

# Modeling and fixed bed column adsorption of As(III) on laterite soil

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## Abstract

The performance of a fixed bed column for the removal of As(III) from aquatic environment was studied. Laterite soil was used as the adsorbent material. The column with 2-cm diameter, different bed heights such as 10 cm, 20 cm and 30 cm could treat 1.3 l, 7.9 l and 14.88 l, respectively, of As(III) bearing (conc. 0.5 mg/l) water at a flow rate of 7.75 ml/min. Bohart and Adams sorption model was employed for the determination of different parameters like height of exchange zone, adsorption rate, time required for exchange zone to move, and the adsorption capacity. Effect of flow rate and initial concentration was studied. The adsorption capacity and the adsorption rate constant of the adsorbent laterite soil for 0.5 mg/l of As(III) were found to be 108.02 mg/l and 0.6523 l/(mg h), respectively. The column was designed by the bed depth service time (BDST) model. Column design parameters were also tested with varying flow rate and initial As(III) concentration of the influent. Freundlich isotherm model was used to compare the theoretical and experimental breakthrough profile in the dynamic process. The bed saturation obtained was 53–71%. Regeneration of the exhausted column was possible with 1 M NaOH.

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**Keywords:** Laterite soil; As(III) adsorption; Column study; Breakthrough curve; BDST model

## 1. Introduction

Arsenic contamination in drinking water particularly in ground water has become a worldwide problem in recent years. Different parts of the world including India and Bangladesh are severely affected by such pollution. It is estimated that about 40 million people are at risk of arsenic problem in Bangladesh [1]. In India many districts of West Bengal [2–4] are facing the arsenic contamination in ground water. Leaching of arsenic in to the ground water can be associated with natural conditions or the industrial practices of mankind. Inorganic arsenic is present in natural water in the two predominant oxidation states As(III) (arsenite) and As(V) (arsenate). Arsenite is more mobile, and 60 times more toxic than arsenate. Literature review suggests that in the aerobic conditions As(V) is the dominant species, existing as the pH-dependent deprotonated oxyanions of arsenic acid ( $\text{H}_2\text{AsO}_4^-$  and  $\text{HAsO}_4^{2-}$ ) at natural pH. On the other hand, arsenite is the dominant species in the ground water and exists as neutral species at natural pH conditions (pH 6.5–7.5). Con-

sequently, arsenite is more difficult to be removed from water, and in many cases it was made to oxidise to arsenate before final treatment. Gradual intake of high arsenic contaminated water (maximum contaminant level (MCL) is 0.01 mg/l [5,6]) caused the severe health effects ranging from lethality to chronic and carcinogenic effects [7,8].

A variety of technologies have been developed for the treatment of arsenic in water. The major technologies include precipitation–coagulation, membrane separation, ion exchange and adsorption [9–11]. Among these technologies, adsorption is a cost-effective and user friendly technique for arsenic removal from water, and it can be used in small scale household units. Different types of synthetic adsorbents have been reported in the literature, which are more effective for As(V) removal rather than As(III). Some of these include [12–16] hardened paste of Portland cement (HPPC), iron oxide coated cement (IOCC), granular ferric hydroxide (GFH), aluminium loaded Shirasu-zeolite, iron(III)-doped alginate gels, etc. But some adsorbents like iron oxide-coated sand (IOCS), iron(III) phosphate, coconut husk carbon, etc., are more efficient for As(III) removal [17–19]. Recently, natural solids are also used as adsorbents [20–24] for arsenic removal as their elemental compositions are similar with the synthetic adsorbents used. Natural

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adsorbents help in reducing the time and cost for preparing the material.

With the understanding that the natural presence of Fe(III) and Al(III) in laterite soil may open up the possibility of laterite soil to be used as a potential adsorbent for arsenic removal, the systematic study to evaluate the performance of laterite soil as an adsorbent for As(III) was undertaken. Laterite soil is a red-colored clay-rich soil found in the tropics and subtropics. It needs the high temperatures of the tropics and the abundant rainfalls to form. The water washes out the bases and the silicic acid, and enriches it with aluminium silicates, aluminium hydrosilicates, iron oxides and iron hydroxides. The laterite soil is ubiquitous in several parts of West Bengal (India). As for example Purulia, Bankura and West Midnapore are enriched in laterite soil. In the present study, a locally available low-cost laterite soil has been selected for the removal of arsenic from aqueous environment.

Most of the studies for arsenic removal have been conducted in batch operation, excepting a few, which deals with activated alumina, HPPC, IOCC, GFH, aluminium-loaded Shirasu-zeolite, iron oxide coated sand, natural iron and manganese enriched sample, hybrid ion exchanger, iron oxide impregnated activate alumina, etc. [4,12–15,17,24–26]. Fixed bed column study is important to predict the column breakthrough or the shape of the adsorption wave front, which determine the operation life span of the bed and regeneration time. Further, in order to obtain basic engineering data, it is essential to study the continuous flow system. Adsorption capacities from batch studies may not give accurate scale up information in the column operation system [27] because of several factors. Present paper deals, for the first time, with the study of continuous flow of column type arsenic adsorption from water by laterite soil. The effect of flow rate, initial arsenic concentration, bed height with their shape of breakthrough curves was investigated. The dynamics of adsorption process was modeled using bed depth service time (BDST) approach.

## 2. Materials and methods

### 2.1. Reagents

All aqueous solutions were prepared in double distilled water. The solutions containing As(III) was prepared using NaAsO<sub>2</sub> (Loba Chemicals, GR) to get the 10 mg/l stock solutions. Solutions of As(III) of appropriate strength were prepared by diluting the stock solution. Zinc fillings, conc. HCl, SnCl<sub>2</sub>·2H<sub>2</sub>O, KI, sodium dodecyl sulfate (SDS) and AgNO<sub>3</sub> (all from Merck), Pb(OAc)<sub>2</sub>·3H<sub>2</sub>O (from BDH) were used as received. Aqueous 10<sup>-2</sup> M solution of SDS and 2 × 10<sup>-2</sup> M solution of AgNO<sub>3</sub> were used as stock solutions.

### 2.2. Instrumentation

All the apparatus used were soaked in conc. HNO<sub>3</sub> for 12 h and then thoroughly washed initially with tap water and finally with distilled water, and were dried in hot air oven. Modified Gutzeit apparatus containing scrubber with lead acetate soaked glass wool, and delivery L tube, were used for the production

of AsH<sub>3</sub> gas. A digital pH meter (Orion, London) was used for all pH measurements. A high precision electrical balance (Sartorius GmbH) was used for weighing. All absorbance measurements were carried out using a spectrophotometer (Thermo Spectronic UV1, UK) equipped with 1-cm quartz cells. Atomic absorption spectrophotometer (Shimadzu AA 6650, Japan) was used for the analysis of Fe, Al and Cu. Sorptomatic 1990 was used for BET analysis. JEOL JSM-5800 scanning electron microscope was used for SEM and EDX analysis. Gilson micropipette with disposable tips was used to add sample.

### 2.3. Analytical determinations

Quantification of arsenic was made using either the method developed in our laboratory [28] and/or using the standard silver diethyldithiocarbamate (SDDC) method [29].

### 2.4. Preparation and characterization of adsorbent

The laterite soil was collected from West Midnapore, West Bengal, India. The material was thoroughly washed with tap water, dried in the Sun and then crushed and sieved to get the particles having geometric mean size of 0.164 mm. After that it was again washed initially with tap water and finally with distilled water and dried in the hot-air oven at 90–100 °C. This as-prepared particle was used for arsenic adsorption. The specific surface area and pore volume of the laterite soil was 15.365 m<sup>2</sup>/g and 0.013 cm<sup>3</sup>/g, respectively, as obtained from the BET analyses. The pH<sub>ZPC</sub> (point of zero charge) of laterite soil was 6.96. The chemical and physical characteristics of laterite soil are given in Table 1.

Energy dispersive X-ray analysis (EDX) is a useful tool to identify within short analysis time the kinds of element contained in the solid specimen. The surface morphology of the adsorbent was obtained from the SEM studies (Fig. 1) and the elemental composition from EDX analyses. The adsorbent contains Fe, Al, Si and Cu (Table 1).

### 2.5. Experimental studies

Fixed bed column experiments were conducted using borosilicate glass columns of 2 cm internal diameter and 55 cm length. The column was packed with laterite soil between two supporting layers of glass wool to prevent the floating of adsorbent

Table 1  
Physical and chemical characteristics of laterite soil

Properties	Quantitative value
Geometric mean size (mm)	0.164
Bulk density (g/cm <sup>3</sup> )	2.5
Surface area (m <sup>2</sup> /g)	15.365
Pore volume (cm <sup>3</sup> /g)	0.013
Al (%)	8.61
Fe (%)	52.05
Si (%)	35.04
Cu (%)	4.31
pH <sub>ZPC</sub>	6.96

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