Clay-polymer nanocomposites for pollutant adsorption – from design to application

Clay-polymer nanocomposites (CPNs) have been studied for more than two decades as sorbents for water pollutants, but their applicability remains limited. Our aim in a recent review in Water Research was to present the latest progress in CPN research using a meta-analysis approach and point out the key steps necessary to bridge the gap between the basic research and CPN application. Based on results extracted from 99 research articles on CPNs and 8 review articles on other widely studies sorbents, CPNs had higher adsorption capacities for several inorganic and organic pollutant classes (including heavy metals, oxyanions, and dyes, n = 308 observations). We applied principal component analysis, analysis of variance, and multiple linear regressions to test how CPN and pollutant properties correlated with Langmuir adsorption model coefficients. Adsorption was mainly influenced by CPN fabrication method, polymer functional groups and pollutant properties. For example, among the pollutant classes, heavy metals had the highest adsorption capacity but the lowest adsorption affinity. On the other hand, dyes had high adsorption affinities, as reflected by the linear correlation between adsorption affinity and pollutant molecular weight. Scaling from 'Scientific investigation' to a 'technological application' requires testing CPN performance in real water, application in columns, comparison to commercial sorbents, regeneration, and cost evaluation. However, our survey indicates that of the 158 observations, only 20 compared the CPN's performance to that of a commercial sorbent.

We suggest that future research must also consider the overlooked aspect of polymer conformation on the clay mineral surface, and its influence on CPN adsorption performance. Polymer adsorption on a clay mineral often transitions from a flat conformation, as monomer "trains", to an extended conformation, as monomer "loops and tails". Polymer loading, chemistry, and conformation on the clay surface should be thoroughly characterized in future studies, and the effects of these physicochemical properties on adsorption performance should be tested to optimize CPNs.

Our recent studies indeed addressed this approach. Polycation configuration at the adsorbed state - as trains, loops and tails - was controlled by 1. solution ionic strength 2. polycation concentration 3. polycation charge density. Composite micro- and nano-structure was characterized by zeta potential, FTIR, X-ray diffraction and thermal gravimetric analyses. The removal of the micropollutants from tap water or from treated wastewater by composites in which the polycation adsorbs as loops and tails, was significantly higher than by the composites in which the polycation is dominantly as trains, even upon normalizing to the polymer loading. On the other hand, polymer configuration did not affect dissolved organic matter (DOM) removal. The removal by both composites was obviously higher from tap water but the reduction in micropollutant removal from treated wastewater was not dramatic. Furthermore, the degree of reduction in micropollutant removal was specifically low by the composite with a loops and tails configuration. We identified three diverse adsorption sites for the removal of anionic, cationic and nonionic micropollutants. These results supported our hypothesis that a micropollutants and DOM by composite columns was more efficient than by columns of commercial granulated activated carbon.

We hope that our studies will promote the design of smart and functional CPNs, which can then evolve into an effective water treatment technology.

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Prof. Yael Mishael received her BSc in Chemistry (1996) and completed her PhD in Soil and Water both from Hebrew University of Jerusalem (2003). Upon completing her postdoc in environmental chemistry at the University of Indian-Purdue, she joined the department of Soil and Water Sci., at Hebrew University (2005).
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Her scientific interests are within the field of soil chemistry centers on colloid and interface phenomena. Her approach has been to conduct basic science studies which serve as a basis for environmental application-oriented research. In her research she harnesses classical colloid and interface scientific knowledge to advance the design of composite materials, for environmental applications. She designs composite materials based on adsorbing or grafting organic molecules to or from the clay surfaces, respectively, and focuses on characterizing these composites with an array of classical and advanced tools to better understand the nano- and micron composite structures and link between composite structure and performance. Material performance is optimized, as a function of its application, including; pollutant adsorption from water, slow-release pesticide formulations, toxin removal from agricultural produce, disruption of parasite-plant interactions and more.

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