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Acid-activated natural zeolite clinoptilolite functionalized with curcumin for superior methylene blue adsorption: Insights into optimization, characterization, and adsorption mechanisms

Abstract

This study investigates the treatment of natural zeolite clinoptilolite (NZC) through acid and base pretreatments, aiming to enhance its adsorption efficiency for methylene blue (MB) dye removal. The results indicate that NZC treated with 3.0M HCl (hydrochloric acid) exhibits superior MB removal efficiency (93.24%) compared to 1.0M NaOH (sodium hydroxide)-treated NZC (91.40%), accompanied by a higher Brunauer-Emmett-Teller (BET) surface area (135.5002m2/g) in contrast to (43.6059m2/g). The optimized 3.0M HCl-treated NZC is further functionalized with curcumin, resulting in CUR-HCl-NZC, which demonstrates enhanced MB removal efficiencies of 95.09% at 45min and 83.81% at 90min, surpassing untreated NZC. The adsorption parameters, including contact time (45min), adsorbent dosage (0.2g), and initial dye concentration (25ppm), are systematically varied to optimize the conditions for CUR-HCl-NZC. Characterization through Fourier-transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), and BET analysis confirm the successful binding of curcumin to HCl-treated NZC, revealing structural and surface modifications. BET analysis shows that the surface area of CUR-HCl-NZC is 100.0382m2/g, indicating changes in porosity due to curcumin modifications. The isotherm analysis identifies the Langmuir isotherm model as the best fit, with a correlation coefficient (R 2) of 0.9996 and adsorption capacity of 41.203mg/g, suggesting monolayer adsorption dominance. This study establishes CUR-HCl-NZC as an effective, low-cost adsorbent for the removal of MB, offering a promising solution for water purification applications.

Keywords

acid-base pretreatments; curcumin functionalization; ICYC 2024; methylene blue adsorption; natural zeolite clinoptilolite; water purification