Design and testing of two-step arsenic - remediating

Water filtration system

Joseph Bonavita

Abstract

Arsenic is a natural occurring mineral found in soil, bedrock, and water. It is used to preserve wood, to make glass and also used to make other metals. It has no odor or taste and is very poisonous. It is sometimes found in soil around wells and may contaminate drinking water. A well contaminated with arsenic can potentially poison anyone who drinks its water. Safe arsenic consumption levels are lower than 10 ppb (parts per billion). The purpose of this project was to develop a working, inexpensive water filter using charcoal and a sand/iron mixture to remediate the arsenic levels in water to make the water safe for drinking use. The test water had arsenic levels at 500 ppb. The filter was a two step system that was construed out of PVC: the first step was a sand/iron mixture; the second was charcoal. The filter, in different configurations, was capable of remediating between 90-99% of the arsenic in the test water samples. The filter was effective for multiple uses.

Introduction

Arsenic is a natural occurring mineral which behaves like a metal, but it is actually a Metalloid (US EPA, 2006). It is naturally in the Earth's crust generally found in rock, soil, water and the air. It is highly poisonous and has no smell, color, or taste, making it so much more dangerous to the environment because it makes it impossible to know if it is present. Arsenic can be consumed by drinking water from ground wells, and coming in contact or using products it is used in such as tobacco, laundry detergent, pressure treated wood, and beer. Arsenic in food or water does not evaporate into the air. However, burning arsenic-containing materials such as treated lumber will release arsenic fumes into the air.

Measuring arsenic

Arsenic is measured in ppb (parts per billion), a safe level for consumption of arsenic is 10 ppb. In water, if arsenic levels are above 10 ppb, it should not be ingested. Once arsenic gets to higher levels such as from 50 ppb to 100 ppb it should not be used to bath in, at 500ppb and greater the water is said to not even be used in toilet water (US EPA, 2006). To test for the presents of arsenic a Hach test kit can be used which is a test kit that uses 50mL of sample water, two different reactants, and a vial with a hole on the top where a test strip is placed. Water is placed into a vial, then two reactants are added. The vial is sealed with the test strip on the top. After 20 minutes a color will show up on the test strip and that is compared to the arsenic scale and the levels of arsenic can be determined (Hach, 2000).

Atomic absorption spectroscopy is another way to measure levels of arsenic. Atomic absorption methods measure the amount of energy absorbed by a sample. A detector measures the wavelengths of light transmitted by the sample and compares them to the wavelengths, which originally passed through the sample. A signal processor then integrates the changes in wavelength, which appear in the readout as peaks of energy absorption at discrete wavelengths (Huff, 1998). Arsenic levels from the test samples are compared to a standard curve for analysis purposes.

Arsenic in the environment

CCA decks. Before 2001, pressure treated wood was treated with CCA (cooper chromium arsenic) to make the wood more durable so it would resist degradation from environmental pressures including: water, rotting, termites, and fungus (US EPA, 2008). When rain or acidic compounds permeate pressure-treated wood, the arsenic leaches from the wood and potentially changes into its gas form (US EPA, 2008). Therefore, the soil or rock under any building, playground, or structure built with CCA pressure treated wood could then be potentially contaminated with arsenic. This wood was used extensively to build decks, playgrounds, and other building structures. Potentially compounding the problem would be a drinking water well that CCA-treated wood would runoff.

Impact on livestock. In Maine, California, Texas, and other states there is natural arsenic in the soil that contaminates drinking water (US EPA, 2006). In Texas, livestock such as beef cows drink the contaminated water making the beef contaminated and then not be used for sale or consumption. If eaten, the consumer has a high risk of getting arsenic poisoning the common cold, headaches, stomach pains, confusion, and sleepiness. Then the symptoms develop to pigments on the skin, color changes of the skin, and extremely high risk of cancers.

Wells in India. In India, almost the entire country is affected by arsenic. The river bottoms and soil is contaminated with natural arsenic that ranges from 50 ppb to greater than 500 ppb. The arsenic gets into river bottoms from the soil and sand where it naturally occurs. Subsequently, the contaminated water gets into the underground water wells that are used for drinking water. These wells are called "tube-wells." The wells are long tubes that go hundreds to thousands of meters into the ground to underground deposits of water (Stevenson, n.d.). The water is pulled up by the "tube-wells" and run off into pool-like reservoirs and the people get their drinking water from these reservoirs. These underground water wells are contaminated with arsenic levels averaging to 500 ppb. So the Indian people drink water contaminated with levels of arsenic so high it is said to not even be used as toilet water. With India having populations of 1,139,964,932 in 2008 according to "World Bank, World Development Indicators" (2008), most of these people who are too poor to afford current arsenic filters that are available today that cost anywhere from $500 to well over $5000 are dying daily and getting arsenic poisoning.

Filtration

Current arsenic water filters available today are expensive and are made for "in home use" so if individuals in India had one of these filters that are available today they still would have to take the water they get from the reservoirs and run it through the filter at their home. The "SONO filter" is an in house bucket type of arsenic water filter that uses sand, 20lbs of iron, charcoal, and bricks to filter out arsenic out of India's drinking water (Stevenson, n.d.). The downfall with this filter is it does not remediate arsenic levels lower than 20ppb – 50ppb and it is an in house filter system so the user still has to get the contaminated water from the well and run it through the filter which takes time and more effort that should be used to get drinking water. This filter is also not cheap with prices from $50 to $100 US dollars.

So to make things simpler, cheaper, and safer, a filter that would go into the "tube-well" would be an effective way to accomplish the goal of making the drinking water safe to consume, make it cheaper so it is affordable and also make it simpler. Research was done to find cheap components to put into a filter that would also be effective. Charcoal is one component to the filter that would be cheap and effective. Charcoal briquettes are very cheap and are used in many different types of water filtration systems such as filters for Radon. Charcoal briquettes make a good compensate for a water filtration system because they reduce bacteria levels in water, and do not change the pH level of the water, have a very high absorbance level, and has a long life time so it does not have to be changed that frequently. Iron was another component to the filtration system that would be both effective and cheap. Iron that is found in India river bottoms attracts the arsenic that is found in the river bottoms and soil to it and binds to it by chemisorption. Chemisorption is a type of adsorption characterized by a strong interaction between an adsorbate and a substrate surface. Sand would be another component to the filtration system that would have two purposes. One purpose would be to act as a holder for the iron and its other purpose would be to remediate the levels of the arsenic in the water long with the charcoal and iron.

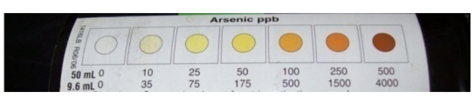
Materials and Methods

Preparation of CCA Treated Wood

100g of CCA pressure treated wood was ground up to prepare an arsenic contaminated water solution. The sawdust was put into a 1000ml filter paper funnel and was passed through 1000mls of distilled water and the water was collected. Then the water was tested for the presence of arsenic using a Hach Arsenic test kit by following the manufacturer's instructions.

Quantification of Arsenic

The Hach Arsenic test kit works by taking the test kits vessel and putting a test strip under the flap so the reactant pad is over the opening on the cap and completely covers it, then securing the flap back in place. 50 mL of the test water was added to the vessel and add one reactant #1 and was swirled to dissolve then one reactant #2 was added and swirled to dissolve. Then after 20 minutes, the test strip results were compared to the arsenic ppb scale.



Filter construction

"Kingsford" charcoal briquettes were broken up into smaller pieces approximately 6cm in length and 150g of broken up charcoal was put into a section of PVC tubing with two sheets of fiberglass screen on each end of the tubing. Sample water was run through the PVC tubing containing the charcoal and fiberglass screens. Then the water was collected in a beaker and was tested using a Hach test kit, to test the water for the presents of arsenic. This was repeated three times with 150g of charcoal then repeated using 300g of charcoal and 450g of charcoal and the data was recorded.

4 g of iron tablets were ground up using a mortar and pestle until the tablets were in a dust form. Then the ground up iron was put into a section of PVC tubing with two sheets of fiberglass screen on the top and five sheets on the bottom. Test water was run through the PVC containing the ground up iron and fiberglass screen and the water was collected in a beaker. The water was then tested using a Hach test kit to test for the presents of arsenic. The procedure was repeated using 8g, 12g, and 16g of iron tablets that were ground up and the data was recorded.

100 g of sand was put into a section of PVC with two sheets of fiberglass on each end of the tubing and sample water was run through the PVC tubing containing the sand and fiberglass screen. The water was then collected in a beaker and was tested using a Hach test kit for the presents of arsenic. The procedure was repeated with 200 g, 300 g, and 400 g of sand and the data was recorded.

12 g of iron tablets was ground up using a mortar and pestle and was added to 300 g of sand then was added to a section of PVC tubing with two sheets of fiberglass screen on the top and five sheets of fiberglass screen on the bottom. A PVC connector was added and connected the PVC tubing to another section of PVC containing 300 g of broken up charcoal that was approximately 6 cm in length with two sheets of fiberglass screen on top and two sheets of fiberglass screen on the bottom. Another PVC connector was added to another section of PVC that had two sheets of cheese cloth on the bottom and two sheets of fiberglass screen under the cheese cloth. Under the PVC tubing was a 2000 mL beaker to collect the water. Sample water was run through the connected sections of PVC tubing and collected in the beaker and was then tested using a Hach test kit for the presents of arsenic. This procedure was repeated 12 more times and the data was recorded.

Results

Table 1. Filtration conditions results. Based on different concentrations of charcoal iron and sand, the data indicates the most effective method for filtration.

Experimental Conditions			Filtration results	
Charcoal	Iron	Sand	Color	ppb
150	0	0	Orange	100
150	0	0	Orange	100
150	0	0	Orange	100
300	0	0	Yellow	50
300	0	0	Yellow	50
300	0	0	Yellow	50
450	0	0	Yellow	50
450	0	0	Yellow	50
450	0	0	Yellow	50
0	4	0	Orange	100
0	4	0	Orange	100
0	4	0	Orange	100
0	8	0	Yellow	50
0	8	0	Yellow	50
0	8	0	Yellow	50
0	12	0	Light Yellow	10
0	12	0	Light Yellow	10
0	12	0	Light Yellow	10
0	16	0	Light Yellow	10
0	16	0	Light Yellow	10
0	16	0	Light Yellow	10
0	0	100	Dark Orange	250
0	0	100	Dark Orange	250
0	0	100	Dark Orange	250
0	0	200	Orange	100
0	0	200	Orange	100
0	0	200	Orange	100
0	0	300	Yellow	50
0	0	300	Yellow	50
0	0	300	Yellow	50
0	0	400	Yellow	50
0	0	400	Yellow	50
0	0	400	Yellow	50
300	12	300	Very Light Yellow	5
300	12	300	Very Light Yellow	5
300	12	300	Very Light Yellow	5

Figure 1. This graph shows the average remediation based on the most effective strategies for filtrations. The most effective and efficient remediation occurred with 300g of charcoal, 12g of iron, and 300g of sand. More iron did not significantly improve remediation.

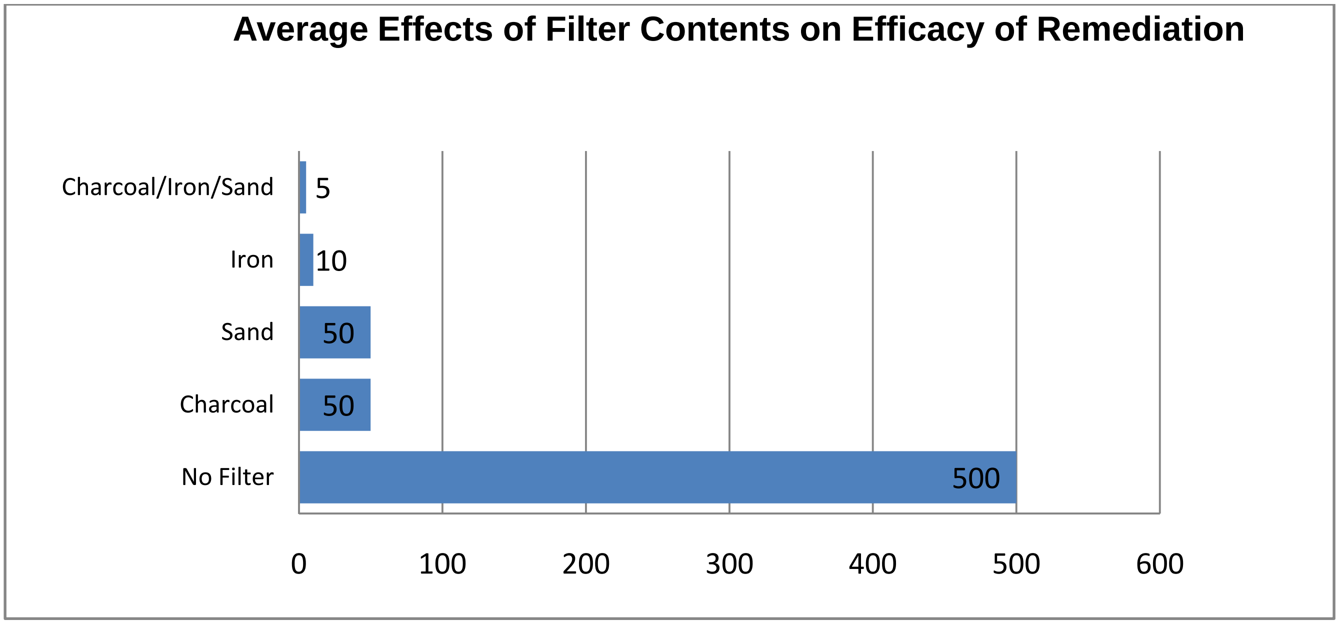
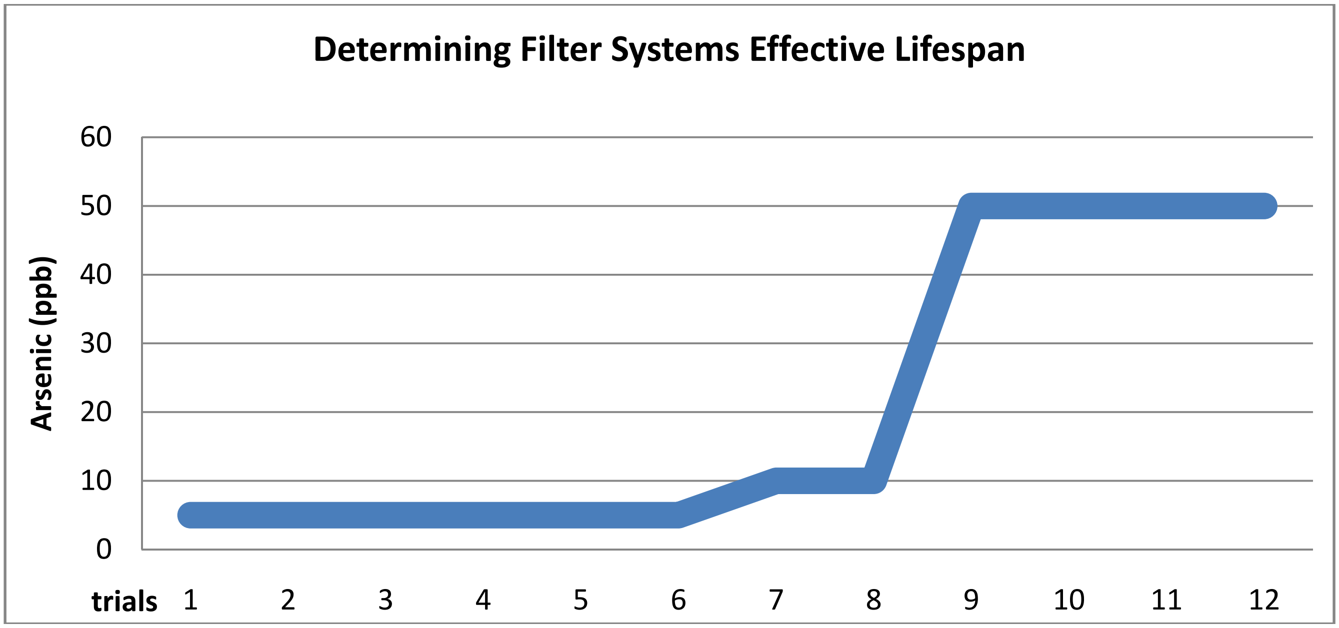


Table 2. Analysis of Variance (ANOVA) Test of Between-Subjects Effects. A one-way ANOVA was calculated to see if there is a significant difference between the original arsenic levels in the water and the treatment averages (Figure 1, above). The ANOVA demonstrates that there is a statistically significant difference ($p<.05$) between groups, indicating that the remediation strategies worked effectively.

Source	Type III Sum of Squares	df	Mean Square	F	Significance	Partial Eta Squared
Remediation	1431153.85	1	1431153.85	2209.95	.001	.99
Error	15542.31	24	647.60			
Corrected Total	1446696.15	25				

Figure 2. Optimal Charcoal, sand, and iron (300g of charcoal, 12g of iron, 300g of sand) were tested to determine at what level they would affect arsenic remediation over multiple uses. Efficacy of the filter began to decline after 6 trials and more markedly declined after 9 trials.



Discussion

These results show that this two-step filtration system was effective in remediating the levels of arsenic in drinking water by 90 to 99%. Charcoal only remediated the levels of arsenic in the contaminated water from 500ppb to 50ppb (90%), sand only remediated the levels to 50ppb (90%), sand and iron only remediated the levels to 10ppb (98%). Using all filtration components together, the filtration system remediated the levels of arsenic from 500ppb to 5ppb (99%). This shows that the filtration system is effective by remediating the levels of arsenic in the water making it a safe level for consumption.

The results also show that the filter has a limited lifetime of 6 uses before the iron's chemisorption takes up to much arsenic and does not remediate them low enough for consumption. This happens because the iron/sand mixture starts to become dry and hardens by the sixth trial and by the eighth trial the mixture becomes hard and dry. If there is a constant flow of water being ran through the filter system this effect might not take place and the lifetime on the filtration system might be much longer. Future testing is warranted to examine this possibility. Another way to prevent the iron/sand mixture from getting hard and drying out would be to develop a type of cover system that would seal the filter system when it is not in use. Future studies are needed to develop and test a cover system that would seal the filter system to prevent the iron/sand mixture from drying up and getting hard; and more resources are needed to test a constant water flow on the filtration system.

The results are important to the arsenic problem in the environment in areas where there are high concentrations of arsenic in the soil, rock and water, like India and some parts of the United States. Since arsenic naturally occurs in the environment, a cheap and effective water filtration system is needed to lower or remove arsenic levels in the water making it safe for it to be used for cooking, drinking, and bathing. If a filtration system is too expensive than it does not matter whether it is effective or not because most people in the areas of where there is a high concentration of arsenic in the drinking water cannot afford it. Therefore a cheap and effective arsenic water filtration system is very important to the problem of high concentrations of arsenic in soil, rock, and water.

These results are novel because they demonstrate that using charcoal briquettes, iron tablets, and sand inside of a PVC tubing with fiberglass screens as materials works effectively. Fiberglass screen was used to hold the components together and also acted as a flow restrictor to slow the flow rate down giving the charcoal, iron, and sand time to allow the arsenic to absorb and filter. Most arsenic filters that are already in use today are expensive and take time to filter out the arsenic from the water, averaging 2 – 15 minutes. This two-step filtration system takes approximately 10 to 20 seconds to filter out the arsenic from the contaminated water. The filtration system is inexpensive, costing approximately 15 dollars.

Conclusion

1. It was concluded that charcoal and an iron/sand mixture is an effective way to remove and reduce arsenic from contaminated water with arsenic levels above 500 ppb.

2. Remediation was improved by using fiberglass screens as flow restrictors to slow down the water flow rate giving the charcoal, and iron/sand mixture to remediate arsenic levels in water.

3. Remediation was optimized at 300g charcoal, 12g iron and 300g sand because using less or more charcoal, iron and sand did not remediate the levels of arsenic anymore effectively than 300g charcoal, 12g of iron and 300g of sand.

4. This filter method decreases arsenic concentration in contaminated water by 90-99%.

Limitations

Because the filter has a limited life, more research is needed to be conducted to try and extend the life of the filter use. Different tests are needed to be done by preventing the sand/iron from drying and/or trying to add a cap system to the filter so it seals it closed so it can not try out.

Future Study

Improving the water flow rate but keeping the levels of arsenic in the water the same or improving the levels.

Making the filter “home-friendly” so it can be put into home water systems.

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