Environmental Research 140 (2015) 661–672

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Approach on environmental risk assessment of nanosilver released from textiles

Doris Voelker[a,*], Karsten Schlich[b], Lars Hohndorf[a], Wolfgang Koch[a], Ute Kuehnen[a], Christian Polleichtner[c], Carola Kussatz[c], Kerstin Hund-Rinke[b]

[a] Federal Environment Agency Germany, Section IV 2.2, Wörlitzer Platz 1, 06844 Dessau-Rosslau, Germany
[b] Fraunhofer Institute for Molecular Biology and Applied Ecology, Department of Ecotoxicology, Auf dem Aberg 1, 57392 Schmallenberg, Germany
[c] Federal Environment Agency Germany, Section IV 2.4, Schichauweg 58, 12307 Berlin, Germany

ARTICLE INFO

Article history:
Received 11 February 2015
Received in revised form
22 April 2015
Accepted 11 May 2015
Available online 12 June 2015

Keywords:
Nanosilver
Textile
Environmental risk assessment
PEC
PNEC

ABSTRACT

Based on the increased utilization of nanosilver (silver nanomaterials=AgNM) as antibacterial agent, there is the strong need to assess the potential environmental implication associated with its new application areas. In this study an exemplary environmental risk assessment (ERA) of AgNM applied in textiles was performed. Environmental exposure scenarios (via municipal sewage treatment plant (STP)) with wastewater supply from domestic homes) were developed for three different types of textiles equipped with AgNM. Based on these scenarios predicted environmental concentrations (PECs) were deduced for STPs and for the environmental compartments surface water, sediment as well as soil. These PECs were related to PNECs (predicted no effect concentrations). PNECs were deduced from results of ecotoxicity tests of a selected AgNM (NM-300K). Data on ecotoxicology were derived from various tests with activated sludge, cyanobacteria, algae, daphnids, fish, duckweed, macrophytes, chironomids, earthworms, terrestrial plants as well as soil microorganisms. Emission data for the AgNM NM-300K from textiles were derived from washing experiments. The performed ERA was based on the specifications defined in the ECHA Guidances on information requirements and chemical safety assessment. Based on the chosen scenarios and preconditions, no environmental risk of the AgNM NM-300K released from textiles was detected. Under conservative assumptions a risk quotient for surface water close to 1 indicated that the aquatic compartment may be affected by an increased emission of AgNM to the environment due to the high sensitivity of aquatic organisms to silver. Based on the successful retention of AgNM in the sewage sludge and the still ongoing continual application of sewage sludge on farmland it is recommended to introduce a threshold for total silver content in sewage sludge into the respective regulations. Regarding potential risk mitigation measures, it is emphasized to preferably directly introduce AgNM into the textile fiber since this will strongly minimize the release of AgNM during washing. If this is not possible due to technical limitations or other reasons, the introduction of a threshold level controlling the release of AgNM from textiles is suggested. It has to be noted that this study is a case study which is only valid for the investigated NM-300K and its potential application in textiles.

1. Introduction

Nanosilver (AgNM) is currently utilized in various products and applications for a broad range of purposes. Toxicity and ecotoxicity of silver in general is well known (Ratte, 1999) and currently knowledge indicating harmful implications of AgNM on human health and the environment is increasing (e.g. as summarized in Schafer et al. (2013)). However, based on insufficient data, an overall assessment of the risks posed by all current products and applications using AgNM is not possible. As a starting point, in the presented case study, data on release rates, ecotoxicity and behavior of one selected AgNM were used to assess the potential environment risk posed by AgNM released from an exemplary chosen application (textiles).

Abbreviations: AgNM, silver nanomaterials; AF, assessment factor; dw, dry weight; EC10, effect concentration at which 10% of the test population are affected; EC50, effect concentration at which 50% of the test population are affected; ERA, environmental risk assessment; STP, (municipal) sewage treatment plant; PEC, predicted environmental concentration; PNEC, predicted no effect concentration; TG, test guideline; WWTP, wastewater treatment plant

* Corresponding author. Fax: +49 340 2104 3094.
E-mail address: doris.voelker@uba.de (D. Voelker).

http://dx.doi.org/10.1016/j.envres.2015.05.011

1.1. Application and production

Nowadays, it is possible to produce specific AgNM of defined properties. Thereby new application areas for AgNM evolve. According to the inventory of nanotechnology-based consumer products (Woodrow Wilson International Center for Scholars, 2015), AgNM are utilized in about 438 commercially distributed goods (March 13, 2015), mainly due to their antimicrobial properties. These goods include health care and fitness products which comprise personal hygiene agents and cosmetics. Furthermore AgNM are also introduced to textiles (Blaser et al., 2008). AgNM are intended for utilization in food packaging, interior fitting of cars and different construction materials. AgNM are also used for medical purposes, including bandages as well as surfaces of neurosurgical shunts and catheter. The applications of AgNM are supposed to have increased remarkably in the last years. The European Commission published estimated annual marketed quantities of AgNM of approximately 20 tons in its staff working paper (European Commission, 2012). However, estimations on market sizes of AgNM need to be taken with caution since no global or EU wide mandatory tool for reporting on production quantities exists so far.

Global production of textiles exhibiting antimicrobial properties was estimated to be around 100,000 tons in 2000 with an European annual growth of more than 15% (Gao and Cranston, 2008). Based on calculations of the "Silver Institute" (Silver Institute, 2011) 9 (Burkhardt et al., 2011) to 45 (Hund-Rinke et al., 2008) tons of silver are applied in textiles. Of these 13% to 79% are estimated to be in the size of the definition of nanoparticles (1–100 nm in three dimensions). In consequence, the global use of AgNM in textiles would be calculated as 1.2 to 36 tons (as reported in Windler et al. (2013)). However, it has to be considered that the estimations employed for the utilization of AgNM in textiles strongly vary. For instance, estimations focusing on the European Market vary by a factor of 10 (0.2 t/a reported in Burkhardt et al. (2011) and $\sim$2.25 t/a converted from Piccinno et al. (2012). Based on the information of the staff working paper of the European Commission it seems that up to 10% of the annual market quantity of AgNM would be utilized in textiles on the European Market (European Commission, 2012). The increased utilization of silver – and thus, also AgNM – as antimicrobial is also influenced by the general interest to decrease the use of organic chemicals and to select alternatives, which can be applied in minor concentrations and feature broad application areas (Nowack, 2010).

1.2. Release from textiles and environmental exposure

Based on the utilization of AgNM in various commercial goods, various extents of release of AgNM from products are expected and diverse routes of entry into the environment need to be considered. The differences in release and entry will result in differing environmental consequences, i.e. with respect to the extent of accumulation of AgNM in freshwater, sediments and soil. Unfortunately, data on release rates for the different sources of AgNM do not exists and thus an overall estimation of environmental exposure of AgNM is currently not possible. Thus, the presented study exclusively focuses on the release of AgNM from textiles and subsequently, on the exposure to the environment.

There are different possibilities to finish textiles with silver or AgNM, respectively. The surface of the textiles can be impregnated with silver. The silver can also be adsorbed to the fiber or it can be directly integrated into the fiber. 90% of all applications represent textiles processed with silver (i.e. surface impregnation or adsorption). Only in 10% of all cases silver is integrated into the fiber (Burkhardt et al., 2011). It is assumed, that the way of equipping the textile plays a major role in the amount of AgNM released from the textile.

With growing commercial application and-in turn-growing production volume the likelihood of emission of AgNM in the environment rises. In principal AgNM can be introduced into the environment via different routes. AgNM from major application areas like textiles and cosmetics may enter the environment via the sewer system (Kaegi et al., 2013). It was shown by a number of publications that AgNM-functionalized textiles release significant amounts of silver during the washing process (Benn and Westerhoff, 2008; Danish Ministry of the Environment, 2012; Geranio et al., 2009; Lorenz et al., 2012). Also colloidal as well as ionic silver was found to be released during washing. Depending on the surrounding media, the released AgNM reacts with ions. Especially sulfidation is an important process in the environment since metal nanomaterials as nanosilver feature a high affinity for sulfur molecules. Here, they react with e.g. inorganic sulfur in sewage sludge, sediments, soils and air (Levard et al., 2011; Lombi et al., 2013; Lowry et al., 2012). Silver, regardless of the specification, released via this source will inevitably reach sewer systems and will end up in a sewage treatment plant (STP). From recent publications it is assumed that the main part of AgNM introduced to the STP will accumulate in the sewage sludge (Kaegi et al., 2011; Schlich et al., 2013). In case sewage sludge is used as fertilizer in agricultural practice, AgNM will subsequently reach the terrestrial environment. A very low part is also released into the aquatic environment (surface water, sediments) via the effluent of the STP (Kaegi et al., 2011; Schlich et al., 2013).

1.3. Ecotoxicity

Within the scientific community it is widely acknowledged that the toxicity of manufactured AgNM mainly depends on the toxic effects of the silver ions released from the nanomaterial. However, there is an ongoing discussion if AgNM exhibits a particle-specific toxicity which is mediated by a physical interaction of the nanomaterial (Asghari et al., 2012; Bilberg et al., 2012; Kennedy et al., 2010; Navarro et al., 2008). The ecotoxicity of the different specifications of silver is well known (Ratte, 1999): dissolved silver is highly toxic to prokaryotes as well as many aquatic invertebrates and fish. The ecotoxicity of silver compounds such as AgCl or Ag_2S is much lower (Ratte, 1999). Based on their ionic properties, silver ions have the ability to bioconcentrate in organisms by using cell membrane ion transporters (Luoma, 2008). The aquatic toxicity of silver depends on the bioavailability of free silver ions, which in turn depends on the characteristics of the surrounding media: the presence of complex building agents, dissolved organic carbon or competing ions influences the amounts of free and active silver ions.

Since AgNM represents a biological active substance of known toxicity, it is mandatory to elucidate if an increase of AgNM in the environment results in further risks to organisms.

1.4. Scope of the study

The scope of this study was to perform an exemplary environmental risk assessment (ERA) of AgNM applied in textiles. Risk assessment of nanomaterials is currently considered as a scientific challenge for stakeholders and there is an ongoing discussion on how to consider nanomaterials in well-proven risk assessment approaches which initially were developed for conventional chemicals. Chemical reactions such as dissolution or transformation processes (e.g. ion release, binding of released ions with components of the ambient media, modifications of the crystalline structure of the nanomaterials, surface modifications, degradation of coatings) are currently not addressed in risk assessment approaches. In our study, we considered AgNM as a