Continuous conversion of water into hydrogen peroxide in a flexible microwave plasma reactor. Concept and progress

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Highlights

- Commercial level concentrations have been achieved
- Only water and argon plasma are used
- Microwave nanosecond pulsation and quenching are integrated for maximized production of H_2O_2

1. Introduction

Hydrogen peroxide is a key oxidant for environmentally friendly oxidation processes and water treatment. However, today it is produced almost exclusively by the anthraquinone process in large, centralized plants that depend on a constant supply of fossil fuels. This makes on-site, flexible use difficult. Plasma-based routes have the potential to generate H_2O_2 directly from water and electricity, however, current concepts struggle to combine continuous operation, commercially relevant concentrations and acceptable energy yields.

2. Methods

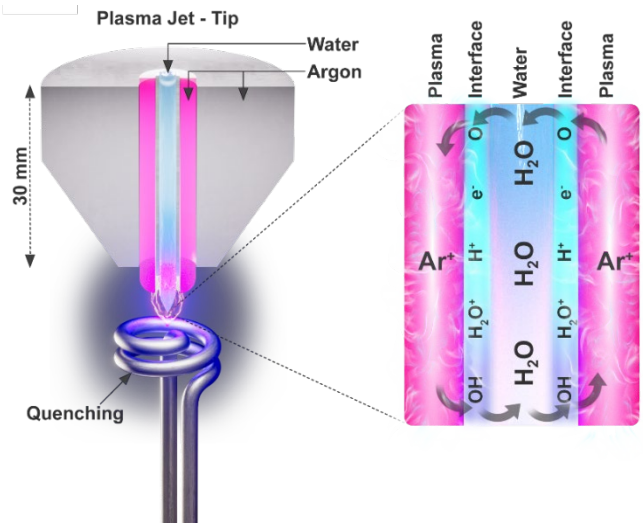

Fig. 1. Schematics of the plasma-liquid interface at the tip of the reactor and quenching system. Modified from [1]

We developed a nanosecond-pulsed coaxial microwave plasma reactor that converts water directly into H_2O_2 using argon plasma. A 2.45 GHz microwave torch is driven with microwave pulses of 300–700 ns, while water is fed as a fine spray (0.2–2.5 mL·min^{-1}) into the afterglow. A compact cooling coil provides strong quenching of the post-discharge. H_2O_2 is quantified by titration/UV–vis. Gas-phase H_2 and O_2 are monitored online with a high-sensitivity gas analyzer, and time-resolved optical emission spectroscopy provides qualitative trends in excitation and electron density. A simple plug-flow model is used to separate effective H_2O_2 formation and decomposition terms as a function of residence time and peak power.

3. Results and discussion

Under optimized pulsed conditions and with quenching, the reactor produces H_2O_2 continuously at concentrations up to 50–54 mM (0.17 wt%), i.e. in the range of commercial formulations, with energy yields up to 1.2 g·kWh^{-1} based on absorbed power. A systematic parametric study shows that duty cycle

and pulse time control the balance between formation and thermal degradation, whereas the water flow (residence time) governs the achievable concentration. The initial PFR analysis indicates that the apparent formation rate is nearly independent of power, while the decomposition rate increases sharply at high peak power, consistent with thermally activated pathways. Long-term experiments demonstrate stable operation over several hours. We will discuss the resulting design rules for nanosecond-pulsed plasma–liquid reactors, implications for scale-up, and opportunities to integrate such electrified reactors as modular, on-site H_2O_2 sources in chemical and environmental processes.

4. Conclusions

- Contrary to the typical claim plasmas can be selective if activation is considered separately from decomposition.

-It is possible to continuously produce hydrogen peroxide using a system based on warm plasmas despite the thermal sensitivity of this product.

- Achieving commercial concentration levels was possible by the integrated use of nanosecond pulsation of microwaves and quenching of the plasma-liquids interface.

- Parametrization of the reacting system is possible which lays the ground for a potential design route.

References

[1] M.S hernandez et al. J. Am. Chem. Soc. **in press.**

Keywords
hydrogen peroxide; microwave plasma; plasma–liquid reactor; process intensification; renewable electricity; plasma-liquid interface