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Photochemistry and scale-up of chemical-free AOP by VUV light for water treatment

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Motivation

Organic micropollutants (OMP) are increasingly found in sources of drinking water. In our daily life we contribute to multiple sources for OMPs entering our water bodies (eg., from the medicines we consume to the shower gel we lavish). They can be persistent and difficult to degrade leading to possible negative effects on human health and aquatic life, which may e.g. be of mutagenic, genotoxic, or endocrine disrupting nature. For instance feminization of fish has been observed in several rivers globally. Advanced Oxidation Processes (AOPs) can convert OMPs to less harmful coumpounds. AOPs are the oxidation processes that use hydroxyl radical (·OH) for degradation of the OMPs via oxidation. Conventional AOPs have been optimized to an extent that the application is economically feasible (for eg., H_2O_2 /UV or O_3/UV). However, a number of alternative AOPs are promising on lab scale like the vacuum UV-185nm (VUV) based AOP, which produces ·OH radicals in-situ without the addition of chemicals like H_2O_2 or O_3 [1]. However, scale-up and optimized reactor concepts have not been developed yet for applications of the VUV process such OMP reduction in drinking water or biologically treated wastewater.

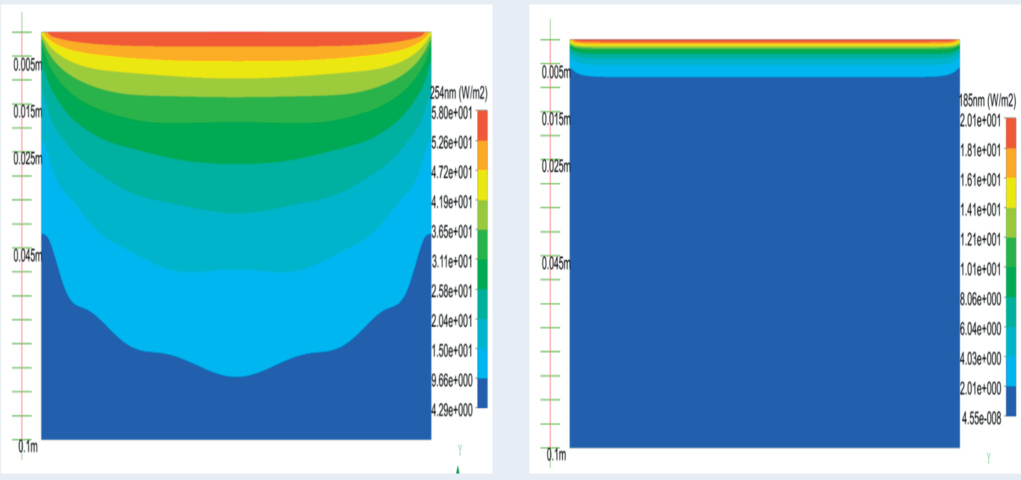
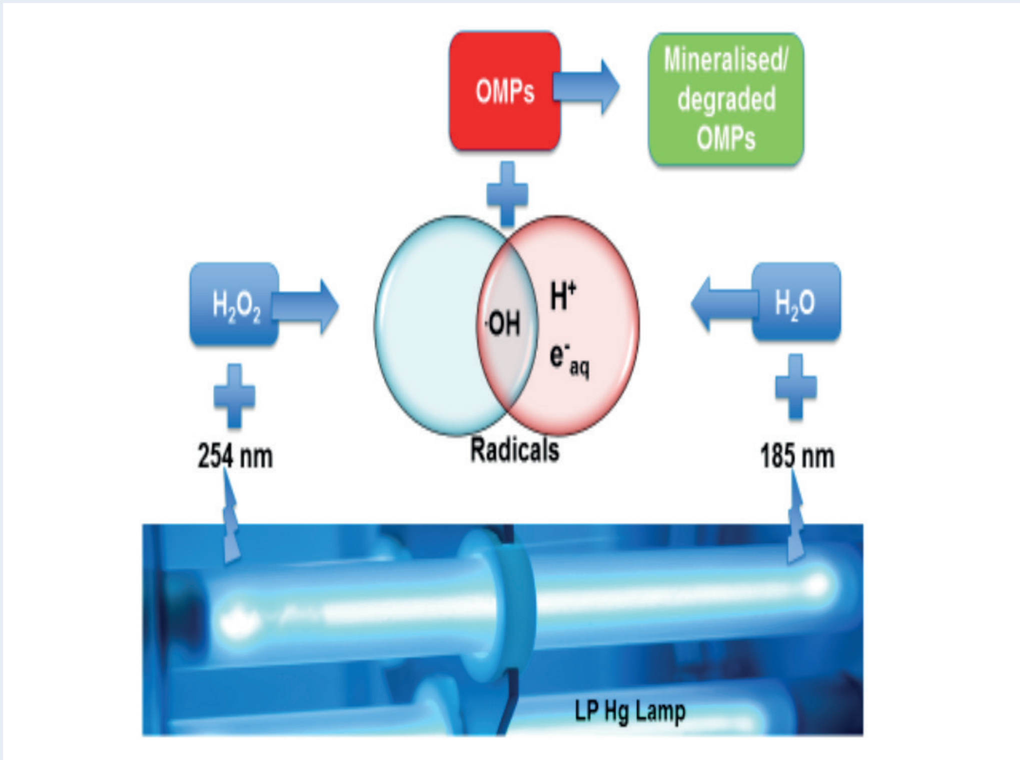


Fig. 1 CFD simulations showing the inhomogenity in irradiated volume of water irradiated at 254nm and 185nm. The higher absorbance of water at 185nm (1.8cm^{-1}) compared to absorbance at 254 nm (<0.01cm^{-1}) resulting in 90% of 185nm photons absorbed within approximately 5mm of water layer.



H_2O_2 /UV	• $H_2O_2 + h\vartheta(254nm) \rightarrow 2{\cdot}OH$ Φ (+·OH)=0.5
VUV/UV	• $H_2O + h\vartheta(185nm) \rightarrow {\cdot}OH + H{\cdot}$ Φ (+·OH)=0.33 • $H_2O + h\vartheta(185nm) \rightarrow {\cdot}OH + H^+ + e^-_{aq}$ Φ (+e_{aq})=0.045 • H_2O_2(in-situ) $+ h\vartheta(185nm) \rightarrow 2{\cdot}OH$ Φ (+·OH)=0.5

Technological Challenge

- A reactor design optimization is necessary to realize VUV AOP on large scale.
- High molar absorption coefficient of water at 185nm results in optical pathlengths in orders of millimeters inducing heterogeneous radical concentration in the reactor.
- Major solutes (i.e., chloride, sulphate, etc.) in water also (photo) chemically generate less reactive and long lived radical species.
- The undesired radical species formed from the aforementioned pathway may form harmful byproducts from dissolved (in)organic matter.

Research Goals

Related to Photochemistry:

- Understand matrix dependent micropollutant degradation
- Analyse formation of disinfection byproducts
- Understand the synergistic effects of 185nm and 254nm irradiation on micropullutant degradation
- Analyze the reactive species (radicals, solvated electrons) and their effects on the degradation kinetics of OMPs

Related to Hydrodynamics:

- Develop reactor models using computational fluid dynamics that effectively overcome the issues caused by inhomogeneous illumination of the reactor system due to the high absorption coefficient of water at 185nm
- Understand the effect of addition of H_2O_2 in the system
- Construct and experimentally evaluate a scaled up photoreactor with a minimum flow of 0.5 m^3/h

Reference: [1] Kristin Zoschke et al (2014) Water Research 52 (2014), 131-145

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