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Arsenic removal using bagasse fly ash-iron coated and sponge iron char

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ABSTRACT

The present work reports the adsorption capacity of bagasse fly ash-iron coated (BFA-IC) and sponge iron char (SIC) for arsenic removal. Different kinetic models were used to the kinetic data amongst which pseudo-second order model was best fitted. Batch equilibrium adsorption was carried out to determine the adsorption capacity of the BFA-IC and SIC. The adsorption data were fitted to the Langmuir, Freundlich, Tempkin and Redlich–Petersion isotherm adsorption model. The maximum adsorption capacity (q_m) of both BFA-IC and SIC were also determined. The maximum uptake capacity (q_m) of BFA-IC and SIC for As(III) was 39.53 and 27.85 μg/g, respectively, and for As(V) was only 25.82 and 28.58 μg/g, respectively. The surface area of the BFA-IC and SIC was determined to be 168 and 78.63 m^2/g, respectively, using BET method. The zero point charge was determined using solid addition method. In the present work, it is found that the after substantial chemical modification of BFA and SIC have potentials to be used as low cost adsorbents for arsenic removal from waste water.

Introduction

Arsenic is a well known element for its notoriety in drinking water and giving several adverse impacts on health, and causing several diseases if its concentration is having more than 100 μg/l in drinking water [1]. Due to this reason, several agencies of the world have set the limit of arsenic in various water bodies. World Health Organization (WHO) in 1993 and National Health and Medical Research Committee (NHMRC), Australia, in 1996 had recommended maximum contaminant level (MCL) of arsenic in drinking water as 10 and 7 μg/l, respectively [2,3]. The MCL of arsenic in drinking water has also been reduced from 50 to 10 μg/l by European Commission in 2003 [4]. Environmental Protection Agency (EPA), USA, has decided to move forward in implementing the same MCL of arsenic that is recommended by WHO for drinking water in 1993. Japan and Canada have reduced the MCL for arsenic in drinking water to 10 and 25 μg/l, respectively [5]. The MCL for arsenic in countries like India, Bangladesh, Taiwan, China, Vietnam, etc. is also 50 μg/l. About 40–60% of the people in Bangladesh have been estimated to be adversely affected by arsenic-contaminated drinking water. As a result, the arsenic contamination of drinking water continues to be a problem, with increasingly stringent standards making it more and more important to find new technologies [6].

Literature revealed that oxidation and filtration, biological oxidation followed by removal for iron and manganese oxides, co-precipitation followed by coagulation, sedimentation and filtration, ion exchange through suitable cation and anion exchange resins, adsorption and membrane technology including reverse osmosis, nanofiltration and electrodialysis are the available technologies for arsenic removal [7,8]. Among various treatment technologies, adsorption is the most popular physico-chemical treatment process due to high removal efficiency, easy operation, low cost and sludge-free operation for the removal of organic pollutants/toxic metals from wastewaters. A number of non-conventional, low cost adsorbents have been tried for arsenic removal [9]. Use of surface modified low cost adsorbents can be a viable option for arsenic removal from aqueous effluents. This has led to a search for cheaper alternative materials as adsorbents such as lignin, bagasse pith; saw dust, coal and bagasse fly ash, rice husk ash, sponge iron char and other, etc. After modifying their surfaces, these materials have good potential for removing arsenic from wastewaters.

The purpose of the present study is, therefore, to study the process of adsorption of arsenic onto indigenously prepared low-cost surface modified adsorbents from industrial waste such as bagasse fly ash (BFA) and sponge iron char (SIC), and to research the possibility of using them as low-cost adsorbents. This investigation also examines the influence of various process parameters for their optimal performance such as effect of adsorbent dosage (w), pH, contact time (t) and initial concentration

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(C_0) at ambient temperature. The adsorption capacity of both adsorbents BFA-IC and SIC were estimated using the Langmuir model.

Material and method

Adsorbent and its preparations

BFA (ash from bio fuel producer) and SIC (sponge iron industry waste) were obtained locally in the vicinity of Rourkela, Orissa washed with hot water (70 °C) and dried. Amount of iron content in BFA was checked by soaking 1 g of BFA in 10 ml 65% nitric acid for 24 h at room temperature so as to dissolve the Fe from BFA. Iron concentration in the filtered solution was determined using atomic absorption spectrophotometer (AAS) [10]. No iron was detected in the BFA using this procedure. BFA (granular size 150 μm) was treated with 2 M $FeCl_3$ solution, the solution was decanted and dried at 105 °C for 12 h and then used as an adsorbent. SIC, obtained from sponge iron industry was shredded using ball mill and sieved for obtaining the particular granular size of 110 μm, and then used.

Adsorbate

All the chemicals used were of analytical reagent grade. A 1000 mg/l As(III) and As(V) individual stock solution were prepared by dissolving 0.1734 g $NaAsO_2$ and 0.416 g $Na_2HAsO_4{\cdot}7H_2O$ in 1000 ml of double distilled water (DDW), respectively. Arsenic bearing water was further diluted using DDW to prepare the stock solution of 1000 μg/l. The initial concentration ($C_0 = 50–150$ μg/l) was ascertained before the start of each experimental run. pH of the different concentration solutions were adjusted using 1 M HCl and/or NaOH.

Batch experimental program

For each experiment, 50 ml of arsenic solution of known C_0 and a known amount of the each adsorbent was taken in a 100 ml air-tight conical flask with a glass stopper. This mixture was agitated in a temperature-controlled shaking water bath at a constant shaking speed of 250 rpm. After predetermined time of shaking, adsorbent was separated from the adsorbent–solution mixture by centrifugation of the slurry at 10,000 rpm for 5 min [11]. The percent removal and uptake q_t (μg/g) of arsenic at any time, t was calculated as:

$$\%R = \left(\frac{C_0 - C_t}{C_0}\right) \times 100 \qquad (1)$$

$$q_t = \left(\frac{C_0 - C_t}{w}\right) V \qquad (2)$$

where C_0 is the initial arsenic concentration (μg/l), V is the volume of the wastewaters in the flask (l), C_t is the adsorbate (arsenic) concentration (μg/l) after time t, and w is the mass of the adsorbent (g) used in the experiment. Reported results are average of two replicates. In study of each parameter, control experiments were carried out without adsorbents (and with adsorbates only). Similarly, experiments were also carried out with distilled water and the adsorbents so as to check leaching of arsenic from the adsorbents.

Analytical measurements

The arsenic concentrations in the solutions were measured by SDDC (silver diethyldithiocarbamate) method having detection limit 1 μg/l [12].

Error analysis

Marquardt's percent standard deviation (MPSD) error function [13] was also employed in this study to find out the most suitable kinetic and isotherm model to represent the experimental data. MPSD error function is given as:

$$\mathrm{MPSD} = 100\sqrt{\frac{1}{n-p}\sum_{i=1}^{n}\left|\frac{q_{e,\exp} - q_{e,\mathrm{cal}}}{q_{e,\exp}}\right|_i^2} \qquad (3)$$

Adsorbent characterization

The Brunauer–Emmett–Teller (BET) method was used to determine surface area for BFA-IC and SIC. The zero point charge (ZPC) of the materials is a tool to determine the surface charge, which is normally determined by potentiometric mass titration method. PZC was determined by salt addition method.

Result and discussion

Adsorption study

Effect of adsorbent dosage

To optimize the minimum dosage required for bringing down the arsenic level to the tolerance limit, a dosage of adsorbent (0.4–10 g/l) was varied. The percentage removal of arsenic with different adsorbent dosage is shown in Fig. 1. The BFA-IC and SIC were found to be efficient for the removal of arsenic from 100 to 2 μg/l and 0.5 μg/l, respectively, with 6 g/l dosage. The percentage removal of arsenic significantly increased with sorbent dosage, which was obvious because of the increase in the number of active sites as the dosage increases [14]. Hence, in all the subsequent experiments, 6 g/l of adsorbent was fixed as the optimum dosage to give reasonable dearsenification efficiency.

Effect of contact time

As shown in Fig. 2, the effect of contact time between adsorbate and sorbent on the sorption capacity of arsenic, it is followed that the adsorption of arsenic took place within 100 min. Subsequently, adsorption became slow and almost reached to equilibrium within 180 min. With further increase in contact time up to 6 h, no appreciable removal of arsenic takes place, indicating that complete adsorption occurred within 3 h. Therefore, $t = 3$ h is taken as equilibrium time for arsenic sorption. Thus, subsequent adsorption experiments were conducted for a period of 3 h.

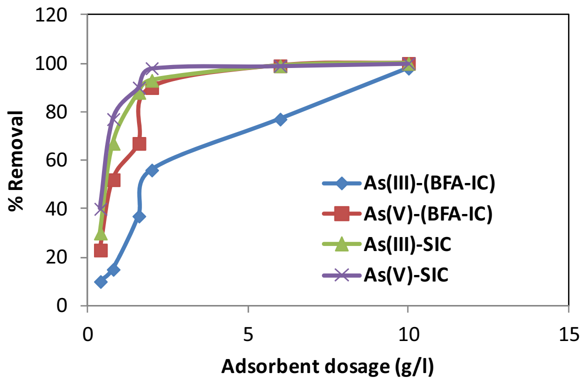

Fig. 1. Variation of adsorbent dose on the removal of arsenic. pH natural, $t = 6$ h, T = ambient temperature, and $C_0 = 100$ μg/l.