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Editorial

Advances in Smart Nanomaterials: Environmental Perspective

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There has been a remarkable progress in synthesis of “smart” nanomaterials over the past decade from realizing lightweight graphene structures, carbon-metal nanohybrids, biohybrid self-assembly nanoarchitectures, and stimuli-responsive polymeric materials to shape-controlled inorganic nanoparticles. These new nanomaterials have opened transformative possibilities in application, beyond our current technologies. They have catalyzed key innovations in flexible electronics, drug delivery, catalysis, environmental remediation, and sustainable agriculture. Amid these emerging new materials, risk assessment of nanomaterials has been a major research thrust for our field over the past decade. New nanometrology parameters have been established to suitably depict the properties and behavior of novel nanomaterials in the environment. Emerging material characterization techniques realized over the past decade have facilitated transformative advances in understanding complex properties of smart nanomaterials for new applications. There is a tremendous environmental significance to the progress of each of these in advanced nanomaterials. Though risk assessment has been widely reported in the field of environmental nanoscience, the huge potential of new nanomaterial-based technologies for environmental applications has not been closely captured. In this thematic special issue, we aim to highlight both the emerging applications of smart nanomaterials and the discoveries in nanomaterial toxicity from an environmental perspective. The following sections briefly describe the accepted papers in this special issue.

In the feature article by A. Boutchuen et al., plant growth in legumes was significantly enhanced by nearly 230-830% with one drop of hematite nanoparticles. Unlike conventional fertilizers that have to be directly added to the soil or hydroponic environment in large quantities, the nanoparticle dispersions were applied via a highly sustainable and novel seed presoaking approach. The hematite nanoparticles served as a more efficient and high-throughput Fe-enriching nutrient for the plants as compared to the currently available bulk fertilizers. The method is immensely attractive from an environmental aspect as a small quantity of the nanofertilizer could induce increased plant growth and vitality without the need for direct addition of chemicals to the environment. Another novelty of the study was a new, multimodal material characterization approach to assess the uptake and transport of hematite nanofertilizer within the plants using Fourier transform infrared spectroscopy (FTIR), hyperspectral imaging, and inductively coupled plasma optical emission spectroscopy (ICP-OES).

The feature review article by B. Gayen et al. captured one of the newest members of the nanoworld, carbon dots. Carbon dots were invented accidentally during the purification of single-walled carbon nanotubes in 2004. These nanoparticles, typically <10 nm in size, have the structural advantage of containing both sp^2 and sp^3-hybrid carbon networks compared to the sp^2 hybridization of graphene quantum dots. The detailed architecture, progress in synthesis strategies, and novel applications of the quantum dots are presented in the article. The combination of upconversion photoluminescence, chemiluminescence, phosphorescence, and band gap transition properties makes carbon dots a unique class of material. In addition, carbon dots show highly promising results in a variety of key application areas including environmentally friendly light harvesting devices, drug delivery and bioimaging, chemical sensors, surface-enhanced Raman spectroscopy, and detectors. Therefore, this nanomaterial will be notable in terms of future technological progress.

K. Workeneh and team suggested a new and sustainable hydroxyapatite-adsorbent material synthesized from egg-shell waste for fluoride remediation from groundwater. The authors reported Langmuir and Freundlich adsorption isotherm models for this novel hydroxyapatite adsorbent, based on detailed fluoride adsorption experiments. The removal of fluoride was highly influenced by the pH, and a near complete removal of fluoride was achieved at pH 3 under controlled study environments. The egg-shell-derived hydroxyapatite showed 81% removal of fluoride with real groundwater samples, suggesting highly promising application of this material in groundwater remediation.

In the paper by M. V. Nsom et al., a pectin-starch magnetite nanocomposite was demonstrated as a new and more efficient adsorbent for methylene blue dye to purify the recycled waters from textile industries. The sponge-like nanocomposite was synthesized using a coprecipitation technique and characterized in detail. It was found that a higher starch : pectin ratio in the nanocomposite material facilitated increased adsorption of the dye from the textile effluent. This study further highlights the progress in new nanomaterials for environmental remediation applications.

P. D. Du et al. synthesized a new class of metal-organic framework, MIL-101, as a highly efficient heterogeneous photocatalyst for the degradation of Remazol Black B dye. The paper reported detailed material characterization, adsorption/desorption isotherms, and the catalytic activity of MIL-101. The mechanism of photocatalytic activity of this novel metal-organic framework was also suggested by the authors. Photocatalysis in MIL-101 was facilitated through electron transfer from the photoexcited organic ligands to the metal cluster of the metal-organic framework. This new photocatalyst exhibited excellent performance from the recyclability and stability perspective. The MIL-101 catalyst reported for the first time in this special issue could have transformative impacts in sustainable remediation of organic pollutants.

Another key review article of this special issue by T. A. Dontsova et al. highlighted the immense progresses made in the synthesis of metal oxide nanomaterials and nanocomposites and their significance in our current ecology and environmental applications. Metal oxides have been one of the most heavily researched families of nanomaterials over the past decade, both due to their unique structure and application potential. Special focus was given to TiO_2, ZnO, SnO_2, ZrO_2, and Fe_3O_4 nanomaterials. Different synthesis strategies, material properties, and application prospects of metal oxide nanomaterials were discussed in detail in this review.

Z. Yao et al. addressed another major area of environmental remediation, removal of nitric oxide pollutants released from industrial and vehicular sources. The paper reported new MnO_x-CeO_x hybrid nanoparticles supported on a lightweight and flexible graphene aerogel interface as monolithic catalysts for low temperature selective catalytic reduction of nitric oxide by ammonia. The hierarchically porous network of graphene aerogel and the nanoscale size provided key advantages to this material in terms of catalytic activity at lower operational temperatures. As a result, the novel nanocomposite catalyst induced a significantly high (90%) conversion rate of nitric oxides over a wide temperature range of 200–300°C, which is highly attractive for practical applications.

In the paper by X. Hu et al., novel MnO_2 nanospheres of hollow morphology were synthesized via a selective etching technique using $MnCO_3$ sacrificial templates. This new nanomaterial was applied as an adsorbent for pollutant dyes from water using methyl orange as a model dye. The influence of pH, contact time, and dye concentrations on the adsorption capacity of the hollow MnO_2 nanospheres was reported in this paper. The study also presented the adsorption kinetics of these novel nanoparticles and the fundamental thermodynamics behind their adsorption capacity. This new report is highly beneficial for applications in wastewater purification.

New findings on the risk assessment aspect of nanomaterials were captured by M. Patel et al. in this special issue. *Caenorhabditis elegans* (*C. elegans*) have been widely used as complete model organisms in risk assessment of different nanomaterials, but toxicity effects on subsequent generations of the organism are largely unknown. The article by M. Patel et al. reported key findings about the impact of engineered Au nanoparticles on generations of *C. elegans*. Au nanoparticles used in this study were synthesized via a facile biological route from chloroauric acid with pomegranate peel extract as the reducing agent. It was discovered that the Au NPs negatively affected the fertility of *C. elegans* and the reproductive toxicity was inherited by the next generations.

Conflicts of Interest

The authors declare no conflict of interest.

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