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Chronic Impact of Silver Nanoparticle on Aerobic Wastewater Biofilm

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Abstract : The application of silver nanoparticles (AgNPs) in personal care products, various household and industrial products has resulted in an inevitable environmental exposure of such engineered nanoparticles (ENPs). Ag ENPs, released via household and industrial wastes, reach water resource recovery facilities (WRRFs), yet the fate and transport of ENPs in WRRFs and their potential risk in the biological wastewater processes are poorly understood. Accordingly, our main objective was to elucidate the impact of long-term continuous exposure to AgNPs on biological activity of aerobic wastewater biofilm. The fate, transport and toxicity of 10 µg.L-1and 100 µg.L-1 PVP-stabilized AgNPs (50 nm) were evaluated in an attached growth biological treatment process, using lab-scale moving bed bioreactors (MBBRs). Two MBBR systems for organic matter removal were fed with a synthetic influent and operated at a hydraulic retention time (HRT) of 180 min and 60% volumetric filling ratio of Anox-K5 carriers with specific surface area of 800 m2/m3. Both reactors were operated for 85 days after reaching steady state conditions to develop a mature biofilm. The impact of AgNPs on the biological performance of the MBBRs was characterized over a period of 64 days in terms of the filtered biodegradable COD (SCOD) removal efficiency, the biofilm viability and key enzymatic activities (α-glucosidase and protease). The AgNPs were quantitatively characterized using single-particle inductively coupled plasma mass spectroscopy (spICP-MS), determining simultaneously the particle size distribution, particle concentration and dissolved silver content in influent, bioreactor and effluent samples. The generation of reactive oxygen species and the oxidative stress were assessed as the proposed toxicity mechanism of AgNPs. Results indicated that a low concentration of AgNPs (10 µg.L-1) did not significantly affect the SCOD removal efficiency whereas a significant reduction in treatment efficiency (37%) was observed at 100 µg.L-1AgNPs. Neither the viability nor the enzymatic activities of biofilm were affected at 10 µg.L-1AgNPs but a higher concentration of AgNPs induced cell membrane integrity damage resulting in 31% loss of viability and reduced α-glucosidase and protease enzymatic activities by 31% and 29%, respectively, over the 64-day exposure period. The elevated intercellular ROS in biofilm at a higher AgNPs concentration over time was consistent with a reduced biological biofilm performance, confirming the occurrence of a nanoparticle-induced oxidative stress in the heterotrophic biofilm. The spICP-MS analysis demonstrated a decrease in the nanoparticles concentration over the first 25 days, indicating a significant partitioning of AgNPs into the biofilm matrix in both reactors. The concentration of nanoparticles increased in effluent of both reactors after 25 days, however, indicating a decreased retention capacity of AgNPs in biofilm. The observed significant detachment of biofilm also contributed to a higher release of nanoparticles due to cell-wall destabilizing properties of AgNPs as an antimicrobial agent. The removal efficiency of PVP-AgNPs and the biofilm biological responses were a function of nanoparticle concentration and exposure time. This study contributes to a better understanding of the fate and behavior of AgNPs in biological wastewater processes, providing key information that can be used to predict the environmental risks of ENPs in aquatic ecosystems.

Keywords : biofilm, silver nanoparticle, single particle ICP-MS, toxicity, wastewater
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