Relevance of Radial Mixing in Tubular Membrane Reactors for Advanced Oxidation Processes

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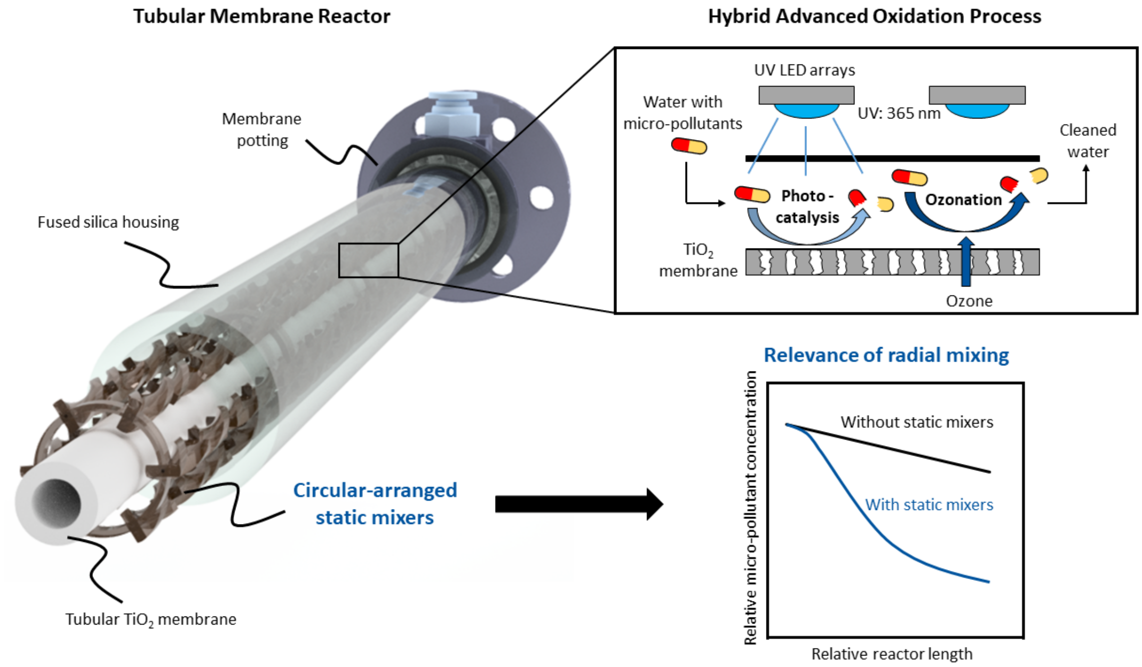

Figure 1: Graphical abstract.

Abstract:

Ozonation is a promising method to encounter rising levels of persistent micro-pollutants (e.g., pharmaceuticals) in the effluent of wastewater treatment plants.[1-3] To protect the aquatic environment, the wastewater flows through a fourth treatment stage where ozone is typically dissolved from gas bubbles and oxidizes the micro-pollutants.[4] However, ozonation has significant drawbacks: firstly, the gas bubbles distribute unevenly, leading to ozone hotspots, where naturally occurring bromide reacts with ozone to toxic bromate.[5, 6] Secondly, the degradation of some micro-pollutants with ozone is below 35%, thus insufficient for a sustainable water cycle.[7]

Here we show a method to decrease bromate formation during ozonation using a membrane reactor with static mixers. A tubular ceramic membrane provides a controlled phase boundary to dissolve ozone in water aiming for smaller ozone concentration gradients. In addition, circular-arranged static mixers promote radial mixing and further decrease concentration gradients. The ozonation is coupled with photo-catalysis to a hybrid advanced oxidation process to degrade a wide range of micro-pollutants.

To study local ozone and bromate concentrations in the membrane reactor, a 3D simulation model was developed, including fluid flow, mass transport of ozone, and chemical reactions (ozone decomposition, bromate formation, micro-pollutant degradation). For the first time, ozone transfer and bromate formation in a complex-shaped reactor can be studied in detail with our model, revealing the relevance of ozone hotspots for bromate formation. Further, we show the effects of static mixers in the reactor: a significantly increased ozone mass transfer and micro-pollutant degradation, elimination of ozone hotspots, and thus a decrease in bromate formation.

The degradation of four different pharmaceuticals was studied in lab experiments in the membrane reactor using the hybrid process. TiO_2 was used on the membrane's surface as a photocatalyst, and the membrane reactor was irradiated with UV light. According to the simulation results, the experiments showed that static mixers significantly increase the degradation rate of micro-pollutants.

Overall, this work demonstrates the importance of radial mixing in a membrane reactor for advanced oxidation to decrease the formation of toxic bromate, enhance ozone mass transfer, and accelerate and improve micro-pollutant degradation within the reactor. Furthermore, we present a powerful simulation model for ozonation reactor design to solve the global challenge of micro-pollutants in wastewater.

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Keywords: Hybrid Membrane Reactor; 3D Simulation; Advanced Oxidation Process; Ozonation; Micro-pollutants

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