Development of Magnetic Nanocomposite Materials as Low-Cost Reusable Adsorbents for Chlorinated Organics in Contaminated Water

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The constant growth in population worldwide over the past decades continues to put forward the need to provide access to safe, clean water to meet human needs. There is a need for cost-effective technologies for water and wastewater treatment that can meet the global demands and the rigorous water quality standards and at the same maximizing pollutant efficiency removal. Current remediation technologies have failed in keeping up with these factors without becoming cost-prohibitive. Nanotechnology has recently been sought as a promising option to achieve these goals. The use of iron oxide magnetic nanoparticles as nanoadsorbents has led to a new class of magnetic separation strategies for water treatment. We have developed magnetic nanocomposite systems able to capture polychlorinated biphenyls (PCBs), as model organic pollutants, in aqueous solution, providing a cost-effective water remediation technique. Two distinct methods were employed to develop these polyphenolic nanocomposite materials. The polyphenolic moieties were incorporated to create high affinity binding sites for organic pollutants within the nanocomposites. The first method utilized a surface-initiated polymerization of polyphenolic-based crosslinkers and co-monomers on the surface of iron oxide magnetic nanoparticles to create a core-shell nanocomposite. The second method utilized a bulk polymerization method to create macroscale films composed of iron oxide nanoparticles incorporated into a polyphenolic-based polymer matrix, which were then processed into microparticles. Both methods produce nanocomposite materials that can bind chlorinated organics, can rapidly separate bound organics from contaminated water sources using magnetic decantation, and can use thermal destabilization of the polymer matrix for contaminant release and material regeneration. The polyphenol functionalities used to bind organic pollutants were quercetin multiacrylate (QMA) and curcumin multiacrylate (CMA), which are acrylated forms of the nutrient polyphenols quercetin (found in berries) and curcumin (found in turmeric), both with expected affinity for chlorinated organics. The affinity of these novel materials for PCB 126 was evaluated at equilibrium conditions using a gas chromatography coupled to electron capture detection (GC-ECD) for quantification purposes, and the data was fitted to the nonlinear Langmuir model to determine binding affinity (K_D) and maximum biding capacity (B_{max}). The K_D values obtained demonstrated that the presence of the polyphenolic-based moieties, CMA and QMA, as crosslinkers enhanced the binding affinity for PCB 126, and this expected to be a result of their aromatic rich nature which provides sites for $\pi - \pi$ stacking interactions between the nanoparticle surface and the PCBs in solution. These values are lower that the reported affinity coefficients for activated carbon, which is the gold standard for capture/binding of organic contaminants in water and waste water treatment. Furthermore, upon exposure to an alternating magnetic field (AMF) for a period of 5 minutes, over 90% of the bound PCB on these materials was released, offering a low-cost regeneration method for the nanocomposites. Additionally, this novel regeneration strategy does not require the use of large volumes of harsh organic solvents that oftentimes become harmful byproducts. Overall, we have provided strong evidence that these novel nanocomposites have a promising application as nanoadsorbents for specific organic contaminants in contaminated water sources providing high binding affinities, a low-cost regeneration technique and are capable of withstanding use under environmental conditions offering a cost-effective alternative to current remediation approaches.