frontiers in Environmental Chemistry

SPECIALTY GRAND CHALLENGE
published: 20 August 2020
doi: 10.3389/fenvc.2020.00006

Grand Challenges in Sorption Technologies

*Bin Gao**

Department of Agricultural and Biological Engineering, University of Florida, Gainesville, FL, United States

Keywords: adsorption, absorption, emerging contaminant, novel sorbents, low-cost sorbents

Sorption is a physicochemical process and involves the incorporation or attachment of one substance (i.e., sorbate) to another (i.e., sorbent), which can be referred more specifically as either adsorption or absorption. While adsorption is the attachment of a sorbate in gaseous, liquid, or suspended solid form onto the surface of a sorbent; absorption mainly describes the incorporation of a gaseous or liquid sorbate into a different phase. Sorption phenomena have been observed and investigated by many researchers for a long time in both natural and engineered (i.e., man-made) systems. Theories, mechanisms, and models of sorption processes and behavior have also been well documented in the literature (Stumm and Morgan, 1995; Yang, 2003; Swenson and Stadie, 2019). With the improved knowledge on sorption process, various sorption technologies have been developed to protect and benefit the ecosystems and the natural resources. Over the last few decades, novel sorption technologies have been widely applied in the field of environmental chemistry to expand its capacities in environmental protection and pollution control (Kumar et al., 2019; Corda and Kini, in press). Nevertheless, there are still some challenges as well as opportunities in the research on sorption technologies, particularly with respect to their environmental applications and impacts in natural and engineered systems.

In natural environmental matrices, sorption is ubiquitous and strongly affects the distribution, deposition, mobilization, transport, transformation, and removal of a variety of contaminants (Neely and Blau, 2017). For instance, organic contaminants such as pesticides and pharmaceutical residues in soils may be sorbed by various soil components such as natural organic matter, clays, minerals, etc. through both adsorption and absorption, which can directly or indirectly influence their fate and impacts in the environment (Thompson and Goyne, 2012; Lipczynska-Kochany, 2018). A good understanding of the sorption behavior of contaminants in the air, water, and soil matrices under variable environmental conditions (e.g., variations in surrounding chemistry, composition, temperature, etc.) is essential to the development of monitoring and modeling tools for their fate in the environment (Su et al., 2019). Various analytical methods and tools that rely on knowledge of sorption behavior have been developed to detect, characterize, quantify, and monitor different kinds of contaminants in natural environment through *ex situ* and *in situ* measurements (Cecinato et al., 2012; Avino and Russo, 2018). High efficiency sorbents are commonly used in many environmental remediation technologies to stabilize or remove contaminants in air, water, and soil systems (Zhang et al., 2017; Li et al., 2020). Mathematical models based on sorption theories and mechanisms have been successfully applied to describe the fate and transport of contaminants in the environment under various conditions (Song et al., 2016; Simunek et al., 2018). In return, these models and modeling tools have also facilitated and promoted the growth of knowledge on sorption of contaminants in natural environmental matrices, especially with respect to traditional contaminants such as heavy metals and persistent organic pollutants. Recently, emerging contaminants including chemicals of emerging concern (CECs, e.g., pharmaceuticals and personal care products), engineered nanomaterials (ENMs, e.g., carbon nanomaterials and metal nanoparticles), and microplastics (MPs, such as plastic pellets and plastic fibers) have attracted increasing attention in the scientific communities (Wu et al., 2019; Richardson and Kimura, 2020). In comparison to the traditional contaminants, CECs, ENMs, and MPs are of greater concern

OPEN ACCESS

Edited by:
Mika Erik Tapio Sillanpää,
Florida International University, United States

Reviewed by:
Moonis Ali Khan,
King Saud University, Saudi Arabia
Thomas Thiebault,
PSL Research University, Ecole Pratique des Hautes Etudes (EPHE), France
Wen Fang,
Nanjing University, China

***Correspondence:**
Bin Gao
bg55@ufl.edu

Specialty section:
This article was submitted to Sorption Technologies, a section of the journal Frontiers in Environmental Chemistry

Received: *07 May 2020*
Accepted: *14 July 2020*
Published: *20 August 2020*

Citation:
Gao B (2020) Grand Challenges in Sorption Technologies. Front. Environ. Chem. 1:6. doi: 10.3389/fenvc.2020.00006

because their environmental behavior including sorption is not yet fully understood. This presents not only grand challenges but also excellent research opportunities to the research community of sorption technologies to address the open questions on how sorption processes affect the environmental fate and impacts of CECs, ENMs, and MPs in the natural environmental matrices. In-depth theoretical, laboratory, and field investigations are also encouraged to further improve and expand the capacities of current technologies and models of sorption as well as desorption of both traditional and emerging contaminants under the complex and real environmental conditions.

Sorption technologies are among the most popular and effective treatment methods for the removal of contaminants in engineered systems. Both adsorption and absorption technologies are commonly used to reduce the emission of air pollutants in designed gas purification systems (Creamer and Gao, 2016). In comparison to the other methods, adsorption technologies show several advantages such as simple design, easy operation, low cost, high efficiency, low maintenance, etc. in engineered water treatment systems (Inyang et al., 2016). In soil and groundwater remediation, various adsorbents have been applied into soils as the amendment or reactive barriers to immobilize or remove contaminants (Lyu et al., 2020). Sorbents, especially adsorbents, play an important role in controlling the efficiency of sorption technologies for contaminant removal in engineered systems. Commercial adsorbents such as activated carbon, ion exchange resins, zeolites, activated alumina, etc. have been applied in contaminant removal with great success. However, a large demand for novel high-efficiency sorbents remains for environmental applications, which provides great opportunities and challenges to the sorption technology research community. In particular, the synthesis and application of multifunctional and sustainable sorbents such as nanosorbents, nanocomposites, engineered carbon materials, metal-organic-frameworks (MOFs), covalent-organic-frameworks (COFs), etc. would significantly affect the future success of the applications of sorption technologies in contaminant removal. With the booming of nanotechnology and reticular chemistry, these novel sorbents, particularly nanomaterials and MOFs, have attracted increasing attention in the sorption technology research community recently because of the remarkable sorption efficiency and selectivity arising from their extremely high specific surface area, tunable structures, and tailorable surface chemistry (Yang and Xing, 2010; Ghanbari et al., 2020). On the other hand, low-cost adsorbents based on natural minerals, industrial by-products, agricultural and forest wastes, etc. have also been proposed as sustainable alternative contaminant treatment agents because of their abundance and low price (Kurniawan et al., 2006; Inyang et al., 2016). Some of the low-cost adsorbents such as biochar can be modified with simple and cost-effective engineered methods, which can dramatically improve their surface properties and sorptive ability to turn them into value-added products for environmental applications (Wang et al., 2017; Yang et al., 2019). It is thus necessary and commendable to further investigate the design and modification of low-cost adsorbents to promote their applications in engineered systems for contaminant removal. The development of green and sustainable technologies to reduce secondary pollutions during sorbent productions, filed applications, and regeneration and disposal of spent sorbents may also present challenges and opportunities. Nowadays, engineered systems based solely on sorption technologies may not satisfy the needs of environmental cleanup. The integration of sorption technologies with other methods such as photodegradation, biological degradation, advanced oxidation, etc. may produce synergies in the engineered systems to improve efficiency, reduce cost, and promote sustainability (Zou et al., 2019). This is another big challenge/opportunity in the sorption technology field that is worthy of additional research. It should also be noted that some of the publish papers may have unintentionally introduced confusions into the field due to the inappropriate research designs or inaccurate data interpretation (Tien, 2008). To accelerate rather than delay advances in the field of sorption technologies, full literature reviews and thoughtful analyses of the studied sorption phenomena, taking into account all relevant parameters, are critical to the authors before collecting data and drawing conclusions. As a ubiquitous phenomenon, sorption has been investigated from many different aspects by the research communities. Full literature reviews that cover the experimental approaches, theories, and models in neighboring communities such as geochemistry and chemical engineering would benefit not only the authors but also the journal to bridge the gaps among chemists, engineers, and environmental scientists and thus promote multidiscipline research on sorption technologies.

In conclusion, this work outlines several grand challenges that are critical to the environmental applications and impacts of sorption technologies. To address these challenges, it requires in-depth investigations to further advance current knowledge and understanding of the "evolved" sorption technologies in natural and engineered systems, which would be at the Frontiers in Environmental Chemistry.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

REFERENCES

Avino, P., and Russo, M. V. (2018). A comprehensive review of analytical methods for determining persistent organic pollutants in air, soil, water and waste. *Curr. Org. Chem.* 22, 939–953. doi: 10.2174/1385272822666180404144834

Cecinato, A., Balducci, C., Mastroianni, D., and Perilli, M. (2012). Sampling and analytical methods for assessing the levels of organic pollutants in the atmosphere: PAH, phthalates and psychotropic substances: a short review. *Environ. Sci. Pollut. R* 19, 1915–1926. doi: 10.1007/s11356-012-0959-0

Corda, N., and Kini, M. S. (in press). Recent studies in adsorption of Pb(II), Zn(II) and Co(II) using conventional and modified materials:a review. *Sep. Sci. Technol.* doi: 10.1080/01496395.2019.1652651

Creamer, A. E., and Gao, B. (2016). Carbon-based adsorbents for postcombustion CO_2 capture: a critical review. *Environ. Sci. Technol.* 50, 7276–7289. doi: 10.1021/acs.est.6b00627

Ghanbari, T., Abnisa, F., and Daud, W. M. A. W. (2020). A review on production of metal organic frameworks (MOF) for CO_2 adsorption. *Sci. Total Environ.* 707:135090. doi: 10.1016/j.scitotenv.2019.135090

Inyang, M. I., Gao, B., Yao, Y., Xue, Y. W., Zimmerman, A., Mosa, A., et al. (2016). A review of biochar as a low-cost adsorbent for aqueous heavy metal removal. *Crit. Rev. Environ. Sci. Technol.* 46, 406–433. doi: 10.1080/10643389.2015.1096880

Kumar, P. S., Joshiba, G. J., Femina, C. C., Varshini, P., Priyadharshini, S., Karthick, M. S. A., et al. (2019). A critical review on recent developments in the low-cost adsorption of dyes from wastewater. *Desalin Water Treat.* 172, 395–416. doi: 10.5004/dwt.2019.24613

Kurniawan, T. A., Chan, G. Y. S., Lo, W. H., and Babel, S. (2006). Comparisons of low-cost adsorbents for treating wastewaters laden with heavy metals. *Sci. Total Environ.* 366, 409–426. doi: 10.1016/j.scitotenv.2005.10.001

Li, F., Chen, J., Hu, X., He, F., Bean, E., Tsang, D. C. W., et al. (2020). Applications of carbonaceous adsorbents in the remediation of polycyclic aromatic hydrocarbon-contaminated sediments: a review. *J. Cleaner Product.* 255:120263. doi: 10.1016/j.jclepro.2020.120263

Lipczynska-Kochany, E. (2018). Humic substances, their microbial interactions and effects on biological transformations of organic pollutants in water and soil: a review. *Chemosphere* 202, 420–437. doi: 10.1016/j.chemosphere.2018.03.104

Lyu, H., Tang, J., Cui, M., Gao, B., and Shen, B. (2020). Biochar/iron (BC/Fe) composites for soil and groundwater remediation: synthesis, applications, and mechanisms. *Chemosphere* 246, 125609. doi: 10.1016/j.chemosphere.2019.125609

Neely, W. B., and Blau, G. E. (2017). *Environmental Exposure From Chemicals: Volume I*. Boca Raton, FL: CRC Press. doi: 10.1201/9781351071772

Richardson, S. D., and Kimura, S. Y. (2020). Water analysis: emerging contaminants and current issues. *Anal. Chem.* 92, 473–505. doi: 10.1021/acs.analchem.9b05269

Simunek, J., van Genuchten, M. T., and Sejna, M. (2018). The HYDRUS software package for simulating two- and three-dimensional movement of water, heat, and multiple solutes in variably-saturated media. *Tech. Manual Version*.

Song, J. H., Lee, Y., and Lee, D. S. (2016). Development of a multimedia model (POPsLTEA) to assess the influence of climate change on the fate and transport of polycyclic aromatic hydrocarbons in East Asia. *Sci. Total Environ.* 569, 690–699. doi: 10.1016/j.scitotenv.2016.06.127

Stumm, W., and Morgan, J. J. (1995). *Aquatic Chemistry: Chemical Equilibria and Rates in Natural Waters, 3rd Edn*. New York, NY: John Wiley & Sons.

Su, C., Zhang, H., Cridge, C., and Liang, R. Y. (2019). A review of multimedia transport and fate models for chemicals: principles, features and applicability. *Sci. Total Environ.* 668, 881–892. doi: 10.1016/j.scitotenv.2019.02.456

Swenson, H., and Stadie, N. P. (2019). Langmuir's theory of adsorption: a centennial review. *Langmuir* 35, 5409–5426. doi: 10.1021/acs.langmuir.9b00154

Thompson, A., and Goyne, K. W. (2012). Introduction to the sorption of chemical constituents in soils. *Nat. Educat. Knowledge* 4:7.

Tien, C. (2008). Remarks on adsorption manuscripts revised and declined: an editorial. *J. Hazardous Mater.* 150, 2–3. doi: 10.1016/j.jhazmat.2007.04.015

Wang, B., Gao, B., and Fang, J. (2017). Recent advances in engineered biochar productions and applications. *Crit. Rev. Environ. Sci. Technol.* 47, 2158–2207. doi: 10.1080/10643389.2017.1418580

Wu, P. F., Huang, J. S., Zheng, Y. L., Yang, Y. C., Zhang, Y., He, F., et al. (2019). Environmental occurrences, fate, and impacts of microplastics. *Ecotoxicol. Environ. Safety* 184:109612. doi: 10.1016/j.ecoenv.2019.109612

Yang, K., and Xing, B. S. (2010). Adsorption of organic compounds by carbon nanomaterials in aqueous phase: polanyi theory and its application. *Chem. Rev.* 110, 5989–6008. doi: 10.1021/cr100059s

Yang, R. (2003). *Adsorbents: Fundamentals and Applications*. Hoboken, NJ: John Wiley & Sons, Inc. doi: 10.1002/047144409X

Yang, X. D., Wan, Y. S., Zheng, Y. L., He, F., Yu, Z. B., Huang, J., et al. (2019). Surface functional groups of carbon-based adsorbents and their roles in the removal of heavy metals from aqueous solutions: a critical review. *Chem. Eng. J.* 366, 608–621. doi: 10.1016/j.cej.2019.02.119

Zhang, X. Y., Gao, B., Creamer, A. E., Cao, C. C., and Li, Y. C. (2017). Adsorption of VOCs onto engineered carbon materials: a review. *J. Hazardous Mater.* 338, 102–123. doi: 10.1016/j.jhazmat.2017.05.013

Zou, W. X., Gao, B., Ok, Y. S., and Dong, L. (2019). Integrated adsorption and photocatalytic degradation of volatile organic compounds (VOCs) using carbon-based nanocomposites: a critical review. *Chemosphere* 218, 845–859. doi: 10.1016/j.chemosphere.2018.11.175

Conflict of Interest: The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.