Fate, behaviour, and implications of ZnO nanoparticles in a simulated wastewater treatment plant

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ABSTRACT

Increased use of engineered nanoparticles (ENPs) has resulted in their entry into municipal wastewater treatment plants (WWTPs) as their final sinks. However, the adverse impact of ENPs on the bacterial activity in the activated sludge WWTPs is not yet well understood, despite their increased release into such systems. In this study, the impacts on WWTPS associated with the disposal of zinc oxide (ZnO) ENPs was investigated using a simulated WWTP developed as per the prescribed Organization for Economic Co-operation and Development (OECD 303A) specifications. Analyses were done to determine zinc concentrations at various stages of the setup, mainly in the raw wastewater and treated effluent, using inductively coupled plasma optical emission spectrometry (ICP-OES). The results obtained indicated low levels of zinc residue (about 50–200 µg/L) in the treated effluent compared to relatively high concentrations of Zn in the sludge (about 3 000 mg/kg). Results reported herein imply precipitation of ZnO ENPs during wastewater treatment processes and hence its high levels in the sludge. The presence of solid Zn in the sludge was determined using X-ray diffraction spectroscopy (XRD). Overall, no significant impact of ZnO ENPs on the performance of the simulated WWTP was observed, in terms of the removal levels of chemical oxygen demand (COD) during the treatment process

Keywords: wastewater, activated sludge, nanoparticles, zinc oxide, OECD 303A

INTRODUCTION

Biological wastewater treatment processes employ a consortium of heterotrophic and autotrophic bacteria, essentially to degrade organic matter present in wastewater. Generally, the activated sludge process treats biodegradable organic material in domestic sewage as well as effluents from other sources such as pulp and paper mills, food industries, abattoirs, textile mills, edible oils, coal gasification wastes, petrochemical wastes, and oil refinery wastes (Henze et al., 2002; Metcalf and Eddy, 2002). The sorption of pollutants on activated sludge is among the fundamental processes for the removal of toxic substances including metals, synthetic organic chemicals, suspended solids, and pathogens in wastewater (Dobbs et al., 1989; Musee et al., 2007; Sheng et al., 2008). However, the sorption process may be ineffective as the bacteria used for wastewater treatment can be inhibited by toxic substances, e.g., heavy metals (Çeçen et al., 2010), thus adversely impacting the biologically-based treatment processes.

The advent of nanotechnology has resulted in fast production and wide usage of engineered nanoparticles (ENPs) in consumer products and industrial applications. This has led to unintended release of ENPs into environmental systems at different stages of their product life cycles (e.g. manufacturing, use, etc.) (Koehler et al., 2008; Musee, 2011). For instance, zinc oxide (ZnO) ENPs are incorporated in numerous products including sunscreens, paints, cosmetics, dye-synthesized cells, plastic additives, catalysts and electronics (Woodrow Wilson, 2009; BCC Research, 2012; Piccinno et al., 2012); which in turn could lead to their release into natural and technical systems, e.g., wastewater treatment plants (WWTPs).

For example, ENPs released into wastewater from various sources eventually enter WWTPs (Kiser et al., 2009), and currently ENPs are considered among the rapidly emerging contaminants in municipal wastewater systems (Brar et al., 2010; Musee et al., 2011). Therefore, WWTPs are likely potential major point sources of ENP release into the environment, due to broad-scale and increasing usage of nanoproducts (Woodrow Wilson, 2015; BCC Research, 2012; Piccinno et al., 2012). Among the likely pathways of ENP release into the environment from WWTPs are water systems, soils, and air, through treated effluent, bio-solids, and plant-generated aerosols, respectively, (Limbach et al., 2008; Kiser et al., 2010; Musee, 2011; Westerhoff et al., 2011).

The effects of ZnO ENPs on aquatic organisms such as bacteria in different media have been investigated, and the observed toxicity was attributed to either soluble (dissolved) Zn^{2+} species, ZnO particulates, or both forms (Jiang et al., 2009; Wong et al., 2010; Thwala et al., 2013). Padmavathy and Vijayaraghavan (2008), using the disk diffusion method, and Premanathan et al. (2011), using the resazurin incorporation method, found the minimum inhibitory concentration (MIC) of nano ZnO against *Escherichia coli* to be 400 and 500 µg/mL, respectively. Moreover, Premanathan et al. (2011) indicated that the inhibitory activity was due to the generation of reactive oxygen species (ROS) which, in turn, induced apoptosis. However, a study by Liu et al. (2011) indicated that ZnO ENP toxicity to the biological populations in activated sludge (i.e. endogenous respiration, BOD biodegradation and nitrification) was solely due to soluble Zn^{2+} generated upon ZnO ENP dissolution. This finding points to the role of ENP dissolution for the generation of toxic effects on activated sludge bacterial communities. However, Musee and co-workers (2014) reported limited dissolution and impact of ZnO ENPs on bacterial viability under typical wastewater conditions.

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