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Applications of Nanomaterials in Environmental Protection

Summary

by

Dr. Sonja Martens

Dr. Bernd Eggers

Thorsten Evertz

Golder Associates GmbH, Celle

On behalf of the Federal Environment Agency (Germany)

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Publisher: Federal Environment Agency (Umweltbundesamt)
P.O.B. 14 06
06813 Dessau-Roßlau
Germany
Phone: +49-340-2103-0
Fax: +49-340-2103 2285
Email: info@umweltbundesamt.de
Internet: http://www.umweltbundesamt.de

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The focus on nanotechnology in public discussion has increased over the past few years. Nanotechnology is considered to be one of the key future technologies. The present study focuses on applications of nanotechnology in environmental protection, especially in the water and air sectors.

First, nanotechnology solutions in the research and development stage and products which are already available in the marketplace were identified. The aim was to present a broad overview of already applicable and upcoming solutions for environmental protection. Then, based on life cycle assessments for two case studies, it was checked how the potential benefits and impacts on the environment for nanotechnology products or processes compare with those for conventional solutions. The first case study deals with the solar treatment of water contaminated with tetrachloroethylene, comparing nanoscale titanium dioxide (photo-catalysis) and a photo-Fenton process. The second case study compared a combination filter for cars with nanofibres and a conventional filter.

As a result of the research the following nanotechnology solutions were identified for purification of water and air:

Water sector

Nanotechnology is applied for drinking and waste water treatment and for groundwater remediation. Besides commercialized products and applications many of the following techniques are still under development or in a testing stage:

- Filtration/separation: Nanomembranes are state of the art technology. As membrane materials organic polymers and inorganic ceramics are used. Applications of nanofiltration can be found, e.g. in drinking water treatment, in the food industry as well as in the textile and dyestuff industry. A great potential for nanotechnology is expected in the field of seawater desalination.
- Surface treatment: Many developments have the objective of giving nanomaterials functions, such as specific chemical or mechanical properties. Nano-based coatings may e.g. minimize fouling processes and deposits on membranes, in heat exchangers and reactors and on ship hulls.
- Sorption: Nano-based sorbents may be used for different water treatment purposes. Examples are arsenic separation from drinking or wastewater and a paper-like material made from nanowire for absorption from water of hydrophobic liquids such as mineral oil.

- Nanocatalysts: Nanoscale titanium dioxide is used as a catalyst in waste water treatment. During photo-catalysis the illumination of the titanium dioxide results in water and oxygen from the air being converted into reactive hydroxyl radicals, which break down organic pollutants resistant to biological degradation in the water. Development is focused on applying photo-catalysis in countries with strong sunlight and/or for the treatment of small amounts of slightly polluted water. Other research concerns the development of a catalyst (ferromagnetic nano-sized carriers containing traces of palladium) for treatment of wastewater contaminated with halogenated hydrocarbons.
- Nanoreagents: Several kinds of nanoparticles on the basis of zero-valent iron are being used for in-situ groundwater remediation. Besides pure nano-iron also bimetallic nanoparticles and iron nanoparticles on activated carbon have been used in lab and pilot tests and already used in part for groundwater remediation. Developments and applications focus on the breakdown of chlorinated organic compounds in the groundwater.

Air sector

Nanotechnology has been used in automotive exhaust catalytic converters for 35 years. Furthermore, nanotechnology products are applied in air filters and in photocatalysis for air purification.

- Catalytic converters: In the automotive sector, catalytic converters are state of the art technology. A three-way catalytic converter has a stainless steel body that contains catalytic material as a layer on a substrate (washcoat). The particles of the noble metal catalyst in the washcoat are nanoscale. Research is currently in progress, amongst other things, to minimize the amount of noble metal but with the same catalytic performance.
- Filtration/separation: In the automobile industry filter media lined with nanofibres are frequently used in filters for passenger cabin air. Nanofibre-coated filter media are also applied for air filtration (e.g. dust removal) at industrial plants and for filtration of the inlet air for gas turbines. Research focuses, amongst other things, on the development and optimization of nano-structured membranes for CO_2 capture from power plant flue gases.
- Nanocatalysts: Nanocatalysts for sustainable air purification are mostly still under development or just at the start of being ready for practical use. For example,

through the use of nanoscale titanium dioxide in cement photo-catalytic active concrete surfaces can be produced for air purification in towns.

Case Study 1: Solar water treatment

Based on DIN EN ISO 14040 und 14044 a life cycle assessment (LCA) was made for two approaches for solar treatment of water contaminated with tetrachloroethylene. The assessed technologies were photo-catalysis using nanoscale titanium dioxide (semi-conductor photo-catalysis) in comparison with a photo-Fenton process using ferrous compounds with hydrogen peroxide.

Data acquisition was performed in co-operation with the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt) in Cologne, which operates reactors for research into photo-catalysis.

In the inventory analysis and the impact assessment phase for both the solar treatment approaches the materials for the set-up of the reactor, including their production, and the energy consumption during the testing phase were considered. The chemicals consumed during operation were also considered, including their manufacture (upstream chains). A potential separation and re-use of chemicals could not be considered due to a lack of information.

The approaches were compared on the basis of the Eco-indicator 99 assessment method. The impact categories evaluated included “Human health”, “Resources” and “Ecosystem quality”. The impacts were considered for the set-up of the reactor and three operating scenarios (batch test, one year and ten years). It turned out in the impact assessment that for both approaches the environmental impact was mainly due to resource consumption.

Summing up, the case study “Solar water treatment” showed that a long-term operation of the solar plant under the given boundary conditions results in a considerably higher potential impact on the environment when nanoscale titanium dioxide is used for photo-catalysis instead of a photo-Fenton process. The increasing environmental impact with time for photo-catalysis is due to the titanium dioxide, which is characterized by a high consumption of resources in its manufacture (upstream chain).

Case Study 2: Cabin-air filters for passenger cars

In this case study a cabin-air combination filter for passenger cars including a coating of nanofibres was compared with a conventional combination filter. Data acquisition was performed in co-operation with Mann + Hummel GmbH. As far as possible, taking account of commercial competition, product-specific information and test data from the co-operation partner were used.

The LCA study inventory analysis and the impact assessment focused on the modules “Production” and “Use in a passenger car”. In terms of fuel savings and CO_2 reduction potential a first assessment showed only extremely small advantages for the nano-based filter medium in comparison with the conventional one. However, two examples illustrate the potential benefits for the environment which can result from the use of nanofibres in cabin-air filters:

- Based on the sales figures of Mann + Hummel GmbH (2006 to 2008: delivery of about 4.1 million cabin-air filters with nanofibres) a reduction of CO_2 emissions of about 1,800 tons can be attributed to nanotechnology. The total CO_2 reduction due to cabin filters with nanofibres was probably significantly higher in this period of time because competitors also offer these kinds of filters.
- There were a total of about 49 million vehicles (41 million passenger cars, 8 million vans, trucks, buses and others) in Germany on January 1, 2008. If all passenger cars were equipped with cabin-air filters with nanofibres that would result in a theoretical reduction of CO_2 emissions of 18,150 tons per filter lifetime (15,000 km) compared with use of conventional filters.

The production and use of both filter types were subsequently analyzed based on the Eco-indicator 99 and CML 2001 methods. The comparison using the Eco-indicator 99 method showed only marginal differences within the impact classes “Human health”, “Resources” and “Ecosystem quality”. It was evident that the results can be mainly attributed to the filter use (car travelling 15,000 km); the filter production, including the upstream chains of materials, only contributed a minor proportion of the overall EI99 number of points and therefore to the environment impact.

Summing up, the case study “Cabin-air filter for passenger cars” showed for the filter with nanotechnology a slight advantage in terms of potential benefits for the environment. However, the actual benefit, e.g. the CO_2 reduction, was very small when only one filter was considered. Only when considering large quantities of filters and the total distances travelled do the potential benefits for the environment when using nanotechnology in air filter construction become clear.