Development of Low-Cost Treatment Options for Arsenic Removal in Water Treatment Facilities

by Kathy Jesperson
NDWC Editor

The arsenic rule is one of the most controversial regulations in the history of the Safe Drinking Water Act. Intended to protect public health, the rule has generated controversy because of its cost to implement rather than its focus on the beneficial effects on health from reduced exposure.

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Arsenic is typically found in groundwater, the source that many small communities rely upon for their drinking water supplies. Until recently, water systems had to comply with a maximum contaminant level (MCL) of 50 ppb. But the U.S. Environmental Protection Agency found that level to be too high to protect people from long-term, chronic exposure to arsenic in drinking water, which can cause serious dermatological conditions such as blackfoot disease* and cancer of the skin, bladder, lung, liver, and kidney, and other ailments. After researching to find what it believed to be a safer arsenic consumption level, the agency set the new MCL at 10 parts per billion (ppb).

Unfortunately, arsenic levels in drinking water from many small water systems continue to exceed this MCL. Problems arise because many of these systems do not have the funds to pay for additional treatment costs. Because of this situation, the Midwest Technology Assistance Center (MTAC) for Small Public Water Systems funded research to help small communities meet the new standard.

A research team at the Illinois State Water Survey and the University of Illinois proposed to develop an inexpensive treatment option for arsenic removal, suitable particularly for small community water systems. By extending and optimizing a reaction that already occurs during iron removal at many drinking water treatment plants, they remarkably improved arsenic removal while increasing chemical costs only slightly and requiring no large capital equipment costs.

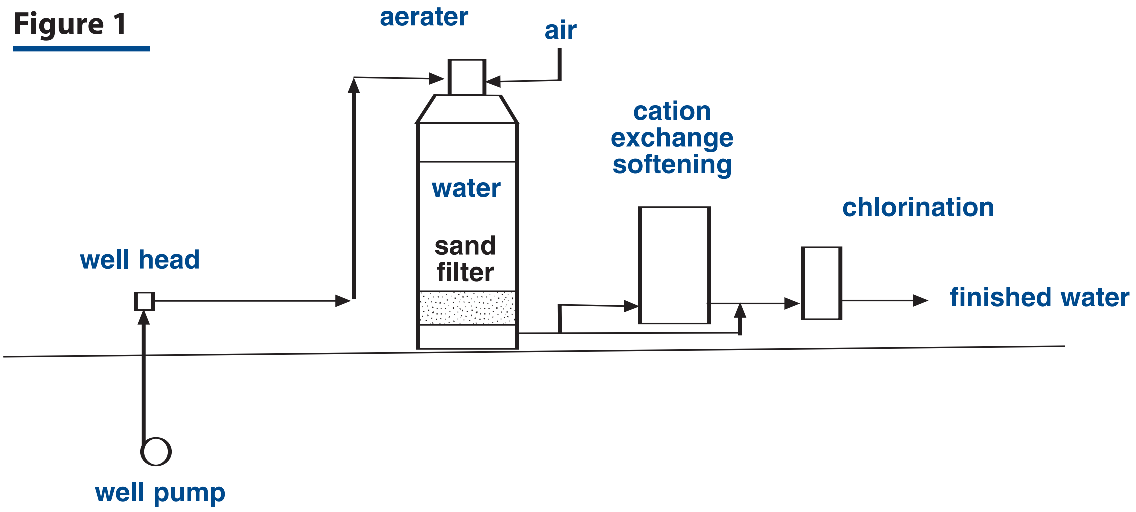
The premise of this project was that 1) the iron already present in the water could be used in conjunction with hydrogen peroxide to produce a strong oxidizing agent to oxidize arsenic to a form that is easier to remove, and 2) that by manipulating the chemistry, the process could be optimized for arsenic removal.

The Fenton reaction, in which hydrogen peroxide and iron combine to form a strong oxidizing agent called hydroxyl radical, was discovered by H.J.H. Fenton in 1894. This reaction, which occurs naturally during aeration treatment of groundwater containing iron, forms hydrogen peroxide as an intermediate. Hydroxyl radical reacts quickly with arsenic (III) changing it to arsenic (V), which is much less toxic and adsorbs more completely to iron as it precipitates during iron removal. When the iron precipitate is removed by filtration, the arsenic is removed with it.

Many water systems already have such treatment procedures in place for iron removal because of aesthetic issues such as taste and laundry staining. Typically, systems that have high concentrations of iron can remove up to 25 percent of total arsenic during standard aeration processes. However, previous research showed that more of the hydroxyl radical is produced using hydrogen peroxide than with aeration alone, which would be helpful in arsenic removal.

Hydrogen peroxide had been tried as a treatment chemical prior to this study, but usually at levels that were too high to be cost effective for a small system.

Figure 1



This experiment showed, however, that the combination of low doses of hydrogen peroxide and iron added to groundwater before it was aerated was capable of oxidizing most of the arsenic (III) in Danvers, Illinois, groundwater and reducing total arsenic from approximately 40 ppb to less than (5) ppb in batch, laboratory flow, and pilot-scale flow experiments (compared to 30 ppb remaining after normal iron removal) in groundwater with a high level of dissolved organic carbon. The estimated chemical costs for this treatment totaled about seven cents per one thousand gallons of treated water.

What they found in this study was that not only was the iron/arsenic ratio critical to arsenic removal, but the hydrogen peroxide concentration was as well. In addition, the researchers found that supplementing the iron already in the water increased the adsorption of arsenic to iron. They also found that arsenic removal is more efficient when hydrogen peroxide is added to the anoxic groundwater. The researchers wanted to be careful not to expose the water to oxygen because oxygen could use up the dissolved iron before it could react with hydrogen peroxide.

The researchers set up a pilot plant that simulated the treatment plant at Danvers, Illinois, to use as an example because this municipal system was already set up to remove iron, and they used water that was expected to be a difficult challenge to treat. Danvers is a small community of about 1,100 people in central Illinois, near Bloomington, that draws its raw water from the Mahomet Aquifer.

The Danvers plant treatment train consists of an aeration/sand filtration unit, cation exchange softening, and chlorination. (See figure 1.) During pilot experiments the researchers connected their pilot plant directly to a sample tap at the wellhead, allowing them to add various doses of hydrogen peroxide and iron to this sidestream of raw water in parallel with the actual water treatment system. The connection consisted of a check valve and a gas-liquid separator that physically divided it from the water in the supply pipe.

In their pilot plant, the researchers added iron and hydrogen peroxide dosing solutions while the water was still anoxic. (See figure 2.) Next, the water was pushed through a static mixer and through a plug flow reactor to give the iron and peroxide time to react. The plug flow reactor provided a 1.5-minute reaction time for the peroxide. Preliminary laboratory experiments had indicated that the complete reaction between hydrogen peroxide and iron required less than 22 seconds.

Following the plug flow reactor, iron was added before the water was introduced into the bottom of the aeration basin, where it would be completely aerated before flowing to a bed of sand for filtration. The space above the sand served as a flocculation basin, with a detention time of approximately 30 minutes. The finished water was collected in a large basin, which was used for backwashing the sand filter between experiments.

For More Information

Development of Low-Cost Treatment Options for Arsenic Removal in Water Treatment Facilities by Gary R. Peyton, Thomas R. Holm, and John Shim, June 2005, was funded by the Midwest Technology Assistance Center at the Illinois State Water Survey on the campus of the University of Illinois. Copies of the final report are available by calling (217) 333-9321.

MTAC provides technical assistance to small public water systems as well as water systems serving Native American communities. Their mission is to provide small system administrators and operators with the information necessary to make informed decisions about planning, financing, and selecting and implementing technological solutions to address needs.

*Blackfoot disease is a severe form of peripheral vascular disease in which the blood vessels in the lower limbs are severely damaged, eventually resulting in progressive gangrene.

Figure 2