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Non-Thermal Plasma-Assisted VOC Decomposition: Influence of Catalyst Type, Electron Energy, and Gas Residence Time

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Volatile organic compounds (VOCs) such as toluene are major air pollutants, contributing to photochemical smog and posing severe environmental and health risks. Conventional abatement methods often require high operating temperatures or show poor efficiency for intermittent emissions. In this study, non-thermal plasma (NTP) assisted VOC decomposition was investigated using a dielectric barrier discharge (DBD) reactor integrated with different catalyst materials (TiO2, Ag/TiO2, BaTiO3, and γ-Al2O3). The effects of discharge characteristics, gas residence time, and catalyst type on toluene degradation, energy efficiency, and by-product formation were systematically examined. Experiments were performed in an N2/O2 (50:50) atmosphere at applied voltages of 12 - 16.5 kV and flow rates of 0.5 - 2.0 L min^{-1}. Infrared spectroscopy analysis identified CO2, CO, HCOOH, and O3 as major oxidation products, indicating partial mineralisation of toluene. Among the tested catalysts, BaTiO3 exhibited superior degradation performance and energy efficiency at lower specific input energy (SIE), emphasising the role of high-dielectric materials in enhancing plasma–catalyst interactions. The Ag/TiO2 catalyst demonstrated further improvement in mineralisation efficiency due to enhanced electron transfer and plasmonic activity of Ag nanoparticles, facilitating deeper oxidation of intermediate species. Additionally, the mean electron energy and reduced electric field (E/N) were calculated for different plasma-catalyst combinations, revealing that plasma-only conditions exhibited higher values compared to plasma-catalyst configurations, consistent with the voltage distribution and energy dissipation across the dielectric materials. These findings provide valuable insights into optimising plasma-catalyst systems for energy-efficient VOC abatement and highlight their potential for scalable, low-temperature air purification applications.

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