Strontium in Water: Critical Review of its Treatment Options and Considerations for its Removal [Project #4604]

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The objective of this project is to research and document available information on viable treatment options for the removal of naturally occurring strontium from water.

BACKGROUND

Strontium (Sr) is a naturally occurring element in the earth’s crust. It is classified as an alkaline earth metal, along with calcium (Ca), barium (Ba), magnesium (Mg), and radium (Ra). In 2014, the U.S. Environmental Protection Agency (EPA) announced a preliminary determination to regulate Sr in drinking water. This action followed a revision of the Health Reference Level (HRL) for Sr in drinking water from 4.2 mg/L to 1.5 mg/L.

This report includes two main components: The first is an analysis of the available data on Sr occurrence in drinking water supplies, followed by an analysis of the available literature on viable Sr treatment technologies.

STRONTIUM OCCURRENCE

Two Sr occurrence databases were analyzed: the first is the UCMR3 database, which included treated water samples collected by municipal water agencies across the United States in 2013 and 2014. It included 38,673 samples covering 3,542 surface water and groundwater sources. The second is an online database posted by the Indiana Department of Natural Resources (DNR). It includes the results of 1,839 samples collected from 866 groundwater sources. The advantage of the Indiana database is that it includes raw water sources instead of treated water sources, and more importantly, included the calcium (Ca) levels in the samples collected. The occurrence data analysis suggests the following:

1. Based on the UCMR3 data, approximately 2.7% of water systems across the United States would require additional treatment to remove Sr to meet the new HRL.
2. The Indiana database did not show any correlation between Sr and Ca levels in the State’s groundwater.
3. Based on chemical saturation analysis, the Indiana database suggests that Sr removal achieved by precipitating SrCO$_3$ will be accompanied by CaCO$_3$ precipitation in more than 99% of the State’s groundwater.

STRONTIUM CHEMISTRY

Analysis of the chemistry of Sr in water was conducted to identify conditions that help with its removal and is presented in Chapter 3. The analysis focused primarily on Sr precipitation as Strontianite, SrCO$_3$, or Celestite, SrSO$_4$, and compared it to the precipitation of CaCO$_3$ and CaSO$_4$. The analysis showed that, while SrSO$_4$ is insoluble, the amount of sulfate required to cause its precipitation is unrealistically high. On the other hand, precipitation of SrCO$_3$ is attainable under the same conditions commonly used to precipitate CaCO$_3$ (e.g., lime softening processes). However, the analysis also showed that utilizing precipitation chemistry for targeted removal of Sr from water without removing other constituents (primarily Ba and Ca) is not technically feasible.

STRONTIUM REMOVAL FROM WATER

A review of technologies capable of removing Sr from water was conducted and is presented in Chapter 4. The technologies reviewed included:

- Membrane Separation
- Precipitation
- Ion-Exchange/Adsorption
  - Organic Resins/Adsorbents
  - Inorganic Resins/Adsorbents

Separation using nanofiltration (NF) or reverse osmosis (RO) membranes is a proven technology for removing ions from water. Since Sr in water is a divalent ion, its removal with NF or RO membranes is expected to exceed 90 to 95% under most conditions. The challenge with implementing an NF or RO membrane process, aside from its high cost, is the generation of a high-volume concentrate stream, which requires proper handling and disposal. Even if the concentrate stream can be discharged to a sewer, its quality may be problematic to the receiving wastewater treatment plant, due to its high total dissolved solids (TDS) concentration.

Sr can be removed from water by precipitating it as SrCO$_3$. This is already achieved in virtually all lime-softening plants, which are designed to precipitate CaCO$_3$. Lime (or caustic soda) is added to raise the pH of the water, which converts bicarbonate, HCO$_3^-$, to carbonate, CO$_3^{2-}$, and then causes the precipitation of CaCO$_3$. Conventional softening processes are typically optimized for either Ca or Mg removal since the reason for implementing it is hardness reduction. It is unclear at this time if and how a conventional softening process could be modified to maximize Sr removal and minimize Ca removal, if not eliminate it. The biggest challenge with a softening process is the generation of large volumes of solids, mainly CaCO$_3$, that require on-site treatment and drying, followed by off-site disposal.

Conventional ion-exchange resins, both anionic exchange (AIX) and cationic exchange (CIX), are used to remove ions from water. These resins are synthesized from organic chemicals,
and are available from multiple suppliers. CIX resins remove positive ions from water, including Sr. In fact, Sr removal is slightly favored over that of Ca and Mg. Still, partial removal of Ca is inevitable with a CIX process operated for Sr removal.

The challenge with the application of CIX is the generation of a liquid waste brine that requires handling and off-site disposal. The quality of the brine, and thus its disposal limitations, will depend on the type and concentrations of the water constituents that will adsorb onto the resin and concentrate in the brine.

A significant volume of literature has been published on the development and application of inorganic adsorbents/resins for Sr removal. However, the focus has been predominantly on removal of radioactive $^{90}$Sr from nuclear power plant waste or from groundwaters contaminated with radioactive waste. The interest in inorganic resins is driven by the fact that organic resins disintegrate in a radioactive environment. Various types of inorganic adsorbents were evaluated, including titanates, silicotitanates, ferric-oxide based adsorbents, phosphate-based adsorbents, and zeolites, with the interest of identifying adsorbents that have a high affinity for Sr. Unfortunately, much of the work was conducted on nuclear waste products containing chemical constituents at levels that far exceed those found in natural groundwater or surface water sources. It is unclear whether these technologies would perform significantly better when treating typical natural waters. This can be determined with targeted bench-scale or pilot-scale testing focused on the most promising adsorbents.

CONCLUSIONS AND RESEARCH NEEDS

This study resulted in the following conclusions:

1. Chemical precipitation and conventional CIX remain the likely top candidates for Sr removal from drinking water.
2. Conventional regenerable organic CIX resins are less costly than synthetic inorganic resins/adsorbents, and have much higher capacities for Sr removal.
3. Natural zeolites are likely to be less costly than organic resins on a unit weight basis, but have much lower capacity for Sr, such that the overall replacement cost will likely be much higher than that of organic resins.

With a focus on chemical precipitation and ion-exchange as the two most viable treatment technologies for Sr removal, there is a need to optimize their design and operation. The following are potential areas of technical improvement for future research:

1. Evaluate and identify chemical precipitation conditions that could maximize Sr removal and minimize Ca removal.
2. Identify commercially available CIX resins that have high(er) capacities for Sr over Ca.
3. Evaluate CIX resin regeneration conditions that minimize waste brine production when operated for Sr removal.

RESEARCH PARTNER

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