



Performance of Iron-oxide Coated Sand for Removal of Arsenic from Drinking Water

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Abstract

Arsenic (As) is a toxic element, its presence in groundwater causes severe human health issues, which require proper treatment before its use as drinking water. Iron oxide coated sand shows good adsorbent property for removal of arsenic from groundwater. The present study describes method for removal of arsenic, total coliform and faecal coliform from contaminated groundwater using iron oxide coated sand and charcoal in batch studies conducted as a function of adsorption time (30, 120 and 240 minutes), flow rate (1, 2, 4 and 7 l h⁻¹), thickness of filter media (5, 7.5 and 10 cm) and initial arsenic concentration (0.10 and 0.25 mg l⁻¹). The maximum As⁺³ removed was 100 percent for initial concentration of 0.25 mg l⁻¹ and 0.10 mg l⁻¹, respectively for adsorption time of 120 minutes at flow rate of 1 l h⁻¹ for thickness of filter material 10 cm. For concentration less than 0.10 mg l⁻¹, thickness of filter media (IOCS + charcoal) can be taken as 10 and 20 cm, flow rate 1 l h⁻¹ and adsorption time 120 minutes for removal for total coliform and faecal coliform. The batch study suggests that iron oxide coated sand can be effectively used to achieve a low level of arsenic in drinking water.

Key words: Arsenic, Groundwater, Iron oxide coated sand, Drinking water, Adsorption

Introduction

India is one of the countries bestowed with high-potential and nature-gifted rich water resources. Despite this, there is a scarcity of potable quality water. Population explosion, economic progress, poor management and contamination of water sources are the main reasons for scarcity of assured quality of water (Garg and Hassan, 2007). Arsenic in drinking water has been reported as the most wide spread geogenic contaminants in water sources worldwide (EPA, 1999). Arsenic occurs in both inorganic and organic forms in natural water. Inorganic arsenic is the result of dissolution from the representing minerals phase, such as arsenolite (As₂O₃) and arsenic oxide (As₂O₅). In natural water, arsenic is mostly found in trivalent [As⁺³] or pentavalent [As⁺⁵] states (Cullen and Reimer, 1989). In India, high arsenic and iron content in drinking water is a major problem in most parts of the north-eastern (NE) region (Singh *et al.*, 2008). The states of Jharkhand, Bihar, West Bengal, Madhya Pradesh, Uttar Pradesh, Punjab etc. are badly affected by groundwater contaminated with arsenic

(Chakraborti *et al.*, 2004; Chakrabarti *et al.*, 2008). South Tripura was also found to have high contamination of water with respect to iron and arsenic (Banerjee *et al.*, 2011).

In Punjab, groundwater serves as the primary source of drinking water for more than 95% of the population. The groundwater quality in the state is deteriorating day by day and is of major concern nowadays. The groundwater pollution could be attributed to anthropogenic as well as result of minerals dissolving from weathered rock and soils. The most important anthropogenic factor responsible for ground water pollution is urban and industrial waste water. This waste water is often not treated before its release into sewerage drains. Direct releases of untreated effluents to water bodies can potentially contaminate ground water. The contamination of ground water by heavy metals is a serious ecological problem as some of these like arsenic and lead are toxic even at low concentrations, are non-degradable and can bio-accumulation through food chain (Kar *et al.*, 2008). The underground water content due to elevated arsenic concentration which are usually

above the World Health Organisation (1996) permissible safe limit of 0.01 mg l^{-1} . The problem is more serious at several sites in South Western districts of Punjab where the arsenic concentration exceeded more than 20 to 30-folds of the WHO safe limit. In the Northern and Central parts of Punjab, the concentration of arsenic in groundwater varied from 0.003 to 0.042 mg l^{-1} and 0.009 to 0.042 mg l^{-1} , respectively (Hundal *et al.*, 2007).

Arsenic in drinking water can impact human health including skins and considered to be one of the prominent environmental causes of cancer mortality in the world (Smith *et al.*, 1992, 2002). For the last decade, cancer mortality has increased with alarming proportion in many villages in South-Western district of Punjab (Singh, 2005; Tandon, 2007) due to elevated arsenic content in drinking water. While providing access to safe drinking water remains an urgent problem, the application of nanotechnology may prove a boon to the mankind by providing an advance way for groundwater treatment. Numerous methods are available for removal of arsenic from water including iron-modified activated carbon, chitosan-coated biosorbent, oxides, clay minerals, etc. (Boddu *et al.*, 2008). However, adsorption of arsenic on iron oxide-coated sand method is one of the emerging technologies for arsenic removal (Joshi and Chaudhuri, 1996; Gupta *et al.*, 2005). Iron (hydr) oxide-coated sand (IOCS) has shown to have high efficiency in removing microorganisms, turbidity and heavy metals (Ahammed and Meera, 2010). 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 along with activated charcoal for arsenic removal with varying thickness of filter media to achieve the permissible concentration in drinking water.

Materials and Methods

A lab study was conducted for preparation of iron oxide coated sand, development of a filter and removal of arsenic from water through nano filter. The following methodology was adopted:

a) Selection of filtration material

The different filtration materials selected on the basis of size are fine sand, coarse sand, gravel and charcoal. Iron oxide coated sand was prepared as per the method described by Bailey *et al.* (1992). The process of coating sand was done in four main steps: Sieving, washing, coating and drying. Sieve analysis was carried for determination of size of sand used for the coating process. In sieve analysis, sand was sieved and operated for 5 min. The total weight taken was 100 g for sieve analysis. The size of sand used for coating process was 0.30 mm. The sand was soaked into the 50 percent sulphuric acid (H_2SO_4) solution for 24 hours in a beaker, containing 200 ml of sand and 100 ml of sulphuric acid. After 24 hours, the acid-soaked sand was washed with de-ionized water until the runoff was clear and pH of water becomes neutral (7.0). After washing, the sand was put in the oven for drying (Bailey *et al.*, 1992). Ferric chloride (FeCl_3) was used for the iron oxide coating and 10 molarity sodium hydroxide (NaOH) was used for making solution basic. 80 ml of 2.47 molarity solution of ferric chloride was added to washed and dried sand and the pH was adjusted to 11.0 by adding 2 ml of NaOH solution and mixed for 2 minutes. After ferric oxide coating on sand, coated sand was placed in the oven for 24 hours for drying. During the drying process the temperature was set at 105°C and after drying coated sand was put in the furnace at 550°C for 3 hours to increase coating strength. After drying, the iron oxide coated sand was washed with distilled water until the runoff was clear for removal of excess coated iron. After washing, iron oxide coated material was stored as shown in Fig.1.



Fig. 1 Iron-oxide coated sand

b) Development of the filter

An acrylic sheet box of height 70 cm, width 20 cm and thickness 12 cm was used for fabrication of filter. The filter is divided into three parts i.e. reservoir tank, material container and filtered storage tank as shown in Fig. 2. The dimension of reservoir tank and filtered storage tank is 20 cm × 20 cm × 12 cm. It can store water up to 4.8 litres. The dimension of material container is 30 cm × 20 cm × 12 cm.

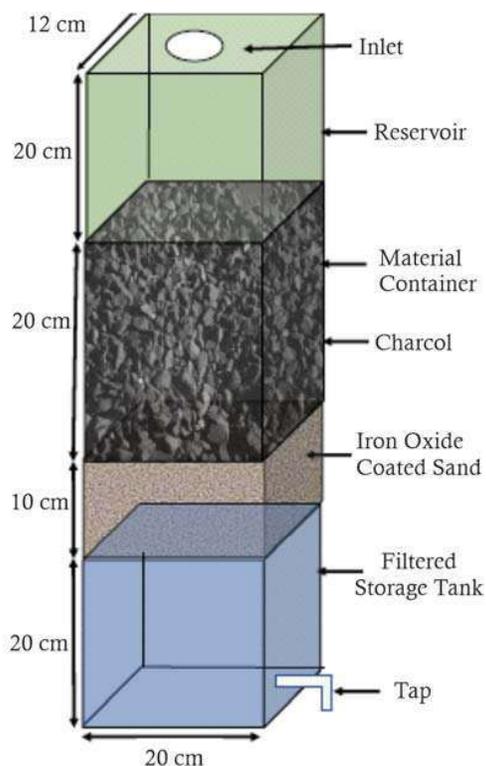


Fig. 2 Schematic diagram of developed filter

c) Arsenic test method

An arsenic test method was used to quantify arsenic (As_2O_3) in samples collected and analysed in the field and the lab. The arsenic field test kit provides a safe, simple, and reliable method to test for aqueous inorganic arsenic. It requires no electricity or refrigeration. The detection range is between 0 and 0.5 mg l^{-1} . The upper detection limit can be extended to 2.5 mg l^{-1} with a simple 1 to 5 dilution. With the exception of a timer, all components are supplied in the kit, including a detailed description of the test method, a colour chart, three chemical reagents with material safety



Fig. 3 Arsenic test kit

data sheets, 2 measuring spoons for the reagents, 100 test strips, 2 reaction bottles, 2 bottle caps and a clip-lock disposal bag for test strips as shown in Fig. 3.

The procedure for determining arsenic is as shown in Fig 4. First of all, reaction bottle was filled with 60 ml treated and untreated water up to mark. Then two drops of reagent As^{-1} was added and swirled. After that one level red dosing spoon was added and swirled until the reagent As^{-2} is completely dissolved. Again, one level green dosing spoon was added with reagent As^{-3} and immediately reclosed the reaction bottle with the screw cap. Then black test strip was flipped up in holder integrated with the screw cap. Obtained solution was allowed to stand for 20 minutes and

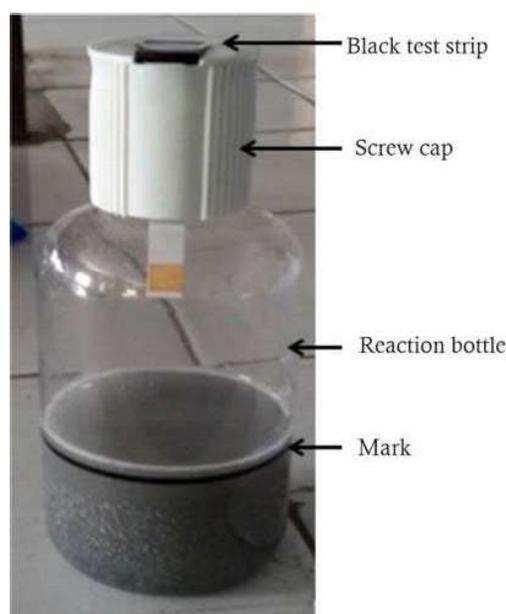


Fig. 4 Testing of As^{+3} sample testing in lab

swirled two or three times during this period. During this process, contact between test strip and solution was strictly avoided. Strip was removed from integrated holder then briefly dipped into distilled water and shaken off excess liquid. Test strip colour was matched with colour filed on label to coincide most exactly.

d) Water sample collection

Arsenic contaminated water sample was collected near the Buddha Nala in village Wallipur, Ludhiana. The arsenic varied from the 0.05 to 0.10 mg l⁻¹, which was above the safe limit from WHO standards.

The pH of water plays very important role in the arsenic removal from the water. The adsorption of arsenic-III (As⁺³) increases as pH becomes more alkaline, because the positive charges on the iron cations attract the negative charges of the arsenic anions, creating ionic bonds (Benadin, 2011). The pH of water was checked by digital pH meter. The total dissolved solids (TDS) represents the total concentration of dissolved substances in water. TDS is made up of inorganic salts, as well as a small amount of organic matter. Common inorganic salts that can be found in water include calcium, magnesium, potassium and sodium, which are all cations, and carbonates, nitrates, bicarbonates, chlorides and sulphates, which are all anions. Digital TDS meter was used for checking the TDS.

Total coliform refers to a large group of Gram-negative, rod-shaped bacteria that share several characteristics. In the laboratory total coliforms are grown in or on a medium containing lactose, at a temperature of 35°C or 37°C. They are provisionally identified by the production of acid and gas from the fermentation of lactose. The water sample was placed in incubator for 48 hours at 37°C with Macconkey broth culture media.

Faecal coliform has been used in water microbiology to denote coliform organisms which grow at 44°C or 44.5°C and ferment lactose to produce acid and gas. The water sample was placed in incubator for 48 hours at 44°C with Macconkey broth culture and the results were compared with Table 1.

Table 1. Most probable number (MPN) index

Number of tubes giving a positive reaction from			MPN
3 of 10 ml each	3 of 1 ml each	3 of 0.1 ml each	
0	0	0	<3
0	0	1	3
0	1	0	3
1	0	0	4
1	0	1	7
1	1	0	7
1	1	1	11
1	2	0	11
2	0	0	9
2	0	1	14

Results and Discussion

In this study, arsenic removal efficiency of simple sand, charcoal and iron oxide coated sand filter media have been evaluated. Different factors such as initial arsenic concentration, thickness of filtration media, adsorption time and flow rate were studied.

Effect of adsorption time, thickness and flow rate on As⁺³ removal efficiency

The effect of adsorption time, thickness and flow rate on As⁺³ removal efficiency are shown in Tables 2 and 3 which indicate the percentage of As⁺³ removed when the thickness of filter media was taken at 5.0, 7.5 and 10.0 cm and As⁺³ contaminated water with initial concentration of 0.25 and 0.10 mg l⁻¹ for different flow rates of 1, 2, 4 and 7 l h⁻¹ was passed through the developed filter for 30 and 120 minutes, respectively. From the data it was clear that for a particular thickness of filter media (IOCS) as the flow rate increases, the As⁺³ removal efficiency decreases. As the thickness of filter media (IOCS) was increased from 5 to 10 cm, there was relatively more improvement in As⁺³ removal efficiency at flow rate of 1 l h⁻¹ for adsorption time of 120 minutes. So it was concluded that the maximum As⁺³ removal efficiency was 100 percent for initial concentration of 0.25 and 0.10 mg l⁻¹, respectively for thickness of filter media (IOCS) 10 cm at flow rate of one l h⁻¹ for adsorption time of 120 minutes.

Arsenic removal from groundwater

As⁺³ contaminated groundwater sample was taken near Buddha Nala in village Wallipur, Ludhiana

Table 2. Effect of adsorption time and flow rate on removal of As^{+3} for initial concentration of 0.25 mg l^{-1}

Thickness of filter media (cm)	Time (min)	Flow rate ($l \text{ h}^{-1}$)			
		1	2	4	7
As^{+3} removal efficiency (%)					
5	30	60	56	48	40
	120	68	64	52	40
7.5	30	80	68	60	40
	120	90	80	68	48
10	30	96	96	80	60
	120	100	96	80	60

Table 3. Effect of adsorption time and flow rate on removal of As^{+3} for initial concentration of 0.10 mg l^{-1}

Thickness of filter media (cm)	Time (min)	Flow rate ($l \text{ h}^{-1}$)			
		1	2	4	7
As^{+3} removal efficiency (%)					
5	30	70	60	50	40
	120	75	70	60	40
7.5	30	80	70	60	50
	120	90	80	60	50
10	30	95	95	75	60
	120	100	95	75	70

having initial concentration of As^{+3} as 0.08 mg l^{-1} . The groundwater sample was passed through filter having thickness of filter media as 10 cm at flow rate of one $l \text{ h}^{-1}$ for adsorption time of 30 and 120 minutes to see whether the developed filter is working efficiently or not. It was clear from Table 4 that final concentration of As^{+3} was 0.005 and 0.0 mg l^{-1} at flow rate of one $l \text{ h}^{-1}$ for adsorption time of 30 and 120 minutes, respectively which was less than maximum permissible limit of 0.01

Table 4. Final concentration (mg l^{-1}) and percentage of As^{+3} removed for thickness of 10 cm for initial concentration 0.08 mg l^{-1} for adsorption time of 30 and 120 minutes

Time (min)	Flow rate ($l \text{ h}^{-1}$)	Final concentration (mg l^{-1})	Maximum permissible limit (mg l^{-1})	As^{+3} removal efficiency (%)
30	1	0.005	0.01	99.3
120	1	0	0.01	100

Table 5. TDS of water before and after filtration

Treatment	Initial TDS (mg l^{-1})	Final TDS (mg l^{-1})
As^{+3} contaminated groundwater passed through IOCS	400	400
As^{+3} contaminated groundwater passed through IOCS and charcoal	400	415

mg l^{-1} . So, it was concluded that for concentrations less than 0.10 mg l^{-1} , thickness of filter media (IOCS) can be taken as 10 cm, flow rate one $l \text{ h}^{-1}$ and adsorption time 30 minutes.

Total dissolved solid (TDS), pH, total coliform and faecal coliform

The TDS of groundwater sample was observed before and after filtration by digital TDS meter as shown in Table 5. When As^{+3} contaminated groundwater was passed through iron oxide coated sand, initial TDS was 400 mg l^{-1} and after filtration was same. Similarly, when As^{+3} contaminated groundwater was passed through IOCS (thickness of filter media 10 cm) and charcoal (thickness of filter media 20 cm) final TDS observed was 415 mg l^{-1} . TDS increased due to use of charcoal. The safe limit of TDS is 500 mg l^{-1} .

The pH of water was recorded before and after filtration. The pH of water before and after filtration was 7.18.

Total coliform and faecal coliform were observed for the As^{+3} contaminated groundwater sample as shown in Table 6 and it was observed that groundwater sample was contaminated having MPN value 11. Above 10 MPN water was not fit for drinking purpose.

When As^{+3} contaminated groundwater was passed through iron oxide coated sand, initial and final MPN was 11. Similarly, when As^{+3} contaminated groundwater was passed through IOCS (thickness of filter media 10 cm) and

Table 6. Total coliform and faecal coliform water before and after filtration

Sample	3 of 10 ml	3 of 1 ml	3 of 0.1 ml	MPN
As ⁺³ contaminated groundwater	1	2	0	11
As ⁺³ contaminated groundwater passed through IOCS	1	2	0	11
As ⁺³ contaminated groundwater passed through IOCS and charcoal	0	0	0	0

MPN=Most probable number

charcoal (thickness of filter media 20 cm) final MPN observed was zero. So, it can be concluded that charcoal helps to remove bacteria from groundwater and filtered water can be used for drinking purposes.

Conclusions

Iron oxide coated sand (IOCS) showed good adsorbent characteristics for As⁺³ removal from arsenic contaminated water. The maximum As⁺³ removed was 100 percent for initial concentration of 0.25 mg l⁻¹ and 0.10 mg l⁻¹, respectively for adsorption time of 120 minutes at flow rate of one l h⁻¹ for thickness of filter material 10 cm. For concentrations less than 0.10 mg l⁻¹, thickness of filter media (IOCS) can be taken as 10 cm, flow rate 1 l h⁻¹ and adsorption time 30 minutes. For concentration less than 0.10 mg l⁻¹, thickness of filter media (IOCS + charcoal) can be taken as 10 and 20 cm, flow rate 1 l h⁻¹ and adsorption time 120 minutes for removal for total coliform and faecal coliform. Batch study results showed that iron oxide-coated sand (IOCS) can be effectively used to achieve a low level of As⁺³ in drinking water. The filter produced water at normal drinking water pH levels (~ pH 7) and no leaching of the iron-oxide coating into the effluent was observed.

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