

Water remediation treatments: the application of different sorbents for mercury removal

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Abstract:

Water contamination by the disposal of toxic metals is recognized as a worldwide concern. Mercury is known as relevant hazardous pollutant due to its toxicity and biomagnifications along the food chain, causing serious impacts on environment and human health.

A variety of processes are available for the treatment of contaminated aqueous waste streams. Sorption processes are considered better alternatives because they are easy to operate, economic and allow to treat solutions with realistic concentrations. Among the different solids for sorption processes, the synthetic sorbents, such as the zeolite-type materials, are very selective and present high surface areas and great removal capacities. Niobium silicates, like AM-11 and NS91, and vanadium silicates like AM-14, have showed excellent performances for Hg(II) removal.

On the other hand, biological wastes from agriculture and industry represent lower cost options for sorption operations. The biosorbents are largely available in nature and contain functional groups capable to bind the target metal in solution. They require few or any chemical and thermal pretreatments and may provide alternative options for water treatment and waste management. Banana and potato peels, egg shells, Eucalyptus globulus bark and leaves, mushrooms, water hyacinth and etc, are examples of efficient biosorbents applied in this work.

The right choice for each process is not a trivial task. In line with one of the goals of 2030 Agenda for Sustainable Development of United Nations, which promotes the improving of water quality by reducing water contamination and fomenting an enhance in wastewater treatment, this work encourages the safe water reuse by investigating and evaluating new efficient and viable sorbents for the application in remediation processes for mercury removal.

Mercury (Hg) is a toxic heavy metal that has been regarded as one of the "ten leading chemicals of concern". According to the United Nations Environment Programme (UNEP) report, it is estimated that global mercury emissions to air from anthropogenic sources were about 2220 tons. Among the anthropogenic sources, stationary combustion of fossil fuels accounts for twenty-four of the estimated emissions, primarily from coal-burning (21%). Other anthropogenic sources include cement production, iron and steel production, nonferrous metal smelting, gold production, chloralkali industry, waste disposal also as direct production of mercury. Mercury contamination is of serious concern worldwide due to its toxic effect on human health. Among the forms of inorganic mercury, the mercuric cation, Hg²⁺, has proven to be a predominant toxic agent that can cause damage to kidney and lung. Once transformed into its organo mercuric forms like methyl mercury (MeHg), Hg acts as a potent neurotoxin which impairs brain function. Apart from the high toxicity of this type of mercury, it's raised particular concern for its

capability to bio magnify up the organic phenomenon.

Once emitted to the atmosphere, Hg can be transported and thoroughly mixed in its elemental form [Hg(0)]. The major sink of elemental mercury is deposition to soil or water bodies after oxidation to divalent mercury [Hg(II)]. Aside from deposition, point sources of mercury contamination are the predominant cause of Hg pollution in soil and water. Like other heavy metals, mercury cannot be degraded in ecosystems, and therefore remediation should be based on removal or immobilization processes. Removal technologies involve the mechanism of adsorption, desorption, oxidation and reduction. The major aim of these technologies is to separate mercury from the contaminated media or transform toxic mercury species into less toxic ones. The most widely adopted immobilization techniques are stabilization and containment, which prevent mercury migration by chemical complexation or physical trapping, respectively.

More recent research are ongoing to develop novel materials and technologies for Hg remediation. Novel materials, especially materials possessing high area, large porosity also as active sites for adsorption, are examined extensively in recent studies. Apart from adsorption capacity which is the key determinant of these materials, other issues such as generation method, stability and reusability should be seriously considered as well. Compared to conventional remediation technologies such as thermal desorption or activated carbon adsorption, innovative methods have proved to be more cost-efficient and environmentally friendly. Interestingly, most of these technologies treating Hg contaminated soil, water and air can either be based on emerging materials or the metabolism of organisms, namely plants, algae and bacteria.

Adsorption and desorption

The aim of this work is to review current knowledge on emerging materials as well as innovative technologies for mercury remediation in soil, water and air. This review discusses the synthesis method, morphology, adsorption behavior, reusability, stability as well as other characteristics of emerging materials. The review also focuses on the remediation mechanisms and remediation efficacy of novel technologies and proposes critical future research directions in this field. When it comes to the remediation of Hg contaminated soil, Hg-containing waste or sludge, thermal desorption has been established as an effective approach. In situ thermal desorption is encouraged, as there is no need to dig up the contaminated environmental media, especially the soil. In this process thermal conductive heating (TCH) elements are inserted into the soil in order to directly transfer heat. During the heating process, the rise of the volatility of mercury leads to the separation of mercury from the soil. Various species of mercury exist in soils, such as HgO, HgS, HgCl₂, and mercury associated with organic matter. These mercury species are volatilized when the heating temperature is above 600 °C, and the

treatment can achieve an acceptable decontamination level. The major disadvantage of conventional thermal desorption is the high energy cost, warranting the need for further studies to find low-temperature desorption methods. Many full-scale and pilot-scale applications of thermal desorption have been summarized in other literature the cost of this technology is estimated to be 480 USD/t soil.

Oxidation and reduction

Coal-fired power plants continued to be the predominant sources of anthropogenic mercury emission to the atmosphere. In typical coal combustion flue gas, mercury exist in three forms: elemental mercury [Hg(0)], divalent mercury [Hg(II)] and particulate bounded mercury [Hg(P)]. Among these forms, elemental mercury was recognized to be the

hardest to be removed by conventional air pollution control devices owing to its volatility and low water solubility. The oxidation of Hg(0) has proven to be an effective way to decrease mercury emission. In most cases, Hg(0) was oxidized to Hg²⁺, which can be easily captured by an electrostatic precipitator (ESP) or wet flue gas desulfurization scrubbers (WFGD) due to its high solubility and sorption on particulate matter. Compared to the adsorption method (i.e. activated carbon injection, around 3–4 USD/kW), oxidation is more cost-effective. A number of studies have focused on a novel oxidation method, i.e., catalytic oxidation of elemental mercury from the flue gas, which will be elaborated in Section 4.3.1. Apart from the catalytic oxidation method, free radical advanced oxidation of Hg(0) is also utilized sometimes, but Hg(0) removal capacity using this technology remains limited thus far.