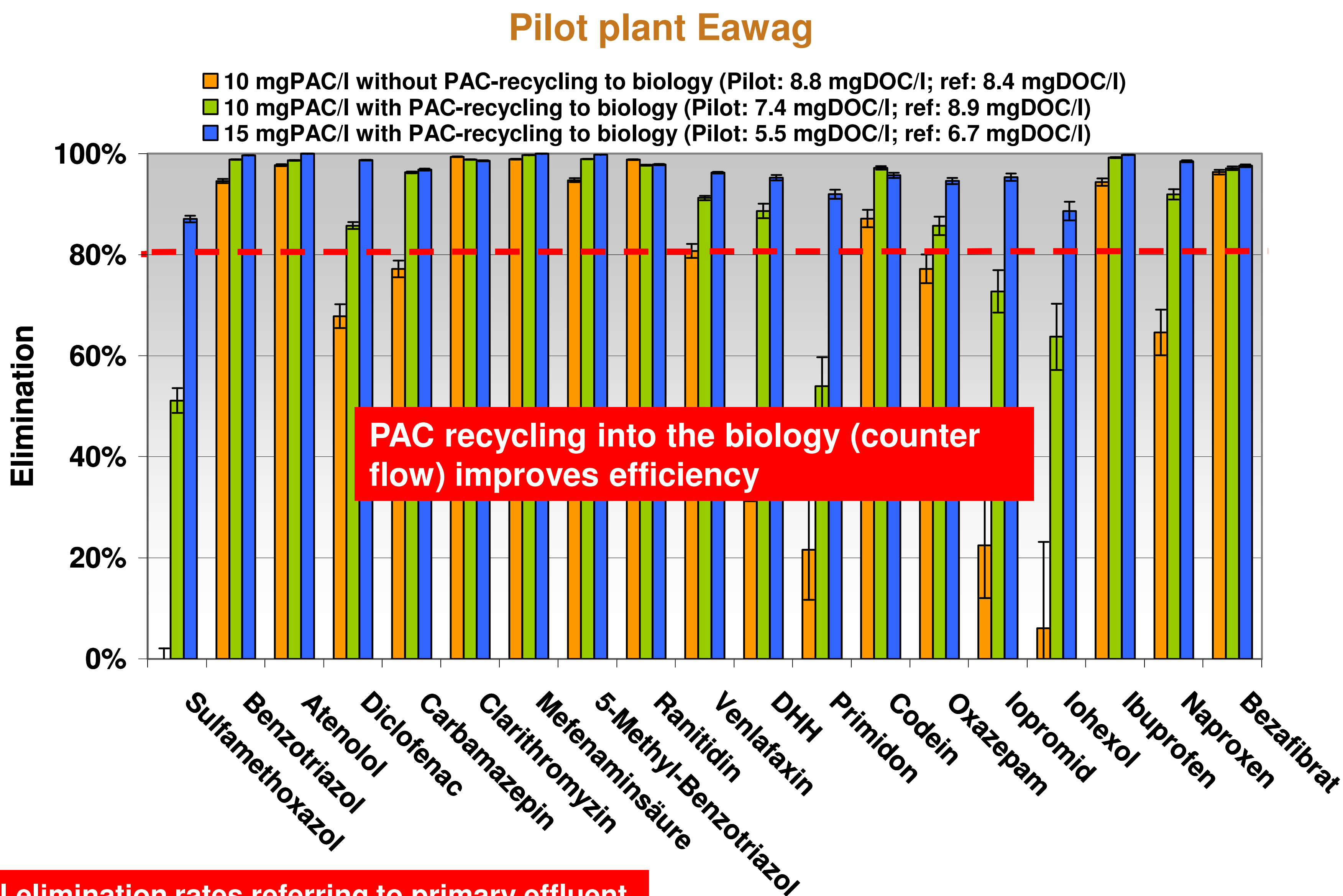






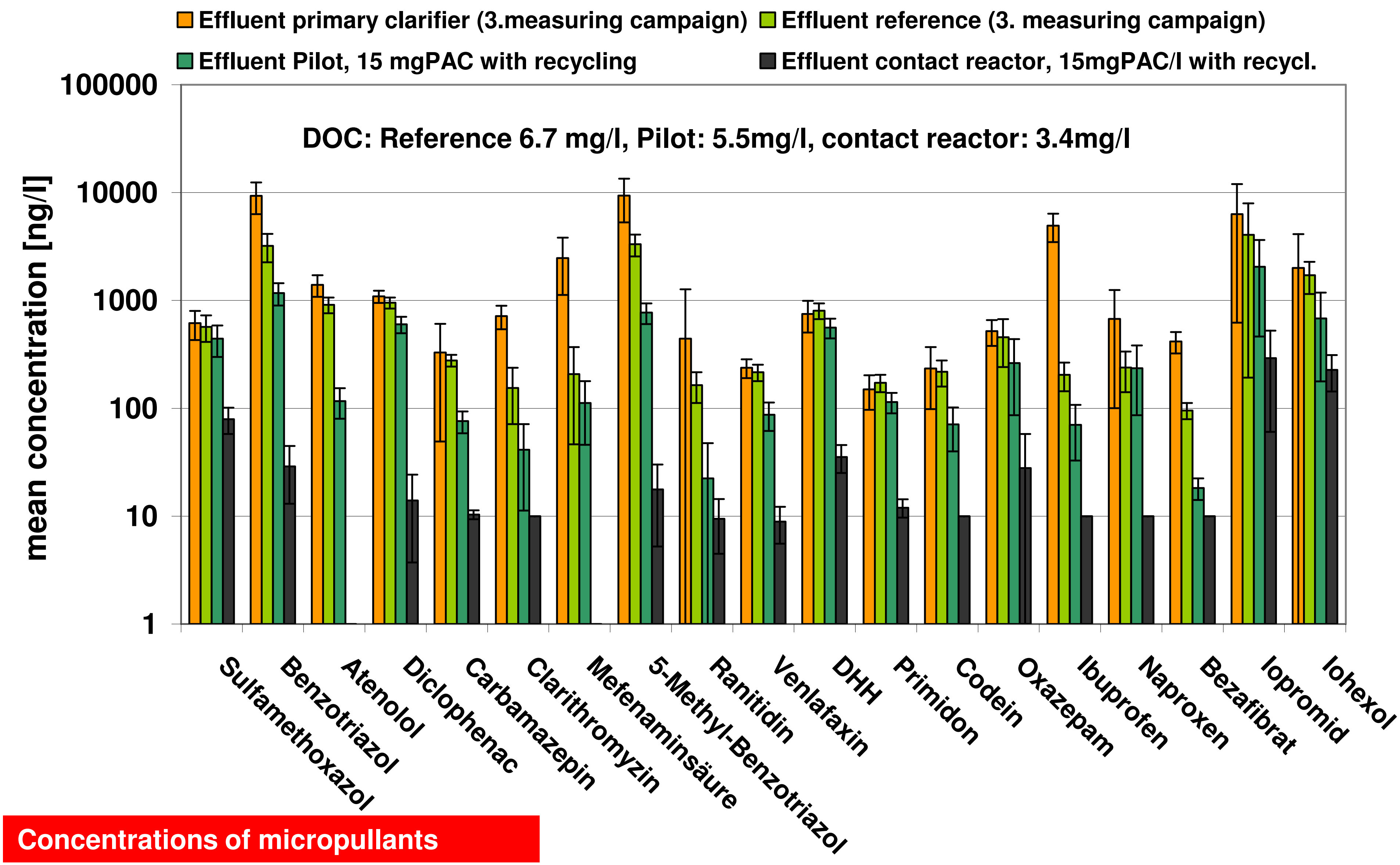


PAC addition to secondary effluent (SBR)



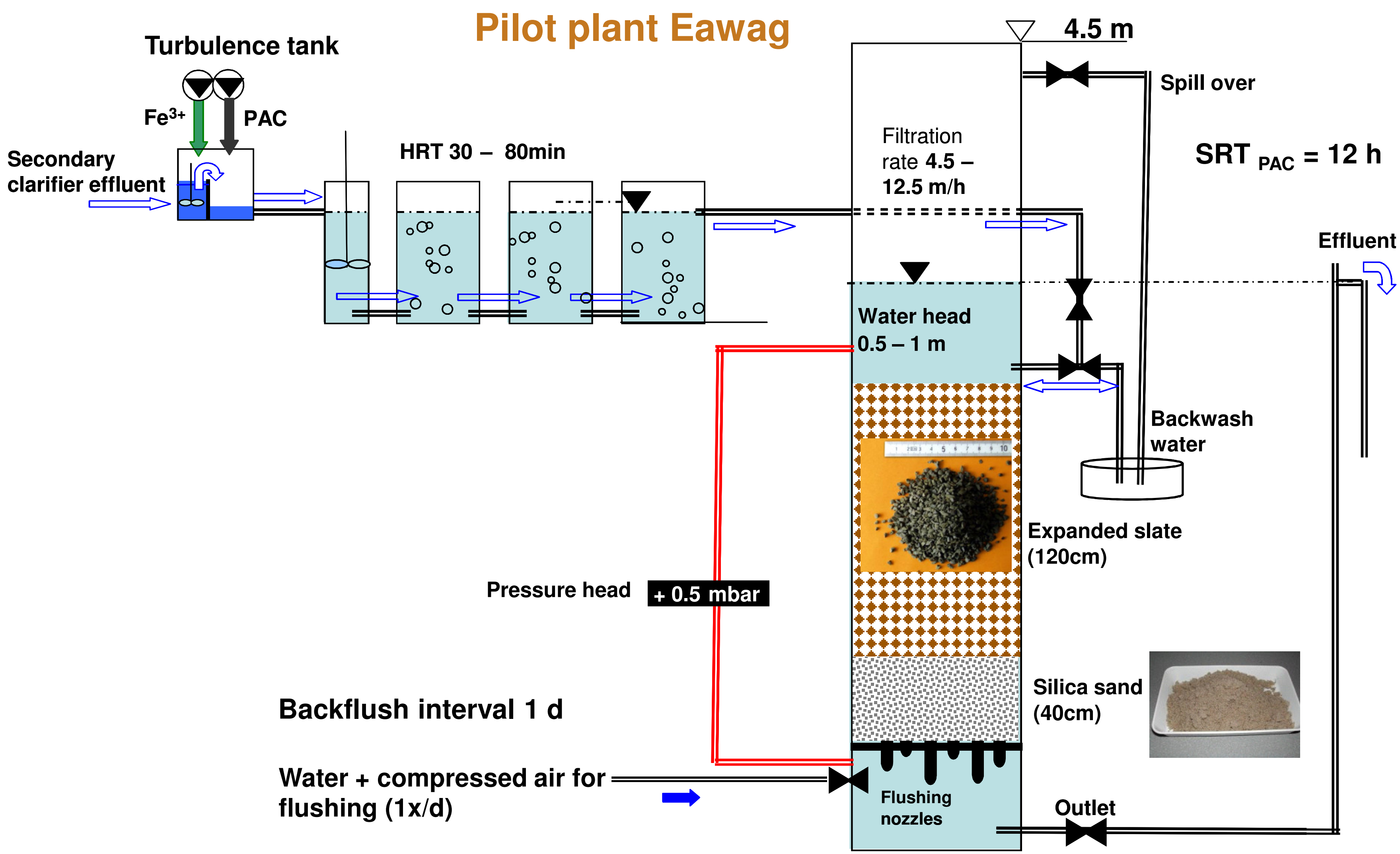
All elimination rates referring to primary effluent

PAC addition to secondary effluent (SBR)



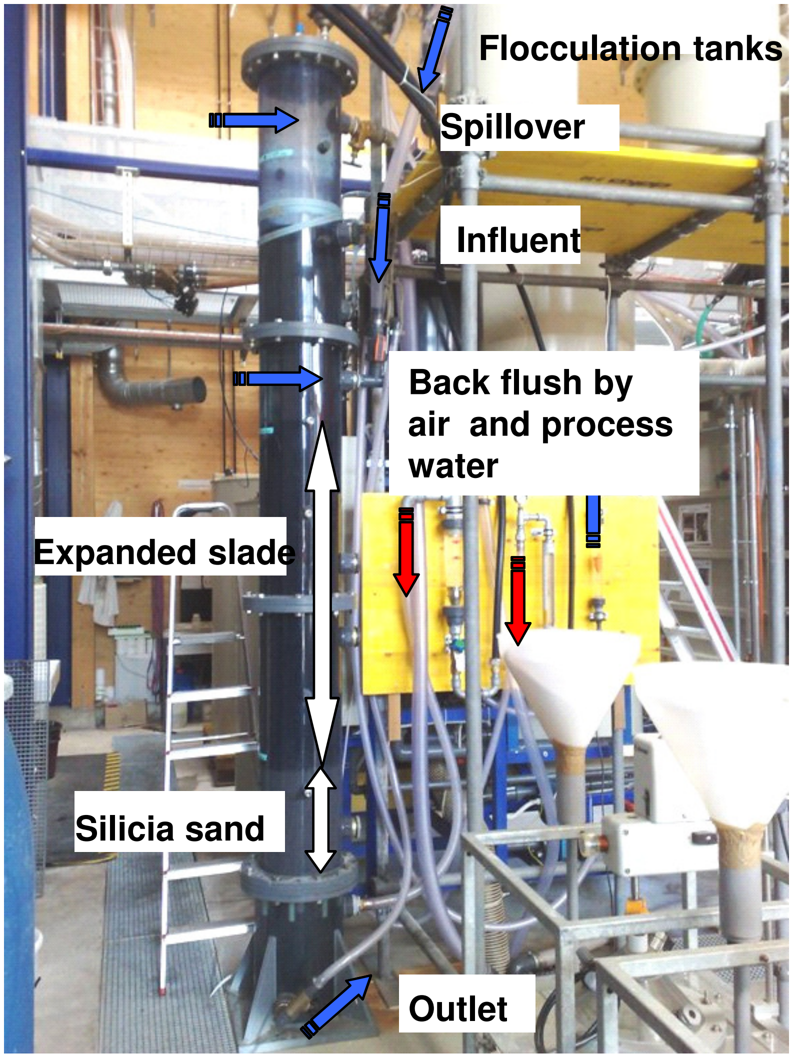
Concentrations of micropullants

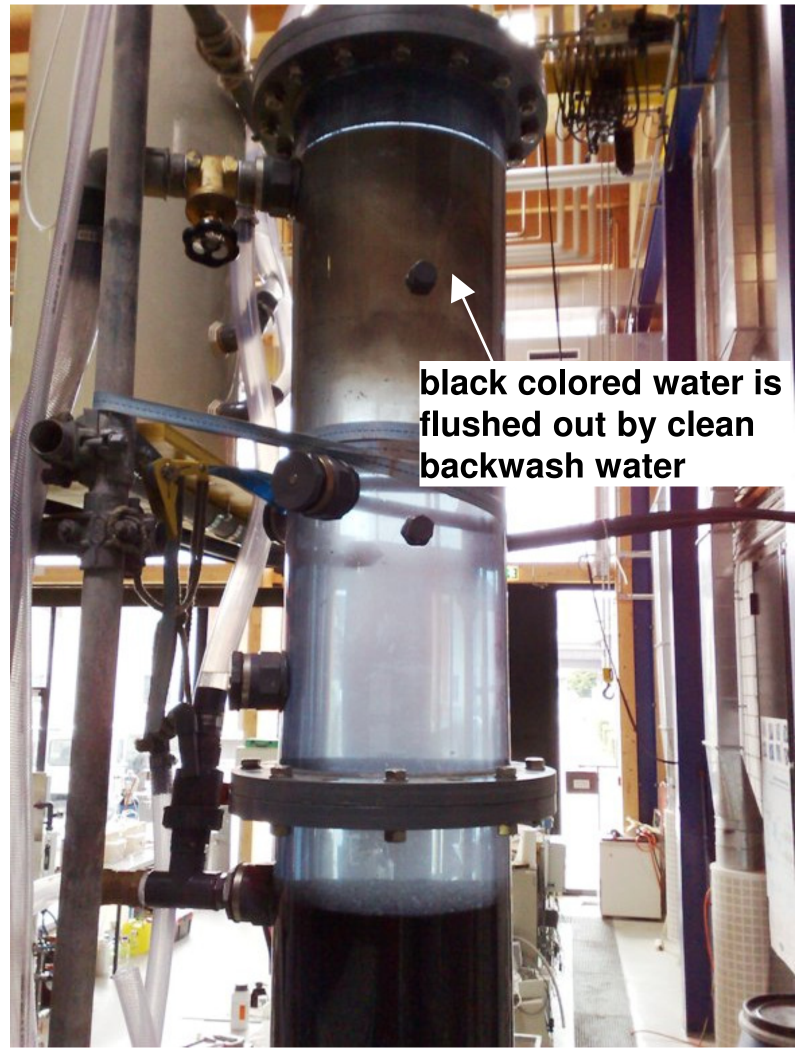
PAC addition to sand filtration (single stage)



PAC addition to sand filtration

Pilot plant Eawag



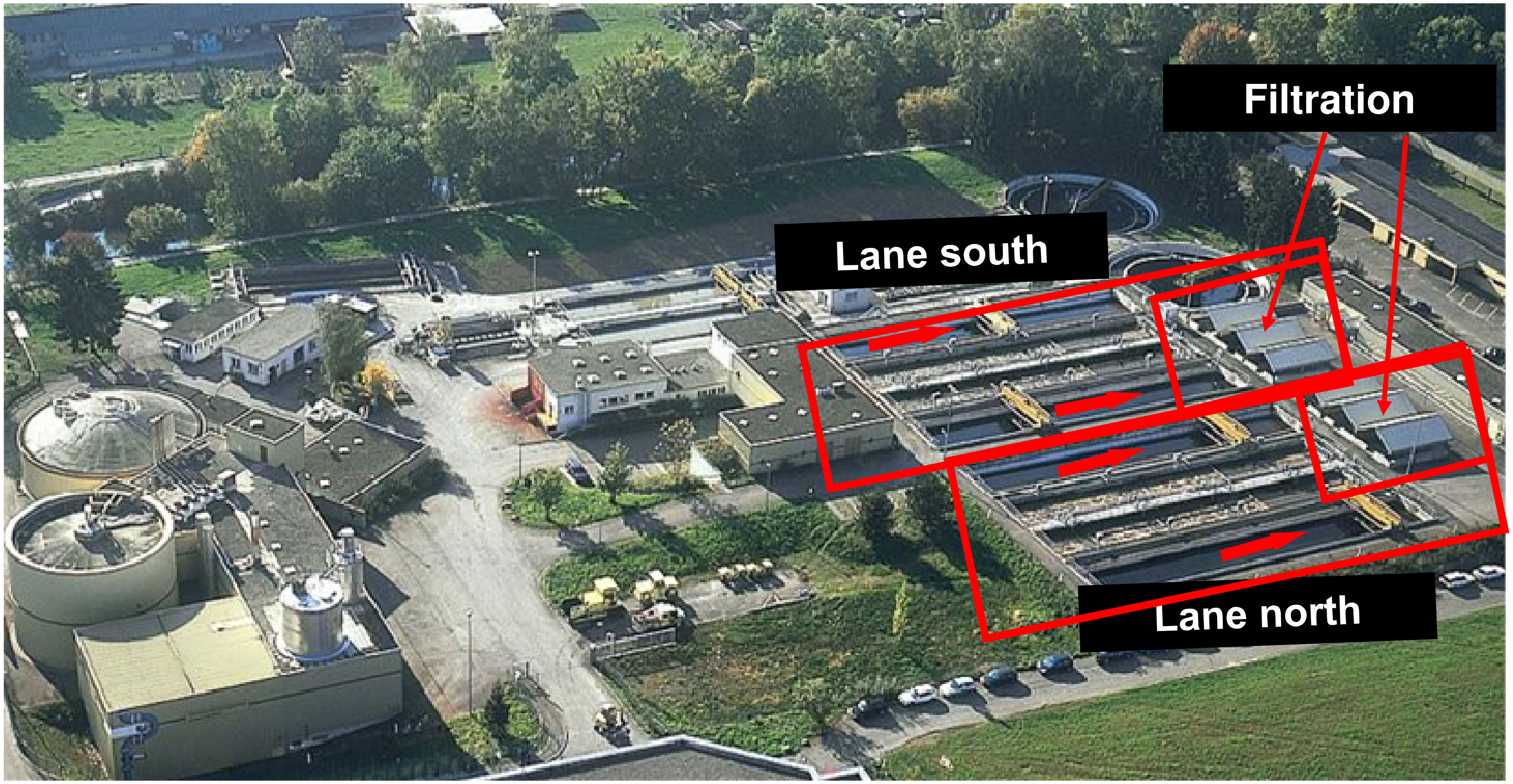


Full-scale experiments at WWTP Opfikon

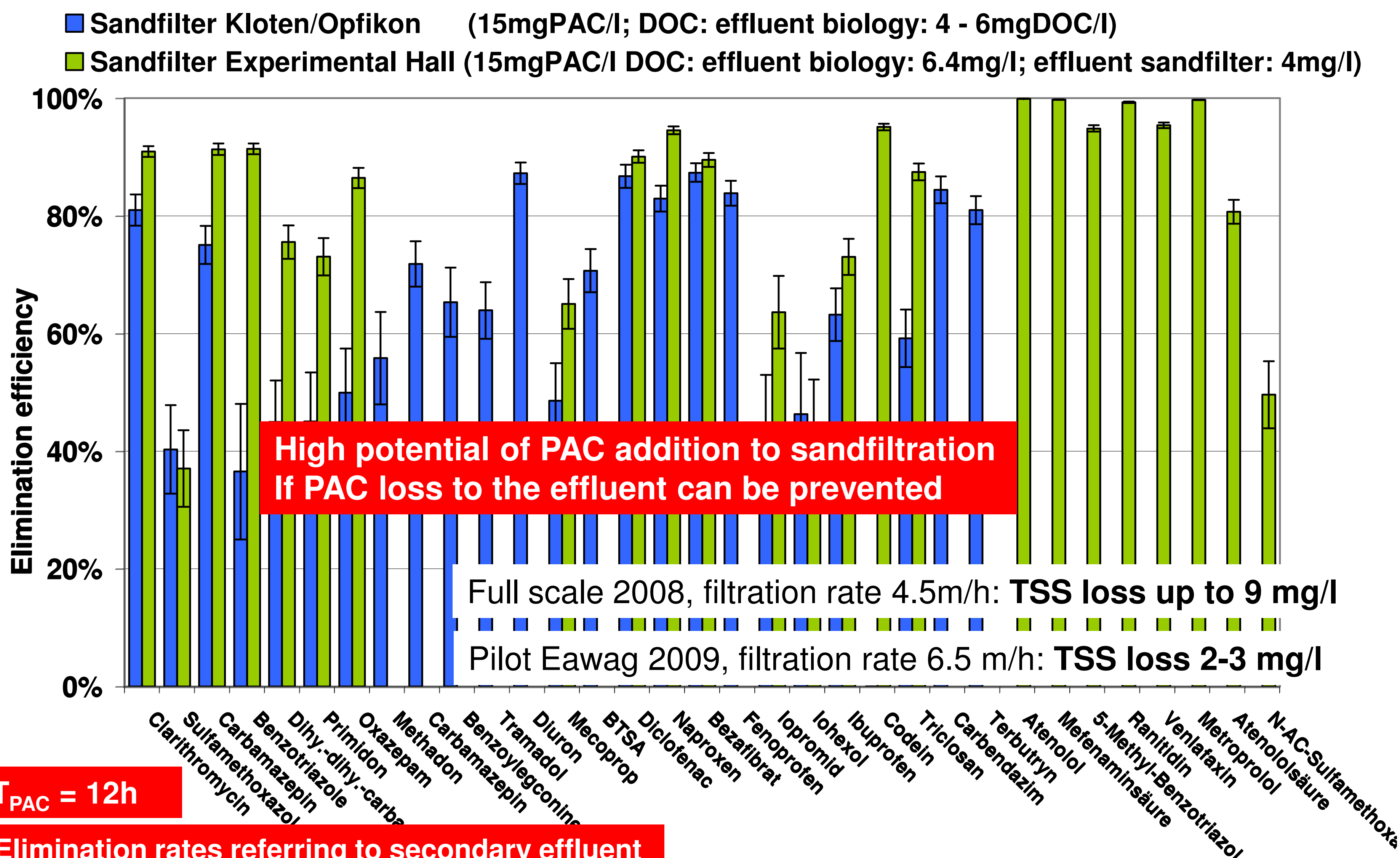
Activated sludge system with two lanes for nitrification and denitrification for 60‘000 PE, each lane has two biology tanks with two secondary clarifiers

Each lane has one flocculation reactor followed by four two layer filters

Fe and PAC were only added to the flocculation tank **(HRT = 0.9 h)** of lane south with one filter in operation **(hydraulic load 4.3 m/h, SRT of PAC in the Filter was 12 hours, backflush intervall 1x/d)**



PAC addition to sand filtration



SRT_{PAC} = 12h

All Elimination rates referring to secondary effluent

All trials without PAC recycling via back flush water into biology

Elimination of background DOC

Dosage	Treatment	System	effluent secondary clarifier Reference	 Pilot	effluent contact reactor / sandfilter	Elimination efficiency
mgPAC l-1			*mgDOC l-1*			%
10	single stage	SBR without recycle	8.4	8.8	7.5	15
10	two stage	SBR with recycle	8.9	7.4	5.5	38
15	two stage	SBR with recycle	6.6	5.5	3.4	48
15	single stage	Sandfiltration pilot	6.4		4	37

PAC addition to activated sludge system

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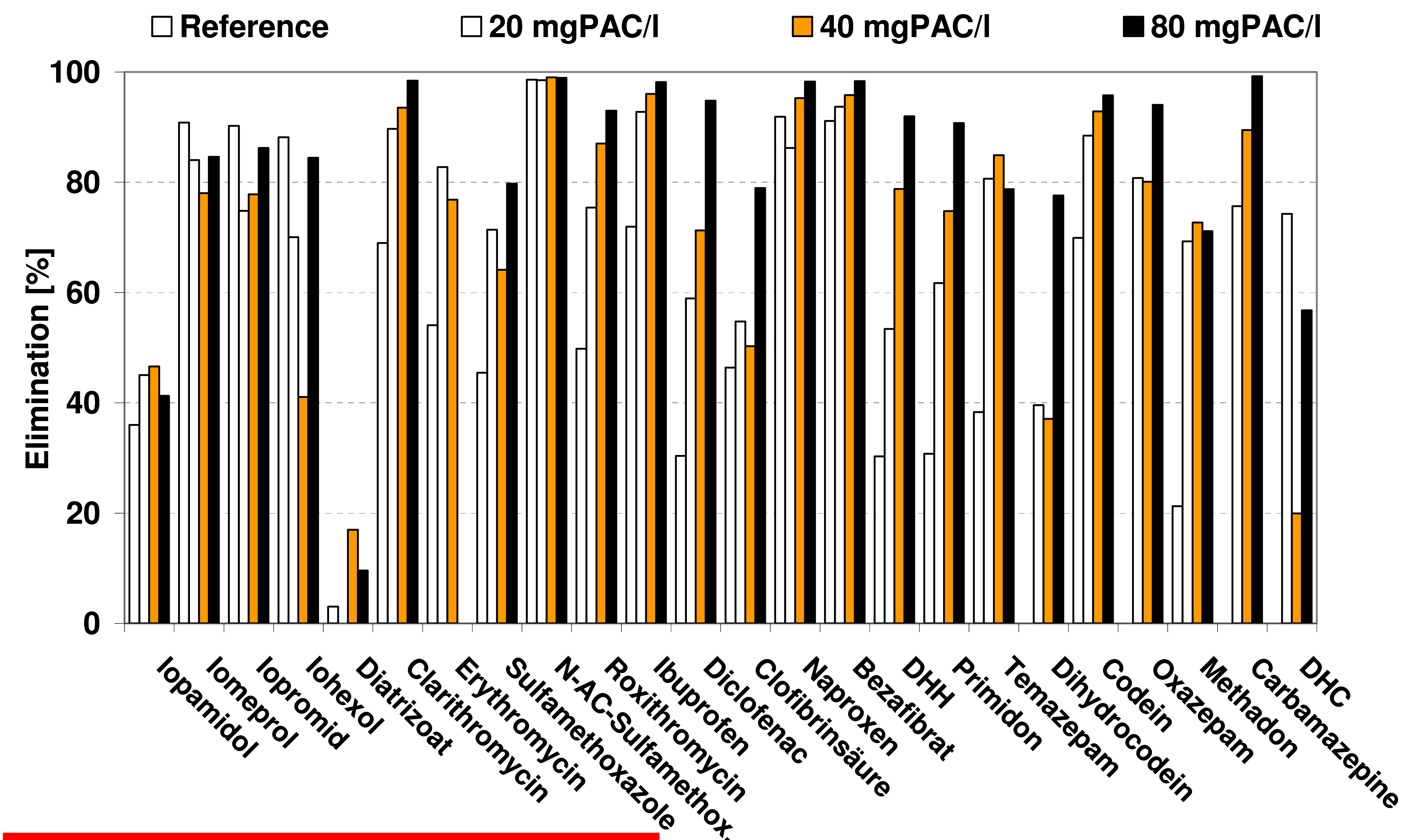
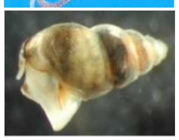
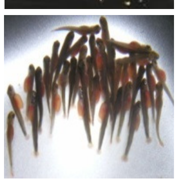
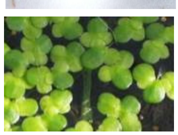


All Elimination rates referring to primary effluent

In-vivo Tests in a flow-through system

	Organism	Endpoints	OZ	SF	AC
	*Chironomus riparius*	Mortality Emergence time	[yellow] [yellow]	[yellow] [yellow]	[yellow] [yellow]
	*Lumbriculus variegatus*	Reproduction Biomass	[red] [red]	[yellow] [yellow]	[yellow] [yellow]
	*Potamopyrgus antipodarum*	Reproduction	[green]	[green]	[green]
	*Dreissena polymorpha*	DNA damage	[red]	[yellow]	[green]
	*Daphnia magna*	Reproduction Mortality	[yellow] [yellow]	[yellow] [green]	
	*Oncorhynchus mykiss* (FELST)	Development Biomass Vitellogenin	[red–yellow] [red–yellow] [green]	[yellow] [yellow] [green]	[yellow] [yellow]
	*Lemna minor*	Frond area Biomass	[yellow] [yellow]	[yellow] [yellow]	[yellow] [yellow]

Significant effects compared to sec. effluent: [red] negative; [green] positive; [yellow] no effect

Neptune FP6 Project

Energy and cost for Ozon and PAC

Treatment	Dosage [mg L^{-1}]	Electrical energy [kWh m^{-3} ww]	Primary energy [kWh m^{-3} ww]	Annual Costs[c]	
				30'000 p.e. [€ m^{-3} ww]	500'000 p.e. [€ m^{-3} ww]
O_3	3[a] - 10	0.05[b] - 0.15	0.15 - 0.45	0.07[d] - 0.1	0.02[d] - 0.03
O_3 incl. sand filter	3[a] - 10	0.1 - 0.2[e]	0.3 - 0.6	0.15[d] - 0.2	0.05[d] - 0.07
PAC	10 - 20	0.005[f]	0.35 - 0.7[g]	0.15 - 0.2	0.06 - 0.08
PAC incl. sand filter	10 - 20	0.05[e,f]	0.5 - 0.8[g]	0.25 - 0.3	0.09 - 0.11

[a] Ø Operating conditions @ WWTP Regensdorf (5mg DOC L^{-1} ≅ 600g O_3 kg^{-1} DOC)

[b] Measured @ WWTP Regensdorf (production of O_3 (incl. O_2), thermal residual-O_3 destructor, control system, cooling aggregate ≅ 15kWh kg^{-1} O_3)

[c] Detailed, realistic cost study by Hunziker Ltd. (~300L c^{-1} d^{-1} ⇒ 100m^3 c^{-1} y^{-1})

[d] extrapolated from O_3 5-10mg L^{-1}

[e] Sand filter (experience from conventional treatment)

[f] Mixing (experience from conventional treatment)

[g] Primary energy consumption of PAC (no regeneration) 3.5 kg carbon needed for 1 kgPAC: 3.5kgC/kgPAC x 2.6kgCOD/kgC x 14MJ/kgCOD / 3.6MJ/kWh = 35kWh/kgPAC

Conclusions for PAC addition

- Sorption efficiency of PAC reduced with increasing DOC
- Adequate treatment of sec. effluent requires 10 - 20 gPAC/m^3 depending on DOC background concentration (5 – 10 gDOC/m^3)
- PAC dosage results in an increase of sludge production of approximately 5-10% (10-20 gPAC/m^3)
- Due to the low sorption kinetics PAC sludge age in the sludge treatment system should be above 1 day, this requires a system with PAC retention (e.g. filter, sedimentation or membrane)
- **PAC recycling into the biology clearly increases elimination efficiency due to counter flow (conc. step and DOC pre-sorption)**
- The embryo test with rainbow trouts shows a considerable developmental retardation after ozonation but not after filtration (formation of by-products that are again degraded in filtration?)
- Primary energy consumption is higher for PAC than ozon, but electrical energy for ozonation increases consumption of WWTP about 20-40%
- Investment and operation costs incl. filtration amount to 0.05-0.2 € m^{-3} for ozonation and 0.1-0.3 € m^{-3} for PAC (5-30€/p/y for 100m^3/p/y)

Thank you for your attention

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Staff of WWTP Regensdorf and Opfikon

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