Functionalized Carbon Adsorbents via Ball Milling for Enhanced Removal of Toluene

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Abstract

With the continuous advancement of industrialization and urbanization, atmospheric environmental issues have become increasingly prominent. Among them, the emission of volatile organic compounds (VOCs) poses a serious threat to the ecological environment and human health. As a typical aromatic VOCs pollutant, the efficient removal of toluene is of great significance. In this work, functionalized carbon materials (FG-BM) were prepared using flake graphite as the raw material via a one-step ball milling process. The effects of ball size, ball-to-material ratio, rotation speed, and number of milling cycles on the material structure and catalytic performance were systematically investigated, and various types of commercial carbon materials were selected for comparative validation. The results indicate that the material exhibits optimal catalytic performance under the following conditions: a ball size of 15 mm, a rotation speed of 700 rpm, a ball-to-material ratio of 100:1, and eight milling cycles. Characterization results show that ball milling significantly increased the specific surface area of the material (from 6.0 m^2/g to 448.3 m^2/g), created a hierarchical porous structure, and introduced a large number of structural defects as well as nitrogen- and oxygen-containing functional groups on the surface, effectively increasing the number of active sites. Performance test results indicate that the toluene removal efficiency of the as-prepared FG-BM increased from 67.3% to 99.8%, demonstrating a substantial enhancement. This ball milling modification strategy exhibits good general applicability for enhancing the catalytic oxidation performance of various carbon materials. Mechanistic analysis reveals that the defect structures induced by ball milling and the surface-enriched pyridinic nitrogen and oxygen-containing functional groups (C=O and O-C=O) serve as key active sites. By promoting the formation of oxygen-containing intermediate species, these sites accelerate the adsorption, activation, and oxidation of toluene molecules, thereby significantly improving the catalytic performance. This work provides a scalable, solvent-free route to high-performance functionalized carbon adsorbents for efficient toluene removal.

Keywords

Functionalized Carbon, Toluene Removal, Ball Milling, Adsorption, Catalytic Oxidation