

Sustainable Bacterial Inactivation in Agrochemical Industrial Wastewater Using Magnetic Nanoparticles

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Introduction

Contamination of agrochemical-industrial washing water by bacterial microorganisms represents an important environmental and operational challenge, particularly in tank-cleaning and formulation systems. Residual microbial contamination may lead to biofilm formation, deterioration of agrochemical formulations, and contamination of industrial equipment and disposal systems. Conventional disinfection methods frequently require high consumption of chemicals and may generate secondary residues, making the development of alternative technologies for water treatment essential for improving process sustainability and operational safety. Magnetite nanoparticles (Fe_3O_4 NPs) have attracted considerable interest due to their antimicrobial potential, in addition to their magnetic properties, high surface area, and chemical stability (Hayat et al., 2025; Wojciechowska et al., 2022; Ma et al., 2017). Furthermore, their magnetic behavior enables rapid recovery and reuse after treatment, making them attractive materials for industrial wastewater remediation applications (DAS et al., 2025; ABILIO et al., 2021; MA et al., 2017). Therefore, the present study aimed to synthesize and characterize magnetite nanoparticles and evaluate in a preliminary approach their bactericidal activity against contaminated agrochemical-industrial washing water.

Material and Methods

Magnetite nanoparticles (Fe_3O_4) were synthesized through the co-precipitation method using iron salts under alkaline conditions (Laurent et al., 2008). Preliminary characterization of the synthesized nanomaterials was performed using Fourier Transform Infrared Spectroscopy (FTIR) and Energy Dispersive X-ray Spectroscopy (EDX) to evaluate the chemical structure and elemental composition, respectively. Agrochemical-industrial washing water samples contaminated with bacterial microorganisms were evaluated using the Aquacult® Plate Count Agar (PCA) system, and colony-forming unit (CFU) quantitation was estimated. Different nanoparticle concentrations (0.1%, 0.5% and 1.0% m/m) were investigated to evaluate the antimicrobial performance of the synthesized material. Untreated wastewater samples were used as experimental controls.

Results and Discussion

FTIR analysis confirmed the successful synthesis of magnetite nanoparticles through the identification of characteristic Fe–O vibrational bands associated with the spinel Fe_3O_4 structure (Wojciechowska et al., 2022). EDX analysis demonstrated the predominance of iron signals, validating the elemental composition of the synthesized nanostructures (Figure 1). Bactericidal assays demonstrated important bacterial reduction estimated around 97 % after treatment with 1.0% m/m Fe_3O_4 nanoparticles (Figure 2). Antimicrobial activity may be associated with ROS-mediated oxidative stress and membrane destabilization caused by nanoparticle interaction with bacterial cells, what will be posteriorly investigated (HAYAT et al., 2025; Wojciechowska et al., 2022). Additionally, the magnetic properties of the synthesized material enabled rapid magnetic recovery from the aqueous medium after treatment, highlighting the technological potential of magnetite-based systems for industrial wastewater remediation and reuse application (DAS et al., 2025; MA et al., 2017; ABILIO et al., 2021).

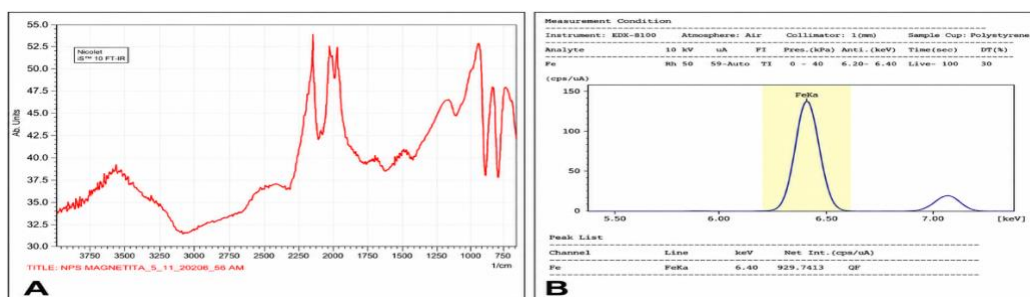


Figure 1. (A) FT-IR spectrum of magnetite nanoparticles, showing the characteristic vibrational bands associated with the synthesized material. (B) EDX spectrum confirming the elemental composition of the synthesized nanostructures.

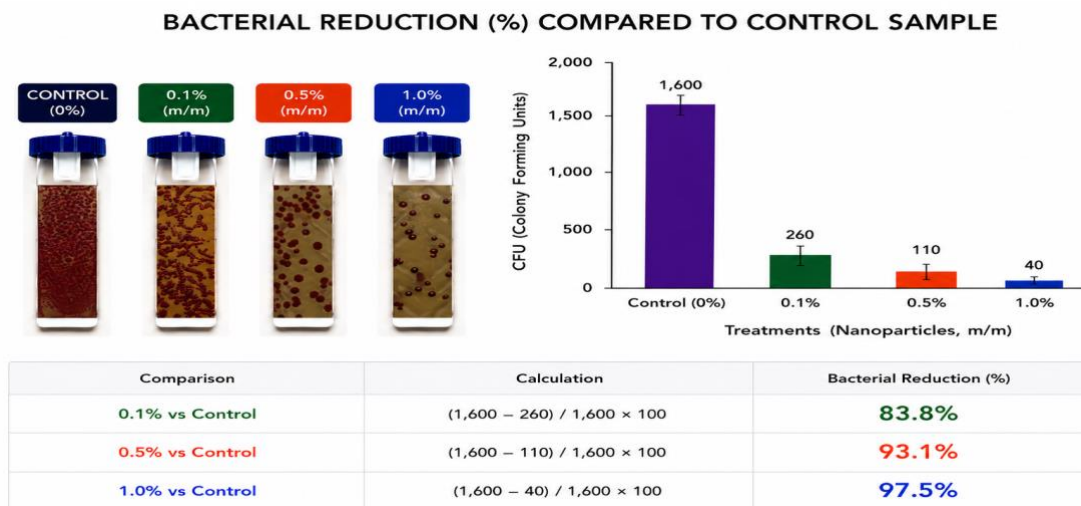


Figure 2. Evaluation panel of the antibacterial activity of Fe₃O₄ nanoparticles in industrial wastewater, showing dose-dependent bacterial reduction by direct CFU counting.

Conclusion

The synthesized Fe₃O₄ nanostructures demonstrated promising activity against contaminated agrochemical-industrial washing water, promoting a substantial microbial reduction while maintaining magnetic recoverability. FTIR and EDX analyses confirmed the successful synthesis of the nanomaterial. These findings highlight the technological potential of magnetic nanomaterials as sustainable alternatives for industrial wastewater treatment and reuse applications associated with agrochemical industries.

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