Diatomite-Assisted Sorption of Humic Acid from Environmental Waters: Kinetics and Interparticle Diffusion in a Highly Porous Material

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Highlights:

- Natural diatomite filtrates humic acid (HA) via sorption in porous frustules.
- Diffusion-controlled uptake, with rapid initial and slow intraparticle transport.
- HA removal decreases with pH; Ca/Mg enhances uptake, phosphate inhibits sorption.
- Sorption occurs through pore diffusion, silanol H-bonding, cation bridging.
- Practical removal of humic substances from environmental waters is demonstrated.

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Abstract

Humic acid (HA), a major fraction of natural organic matter, is a persistent contaminant that impairs water quality and contributes to the formation of disinfection byproducts. In this study, natural, unmodified diatomite was investigated as a cost-effective sorbent for HA removal, with particular emphasis on diffusion limitations within its hierarchical meso–macroporous structure derived from diatom frustules. Equilibrium data (2.5–30 mg L^{-1}, pH 7) were described by the Langmuir and Freundlich models, indicating the coexistence of monolayer and heterogeneous sorption behavior. The uptake kinetics showed rapid initial removal, followed by a diffusion-limited regime. The pseudo-first-order model captured early-stage uptake, whereas the pseudo-mixed-order fractional model best represented the full kinetic profile. HA removal decreased from pH 4 to 9 owing to enhanced electrostatic exclusion above the point of zero charge and increased HA ionization. Divalent cations (Ca^{2+}, Mg^{2+}) enhanced removal through charge neutralization and cation bridging, while phosphate strongly inhibited uptake via site-specific competition. A comparative evaluation identified high-performing diatomite, and integrated evidence from BET, FT-IR, FE-SEM, and zeta potential analyses elucidated diffusion- and surface-controlled sorption pathways. Application to natural water (containing an HA-equivalent concentration of 9.4 mg L^{-1}) achieved up to 87% removal at practical dosages. These results demonstrate that unmodified diatomite is a low-cost, environmentally benign sorbent for HA removal, providing a mechanistic basis for scaling up diatomite-based sorption in column or filtration-assisted configurations for practical water treatment.

Keywords

Diatomite-assisted sorption; Humic acid; Natural organic matter; Sorption kinetics; Porous siliceous sorbent