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Review

Removal of arsenic from water using nano adsorbents and challenges: A review

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ABSTRACT

Many researchers have used nanoparticles as adsorbents to remove water pollutants including arsenic after modifying the properties of nanoparticles by improving reactivity, biocompatibility, stability, charge density, multi-functionalities, and dispersibility. For arsenic removal, nano adsorbents emerged as the potential alternatives to existing conventional technologies. The present study critically reviewed the past and current available information on the potential of nano adsorbents for arsenic removal from contaminated water and the challenges involved in that. The study discussed the separation and regeneration techniques of nano adsorbents and the performance thereof. The study evaluated the adsorption efficiency of the various nanoparticles based on size of nanoparticles, types of nano adsorbents, method of synthesis, separation and regeneration of the nano adsorbents. The study found that more studies are required on suitable holding materials for the nano adsorbents to improve the permeability and to make the technology applicable at the field condition. The study will help the readers to choose suitable nanomaterials and to take up further research required for arsenic removal using nano adsorbents.

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1. Introduction

Water contamination due to increased population and industrial activities is one of the most challenging issues to the researchers, because it is continuously increasing threats to both human health and the environment. The main threats to human health from heavy metals contamination of water are associated with the exposure to different heavy metals and metalloids such as lead, cadmium, chromium, mercury and arsenic. The presence of these heavy metals and their effects on human health are studied and regularly reviewed by international bodies such as the WHO (Järup, 2003). Out of these heavy metals, arsenic is found to pose maximum adverse effects on human health through arsenic contaminated drinking water. Mining wastes, petroleum refining, sewage sludge, agricultural chemicals, ceramic manufacturing industries, and coal fly ash are some of the anthropogenic activities that increase arsenic concentrations in surface water as well as groundwater (Viraraghavan et al., 1999). Natural sources such as weathering, erosion of rocks/soils and volcanic emissions also contribute arsenic in aqueous system. Naturally, arsenic occurs more than 200 different mineral forms. Of these, approximately 60% are arsenates, 20% are sulphides and sulphosalts, and the remaining 20% are arsenide, arsenite, oxides, silicates and elemental arsenic (Onishi, 1969). The main arsenic containing mineral arsenopyrite is formed by hydrothermal activity associated with the intrusion of granitic magma and orogenesis (Duarte et al., 2009). The occurrence of arsenic in drinking water can occur as a result of its natural geological presence in local bedrock (Garelick et al., 2008). In drinking water, it predominantly occurs as inorganic (arsenite, arsenate) and organic forms (methyl and dimethyl arsenic compounds) mainly in surface water (Smedley and Kinniburg, 2002). High-arsenic bearing waters are not expected where there is a high concentration of free sulphide, because in reducing condition it forms precipitate with arsenic (Moore et al., 1988). A recent publication reported that arsenic is a unique carcinogen. It is the only known human carcinogen for which there is adequate evidence of carcinogenic risk by both inhalation and ingestion (Centeno et al., 2006). In six administrative blocks of the district Murshidabad of West Bengal, India, about 1.25 million people are exposed to groundwater arsenic concentrations above 0.05 mg/L (Samadder, 2011). Considering its toxicity, WHO decided maximum permissible limit for arsenic as 0.01 mg/L in drinking water. Increasing risk of arsenic carcinogenicity for developing countries drawn the attention of the researchers to do more research on arsenic contamination and treatment for its removal. To treat the contaminated groundwater or surface water economically, methods such as oxidation (Pierce and Moore, 1982; Sorlini and Gialdini, 2010), co-precipitation (Choong et al., 2007; Kumar et al., 2004), adsorption (Zaspalis et al., 2007; Bhatnagar et al., 2010), ion-exchange (Anirudhan and Unnithan, 2007), and membrane technologies (Brandhuber and Amy, 2001) were used.

But the adsorption evolved as the most promising method among the available methods as this method does not add undesirable by-products and the used adsorbents can be regenerated for reuse upto reasonably good number of cycles. However, adsorption has certain limitations also, such as it could not achieve a good status at commercial levels due to the lack of suitable adsorbents of high adsorption capacity and unavailability of commercial scale columns (Grassi et al., 2012). Moreover, same adsorbent is not effective for different types of water pollutants. For adsorption, various materials were used as adsorbents such as surfactants, synthetic activated carbon, industrial byproducts and wastes, ferrous material, iron based soil amendment, and mineral products (Hashim et al., 2011). To fulfil the objective of the development of an effective adsorbent that is active and rapid for arsenic removal, nano size adsorbents were developed by researchers. Macromolecules have intra-particle diffusion that decreases the adsorption rate and available capacity of the adsorbent, while nanoparticles have small diffusion resistance that increased the significance of the application of nanoparticles as adsorbent (Attia et al., 2012). Nanoparticles also have some distinctive properties such as small size, catalytic potential, large surface area, high reactivity, easy separation, and large number of active sites that facilitate better arsenic removal efficiency compared to other available adsorbents. Ngomsik et al. (2005) compared efficiency of nano and micro sized particles and concluded nano adsorbents as comparatively better than micro adsorbents, though micro particles have been studied extensively for metal extraction and have the advantage of easy separation. In the process of developing nano adsorbents, various transition metal based compounds have been explored as arsenic removing adsorbents such as Cu, Fe, and Ti. Other materials like alumina and polymers like vinylpyridine have also been modified for the preparation of nano adsorbents. Though nano adsorbents give better results compared to other adsorbents for arsenic removal, but there are two main challenges in using nanomaterials for water purification; one is the non-availability of nanomaterials at economically affordable prices and the other is the toxicity and the environmental fate of nanomaterials (Mostafa and Hoinkis, 2012). The cost is mainly dependent on availability, types, preparation and applicability in actual field conditions. Toxicity of nanomaterials increases with atomic number with the exceptions of Fe_2O_3 (lower toxicity than expected) and CoO (higher toxicity than expected) (Huang et al., 2010). There are many review papers available on arsenic removal using nano adsorbents, but this paper critically reviewed the comparative study of applicability and the challenges of selecting nanomaterials as adsorbents for removal of arsenic from drinking water.

2. Applicability of various nano adsorbents

Development of nano adsorbent is regarded as the major step towards achieving the nanoscaling effects and properties that have been utilised by nature for millions of years. Nanoparticles are small atomic clusters with <100 nm size (Husein and Nassar, 2008) and are efficient to remove arsenic 5–10 times more effectively than their micron size counterparts (Ponder et al., 2001; Sharma et al., 2009).