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The aquatic ecotoxicity of manufactured silica nanomaterials and their interactions with organic pollutants

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Abstract

Manufactured silica nanomaterials are one of the nanomaterials consumed in the highest volumes and are used in a wide range of products such as food, cosmetics, coatings, paints, textiles, concrete and paper. They also provide promising properties that help solving societal challenges, such as water remediation, by binding contaminants. However, their large and wide use leads to an inevitable release into surface waters, which raises concerns of potential environmental impacts, because of their small size, reactive surfaces and the risk of facilitating biological uptake of other co-occurring chemicals ("trojan horse effect"). Therefore, this thesis systematically investigates the aquatic ecotoxicity of manufactured silica nanomaterials alone and in combination with toxic organic chemicals. The thesis is based on an in-depth ecotoxicological evaluation of nine silica nanomaterials with different size, charge, surface modification and shape in experiments with bacteria, algae, crustacean and fish gill cells. These data are then complemented with data from other scientific publications in a systematic review, in order to derive the maximum acceptable environment concentration in the aquatic environment (PNEC, the predicted no effect concentration). Finally, this thesis examines the ability of silica materials to adsorb organic pollutants with different charges.

The results show that impacts are a result of surface area, surface chemistry and exposed organism/cell type. Silica nanomaterial that is sterically stabilized with glycerol propyl tails is benign in all assays showing no signs of toxic action. This is likely due to a steric hindrance that prevents contact between the material and the cells/species. Weakly anionic (non-modified) and strongly anionic (aluminium-modified) silica are toxic to fish gill cells which depends on the total surface area of the nanomaterial. In contrast to experiments with fish cells, strongly anionic silica is not toxic to algae, likely due to the presence of a cell wall, which hampers nanomaterial-cell interactions. However, cationic and non-modified silica nanomaterials cause an inhibition of algal growth. This is likely caused by an adsorption of the material to the algae, which leads to shading.

The results from the exposures to mixtures of silica nanomaterial and organic pollutants show that strongly anionic nanomaterials bind cationic paraquat and thereby reduce paraquat toxicity to algal cells. In addition, the cationic material can bind and reduce toxicity of anionic pentachlorophenol in algae, which is likely pH and phosphate dependant. Experiments with fish cells indicate that the anionic NMs bind the cationic hexadecylpyridinium, but do not reduce the toxicity in exposed fish cells. Instead, the observed effects correspond well with the effects predicted with the two concepts independent action and concentration addition. In general, the mixture experiments indicate that silica nanomaterials possess promising properties to bind and remove certain pollutants in water. However, the use of silica nanomaterials for such purpose in industrial applications requires additional research.