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Environmental-Friendly Wastewater Treatment through Non-Thermal Plasma: Mechanistic Insights into Dye Degradation

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Crystal Violet (CV) and Reactive Black 5 (RB5) are extensively used dyes from the triphenylmethane and azo dye classes, respectively, and are major contributors to water pollution from textile effluents [1],[2], [3]. This study demonstrates the potential of non-thermal plasma as a sustainable and effective solution for dye degradation, addressing the gap in understanding the specific degradation mechanisms and the influence of water components. We investigated the effects of plasma power, initial dye concentrations, and various water constituents on the plasma-driven degradation of CV and RB5. Our results reveal that at 36.2 W of plasma power and a treatment time of 15 minutes, 50 mg L^{-1} of CV and 100 mg L^{-1} of RB5 were almost fully degraded, with a substantial reduction in toxicity. Notably, carbonate ions enhanced the degradation of CV but inhibited RB5, while chloride, sulphate, and nitrate ions consistently suppressed the degradation of both dyes. Hydroxyl radicals were identified as the primary reactive species through scavenger experiments using methanol and isopropyl alcohol. Furthermore, pH played a critical role: CV degradation was significantly faster in basic conditions, whereas RB5 degradation was less favourable in both acidic and basic environments. Advanced analytical techniques like high-resolution mass spectrometry, surface-enhanced Raman spectroscopy, and UV-visible spectroscopy were used to identify degradation intermediates and propose degradation pathways. Additionally, phytotoxicity and cytotoxicity assays were conducted, revealing that after plasma degradation, the treated solution was free from toxicity, making it suitable for agricultural applications.

References

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