Characterization of waste from nanoenabled products - DTU Orbit (13/12/2018)

Characterization of waste from nanoenabled products: Occurrence, distribution, fate and nanoparticle release

In the last decades, benefits provided by nanotechnology have been utilised for example to increase the sustainability and functionality of consumer products. Engineered nanomaterials (ENMs) are widely used in consumer products across different applications, but their use in nanoproducts has not been regulated specifically - as is the case for other chemicals and substances. This has caused concern regarding the possible release and effects of ENMs during the life cycle of nanoproducts. Specifically knowledge regarding the end-of-life phase is limited. In order to assess the potential environmental exposure or risks associated with ENMs in waste from nanoproducts, it is necessary to investigate what ENMs are being used and to which extent, how they are treated at the end-of-life of the nanoproduct and, finally, what is the likelihood of them being released during waste treatment. This PhD project addressed these knowledge gaps by mapping and analysing available nano-enabled products, developing a method for categorising waste material fractions of nanoproducts and estimating their likely waste treatment. Furthermore, new experimental data regarding ENM release from nano-enabled products was provided, applying a standardised waste characterisation test. To investigate the abundance and distribution of nanoproducts, different product inventories exist, such as BUND, PEN CPI and The Nanodatabase. However, they are all limited by the lack of available quantitative information about ENM mass or particle number in the products. Overall, the most common product applications for ENMs are the “Health & Fitness” or “Home & Garden” sector, which was still the case, despite the increasing number of nanoproducts. The product inventories PEN CPI and The Nanodatabase are based on manufacturers’ claims regarding nanotechnology, which are often unsubstantial leading to many products being registered with an unknown ENM, such as 64% of all products registered on The Nanodatabase. It was discovered that out of all ENMs registered on The Nanodatabase nano-Ag was used in the greatest number of products and in a range of product applications (e.g. in cosmetics, textiles and food containers). By utilising The Nanodatabase product inventory, a method was developed for analysing the distribution of ENMs in waste, which involved the estimation of ENM fate in selected waste treatments based on their main matrix material. This information was included on The Nanodatabase to enable the online analysis of different waste treatment scenarios. The waste treatment analysis revealed that the most significant waste material fraction was “Plastic packaging” followed by “Electronic”, “Textile” and “Multi material” waste. “Plastic packaging” waste involved mainly the large number of products sold in plastic containers, meaning that the remaining ENM mass at the time of disposal is expected to be minor. Nano-Ag was widespread across the identified waste fractions, thereby corresponding with the wide use of the material in different product categories. Furthermore, titanium-, silicon- and carbon-based ENMs were also present in several different waste material fractions (i.e. “Electronic”, “Multi material”, “Unknown”, “Plastic, other” and “Plastic packaging”), whereas nano-phosphate and bamboo charcoal were only found in “Batteries” and “Textile” waste, respectively. In terms of waste treatment, it was estimated that on average in the EU around 50% of nano-enabled products are recycled, 19% are incinerated and 26% landfilled. However, these percentages depend on the specific waste treatments available in the investigated region. It is also expected that more ENMs will eventually enter a landfill, since they may accumulate in sewage sludge or waste incineration ashes, both of which are often landfilled. Another prerequisite for ENM characterisation in a waste scenario is the ability to quantify the potential ENM release from a nanowaste matrix. Experimental characterisation of ENM release from nano-enabled products or waste matrices is scarce, and most studies are limited by analytical constraints to detect the ENMs, or have investigated an artificial or “spiked” waste matrix. These studies cannot identify the behaviour of ENMs released from a real nano-enabled product nor how realistic environmental conditions will influence this release. The main challenges facing experimental nanowaste characterisation relate to the complexity of the matrices (both the waste matrix itself and the variety of ENM and product matrix combinations), the low concentration of ENMs present in the waste and, for some ENMs, the background quantities of natural particles being high making it near impossible to distinguish between engineered and natural entities. In this thesis, selected nanoproducts were investigated using a standardised waste characterisation test and the potential ENM release was characterised using nano-specific methods, namely single particle-ICP-MS, TEM/EDX and zeta potential. Since more than 50% of ENMs are expected to be landfilled on a global scale, a standardised batch leaching test was applied to characterise the nanoproducts. The case studies represented two different types of ENMs and product matrices: self-cleaning ceramic tiles with a nano-TiO2 coating and wood painted with nano-CuO wood protection paint. Different environmental conditions were mimicked i.e. high ionic strength (added CaCl2) and addition of organic matter. For both materials, the potential ENM release under these conditions was considered to be low, but they indicated that, there was an effect of media conditions on the particles released from a nano-enabled product. For nano-TiO2-coated tiles, total titanium release was approximately 0.01 µg/g material or below detection limit, slightly higher concentrations were found in leachates from nano-enabled tiles. Particle sizes and number concentrations were below calculated limits of detection (with the exception of one sample, “TI CAL”) and the sp-ICP-MS analysis generally suffered interference from calcium. For wood painted with nano-CuO paint, presence of nano-Cu particles, of approximately 60-80nm in size, was confirmed using sp-ICP-MS. However, these findings are associated with uncertainty, and so additional tests are needed to assess quantitatively the nano-CuO release in terms of particle size and number concentration. While these two case studies showed limited release, it cannot be excluded that other matrix and ENM combinations may cause more significant releases. New approaches concerning nanowaste characterisation, both indirect and direct methods, were presented in this thesis, but further research is needed to develop and validate these methods. Future studies, assessing the potential release of ENMs from waste, should apply nano-enabled products and different product matrix combinations to take into account the transformations of the ENMs which may occur during the product life cycle. The development of analytical methods is promising e.g. the use of fingerprinting or other tracer techniques for ENMs, and sp-ICP-MS is becoming a routine analysis, though large challenges regarding matrix complexity and interferences still persist. Considering the large number of nanoproducts available, the potential release of ENMs from these products would have to be understood to perform a risk assessment of these products. Since ENMs are considered possible contaminants of the solid waste, it is important to include nano-specific characterisation tests in waste characterisation to ensure a safe disposal of the nanowaste.