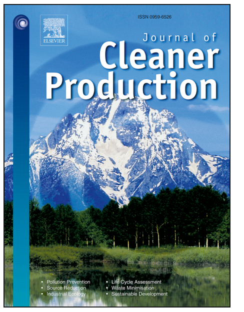

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Stochastic fate analysis of engineered nanoparticles in incineration plants

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Abstract

Worldwide waste is increasing and can contain engineered nanoparticles (ENP) made from almost the entire spectrum of the periodic table. An increasing amount of waste (including nanowaste) is incinerated. A full-scale experiment in a modern waste incineration plant showed that even inert nanoparticles (nano-CeO_2) are successfully removed from the flue gas and transferred to the solid incineration residues. Predicting the fate of nanomaterials in incineration plants with models based on real measurements would reduce the immense efforts (time and resources) for real-scale experiments. Here, we develop a model for the ENP fate in incineration plants, based on the data of the nanoCeO_2-experiment. We investigated all possible transfers and sinks of ENP throughout the incineration by linking ENP concentration measurements to the nanomaterial flows and retention times. The model also delivers information on the associated uncertainties and how they propagate through the incineration system by using a fully probabilistic material flow analysis. The model can be generalized to other ENP and also to other incineration plants. We show that the output of the measurements was consistent albeit relying on multiple measurement methods, and that a one day sampling period is sufficient to obtain an overview on the fate of nanoparticles in incineration plants. In addition to the dynamic results, a generalized steady state mass flow with transfer factors is provided and can be used for modeling purposes of CeO_2 or other nano sized metals with similar physic-chemical properties.

1. Introduction

1.1. Sustainable treatment of nanowaste is increasingly important

Nanoparticles from natural sources such as sea salt, soil dust or pollen lead to ambient concentrations of a few thousand particles per cm^3 (Shi et al., 2001). Anthropogenic sources such as traffic or heating further increase human exposure to nanoparticles. A new emission source is arising from the growing production and application of engineered nanoparticles (ENP) in industrial and consumer products (Gottschalk et al., 2010), which already represents a multiple billion USD industry (Becker, 2013). Various emission hotspots of ENP along their lifecycle in nanoenabled products have already been identified (Koehler et al., 2008), such as indoor emissions from nanopowder production and handling (Savolainen et al., 2010) or nanosilver release from textiles into wastewater (Lorenz et al., 2012). A further potential hotspot of accumulated and potentially re-emitted ENP are waste treatment systems (Musee, 2011), which have to deal with an increased amount of products containing ENP that have reached the end of their use. So-called nanowaste, i.e. discarded products that contain ENP, needs to be carefully evaluated with respect to sustainable waste management options. Increasingly important worldwide is incineration, which is a popular disposal option for conventional as well as for hazardous waste. Unfortunately, the amount and fate of nanoparticles in incineration plants is poorly understood because of virtually no experimental study and very simplistic modeling (Asmatulu et al., 2012; Bystrzejewska-Piotrowska et al., 2009; Mueller et al., 2013; Musee et al., 2011; Walser et al., 2012). Complicating aspects of nanoparticles are that they combine characteristics from gases (e.g. no sedimentation) and from larger particles (e.g. carrier for other compounds). Moreover, the complex chemical and physical conditions in real incineration plants make *mechanistic* fate modeling of ENP even more unrealistic. However, a real-scale experiment to test whether incineration plants are a favorable solution for the disposal of nanowaste is a theoretical and practical challenge. Such studies have to deal with (i) the development of cutting-edge measurement capabilities, (ii) the extremely low nanoparticle concentrations on top of a commonly high elemental background concentration, and (iii) a complex large scale experimental setting. A recent study (Walser et al. 2012) showed that modern incineration plants can remove inert nanoparticles from the flue gas and deposit them in the solid incineration residues. This experimental study also showed that location, residence time and residence form of ENP during the waste treatment process cannot be modeled in detail without adding dynamics to the temporally and spatially resolved ENP fate parameters.