

Chemical Oxidation for Arsenic Removal from Drinking Water

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When the Arsenic Rule was promulgated in 2002, some water utilities were faced with the task of either improving arsenic (As) removal or developing new sources of water to meet the new maximum contaminant level (MCL) of 10 $\mu\text{g/L}$. Arsenic speciation (the chemical form of arsenic in water) and the iron (Fe) concentration are significant factors in As removal. The goal of this research was to characterize the effects of these factors on As removal in facilities that currently exceed the MCL.

Background

Groundwater with a high As concentration usually has a moderately high Fe concentration. Fe removal involves oxidizing soluble ferrous iron (Fe^{2+}) to insoluble hydrous ferric oxide (HFO) and removing the HFO by filtration. Arsenic adsorbs to HFO and, as a result, some As is removed in Fe-removal plants. Aeration is the most common Fe oxidation process, but sodium hypochlorite (NaOCl) and potassium permanganate (KMnO_4) are also used as oxidants in some treatment plants. The Fe:As ratio is expected to be an important factor in As adsorption and, as a result, in As removal.

Arsenic occurs in two chemical forms in natural water, As(III) and As(V). The predominant form in Midwest glacial aquifers is As(III). Arsenic(V) is more readily removed from water by coagulation with ferric chloride (FeCl_3), so oxidation of As(III) in groundwater may improve As removal in Fe-removal plants. Aeration is ineffective at oxidizing As(III), but NaOCl and KMnO_4 readily oxidize both Fe^{2+} and As(III).

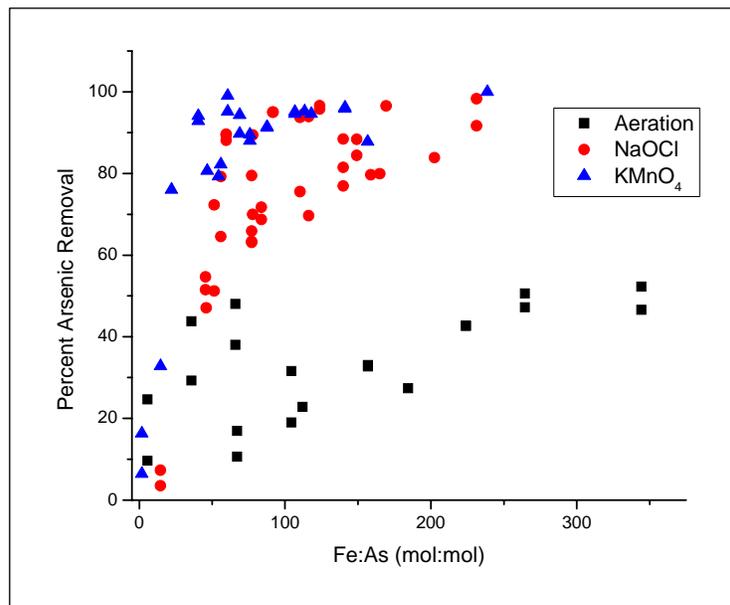
Methods

Groundwater was collected from municipal wells in Kenney, Grand Ridge, and Waterman, IL. The oxidant (NaOCl or KMnO_4) was added immediately after sample collection. The oxidant dose was based on the Fe concentration. In some cases FeCl_3 was also added. After a reaction time of 10 minutes (typical residence time in an aeration plant) the treated water was pumped through a sand filter. The filter loading rate (4 gallons per square foot per minute) was typical of full-scale sand filters. Water samples for laboratory experiments were collected without headspace to avoid air oxidation. The laboratory experiments included aeration (to serve as a basis for comparison) as well as NaOCl and KMnO_4 addition. Anion exchange was used to separate As(III) in the laboratory experiments. Samples were analyzed for As by graphite furnace atomic absorption spectrometry.

Results

Arsenic removal was affected by both the Fe:As ratio and the oxidation process. Aeration gave the poorest As removal for a given Fe:As value and also had the least As(III) oxidation. Addition of KMnO_4 generally gave the best As removal. The extent of As removal was better than 80% for Fe:As values greater than 50. As(III) was completely oxidized by all KMnO_4 doses.

For the highest NaOCl doses, As(III) oxidation was complete and As removal was comparable to that of KMnO_4 addition. For lower doses, As(III) oxidation was incomplete and As removal was intermediate between aeration and KMnO_4 addition. The likely reason for incomplete oxidation was formation of monochloramine in competition with As(III) and Fe^{2+} oxidation.



Recommendations

Arsenic removal at aeration plants may be improved by prechlorination (NaOCl addition before aeration) or KMnO_4 addition. If the source water has a low Fe concentration or high As concentration, addition of FeCl_3 may also be necessary to give a molar Fe:As ratio of at least 50 (weight ratio of at least 67). The KMnO_4 dose should be equivalent to the Fe concentration (roughly 0.9 mg KMnO_4 /mg Fe). The NaOCl dose should be at least equivalent to the Fe concentration (roughly 0.7 mg as Cl_2 /mg Fe). However, if the source water contains ammonium, then the NaOCl dose should be equivalent to at least 35% of $\text{NH}_3\text{-N} + \text{Fe}$.