journal home page: www.biologicalinsights.com
ISSN:2456-7604
Biological Insights 3(2017)7-11

Review Article

Nanobiotechnology

A critical evaluation: intimation of nanowaste management and pollution prevention

Rajan Kumar[1*] and Shivani Kundu[2]
[1]Department of Mechanical Engineering, S.D. College of Engineering & Technology, Muzaffarnagar, Uttar Pradesh, India
[2]Department of Computer Science Engineering, Ajay Kumar Garg Engineering College, Ghaziabad, Uttar Pradesh, India

A R T I C L E I N F O

Received 11 September 2017
Revised 18 October 2017
Accepted 2 November 2017

K E Y W O R D S

Nanowastes
Nanowaste classification
Nanowaste treatment
Nanomaterials
Nanotechnology
Waste management

*Corresponding author: Rajan Kumar
E-mail: rajankumarvats@gmail.com
Tel:+919897745912

A B S T R A C T

In recent times there has been an unprecedented development in the field of nanotechnology with the application of nanomaterials in virtually all spheres of day to day life. Nanomaterials (NMs) and nanoproducts have increased in volume from few kilograms to thousands of tonnes over the last fifteen to twenty years, and their uncontrolled release into the environment is anticipated to grow dramatically in future. However, their potential impacts on the biological systems are still unknown. Currently used waste management technologies are either inefficient or have very low efficiency in the treatment of nanowastes so the need of the hour is to find alternative waste management solution for treatment of nanowastes. This paper reviews several aspects such as impact assessment of an uncontrolled release of NMs in the environment, their applications, advantages, and limitations in waste management as compared to existing processes.

1. Introduction

Nanotechnology is an enabling technology and exploits the properties that emerge when a material is produced at the nanoscale to revolutionize or at least improve and optimize, existing processes in several industries. For example, silver nanoparticles (Ag NPs), more commonly known for their incorporation into consumer products, are being utilized as antifouling coatings for membrane systems to improve their efficiency. They are also currently being used as a chemical reducing agent for contaminated site remediation. These are just a few examples of the various applications of nanotechnology, and with the number continuing to grow, nanotechnology will likely impact and contribute to waste minimization. The goal of this report is to initiate discussion on the use of nanotechnology to facilitate waste minimization and prevention of hazardous waste. Although this report attempts to focus on the substitution and source reduction objectives of waste minimization, the utilization of nanotechnology for this application is relatively new. Therefore, the use of current nanotechnology based waste remediation techniques for hazardous waste treatment is also explored. As it is important to assess emerging technologies from a life cycle perspective, the mechanisms involved in the potential release of nanomaterials into the environment due to their use in waste minimization and treatment application is also briefly discussed.

After the establishment of the National Nanotechnology Initiative (NNI) in 2001, the field of nanotechnology boomed resulting in the rapid development of new nanotechnology applications. Reviews on nanotechnology and the state of the science written by many experts in the field are constantly being published, and therefore this section will merely serve as a brief introduction. Although many definitions of nanotechnology exist, as the NNI serves to coordinate the national efforts in nanotechnology, this report will follow the NNI definition. According to the NNI, nanotechnology is “the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications. Encompassing nanoscale science, engineering, and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale” (NNI 2007). Engineered nanomaterials, or “nanomaterials” from this point on, are “materials consisting of, or containing structures [particles, crystals, fibers, films, or composites] between 1 and 100 nanometers (nm) that make use of properties unique to nanoscale forms of materials” (U.S. DOE 2008). Nanoparticles (NPs), according to the ASTM standard definition, are particles with lengths that range from 1 to 100 nanometers in two or three dimensions (ASTM 2007). The success of nanotechnology stems from the novel properties that become prominent at the nanoscale. Nanomaterials have a higher surface area to volume ratios than larger particles of the same material, which can be manifested as increased reactivity or catalytic activity.

1.1. Problem, Concerns, and Confronts of Nanowastes Management

In recent years, numerous publications and proceeding articles have highlighted the exponential growth in global nanotechnology research activity. Yet, these publications contain little scientific data on feasible approaches of dealing with nanowaste streams generated at various phases of the nanotechnology-based products and materials life cycle. Due to these data and knowledge gaps imply that the nanotechnology industry is likely to address such concerns reactively rather than proactively as the window of opportunity is rapidly diminishing. The lack of scientific publications to address the management of nanowaste streams is evidence of limited or no funding, or limited concerted effort by researchers in this field. However, nanowastes are potentially the single pathway of introducing NMs into the environmental systems.

1.1.1.Hidden nanowaste hazard concerns

Since the introduction of nanowastes from nanoproducts it has been assumed that the existing waste management technologies have the capability to remove NMs from the solid and liquid waste streams effectively and efficiently. Yet, there are no hard data available to validate such an assumption as this largely remains unknown—with potentially far-reaching ramifications for the promotion of sound waste management practices.Leppard et al. study showed that standard wastewater treatment technologies are poorly suited to remove NMs from effluents, with non-manufactured nanoparticles being detected in discharges from wastewater treatment plants—possibly providing an escape route for dissolved chemicals(Leppard et al. 2003). Recently, the laboratory-scale findings illustrated the wastewater treatment systems' inability to remove NMs from drinking water because of low removal efficiencies ranging between 0 and 40% as a function of the NM under question (Westerhoff et al. 2008). Such data implies the potential presence of NMs in potable drinking water and may pose an exposure pathway to humans (Westerhoff et al. 2008).

1.1.2.*Nanowaste challenges to the innovative regulatory frameworks*

Several publications have comprehensively addressed the challenges NMs are likely to pose to the current legislative frameworks and only a few salient aspects are addressed here. The rapid developments in the field of nanotechnology have started to challenge established waste management practices and technologies in addressing the potential nanowastes specifically with respect to the suitability of the current legislation. This is because of several reasons. Firstly, this is attributable to data and knowledge gaps concerning risk assessment of NMs in different environmental compartments. This makes it difficult to develop legislative and policy frameworks that can address potential new forms of waste streams, or find best fits of current regulations in dealing with them. For instance, experts agree that little is known about appropriate ways of cleaning up NM spills and disposing of NMs in an R&D environment, let alone an industrial scale.

1.2. Measurement of nanowaste volumes

The diversity of NM applications, large variation in production quantities, as well as wide geographic areas of their uses are among the reasons to pay attention in developing effective and efficient tools of managing current and future anticipated nanowaste streams. Present and envisaged future applications of NMs are the most significant sources of large quantities of NMs into the waterways through waste streams (Powell et al. 2008). However, guidelines and protocols for handling and disposing of nanowastes safely and responsibly are undeveloped. For illustrative purposes, in this section, the growing challenges associated with nanowaste management are presented, for now, and future. This will be achieved indirectly using surrogate data through summarizing the emerging trends on the production of NMs, commercialization of nanoproducts, and quasi-exponential growth of intellectual properties (IP) held by companies and institutions working in the fields of nanotechnologies and nanosciences. The complex linkages of these parameters are likely to trigger increasing quantities of nanowaste streams production and releases into the environment as illustrated in Fig. 1.

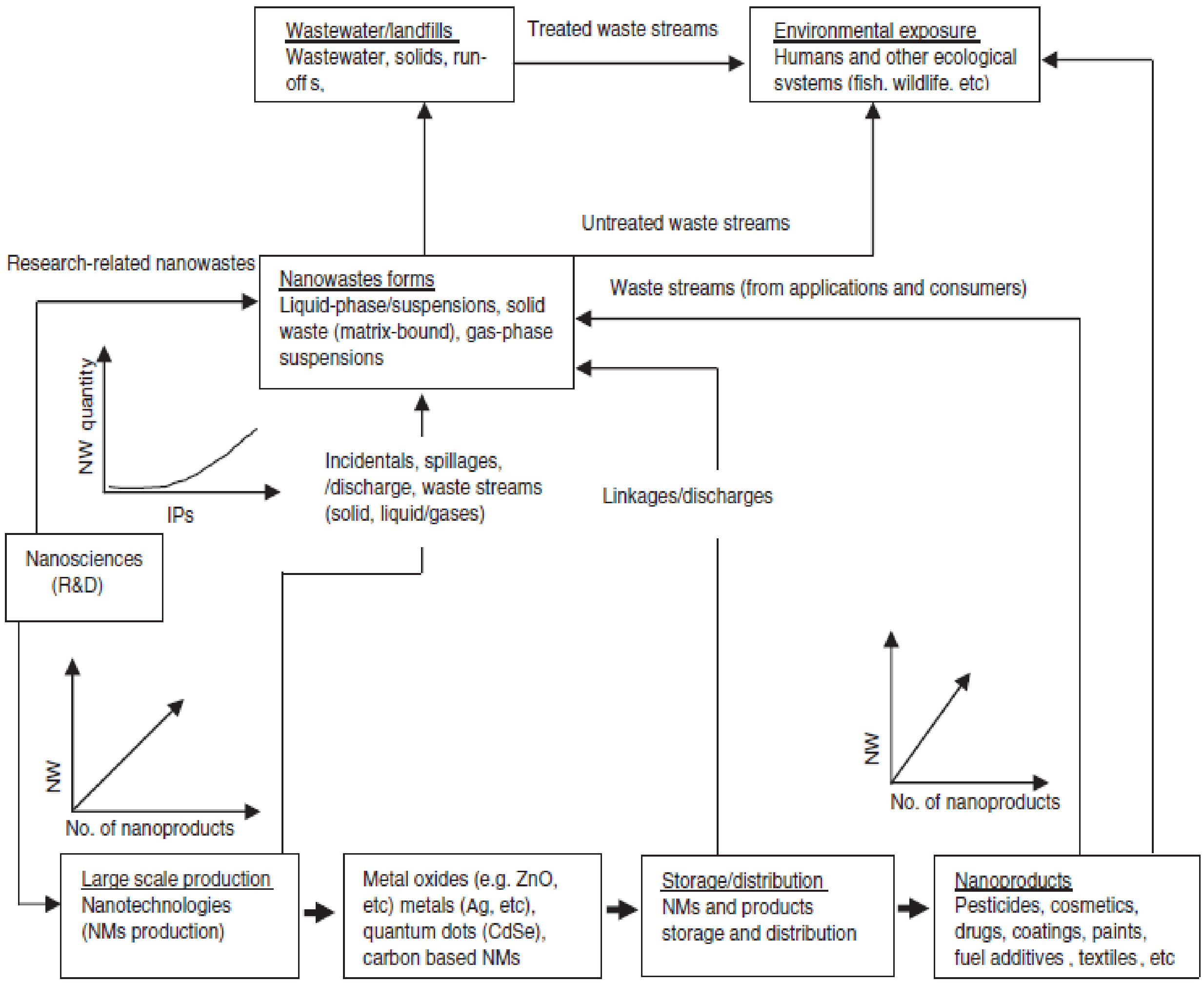

Figure 1: Nanowastes generation and experience pathways into ecological systems.

1.3.Nanowaste streams treatment and disposal

Only recently scientific studies on the treatment of nanowastes in water, and sludge environmental compartments, or the behavior of NMs in wastewater systems have begun to emerge. However, the available data and knowledge are insufficient to outline the general requirements for the identification of candidate streams meriting treatment before release into the environment. This can be attributed to lack of universally acceptable nanowastes classification essential in expressing their degree of hazardousness, or due to the limited appreciation of the large of volumes of nanowastes generated because partly nanotechnology is largely viewed as a green technology. In this section, available findings on the treatment, behavior, and fate of NMs in water and solid waste streams are summarized.

1.3.1.Removal of NMs in wastewater treatment plants

The removal of Ag NPs from wastewater was recently investigated by Benn and Westerhoff in their experiment they leached out Ag NPs from the socks – and adsorbed into the WWTP biomass which was then used in developing a model for predicting how a typical wastewater facility could treat effluent containing Ag NPs. The simulated model results suggested that WWTP have the capability to remove higher concentrations of Ag load from an influent stream than expected due to increased consumer nanoproducts containing Ag NPs (Benn and Westerhoff 2008). Whilst the removal of Ag NPs was found to be adequate, however, the concentration of Ag in the biosolids was found likely to exceed the recommended limit by the United States of America Environmental Protection Agency

(USEPA). For example, the model results suggested that an influent with Ag concentration of 180 µg/l; the resultant Ag concentration in biosolids would exceed the 5 mg/l Toxicity Characteristic Leaching Procedure (TCLP) as prescribed by the USEPA.

1.3.2.Treatment of solid nanowaste streams

Up to now, there are limited or no scientific studies on the detoxification of solid nanowastes. Solid nanowastes are disposed of in landfills where they can potentially leach out NMs into the soil systems. This may result in widespread nanopollution to both underground water as well as the domestic water supplies. For the treatment techniques of solid nanowastes to be effective—they should either be effective in strongly binding the NMs in a solid matrix, or firmly secure them in an impermeable container, or facilitate the recovery of NMs. Alternatively, poorly treated or untreated solid nanowastes may aid in widespread of NMs exposure to the aquatic and terrestrial organisms. For example, methods such as verification previously applied in the immobilization of high-level waste streams such as nuclear, urban and industrial waste streams mostly characterized by leaching of pollutants into the environment should be considered as potential candidates for the treatment of solid nanowastes. Notably, it is proposed that before such methods are considered a multi-criterion decision support model consisting of evaluation criteria like; cost, effectiveness, ease of use, among others be considered at the initial phases of the treatment technology development.

1.4.Nanowaste classification

Bulk-based chemicals waste streams generated at different phases of materials and products life cycle are generically classified as benign to extremely hazardous. The classification is based on the inherent characteristics of constituent chemicals (or compounds), the expected exposure dose, and the waste stream quantity. However, such classification is inadequate for waste streams containing nanoscale materials whose properties cannot be predicted from the current knowledge of the counterpart bulk parent chemical properties. Currently, there is no internationally agreed on nanowastes classification system or paradigm that can support the waste management industry and regulators in developing precautionary and practical approaches of managing different classes of waste streams containing nanoscale materials.

Table 1: Nanowaste classification as a function of ingredient NMs toxicity and exposure strength as a function of NMs in the nanoproducts.

Nanowaste classes	Description	Comments/description	Examples of waste streams in terms of nanoproducts
Class I	NM hazard: non-toxic; Exposure: low to high	Concerns on waste management may only arise if the bulk parent materials (Trojan horse effects) can cause toxicity to humans and the environment through accumulation beyond a certain threshold concentration limit. Otherwise, nanowaste can be handled as benign/safe. No special disposal requirements. Risk profile: none to very low.	Display backplanes of television screens, solar nemory chips, polishing agents
Class II	NM hazard: harmful or toxic Exposure: low to medium.	Toxicity of NMs may warrant establishing potential acute or chronic effects to determine the most suitable and optimal management approach during handling, transportation or disposal processes	Display backplane, memory chips, polishing agents, solar panels, paints and coatings
Class III	NM hazard: toxic to very toxic; Exposure: low to medium	Protocols appropriate for managing hazardous waste streams in the entire waste management chain are desirable/recommended. Need for research to determine if current waste management infrastructure is adequate to deal with hazardousness of waste streams due to nanoscale materials. Risk profile: medium to high	Food packaging, food additives, wastewater containing personal care products, polishing agents, pesticides
Class IV	NM hazard: toxic to very toxic; Exposure: medium to high	Waste streams should be disposed only in specialized hazardous wastes designated sites. Inadequate WM could lead to serious threats to humans and environmental systems. Risk profile: high	Paints and coatings, personal care products, pesticides, etc.
Class V	NM hazard: very toxic to extremely toxic; Exposure: medium to high	Dispose only in specialized hazardous waste streams designated sites. Poor waste management can cause extensive nanopollution to diverse ecological and water systems, which may prove to be costly, laborious, and time consuming to remediate. Immobilization and neutralization techniques among the most effective treatment techniques. Risk profile: high to very high	Pesticides, sunscreen lotions and food and beverages containing fullerenes in colloidal suspensions

3.Conclusion

Since the industrial revolution age, waste generation both in terms of quantities and nature have continued to increase. Therefore, from the laboratory and industrial fabrication processes of NMs /nanoproducts has caused the generation of nanowastes. This, in the context of rapidly growing nanotechnology industry with corresponding increases in uncontrolled releases of NMs into the environment particularly through post-consumer nanowastes streams, may cause expansive adverse effects to humans and the environment. For the nanotechnology to be sustainable, nanowaste streams must be effectively managed. In this paper, different aspects that potentially can improve nanowastes management have been discussed. These aspects include; the quantification of nanowastes volumes, hazard evaluation of the actual toxicity of nanowaste streams, examination of the potential impacts to the present legislative frameworks, nanowastes classification as well as treatment. This paper concludes the suggestions on how to address some of the identified data and knowledge gaps in dealing with nanowastes have been described to aid in developing efficient nanowaste management systems. Finally, as the excitement generated by new applications of nanotechnology into nanoproducts has been witnessed in the last few years, an equal corresponding measure is fundamentally essential in parallel towards appreciating or understanding of NMs potential toxic effects in humans and the wider ecology.

3.References

1. Powell M, Griffin M, Tai S.2008.Bottom-Up Risk Regulation? How Nanotechnology Risk Knowledge Gaps Challenge Federal and State Environmental Agencies. Environmental Management. 42:426-443
2. Benn T, Westerhoff P.2008.Nanoparticle Silver Released into Water from Commercially Available Sock Fabrics. Environmental Science & Technology. 42:7025-7026
3. Westerhoff P, Zhang Y, Crittenden J, Chen Y.2008.Properties of Commercial Nanoparticles that Affect Their Removal During Water Treatment. In: Grassian V. Nanoscience and Nanotechnology: Environmental and Health Impacts.John Wiley & Sons; 69-90
4. Leppard G, Mavrocordatos D, Perret D.2003.Electron-optical characterization of nano- and micro-particles in raw and treated waters: an overview. In: Boller M. Proceedings of nano and microparticles in water and wastewater treatment.London.IWA Publishing. Water Sci Technol.50(12):1-8

How to cite this paper: R.kumar et al.2017.A critical evaluation: intimation of nanowaste management and pollution prevention. *Biological Insights 3(2017)7-11*