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Editorial

Novel Adsorbents for Environmental Remediation

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1. Environmental Remediation and the Application of Adsorbents

Exposure to environmental pollution due to the contamination of soil, surface and groundwater, and air poses potential health risks to biotic and abiotic ecosystems. The remediation of these risks should be prioritised to ensure sustainable ecosystems. Among the many remediation technologies, adsorption has become promising due to its efficiency, biocompatibility, and low operating costs [1]. The development of sustainable, environmentally friendly, and cost-effective adsorbent materials for long-term use in remediation is critical. "Green" or "eco-friendly" adsorbent materials are usually prepared from renewable or recycled resources, have minimal environmental toxicity, involve synthesis processes with a reduced chemical or energy footprint, have high reusability, and do not contribute to further waste or contamination. Evaluating their cost-effectiveness and long-term environmental effects involves considering how they are made and their regeneration potential.

This Special Issue, "Novel Adsorbents for Environmental Remediation", contains eight original articles and one review article that cover the preparation of sorbent materials and their application in soil and water remediation. They discuss soil, water, and air remediation using low-cost resources, e.g., smelter slag, biochar, red mud, clay minerals, nanoparticles, and biomass. The contaminants studied are heavy metals, phosphorus, chlorobenzenes, polychlorinated biphenyls (PCBs), and CO_2. The abovementioned materials have the potential to serve as green and eco-friendly sorbents, and the incorporation of circular economic principles in their preparation will help address the sustainable development goals.

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2. Low-Cost and Sustainable Precursor Materials

Low-cost, renewable, and waste materials are being investigated as precursor materials for the preparation of eco-friendly adsorbent materials. These include earth materials like clays and zeolites, agricultural and industrial wastes such as plant biomass and slag, and recycled materials such as plastics. This represents an increasing trend in this research area, as evident from review articles published elsewhere [2]. The use of low-cost and waste materials as precursors of adsorbents is increasing, partly because governments, environmental regulators, and industries are burdened with their disposal and recycling [3]. To achieve the sustainable development goals (SDGs) of the United Nations [4] and create a circular economy [5], increased research efforts are required in this area. Using waste or low-cost sorbent materials may not reduce waste as much as waste-to-energy or waste-to-building/construction materials approaches; however, it can still provide significant benefits, including reducing waste volume, decreasing environmental pollution, and improving resource efficiency. Value-added products can also be generated from waste and low-cost materials to provide additional economic value and social benefits.

Raw or waste materials may include biosorbents from agricultural waste [6], shell-based waste adsorbents [7], red mud- and fly ash-based materials [8,9], biosolid-to-biochar materials [9] and clay minerals [10]. However, thanks to extensive research efforts in this field, this list is growing and could extend beyond our current inventory. This Special Issue hosts several papers that describe research using candidates for these types of precursors. For example, Zhang et al. produced a biochar from wood pyrolysis in oxygen-limited conditions (650 °C for 4 h). This char was used to immobilise cadmium (Cd) and copper (Cu) from soil [11]. The use of chitosan–ethylenediaminetetraacetic acid (EDTA)-modified biochar [12,13] and rubber-seed-shell-based activated carbon [14] was also reported for the remediation of heavy metals in soil and water, in addition to CO_2 capture. Additionally, Li et al. prepared a sorbent—iron-modified bacterial biomass—for the removal of antimony(III), and they argued it had a higher sorption capacity than some previously reported sorbents [15]. Natural biopolymers, such as chitosan or bacterial-based adsorbents, are deemed to be biocompatible and environmentally friendly, making them valuable alternatives for the preparation of sorbent materials.

Animal wastes (e.g., feathers, hair, manure, bones) are also among the most investigated waste materials for the development of adsorbent materials. We continue to see a considerable amount of research whereby keratin protein in feathers and hair, organic matter and nutrients in manure, and calcium and phosphate minerals in animal bones are chemically or thermally modified for the preparation of sorbent materials. Industrial wastes (e.g., smelter slag [16]) can also contain various metal oxides and carbonates, and their functional groups can be used as sorbents. For example, the iron and other metallic oxides in smelter slag contribute to the remediation of contaminants. A review of current knowledge and prospects regarding such insights is available in this issue [16].

Continuously exploring the options and providing case-by-case solutions for the utilisation of waste materials as sorbents will contribute to achieving the sustainable development goals and a circular economy. The application of different materials exhibiting various active sites, functional groups, and chemical/physical properties will be beneficial for industrial development.

3. Greener Preparation Processes

Precursor materials normally undergo various treatments for maximised sorption capacity and to maintain their cost-effective and "eco-friendly" features. Adsorption performance, kinetics, stability, selectivity, regeneration, and cost-effectiveness are among the research topics intensively studied to achieve green or eco-friendly adsorbents [17]. This field of research aligns with those of green chemistry [18] and renewable and biodegradable resources, where achieving low environmental impact during production, use, and disposal is expected [19]. Biswas and Naidu [20] utilised an Australian palygorskite clay mineral to make a lanthanum-doped clay sorbent. They argued that this material could effectively bury phosphate ions from lake water without having a toxic effect on water microorganisms thanks to the preparation process, where the authors chose to use a trace amount of lanthanum to avoid its potential inherent toxic effect.

Developing novel adsorbents with the desired properties is a vital part of environmental remediation. As studies presented in this Special Issue, possible synthesis methods can be applied to achieve these properties through applying physical (e.g., milling, centrifugation), chemical, and thermal treatments. Technical challenges may exist in achieving all the properties required for "green" or "eco-friendly" sorbent materials in a single adsorbent, and in finding a balanced approach which is fit for purpose. In some cases, if the regeneration of adsorbent materials is desired, compromises in sorption capacity might be required.

It is increasingly emphasised in the literature that the green synthesis approach will also consider reducing chemical usage where possible [21]. It is also worth noting that the costs of sourcing precursor minerals and the preparation process also depend on various parameters and vary from country to country. Therefore, it is difficult to verify the degree to which an adsorbent is 'green/eco-friendly' by relying only on the reported outcome; it requires a comprehensive assessment of its chemical footprint and cost analysis.

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