Development of Iron-Oxide-Coated Fiberglass for Arsenic (V) Removal

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Introduction

Heavy metals and natural organic matter in drinking water are causes of health concerns. Different types of coated media such as iron-oxide coated media have been used to remove these contaminants. Iron-oxide-coated sorbents (IOCS) remove oxyanions (such as arsenate), cations (such as copper and lead), and natural organic matter. Iron loading depends on material's specific surface area and surface functional groups (such as silanol, hydroxyl, carboxyl, ammonium). Coating conditions such as coating pH, temperature, initial iron concentration and coating steps also govern the extent of iron loading. Sand, zeolites, resin, activated carbon, cellulose have been used so far as raw materials for developing IOCS. These materials possess high surface area and surface functional groups. Fibers could also be used for developing IOCS as they provide higher specific surface area. For example, Fiberglass (FG) provides ~8 to 30 times higher specific surface area (m^2/m^3) than sand due to their small diameters ranging from micron to nanometer range (Bismarck et al., 2004). It also possess silanol surface functional groups, which is capable of binding iron oxide. Besides, it is relatively inexpensive, which makes it competitive with other raw materials. The objective of this study is to (i) evaluate the feasibility of iron-oxide coating on fiberglass using alternative coating techniques, and (ii) evaluate the arsenate removal potential of these fibers in batch sorption experiments.

Materials and Methods

Coating Experiments

(1) Selection of appropriate type of fiberglass (FG) such as fiberglass insulation fibers, fiberglass cloth and fiberglass mat to achieve highest iron loading (Coating conditions: Temp: 25⁰C and 110⁰C, pH 1.3, 7 and 8.5, and initial iron concentrations 0.25M and 2.5M)

(2) Comparative study of iron loading on sand and fiberglass fibers (Coating conditions: Temp: 25⁰C and 110⁰C, pH 1.3 and 7, 0.25 M $Fe_{initial}$)

(3) Study of the effect of initial iron concentration on fiberglass insulation (Coating conditions: 110⁰C, pH 1.3, Single-step coating)

(4) Study of the effect of two-step iron-oxide coating on fiberglass using alternate dipping and drying procedure (Coating conditions: 110⁰C, pH 1.3, 0.25M $Fe_{initial}$)

Characterization

(1) Study of surface morphology of coated fibers (Coating conditions: 110⁰C, pH 1.3, 0.25M $Fe_{initial}$) using Field Emission Scanning Electron microscope (FEI/ Phillips XL30) at 10kV and 650X.

(2) Determination of exchangeable cation capacity of the uncoated FG following the method used by Ghimire et al. (2003): Material was equilibrated with NaOH for 24 h at 25⁰C and residual NaOH was determined. Maximum amount of exchangeable cations is equal to the decrease in basicity.

Arsenate Removal by coated fiberglass fibers

(1) Determination of equilibrium time in batch kinetic study
Conditions
- 10 g L^{-1} fiberglass fibers with loading 231 mg Fe g^{-1} (coating conditions: 110⁰C, pH 1.3, 0.25 M $Fe_{initial}$, single step)
- pH 7.6, room temperature (25⁰C),
- Synthetic El Paso water containing 100 μg L^{-1} arsenate
- Sampling at 12h, 24h and 48h interval

(2) Determination of equilibrium arsenate adsorption capacity in batch equilibrium study
Conditions
- Sorbent: Fiberglass fibers with iron loading 231 mg Fe g^{-1} (coating conditions: 110⁰C, pH 1.3, 0.25 M $Fe_{initial}$, single step)
- Sorbent concentrations: 1, 2.5, 5, 7.5 and 10 g L^{-1}
- pH 7.6, room temperature (25⁰C),
- Synthetic El Paso water containing 1000 μg L -1 arsenate
- 24 h equilibrium time

Analytical Methods

(i) Iron determination: US EPA Acid Digestion Method 3050 B and US EPA 600 Method 200.7
(ii) Arsenic determination: US EPA 600 Method 200.7

Results

Iron-Oxide Coating

Screening of fiberglass types

(1) Fiberglass Cloth vs. Fiberglass Mat

Fiberglass cloth retains higher iron loading of 34 mg Fe g^{-1} than fiberglass mat (11 mg Fe g^{-1}media) for coating conditions (25⁰C, pH 8.5 and 2.5M $Fe_{initial}$) probably due to the impacts of fiber diameter or porosity of cloth and mat forms.

=> Fiberglass cloth was chosen for further coating experiments.

(2) Fiberglass Fibers vs. Fiberglass cloth

Coating conditions			Fiberglass Types	
Temp (⁰C)	pH	Initial Iron Conc., M	Fiberglass Insulation	Fiberglass Cloth
25	8.5	2.5	33	34
110	1.3	0.25	231	22
110	8.5	2.5	76	32

Comparable with reported iron loadings on sand

21 mg Fe g^{-1} sand (Xu and Axe, 2005) (Single-step coating, 110⁰C)

45 mg Fe g^{-1} sand (Thirunavukkarasu et al., 2003) (Two-coating steps, one at 110⁰C and one at 550⁰C)

⇒ Fiberglass fibers retain higher iron loading than fiberglass cloth and thus, were chosen for further detailed coating experiments.

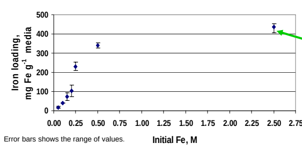
Comparison of Iron loadings on Sand and Fiberglass

Material	pH	Temp (⁰C)	Iron loading (mg Fe g^{-1} media)#
Sand	1.3	25	25 (22,28)*
Fiberglass	1.3	25	32 (19,44)
Sand	7.0	25	35 (18,51)
Fiberglass	7.0	25	32 (16,45)
Sand	1.3	110	29 (27,30)
Fiberglass	1.3	110	**231 (210,252)**
Sand	7.0	110	42 (38,45)
Fiberglass	7.0	110	90 (61,118)

\# Two replicates, * average value (minimum, maximum value)

~ 8 times higher iron loading on fiberglass than sand

Effect of initial iron concentration on iron loadings of fiberglass



Error bars shows the range of values.

Comparable with **468 mg Fe g-1 cellulose bead** (Guo et al., 2005)

=> Iron loading increases with increase in initial iron concentration but diminishing effects at concentration above 0.5 M $Fe_{initial}$.

Effect of multi-step coating using alternate dipping and drying procedure

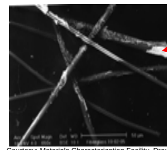
Coating Steps	Iron loading (mg Fe g^{-1} media)#
Single-step	231 (210, 252)*
Two-Steps	286 (202, 370)

\# Two replicates, * average value (minimum, maximum value)

⇒ No significant difference in iron loading on fiberglass for single- and two-step coating (95% confidence, p-value = 0.36)
⇒ No significant improvement in iron loading possibly due to dissolution of iron-oxide during re-wetting process.

Characterization of fiberglass

(1) Surface morphology



Courtesy: Materials Characterization Facility, Drexel University

⇒ (i) Under-utilization of available fiber surface area. (ii) Shearing of coating, probably due to the loose attachment

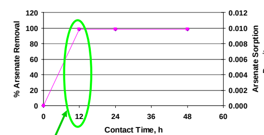
(2) Maximum Exchangeable Cations and Iron loading

Exchangeable cation (mole kg^{-1})	Iron-oxide Coating Conditions	Iron loading (mole kg^{-1})
4.3	110⁰C, pH 1.3, 0.25M $Fe_{initial}$, single step	4.1
4.3	110⁰C, pH 1.3, 2.50 M Fe initial, single step	7.8

=> Cation exchange capacity of fibers can exceed the observed 4.3 mole cation kg^{-1} by using high initial iron concentration.

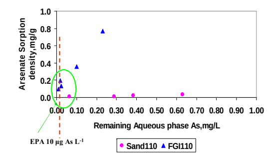
Arsenate Removal by coated fiberglass fibers

(1) Kinetics



⇒ More than 90% arsenate removal within 12 h of the initiation of kinetic experiment.

(2) Equilibrium Study



⇒ Fiberglass provides higher arsenate adsorption capacity at lower remaining aqueous phase arsenic.

Application of findings to Drinking Water Community

➢Fibers could be used for developing iron-oxide coated sorbents.

➢The iron density of the coated fiberglass (43% by wt.) is now approaching that of commercially available iron-impregnated media.

➢Fiberglass is a promising raw material as
❖relatively inexpensive
❖stable in aqueous solution at neutral pH
❖retains higher iron loading than sand for coating at room and higher temperature.
❖offers the prospect of rapid kinetics, due to its high surface area and high iron loading.

➢To confirm the potential of this new adsorbent material, arsenate removal in column study is underway.

References

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