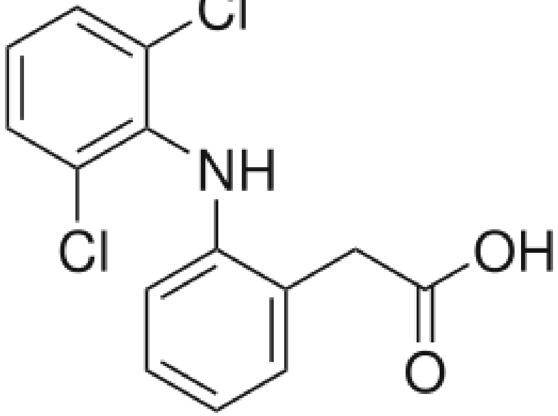
Organic micropollutant (oMP) treatment III: processes

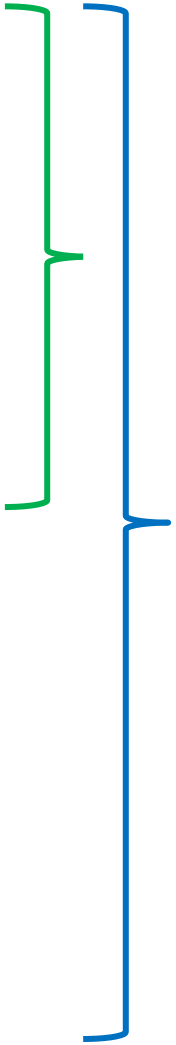
Applied wastewater engineering

Michael Jon MATTLE



Processes for oMP removal in wastewater

- biological treatment
- ozonation
- powdered activated carbon (PAC)
- granulated activated carbon (GAC)
- micro-grain activated carbon (µGAC)
- combined processes
  - ozonation and PAC
  - ozonation and GAC
- ferrate (VI)
- advanced oxidation processes (AOP)
  - Fenton reaction
  - H_2O_2 + UV
  - TiO_2 + UV
  - …
- UV
- tight membrane filtration
- …



treatment processes used/tested for **communal** wastewater treatment

treatment processes used/tested for **industrial** wastewater treatment

Processes for organic micropollutant treatment

Why are certain processes not applicable to communal wastewater

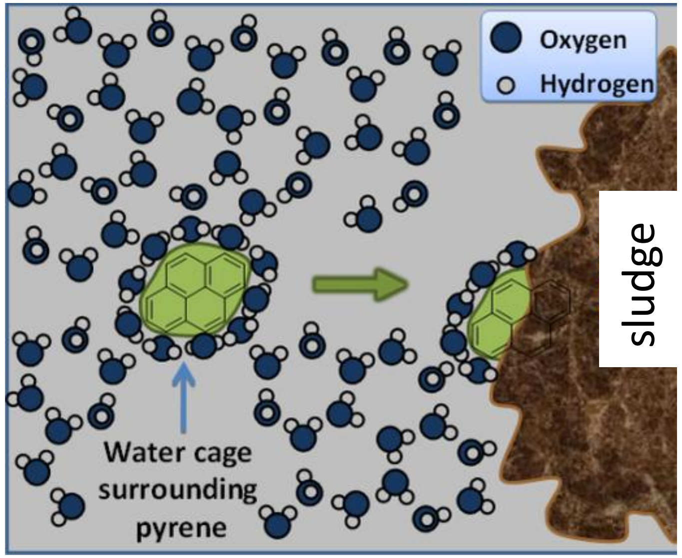
- A) the running costs are too expensive
- B) the removal of oMP is too specific (only few compounds)
- C) the production of toxic substances is too problematic
- D) the removal of oMP is too broad
- E) the footprint (surface required) of the process is too large
- F) too many substances are removed

https://web.speakup.info/room/join/26759

Biological oMP removal

- biodegradation
  - increased sludge age increases diversity of bacteria present in activated sludge
  - ➡ increased sludge age increases degradation of oMP removal by bacteria
  - ➡ nitrifying biology (sludge age > 8 – 10 days) has increased oMP removal as compared to carbon treating biology (sludge age around 4 – 5 days)

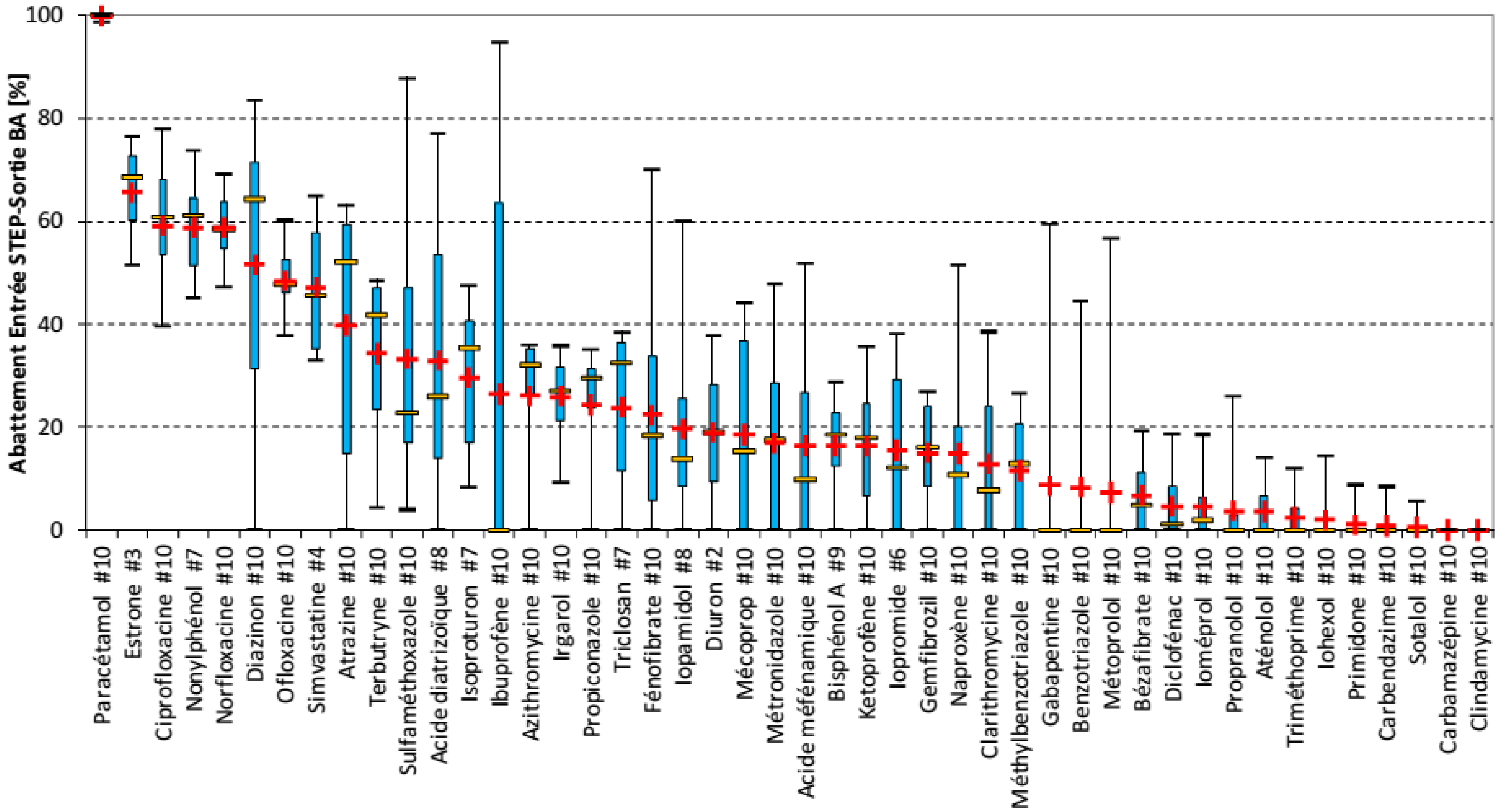
- sorption to sludge
  - a**d**sorption to surface of sludge/bacteria (typically hydrophobic substances)
  - a**b**sorption/uptake into sludge/bacteria (typically hydrophilic substances)



Biological oMP removal (low sludge age)

- non-negligible removal of oMP even with low sludge age (for most substances between 10 % to 50 % removal)
- however, clearly less than 80 % removal for almost all substances

➡ biological removal of oMP with low sludge age is rather limited

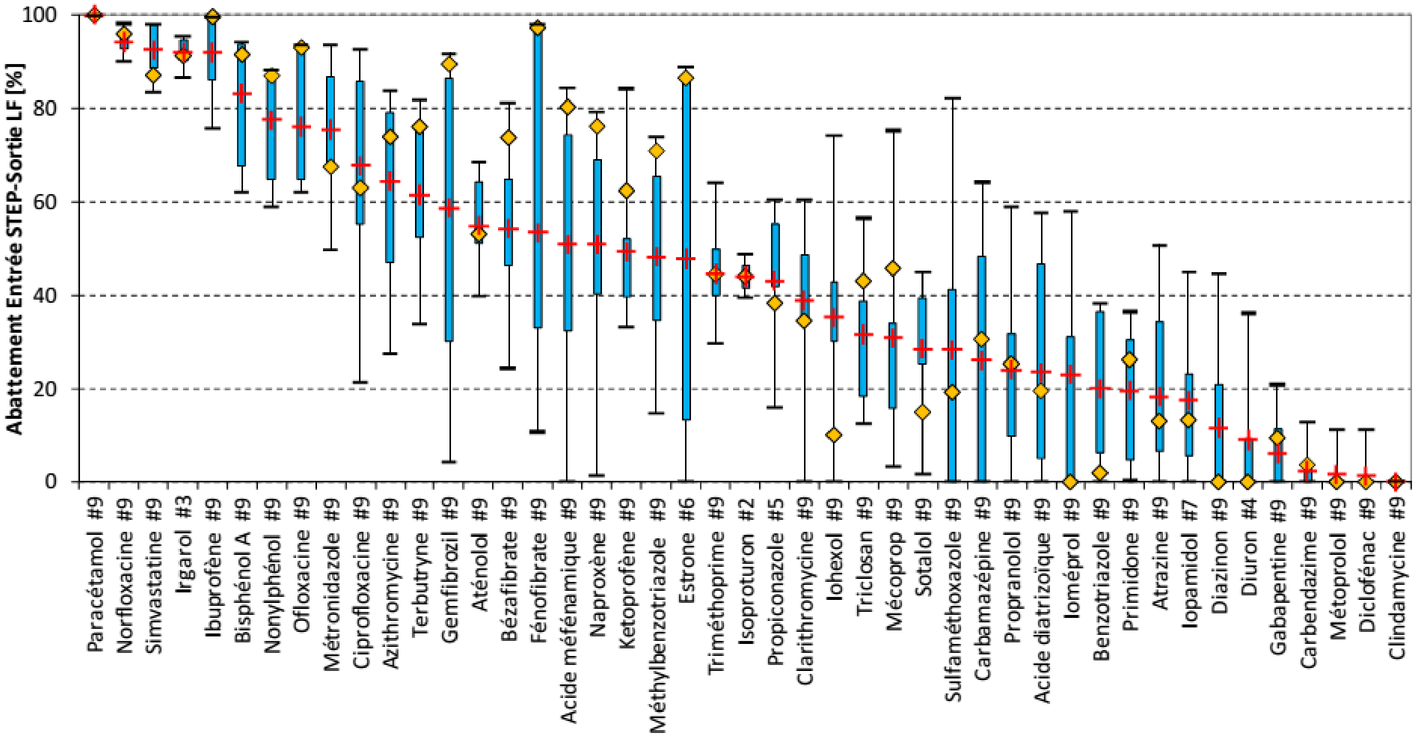


removal of oMP in a low sludge age (only carbon removal), wastewater treatment plant of Lausanne (2009)

(#) number of analyses, quartiles 25 % - 75 % (blue bars), maximum and minimum values (in black), median (-) and average value (+)

Biological oMP removal (increased sludge age)

- increased removal of oMP due to increased sludge age (nitrification): for most substances > 20 % removal
- still clearly less than 80 % removal for most substances
- biological removal of oMP with increased sludge age is important but not sufficient to reach a removal yield of 80 %



removal of oMP in a elevated sludge age (carbon removal and ammonia oxidation by moving bed biofilm reactor (MBBR), wastewater treatment plant of Lausanne (2009)

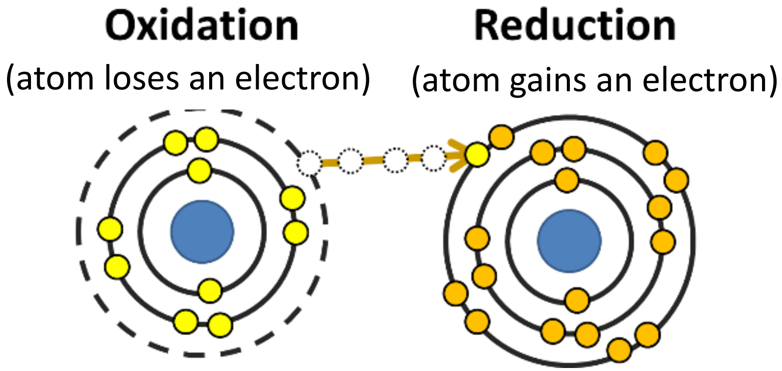
(#) number of analyses, quartiles 25 % - 75 % (blue bars), maximum and minimum values (in black), median (-) and average value (+)

Importance of efficient biological treatment/ secondary clarification for oMP unit

- removal of oMP by biological treatment reduces efficiency required of oMP treatment
- a correctly designed nitrifying biology reduces the following important parameters for oMP treatment design
  - dissolved organic carbon (DOC)
  - nitrite (NO_2^--N, toxic and reacts quickly with ozone (higher dosage required))
- a correctly designed secondary clarifier reduces the following parameters which may disturb the oMP treatment
  - total suspended solids (TSS)

➡ efficient biological treatment/secondary clarification reduces operation costs of oMP unit and potentially also the initial investment costs

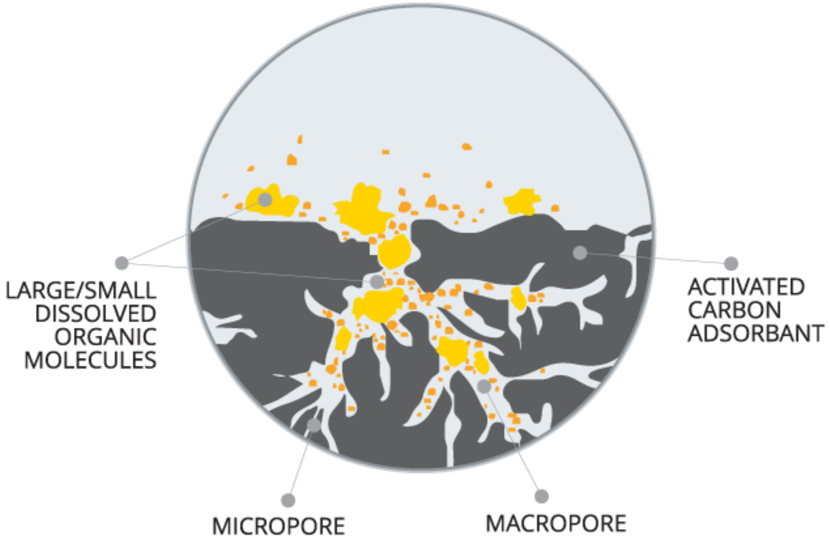
Advanced oMP removal



similarly to biological removal, advanced processes for oMP removal rely either on:

- oxidation
  - oxidation of compounds by highly reactive oxidants (e.g. ozone, hydroxyl radicals)
  - compounds are not completely removed but transformed
    - formation of oxidation products → toxicity generally lower than parent compounds
  - ozonation is the most common oxidation-based technology used for oMP treatment in communal wastewater
    - formation of ozone in gas form, injection into wastewater stream
  - other oxidation technologies are ferrate, and advanced oxidation (e.g. based on the Fenton reaction, TiO_2-UV,…)

Advanced oMP removal



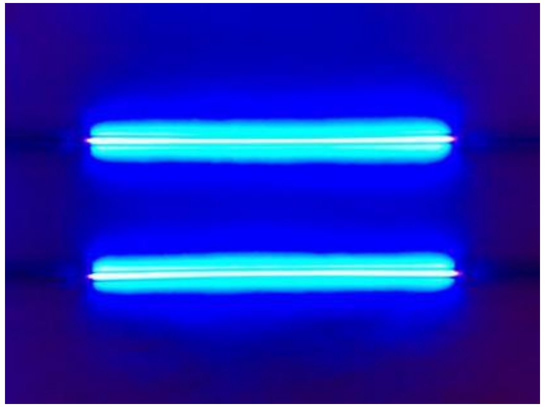
- similarly to biological removal, advanced processes for oMP removal rely on (continued):
- adsorption
  - compounds are adsorbed on highly porous materials (large surface area): activated carbon
  - compounds are adsorbed and not transformed (oxidation) → no by-product formation
  - activated carbon is brought in contact with wastewater, compounds adsorbed on activated carbon are removed while the porous material is removed from the wastewater (small fraction of activated carbon is always lost)
  - processes: powdered activated carbon (PAC), granular activated carbon (GAC), micro-grain activated carbon (µGAC)

➡ both oxidation and adsorption processes have already been used for several decades in drinking water treatment

Advanced oMP removal

further processes to remove oMP include:

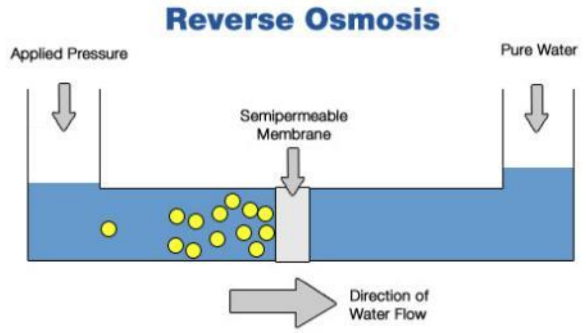
- combined processes
  - combination of activated carbon processes with ozone treatment (implemented at WWTP in Altenrhein and WWTP ProRheno in Basel)
- UV-light excitation
  - UV light may be absorbed by oMP and leads to excited molecules
  - excited molecules may decompose while reacting with other water constituents or simply return to the ground state (no reaction, but light emission)
  - as for oxidation of oMP, UV-light treatment does transform oMP but not completely decompose them (formation of transformation products)
  - technology potentially applicable to wastewaters containing few oMP (industrial wastewaters) which readily absorb UV-light and decompose afterwards



Advanced oMP removal

further processes to remove oMP include (continued):

- nano-filtration or reverse osmosis (tight membrane filtration)
  - wastewater is filtered through a very tight membrane (very small pores)
  - oMP are partially or completely retained (retentate) while most of the water crosses the membrane (permeate)
    - treatment of retentate necessary?
  - very high investment and operation costs
  - interesting technology when high effluent water quality is required (e.g. water reuse)



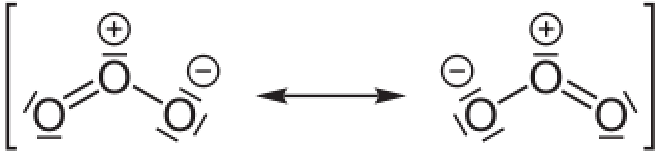
retentate permeate

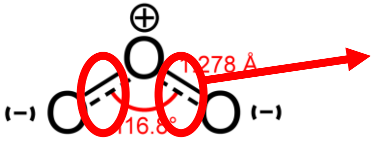
➡ ozone, processes based on activated carbon, and combination of these two technologies are so far used/planned for oMP removal of communal wastewater in Switzerland

➡ other processes are either employed for wastewater with special compositions (e.g. industrial wastewater with only one or few oMP present) or if very high effluent water quality is required (e.g. water reuse)

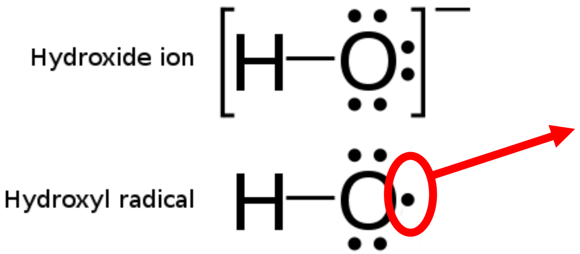
Oxidation processes

- oxidation of compounds in water is basically like burning them
- instead of using heat and oxygen, we use more reactive oxidants than oxygen (with lower activation energy)
    - ozone O_3 (selective oxidant, reacts only with certain chemical groups)
    - hydroxyl radical $\dot{}OH$(non-selective oxidant, reaction is diffusion limited with most compounds)





bond is easier to break than the O=O bond (reduced activation energy required)



radical = highly reactive

Oxidation processes

- chemical oxidation of compounds with ozone or hydroxyl radicals is rarely complete and transformation/oxidation products are formed
  - oxidation products are generally more biodegradable than their parent compounds
  - oxidation of organic micropollutants generally reduces their toxicity
  - oxidation products generally have lower reactivities than their parents compounds (reaction with ozone may stop after one/several reactions with ozone)

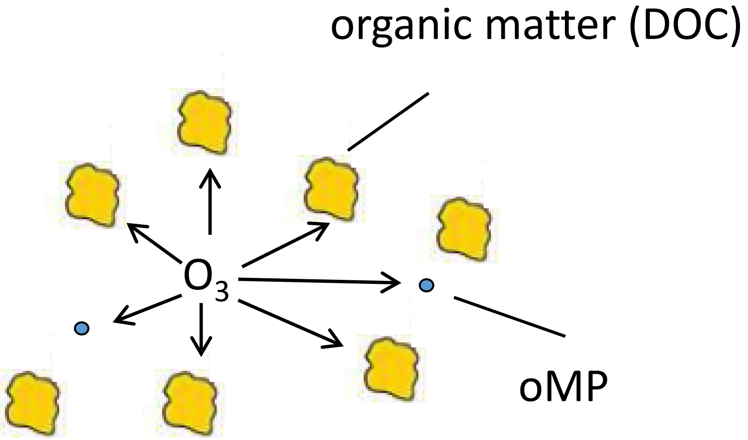
- production of ozone or hydroxyl radicals is expensive (energy, pure O_2 or chemicals)
  - biological oxidation is much cheaper (done with oxygen)

Competition between oMP and other substances present in wastewater (ozonation)

- ozone may react with
  - organic micropollutants (oxidation of organic micropollutants)
  - other substances present in wastewater (e.g. dissolved organic carbon (DOC), nitrite (NO_2^-),…)

$$O_3 + NO_2^- \rightarrow O_2 + NO_3^-$$

  - nitrite is rapidly oxidised by ozone inducing increased ozone consumption (energy consumption) of wastewater treatment plant
  - the higher the DOC and nitrite content of wastewater, the higher the ozone requirements to achieve the same organic micropollutant removal (competition reactions)



➡ the better the wastewater is treated biologically (total nitrification) and efficiently clarified, the higher the efficiency of the organic micropollutant removal process and the lower the ozone requirements

➡ ozone added to wastewater is generally expressed as g O_3/g DOC (dissolved organic carbon), as DOC is the main ozone consumer in wastewater

Oxidation processes

$$\frac{dc_{compound}}{dt} = -k_{compound,oxidant} c_{compound} c_{oxidant}$$

reaction rate constant [$M^{-1}s^{-1}$]

- the higher the reaction rate constant, the faster the degradation of the compound
- the reaction rate constant may be pH dependent (protonation state of organic micropollutant)
- reaction rate constants with ozone: highly variable for different compounds
- reaction rate constants with hydroxyl radicals: low variability for different compounds

$$\ln\left(\frac{c_{compound,i}}{c_{compound,f}}\right) = k_{compound,oxidant} \underbrace{c_{oxidant} t}$$

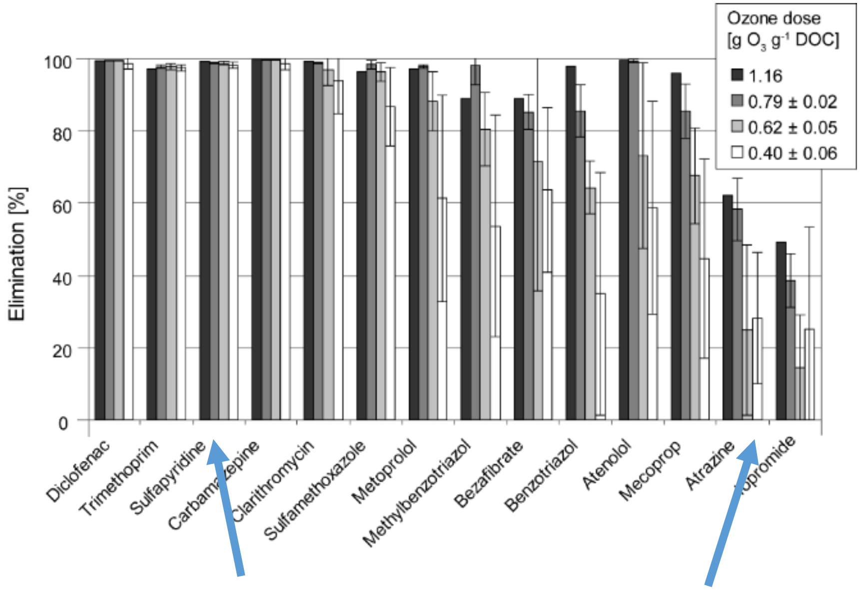
oxidant dose (the higher the dose, the lower the final concentration of the compound)

Oxidation processes (hydroxyl radicals)

- hydroxyl radicals ($\dot{O}H$) can be produced by advanced oxidation processes (AOP):
- e.g. the Fenton reaction

$$Fe(II) + H_2O_2 \rightarrow Fe(III) + OH^- + \dot{O}H$$

- but hydroxyl radicals are also formed during the ozonation process via the reaction of ozone with organic matter present in wastewater
  - hydroxyl radicals are very reactive, therefore their concentration in wastewater is always very low
  - production of hydroxyl radicals during ozonation explains the degradation of compounds that do not react (or react extremely slowly) with ozone

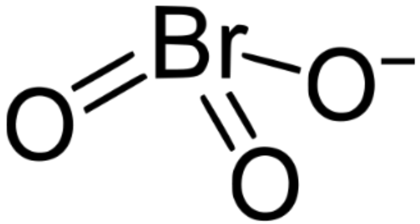


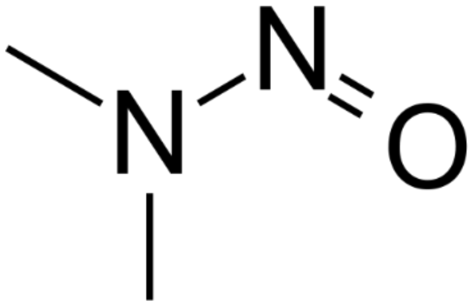
mainly O_3

mainly $\dot{O}H$

Oxidation by-products

- as in drinking water treatment, oxidation with ozone generates oxidation by-products some of which are toxic
- the following compounds are known for their toxicity
  - bromate (oxidation product of bromide)
    - potential human carcinogen
    - biological removal possible only under anaerobic conditions
    - Swiss tolerance value for drinking water: 10 µg/L
  - NDMA (*N*-Nitrosodimethylamine)
    - potential human carcinogen
    - biological removal under aerobic conditions
    - sand filtration following an ozonation removes part of the NDMA formed during ozonation (aerobic degradation)
    - WHO guideline: 0.1 µg/L

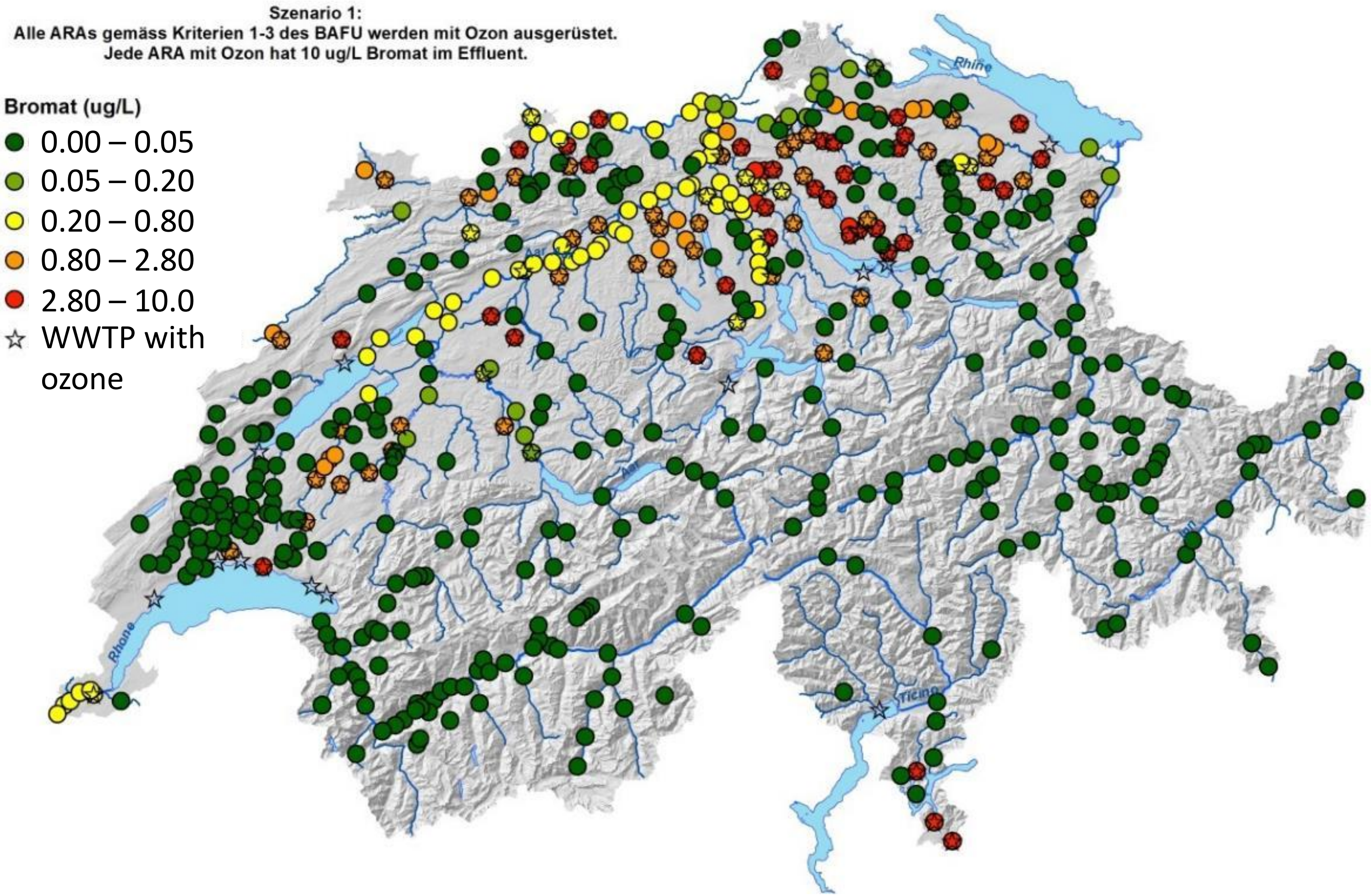




➡ conduct trials at lab-scale to verify that these compounds are not formed at elevated concentrations

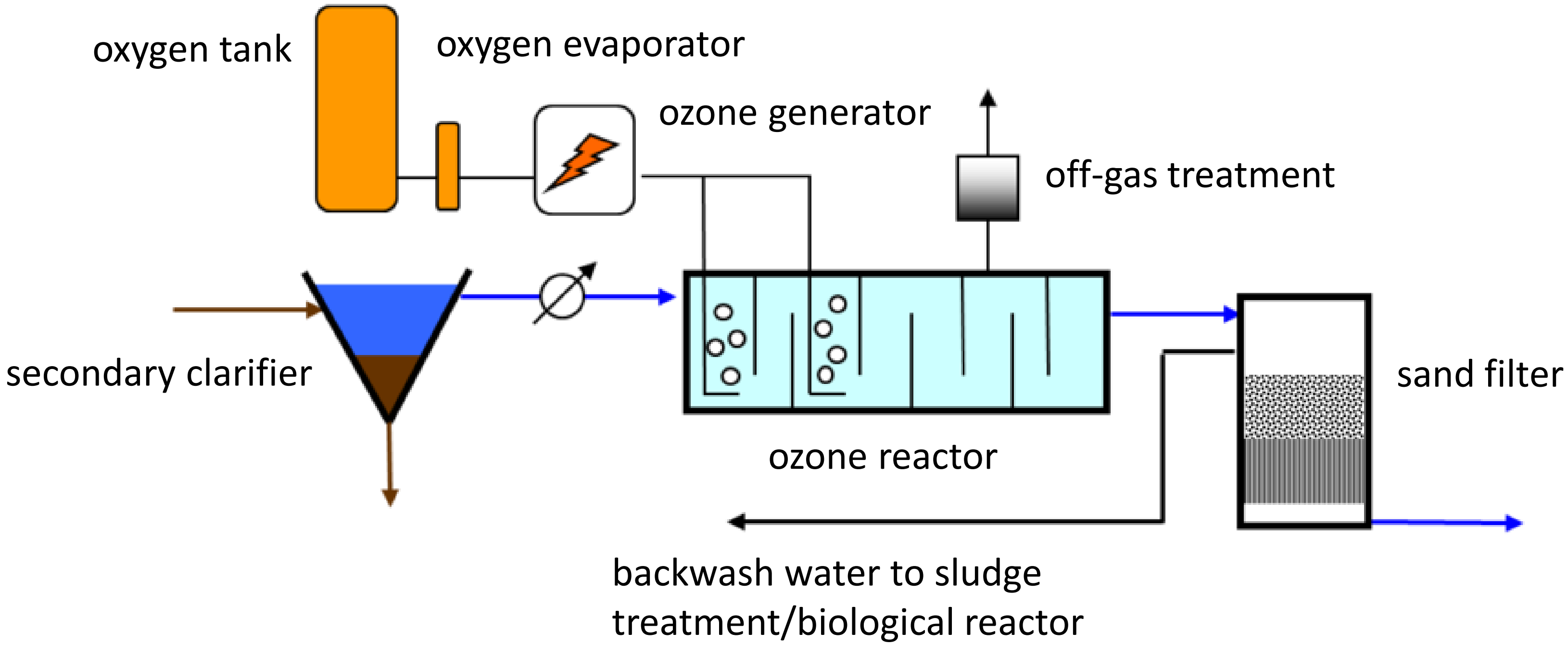
Oxidation by-products

- computed bromate concentrations in Swiss rivers
    - if all wastewater treatment plants (criteria 1-3) were equipped with an ozonation (10 µg/L in the effluent)
- concentrations remain low in most rivers (below 1 µg/L)
- certain river waters would contain high bromates concentrations



Oxidation-based methods (ozonation)

- ozone is generated from oxygen (pure oxygen is either purchased and transported to wastewater treatment plants or produced on site (only interesting for large installations))
- ozone is brought in contact with biologically treated wastewater
  - ozone reacts directly (ozone: O_3) or indirectly (hydroxyl radical: $OH^{\cdot}$) with organic micropollutants and other substances
- off-gas has to be treated (ozone is a toxic gas)
- ozonated wastewater is sand filtered (biological activity removes certain oxidation by-products)



Ozone injection required

- ozone quantity necessary to achieve the required yield:

$$x\left[\frac{kg_{O_3}}{kg_{DOC,sec.\,clarified\;wastewater}}\right]kg_{DOC,sec.\,clarified\;wastewater}$$

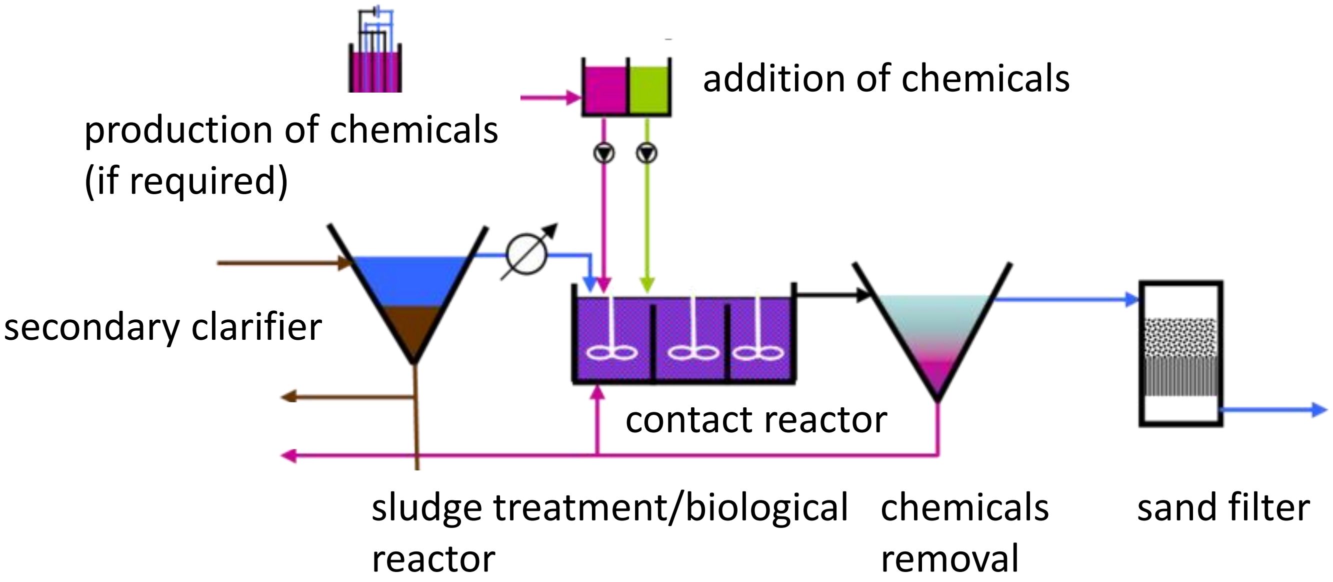
$$+3.43\left[\frac{kg_{O_3}}{kg_{NO_2^--N,sec.\,clarified\;wastewater}}\right]kg_{NO_2^--N,sec.\,clarified\;wastewater}$$

- *x* depends on the reactivity of the dissolved organic carbon (DOC)
  - *x* = 0.8 are sufficient to achieve 80 % removal over the entire WWTP
  - lower values have been obtained after optimisation at WWTP Neugut in Dübendorf (0.33 – 0.50 g O_3/g DOC)
  - determine *x* in laboratory experiments

➡ nitrite (NO_2^-) reacts very quickly with ozone, an entire conversion to nitrate can be assumed

Oxidation-based methods (ferrate treatment or advanced oxidation)

- biologically-treated wastewater enters contact reactor
- chemical(s) are dosed into contact reactor (e.g. ferrate)
    - oxidants react directly or indirectly with organic micropollutants and other substances
- chemicals are separated from wastewater
- wastewater is sand filtered (biological activity removes certain oxidation by-products)



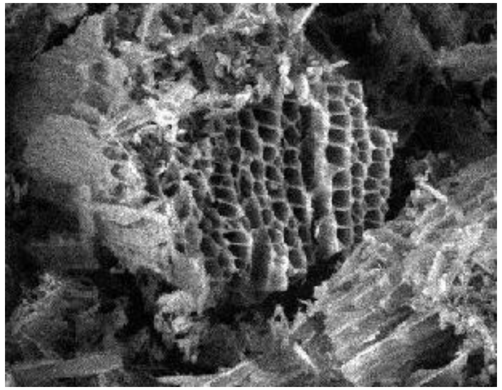
Adsorption by activated carbon

- activated carbon has an extremely high surface (500 – 1500 m^2/g)

10 g

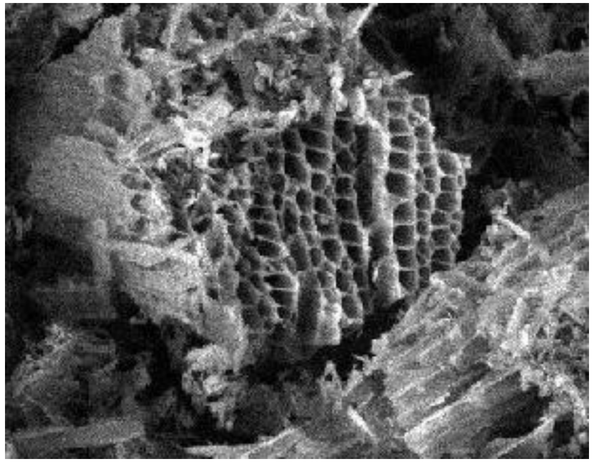
≈ surface of

- about 10 g of activated carbon has a surface of a football field!



- activated carbon is classified in different categories:
  - powdered activated carbon (PAC: ≈ 5 to ≈ 50 µm)
  - granular activated carbon (GAC: ≈ 100 to ≈ 2’400 µm)
  - micro-grain granular activated carbon (µGAC: ≈ 200 to ≈ 900 µm)

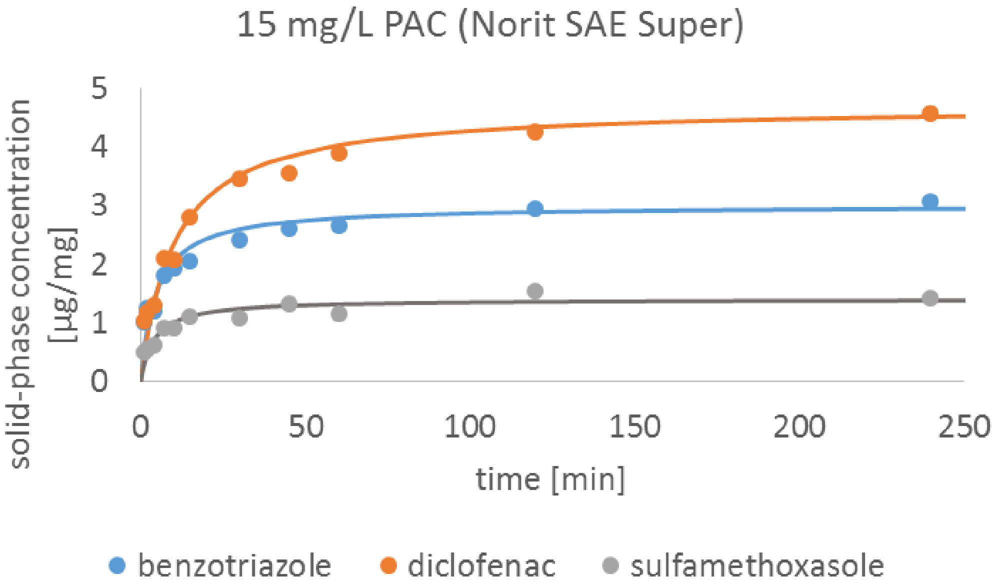
Adsorption by activated carbon

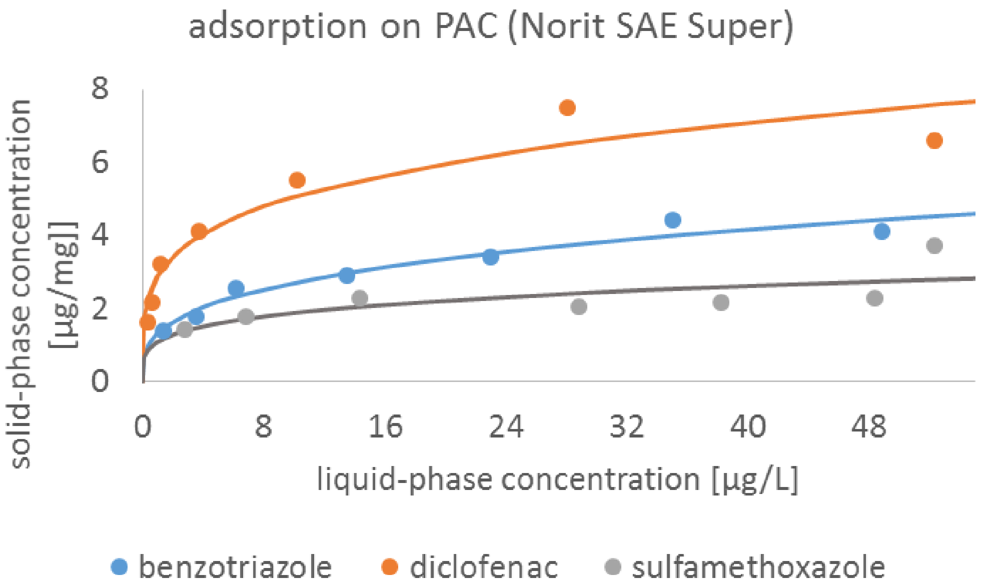


- activated carbon is derived from an organic base material: e.g. wood, coal, coconuts, almond, or walnut hulls
- pyrolysis of raw material (thermochemical decomposition at elevated temperatures in the absence of oxygen): production of elemental carbon
- followed by an activation process
  - either by exposure to oxidising gases such as steam and CO_2 at high temperatures
  - or by chemical activation with phosphoric acid at high temperatures
- the raw material and the activation process both have an influence on the pore sizes of the final material

  ➡ there are many different products of activated carbon on the market with highly variable specific surfaces areas (m^2/g), pore sizes, adsorption capacities and prizes
- Production of activated carbon requires resources (raw material, energy and chemicals) and its elimination generates CO_2

Adsorption of oMP on activated carbon





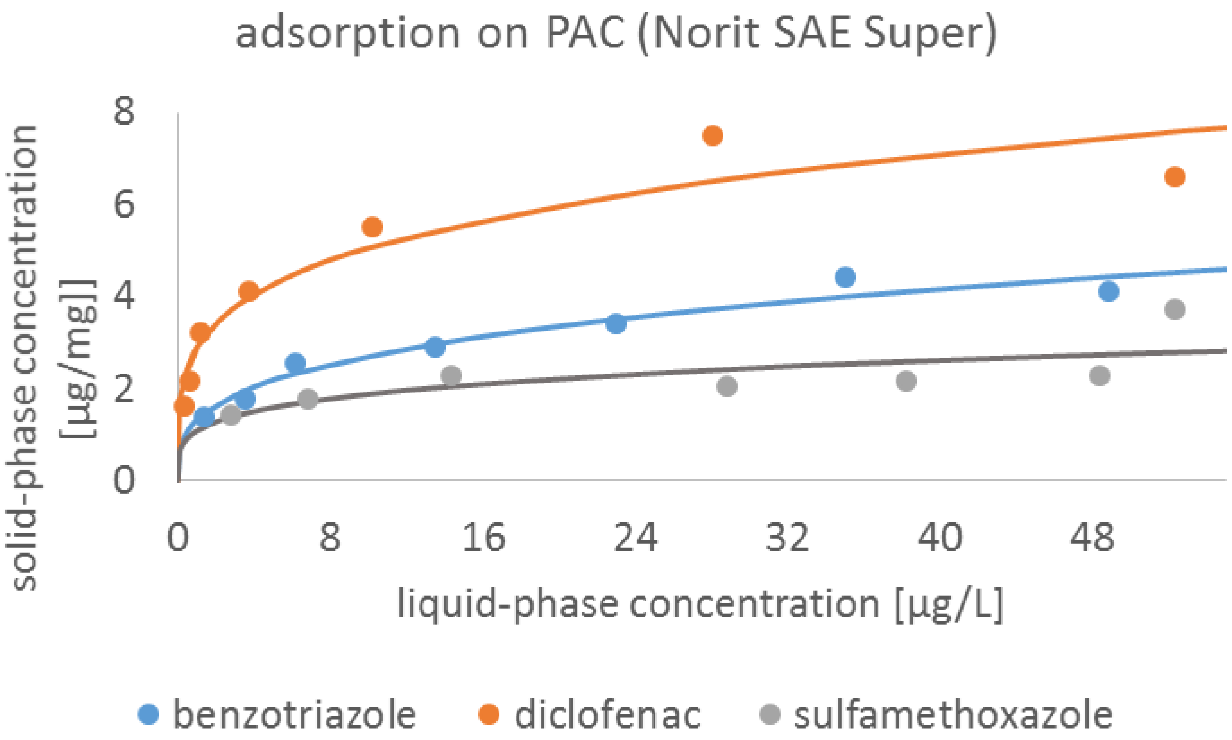
- adsorption of three oMP on a superfine PAC (Norit SAE Super) over time
- adsorption efficiency on PAC (Norit SAE Super): diclofenac > benzotriazole > sulfamethoxasole
- concentration in liquid-phase decreases with time (until equilibrium)

→ concentration on solid-phase increases with time (until equilibrium)

Adsorption isotherm of oMP on activated carbon

- each curve (adsorption curve over time) generates one point (at equilibrium) on the adsorption isotherm (see figure)
- a certain liquid-phase concentration corresponds to a certain solid-phase concentration
- the higher the liquid-phase concentration, the higher the solid phase concentration

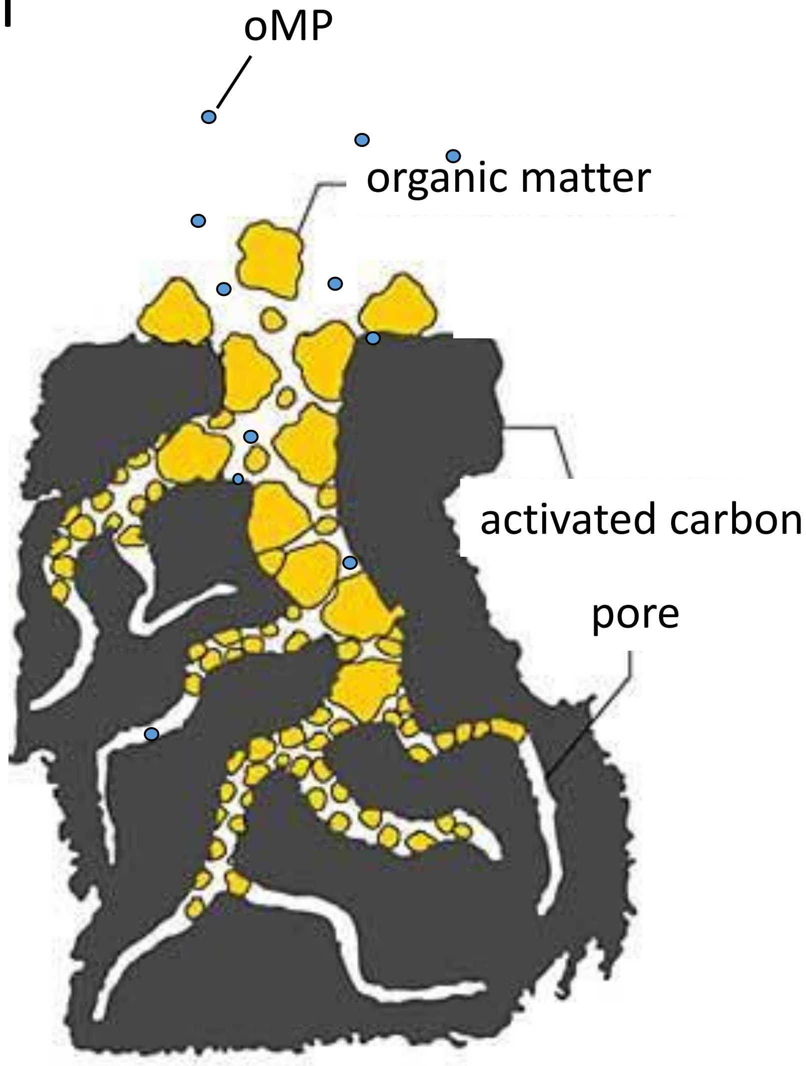
→ the lower the final liquid-concentration required, the higher the activated carbon concentration required



Competition between organic micropollutants and other substances present in wastewater

- activated carbon has activated sites which may be occupied by
  - organic micropollutants (removal of organic micropollutants)
  - other substances present in wastewater (e.g. dissolved organic carbon (DOC) or small particles)
  - the higher the DOC-content of wastewater, the less efficient the organic micropollutant removal (competition for adsorption sites)

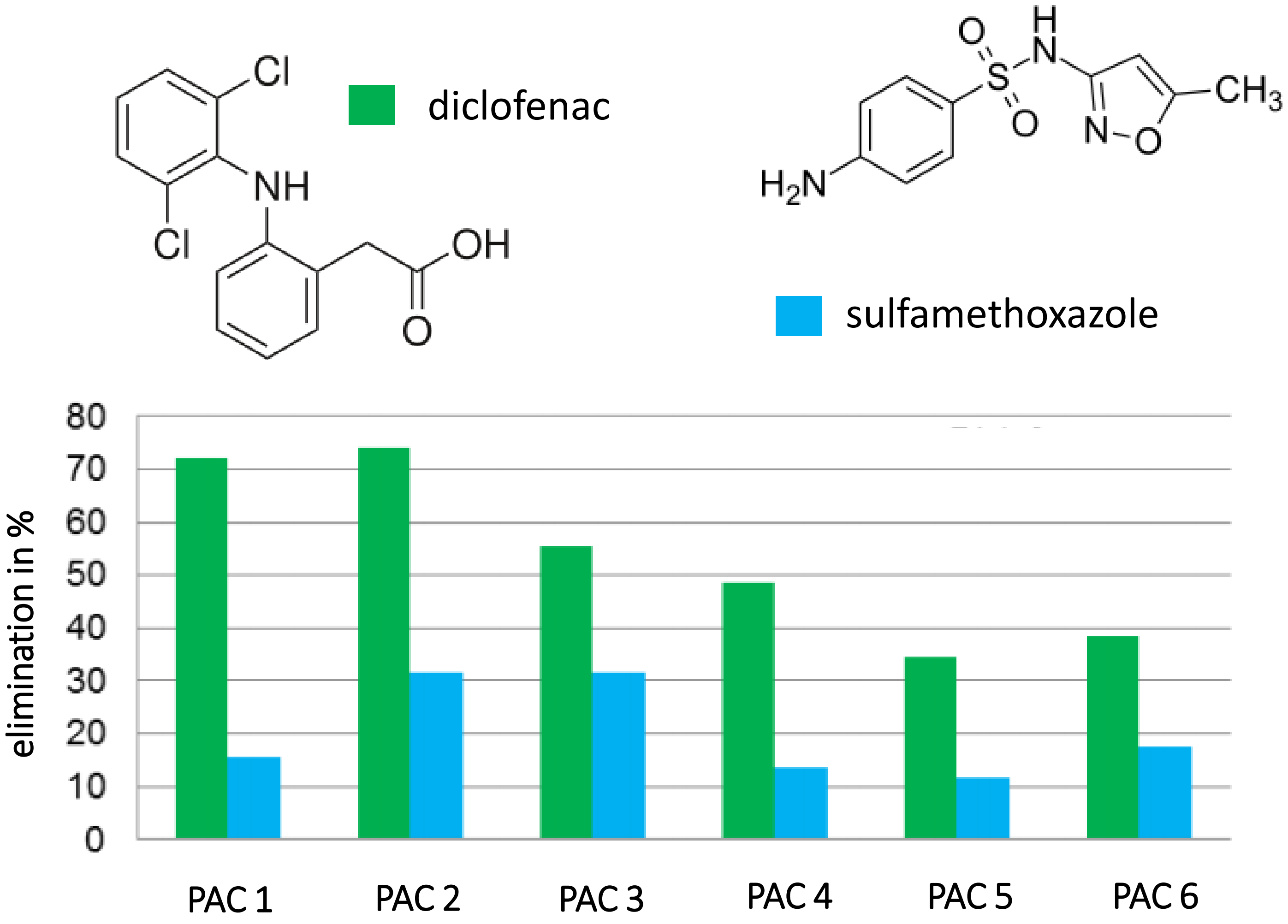
→ the better the wastewater is treated biologically and efficiently clarified, the higher the efficiency of the organic micropollutant removal process and the lower the activated carbon requirements to achieve the same removal yield of organic micropollutants



Adsorption of oMP by activated carbon

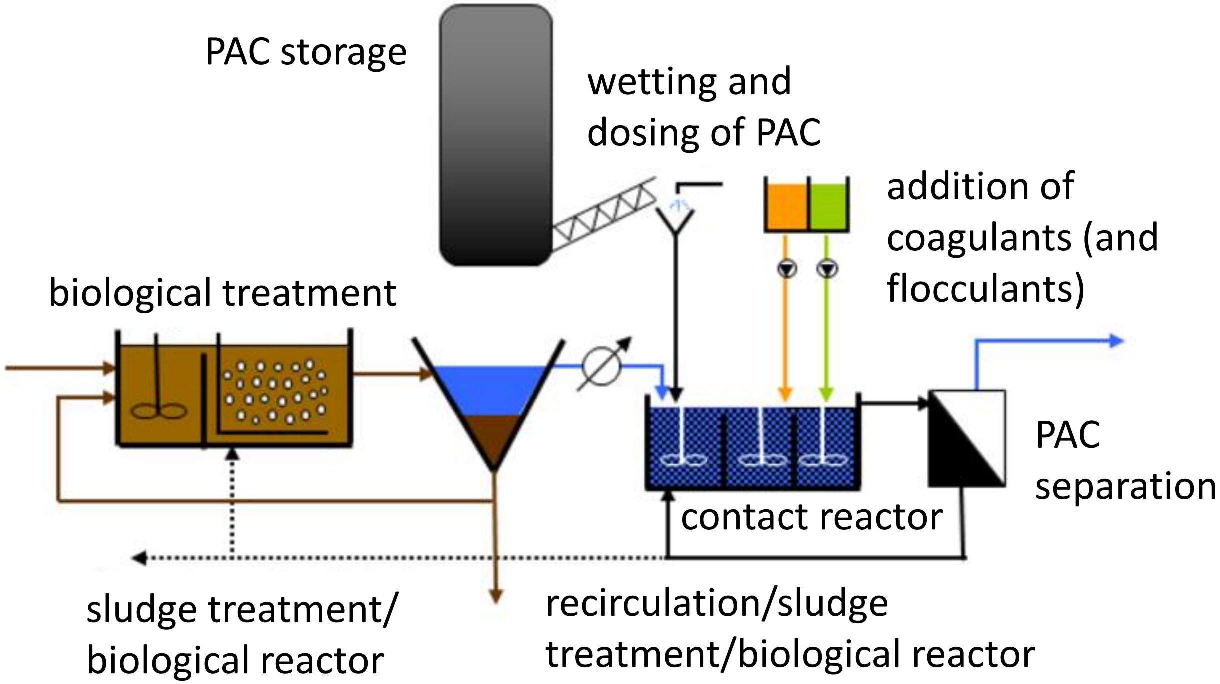
- adsorption is highly variable
  - depending on organic micropollutants
  - depending on activated carbon material
  - depending on wastewater matrix (e.g. DOC concentration, temperature, pH,…)

➡ initial laboratory tests should be conducted to determine the ideal activated carbon (prize versus adsorption efficiency) for each WWTP



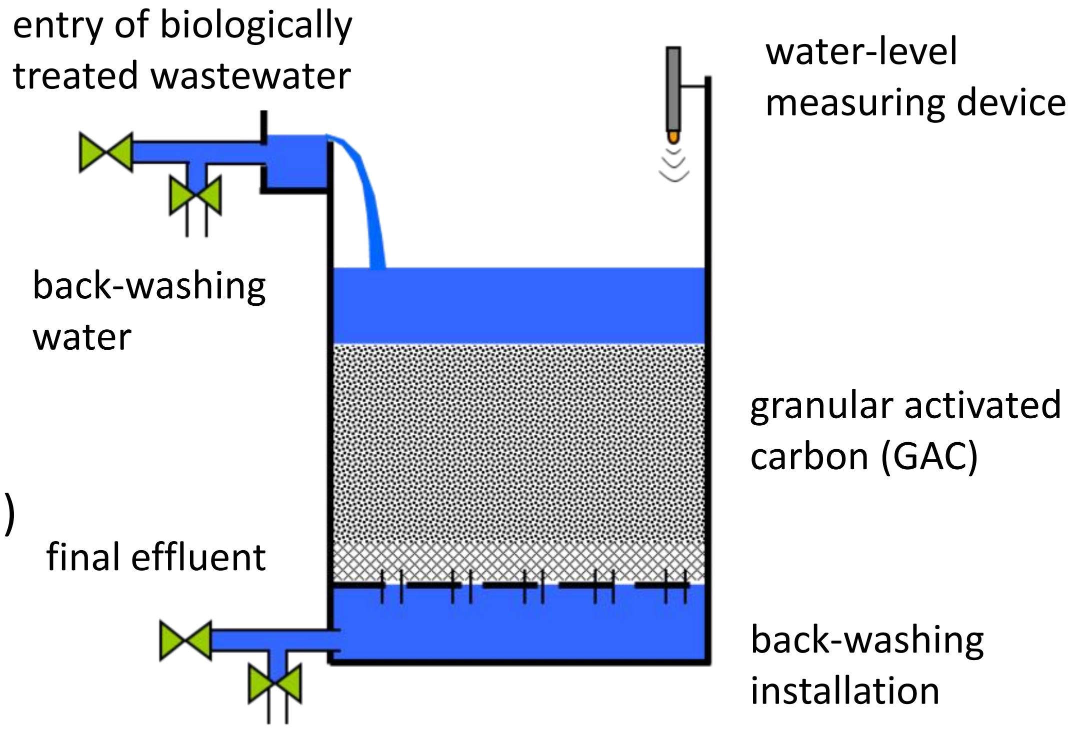
Processes using powdered activated carbon

- powdered activated carbon (PAC) is transported to the wastewater treatment plant
- PAC is put into water (wetting process)
- PAC is added to the contact reactor (can be biological tank)
- coagulants (metal salts (and potentially polymers) are added to help coagulante/flocculate the PAC
- PAC is separated from wastewater:
  - sedimentation (Ulmer-process)
  - sand filtration
  - membrane filtration
- sand filter assures no PAC losses (e.g. at high flowrates)
- PAC is removed or recycled
  - introduced to biological tank (activated sludge treatment: enhanced organic micropollutant removal)
  - otherwise removed via sludge treatment or separate evacuation line (large installations)



Activated carbon-based processes (GAC, powder or micro-grain activated carbon)

- activated carbon is transported to the wastewater treatment plant
- organic micropollutants are removed in a filter bed
  - fixed-bed like a sand filter (GAC)
  - fluidised-bed kept in suspension due to flow of wastewater (µGAC)
  - fluidised-bed kept in suspension due water pulses (PAC)
- backwashing periodically required for GAC-filters
- optional sand filter
  - assures no PAC/µGAC or losses (e.g. at high flowrates)
- activated carbon is removed and may be regenerated
  - saturated activated carbon is removed and can be regenerated (only for GAC and µGAC) to be reused



Summary of oMP removal processes

- adsorption processes
  - activated carbon has to be transported to wastewater treatment plant
  - activated carbon is brought into contact with biologically-treated wastewater either in contact tanks (PAC) or in filter beds (GAC, micro-grain/powdered activated carbon)
  - organic micropollutants are removed from wastewater by adsorption processes
  - activated carbon is separated from wastewater (powdered activated carbon)
  - activated carbon is dosed into activated sludge treatment (PAC) or regenerated (GAC or micro-grain activated carbon) or evacuated (sludge treatment or separated treatment)

Summary of oMP removal processes

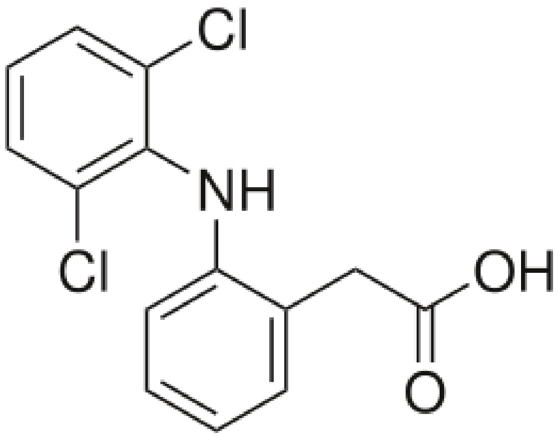
oxidation processes

- oxidant is generated (if required) and brought into contact with biologically treated wastewater
- oxidants react with oMP in contact reactor (oxidation of oMP)
- no complete oxidation but transformation of oMP occurs (oxidation by-products)
- off-gas is treated (ozonation) or chemicals are separated from wastewater (ferrate treatment or advanced oxidation)
- a biologically active sand filter removes certain oxidation by-products

Organic micropollutant (oMP) treatment IV: plants in operation

Applied wastewater engineering

Michael Jon MATTLE

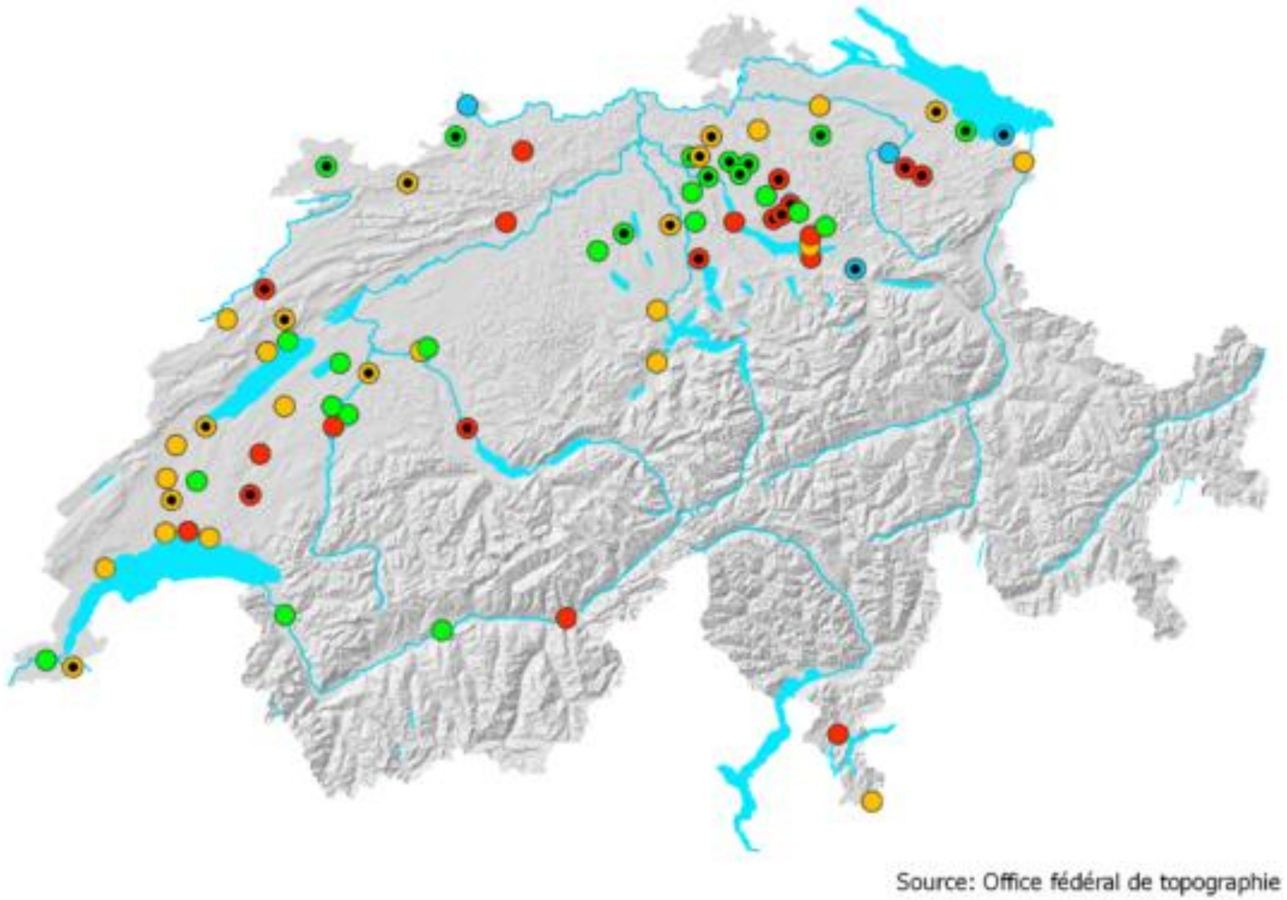


Where are we currently in Switzerland

○ in planning/ under construction

◉ constructed

- ozone
- powdered activated carbon
- granulated or micro-grain activated carbon
- combined processes



Source: Office fédéral de topographie

image taken from webpage: https://www.micropoll.ch/fr

First ozonation of communal wastewater in Switzerland

○ in planning/ under construction
◉ constructed

- ozone
- powdered activated carbon
- granulated or micro-grain activated carbon
- combined processes

wastewater treatment plant Neugut, Dübendorf (Canton of Zürich)

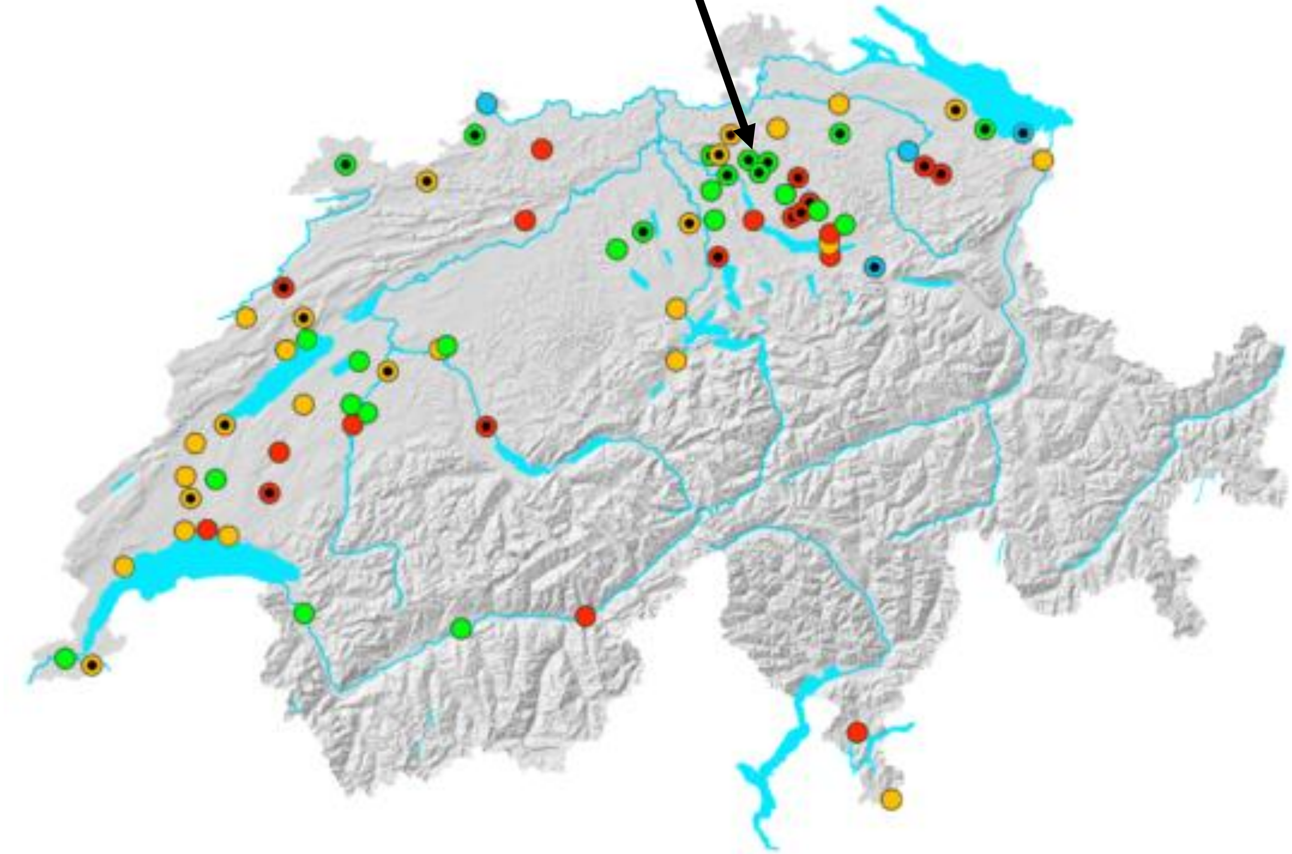


image taken from webpage: https://www.micropoll.ch/fr

First ozonation of communal wastewater in Switzerland (WWTP Neugut in Dübendorf)

- large fraction of industrial wastewater (mainly food industries):
- 50’000 inhabitants + commuters
- 55’000 population equivalents (industries)
- capacity of wastewater treatment plant: 150’000 PE
  - large industrial fraction does not necessarily mean difficulties with the ozonation process

- wastewater treatment train:
  - activated sludge treatment (C + N + bio-P)
  - ozonation
  - sand filtration (existed previously to construction of ozone contactor)

ARA Neugut
Dübendorf, Switzerland

BARRY CALLEBAUT

Givaudan

Secondary clarified wastewater of WWTP Neugut

ARA Neugut
Dübendorf, Switzerland

wastewater quantities	
$Q_{average}$	200 L/s
Q_{min}	80 L/s
Q_{max} (rainy weather)	660 L/s

high phosphorous removal (partially done biologically: bio-P)

very efficient nitrification

efficient secondary clarifier

efficient carbon removal

average pollutant concentrations (entry ozone contactor) of 2014			
pH	7.4	Ptot	0.3 mg/L
TSS	3 mg/L	NH_4-N	0.08 mg/L
DOC	5 mg/L	NO_2-N	0.03 mg/L
COD	16 mg/L	Br^-	60 µg/L
BOD_5	5 mg/L	temperature	18 (13 – 23) °C

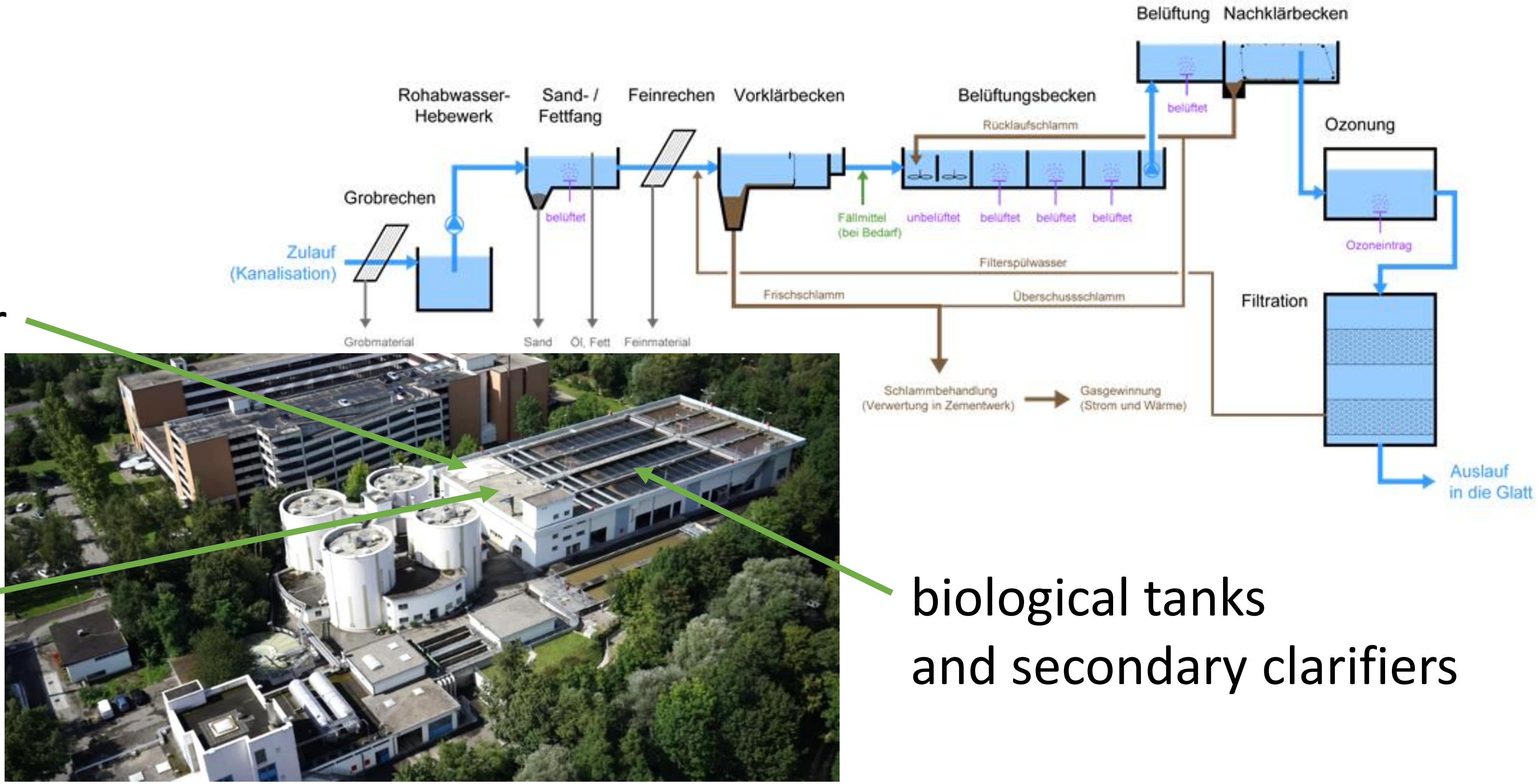
‘normal’ bromide content (salt: cannot be removed by biological treatment)

- highly efficient ‘conventional treatment’

➡ very low average concentrations of pollutants.
However, ozonation must also work properly with wastewater containing higher pollutant concentrations (daily, weekly and monthly variations)

First ozonation of communal wastewater in Switzerland (WWTP Neugut in Dübendorf)

ARA Neugut
Dübendorf, Switzerland



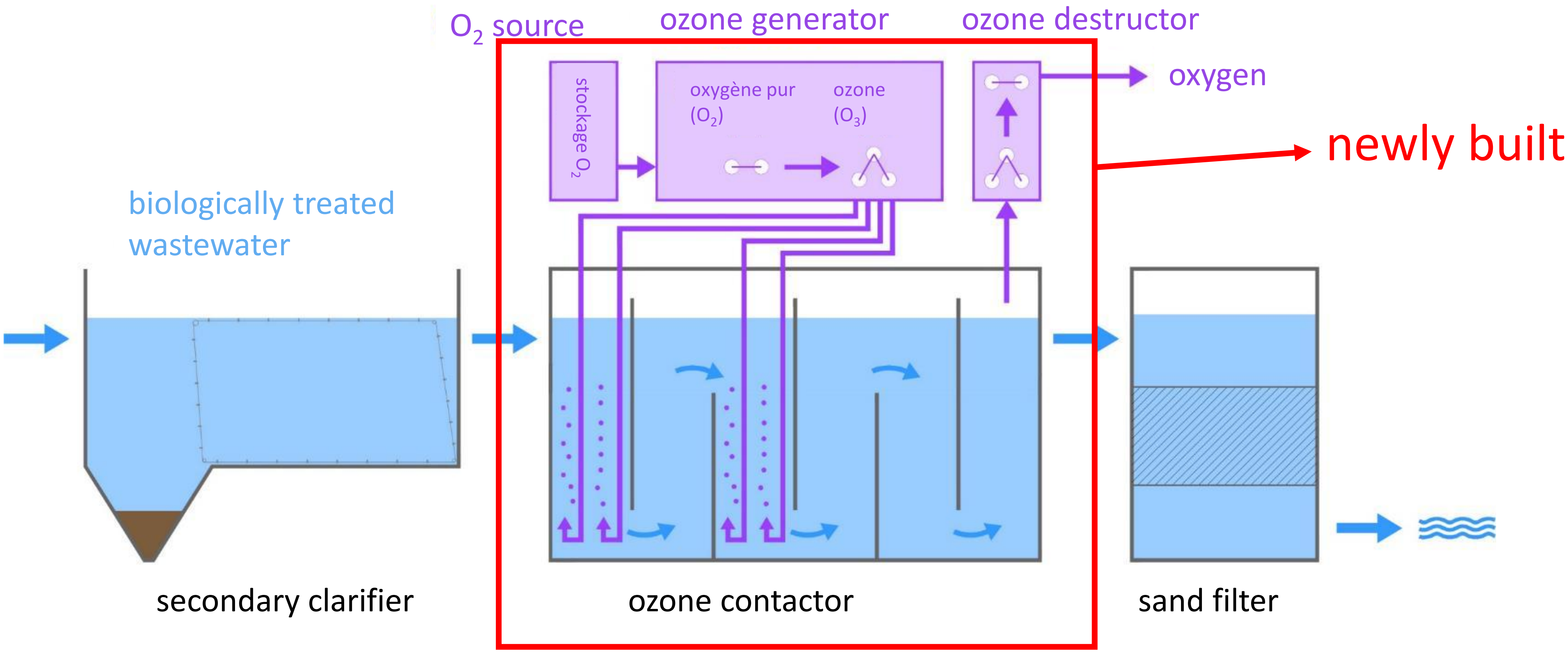
ozone contactor

sand filter
(pre-existing)

biological tanks
and secondary clarifiers

First ozonation of communal wastewater in Switzerland (WWTP Neugut in Dübendorf)

ARA Neugut
Dübendorf, Switzerland



Ozone generation

ARA Neugut
Dübendorf, Switzerland

- ozone is generated from pure oxygen at WWTP Neugut
  - pure oxygen (liquid form) is transported to site
  - oxygen is stored on-site
  - security measures due to oxygen storage (oxygen is an oxidising liquid)

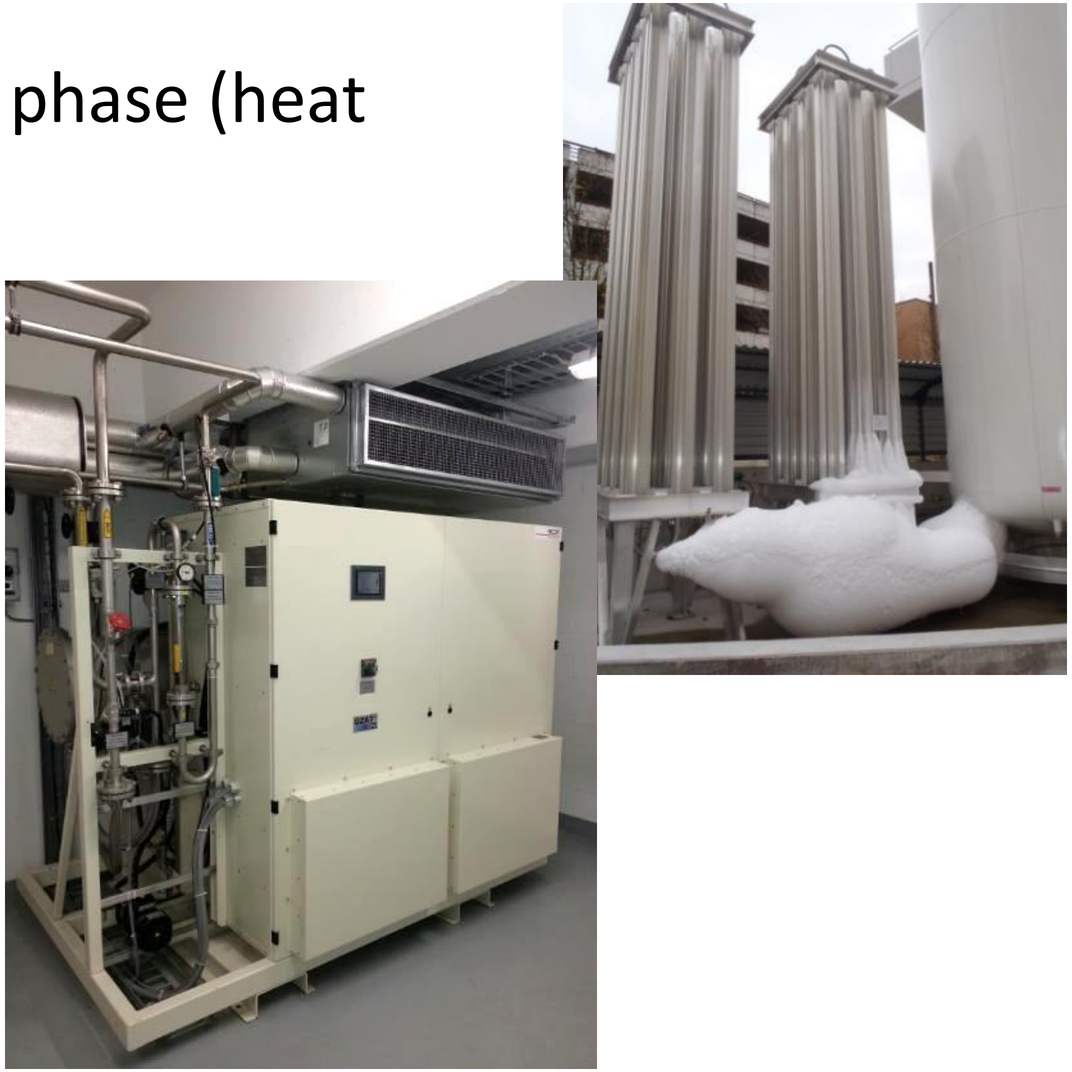
- ozone can also be generated directly with air
  - no transport nor storage of oxygen on site
  - less efficient ozone generation → higher energy consumption
  - potentially interesting for small installations (low ozone consumption)
- pure oxygen can also be generated on-site
  - no transport of pure oxygen
  - relatively complex process to manage
  - only interesting for large installations (high ozone requirements)

oxygen supply to oxygen storage tank

Ozone generation

ARA Neugut
Dübendorf, Switzerland

- pure liquid oxygen is evaporated → gas phase (heat consumption)
- ozone is generated by electrical discharge (WWTP Neugut)
  - 6 – 12 % ozone (if pure oxygen is used)
  - 1 – 5 % ozone (if air is used)
- ozone can also be generated by UV light (technology sometimes used for laboratory equipment)



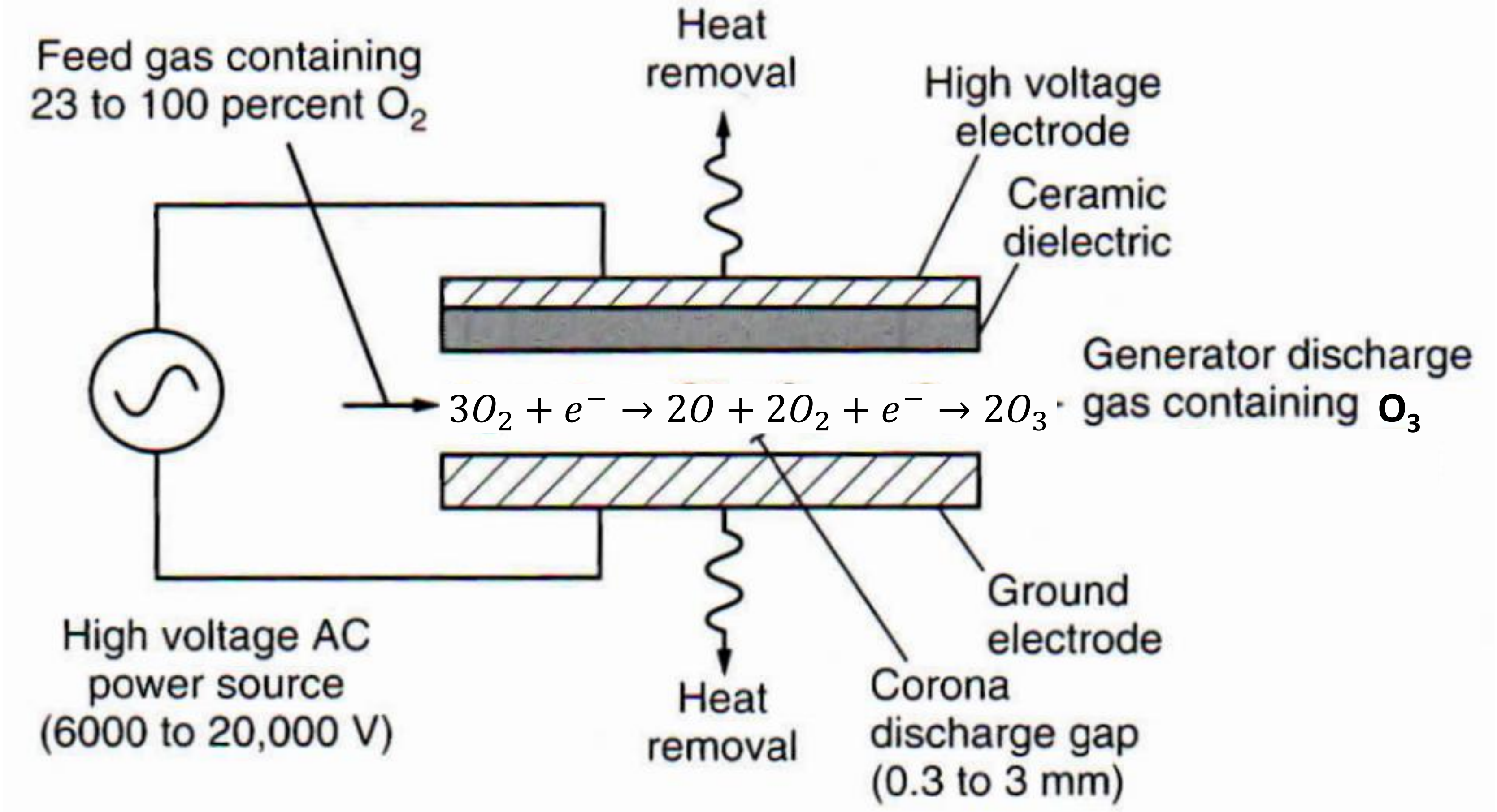
Ozone generation (electrical discharge)

- electrical discharge splits oxygen diatoms (O_2)

$$3O_2 + e^-(kinetic\ energy) \rightarrow 2O + e^-\ (reduced\ kinetic\ energy)$$

- oxygen atom (O) reacts with dioxygen (O_2) to form ozone (O_3)

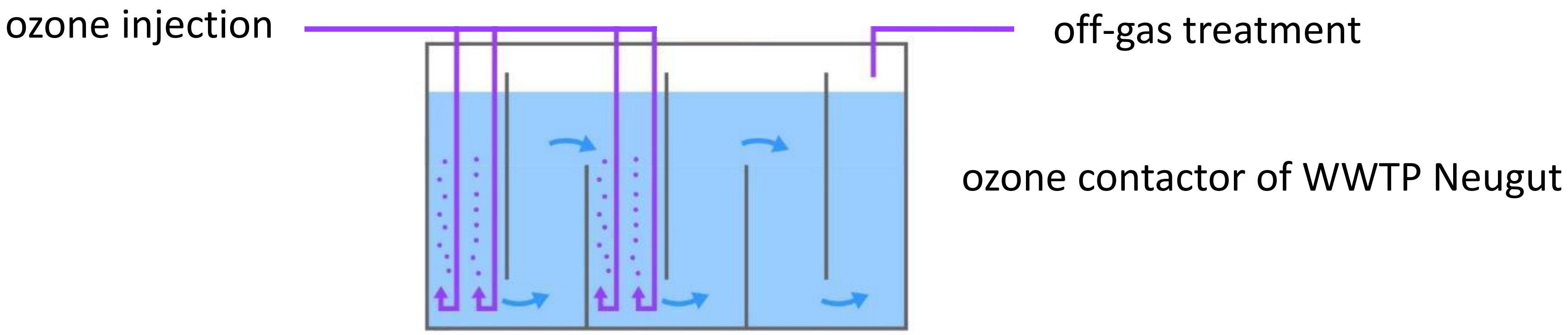
- ozone is not stable (highly reactive, low half-life) and has to be used immediately
- hence, ozone has to be produced on site



$$3O_2 + e^- \rightarrow 2O + 2O_2 + e^- \rightarrow 2O_3$$

Ozone contactor of WWTP Neugut

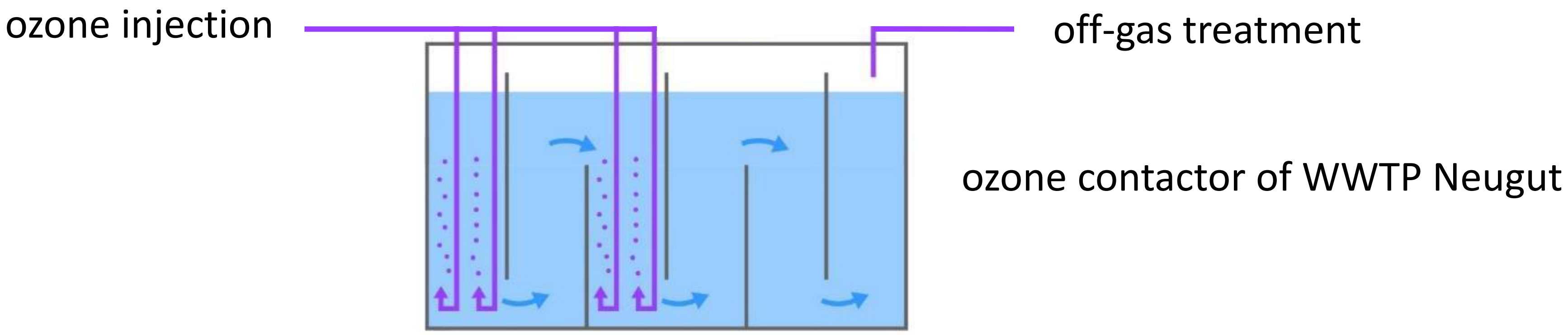
ARA Neugut
Dübendorf, Switzerland



- two ozone injection chambers (wastewater flowing downwards, ozone bubbling upwards)
  - ozone is introduced into wastewater as O_2/O_3 gas
  - ozone dissolves in wastewater and starts to react with organic micropollutants and other wastewater constituents
  - plug flow of wastewater partially disturbed due to gas introduction
- reaction chamber after each injection chamber
  - ozone continues to react with organic micropollutants and other wastewater constituents (ozone concentration reduces)
  - plug flow of wastewater (no gas introduction)

Ozone contactor of WWTP Neugut

ARA Neugut
Dübendorf, Switzerland



- final reaction chamber
  - permits further reduction of organic micropollutants if ozone is still present in wastewater (high flowrates: e.g. rain events)
  - permits, if sufficiently large, complete consumption of ozone (it is a highly irritating and toxic gas)
  - if ozone is still present at the end of the contactor, addition of a reducing agent (e.g. sodium sulphite salt (Na_2SO_3)) is required to completely consume it:

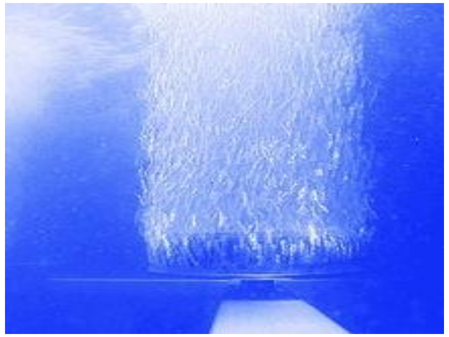
$$SO_3^{2-} + O_3 \rightarrow SO_4^{2-} + O_2$$

Ozone contactor of WWTP Neugut

ARA Neugut
Dübendorf, Switzerland


next chamber

ozone injection chamber with ceramic diffusors




- ceramic diffusors (resistant to ozone) permit the introduction of fine O_2/O_3 bubbles
- **injection chambers** need to be relatively deep for efficient ozone transfer: from gas to dissolved phase (chambers in Neugut are **6 m high**)

Off-gas treatment

- ozone is a highly irritating and toxic gas

➡ ozone has to be destroyed before the off-gas can be released from the wastewater treatment plant

- different techniques are employed to destroy ozone in the gas phase
  - thermal treatment: heating of gas (≈ 400°C) reduces half-life of ozone dramatically
  - catalytic destruction: catalyst (metal oxides) reduces half-life of ozone without substantial heating
    - slight heating is required to remove humidity and prevent condensation on catalyst
  - semi-catalytic destruction of ozone via activated carbon
    - these filters are generally only used in small installations (low gas flow and/or low ozone content)

Construction of ozone contactor

ARA **Neugut**
Dübendorf, Switzerland

ozone contactor (space was initially allocated for an additional sand filter)

anaerobic digester

ozone contactor during construction

Construction of ozone contactor

ARA Neugut
Dübendorf, Switzerland

only limited space was available during construction of ozone contactor (concrete wall construction)

behind the wall:

- sand filters
- ozone contactor

digester

Rapid sand filters of WWTP Neugut

ARA Neugut
Dübendorf, Switzerland

- pre-existing rapid sand filters
  - biological activity (water is close to saturation with oxygen exiting an ozone contactor)
  - biological oxidation of transformation products (e.g. NDMA (*N*-Nitrosodimethyl-amine)

➡ rapid sand filters are required for ozonation plants in Switzerland

First ozonation of communal wastewater in Switzerland: summary

ARA Neugut
Dübendorf, Switzerland

- ozone contactor was built while the rest of the wastewater treatment plant was fully operational
- space available for ozone contactor was limited
- plant fully operational since spring 2014
- many research projects conducted since 2014 (first ozonation plant of communal wastewater in Switzerland, plant is very close to Eawag)
- **ozone dosage (after optimisation): 0.33 – 0.50 g O_3/g COD**
- **minimal retention time in ozone contactor: 13 minutes**
- **ozone transfer efficiency: > 98 %**

ozone contactor under construction

First PAC treatment of communal wastewater in Switzerland

○ in planning/ under construction

◉ constructed

- ozone
- powdered activated carbon
- granulated or micro-grain activated carbon
- combined processes

wastewater treatment plant Bachwis, Herisau (canton of Appenzell Rhodes-Extérieures)

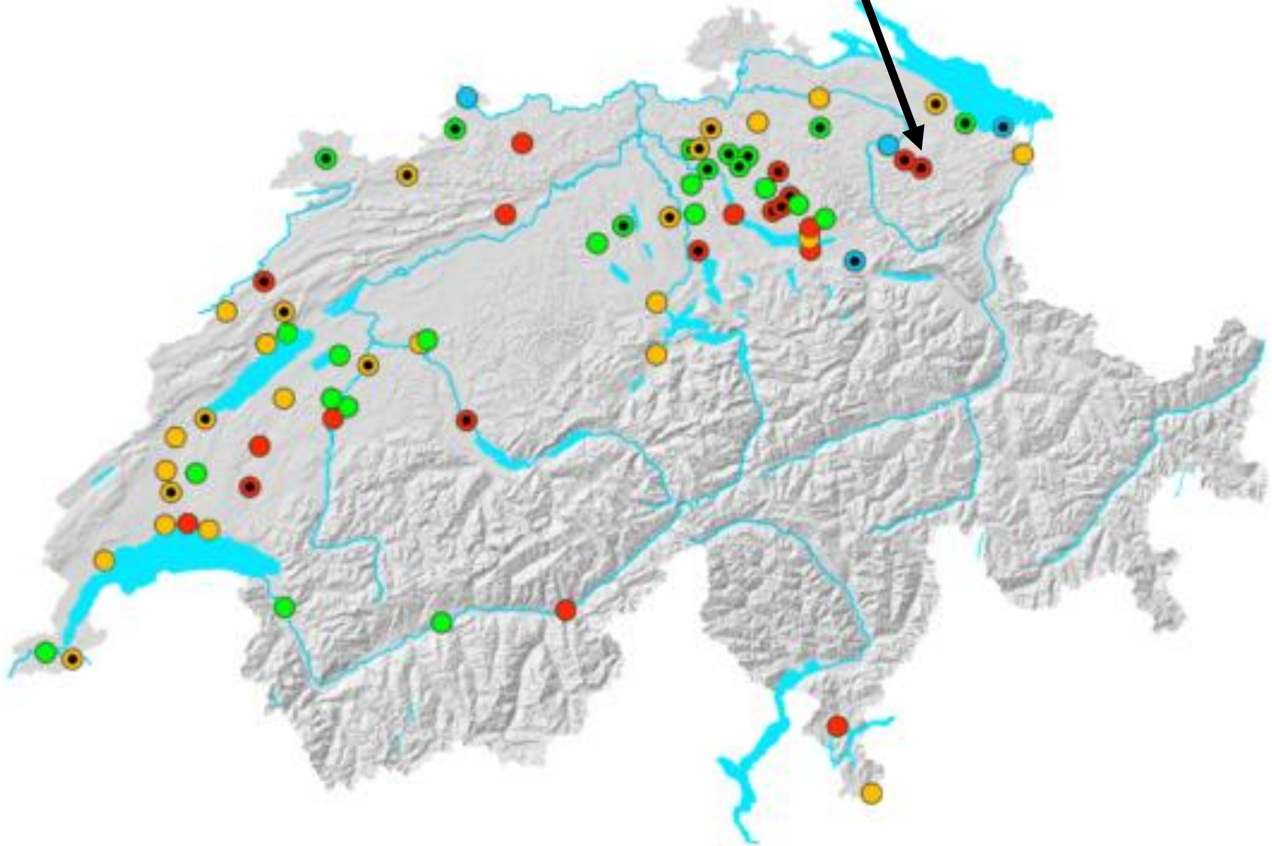


image taken from webpage: https://www.micropoll.ch/fr

Activated carbon treatment

Why does PAC have a higher surface area than GAC?

- A) the particles of PAC are smaller and hence the outer surface is larger
- B) this statement is wrong
- C) the grinding of GAC opens certain closed pores and increases the total surface area
- D) the activation process is more efficient for PAC than for GAC

https://web.speakup.info/room/join/26759

First PAC treatment of communal wastewater in Switzerland (WWTP Bachwis in Herisau)

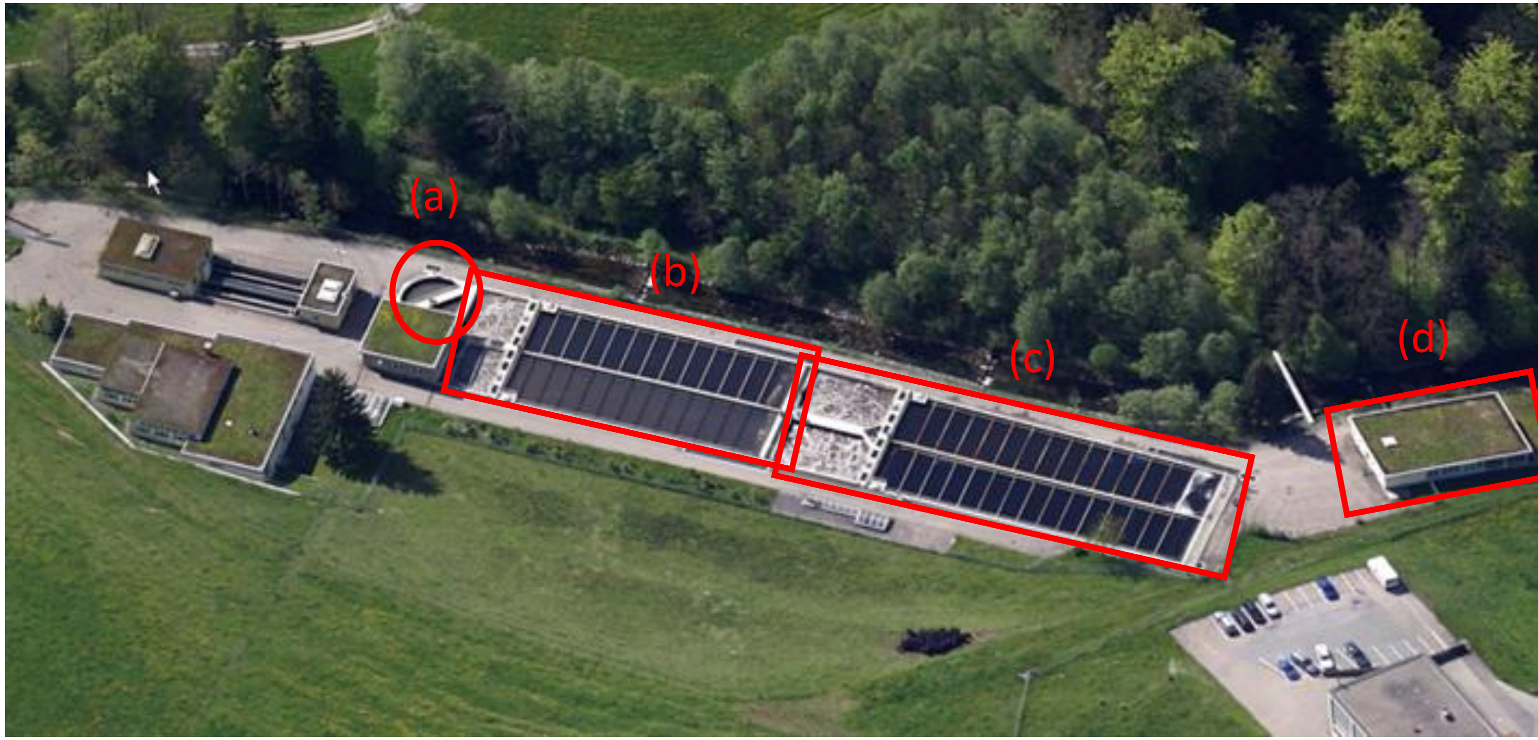
- large fraction of industrial wastewater:
  - ≈ 16’500 inhabitants
  - ≈ 17’500 population equivalents (industries)
- presence of industrial wastewater caused colour and foaming problems at the effluent
- low dilution of wastewater in the river Glatt
  - oMP treatment
  - low DOC levels (6 mg/L) imposed by Canton
  - low P_{tot} levels imposed (sand filtration pre-existing)


left: raw wastewater,
right: final effluent without PAC treatment


foaming after treated wastewater is discharged into river Glatt

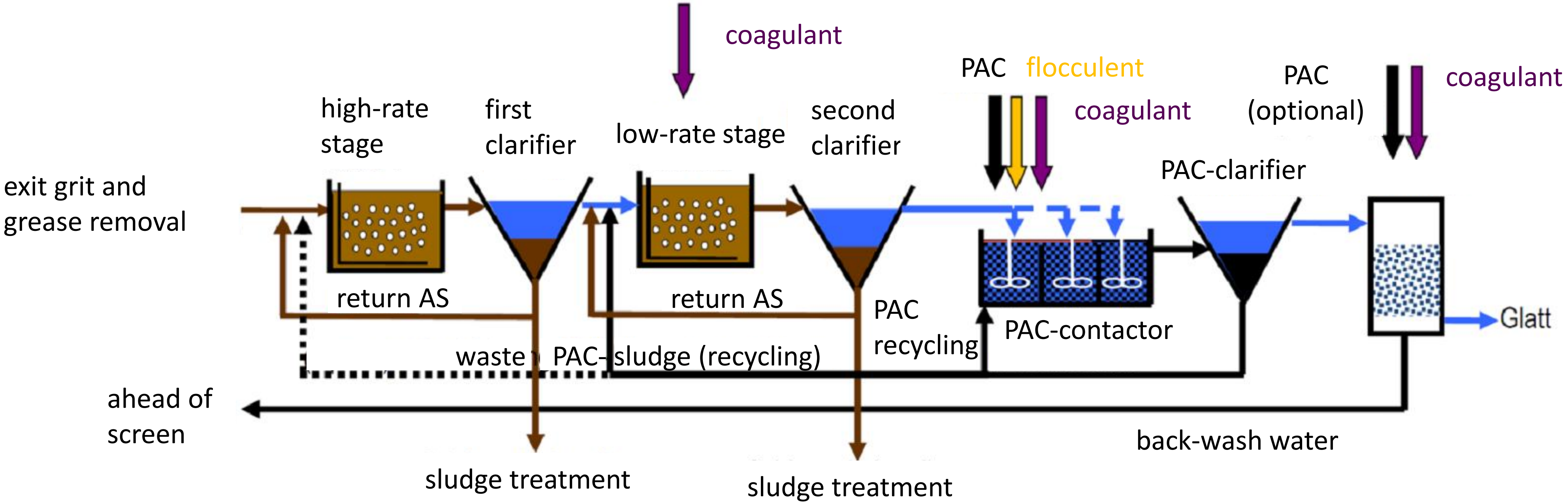
First PAC treatment of communal wastewater in Switzerland (WWTP Bachwis in Herisau)

- wastewater treatment train installation before construction of PAC treatment:
  - coarse screen, (a) grit and grease removal, fine screen
  - activated sludge treatment: two stage system (each stage having two aerated tanks and two sedimentation tanks:
    - (b) high-rate (C-removal)
    - (c) followed by low-rate (nitrification)
  - (d) sand filtration (pre-existing)



First PAC treatment of communal wastewater in Switzerland (WWTP Bachwis in Herisau)

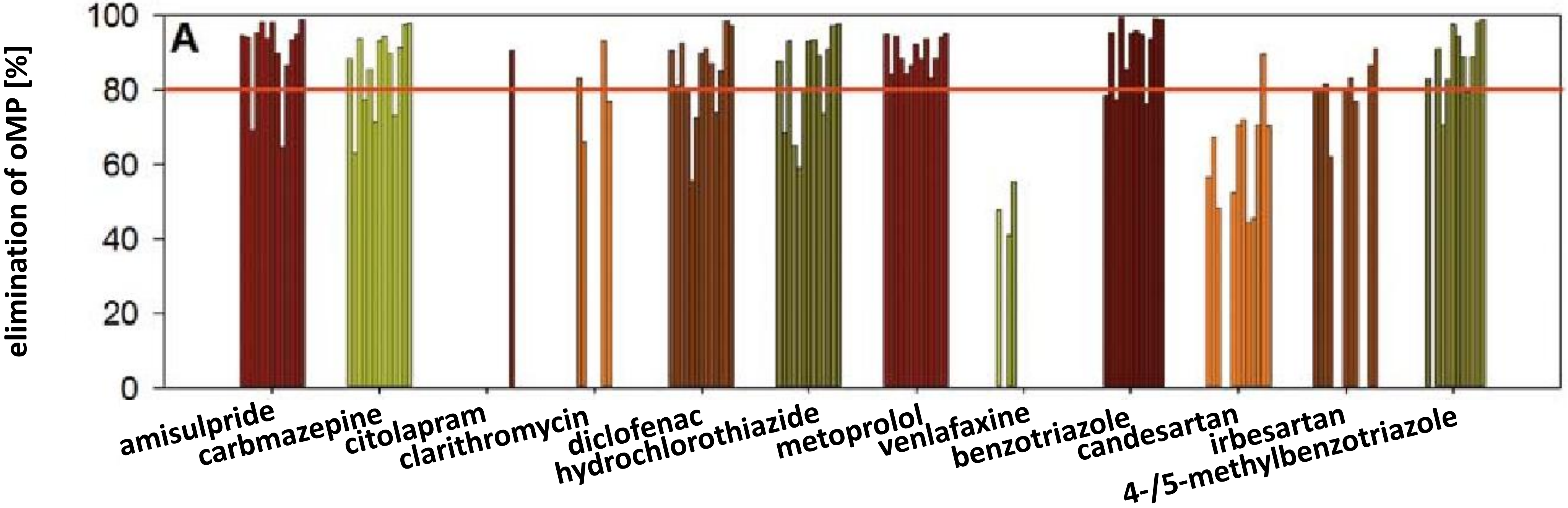
- like in Dübendorf, the oMP treatment was introduced between the secondary clarifier and the pre-existing rapid sand filters
- the PAC system installed is called Ulmer-process: PAC-contactor followed by clarifier
  - PAC-contactor is followed by PAC-clarifier: PAC is recycled from PAC-clarifier to PAC-contactor
  - saturated PAC is recycled to low-rate activated sludge tank
  - wastewater treatment train includes three clarifiers



Design criteria of PAC treatment at WWTP Bachwis

design criteria	value
• **flowrates**	
max. flowrate of wastewater treatment plant (including rapid sand filters)	310 L/s
max. flowrate of PAC unit	170 L/s
average yearly flowrate of wastewater treatment plant (including sand filters)	3.7 million m^3/year
percentage of wastewater treated by PAC unit	90 %
• **PAC contactor**	
PAC dosage	10 – 30 mg PAC/L
$FeClSO_4$ dosage	3 mg/L
minimal residence time	30.4 min
PAC concentration in contactor	~ 3.5 g/L TS
• **PAC clarifier**	
max. surface loading rate	2.07 m/h
min. residence time	1.93 h
• **sand filter**	
max. filtration rate	15.5 m/h

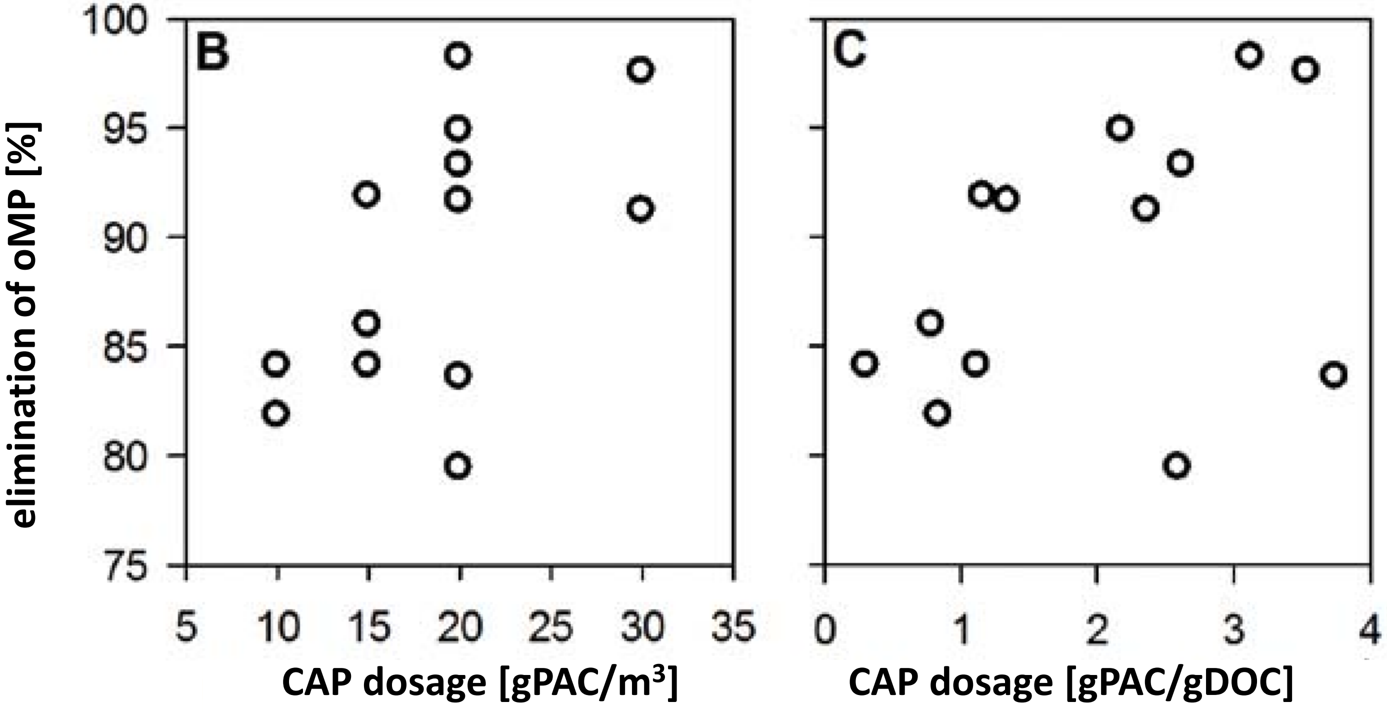
PAC treatment results of WWTP Bachwis



- quantification of all substances not always possible
- efficient removal of most substances (> 80 %; exceptions: venlafaxine and candesartan)

PAC treatment results of WWTP Bachwis

- ≈ 10 – 15 mgPAC /L (≈ 1 gPAC/gDOC$_{\text{sec. clarified wastewater}}$) dosage was sufficient to achieve required treatment levels of oMP
- low PAC requirements because PAC can be recycled into biological tank (two step adsorption process)
- PAC treatment plant works well. However, initially clogging-problems happened in PAC wetting device and PAC dosing pipes



removal of oMP at WWTP Bachwis

Impressions of PAC-treatment of WWTP Bachwis, Herisau

clarifiers for PAC removal

PAC storage and dosing system

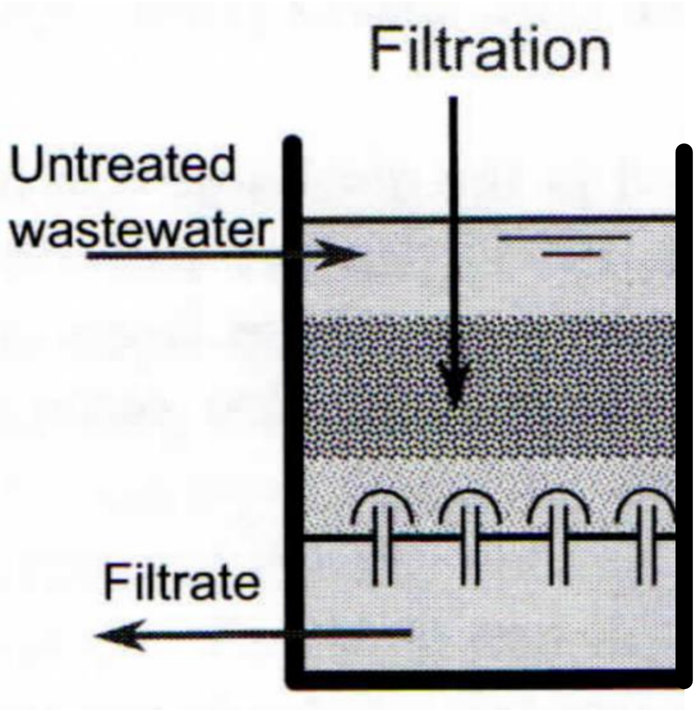
PAC contactors

Impressions of PAC-treatment of WWTP Bachwis, Herisau

- conventional rapid sand filters
  - TSS reduction
  - residual PAC retention

Rapid sand filtration

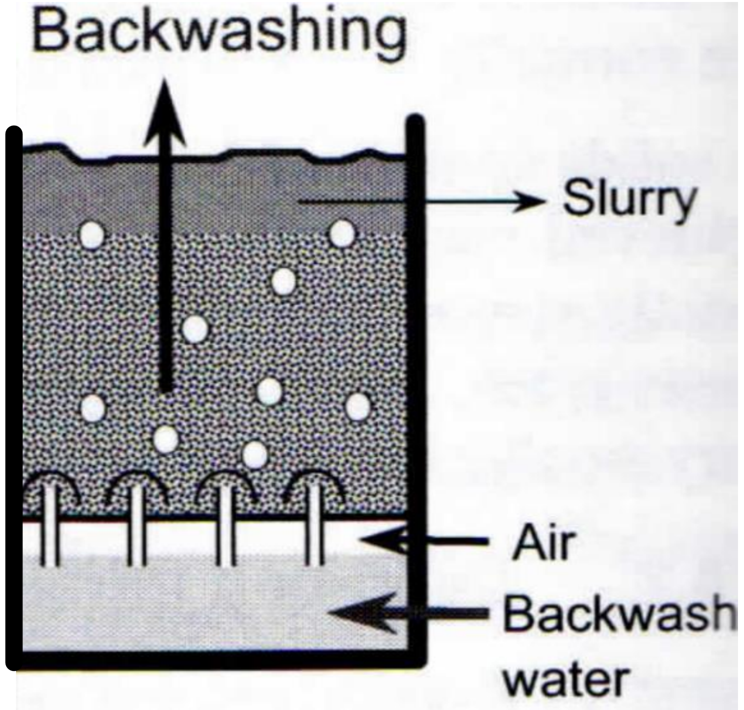
- (a) wastewater is being filtered
  - wastewater flows from top to bottom: particles (TSS) are being retained by sand particles
    - top: wastewater coming from PAC treatment
    - bottom: filtered wastewater (filtrate) leaving wastewater treatment plant
  - head loss over sand filter increases with filtration time (more and more particles are retained in sand filter)
    - either water level above filter increases or filtration rate decreases



(a)

Rapid sand filtration

- (b) backwashing of filter (using filtered wastewater water)
  - injection of filtered wastewater and air removes particles (TSS) that where retained during the filtration period
  - the backwash water is returned to wastewater treatment train
    - removal of retained particles (e.g. return to primary clarifier)
    - increased flow rate over wastewater treatment plant (including sand filters)
    - increased pumping due to backwash water



(b)

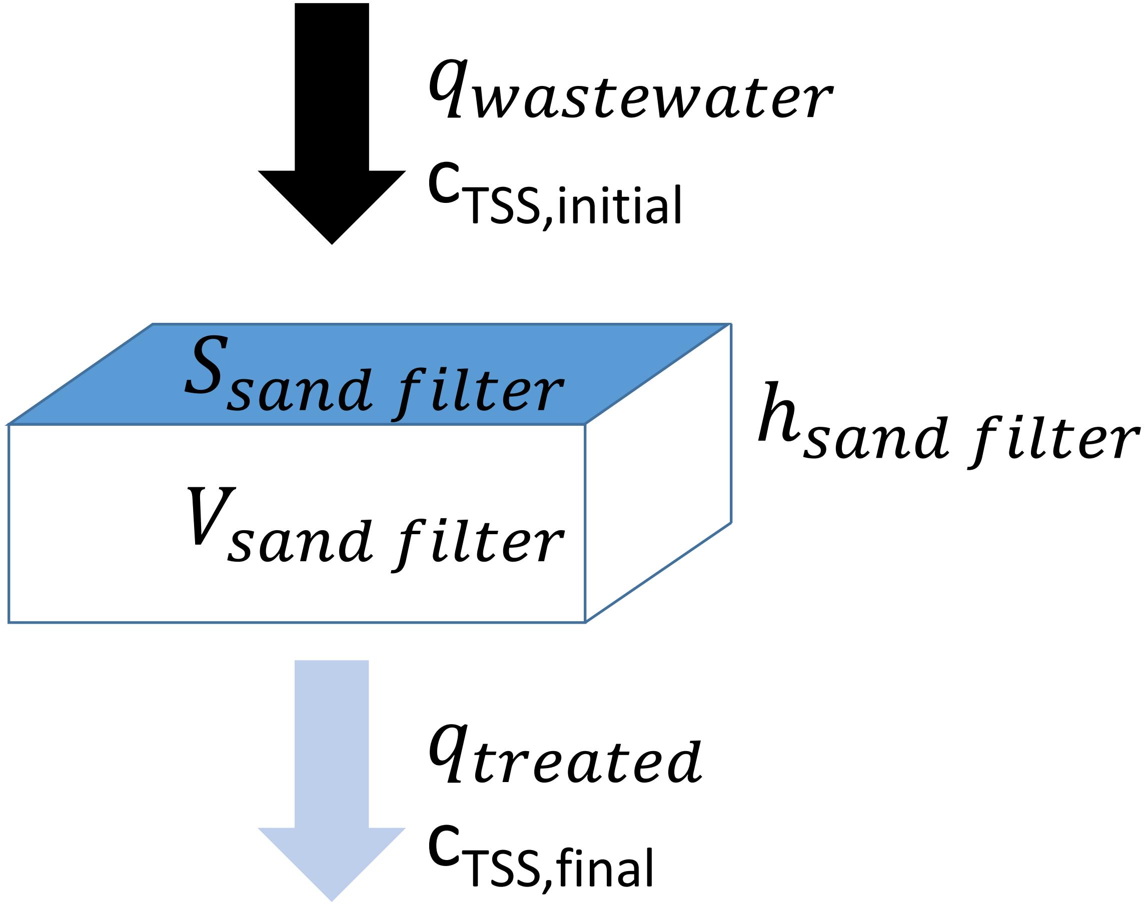
Typical design parameter for rapid sand filtration

- (maximal) filtration rate:

$$= \frac{q_{wastewater,max}}{S_{sand\ filer}}$$

$$= \frac{m^3/h}{m^2} = \frac{m}{h}$$

where $q_{wastewater,max}$ is the maximum wastewater flow rate entering the sand filters and $S_{sand\ filters}$ is the total surface area of the sand filers



$q_{wastewater}$

$c_{TSS,initial}$

$S_{sand\ filter}$

$V_{sand\ filter}$

$h_{sand\ filter}$

$q_{treated}$

$c_{TSS,final}$

First PAC treatment of communal wastewater in Switzerland (WWTP Bachwis in Herisau): summary

- PAC dosage for oMP removal efficiently implemented at WWTP Bachwis
- both foam and colour problems were solved/reduced thanks to PAC-treatment
- A relatively difficult process is the introduction of PAC into the water phase and the transport of the wetted PAC
- PAC is efficiently retained by the system (sedimentation + sand filtration: 1.4 mg/L TSS)
- reduction of DOC-value below 6 mg/L is difficult to achieve at WWTP Bachwis in Herisau even with PAC-treatment

Other wastewater treatment plants with a micropollutant removal unit in Switzerland (not discussed)

○ in planning/ under construction

◉ constructed

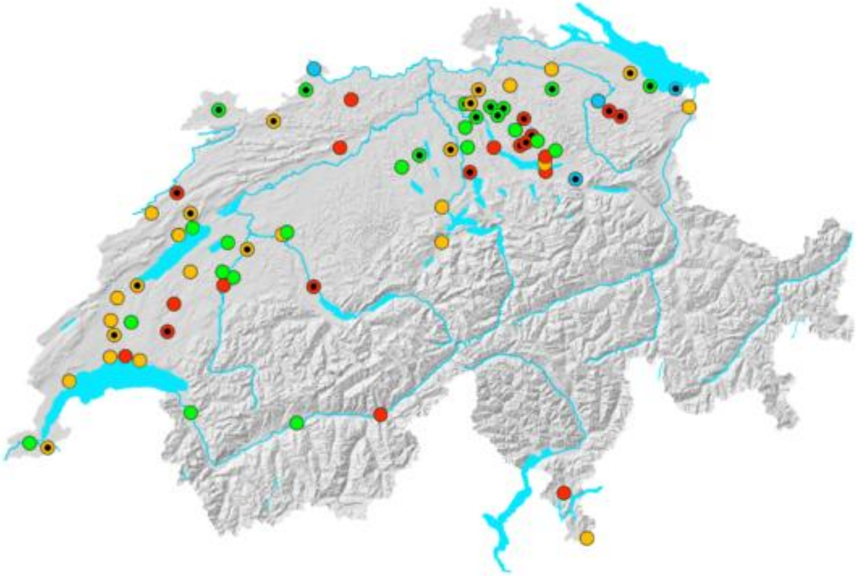


image taken from webpage: https://www.micropoll.ch/fr

- ozonation: WWTP Zurich, Reinach Oberwynental, Bassersdorf, Porrentruy, Morgental, Furthof, Lützelmurgtal,…
- powdered activated carbon: WWTP Thunersee, Schönau Cham, Flos Wetzikon, Egg-Oetwil am See, Gossau-Grüningen, Oberglatt, VOG (-> field visit),…
- micro-grain or granulated activated carbon: WWTP of Penthaz (-> field visit), Moss (Amriswil), Delémont,…
- combined processes: WWTP Altenrhein (ozone and GAC), ProRheno

Short survey of the course

How is the lecturing speed?

- A) too fast, I have a hard time to follow, please slow down
- B) perfect and I have time to ask questions
- C) good but I cannot ask my questions
- D) too slow, please speed-up

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