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Nanosecond-pulsed microbubble plasma reactor for plasma-activated water generation and bacterial inactivation

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The research on cold atmospheric pressure gas discharge plasma has been deepening, and this emerging technology has been increasingly applied in various fields. Gas ionization diffuses/dissolves abundant active species into water to produce plasma activated water (PAW). PAW is created through the interaction between gas discharge and liquid at atmospheric pressure and is considered a green and promising solution with a wide range of applications. While many researchers focus on discharge occurring above or at the liquid surface, there is a loss of active particles in the process of transferring them to the liquid phase. Discharging directly in water or solution requires a power supply with excellent parameters. To address this, a micro-bubble induced plasma reactor was developed to enhance the process of gas discharge and enable the controlled production of active substances. The characteristics of PAW under different conditions were investigated.

An electrode was designed using microbubble technology to create liquid gas discharge in an aqueous phase. The presence of microbubbles reduced the breakdown voltage and increased the efficiency of discharge. The study also analyzed the characteristics of microbubble rupture under electric stress. To analyze the impact of different pulse parameters (rising) and pulse width on the properties of active nitrogen, we used three different pulse power parameters to produce PAW. Active nitrogen species are the most abundant particles in PAW and are easier to measure. The impact of different pulse parameters on the characteristics of active species was studied. The results indicated that a pulse with a short rise time and a peak width of hundreds of nanoseconds is favorable for the production of PAW.

The experiment used nanosecond pulsed power with a short rise time and hundreds of nanoseconds of peak width for further studies. The physicochemical characteristics of PAW at different temperatures were evaluated, and the corresponding antimicrobial effects of PAW against Escherichia coli (E. coli) were investigated. The concentrations of NO_3^-, NO_2^-, H_2O_2, and O_3, pH value, and Oxidation-reduction potential (ORP) suggested that a low temperature is conducive to the production and antimicrobial activity of active species, resulting in a 2.43±1.02-$\log_{10}$ CFU/ml reduction of E. coli. The excellent energy efficiency in PAW is 10.37 $g \cdot kW^{-1}h^{-1}$. This work is supported by the National Science Fund for Distinguished Young Scholars (grant no. 51925703), the National Natural Science Foundation of China (grant no. 52022096), and the Royal Society–Newton Advanced Fellowship, UK (grant no. NAF/R2/192117).

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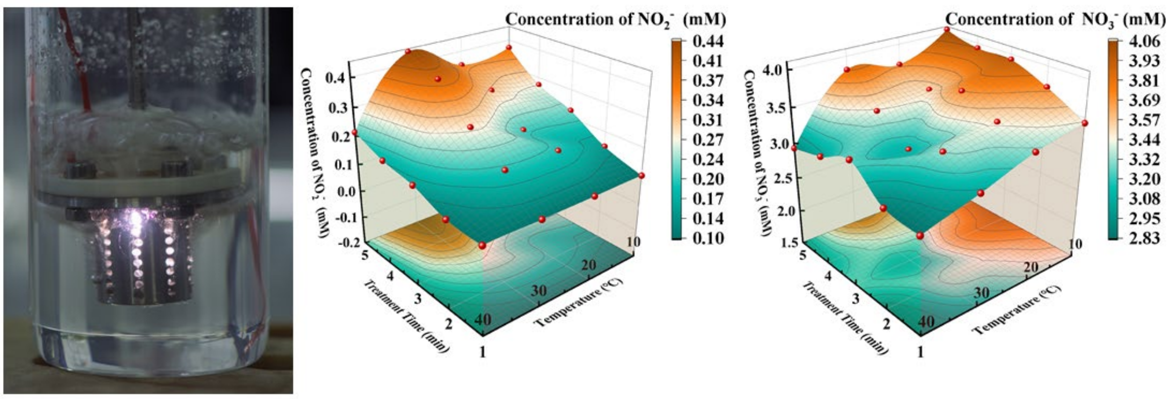

Figure 1. Image of the microbubble-enabled plasma reactor, dependence of nitrate and nitrite concentrations as a function of the treatment time at different temperatures.