Sustainable ammonia production via non-thermal plasma in liquid

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Abstract: A novel non-thermal plasma-based technology for ammonia production, called Concentrated High-Intensity Electric Field (CHIEF) technology was developed. At the core of this innovation is the CHIEF reactor vessel, enhanced by the integration of fine bubbles, catalytic materials, and an ion-exchange concentration system. This technology aims to serve as a sustainable alternative to the traditional Haber-Bosch process, offering key advantages such as green electrification, in-situ hydrogen production, and potential highly efficient electrosynthesis.

1. Introduction

Ammonia is a critical component for crop growth, playing a vital role in supporting global food production and population growth. Beyond agriculture, ammonia is gaining attention as a potential alternative fuel source. For over a century, the Haber-Bosch process has been the dominant commercial technology for ammonia (NH3) production. However, this process has substantial environmental drawbacks, emitting 1.6 tons of CO2 per ton of ammonia produced and accounting for 1.8% of global carbon emissions and 2% of global energy consumption (Osorio-Tejada et al., 2022; Smith et al., 2020). To address these challenges, we are developing a one-step, non-thermal plasma-based technology for clean and sustainable nitrogen fixation. This patented method, known as Concentrated High-Intensity Electric Field (CHIEF) technology, offers a promising alternative to conventional ammonia production. Previous research by Lv et al. (2024) and Peng et al. (2019) has highlighted CHIEF's effectiveness under various operating conditions, including voltage, solvent conductivity, feeding rate, and reactor configuration. Building on these studies, we are further optimizing the process by integrating fine micro-bubbles, an advanced catalyst network, and an ion-exchange concentration system to enhance nitrogen species yield and improve energy efficiency.

2. Methods

A schematic of our system is shown in Figure 1. The CHIEF reactor was powered by a continuous or pulse power supply system with input from an AC power supply adjusted using a transformer. Power measurements during treatment were recorded using an oscilloscope. Catalysts (Fe, Cu, Ni, Co) were either embedded above or held in the middle section of the reactor, where plasma discharge occurred. The orifice dimensions were adjustable, with depths ranging from 2 to 6 mm and diameters from 0.5 to 2 mm. The reactor was fed with air at flow rates between 20 and 90 ml/min and recirculated with water at flow rates of 20 to 60 ml/min. The water conductivity was adjusted to various levels, ranging from 20 to 300 µS. Prior to entering the reactor, the air and water mixture could pass through a fine bubble generator to enhance interaction. All treatments were conducted at room temperature (25 °C) and standard atmospheric pressure.

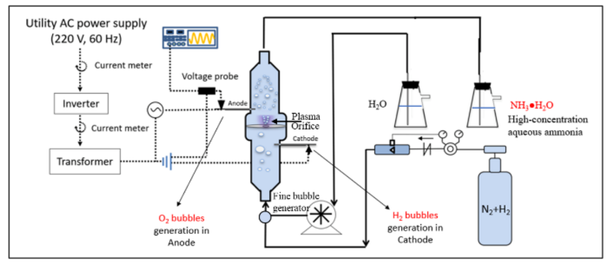

Figure 1. Schematic diagram of the nitrogen fixation system using CHIEF.

3. Results and Discussion

Using continuous AC power with a preliminarily optimized CHIEF configuration and conductivity settings, we achieved an energy cost for nitrogen oxidation fixation in the CHIEF system of approximately 5.6 MJ/mol N (equivalent to 111.04 kWh/kg) for the production of nitrate and nitrite. The nitrogen fixation rates ranged from 46.2 to 70.2 µg/min under varying test conditions, including changes in orifice size, catalyst selection, and the incorporation of fine bubble generation. About 4% of produced nitrogen was characterized as NH_3-N. In the next step, the ammonia yield is expected to increase with 1) minimizing the oxidation effect, 2) elevating the reduction effect, 3) incorporating ammonia absorbents, and 4) optimizing the hydrogen content in the feeding gas.

4. Conclusions

CHIEF technology eliminates the dependency on steam reforming of methane gas and operates under ambient conditions. Preliminary results have demonstrated its potential for nitrogen fixation, achieving rates of up to 70.2 µg/min with an energy cost of 5.6 MJ/mol N. These findings highlight CHIEF as a promising alternative for aqueous-phase nitrogen fixation, with significant potential for sustainable and scalable applications.

References

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