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Editorial: Emerging trends in adsorption process for environmental applications

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Editorial on the Research Topic
Emerging trends in adsorption process for environmental applications

Adsorption, a fundamental process defined as the mass transfer of substances from gaseous /liquid phase to the surface of a solid phase, is extensively employed in water and air pollution control. It is generally regarded as an efficient and cost-effective approach for removing a diverse array of contaminants, including heavy metals, synthetic dyes, and emerging contaminants, from environmental media. Despite the wealth of existing research and the numerous reports already published on adsorptive pollution control, significant knowledge gaps and challenges remain. These include the need for more sustainable and economical adsorbents, the integration of adsorption with other processes, and strategies for scaling up laboratory applications to real-world ones. Therefore, continued and innovative research in this field is still in urgent demanded. This Research Topic aims to make contributions to this endeavor by featuring several insightful contributions that advance our understanding and practical application of adsorptive pollution control.

The past years have witnessed the development of a range of novel materials, driven by their promising potential for adsorption applications. However, given that the goal of environmental applications is pollutant removal rather than producing high-value products, adsorbent cost is a paramount concern from a practical standpoint. For instance, targeting at the removal of heavy metal ions as a group of conventional contaminants, Tenza et al. investigated Chlorella sp. biomass as a sustainable alternative. Characterization of this biomass revealed the presence of abundant functional groups such as carboxyl, hydroxyl and amide, which were crucial for adsorptive heavy metal removal. The biomass was simply ground, sieved, and used directly as an adsorbent, underscoring its potential as an exceptionally low-cost sustainable solution for water purification.

In addition to inorganic metal ions, synthetic dyes constitute a conventional class of organic pollutants commonly addressed in adsorption processes. Using methylene blue as a model synthetic dye pollutant, Araujo et al. explored the potential of bone meal as another sustainable adsorbent. In a similar manner to the aforementioned Chlorella sp., bone meal was merely ground and sieved before being employed for methylene blue adsorption. Mechanism studies indicated that the adsorption of methylene blue onto bone meal was driven by multiple interactions, in which the inherent phosphate groups and calcium ions in bone meal played indispensable roles.

In recent years, beyond conventional pollutants, emerging contaminants have attracted significant worldwide attention. Emerging contaminants refer to substances that exist in low concentrations, persist long-term, and pose potential hazards, such as pharmaceuticals, endocrine-disrupting chemicals, per- and polyfluoroalkyl substances, and microplastics. Their resistance to the conventional four-step water treatment processes presents a unique challenge, thus prompting the need for alternative solutions like adsorption, advanced oxidation, and membrane filtration. A variety of adsorbents have been utilized for emerging contaminants, such as carbon materials, polymers, biomaterials, metal-based materials, and their hybrids. Focusing on one type of these adsorbents, Mumtaz et al. reviewed the synthetic methods of metal-based materials and their applications for the adsorptive removal of various emerging contaminants. The synthetic methods were classified as chemical, physical, and biological ones, along with discussions on their respective advantages and disadvantages. The authors also noted several challenges associated with these metal-based adsorbents, including maintaining composition and structure uniformity of adsorbents in mass production, and potential long-term environmental ecotoxicity of the employed metal-based nanoparticles.

Beyond those adsorbents synthesized in complex procedures, Luttah et al. employed low-cost geopolymers prepared starting from municipal waste incineration fly ash, valorizing a solid waste otherwise posing the risk of secondary pollution. After reacting with alkaline activator solutions, various morphologically different waste-based geopolymers were obtained, which were then evaluated to adsorb aqueous endosulfan, which is a broad-spectrum organochlorine insecticide posing persistent threat to the environment, verifying the possibility of utilizing sustainable alternatives for adsorptive removal of emerging contaminants.

Moving forwards, some issues still remain unclear and need further clarification. One of them is the regeneration method of used adsorbents, which primarily fall into two categories in reported literature: washing and calcination. However, a major limitation of these methods is the consumption of resources and generation of waste. Specifically, washing consumes solvents and produces liquid waste, and calcination consumes electric energy while generating gaseous emissions. The employment of cost-effective sustainable adsorbents, such as the Chlorella sp. biomass, bone meal and geopolymers mentioned above, is a promising alternative. However, discarding these cost-effective adsorbents after a single use inevitably generates solid waste, offsetting their sustainability advantage.

One possible solution is to combine with other remediation technologies, such as advanced oxidation. In this way, the adsorbed pollutants can be degraded, achieving pollutant treatment and adsorbent regeneration simultaneously. Compared to standalone advanced oxidation, the sequential adsorption-regeneration process offers a dual benefit: it concentrates pollutants and minimizes the uncontrolled release of secondary pollution. In addition, recent years have seen growing interest in the oxidative polymerization approach, which polymerizes aqueous pollutants into valuable products rather than mineralizing them, offering a more economical alternative from the perspective of waste utilization. When heterogenous catalysts are used in oxidative polymerization, the resulting polymers deposit on their surface and can be further processed into carbon-based materials. The oxidative polymerization process is macroscopically analogous to the adsorption process, both of which are mass transfer of substances from bulk solution to the surface of a solid. Thus, the adsorbed pollutants on the surface of used adsorbents may also be converted into valuable products under specific conditions. Nevertheless, for practical applications, the complex compositions of wastewater may result in the co-adsorption of non-target components, challenging the selectively of the adsorbents and the subsequent transformation process. These challenges underscore the critical need for further in-depth research. It is our hope that this Research Topic will inspire concerted efforts to advance these technologies, ultimately paving the way for a more sustainable and cost-effective future of the adsorption process.

Author contributions

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