Enhanced Nitrogen Fixation Using a Plasma Spinning Disk Reactor

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Abstract: This study investigates the performance of a plasma spinning disk reactor (SDR) for enhanced nitrogen fixation compared to a conventional bubbling reactor (BR). Results demonstrate that the SDR significantly outperforms the BR, particularly in the presence of argon, due to improved bulk liquid hydrodynamics and a higher surface-area-to-volume ratio.

1. Introduction

Nitrogen fixation is a process that converts atmospheric nitrogen into chemical products suitable for agricultural and industrial applications. However, due to the high bond dissociation energy of molecular nitrogen, many of the traditional fixation methods require significant energy input and contribute to high carbon emissions. Plasma-based nitrogen fixation offers a promising alternative by generating reactive nitrogen and oxygen species (RONS) in aqueous media under ambient conditions.[1]

This study compares the production of nitrate ions in water from air using two gas discharge reactors, each with unique hydrodynamics and operating in a semi-batch mode. In the bubbling reactor (BR), air is introduced at the bottom through a diffuser, creating rising bubbles that agitate the solution and the gas-liquid interface. In the spinning disk reactor (SDR), liquid is introduced onto a rapidly rotating dielectric-covered disk, which serves as a grounded electrode. Centrifugal forces spread the liquid into a thin, mm-thick film, which interacts with the plasma for the duration of its residence time on the disc.

2. Methods

In the BR, 500 mL of deionized (DI) water was treated using a point-plane electrode configuration, with the high-voltage (HV) electrode positioned above the water surface. Air was introduced through a diffuser at the reactor bottom at a flow rate of 2 L/min. In the SDR, a peristaltic pump recirculated 250 mL of DI water over a stainless-steel disk covered with a dielectric and connected to a rotating shaft, which served as the ground electrode. A tungsten tube acted as both the HV electrode and the gas inlet. Either air or a 1:1 air-argon mixture was supplied at 2 L/min. In both reactors pulsed plasma was generated at 30 kV. The temperature was maintained at 10°C.

3. Results and Discussion

Fig. 1 compares nitrate production in the BR and SDR. The results show that the SDR outperforms the bubbling reactor, particularly in the presence of argon. Enhanced nitrate production in the SDR is attributed to bulk liquid hydrodynamics and, especially, the higher surface-area-to-volume ratio of the thin film, which facilitates more effective transport of nitrogen-generated species across the plasma-liquid interface. The presence of argon likely increases electron density and, in turn, enhances the production of RONS.

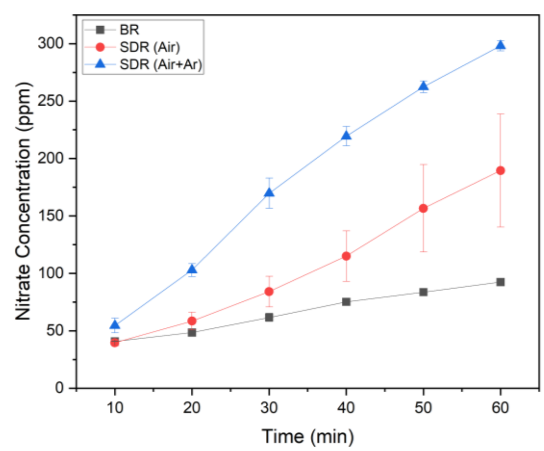

Fig. 1. Comparison of nitrate concentration evolution in the bubbling reactor (BR) and spinning disc reactor (SDR).

4. Conclusions

Bulk liquid hydrodynamics significantly influences RONS production. Fast-moving liquid films outperform bubbling reactors due to their higher surface-area-to-volume ratios.

References

[1] M. Gromov *et al.*, “Electrification of fertilizer production via plasma-based nitrogen fixation: a tutorial on fundamentals,” *RSC Sustainability*, vol. 3, no. 2, pp. 757–780, 2025, doi: 10.1039/D4SU00726C.