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AOPs for drinking water treatment: state of art and research experiences

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AOPs for drinking water treatment (1.1)

Processes that utilize powerful oxidizing intermediates (e.g. OH• radicals) to oxidize contaminants

Oxidant	Oxidation potential (volt)
OH°	**2,7**
O_3	2,07
H_2O_2	1,76
MnO_4	1,68
HOCl	1,49
Cl_2	1,36
ClO_2	0,95
I_2	0,54
O_2	0,40

OH•

- low selectivity
- high oxidation potential

Combined use of different oxidizing agents:

- **UV/H_2O_2**
- **$UV/Fe^{2+}/H_2O_2$**
- **UV/O_3**
- **UV/TiO_2**
- **O_3/H_2O_2**
- $O_3/H_2O_2/UV$
- H_2O_2/CH_3COOH
- UV/CH_3COOH

AOPs for drinking water treatment (1.2)

Advantages

- Progressive oxidation of organic substances (by intermediate forms) until the complete mineralization
- alternative to processes in which the contaminant is transferred from the liquid phase to the gaseous phase (eg. stripping) or solid phase (eg. activated carbon adsorption)
- low selectivity→ reaction with a wide range of contaminants
- effective against many organic pollutants compounds refractory to conventional oxidation treatments: pesticides, chlorinated solvents, odorous compounds, etc.

Disadvantages

- the efficiency is influenced by water matrix
- possible by-product formation
- plant complexity
- costs

AOPs for drinking water treatment (1.3)

The recent interest in these processes comes from the necessity to meet the more stringent drinking water quality standards (EU, 1998; WHO, 2011; Italian Leg. Decree 31/2001), especially:

- need to **remove organic micropollutants**, which may be present in water at very low concentrations (of the order of ppb) and that are generally refractory to conventional oxidation treatments
- need to **reduce the formation of Disinfection By-Products (DBPs)**, which generally occur during the use of conventional chemical oxidants

Emerging contaminants, even if not yet regulated, has led many researchers to study the application of AOPs for the removal of specific compounds such as: N-nitrosodimethylamine (NDMA), Methyl-tertiary-butyl ether (MTBE), odorous compounds (geosmin and methylisoborneol), algal toxins (microcystin-LR), pharmaceuticals and personal care products (PPCPs), pesticides, surfactants, natural fatty acids, perfluoroalkyl substances (PFAS) etc ..

1. UV/H_2O_2

reactions: hydrogen peroxide photolysis $H_2O_2 + hv \rightarrow 2\mathbf{OH^\bullet}$ (quantum yield of OH• generation=1)

main parameters:

H_2O_2 concentration: since the molar adsorption coefficient of H_2O_2 are low, high H_2O_2 dosage (> 25 mg/L) is required so that a significant fraction of UV with λ=200-300 nm is adsorbed (problem of high H_2O_2 residuals)

an optimal dosage can be identified beyond which the performance decreases because H_2O_2 works as a $OH^{\cdot}$ scavenger $H_2O_2 + OH^\bullet \rightarrow HO_2^\bullet + H_2O$

UV dose: efficiency increases with increasing UV dose

UV wavelength: λ=200-250 nm

pH: efficiency increses with increasing pH until 8 ($OH^\bullet$ formation predominates), and then it decreases

water alkalinity: efficiency decreases with increasing alkalinity

- *carbonates* $OH^\bullet + CO_3^{=} \longrightarrow OH- + CO_3^\bullet -$ $K = 2*10^8$ [1/Ms]
- *bicarbonates* $OH^\bullet + HCO_3^- \longrightarrow OH- + HCO_3^\bullet$ $K = 1,5*10^7$ [1/Ms]

advantages:

- ➢ plant simplicity
- ➢ cost lower than O_3 based process

disadvantages:

- ➢high H_2O_2 dosages → high H_2O_2 residuals
- ➢H_2O_2 $OH^{\cdot}$ scavenger

1. UV/H_2O_2: RESEARCH EXPERIENCES

Contaminant	UV lamp	Reference
Natural organic matter (NOM)	HPUV	Wang et al., 2000; Wang et al., 2006
	VUV 185, UVC	Thomson et al., 2004
	MPUV	Speitel et al., 2000; Hofbouer and Andrews, 2004
	UVC	Kleiser and Frimmel, 2000; Parkinson et al., 2001
	MPUV, LPUV	Liu et al., 2002
	LPUV	Berube et al., 2004; Toor and Mohseni, 2005; Goslan et al., 2006; Sarathy et al., 2006; Sarathy and Mohseni, 2007; Toor and Mohseni, 2007; Song et al., 2008; Bazri et al., 2012; He et al., 2013; Sindelar et al., 2014
Phenol	MPUV	Esplugas et al., 2002
	LPUV	Han et al., 2004
	Policromatic	Fasnacht and Blough, 2002
Bisphenol-A	LPUV	Chen et al., 2006
N- Nitrosodimethylamine (NDMA)	MPUV	Stefan and Bolton, 2002
	LPUV, MPUV	Sharpless et al., 2003
	LPUV, HPUV	Plumlee et al., 2008
MTBE hydrocarbons	LPUV, MPUV	Kavanaugh et al., 2003
	MPUV	Cater et al., 2000; Stefan et al., 2000; Sutherland et al., 2004; Mascolo et al., 2006
	LPUV	Chang and Young, 2000
Ebicides Pesticides	MPUV	Kruithof et al., 2001-2002-2005; Martin et al., 2005; Stefan et al., 2005; Williams et al., 2005
	LPUV	Muller and Jekel, 2001; Sanches et al., 2010
	HPUV	Benitez et al., 2002
	LPUV, MPUV	Koratgere et al., 2005; Linden et al., 2004
Microcystin-RR	LPUV	Qiao et al., 2005
Microcystin-LR	LPUV	He et al., 2012
Cylindrospermopsin (CYN)	LPUV	He et al., 2013
MIB and geosmin	LPUV, MPUV	Koratgere et al., 2005, Linden et al., 2004; Collivignarelli and Sorlini, 2005; Paradis et al., 2005; Royce et al., 2005; Zoschke et al., 2012
Microorganisms	LPUV	Koivunen and Heinonen-Tanski, 2005; Mamane et al., 2006

HPUV = high pressure ultraviolet; MPUV = medium pressure ultraviolet; LPUV = low pressure ultraviolet; VUV = vacuum ultraviolet

1. UV/H_2O_2: RESEARCH EXPERIENCES (1.1)

DBP precursors (Sarathy et al., 2006)

- LPUV lamp (λ=254 nm), UV dose 0-1500 mJ/cm^2
- H_2O_2 dose=20 mg/L
- High SUVA (A254/TOC) removal → high removal of high molecular weight organic molecules
- Efficiency increases with increasing UV dose (up to 1500 mJ/cm^2)
- BDOC increases from 5 o 20% with increasing UV dose
- No influence on THMFP
- HAAFP increases after AOP process

DBP precursors (Kleiser and Frimmel, 2000)

- LPUV lamp (λ=254 nm), 15W
- H_2O_2 dose=8 mg/L
- THMFP and AOXFP increase at low contact time and UV dose, while they decrease of about 25-30% at the maximum contact time (300 minutes)

1. UV/H_2O_2: RESEARCH EXPERIENCES (1.2)

Microcystin-RR (Qiao et al., 2005)

- LPUV lamp (λ=254 nm)
- H_2O_2 optimum dose=1 mmol/L
- 95% removal at 60 minutes with UV light intensity=3,66 mW/cm^2
- pH: removal increases with increasing pH up to 8, and then it decreases
- Removal decreases with increasing initial MC concentration

Bisphenol-A (Chen et al., 2006)

- AOP: UV and UV+H_2O_2
- LPUV lamp (λ=254 nm), dose=0-1500 mJ/cm^2
- H_2O_2 dose=10-50 mg/L
- UV: no removal till the maximum tested UV dose
- UV+H_2O_2 : efficiency increases with increasing H_2O_2, and removal yields at the maximum dose are 65%, 90% and 100% respectively with 10, 25 and 50 mgH_2O_2/L

2. Fenton ($Fe^{2+} + H_2O_2$) and photoFenton ($Fe^{2+} + H_2O_2 + hv$)

PhotoFenton is based on the photoreduction of ferric ion (Fe^{3+})

$Fe^{III}(OH)^{2+} + hv \rightarrow Fe^{2+} + OH^{\bullet}$ (quantum yield of OH• generation=0,15)

The resulting Fe^{2+} then reacts with H_2O_2 to generate $OH^{\bullet}$

$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + OH^{-} + OH^{\bullet}$ (Fenton process)

PhotoFenton:

- The process requires a pH = 3 (formation of $Fe(OH)^{2+}$, that with UV produces Fe^{2+} and $OH^{\bullet}$)
- $Fe^{III}(OH)^{2+}$ absorbs UV out to about 400 nm
- > $OH^{\cdot}$ formation than Fenton through photolysis of H_2O_2, and through reduction of Fe^{3+} ions under UV light

2. Fenton-photoFenton: RESEARCH EXPERIENCES

Contaminant	UV lamp	Reference
Natural organic matter (NOM)	Fenton reagent/LPUV at 254 nm	Goslan et al., 2006
	Fenton reagent	Jarvis et al., 2008; Katsumata et al., 2008; Murray and Parsons, 2004
	Fe^{3+} (1.0 mg L^{-1})/H_2O_2/sunlight	Moncayo-Lasso et al., 2008
	Fenton reagent/sunlight	Moncayo-Lasso et al., 2009
	Photofenton UV at 365 nm	Murray and Parsons, 2004
Haloacetic acids (HA)	Fenton reagent/LPUV, mineral particles	Park and Yoon, 2007
	max 365 nm	Sanly et al., 2007
	Iron oxides/Fe^0/H_2O_2/HPUV	Nie et al., 2010
Microcystin-LR	36 W UV lamp	Bandala et al., 2004

3. UV/O_3

reactions: ozone photolysis: $O_3 + H_2O + h\nu \rightarrow O_2 + H_2O_2$

hydrogen peroxide photolysis: $H_2O_2 + h\nu \rightarrow 2\ OH^{\bullet}$

main parameters:

ozone dose: efficiency increases with increasing the dose

alkalinity: low efficiency with high alkalinity

pH: high efficiency with increasing pH

UV dose: under the optimal value it does not decompose all the ozone; above the optimal value, the efficiency of oxidation is constant, but higher energy consumption

UV wavelength: λ=200-280 nm (optimum 254 nm)

advantages:

- combination of O_3 oxidation effect with $OH^{\bullet}$
- high oxidation potential due to high O_3 absorption coefficient at 254 nm

disadvantages:

- plant complexity (O_3 generation)
- high costs
- low O_3 transfer can reduce the process efficiency
- risk of bromate formation

3. UV/O$_3$: RESEARCH EXPERIENCES

Contaminant	UV lamp	Reference
Natural Organic Matter (NOM)	LPUV	Latifoglu and Gurol, 2003; Mischuk et al., 2003; Collivignarelli and Sorlini, 2004; Chin and Berube, 2005
Micropollutants	LPUV	Guzzella et al., 2002
Phenol	MPUV	Teo et al., 2003; Esplugas et al., 2002; Tawabini and Zubair, 2011
Methyl tertiary-Butyl Ether (MTBE)	LPUV	Garoma and Gurol, 2004; Graham et al., 2004
	LPUV	Ramakrishanan et al., 2004
Ebicides Pesticides	LPUV	Collivignarelli and Sorlini, 2004; Muller and Jekel, 2001
	UVC	Ma et al., 2002
	HPUV	Benitez et al., 2002
	LPUV	Nurizzo et al., 1995
MIB and geosmin	LPUV	Collivignarelli and Sorlini, 2004
Bromates	LPUV	Collivignarelli and Sorlini, 2004; Siddiqui et al., 1996; Tawabini and Zubair, 2011

3. UV/O_3: RESEARCH EXPERIENCES (1.1)

DBP precursors (Chin and Berubé, 2006)

- LPUV lamp: UV intensity 9,69*10^{-3}W/cm^2
- O_3 generator: (air) Q=0,29 L/min
- Operating conditions:

  O_3 alone: 3-24 mg/L (from 5 to 60 minutes)

  UV+O_3: 4-62 mgO_3/L; UV dose=0,13-1,61 Ws/cm^2

- TOC: negligible removal with O_3 alone or UV; 50% removal with O_3+UV at 60 minutes contact time
- THMFP: unchanged with UV alone; 50% removal with O_3 (60 minutes) and 85% with O_3+UV (60 minutes)
- HAAFP: 15% removal with UV alone, 40% with O_3 and 80% with O_3+UV

Bromates (Siddiqui et al., 1996)

- LPUV lamp (λ=254 nm)
- O_3 generator
- bromate decreases with increasing UV dose compared to O_3 alone: from 5-7% with 600 J/m^2 to 50% with 6000 J/m^2
- LPUV more efficent than MPUV lamp
- the dose required for a 50% bromate reduction with LPUV lamp is 2500 J/m^2

4. O_3/H_2O_2 (peroxone)

reactions:

$$H_2O_2 + H_2O <=> HO_2^- + H_3O^+$$

$$HO_2^- + O_3 \rightarrow OH^{\circ} + O_2^{\circ -} + O_2$$

main parameters:

O3 dose: 1-2 mgO3/l for 1 mgTOC/L

higher doses for high alkalinity (>100 mg $CaCO_3$/L)

however, an excess O3 dosage increases $OH^{\bullet}$ scavanging

($O_3 + OH^{\bullet} \rightarrow HO_2^{\bullet} + O_2$)

H2O2/O3 ratio: $$\frac{(\text{H2O2 consumed})}{(\text{O3 decomposed})}\left(\frac{\text{w}}{\text{w}}\right) = 0.3 - 0.6$$

pH: slow process at low pH

NOM: quencing effect on $OH^{\bullet}$

<u>advantages:</u>

- no specific reactors
- plant more simple than O3/UV
- cost lower than O3/UV

<u>disadvantages:</u>

- O3 generation
- H_2O_2 $OH^{\cdot}$ scavenger
- risk of bromate

4. UV/TiO_2

reactions: TiO_2 is a photocatalyst that, excited by the UV radiation, can produce $OH^{\cdot}$ through redox processes occurring on its surface

$TiO_2 + h\nu \rightarrow h^+_{TiO2} + e^-_{TiO2}$

•h^+ reacts with H_2O and generates $OH^{\bullet}$ radicals: $h^+_{TiO2} + H_2O \rightarrow OH^{\bullet}_{TiO2} + H^+$

•e^- reacts with O_2 and generates $^{\bullet}O_2^-$ radicals: $e^-_{TiO2} + O_2 \rightarrow {}^{\bullet}O_2{}^-_{TiO2}$

main parameters:

UV intensity: efficiency increases with increasing intensity

TiO_2 dosage: efficiency increases with increasing dosage

rotation speed (in rotating reactors): efficiency increases with increasing speed

alkalinity: efficiency decreases with increasing alkalinity

lamp wavelength: $\lambda>300$ nm

advantages:

- no chemical addition (with fixed TiO_2)

disadvantages:

- sludge extraction (powdered TiO_2)
- low efficiency (recombination of the e^- h^+ couple)

4. UV/TiO_2: RESEARCH EXPERIENCES

Contaminant	UV lamp	Reference
Natural Organic Matter (NOM)	MPUV	Palmer et al., 2002
	LPUV	Le-Clech et al., 2006; Huang et al., 2008; Tercero Espinoza et al., 2008
	max 365 nm	Bekbolet et al., 2002; Kerc et al., 2003-2004; Uyguner et al., 2004; Liu et al., 2008; Liu et al., 2010
	300-400 nm	Gonenc and Bekbolet, 2001
	335 nm	Rizzo et al., 2006
	Suspended Degussa TiO_2/solar UV simulator	Tercero Espinoza et al., 2009
	Suspended Degussa TiO_2/UV	Uyguner et al., 2007
	VUV LP	Azrague and Østerhus, 2015
Algal metabolites	254 nm	Son et al., 2006
Pharmaceuticals	UV-A	Elgendirger et al., 2006
Phenol	sunlight	Toyoda et al., 2000
	310-470 nm	Tryba et al., 2006
Bisphenol-A	254 and 360 nm	Nam et al., 2006
Erbicides Pesticides	MPUV	Hequet et al., 2001
	LPUV	Sanches et al., 2010
	Xenon	Konstantinov et al., 2001
	1000 W Hg	Daneshvar et al., 2000

AOP applications in drinking water treatment plants

UV/H_2O_2

- Several **full-scale applications** in USA, Canada, Holland, England
- Removal of Nitrosodimethylamine (NDMA), 1,4-dioxane, 2-Methylisoborneol (MIB), geosmin, caffeine, trichloroethylene (TCE)

UV/O_3

- Commercially used process also with **some full-scale applications**
- Removal of trichloroethylene (TCE), Perchloroethene (PCE) and trinitrotoluene (TNT)
- Not economic compared to the UV/H_2O_2 process

H_2O_2/O_3

- **Several full-scale applications**
- Removal of odor compounds, herbicides (e.g., atrazine), pesticides, VOCs, halogenated compounds such as 1,1-dichloropropene (DCPE), TCE, 1-chloropentane (CPA), and 1,2-dichloroethane (DCA)
- More economic than to the UV/O_3 process

UV and TiO_2

- **Few full-scale applications**
- **Pilot plants** for the optimization of the process

(Sarathy and Mohseni, 2006; Sarathy et al., 2011; Yang et al., 2014; Wang et al., 2015)

AOP
RESEARCH EXPERIENCES

1. **Geosmin, 2-methylisoborneol and bromate removal by O_3/UV**
2. **Arsenic and terbuthylazine (TBA) oxidation by UV/H_2O_2**

Introduction

- **Geosmin** and **2-methylisoborneol (MIB)** are secondary metabolites produced by actinomycetes (bacteria), and blue-green algae (Cyanobacteria) and are associated with water from surface and/or eutrophic systems

  Geosmin and MIB are volatile organic compounds that cause taste and odour in surface waters, dramatically impacting the esthetic quality and consumer acceptability of drinking water

  No guideline values are fixed by the World Health Organization (WHO)

- **Metolachlor** is an organic compound that is widely used as an herbicide.

- **Bromate** is not normally found in water, but can occur as a result of pollution from industrial sources, sometimes as a consequence of its presence in contaminated soil. However, the main source in drinking-water is its formation during ozonation when bromide ions are present in water

  The WHO derived a provisional guideline value of 10 µg/L for bromate

Materials and methods

- The aim of this work is to investigate the effectiveness of the O_3/UV process on geosmin and MIB removal and on bromate minimization.

- Batch tests were carried out using a pilot plant (10 L/min)

- Operational conditions applied in the tests:
  - O_3 concentration=0-15 mg/L
  - t_c (contact time)=0-17 min
  - UV dose=0-14000 J/m^2

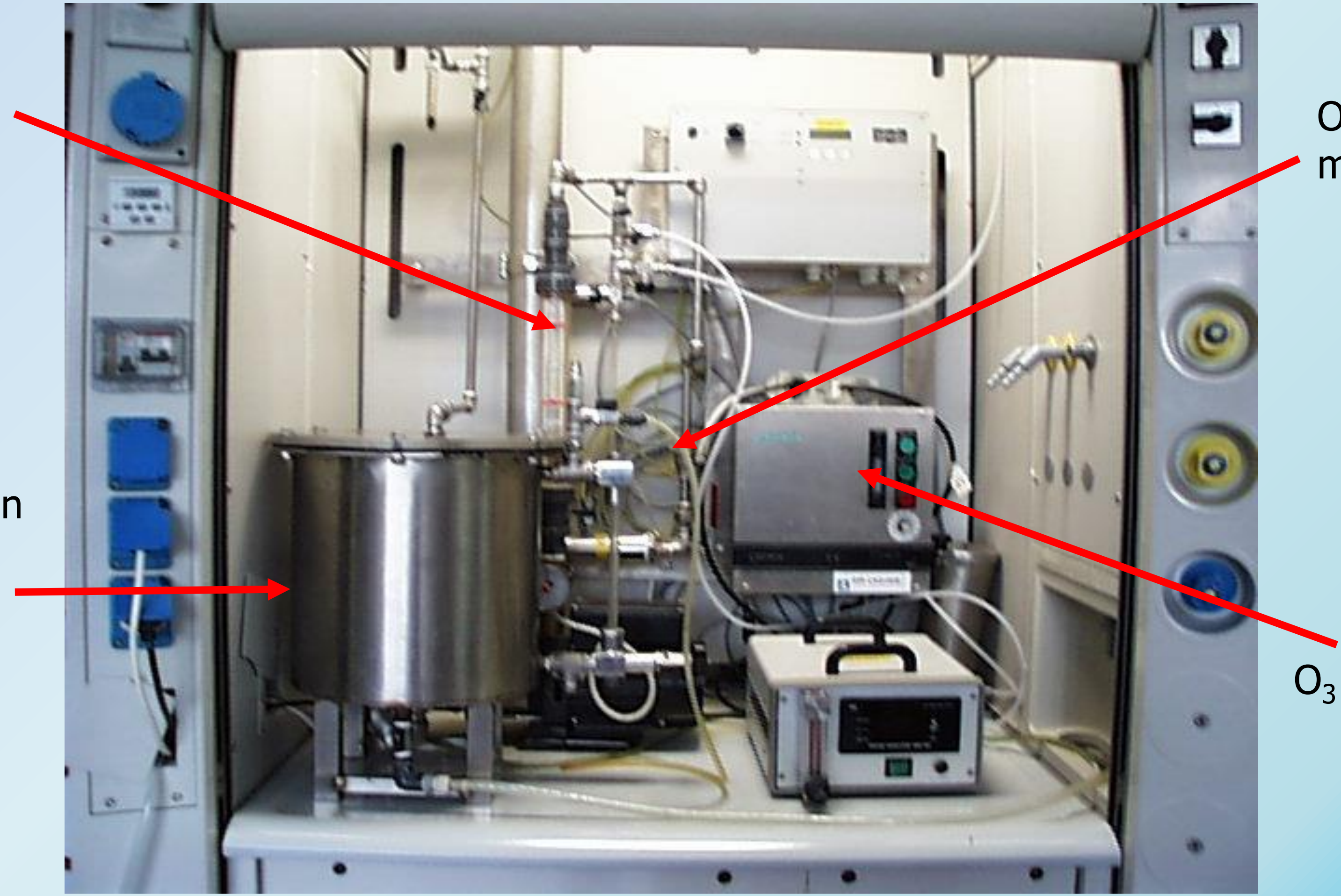
WATER QUALITY

- Surface water from river Secchia (Reggio Emilia, North Italy)

Parameter		**Average**	**Max**	**Min**
pH	(pH unit)	8,0	8,3	7,6
Alkalinity	(mgHCO$_3$/L)	173,9	263,2	136,4
Turbidity	(NTU)	7,9	38,8	1,7
TOC	(mg/L)	1,8	3,4	0,6
UV Abs. 254 nm	(1/cm)	0,360	0,900	0,058
UVT	(%)	63,0	51,0	83,0
THMFP	(μg/L)	76,0	124,5	18,0
Bromide	(μg/L)	32,9	91,0	5,0
Ammonia	(mgNH$_4$/L)	0,050	0,140	<0,005

- Addition of artificial contaminants:
  - 0,5 μg/L **geosmin** (*trans*-1,10-dimethyl-*trans*-9-decalol)
  - 0,2-0,4 μg/L **MIB** (2-methylisoborneol)
  - 7-10 μg/L **metolachlor** [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl)-acetamide

Pilot plant



UV lamp

O_3/water mixing

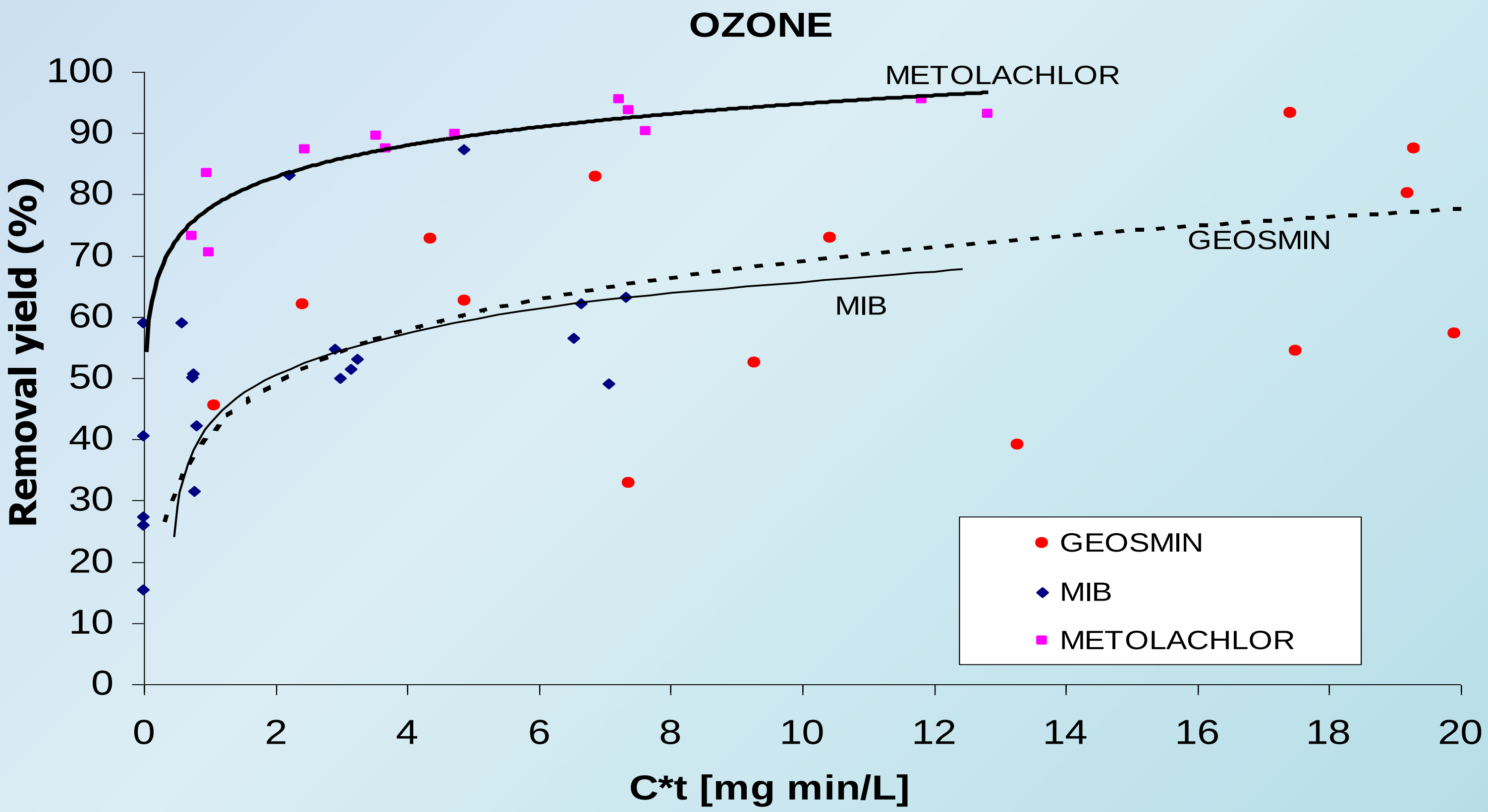
Oxidation reactor V=20 L

O_3 generator

- Q = 10 L/min
- Produced O_3 = 8 gO_3/h (from O_2)
- LPUV lamp λ=254 nm e 185 nm; intensity 25 W/m^2

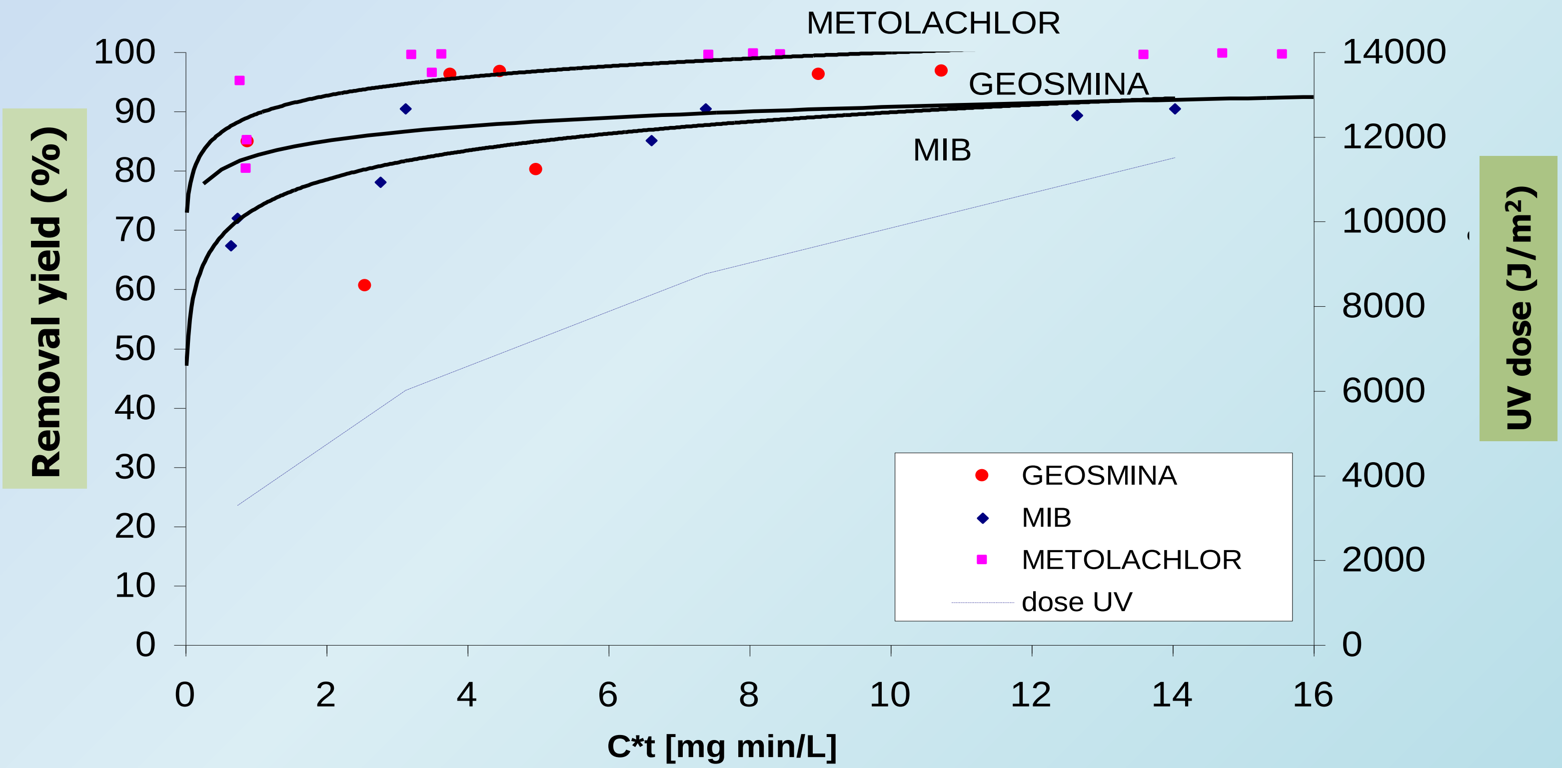
1. Geosmin, 2-methylisoborneol and bromate removal by O_3/UV

Results: O3



- Metolachlor is efficiently removed with C*t= 8-10 mg min/L (O3=1 mg/L and contact time 8-10 minutes)
- Lower removal for MIB and geosmin

Results: O3/UV (254 nm)

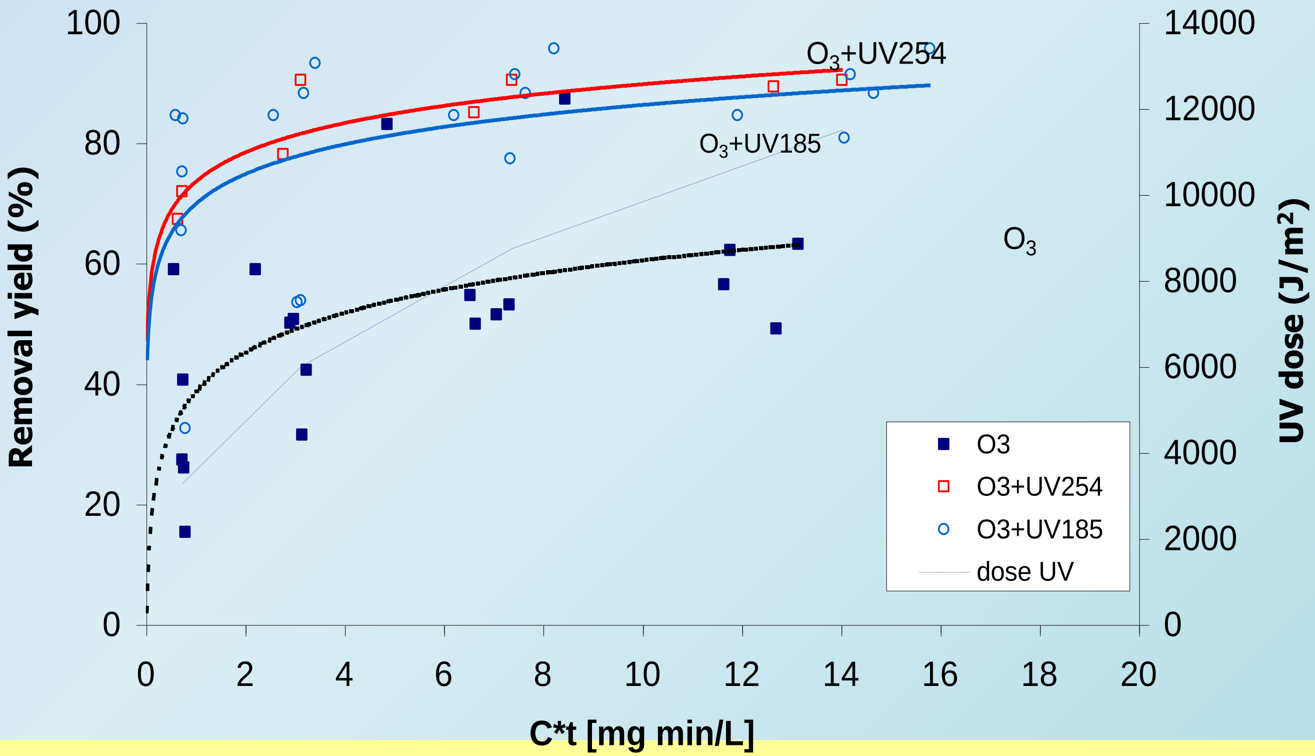


- ⇒ **Metolachlor**: complete removal with low C*t
- ⇒ **Geosmin:** good removal (>90%) for C*t= 10 mg min/L
- ⇒ **MIB:** most refractory contaminant (complete removal never reached)

1. Geosmin, 2-methylisoborneol and bromate removal by O_3/UV

Results

MIB



O_3

⇒ Removal from 20% with C*t=1 mg min/L to 60% with C*t=15 mg min/L (O_3=4-5 mg/L and t_c=4 min)

O_3+UV

⇒ 80-90% removal with C*t=5 mg min/L and UV dose=6.000 J/m²

⇒ Silimar results for O_3+UV254 nm and O_3+UV185nm

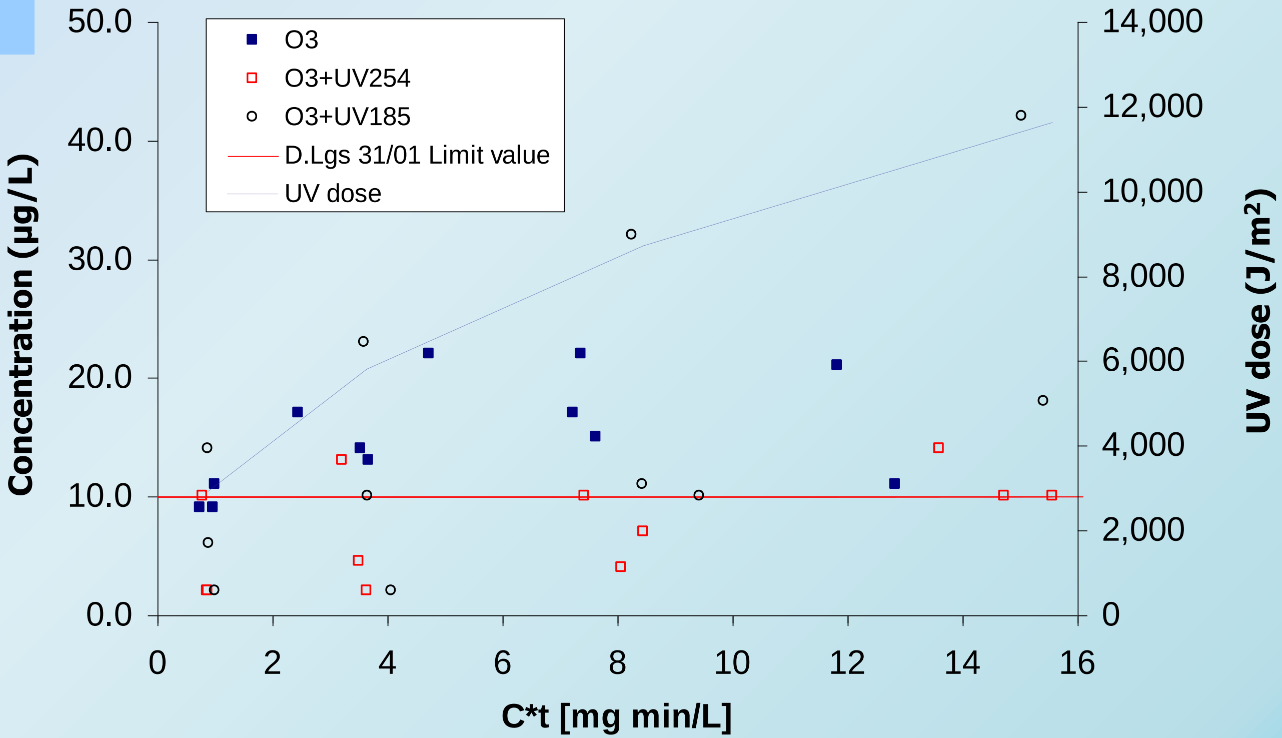
UV λ=180-300 nm

$2\,BrO_3^- + h\nu \rightarrow 2\,BrO_2^- + O_2$

$2\,BrO_2^- + h\nu \rightarrow 2\,BrO^- + O_2$

$2\,BrO^- + h\nu \rightarrow 2\,Br^- + O_2$

Results: bromate formation



- ⇒ Bromate formation with O_3/UV185nm is 10-20% lower compared to O_3 oxidation alone
- ⇒ The minimum bromate formation occurs by using O_3/UV254nm, where bromate formation is 40-50% less compared to O_3 alone. Final bromate concentration is below the regulation limit of 10 µg/L (Italian Leg. Decree 31/2001)

Introduction

- Arsenic (As) is **widespread** in soils, air and water. Even at very low concentrations in drinking water, As causes severe health effects (bladder cancer, renal cancer, etc.)

- The WHO lowered the maximum contaminant level from 50 to 10 µg/L in 1993. The European Union fixed the As **limit** in drinking water to **10 µg/L**

- In natural waters **inorganic As(III) and As(V)** are the most abundant compounds

- As **removal** from water can be obtained by means of different processes: chemical precipitation, adsorption (granular ferric hydroxide or activated alumina), ion exchange and reverse osmosis

- Better yields of removal with chemical precipitation, adsorption on activated alumina and ion exchange are obtained after **As oxidation** [As(III) → As(V)]

- Most full-scale applications are based on **conventional oxidation**. However, the **AOPs** could be successfully applied to the remediation of water contaminated by As and/or organic refractory contaminants

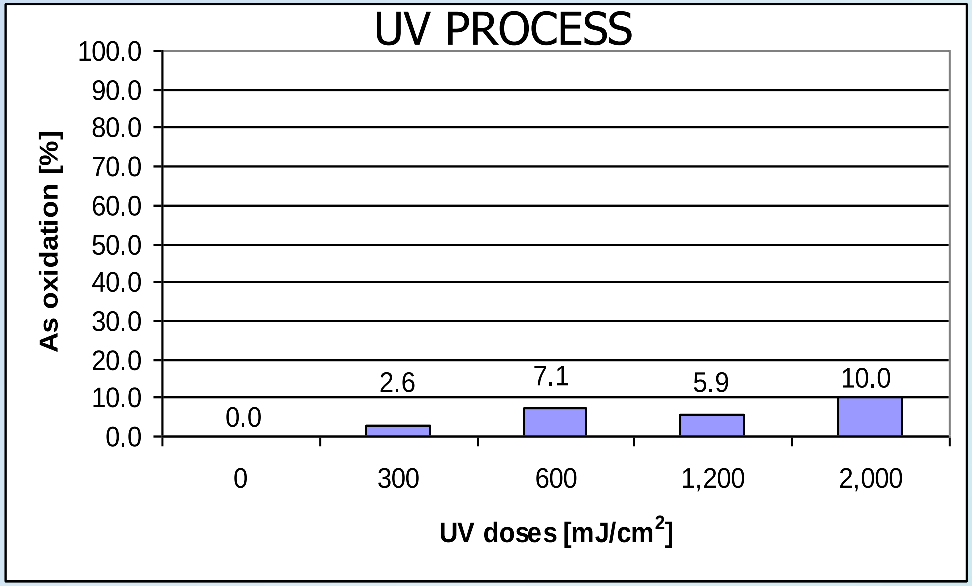
Materials and methods

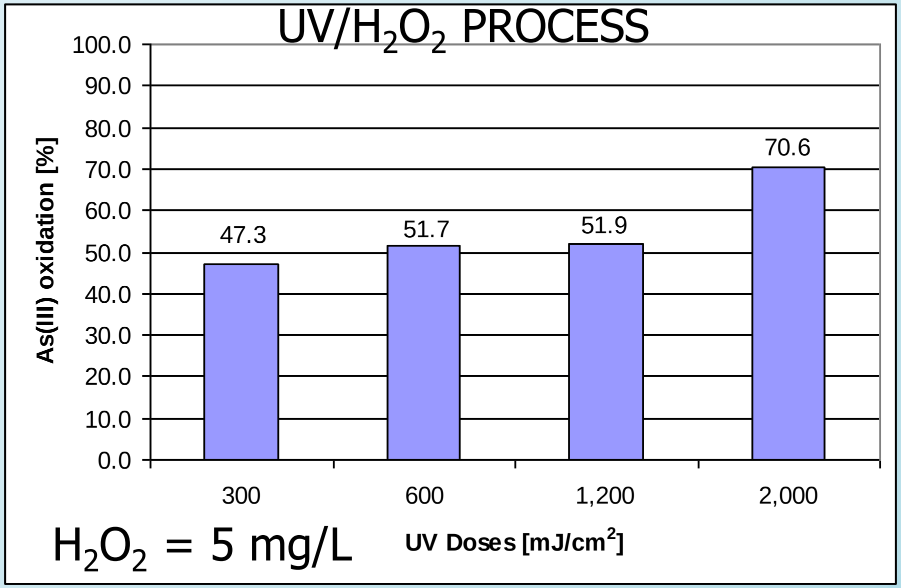
AIM OF TESTS	TYPE OF WATER	INITIAL As CONC. (mg/L)	INITIAL TBA CONC. (mg/L)	FLUENCE LEVELS (mJ/cm^2)	H_2O_2 CONC. (mg/L)
As oxidation	Distilled/ groundwater	0.100	-	0 - 300 – 600 – 1200 – 2000	0 - 5
TBA oxidation	Groundwater	0.015	0.010	0 - 300 – 1200 – 2000	0 - 5 – 10

- Collimated beam apparatus equipped with a low pressure mercury lamp ($E_0 = 0.2$ mW/cm^2)
- Tests with UV alone, H2O2 alone and UV/H2O2
- After each exposure time, the residual H_2O_2 was quenced with a bovine catalase solution
- Total As was determined by HG-AAS
- As(III) was analyzed in water filtered through an As(V)-selective resin. Therefore As(V) was calculated as difference between Total As and As(III)
- TBA was analyzed with SPME-GC-MS

Results

DISTILLED WATER





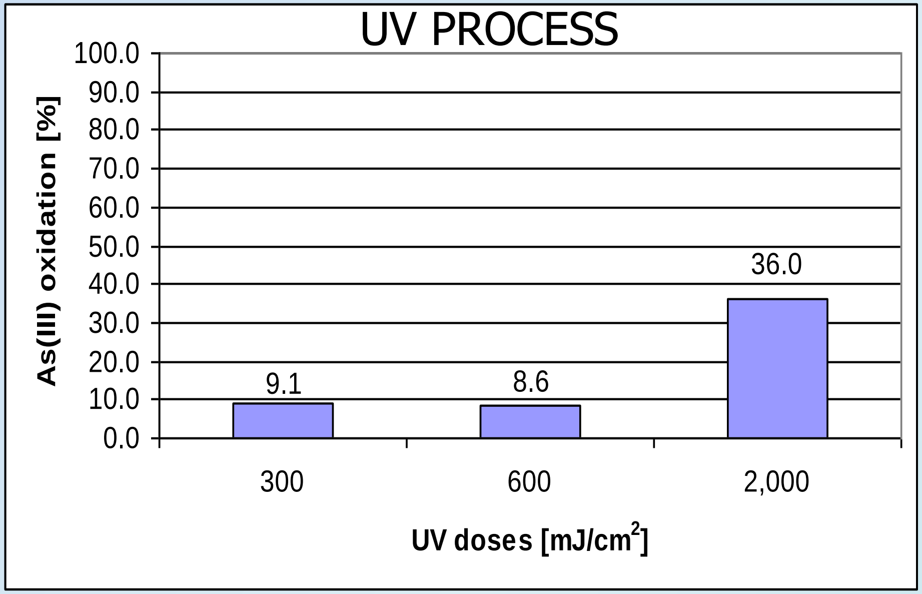
H_2O_2 = 5 mg/L

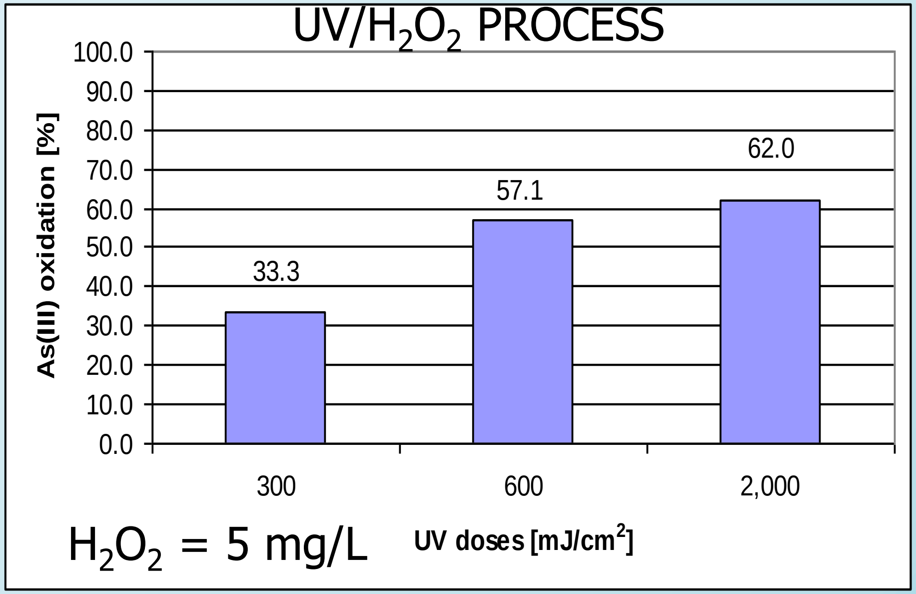
- As(III) oxidation yield with H_2O_2 and UV radiation separately applied is very low.
- UV alone: The maximum oxidation yield (still negligible) is obtained when an UV dose of 2000 mJ/cm² is employed.
- In the UV/H_2O_2 process, As(III) oxidation is relatively constant (~50%) with an UV dose of 300-1200 mJ/cm². Only with an UV dose of 2000 mJ/cm² the oxidation yield is significantly increased, up to 70%

2a. Arsenic oxidation by UV/H_2O_2

Results

GROUNDWATER





- Oxidation with H_2O_2 only is a very slow process, as observed in distilled water.
- Oxidation with UV radiation alone is a slow process too, except for high doses (2000 mJ/cm^2).
- The combination of H_2O_2 with different UV doses can efficiently oxidize As(III). A good oxidation yield (62%) is obtained at 600 mJ/cm^2 with 5 mg/L H_2O_2. The application of higher UV doses does not improve the performance

Introduction

- Terbuthylazine (TBA) is a **herbicide** that belongs to the chlorotriazine family, is used in both pre-emergence and post-emergence treatment of a variety of agricultural crops and in forestry. Degradation of TBA in natural water depends on the presence of sediments and biological activity

- Concentrations in water **seldom exceed 0.2 µg/L**, although higher concentrations have been observed

- There is no evidence that TBA is carcinogenic or mutagenic. In long-term dietary studies in rats, effects on red blood cell parameters in females, an increased incidence of non-neoplastic lesions in the liver, lung, thyroid and testis and a slight decrease in body weight gain were observed

- To protect human health, the **WHO** derived a **guideline value of 7 µg/L** for TBA in drinking water

Materials and methods

- The aim of this work is to assess the combination of H_2O_2 and UV radiation in order to oxidize TBA in groundwater for drinking use

- Operational conditions applied in the tests are shown below

Type of water	**Initial TBA concentration (mg/L)**	**Fluence levels (mJ/cm²)**	**H_2O_2 concentration (mg/L)**
groundwater	0.010	0-300-1200-2000	0-5-10

Results

- UV radiation seems to be effective on TBA degradation while no significant removal is observed with H_2O_2 alone
- Good TBA oxidation yields (>90%) can be reached with H_2O_2 (5 mg/L) combined with a high UV radiation dose (2000 mJ/cm^2)

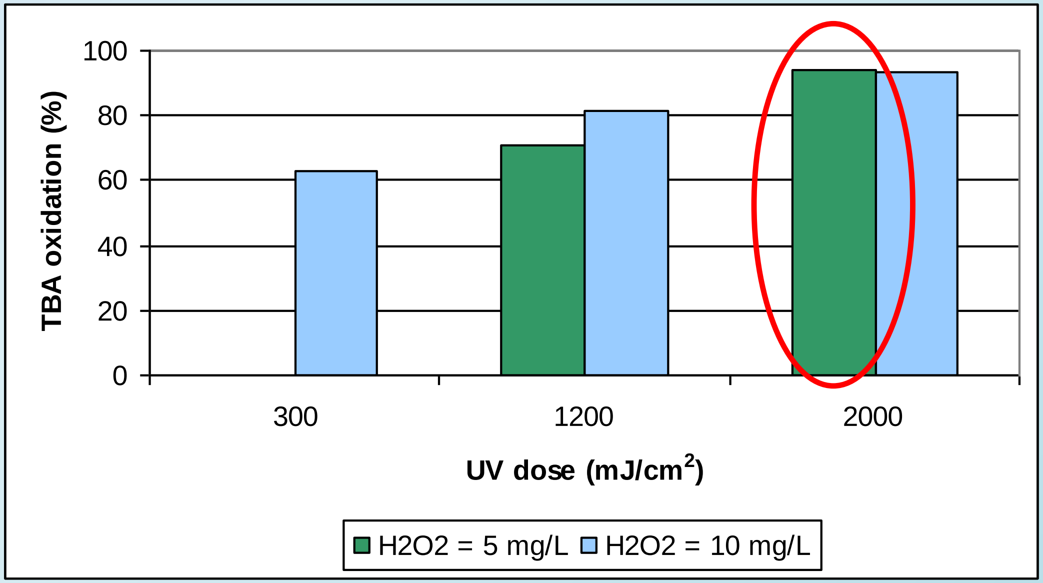


Figure 2b.1 - TBA oxidation yields with different UV and H_2O_2 doses

Practical considerations

- AOPs are effective for destroying organic pollutants that are refractory to conventional oxidation processes
- The most commercially available AOPs for drinking water treatment are O3/H2O2, UV/H2O2 and O3/UV
- Attention to water chemical and physical properties that can have major impact on AOPs because they scavange $OH^{\bullet}$ or absorb UV light:
  - Carbonate species
  - pH
  - NOM
  - Reduced metals (Fe2+ Mn2+)
  - UV light transmittance (UVT)
- The evaluation of these parameters is essential to verify the water treatability with AOPs and investigate pre-treatment and post-treatment options that may be needed
- Experimental tests are necessary for evaluating the applicability of AOPs to specific types of water

Thank you!

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