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Impact of Goethite on the Environmental Fate of Tetracycline: Role of Cationic and Anionic Surfactants in Aqueous Systems

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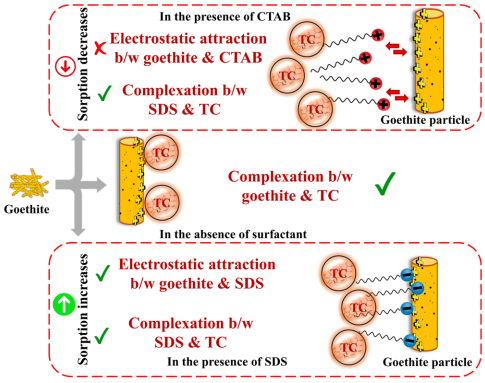

Over the past decades, the increasing release and persistence of organic pollutants in aquatic environments have raised significant global concerns due to their bioaccumulation, toxicity, and detrimental effects on ecosystems. Among these pollutants, tetracycline (TC), a widely used antibiotic, has been frequently detected in surface and groundwater at elevated concentrations. TC readily interacts with mineral surfaces and natural colloids, affecting its transport and bioavailability. Additionally, the post-COVID-19 surge in the use of cleaning and personal care products has led to an increased release of surfactants into aquatic systems, further influencing the fate of antibiotics. Understanding how these components interact in aqueous environments is critical for predicting contaminant behaviour.

This study systematically examines the adsorption behaviour of TC onto goethite under environmentally relevant conditions, both in the absence and presence of anionic (sodium dodecyl sulfate, SDS) and cationic (cetyltrimethylammonium bromide, CTAB) surfactants. The effects of key environmental factors, including pH, ionic strength, temperature, and natural organic matter, were comprehensively analyzed. Our results indicate that SDS significantly enhances TC sorption onto goethite, increasing the adsorption capacity from 11 mg/g to 19 mg/g, whereas CTAB inhibits sorption due to electrostatic repulsion. pH played a critical role in TC-SDS-goethite interactions, while ionic strength exhibited minimal influence. Temperature-dependent studies confirmed that the adsorption process was endothermic, as sorption capacity increased with temperature. The presence of natural organic matter hindered TC sorption, a trend that was also observed in river water containing high organic content.

To gain mechanistic insights, Fourier-transform infrared spectroscopy (FTIR) coupled with two-dimensional correlation spectroscopy (2D-COS) was employed, revealing the molecular interactions governing the goethite-TC system. Our findings provide valuable insights into the complex interplay between antibiotics, mineral surfaces, and surfactants, improving our understanding of contaminant mobility in aquatic systems. This study is particularly relevant for assessing the risks associated with pharmaceutical pollution and for developing effective mitigation strategies in contaminated water bodies.