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Editorial Overview

An improved and simple method for removal of arsenic from drinking water

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Arsenic (As) is a naturally occurring element. The toxicity of arsenic is dependent on the specific arsenic species, and the concentration and duration of exposure to the arsenic species (Moe et al., 2016). Chronic human exposure to high concentrations of inorganic arsenic species has been associated with cardiovascular disease, diabetes, neurological diseases, skin lesions, and various cancers (Naujokas et al., 2013).

A major source of human exposure to inorganic arsenic species arises from groundwater, where inorganic arsenic can be present at elevated concentrations. The World Health Organization (WHO), the United States Environmental Protection Agency (EPA), and the equivalent regulatory agencies in many countries have implemented drinking water guidelines, with a maximum permissible arsenic concentration of 10 $\mu\text{g/L}$ (Environmental Protection Agency, 2018). However, it is estimated that over 200 million people around the world are exposed to arsenic in drinking water exceeding this guideline level (Naujokas et al., 2013).

One solution for reducing human exposure to arsenic is through the use of alternate drinking water sources that have lower arsenic content. In fact, extensive arsenic testing in areas of high arsenic concentrations in groundwater has identified water wells that have lower concentrations of arsenic. However, a study performed in Bangladesh showed that these safer options are less convenient for residents, and only 62% of participants were observed to use these alternative water wells. These residents reported having less preference for the taste and temperature of water from these sources, and found it time consuming to obtain water (Inauen et al., 2013).

Much research has focused on developing cost-effective methods for removal of arsenic from drinking water sources (Yan et al., 2016). Several recent methods on the removal of arsenic are of particular interest.

One method makes use of dithionite - a reducing agent that produces highly reactive reducing radicals. Dithionite can undergo disproportionation, where products from reduction and oxidation of dithionite are simultaneously produced. These products can then create active radicals under UV light, and reduce arsenite [As(III)] to a stable solid which may be filtered out (Jung et al., 2018). However, frequent additions of dithionite or stoppages of UV light are needed to prevent resolubilization of the solid forms of arsenic.

Another common approach for removal of arsenic consists of anchoring metal oxides, such as iron and titanium oxides (Yan et al., 2016), onto activated carbon. For example, adsorption of arsenate [As(V)] onto natural goethite samples provides a simple point-of-use application for removal of arsenate in drinking water. This is important as it allows for remediation in rural communities where these treatments are most needed (Jacobson et al., 2019).

Recently, Nieto-Delgado et al. (2019) utilized Mn^{2+} to improve the use of iron oxides on activated carbon, and increase arsenic adsorption. Similar to the use of natural goethite materials, this adsorption strategy provides an efficient, affordable, and simple method for removal of arsenic from contaminated drinking water.

Previously, the strong sorption of arsenic on iron oxyhydroxides was used in a granular support and in packed column systems for removal of arsenic in drinking water. However, an inherent limitation in the number of available iron oxyhydroxide binding sites must be overcome to achieve a high capacity.

Manganese has been utilized for synthesis of high surface area iron-manganese binary oxides to increase the number of available iron oxyhydroxide binding sites. The intercalation of Mn ions in the iron oxide structure allows for generation of extensive surface areas. Nieto-Delgado et al. (2019) expanded on this by constructing high surface area iron oxide nanostructures

using Mn^{2+} as crystal modulators, resulting in a morphology composed of inter-connected nano-fibrils.

The structure of this activated carbon modified with iron oxyhydroxide is new, and its application to arsenic removal has not been previously reported in literature. The high surface area of these new nanostructures have been made possible with the use of manganese in conjunction with iron, and has allowed for outstanding arsenic adsorption capacity. In particular, the negative aquo-hydroxo Mn^{2+} complex allows for stabilization of the water molecules in the Fe^{3+} aquo-hydroxide complex, and permits modulation of the crystal growth of the iron oxy-hydroxide (Fig. 1).

The activated carbon was modified using a microwave-assisted hydrothermal process that consisted of heating the activated carbon, and a reagent solution containing a 1:1 molar ratio of Fe^{3+} and Mn^{2+} , together at 150°C for 90 minutes. The modified activated carbon was then dried at 100°C for 24 hours. Acid digestion was then performed by adding 20 mL of concentrated $\text{HNO}_3\text{:H}_2\text{SO}_4$ (5:1) to the sample, and heating the solution at 150°C for 1 hour in a microwave digestion system.

The resulting modified activated carbon was then characterized by determining Fe and Mn content using inductively coupled plasma atomic emission spectrometry, analyzing the point of zero charge and surface charge distribution, and performing X-ray diffraction analysis. Nieto-Delgado et al. (2019) achieved an iron content of 3.5% on the modified activated carbon, with an adsorption capacity of 5.9 mg As/g, representing a significant improvement over previous similar methods (2.9 mg As/g).

Evaluation of adsorption kinetics showed that 40% of the arsenic was removed in the first hour using activated carbon modified with iron and Mn. In comparison, 37% of arsenic was removed in the same time frame using pristine activated carbon, 18% using only Mn modified activated carbon, and 30% using only iron modified activated carbon. These results show similarities in the adsorption kinetics of the iron and Mn modified activated carbon and the pristine activated carbon. Arsenic removal over longer periods showed consistent results.

Ultimately, this method allowed for removal of 90% of the initial arsenic content (2.5 mg As(V)/L) in a time period of 6 hours. Thus, the residual concentration of arsenic after removal is approximately 0.25 mg As(V)/L. In comparison,

the pristine activated carbon removed 58% of the initial arsenic content in 4 hours, the Mn modified activated carbon removed 60% of the initial arsenic content in 9 hours, and the iron modified activated carbon removed 78% of the initial arsenic content in 11 hours.

The study by Nieto-Delgado et al. (2019) may be replicated and applied to various water systems. Further studies may be carried out to determine the formation mechanism of the new nanostructure. In addition, the current study tested the removal of arsenate, but not arsenite. As such, future research may be expanded to include removal of both arsenate and arsenite from drinking water. Future research may also test this method for removal of arsenic at lower concentrations that emulate more common arsenic levels in drinking water, for example ranging from $50\ \mu\text{g As/L}$ to $200\ \mu\text{g As/L}$. This will help determine if levels of arsenic can be decreased to values lower than the acceptable guideline of $10\ \mu\text{g As/L}$ for drinking water.

Arsenic contamination in wastewater is also an environmental concern. A recent paper reviewed research progress in the use of TiO_2 for treatment of As-contaminated water, with specific focus on industrial wastewater (Yan et al., 2016). This method by Nieto-Delgado et al. (2019) may also contribute to the removal of contaminants, including arsenic, for waste water treatment. In conclusion, this study will aid in an efficient, affordable, and simple method for removal of arsenic in order to provide safer drinking waters for resource-limited and point-of-use settings, and shows potential for use in waste water treatment.

REFERENCES

- Environmental Protection Agency, 2018. Chemical contaminant rules. Available from: <https://www.epa.gov/dwreginfo/chemical-contaminant-rules>, Accessed date: 10 October 2018.
- Inauen, J., Hossain, M.M., Johnston, R.B., Mosier, H., 2013. Acceptance and use of eight arsenic-safe drinking water options in Bangladesh. *PLoS 8* (1), e53640.
- Jacobson, A.T., Fan, M., 2019. Evaluation of natural goethite on the removal of arsenate and selenite from water. *J. Environ. Sci.* 76, 133–141.

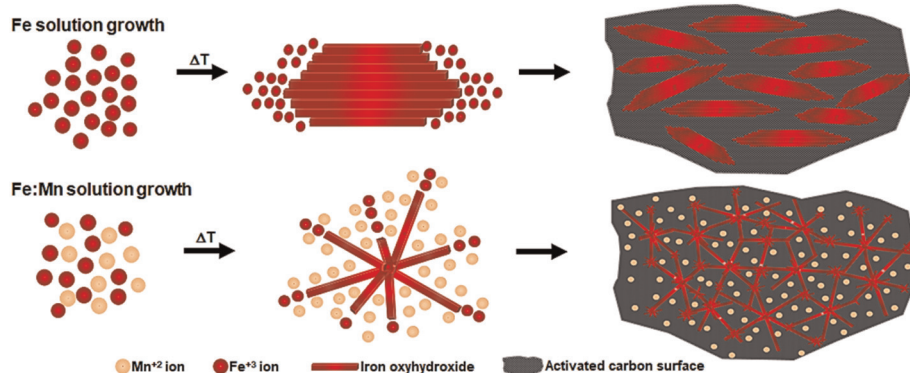


Fig. 1 – Schematic representation of assembly of modified activated carbon in the presence of Mn^{2+} for increased surface area and binding sites (Nieto-Delgado et al., 2019).

- Jung, B., Safan, A., Duan, Y., Kaushik, V., Batchelor, B., Abdel-Wahab, A., 2018. Removal of arsenite by reductive precipitation in dithionite solution activated by UV light. *J. Environ. Sci.* 74, 168–176.
- Moe, B., Peng, H., Lu, X., Chen, B., Chen, L.W.L., Gabos, S., Li, X., Le, X.C., 2016. Comparative cytotoxicity of fourteen trivalent and pentavalent arsenic species determined using real-time cell sensing. *J. Environ. Sci.* 49, 113–124. <https://doi.org/10.1016/j.jes.2016.10.004>.
- Naujokas, M.F., Anderson, B., Ahsan, H., Aposhian, H.V., Graziano, J.H., Thompson, C., Suk, W.A., 2013. The Broad Scope of Health Effects from Chronic Arsenic Exposure: Update on a Worldwide Public Health Problem. *Environ. Health Perspect.* 121 (3), 295–302. <https://doi.org/10.1289/ehp.1205875> (pmid: 23458756).
- Nieto-Delgado, C., Gutiérrez-Martínez, J., Rangel-Méndez, R., 2019. Modified activated carbon with interconnected fibrils of iron-oxyhydroxides using Mn^{2+} as morphology regulator, for a superior arsenic removal from water. *J. Environ. Sci.* 76, 403–414.
- Yan, L., Hu, S., Jing, C.Y., 2016. Recent progress of arsenic adsorption on TiO_2 in the presence of coexisting ions: A review. *J. Environ. Sci.* 49, 74–85.
- Jagdeesh S. Uppal
Division of Analytical and Environmental Toxicology, Department of Laboratory Medicine and Pathology, Faculty of Medicine and Dentistry, University of Alberta, Edmonton T6G 2G3, Canada
- Qi Zheng
Key Laboratory of Optoelectronic Chemical Materials and Devices, Ministry of Education, Institute of Environment and Health, Jiangnan University, Wuhan 430056, China
- X. Chris Le
Division of Analytical and Environmental Toxicology, Department of Laboratory Medicine and Pathology, Faculty of Medicine and Dentistry, University of Alberta, Edmonton T6G 2G3, Canada
Corresponding author.
E-mail address: xc.le@ualberta.ca.