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UNLOCKING THE POTENTIAL OF NEW SPINEL-TYPE MIXED OXIDES FOR RAPID AND EFFICIENT REMOVAL OF HAZARDOUS AQUEOUS CONTAMINANTS

Ionela Grecu, Corneliu Cojocaru, Petrisor Samoila, Bogdan-Constantin Condurache, Bogdan-George Rusu, Andra-Cristina Enache*

Petru Poni Institute of Macromolecular Chemistry, Iasi, 41A Grigore Ghica Voda Alley, 700487, Iasi, grecu.ionela@icmpp.ro, Romania

**corresponding author: enache.andra@icmpp.ro*

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Introduction

The exponential growth of industrialization and urbanization has led to the widespread occurrence of toxic contaminants in aquatic environments, posing significant risks to ecosystems and human health. Among these pollutants, synthetic dyes are of particular concern owing to their extensive use, high chemical stability, resistance to biodegradation, and potential toxic effects. Their persistence in water bodies, coupled with the limitations of conventional treatment technologies, makes their effective removal a major environmental challenge.

Consequently, the development of advanced functional materials capable of rapidly and efficiently removing dye contaminants has become a critical priority in sustainable water remediation.

Materials and methods

New rare-earth-doped spinel ferrites were synthesized by using the sol-gel auto-combustion approach, using citric acid as a fuel and nitrate salts as cation sources. Briefly, stoichiometric amounts of nitrate metal salts were dissolved in ultrapure water and then mixed with citric acid solution. The resulting mixture was heated under stirring on a water bath until a viscous gel was formed. The gel was subsequently placed on a sand bath, heated up to 350 °C to induce self-ignition, and maintained until a dark brown powder was obtained. The resulted powder was further subjected to three thermal treatments at 500 °C for 5h, 700 °C for 5h, and 900 °C for another 7h, to eliminate any remaining organic residues from the fuel agent and to achieve the formation of pure spinel ferrite.

The materials were subjected to extensive structural, morphological, textural, and magnetic characterization by FTIR, XRD, TEM and VSM. Their adsorption performance was evaluated using representative organic dyes as model pollutants, while the magnetic systems were further evaluated in terms of magnetic separation and recovery performance.

Results and conclusions

Magnetic adsorbents offer a distinct advantage in wastewater treatment owing to their rapid and efficient separation from aqueous media under an external magnetic field, enabling facile recovery and reuse. To evaluate their practical applicability, the magnetic properties of the synthesized ferrites were investigated by VSM at room temperature following sample demagnetization. All investigated materials exhibited hysteresis loops characterized by enhanced magnetic response, together with negligible coercivity and remanent magnetization, indicative of their

superparamagnetic nature. This magnetic behavior, which can be attributed to the distribution of cations between the tetrahedral and octahedral sites within the spinel lattice, was preserved following rare-earth doping. These findings suggest that the incorporation of rare-earth ions did not significantly alter the fundamental magnetic characteristics of the ferrite framework, thereby maintaining its inherent magnetic functionality. Notably, rare-earth incorporation resulted in a pronounced refinement of the microstructure while preserving the structural integrity of the spinel lattice.

This microstructural modification was evidenced by a decrease in crystallite size, as determined by XRD analysis. TEM observations further supported these findings, revealing a substantial reduction in particle size for the lanthanide-doped spinel ferrites compared with the undoped reference material. Such microstructural refinement is particularly advantageous for adsorption applications, as the reduction in particle size may increase the accessible specific surface area and promote the exposure of a greater number of active surface sites, thereby potentially enhancing the adsorption performance of the resulting materials.

In summary, rare-earth-doped spinel ferrites were successfully synthesized via the sol-gel auto-combustion route. The synergistic combination of phase purity, nanoscale dimensions, and pronounced superparamagnetic behavior, together with the microstructural refinement induced by rare-earth modification, highlights their considerable potential as magnetically recoverable adsorbents for advanced water treatment applications.

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