Plasma Falling Liquid Film Reactor to Study PFAS Decomposition

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Abstract: This study investigates plasma-liquid interactions in a falling liquid film reactor for degrading Perfluorobutane sulfonic acid (PFBS). Measurements of PFBS decomposition show that degradation transitions from transport-limited to reaction-limited regimes as reactive species flux saturates at higher pollutant concentrations, emphasizing the reactor's efficiency in enhancing reactive species delivery and plasma-assisted degradation.

1. Introduction

Plasmas have emerged as a promising technology for wastewater treatment. Reactive species such as OH radicals, electrons, and photons generated by non-thermal plasma have been shown to degrade persistent organic pollutants, including Poly- and Perfluoroalkyl Substances (PFAS) [1-2]. However, liquid phase transport limitations of the reactants to the plasma-liquid interface often significantly limit conversion.

To study reactions and the transport of reactive species from plasma and reactants from liquid to the interface, we developed a falling liquid film plasma reactor. The plasma treatment of thin films with thicknesses in the range of 10 to 30 µm enables controlled fluid flow while concurrently reducing transport timescales and providing an interesting testbed to study plasma-assisted degradation mechanisms [3].

2. Methods

The plasma-liquid film reactor consists of a DC-driven plasma jet operating at 8 - 9 W at atmospheric pressure, with helium as the working gas at 1 standard liter per minute. The falling liquid film comprises a 2 mm × 35 mm wire loop with a wire thickness of 30 µm, forming water liquid films with thicknesses ranging from 9 µm to 30 µm. Sodium formate and PFBS solutions ranging from 0.5 mM to 13 mM were prepared in a neutral pH buffer with a conductivity of 20 mS/cm for this study.

Quantitative Nuclear Magnetic Resonance (qNMR) was employed for the detection and quantification of PFBS and F^- ions in solution. A 2D transport-reaction model was used to simulate the transport and reactions of plasma-derived species in the liquid phase with plasma-produced reactive species fluxes as boundary conditions.

3. Results and Discussion

Figure 1 shows the PFBS consumption and fluoride ion forming under plasma treatment of the liquid film. PFBS decomposition occurs at the plasma–liquid interface, driven by OH radicals (penetration depth ~1 µm) and solvated electrons (penetration depth ~10 nm). At low concentrations, defluorination increases linearly with concentration, consistent with a diffusion-limited transport of PFBS to the liquid interface. At higher concentrations, the observed plateau in conversion, suggests a reaction-limited regime likely determined by plasma-produced reactive species flux responsible for PFBS decomposition to the liquid.

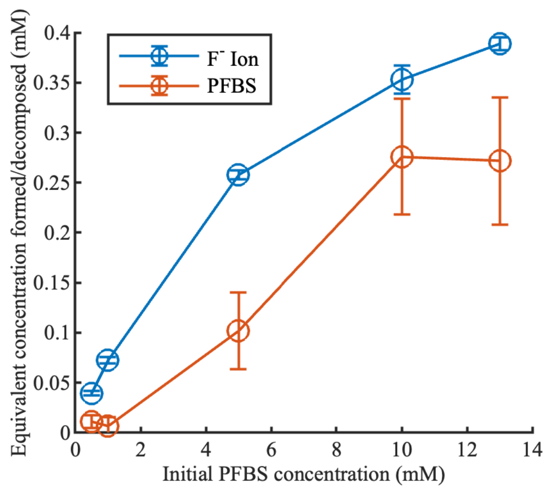

Fig. 1. Equivalent PFBS concentration consumed and fluoride ion concentration formed from defluorination by plasma treatment of a flowing liquid film with a thickness of 15 µm as a function of the initial PFBS concentration.

4. Conclusion

The falling liquid film plasma reactor addresses transport limitations by varying the delivery of reactants in the liquid phase, highlighting transitions from transport-limited to reaction-limited regimes. These findings showcase the reactor's potential to study the processes underpinning plasma-enabled wastewater treatment.

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References

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