Arsenic in Drinking Water

Paul Westerhoff
Department of Civil and Environmental Engineering, Arizona State University

Arsenic in water occurs naturally due to rock/mineral weathering, but arsenic is also used in some pesticides and manufacturing processes. Folklore and documented history includes numerous accounts where arsenic laced food or water has been used to murder people, but the focus here is on lower arsenic levels present in drinking water where the National Research Council concluded that long-term exposure to arsenic in drinking water could be linked to cancer of the bladder, lungs, skin, kidney, liver, and prostate (Pontius, Brown et al. 1994; NRC 1999; NRC 2002). Arsenic in drinking water is a world-wide problem which has arisen to the forefront of human health and regulatory concern over the past decade. The removal of arsenic from drinking water and disposal of arsenic-laden residuals is a significant challenge for developing and developed countries alike.

Public and governmental concerns over arsenic have emerged due to new health effects studies and widescale human illness associated with prolonged exposure to low concentrations of arsenic in drinking water. One of the most traumatic examples comes from the southern Indian continent and the country of Bangladesh. Because of serious health concerns regarding pathogenic microorganisms, that cause serious intestine illness and death, associated with the use of river and lake waters as drinking water sources, the public was encouraged to use more groundwater because such particulate micro-organisms are "filtered" out by the soils. However, the geologic history of this region has resulted in deposits of arsenic-rich soils which slowly dissolve and leach into the groundwater drinking water supply. Over the past few decades millions of people in Bangladesh consumed groundwater with elevated arsenic levels (100 to >500 parts per billion, µg/L). While use of the groundwater decreased the number of microbial-related acute health issues, it has resulted in increased numbers of serious cancer-related health issues associated with chronic (long-term) exposure to arsenic in drinking water. Since 1975, the USEPA maximum contaminant level (MCL) for arsenic in drinking water has been 50 µg/L (ppb). However, new USEPA regulations effective on February 22, 2002 reduces the MCL to 10 µg/L by the year 2006. The states of California and New Jersey may set a standard of less than 10 µg/L. Japan, European Union, World Health Organization also have standards of 10 µg/L. Only Australia has a lower standard (7 µg/L).

The new arsenic regulations and observed health issues in developing countries will have the most dramatic impact on groundwater systems because these commonly have minimal treatment systems, and generally have higher arsenic concentrations than surface waters. To help solve this massive public health problem in developing countries, many agencies including EU, UNICEF, and NAE have made significant contributions to understanding and beginning to solve this problem. The National Academy of Engineering is offering the Grainger Challenge Prize for Sustainability, $1 million to the individual or individuals who design(s) and create(s) a workable, sustainable, economical, point-of-use water treatment system for arsenic-contaminated groundwater in Bangladesh, India, Nepal, and other developing countries (http://www.nae.edu/nae/grainger.nsf?opendatabase). The cost of technologies to remove arsenic are high and will be a burden for both developing and developed countries.

Arsenic can be removed by many different drinking water technologies. For example, arsenic adsorbs onto metal (hydr)oxides formed during coagulation or can be removed by adsorptive packed-beds, ion exchange resins, and membrane separation systems. However, in each case arsenic is concentrated in either solid or liquid wastes which must be safely handled and disposed. Packed bed adsorption systems are usually cost-effective, have minimal waste streams, and are relatively simple to operate. Therefore, packed bed treatment systems are well suited for smaller groundwater-based utilities requiring arsenic treatment to meet the arsenic problems.

Packed-bed treatment systems will be a focus of this presentation. They consist of an adsorbent media placed in a vessel. As water flows through the vessel, arsenic must diffuse from solution onto the surface of the adsorbent media. Mass transfer limitations for this diffusion are impacted by temperature, flowrates, and media properties (pore sizes, surface area). Adsorption of arsenic onto the surface of the adsorbent media is impacted by the surface chemistry of the media and water chemistry (pH, redox conditions, etc.). Arsenic speciation between an oxidized form (arsenate) and an electrochemically reduced form (arsenite) is affected by the local biogeochemistry of the groundwater, which is highly site-specific. Arsenite usually is more difficult to remove because it is non-ionic whereas arsenate is anionic in water and has an electrostatic affinity for positively charged metal (hydr)oxide surface adsorption sites. The presence of other elements (e.g., silica, phosphate, iron, vanadium), organics, and co-contaminants (e.g., nitrate, uranium) in water along with arsenic complicate the ability to remove arsenic from drinking water in a cost-effective processes. There is a fundamental need to better understand how to overcome mass transport and surface chemistry limitations and develop new adsorbent technologies to remove arsenic and other contaminants from drinking waters.

Regardless of the treatment process employed to remove arsenic from drinking water, wastestreams become concentrated with arsenic. For adsorbent materials, arsenic binds onto solids which must usually be disposed of to landfills. Membrane treatment systems usually recover 85% to 95% of the water as product drinking water, but concentrate arsenic and other pollutants in the remaining 5% to 15% which must be treated and/or disposed. Significant concern now exists as many more arsenic treatment systems are implemented, what will be the impact of handling these additional arsenic containing wastestreams. Fortunately perhaps, in the USA it is estimated that this new arsenic laden wastestream will account for < 5% of the arsenic by mass when compared to existing commercial uses of arsenic (pesticides or manufacturing processes).

Arsenic is a world-wide problem that requires an engineering solution to protect human health. For developed countries existing technologies need to be engineered more effectively to address multiple contaminant issues in a cost-effective approach. For developing countries the challenge is not which technology to use, since many proven treatment processes already exist, but how to develop a *very* inexpensive and socially acceptable arsenic treatment strategy. Other challenges include the need for accurate, inexpensive arsenic measurement devices. The long-term question is how to remove arsenic and other contaminants from drinking water supplies and produce inert residuals that pose no adverse environmental impact.

Keywords:

Rapid Small Scale Column Tests (RSSCT): laboratory continuous flow column tests with arsenic containing water and packed-bed adsorbent media that are designed to simulate the mass transport and surface chemistry observed in full-scale packed bed arsenic treatment systems.

Packed Bed treatment systems: vessels containing ~ 1 meter of adsorbent media through which water is pumped under pressure. The empty bed contact time (EBCT) of a packed bed treatment system is calculate by dividing the volume of the packed bed by the flowrate of

water through the system. Arsenic diffuses from the water, across a stagnant film on the outside of the adsorbent media, and then continues to diffuse into the adsorbent media where it finally adsorbs onto the surface.

Homogeneous surface diffusion model (HSDM): A transport model that accounts for both surface or pore diffusion of arsenic within the adsorbent media plus the "driving force" that creates a gradient in adsorbed arsenic concentration within the adsorbent media. The HSDM is used to model arsenic removal from water passing through a packed bed treatment system.

Maximum contaminant level (MCL): a regulatory limit established by the US Environmental Protection agency (USEPA) for pollutants in water. The MCL for arsenic is 0.010 mg/L.