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Journal of Colloid and Interface Science 288 (2005) 55–60

JOURNAL OF
Colloid and
Interface Science

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Adsorption of As(III) from aqueous solutions by iron oxide-coated sand

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Received 4 January 2005; accepted 17 February 2005

Abstract

Arsenic is a toxic element and may be found in natural waters as well as in industrial waters. Leaching of arsenic from industrial wastewater into groundwater may cause significant contamination, which requires proper treatment before its use as drinking water. The present study describes removal of arsenic(III) on iron oxide-coated sand in batch studies conducted as a function of pH, time, initial arsenic concentration, and adsorbent dosage. The results were compared with those for uncoated sand. The adsorption data fitted well in the Langmuir model at different initial concentration of As(III) at 20 g/l fixed adsorbent dose. Maximum adsorption of As(III) for coated sand is found to be much higher (28.57 µg/g) than that for uncoated sand (5.63 µg/g) at pH 7.5 in 2 h. The maximum As(III) removal efficiency achieved is 99% for coated sand at an adsorbent dose of 20 g/l with initial As(III) concentration of 100 µg/l in batch studies. Column studies have also been carried out with 400 µg/l arsenic (pH 7.5) by varying the contact time, filtration rate, and bed depth. Results of column studies demonstrated that at a filtration rate of 4 ml/min the maximum removal of As(III) observed was 94% for coated sand in a contact time of 2 h. The results observed in batch and column studies indicate that iron oxide-coated sand is a suitable adsorbent for reducing As(III) concentration to the limit (50 µg/l) recommended by Indian Standards for Drinking Water.

Keywords: Iron oxide; Coated sand; Adsorbent; Adsorption; Arsenic; Flow rate

1. Introduction

Groundwater is an important source of safe and adequate drinking water. However, in some locations groundwater supplies may be contaminated with toxic inorganic chemicals that may have adverse health effects on humans after prolonged exposure. In recent years, arsenic (As) contamination of water and groundwater has become a major concern on a global scale [1,2]. There have been widespread reports of arsenic poisoning in Argentina [3], Taiwan [4], Mexico [5], and the western Unites States [6]. It is estimated that about 40 million people are at risk of arsenic poisoning in Bangladesh [7]. In India, many districts of West Bengal [8,9] are facing the problem of As contamination of groundwater. Based on human health data, an As concentration of 10 µg/l has been recommended by WHO as a guideline value for drinking water [10], while in India, per BIS 10500 (1991), a maximum arsenic level of 50 µg/l has been permitted in groundwater supplies for drinking purposes.

Conventional water treatment processes remove toxic metal ions through mechanism such as sorption and particle removal. Advanced water treatment techniques, which can be used as either primary treatment or posttreatment, involve ion exchange, reverse osmosis, adsorption, coagulation, precipitation, adsorption–coprecipitation with hydrolyzing metals, and so on. Among these, adsorption currently appears to have the best potential for overall treatment, and it can be expected to be useful for a wide range of compounds, more so than any other listed process. Several studies have demonstrated that arsenic removal can be achieved by various technologies [11–21], namely, activated alumina sorption, polymeric anion exchange, sorption by iron oxide-coated sand, coagulation with ferric chloride, pressurized granulated iron particles, iron oxide-doped alginate, manganese

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doi:10.1016/j.jcis.2005.02.054

dioxide-coated sand, polymeric ligand exchange, and zero-valent iron, and these have been tried in the laboratory and/or in the field. Among these technologies, adsorption on iron oxide-coated sand is considered an emerging technology for arsenic removal. Studies [22] have shown that manganese green sand and iron oxide-coated sand used in a ratio of 20:1 can reduce the As(III) concentration from 200 µg/l to below 25 µg/l. Batch studies [23] have been performed using iron oxide-coated sand and ferrihydrite with natural water containing 325 µg/l arsenic, and the removal of 90% of the arsenic was observed. The application of iron oxide-coated sand-2 prepared by a high-temperature coating process has been demonstrated in batch and column studies [24] to remove As(III) and As(IV) to a level less than 5 µg/l at pH 7.6 in drinking water with an initial arsenic concentration of 100 µg/l. Though adsorption of arsenic on iron-coated sand has been studied by many workers, the information available is limited and more testing is necessary. There is a need to study the effectiveness of iron oxide-coated sand for As removal to achieve the permissible concentration in drinking water. The present study was aimed at examining the potential of iron oxide-coated sand as an adsorbent in batch and column studies for adsorbing As(III) from aqueous solutions under kinetic and equilibrium conditions with a view toward providing an economically feasible solution to the arsenic-contaminated drinking water problem.

2. Material and methods

All reagents were of AR grade. A stock solution of As(III) was made using double-distilled water. Standard acid and base solutions (0.5 M H_2SO_4 and 1 M NaOH) were used for pH adjustments.

2.1. Equipment

pH measurements were made on a pH meter, Model CT No. CL46, Toshniwal, India. Arsenic determination was carried out with an inductively coupled plasma (ICP) instrument, Model Plasmalab 8440, at a wavelength of 189 nm.

2.2. Preparation of synthetic sample

Arsenic trioxide (As_2O_3) was used as the source of As(III). A stock solution (1000 mg/l) was prepared in distilled water by dissolving 1.32 g of arsenic trioxide in 25 ml of 0.36 M potassium hydroxide solution. The resulting solution was neutralized with 3.6 M sulfuric acid to a phenolphthalein endpoint and diluted to 1 l with 0.18 M sulfuric acid.

2.3. Preparation of iron oxide-coated sand

Iron oxide-coated sand was prepared using the procedure described earlier [25]. Washed and dried river sand (200 g) of geometric mean size 0.5 mm, porosity 0.36, and density $2.28\ \mathrm{kg/cm^3}$ was mixed for 2 min with 80 ml of a 2 M ferric nitrate solution of pH 11. The mixture was then dried at 110 °C in an oven for 14 h. The coated sand was washed with distilled water until the runoff was clear, dried at 105 °C, and stored in capped bottles.

2.4. Batch studies

Batch sorption experiments were conducted to obtain rate and equilibrium data, using 500-ml Erlenmeyer flasks kept at room temperature; a magnetic stirrer was used to agitate the solution. The reaction mixture consisted of 250 ml As(III) solution of known concentration and the adsorbent (coated and uncoated sand), which was weighed and added to the solution. Each flask was removed after the required reaction time and the solution was filtered through Whatman No. 2 filter paper. Each experiment was run in triplicate and mean values were reported. All experiments were carried out at room temperature ($27 \pm 2\,^\circ$C).

To study the effect of initial pH (4.5–10.5) on arsenic uptake, experiments were performed with initial arsenic concentrations of 400 µg/l and adsorbent dose of 20 g/l at a fixed contact time of 2 h. Isotherm studies were conducted with varying initial As(III) concentrations (100–800 µg/l), fixed adsorbent dose of 20 g/l, and contact time of 2 h at pH 7.5. The effect of contact time was studied with an initial arsenic concentration of 400 µg/l and adsorbent dose of 20 g/l; pH was kept at 7.5 and contact time was varied from 20 to 180 min. The effect of adsorbent was studied by varying the dose from 5 to 50 g/l at a fixed pH of 7.5 with an initial As(III) concentration of 400 µg/l and a contact time of 2 h.

2.5. Column studies

Column experiments were performed on a laboratory scale to study the effect of certain parameters like contact time, filtration rates, and bed depths for the reduction of As(III) concentration in aqueous solutions. The column used was prepared using PVC pipes of length 160 cm and internal diameter 25.4 mm. Two separate columns were used for coated and uncoated sand studies. These columns were filled with grave decreasing in size from the bottom, up to a height of 60 cm and then up to 52 cm coated/uncoated sand was with a geometric size of 0.5 mm was filled in. Outlets were provided at different depths to determine head losses at different bed depths.

To study As(III) uptake at different filtration rates (4, 7, and 10 ml/min), an As solution of 400 µg/l (pH 7.5) was pumped through the column at the required filtration rate, and samples were collected at various intervals ranging from 1 to 6 h. The samples were analyzed for residual arsenic concentration. The column was backwashed with 0.2 M NaOH solution and then with distilled water after completion of one run (6 h).