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Interactions between engineered nanoparticles and dissolved organic matter: A review on mechanisms and environmental effects

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A B S T R A C T

Dissolved organic matter (DOM) is ubiquitous in the environment and has high reactivity. Once engineered nanoparticles (ENPs) are released into natural systems, interactions of DOM with ENPs may significantly affect the fate and transport of ENPs, as well as the bioavailability and toxicity of ENPs to organisms. However, because of the complexity of DOM and the shortage of useful characterization methods, large knowledge gaps exist in our understanding of the interactions between DOM and ENPs. In this article, we systematically reviewed the interactions between DOM and ENPs, discussed the effects of DOM on the environmental behavior of ENPs, and described the changes in bioavailability and toxicity of ENPs caused by DOM. Critical evaluations of published references suggest further need for assessing and predicting the influences of DOM on the transport, transformation, bioavailability, and toxicity of ENPs in the environment.

Contents

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Introduction

In the past decades, an intensive and growing interest has focused on nanotechnology, and substantial advances have been made. The small size of engineered nanoparticles (ENPs) endows them unique physicochemical properties, which has spurred enormous applications. ENPs are incorporated into household goods, such as detergents, sunscreen creams and water filters, and widely used in industry field such as nanocatalysts, solar cells, and electronic devices (Chaudhuri and Paria, 2012; Mahmoudi et al., 2011; Yu et al., 2013). The significant progress in theranostics like biosensing, bio-imaging and drug-delivery also encourages the use of ENPs for potential treatment of tumors (Lim et al., 2015). Due to the rapid development of nanotechnology, some scholars have considered the current century as the "Nanotechnology Age" (Mahmoudi et al., 2011). However, the vast production and application of ENPs will inevitably bring their input into the environment. In fact, commonly used typical ENPs, such as titanium dioxide nanoparticles (TiO_2 NPs) and silver nanoparticles (AgNPs), have already been detected in natural waters (Gondikas et al., 2014; Pasricha et al., 2012; Wen et al., 1997). Although the predicted concentrations of these ENPs in aquatic systems are currently orders of magnitude lower than those that are known to have environmental effects on aquatic biota (Batley et al., 2013), the concentration would change with the proliferation of ENPs in various applications in the future, leading to public concerns of their potential risks to the aquatic organisms and human health.

Once released into natural systems, ENPs may interact with dissolved organic matter (DOM) in the environment, which would greatly influence the final fate, transport, transformation and the bioeffects of ENPs. DOM, mainly derived from slow microbial decomposition of animal residues, plants and microorganisms, is ubiquitous in the natural environment. The sources, properties and characterization methods of DOM have been thoroughly discussed in previous review papers and books (Chen and Hur, 2015; Connell, 2005; Mopper et al., 2007; Nebbioso and Piccolo, 2013). The DOM concentration in aquatic ecosystems depends on biogeochemical conditions and climate, but typically ranging from 0.1 to 10 mg/L DOC (dissolved organic carbon). Rather than a single compound, it can be regarded as a pool of abundant substances with low molecular weights (MW, less than 2000 Da) and high MW (up to 10,000 Da), and contains numerous functional groups, such as thiols, phenolic-OH, quinones, aldehydes, ketones, carboxyls and methoxyls (Aiken et al., 2011; Nebbioso and Piccolo, 2013). Consequently, DOM can chelate with metals and adsorb organic toxicants, which play important roles in the cycle and transport of inorganic and organic molecules and ions. Interactions of ENPs with DOM may result in a DOM coating on ENP surfaces, thus modifies the surface properties, solubility, stability and toxicity of ENPs (He et al., 2016; Hou et al., 2017; Lowry et al., 2012; Philippe and Schaumann, 2014). Modification of ENPs may make them behave differently from the ENPs originally prepared in laboratories. A thorough understanding of the ENP–DOM interaction is of great importance to evaluate and predict the possible fate, transport and toxicity of ENPs.

Studies on understanding the ENP–DOM interactions and their effects on the environmental behavior of ENPs have been reported quite extensively in recent years, with substantial information scattered in hundreds of research papers based on laboratory experiments and model predictions. Very recently, a few excellent papers reviewed or discussed part of this topic, including a review on interactions of DOM with natural and engineered inorganic colloids (Philippe and Schaumann, 2014); a feature article about the impacts of DOM on the fate of metals, nanoparticles (NPs) and colloids in

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