Activated Carbon

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Adsorption

- Certain components (adsorbate) of a flow are transferred to and held at surface of a solid (adsorbent)

Physical adsorption (weaker)
Chemical adsorption (stronger)

Adsorbent

- High surface per unit mass (porous)

  Surface area (total surface/mass)

  Porosity (pore volume/total volume)

- External surface, macropores, mesopores, micropores, and submicropores

- At equilibrium

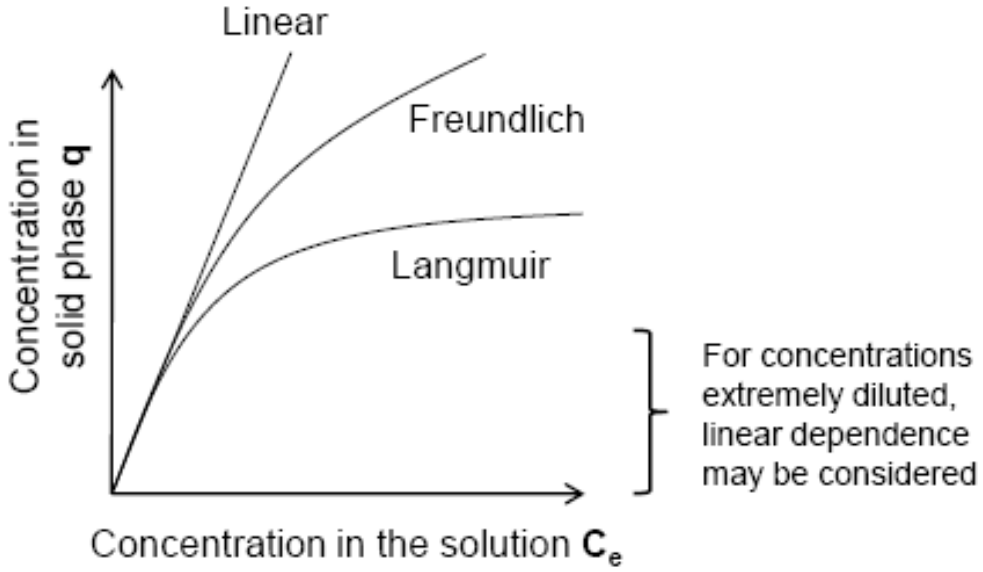
$$Keq = \frac{[adsorbed\ compound]}{[free\ sites][compound]}$$

Adsorption isotherm

- q= Mass of adsorbate/mass of adsorbent

- Concentration ratio
- Nature of adsorbate
- Nature of adsorbent

Adsorption isotherm



At equilibrium

$q = K C_e$ Linear (less common)

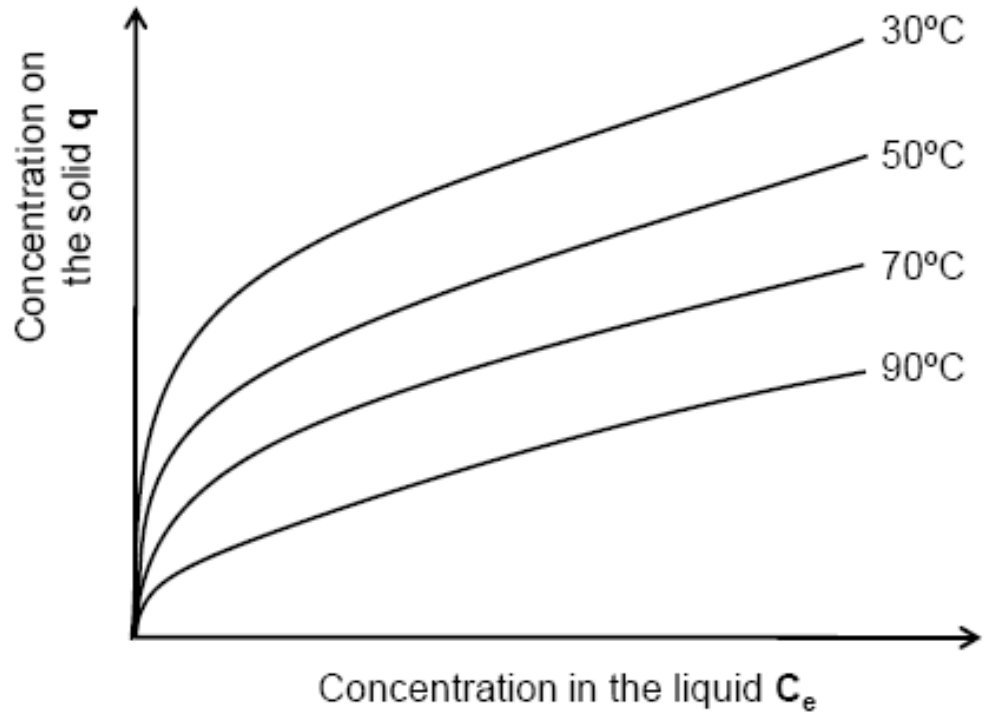
$q = K C_e^{1/n}$ Freundlich (empirical, more common)

} >K ⟹ better adsorbent

$q = \frac{q_0 K C_e}{1 + K C_e}$ Langmuir (con theoretical fundaments)

} $>q_0$ ⟹ higher capacity
} >K ⟹ better adsorbent

Effect of temperature



Activated Carbon

- Obtained from organic materials (bituminous, almonds and coconut hulls, Wood, coal)
- Surface area: 700-1300 m^2 g^{-1}

10 gr activated carbon
~10.000 m^2

1 city block =10.000 m^2

Applications

- Natural Organic Matter, Organic micropollutants , etc.
- Residual amounts of inorganics e.g. nitrogen, sulfides and heavy metals
- Taste and odor compounds (MIB and geosmin)
- Cyst such as giardia and cryptosporidium (0.5 micron)
- Ozone, H_2O_2, Chlorine and Chloramine

Natural Organic Matter

Problems for conventional treatment processes

- Precursors to chlorination disinfection by-products
  - TTHMs (80 µg/L max)
  - HAA5 (60 µg/L max)
- Binding of heavy metals and pesticides
- Bacterial re-growth potential
- Biofilm formation

Natural Organic Matter

Problems for Advanced Oxidation Processes

- Ozone consumption
- Screening of UV
- •OH scavenging

Breaks down into smaller biodegradable compounds

Types of Activated Carbon

- Granular Activated Carbon (GAC)
- Biological Activated Carbon (BAC)
- Powdered Activated Carbon (PAC)

Granular Activated Carbon (GAC)

GAC

- d> 0.1mm, flow-through columns
- Household water treatment (350-700 g)

- Post-filter contactors
  Longer contact times (15-20 minutes) follows filtration

- Filter adsorber
  Shorter contact time, moderate costs and removal

- BAC
  High capital cost

- Removal of DOC, BDOC,
- Removal of Disinfection by-products precursers

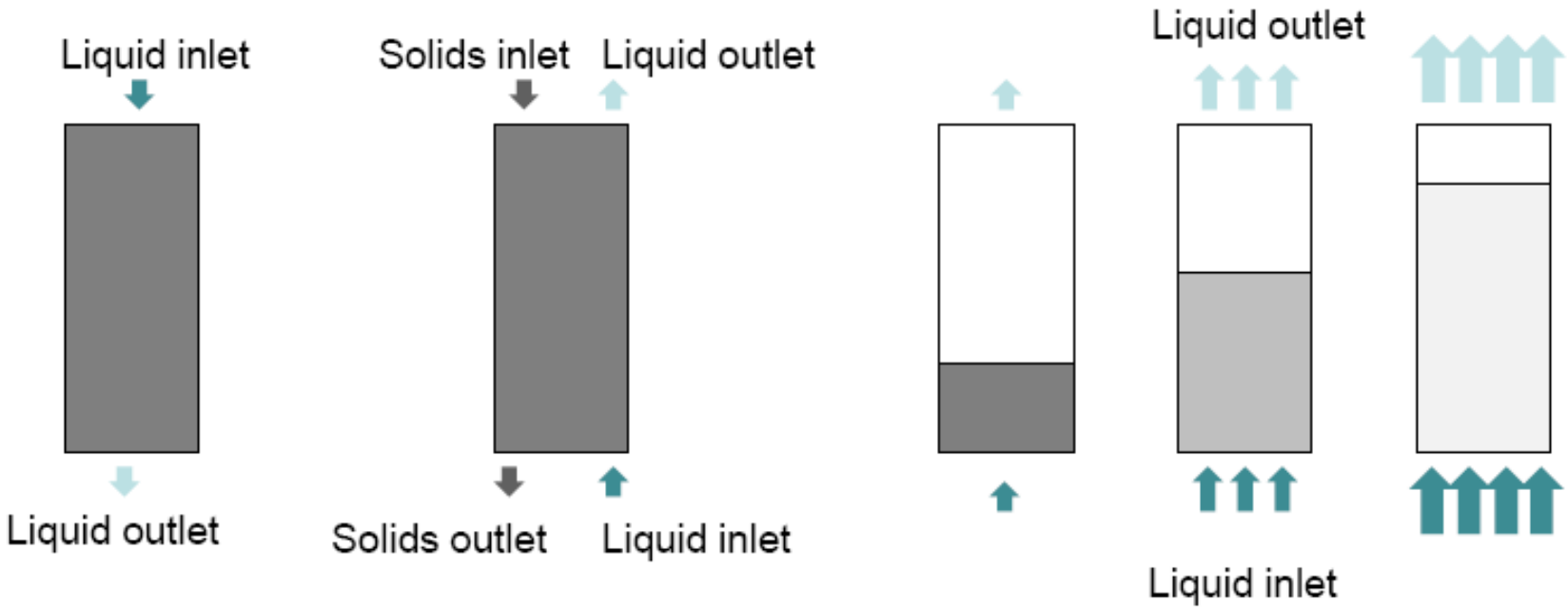
DOC removals typically achieved by BAC columns in the literature.

Water source	DOC (mg/L)	Media	O_3 dose	Removal (%)	Reference
Seagahan, UK	NA[b]	Sand	3.1–4.8 mg O_3/L	25	[36]
Lake Vyrnwy, UK	2.4–4.8	Sand	1.1–2.5 mg O_3/L	26.5	[37]
Norsborg, Sweden	NA[b]	Sand	0.2–1 mg O_3/mg TOC	20–30	[38]
River Dee, UK	3.0–7.9	Sand	0.5 mg O_3/mg TOC	28	[39]
Model Water	4.0–5.0[a]	Sand	6.7 mg O_3/L	34–40	[40]
Plonia River, PL	7.8–11.6[a]	GAC	1.64 mg O_3/mg TOC	39	[41]
Grand River, USA	5–7	GAC	NA	13–23	[42]
Miyun Reservoir	4.9–7.3	GAC	3 mg/L	33.4	[43]
Huangpu River	5.2–7.7	GAC	2.0–2.5 mg/L	31	[44]
Omerli Reservoir	2.9–4.9	GAC	No ozonation	47–72	This study

[a] In terms of TOC.

[b] NA: Data not available.

Operation



Fixed bed **Moving bed** **Fluidized bed**

Fixed bed

- Most common for GAC
- Parallel or series
- Down flow:

  efficient elution, easier regeneration and back washing
- Headloss

Issues

- Efficiency reduction
- Bacterial growth
- Frequent filter change
- Contamination with pollutant
- Low maintenance
- absence of good monitoring parameters

  taste and flowrate

Biological Activated Carbon (BAC)

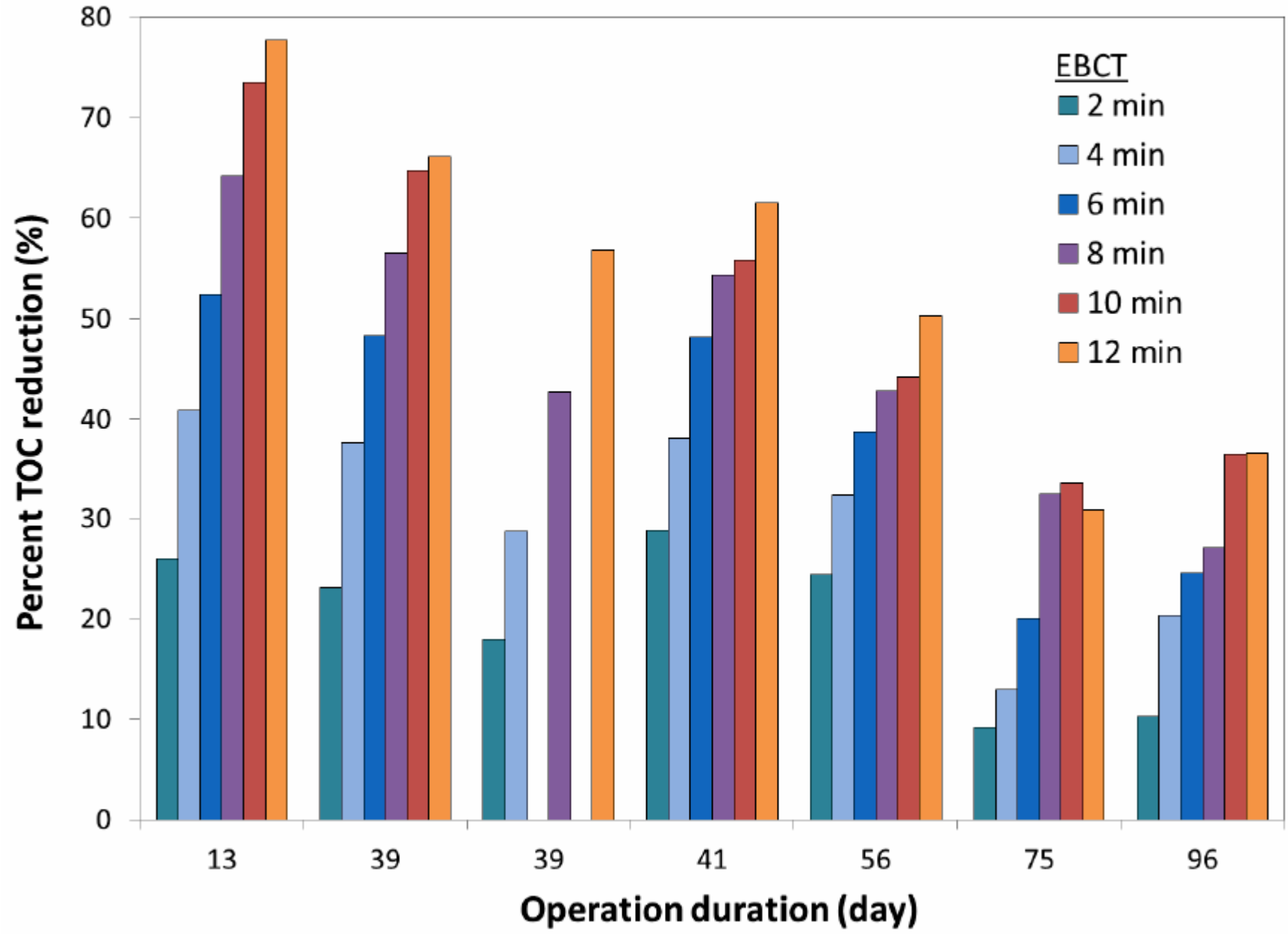
BAC

- Good support for microbial growth
- Empty bed contact time (EBCT) is the primary design parameter ($\propto$ capital cost)
- Better performance than sand filters due to rougher surface
- Short contact time (12-20 minutes)

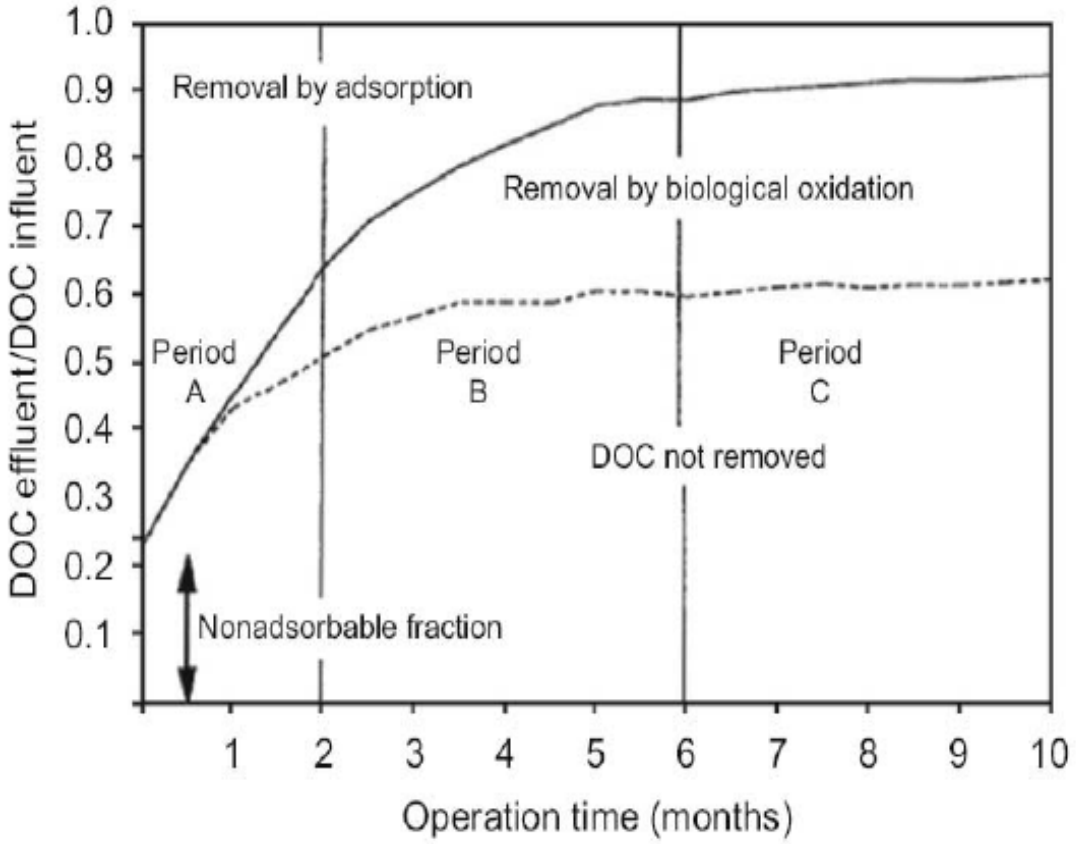
BAC

- H_2O_2 removal (2-4 minutes)
- Nitrite removal (4-8 minutes)
- Limited applicability, pre oxidation is applied
- Inefficient in to remove refractory fractions
- long start up 3-5 months

Removal of TOC



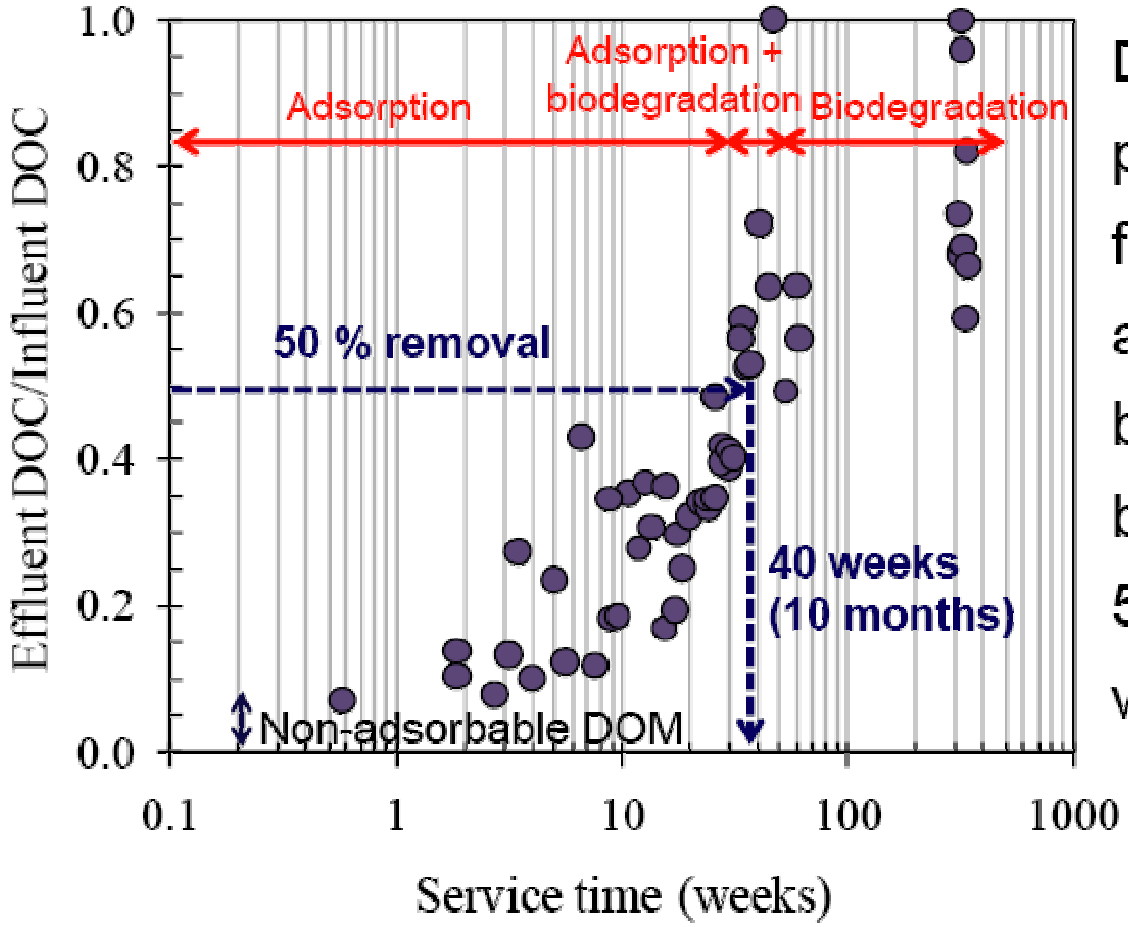
BAC



Adopt from Simpson (2008)

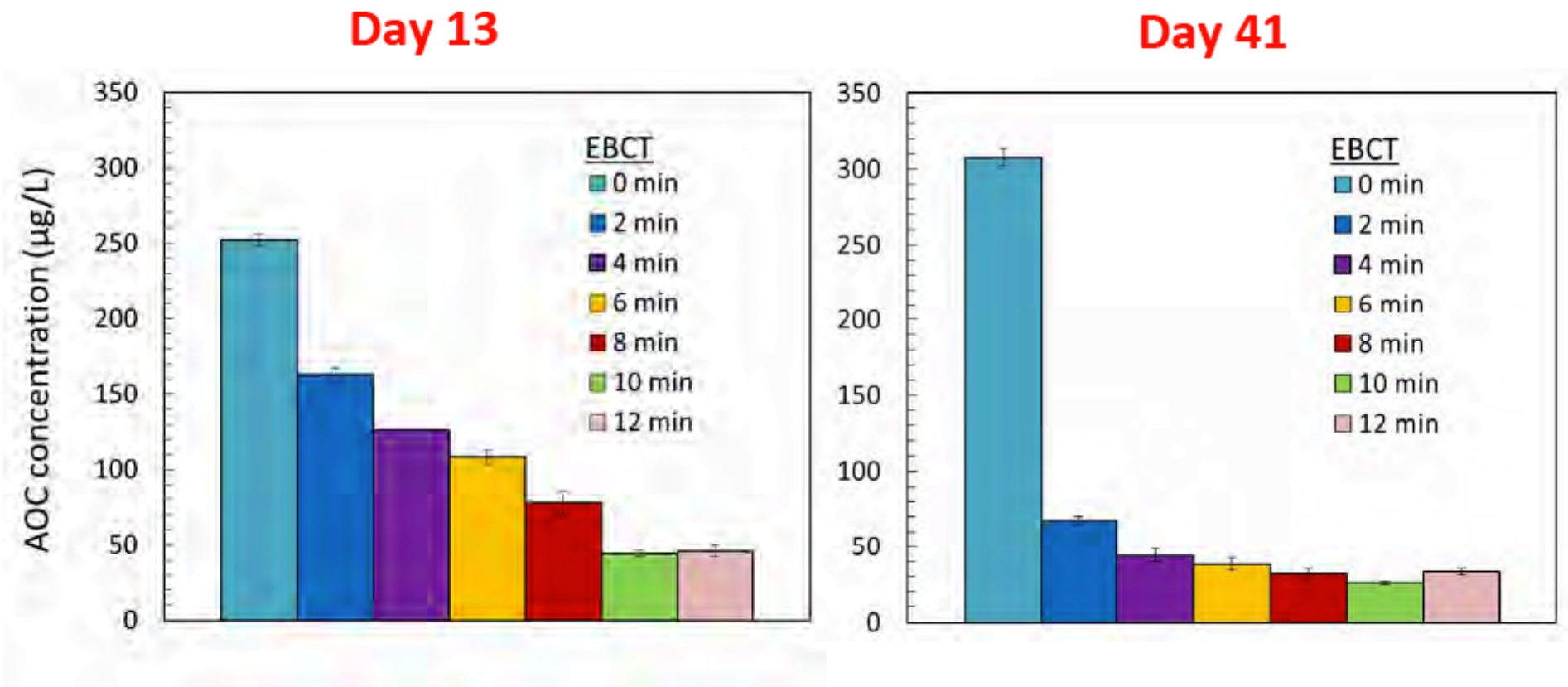
1. **Period A:** Physical adsorption mode.
2. **Period B:** Transition phase i.e., physical adsorption declines, while the degree of biodegradation increases.
3. **Period C:** Mainly biodegradation.

BAC

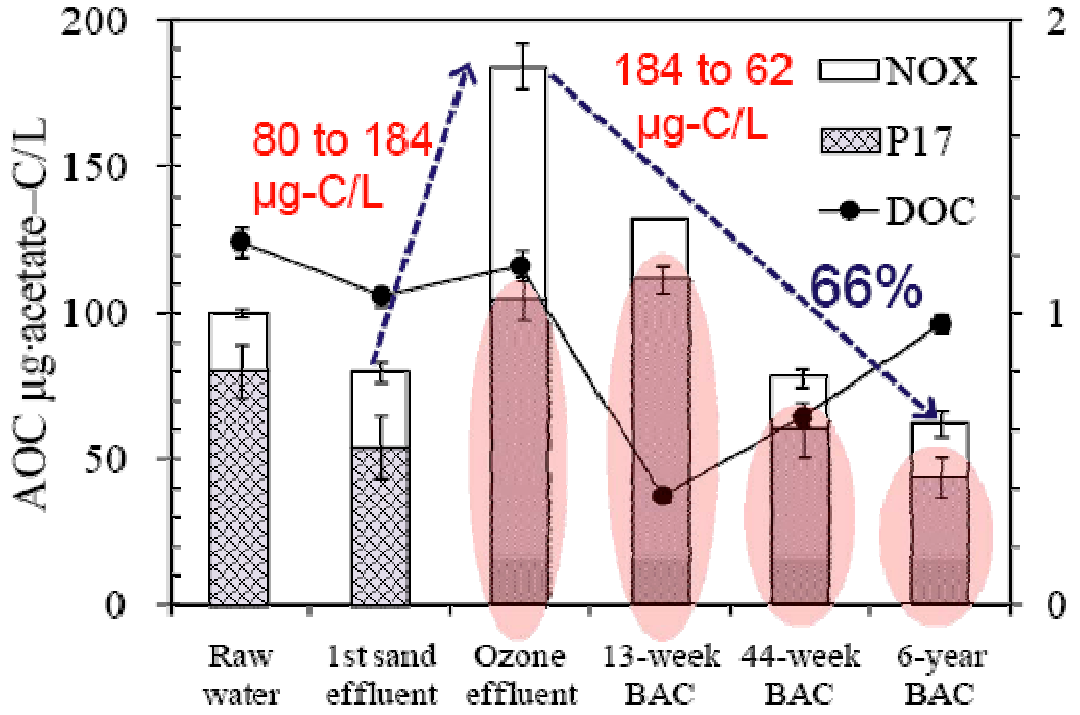


DOM removal process shifted from physical adsorption to biodegradation between 30 and 54 weeks (after 40 weeks service).

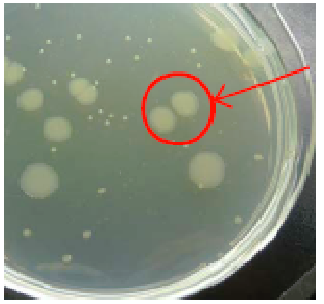
Removal of Synthetic AOC (acetate)



BAC



Total AOC = AOC–NOX + AOC–P17



AOC-P17: e.g. amino acids, carbohydrates, some carboxylic acids, alcohols, some aromatic compounds

- Ozonation remarkably increased the AOC concentration
- The 6-year BAC was effective in removing AOC-P17
- Aged BAC vs. new BAC

Powdered Activated Carbon (PAC)

PAC

- d< 0.074 mm, stirred vessels, difficult to recover and regenerate. Large surface area
- lower capital cost
- Effective for lower concentration
- Shorter contact time
- Effective for taste and odor control

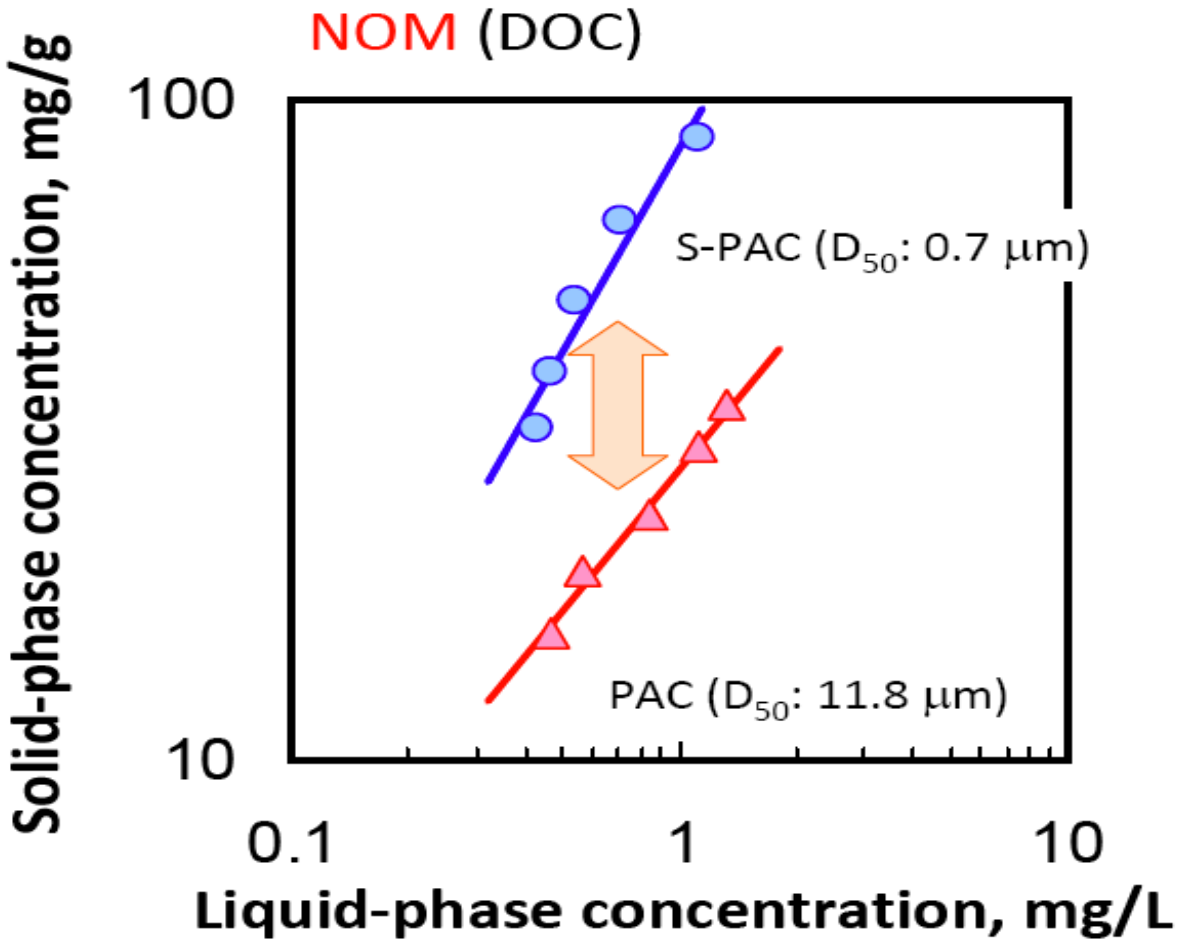
PAC

- Dosage and CT impractical for TOC removal
- Can be applied to the effluent from biological treatment process
- Abrasion, carbon carryover
- Required removal by coagulation/filtration
- Slow NOM adsorption kinetics (size, SPAC)

PAC, Issues

- Loss of capacity and adsorption sites
- Regeneration
  - Chemicals (oxidizing adsorbed materials)
  - Steam cleansing
  - Solvents
  - Biological conversion
  - Loss of capacity (4-10%)

PAC vs. S-PAC

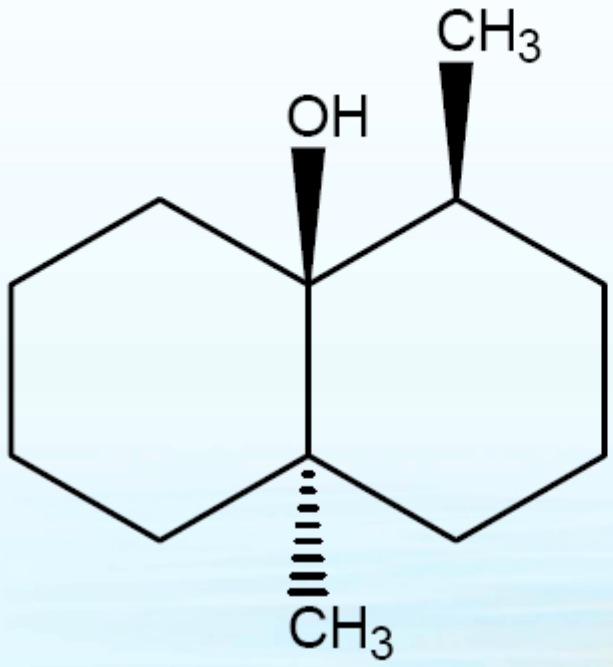

NOM (DOC)
100
10
0.1
1
10
Solid-phase concentration, mg/g
Liquid-phase concentration, mg/L
S-PAC (D_{50}: 0.7 μm)
PAC (D_{50}: 11.8 μm)

Taste and odor removal

- 2-methylisoborneol (MIB) and geosmin
- Excellent removal in DOC presence
- Biodegradation affects MIB removal 10-20 ng/L
- PAC (less frequent) or sand filter-GAC (more frequent)
- DOC competes with MIB and geosmin
- Pre treatment will be valuable

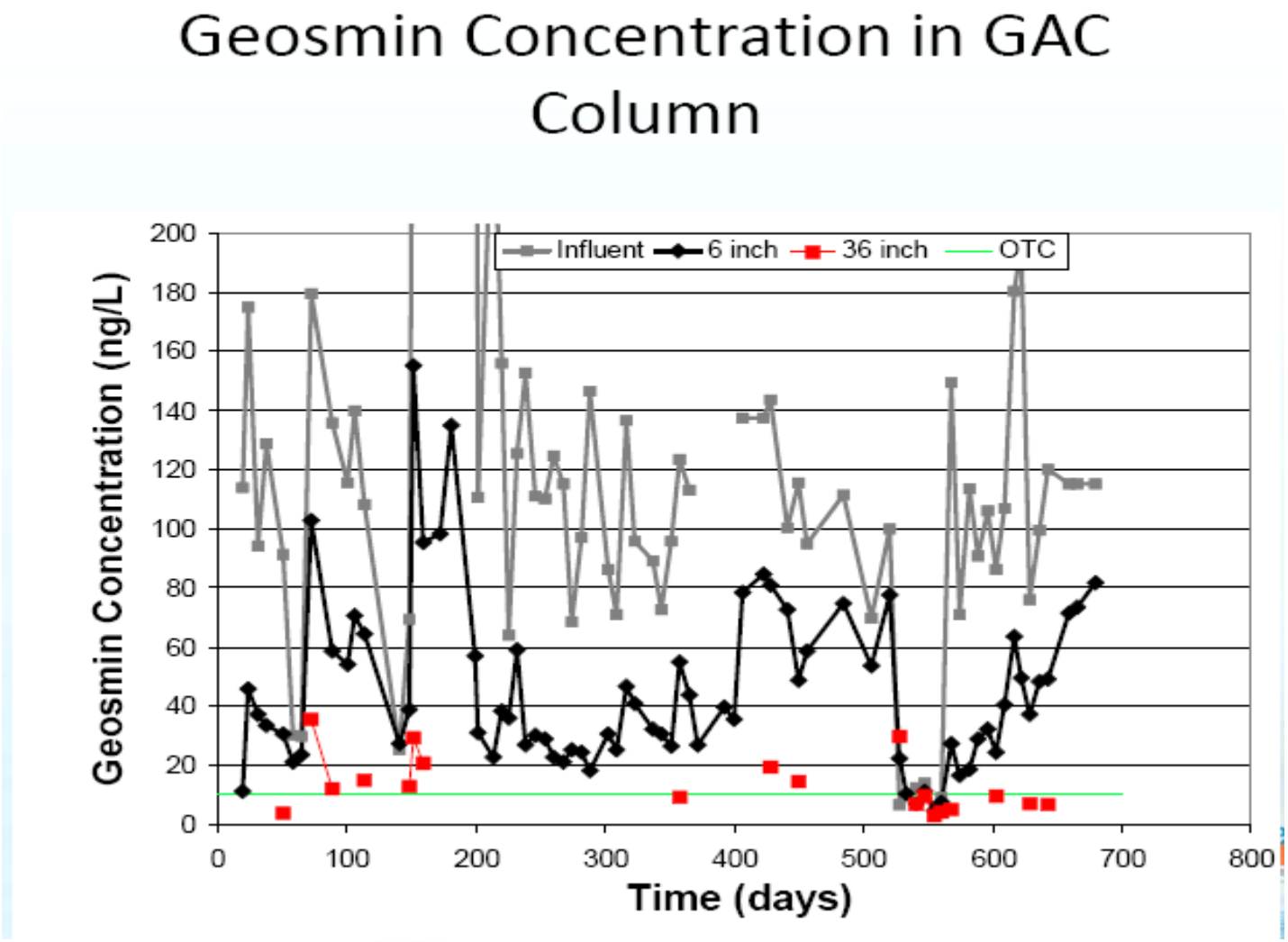
Taste and odor removal

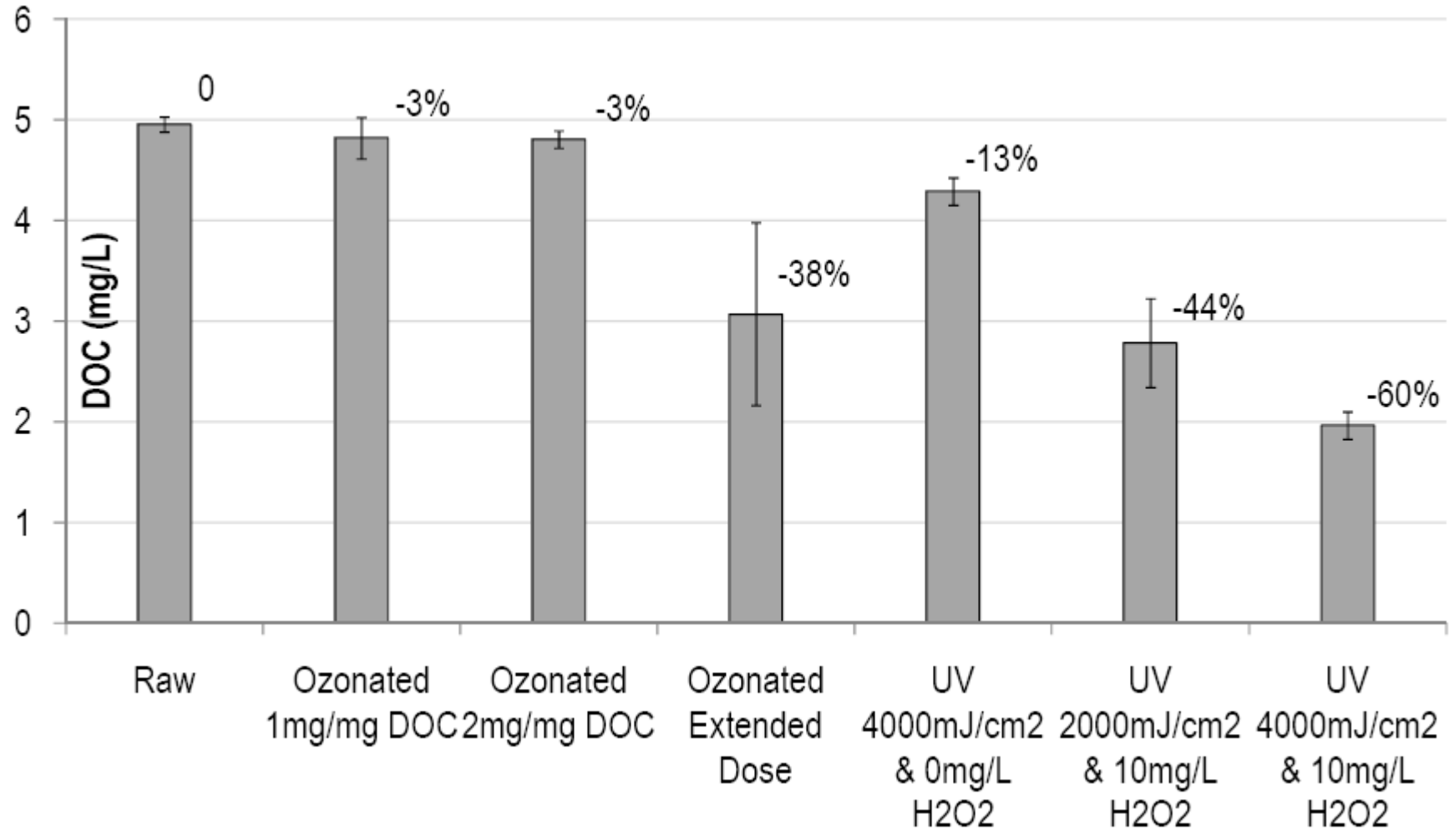
Geosmin



- *trans*-1,10-dimethyl-*trans*-9-decalol
- $C_{12}H_{22}O$
- K_h = 0.0023
- Odor Threshold Concentration (OTC) – 10 ppt
- MW = 182 g/mol
- Earthy Smell

Taste and odor removal



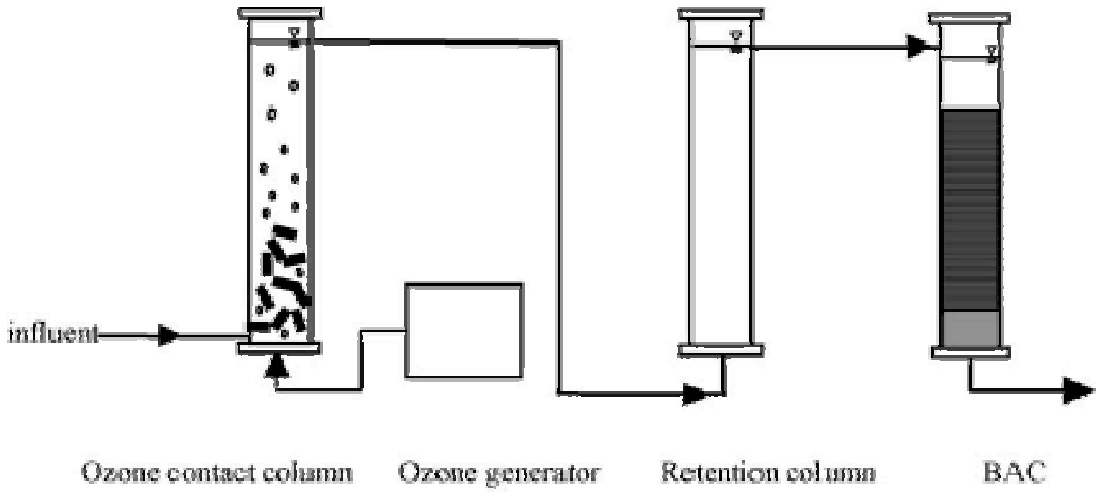

DOC (mg/L)
6
5
4
3
2
1
0
0
-3%
-3%
-38%
-13%
-44%
-60%
Raw
Ozonated 1mg/mg DOC
Ozonated 2mg/mg DOC
Ozonated Extended Dose
UV 4000mJ/cm2 & 0mg/L H2O2
UV 2000mJ/cm2 & 10mg/L H2O2
UV 4000mJ/cm2 & 10mg/L H2O2

AC as pretreatment

- Removing organic upstream of the treatment process
- Oxidation processes
- Reverse Osmosis (organics, chlorine)
- IEX

AC as post-treatment

- Ozonation
- Oxidation processes
- IEX



AC as post-treatment

- Ozonation is for organic pollutant destruction/break down and biodegradability improvement.
- AC/O_3 combination – OH• generation, large site for reaction
- O_3/BAC: Drinking water production, economic, efficient

Influent BDOC and its removal in subsequent BAC unit

Process	BDOC (mg/L)	BDOC removal values (mg/L)
BAC alone	1.12	0.76
O_3-BAC	2.31	1.56
AC/O_3-BAC	2.45	1.75

AC as post-treatment

- Oxidation process : increased biodegradability (optimize)
- Typical Ozonation
  - Small TOC destruction
  - Increased polarity
  - HMW to LMW
- Biofiltration: Removal of BDOC