



# New England Water Treatment Technology Assistance Center

University of New Hampshire • Durham, New Hampshire

## PROJECT SUMMARY REPORT

### Evaluating Arsenic Removal Adsorbents

#### Problem Statement / Objective

The lower arsenic EPA maximum contaminant level (MCL) of 10 ppb set a challenge for many public drinking water systems, especially small systems. Adsorption is one of the primary processes for removing arsenic from drinking water. This study focused on finding inexpensive and effective adsorbents to remove arsenic by testing various granular and powdered materials. Some of these materials were commonly used for drinking water treatment purposes while others were considered innovative.

#### Methodology

A total of 14 different adsorbents were initially evaluated and are listed in Table 1. Some had been previously used for arsenic removal but others were of unknown potential. All experiments were conducted as batch studies. Initial kinetic and isotherm studies for activated alumina, granular ferric hydroxide, magnesium oxide, and diatomaceous earth were run in a constant temperature room (20°C) on a shaker table. Kinetic studies were also done for Carasol and AbsorbaKleen on the shaker table. The initial pH of the reagent solutions was adjusted to pH 6 or pH 8 and the pH was not controlled further in the experiment. The reagent water was distilled water containing 0.01M sodium chloride for ionic strength and 100 ppm sodium bicarbonate (as CaCO<sub>3</sub>) for alkalinity. Arsenic was added as arsenic(V) with an initial concentration of 100 ppb. The concentration of adsorbents added was 267-1333 ppm. Batch solutions of 75 mL were mixed on the shaker table for 3 hours.

After these initial studies, all following experiments were carried out on a computer-controlled automatic titration system (Schott TITRONIC Universal Piston Burettes). The pH was held constant at pH 6 using 1N and 0.1N nitric acid titrants. The temperature was held constant as well (21-22°C). The 180 mL batch solutions were made up of distilled water with 0.01M ionic strength, 50 ppm alkalinity, arsenic(V) standard solution (with initial arsenic concentrations of 150-2000 ppb), and the adsorbent material (56-5556 ppm). In preliminary screening and kinetic studies the adsorbent was mixed with the batch solution for 3 hours to insure equilibrium conditions were reached. In the isotherm studies mixing was done for 2 hours. Preliminary screening was done for all adsorbents. Kinetic and isotherm experiments were run for activated alumina, granular ferric hydroxide, zero-valent iron and goethite.

All collected samples for arsenic analysis were first filtered through Whatman GD/XP syringe filters (<0.45 µm, PTFE), then acidified with 2 drops of concentrated nitric acid and stored in a refrigerator. The arsenic concentration remaining after adsorption was measured by a Shimadzu AA-6650 Atomic Absorption Spectrophotometer. This instrument has a detection limit of 1 ppb. The removals were calculated based on the difference between the initial and the remaining arsenic concentrations and normalized by dry weight of adsorbent added.

---

## Results

In kinetic and isotherm studies run on the shaker table, the initial pH of the solutions was adjusted to pH 6 or pH 8. The pH was not controlled further in the experiment. However, measurements of the end pH showed that the values of pH changed drastically (up to 5 magnitudes difference, depending on the adsorbent material). Since the literature showed that the arsenic adsorbance efficiency is pH dependent, all further experiments were conducted on automatic titration stations to be able to keep the pH constant throughout the runs. The value of pH = 6 was chosen for the pH setting of the experiments based on pH-edge curve runs and existing literature data.

In the preliminary screening phase, the arsenic removal efficiency of 14 different adsorbent materials (Table 1) was tested. Based on the preliminary results the four most efficient adsorbents were selected for detailed kinetic and isotherm analysis. These were granular ferric hydroxide, zero-valent iron, goethite, and activated alumina.

The kinetic study confirmed that all of the selected adsorbent materials were removing arsenic efficiently (Figure 1). Most of the removal took place within the first 30 minutes, and the maximum capacity was almost achieved in 1 hour. However, there was a slight difference in the kinetic performance of the adsorbents (Figure 1b). Granular Ferric Hydroxide was the fastest in removing arsenic, followed by zero-valent iron, activated alumina and goethite. More significant differences were found in the adsorption densities (Figure 1a). Zero-valent iron was the far most efficient, followed by goethite, Granular Ferric Hydroxide, and activated alumina. The kinetic equilibrium time for all four adsorbents was determined to be 2 hours.

The isotherm studies quantified the arsenic removal efficiency of the four materials (Table 2). Zero-valent iron was slightly more efficient than Granular Ferric Hydroxide, activated alumina, and goethite.

---

## Conclusions

Based on the above results, zero-valent iron, Granular Ferric Hydroxide, goethite, and activated alumina were found to be the most efficient in removing arsenic from drinking water from the 14 adsorbent materials tested. The pH conditions were of great influence on arsenic removal. All the results in this study showed removals at pH 6, a value chosen based on pH-edge curves developed or found in literature. The effect of competing ions found in real world samples was not evaluated in this study.

---

## Recommendations

Review of the literature indicates that competing ions play an important role in the removal of arsenic; however, little work has been conducted to identify which ions provide the most competition. Identifying the relative importance of competing ions commonly found in water sources and comparing the competition effects for different adsorbents has not been presented in the literature.

The evaluation of the role of eight competing ions in the removal of arsenic is already in progress for the four most efficient adsorbent materials. The competing ions that are being evaluated include sulfate, phosphate, carbonate, fluoride, nitrate, chloride, silicate, and natural organic matter. The completion of this phase of the project will make it possible to generate a table comparing the four selected adsorbent materials based on competition, removal and cost efficiency providing a useful tool for plant designers and operators in choosing the most suitable treatment technologies.

---

## Disclaimer

This project was funded by the U.S. Environmental Protection Agency grant number X827736-01-0. Mention of specific trade names herein does not imply endorsement on the part of the USEPA or the University of New Hampshire.

## Principal Investigators

Emese Hadnagy  
 M. Robin Collins, Ph.D., P.E.  
 Kevin H. Gardner, Ph.D., P.E.  
 New England Water Treatment Technology Assistance Center  
 University of New Hampshire  
 Durham, NH

**Table 1. Arsenic adsorbed in the preliminary screening studies.**

Adsorbent	As adsorbed/adsorbent mass [ug/g]	%Adsorbed
Granular Ferric Hydroxide	2318	99
magnesium oxide	1329	55
activated alumina	1669	96
MN4 diatomaceous earth	6	24
AbsorbaKleen	252	27
Carasol	157	17
apatite	0	0
zero-valent iron	799	98
bone char	56	8
Celite	27	4
fishbone	17	3
magnetite	120	18
hematite	355	56
goethite	626	100

**Experimental conditions:**

T = 21 - 22 C  
 pH = 6  
 t = 3 hrs  
 I = 0.01 M  
 Alk. = 50 ppm  
 As(0) = 150 - 400 ppb  
 Adsorbent = 167 - 5556 ppm

**Table 2. Arsenic adsorption Freundlich isotherm constants.**

Adsorbent	K(F)	1/n
Granular Ferric Hydroxide	1570.4	0.5
activated alumina	1032.5	0.4
zero-valent iron	4915.9	0.2
goethite	88.2	0.8

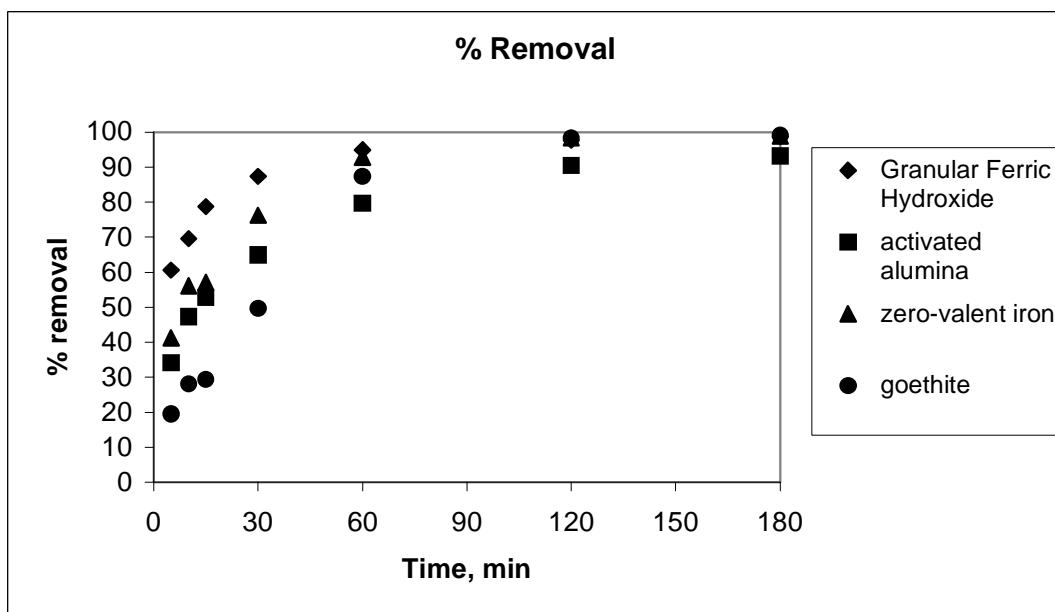
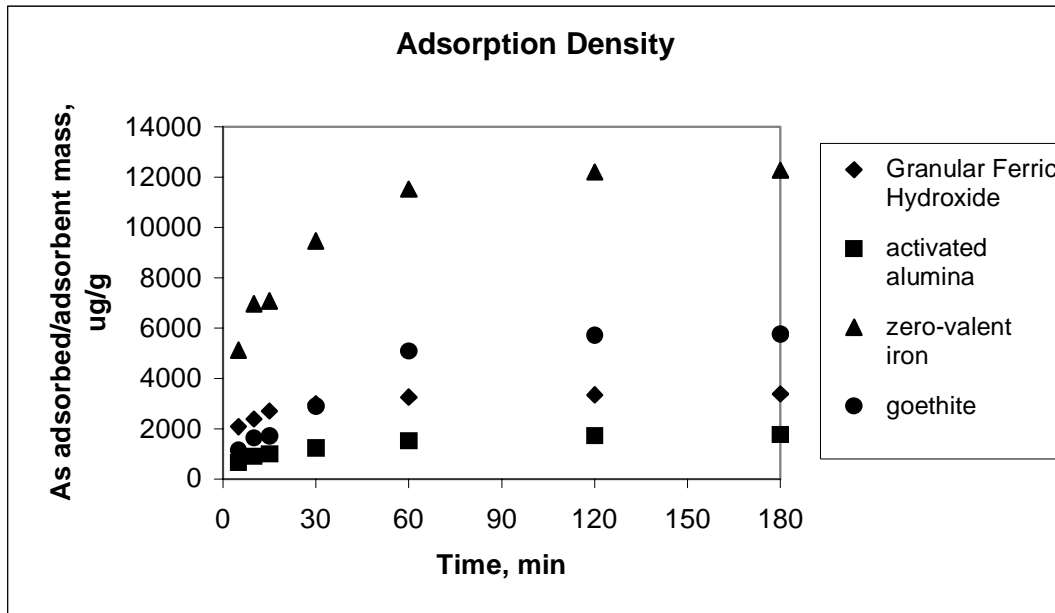
**Experimental conditions:**

T = 21 - 22 C  
 pH = 6  
 t = 2 hrs  
 I = 0.01 M  
 Alk. = 50 ppm  
 As(0) = 1000 - 2000 ppb  
 Adsorbent = 56 - 556 ppm



**Experimental conditions:**

T = 21 - 22 C	I = 0.01 M
pH = 6	Alk. = 50 ppm
t = 3 hrs	As(0) = 400 - 1000 ppb
	Adsorbent = 56 - 167 ppm



**Figure 1:** Comparison of the kinetic curves of selected adsorbents. (a) Mass basis and (b) %removal.