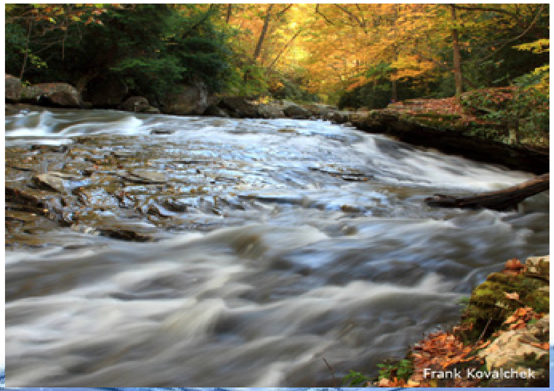
UV Advanced Oxidation

Madjid Mohseni, Ph.D., P.Eng.
Professor
Department of Chemical & Biological Engineering
University of British Columbia
Vancouver, CANADA

Drinking Water



Micropollutants in Water (Global Dimension)

Anthropogenic fluxes affecting water quality

	10^6 tons /year
Global fertilizer production (2000)	140
Global pesticide production	5
Synthetic organic production	300
Oil spills (average 1980-2000)	0.4

source: Science Magazine vol. 313 (2006)

Drinking Water

Treatment necessary before consumption for:

- Disinfection (removal of pathogens)
- Reduction of disinfection by-product (DBP) formation
- Removal of emerging pollutants
- Improving taste and odour

UV Disinfection

Presently

Several thousands drinking water facilities use UV based disinfection

Is the application of UV limited to water disinfection?

Can UV play a role in addressing other water quality challenges?

UV-Based Oxidation Processes

UV photochemical oxidation processes for water treatment involve:

- Direct photolytic action of UV on dissolved matter in water (e.g. micropollutants)
- Photochemically assisted production of oxidants for removing harmful organic matter
- Photochemically assisted catalytic processes

UV-based Oxidation

1879 H_2O_2 decomposition by sunlight (Downes & Blunt)

1899 Photolysis of carbonic acid (Bach)

1907 H_2O_2 decomposition by UV (Thiele)

1922 H_2O_2 photolysis and reaction products (Kornfeld)

1936 Photomineralization by VUV (Fricke & Hart)

1971 Photocatalytic oxidation of single compounds in the gas phase

2004 First full scale UV-H2O2 plant for water treatment

UV Photooxidation

Advanced Oxidation Process (AOP)

hn

H_2O

O_2

Organic Matter

Oxidant (O_3 or H_2O_2)

$\xrightarrow{\cdot OH}$

CO_2

H_2O

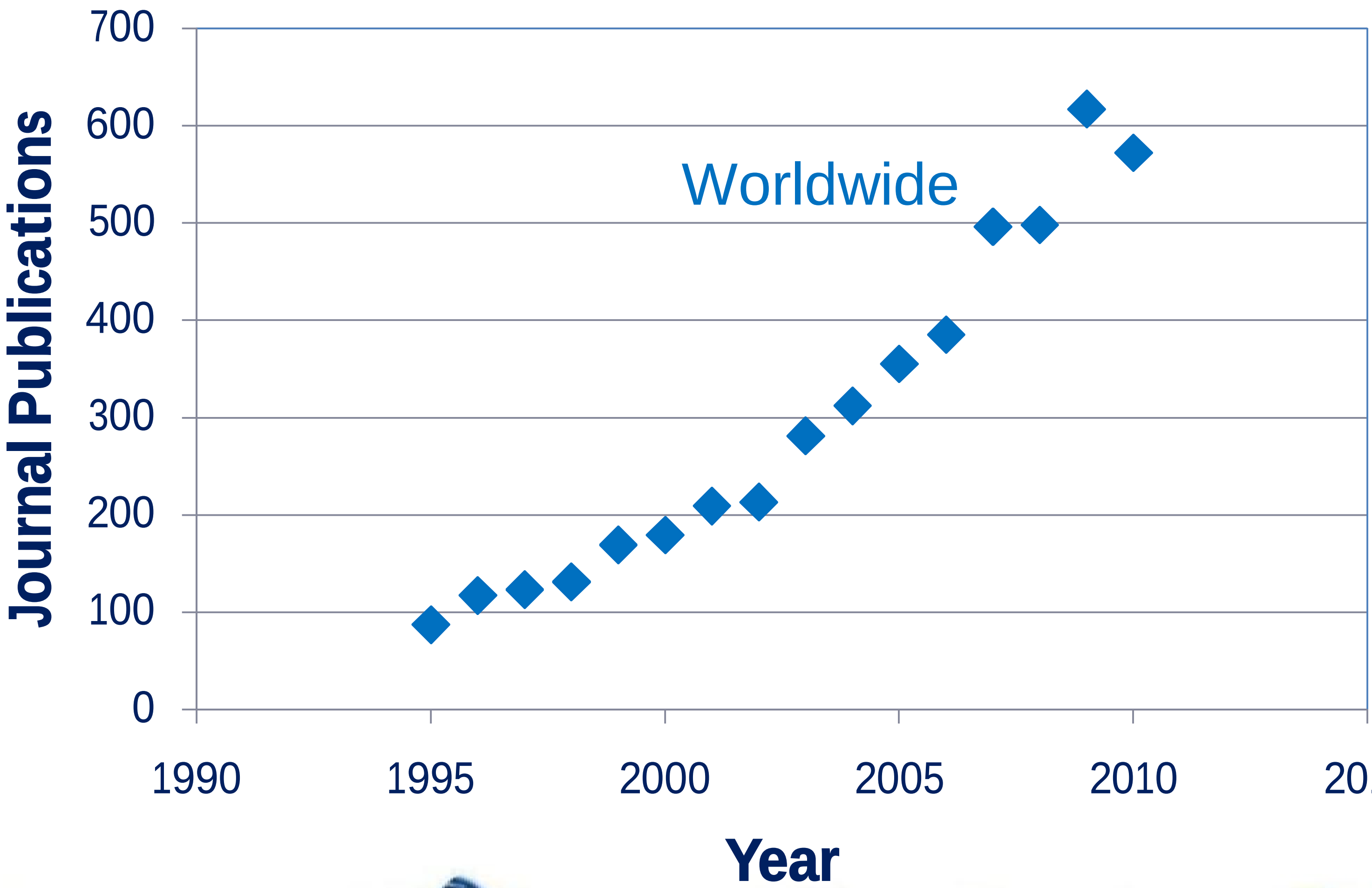
Intermediates

OH Radical
Oxidation Potential

Oxidizing species	Oxidation potential (eV)
Fluorine	3.06
Hydroxyl radical	**2.80**
Atomic oxygen	2.42
Ozone	2.07
Hydrogen peroxide	1.78
Chlorine dioxide	1.57
Chlorine	1.36
Oxygen	1.23

UV Oxidation Research in Water

<u>To Date:</u> Worldwide: ~5500



UV Oxidation for Water Purification Patents

To Date:

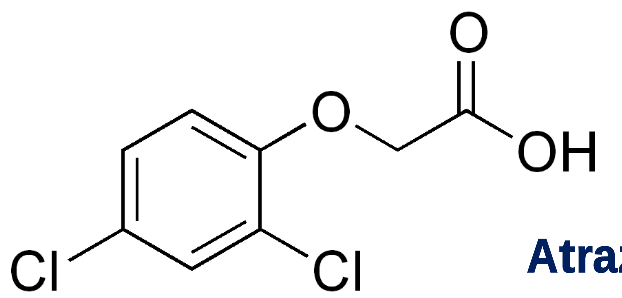
- Number of Patents Worldwide: ~1,100

UV AOP in Drinking Water

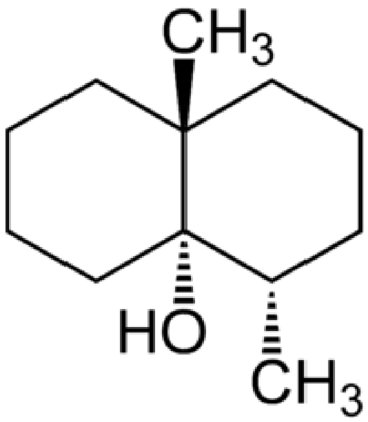
- Ultraviolet + Hydrogen Peroxide: **UV/H_2O_2**
- Photocatalysis: **UV/TiO_2**
- Vacuum Ultraviolet: **VUV**

Target Contaminants

- Micro-pollutants
  - Pesticides
  - Pharmaceuticals
  - Personal care products
- Taste & odor (T&O)
- Gasoline additives
- Surfactants
- Flame retardants



Atrazine

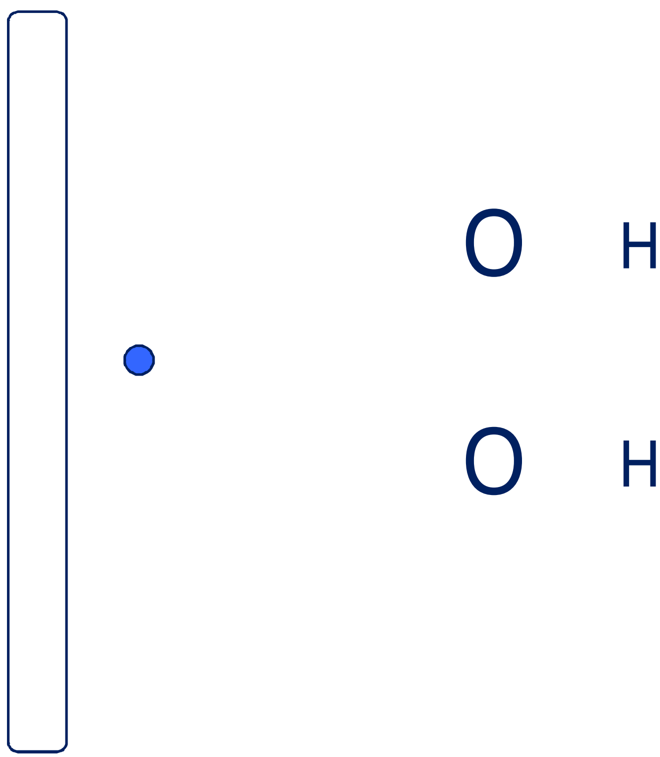


Geosmin

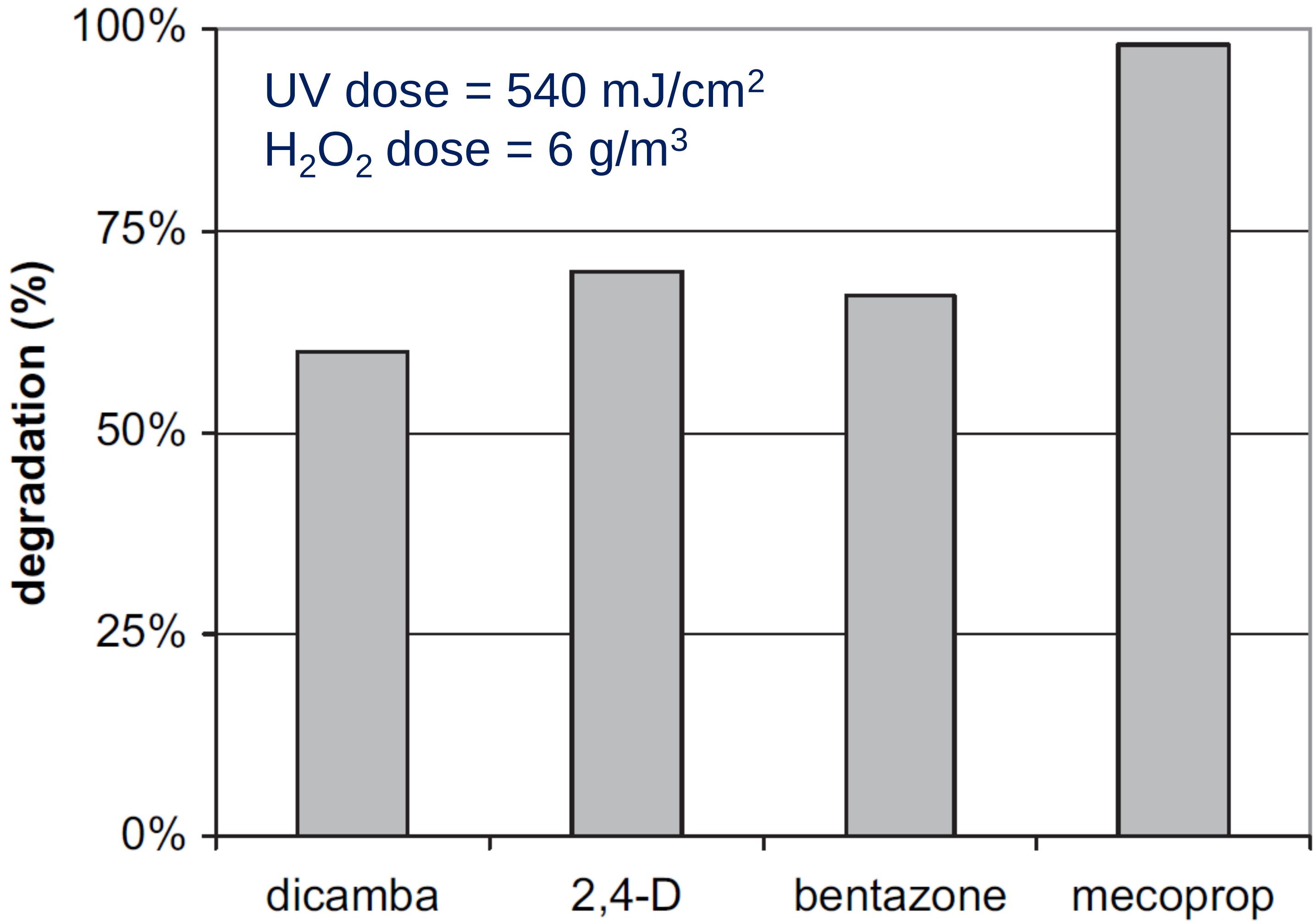
UV-H_2O_2 Advanced Oxidation

UV-H_2O_2 AOP

$$H_2O_2 + hv_{<270\ nm} \rightarrow 2HO\bullet$$

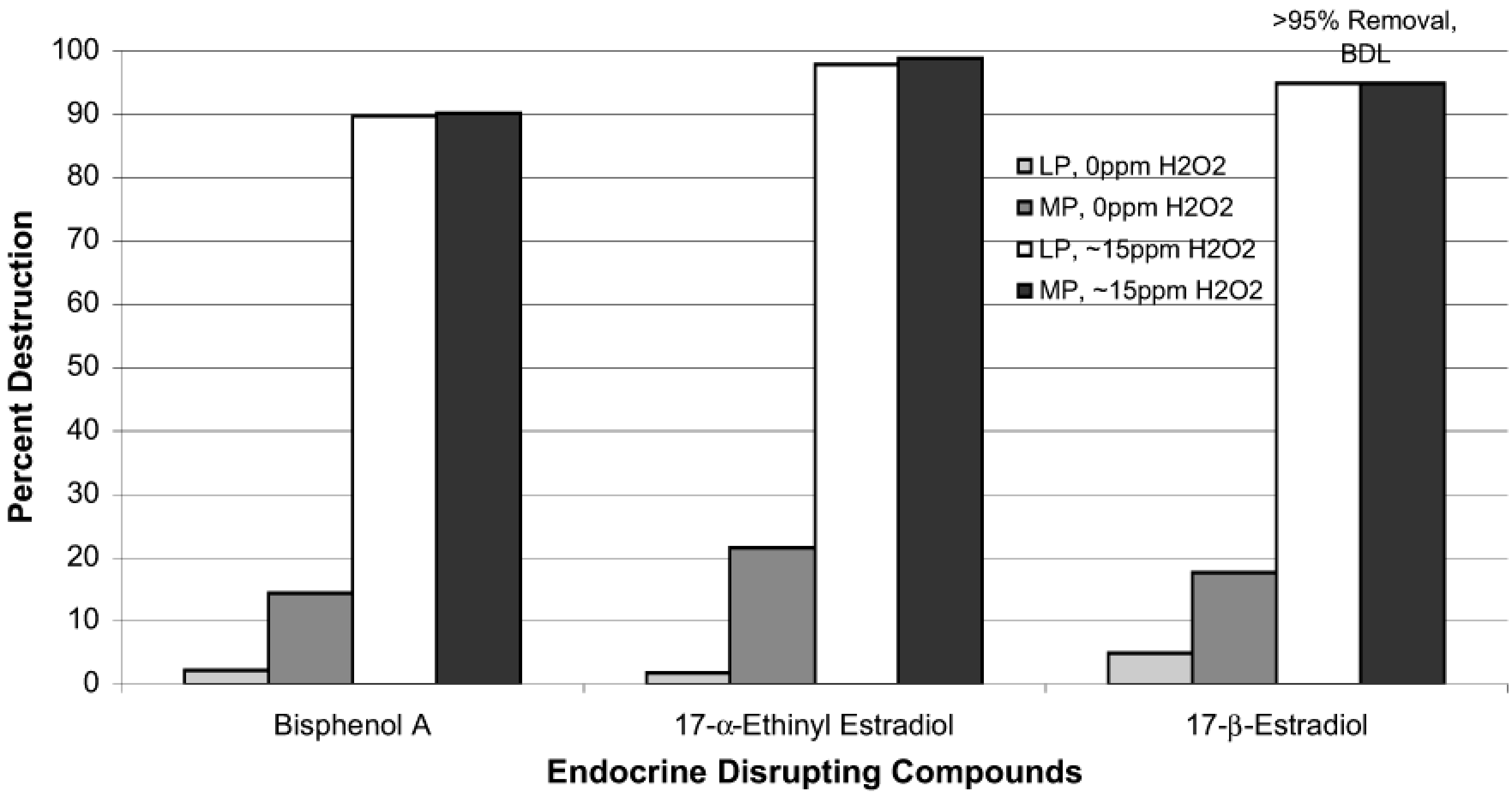


Impact of UV/H_2O_2 on Pesticides



Kruithof et al., 2007

Impact of UV/H_2O_2 on EDCs



Rosenfeldt and Linden, 2004

Drinking Water UV-H_2O_2 AOP

Treatment conditions (commercial applications)

- Fluence: $\geq$ 600 mJ/cm^2
- H_2O_2 dose: 5 to 15 mg/L
- LP and MP Hg lamp technology

Drinking Water UV-H_2O_2 AOP

Commercial drinking water applications

Installation	UV System	Target Pollutant
Orange County Water District, CA, USA	TrojanUVPhox™	NDMA; 1,4-dioxane
West Basin Municipal Water District, CA, USA	TrojanUVPhox™	NDMA
Stockton, CA, USA	TrojanUVPhox™	1,4-dioxane
PWN Treatment Plant Andijk, Netherlands	TrojanUVSwift™ ECT	Pesticides
City of Cornwall, ON, Canada	TrojanUVSwift™ ECT	MIB & geosmin
Salt Lake City Department of Public Utilities, UT, USA	Rayox™	PCE

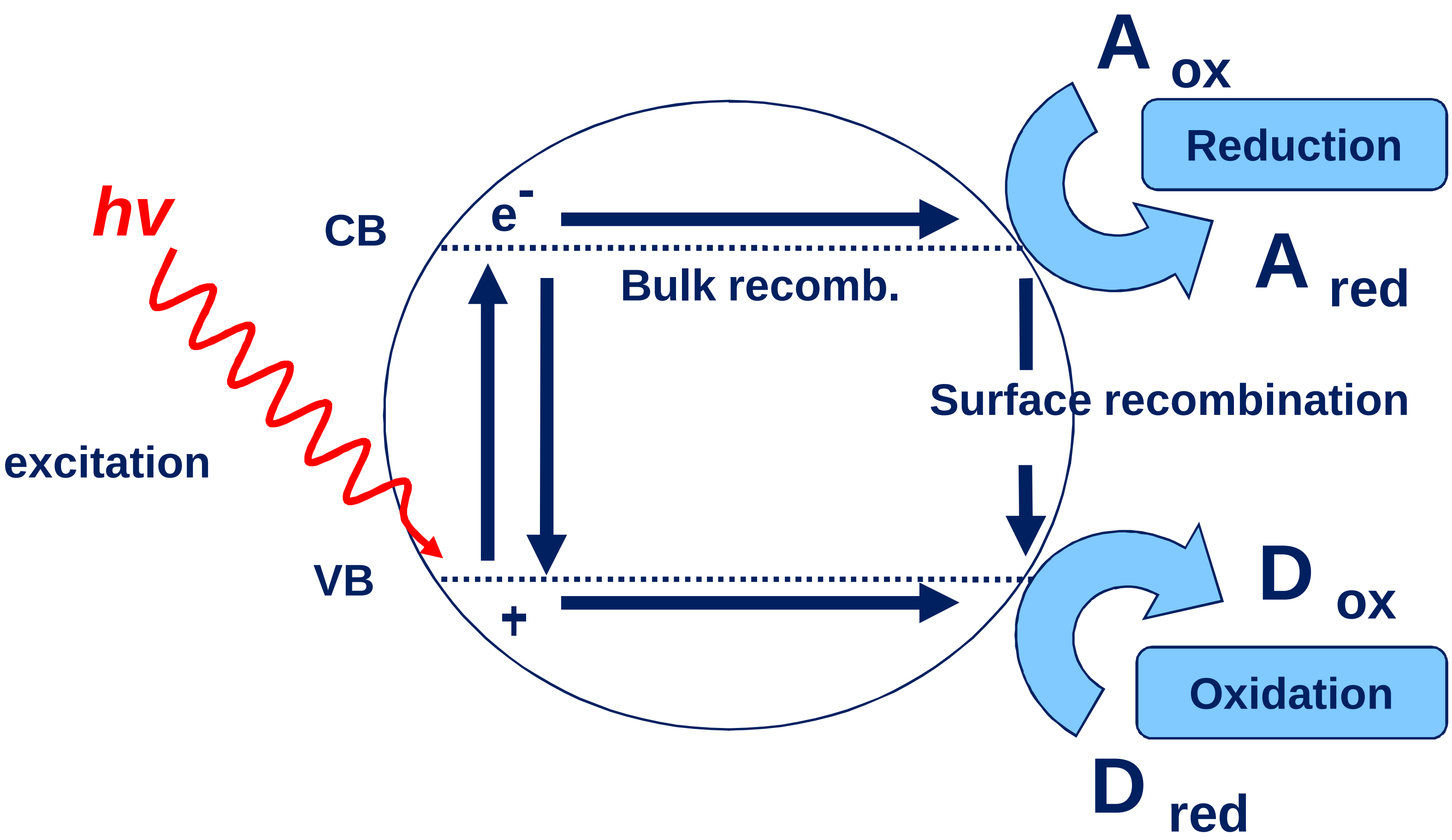
Sarathy, S.R. and Mohseni, M. 2006. An overview of UV-based advanced oxidation processes for drinking water treatment. IUVA News. 8(2): 16-27.


TROJANUVSWIFT ECT

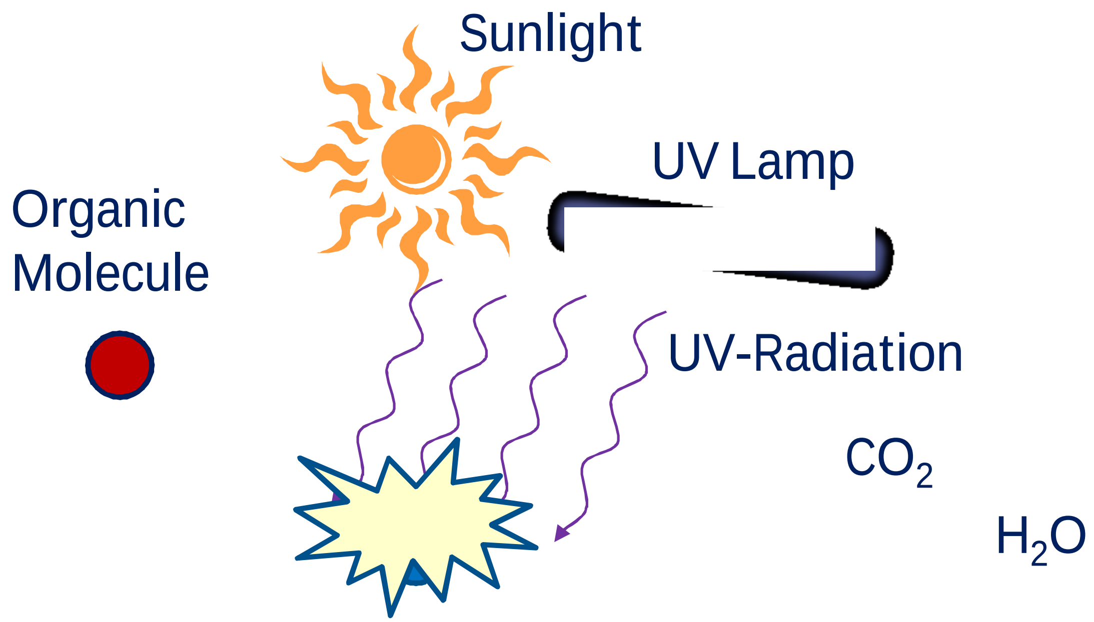

ULTRAVIOLET LIGHT

UV Photocatalysis

UV Photocatalysis



UV Photocatalysis



TiO_2 Photocatalyst

Well known photocatalyst

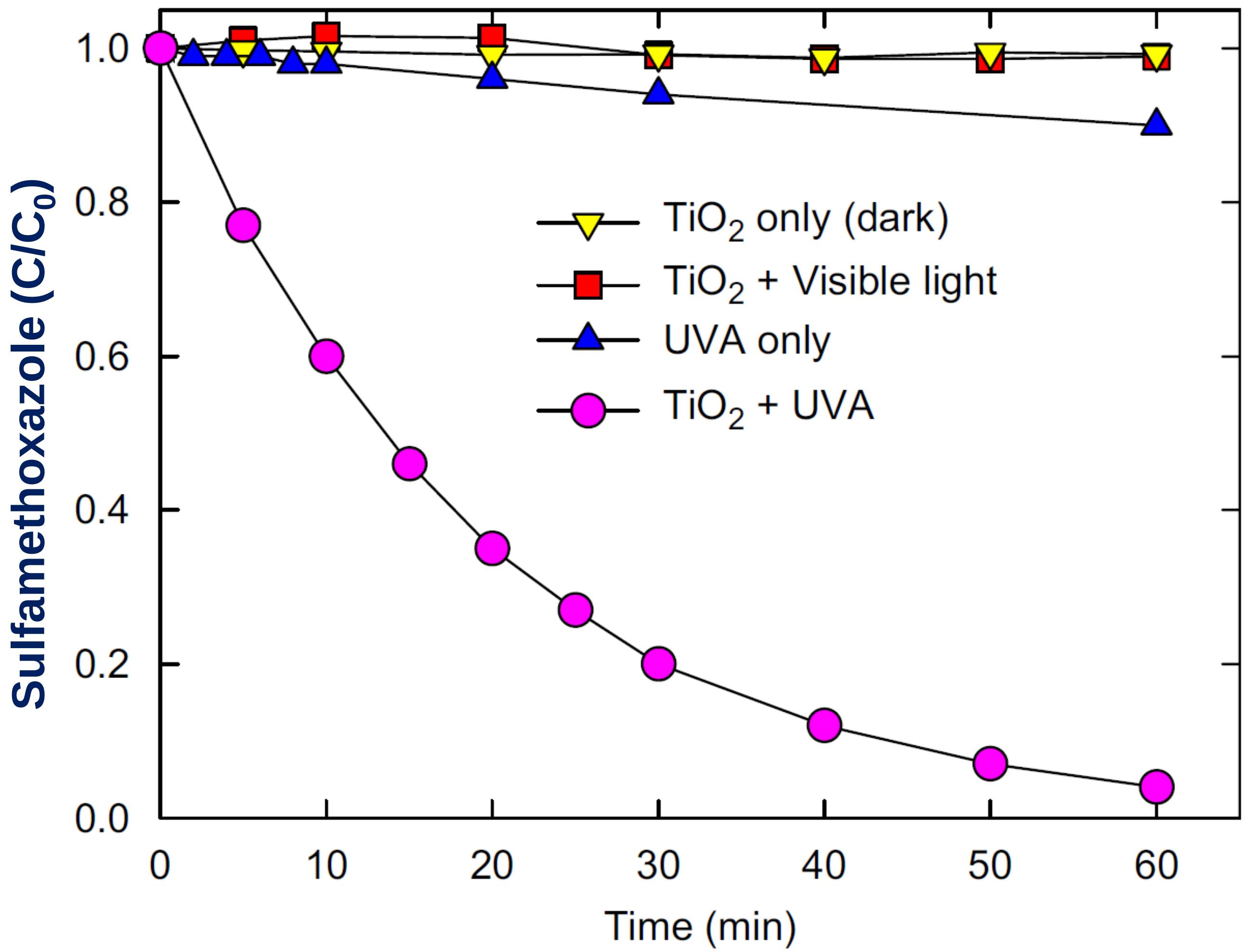
- ✓ Inexpensive
- ✓ Chemically stable
- ✓ Strong oxidation-reduction reactions

Commercial TiO_2

(Degussa P-25)

80% Anatase – 20% Rutile

PCO of Pharmaceuticals
with suspended TiO_2

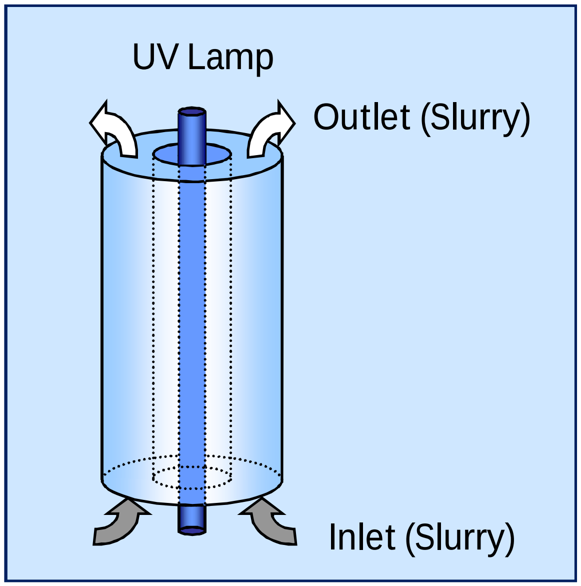


Hu et al., 2007

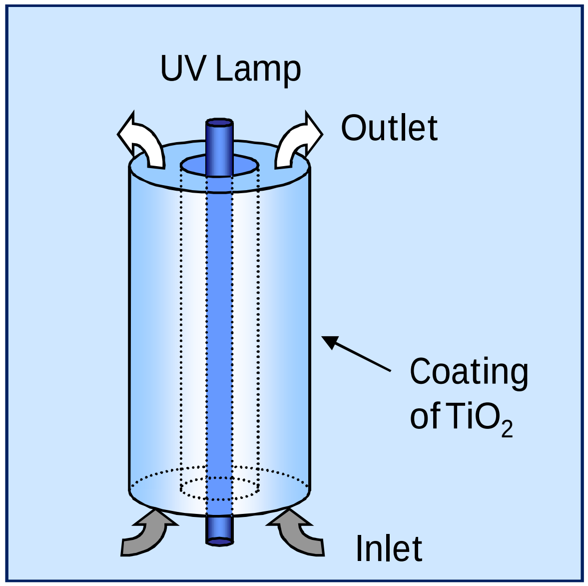
Photocatalytic Reactors

State of the photocatalyst →

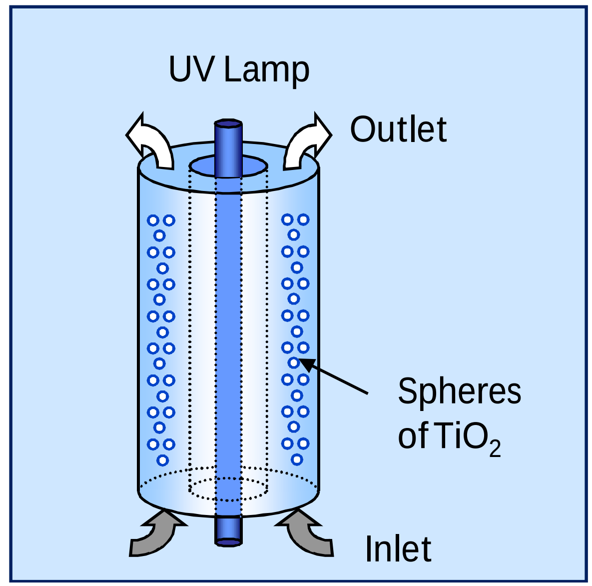
1. Slurry
2. Immobilized
3. Fluidized bed



Slurry

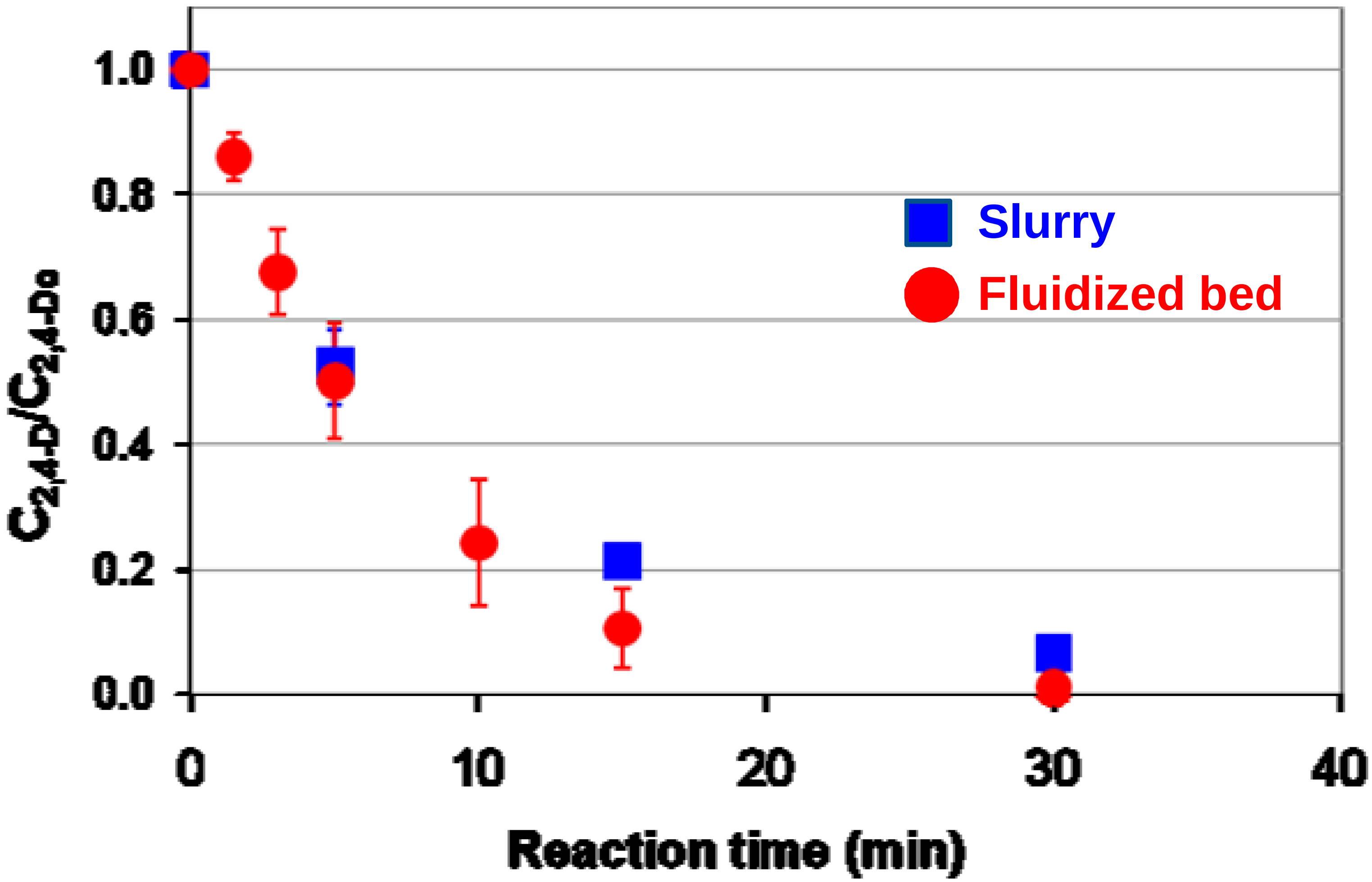


Immobilized



Fluidized bed

Slurry vs. Fluidized Bed PCO



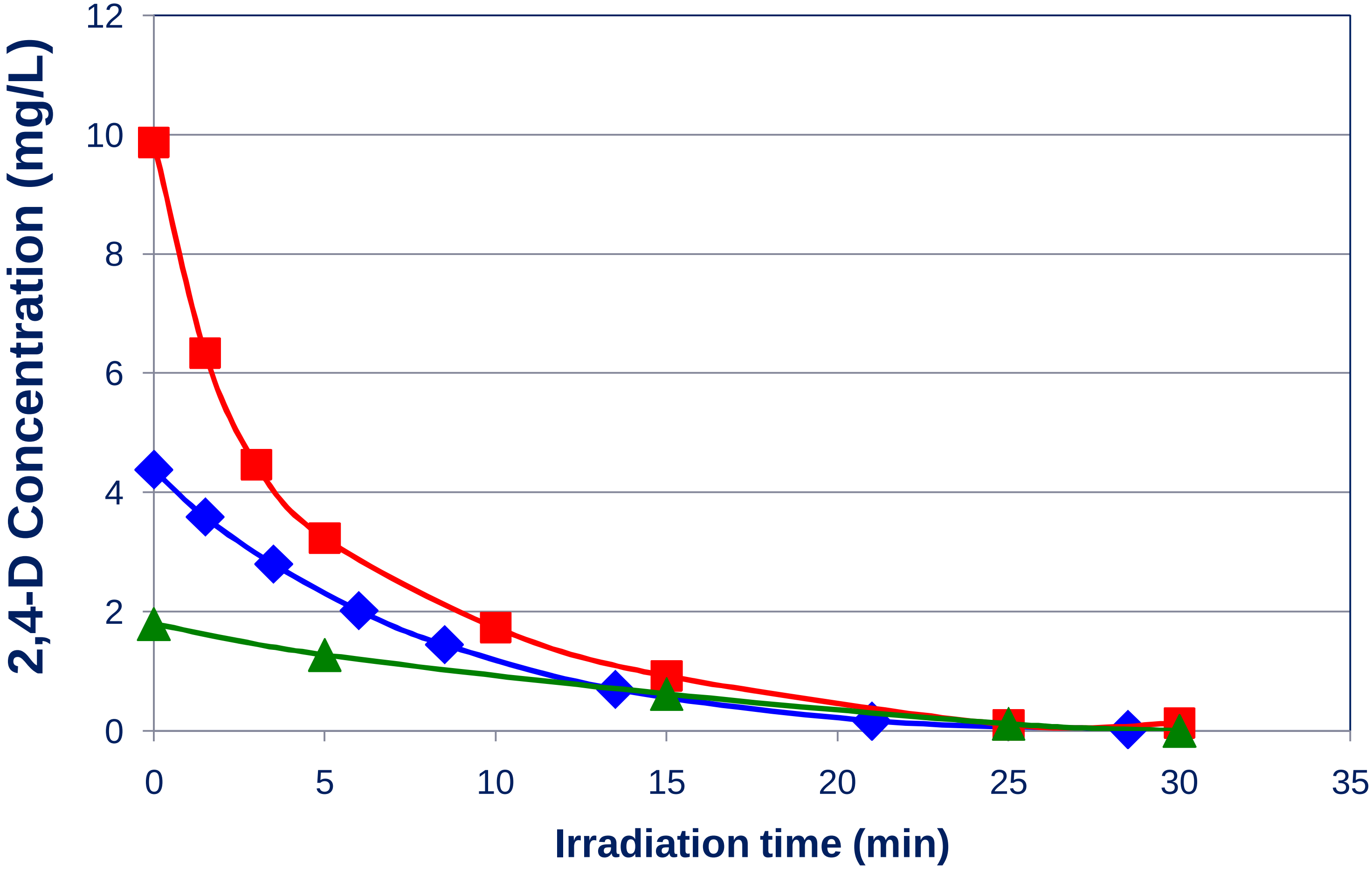
Vega, 2009

Slurry vs. Fluidized Bed PCO

- Comparable degradation of contaminant in slurry and fluidized bed photocatalytic reactor

No need for downstream filtration with fluidized bed process ∴ **More feasible process**

PCO of 2,4-D
(fluidized bed photoreactor)



Vega et al., 2011

Vacuum UV (VUV) Photooxidation

VUV

- Radiation with wavelength between 10 - 200 nm
- VUV photolyzes water molecules, which produce HO• radicals
  - High absorptivity of water at low wavelengths

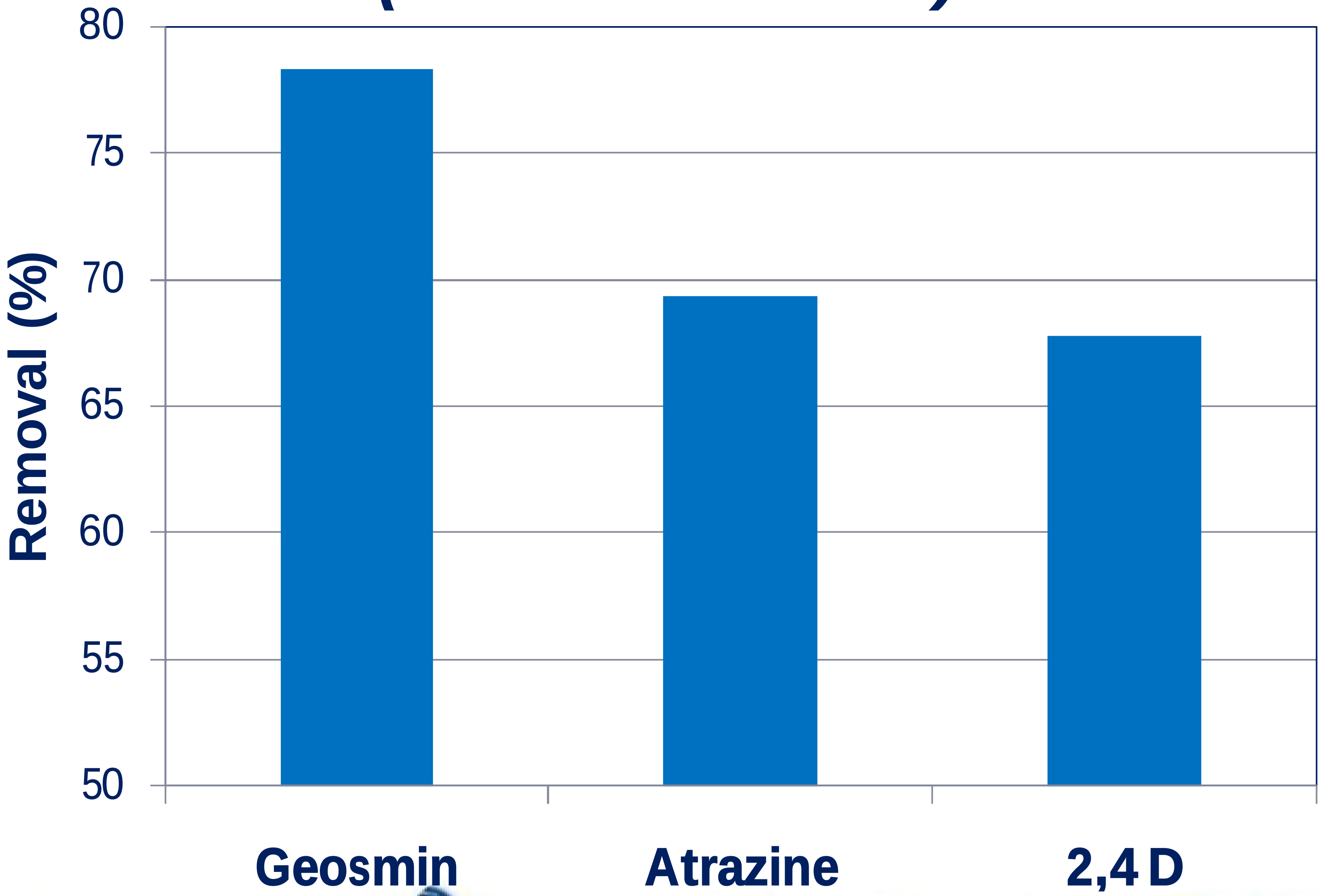
$$H_2O + hv_{vuv} \rightarrow HO\bullet + H\bullet$$

$$H_2O + hv_{vuv} \rightarrow HO\bullet + e^{-} + H^{+}$$

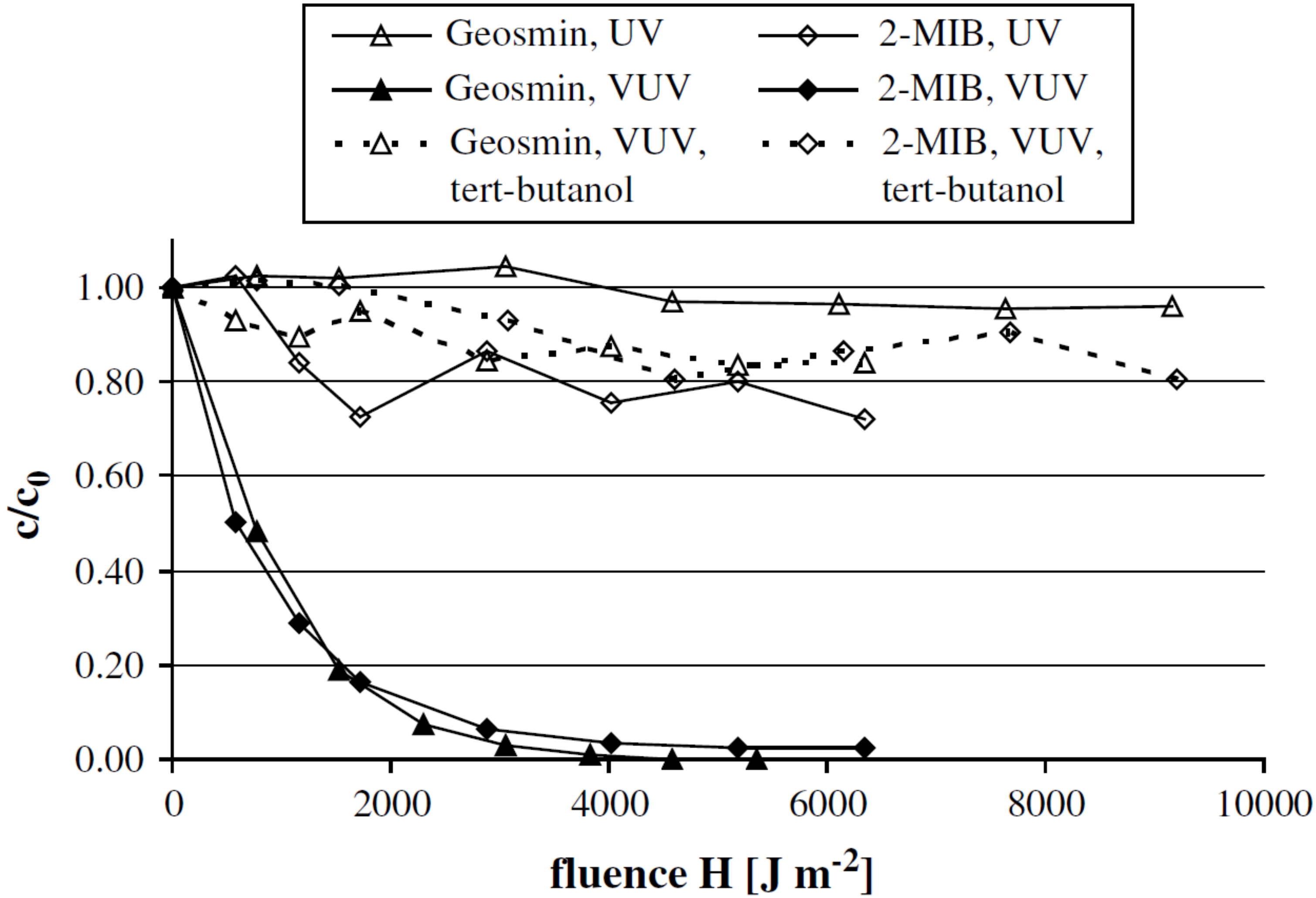
- Two common sources of VUV
  - ✓ Excimer lamp: 173 nm
  - ✓ Hg vapor lamp: 185 nm (+ 254 nm)

VUV Photooxidation

(in natural water)

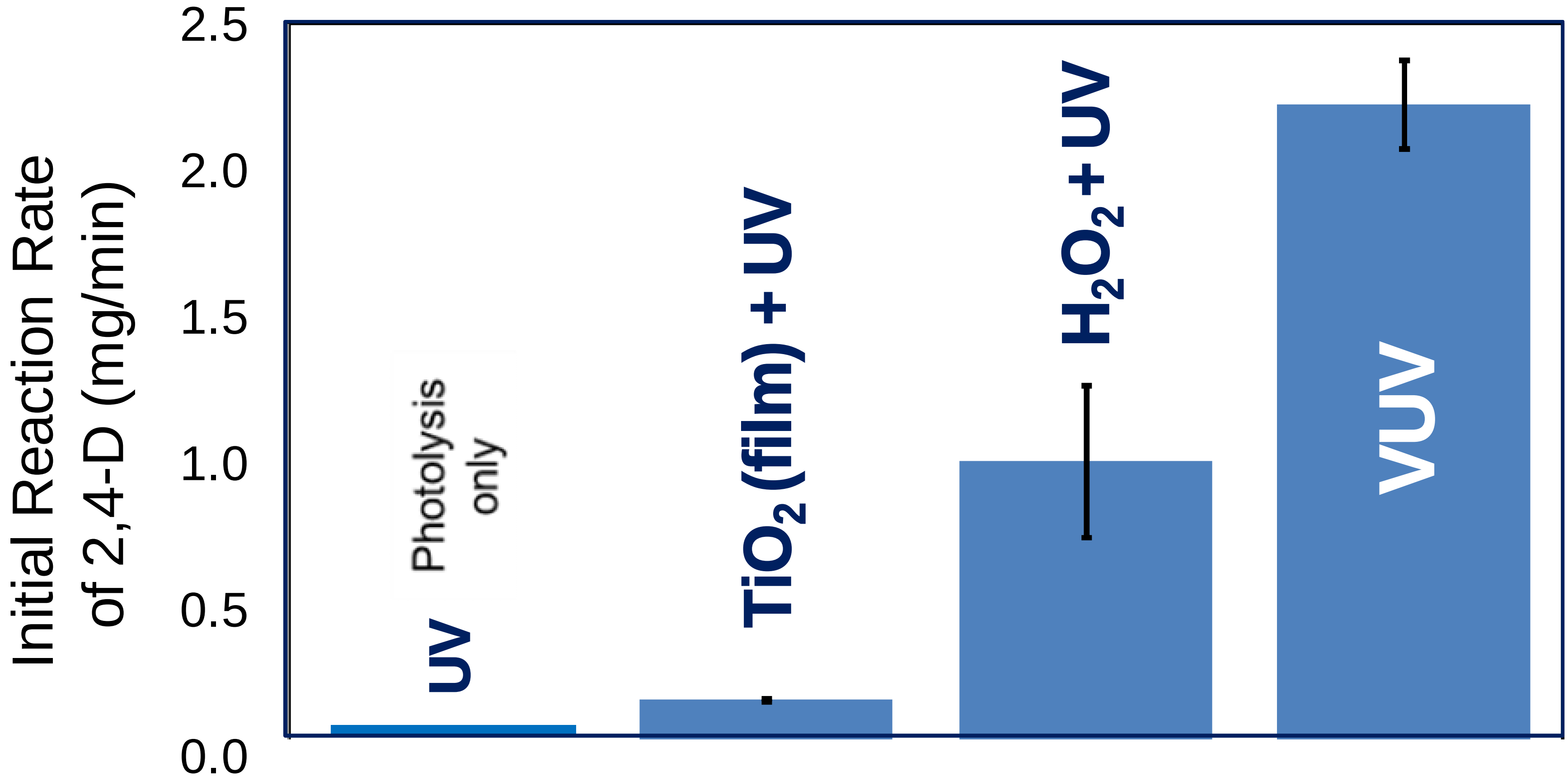


VUV Photooxidation of T&O



Kutschera et al., 2009

Comparison of Different AOPs



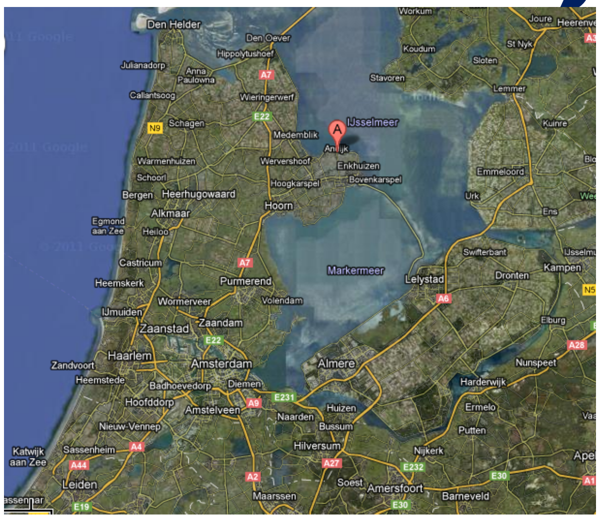
Imoberdorf & Mohseni, 2011

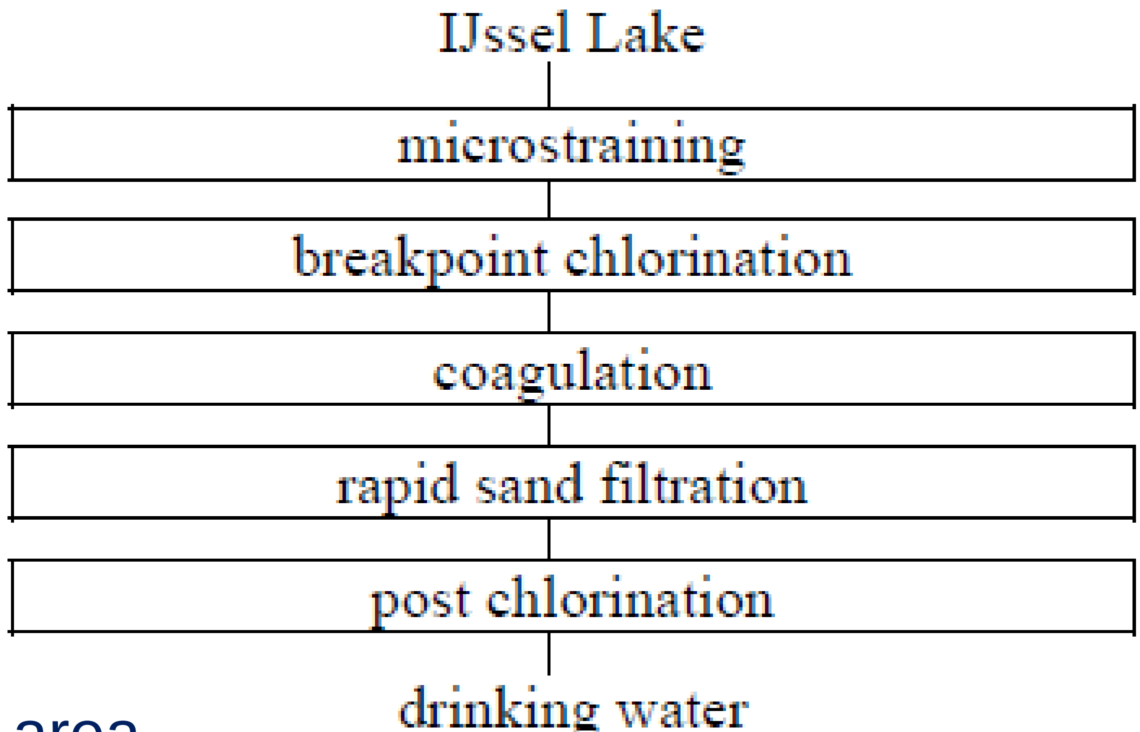
Large Scale Applications

UV-H_2O_2

- There have been more than 100 full scale UV-based AOP installations around the world
- UV-H_2O_2 is the most applied technology in large scale
- Often applied to cases (i.e. contaminants) which show persistence towards ozone and/or cases where formation of bromate in bromide containing source waters is a concern

Full Scale UV-H_2O_2
Andijk – the Netherlands



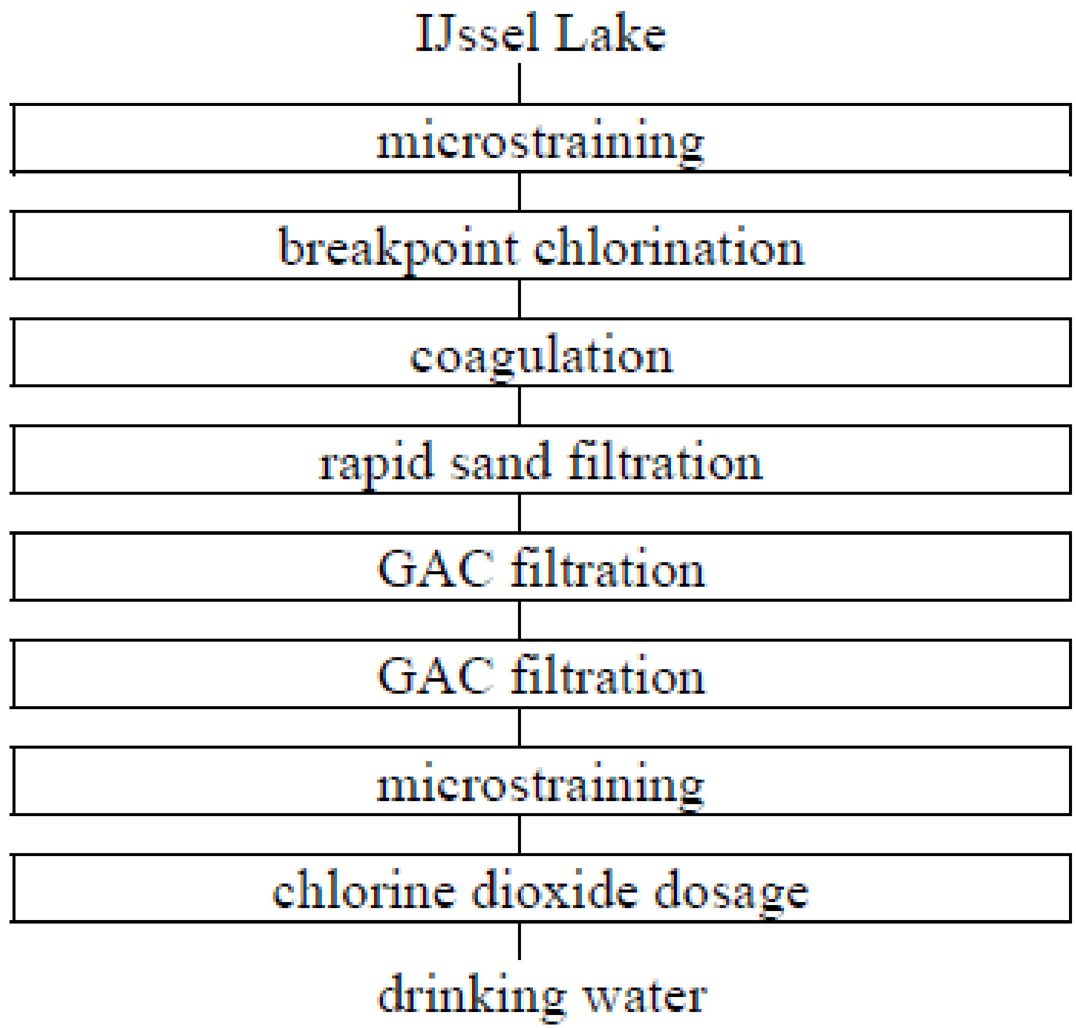


- Surface water (IJssel Lake) – as the source of drinking water to North Holland area
- Conventional water treatment system commissioned nearly 50 years ago

Full Scale UV-H_2O_2

Andijk – the Netherlands

- Taste & Odour problem has been a concern
- GAC was installed about 30 years to address the problem



Full Scale UV-H_2O_2
Andijk – the Netherlands

Issues and Challenges with Conventional Treatment

- Chlorine, as primary disinfectant, was not effective against parasites (Giardia and Cryptosporidium)
- Chlorine also led to DBP formation in the distributions system
- Very small levels of nitrate, pesticides, pharmaceuticals were being detected due to increased industrials activities
- Bromate formation made ozone unfeasible

Full Scale UV-H_2O_2
Andijk – the Netherlands

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Full Scale UV-H_2O_2

Andijk – the Netherlands

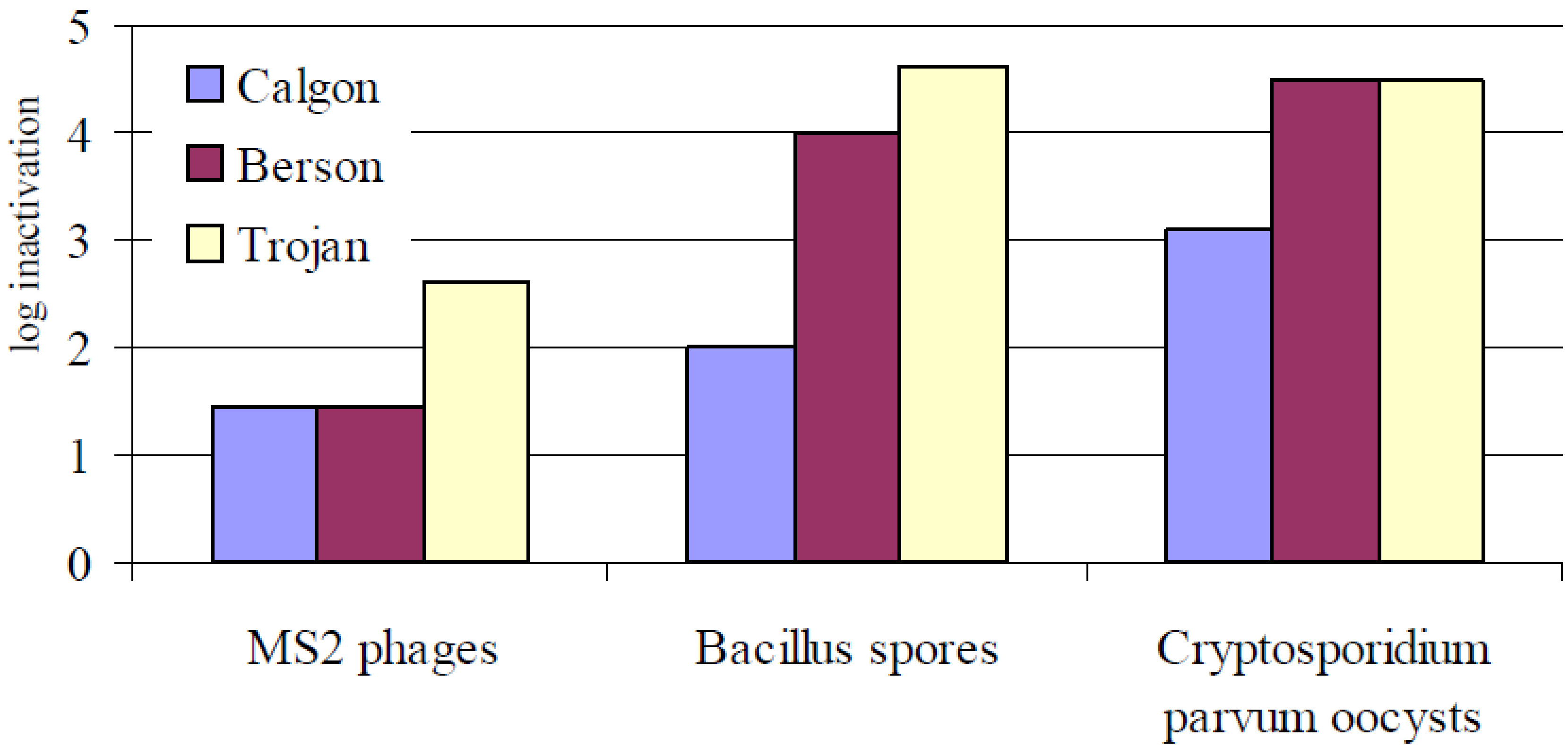
UV-H2O2 AOP was considered as a viable alternative

- It was investigated against a range of contaminants *(e.g., atrazine, NDMA, MTBE, 1,4-dioxane, bisphenol A, microcystine and pharmaceuticals e.g., diclofenac, ibuprofen)*
- Studies focused primarily on medium pressure lamp UV system
- The use of UV also provided primary disinfection, helping to eliminate the use of Cl_2

Full Scale UV-H_2O_2

Andijk – the Netherlands

Inactivation of 3 different pathogens

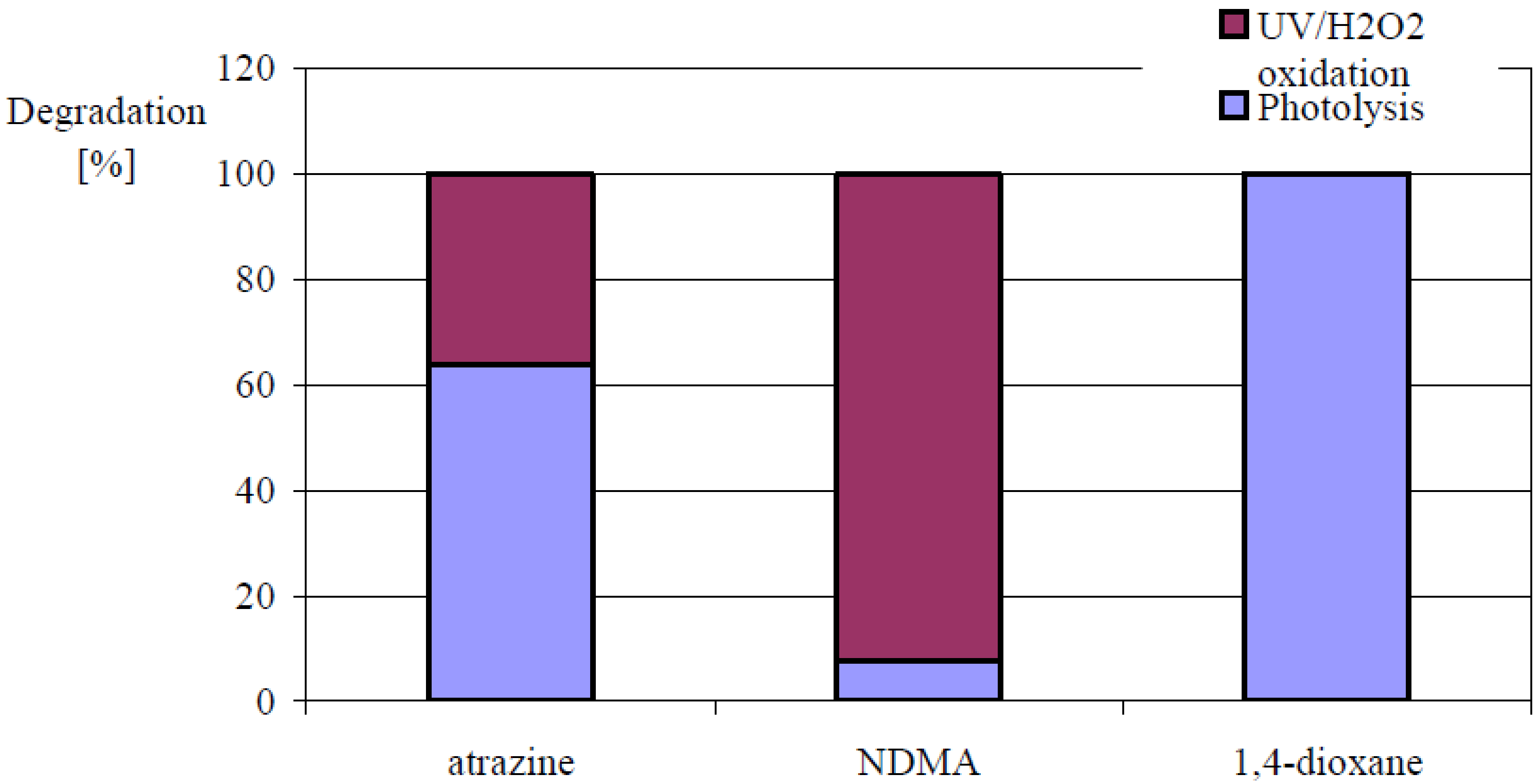


Source: Kruithof et al, 2005

Full Scale UV-H_2O_2

Andijk – the Netherlands

Removal of selected micropollutants



Source: Kruithof et al, 2005

Full Scale UV-H_2O_2
Andijk – the Netherlands

The technology was adopted and a full scale system was installed in 2004, treating a design flow rate of about 4000 m^3/h and 80% destruction of atrazine

- All contaminants were removed at UV doses up to about 540 mJ/cm^2 (0.56 kWh/m^3) and hydrogen peroxide concentrations of about 6 mg/L

Full Scale UV-H_2O_2

Andijk – the Netherlands

IJssel Lake

coagulation

rapid sand filtration

UV/H_2O_2 treatment

GAC filtration

GAC filtration

chlorine dioxide dosage

drinking water

Selected Full Scale UV-H_2O_2

Location	Contaminants	Flow rate (MLD)	Technology used
Region of Peel, ON, Canada	MIB, Geosmin	390	UV-H2O2 (MP UV)
Orange County, CA, USA	NDMA, 1,4-Dioxane	379	UV-H2O2 (LP UV)
PWN Heemskerk, Netherlands	Pesticides	144	UV-H2O2 (MP UV)
Aurora, Colorado, USA	NDMA, 1,4-Dioxane	190	UV-H2O2 (LP UV)
Luggage Point, Brisbane	NDMA, 1,4-Dioxane	70	UV-H2O2 (LP UV)

Summary

UV based AOPs are rapidly growing solution alternatives for:

- Degradation of micro-pollutants in drinking water sources
  - In addition to ***DISINFECTION***
- Removal of taste and odor (T&O) from drinking water
- Water re-use and reclamation

Thank You !

Madjid Mohseni, Ph.D., P.Eng.

Department of Chemical & Biological Engineering

University of British Columbia

Phone: +1(604)822-0047

E-mail: mmohseni@chbe.ubc.ca

a place of mind

THE UNIVERSITY OF BRITISH COLUMBIA