Tracing nanoplastics removal dynamics: Europium-labeled polystyrene adsorption on fungal biomass in a simulated treatment system

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Nanoplastics in environment

Nanoplastics (NPs) are an emerging global concern due to their persistence, mobility, and harmful effects on ecosystems and human health. NPs (<100 nm) are especially problematic because of their high surface area, colloidal stability, and ability to cross biological barriers, causing oxidative stress, inflammation, and genotoxicity. They also adsorb pollutants such as heavy metals and POPs, amplifying their toxicity. Conventional water treatment often fails to remove nanoscale plastics, while adsorption offers a promising alternative. However, traditional adsorbents face cost and reusability challenges. Fungal biomass has emerged as a sustainable solution, with functional groups on fungal cell walls enabling effective NP binding [1,2,3].

Batch adsorption system

The adsorption performance of TRVE biomass was evaluated under different conditions. Removal efficiency of europium-doped polystyrene nanoplastics (EuPSNPs) (0.5 g TRVE; 1400 µg/L EuPSNPs) increased rapidly within the first 3 minutes of contact, reaching about 62%, and then stabilized, indicating fast occupation of active sites followed by equilibrium. Biomass dosage also influenced adsorption: increasing mass from 50 to 400 mg enhanced removal efficiency (77%), while higher amounts produced little further improvement, reflecting saturation of available adsorption sites.

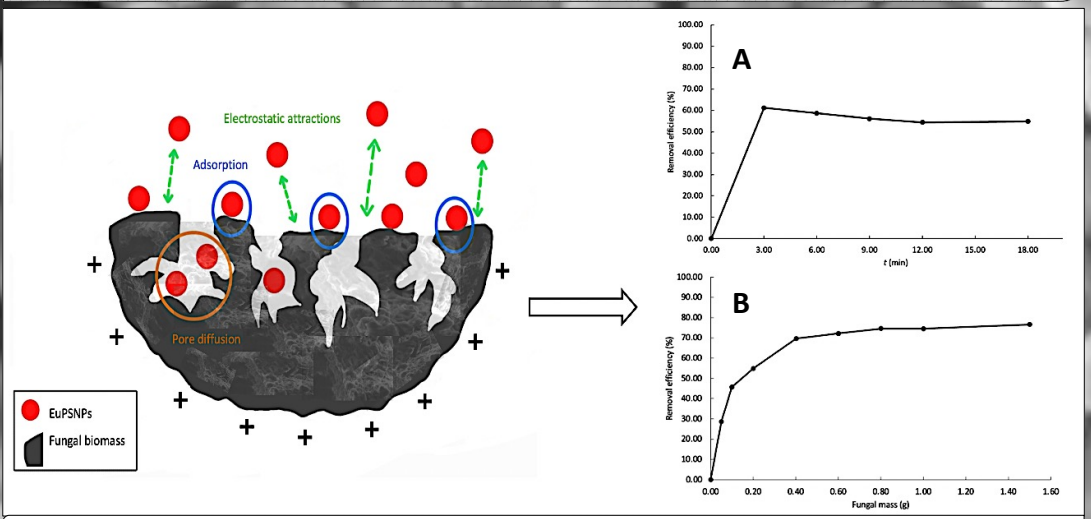


Fig. 1 Dependence of the batch system PSNPs removal efficiency on: A) time of adsorption ; B) added mass of fungal material (0.05 – 1.5 g) in 50 mL of MQ water at stirring speed of 1000 rpm.

Detection of nanoplastics

Eu concentrations in the effluent were quantified using ICP-OES to assess adsorption efficiency. Furthermore, LA-ICP-MS was employed to resolve the presence and distribution EuPSNPs within the biomass-packed column.

Column adsorption system

A fixed-bed column packed with 0.7 g of *T. versicolor* biomass (TRVE) (influent: 1400 µg/L EuPSNPs) showed >95% removal within the first 45 mL of effluent, followed by a gradual decline to ~55% at 70 mL (Fig. 2C). LA-ICP-MS elemental mapping of 153Eu and 151Eu confirmed the presence and distribution of europium within the biomass-packed column (Fig. 2D), with intensity increasing toward the lower layers of the column, indicating nanoparticle migration and accumulation during flow-through. Both isotopes showed consistent spatial patterns, with 153Eu exhibiting slightly stronger signals due to its higher natural abundance.

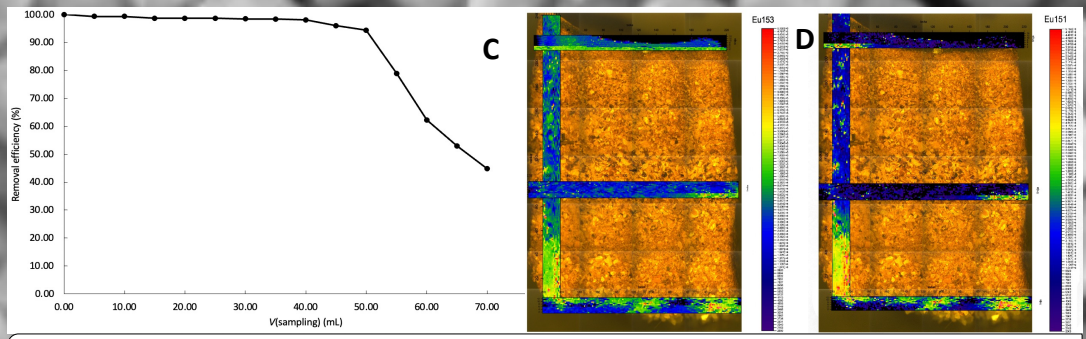
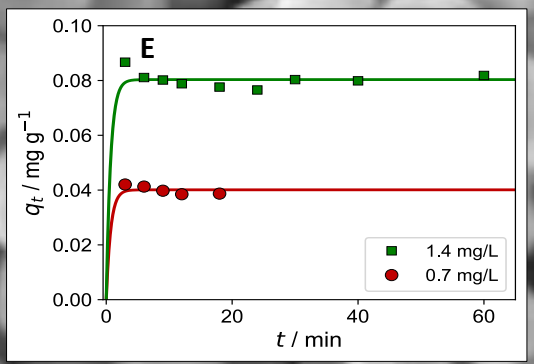


Fig. 2 C) Dependence of the EuPSNPs removal efficiency in a fixed-bed column system on volume of effluent using 0.7 g of fungal biomass at flow rate 1.0 mL min^{-1} of 1400 µg L^{-1} EuPSNPs in MQ; D) LA-ICP-MS image using 0.7 g of fungal biomass with 65 µm circle spot size, 100 µm/s scan speed, 100 Hz repetition rate, 3.0 J/cm^2 fluence and 11.0 x 1.0 mm^2 in dimentions.



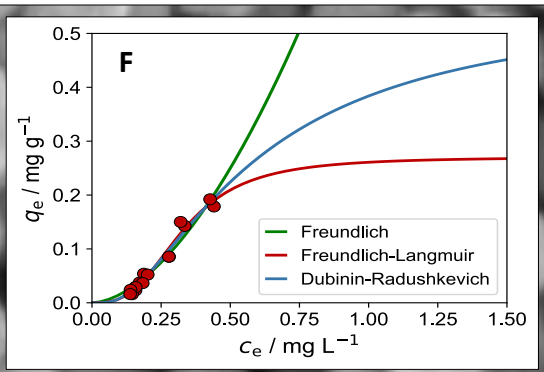


Fig. 3 E) Dependence of PSNPs removal efficiency on the adsorption time in batch system, performed with 0.5 g of fungal biomass and the initial PSNPs concentration of 0.7 mg L^{-1} and 1.4 mg L^{-1} and stirring speed 1000 rpm; F) Evaluation of biosorption isotherms for PSNPs removal in a batch system.

Adsorption kinetics & isotherms

Kinetic analysis of PSNP biosorption by TRVE showed a rapid initial uptake that reached equilibrium and fit well to a pseudo-first-order model, indicating a physisorption-driven process (Fig. 3E). Equilibrium adsorption isotherms (Fig. 3F) were described by the Langmuir–Freundlich model, revealing heterogeneous binding sites and strong TRVE affinity for PSNPs.

Fig. 4 Nanoplastics pollution in ocean.

Results & Conclusion

T. versicolor biomass proved to be a low-cost, renewable biosorbent for polystyrene nanoplastics (PSNPs), achieving high removal in both batch and column setups. Optimized columns reached near-complete adsorption, with LA-ICP-MS confirming uniform particle distribution. Adsorption followed pseudo-first-order kinetics and fit the Langmuir–Freundlich isotherm, indicating physisorption on heterogeneous sites. Together, biosorption and sensing offer an effective, sustainable strategy for nanoplastic removal and monitoring, advancing integrated solutions for water quality protection.

References

[1] Tripathi, M., et al. *Journal of Xenobiotics*, 2025, *15*(1), 30.
[2] Baldrian, P. (2003), *Enzyme and Microbial technology*, *32*(1), 78-91.
[3] Novak, S., et al. *Ecotoxicology and Environmental Safety*, 2025, *301*, 118491.