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Jasur Abdukhalilovich Djalilov

"Tashkent Institute of Irrigation and Agricultural Mechanization Engineers" National Research University,
jasur.djalilov@inbox.ru

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SOFTENING OF DRINKING WATER IN A DEVICE BASED ON HIGH-FREQUENCY DIODES

Djalilov Jasur Abdukhalilovich

Assistant

“Tashkent Institute of Irrigation and Agricultural Mechanization Engineers”

National Research University

E-mail address: jasur.djalilov@inbox.ru

Abstract: Hard water typically has a hardness concentration over 120 mg/L CaCO₃. Hardness is not a regulated drinking water parameter and does not have severe health effects. However, hard water causes more soap and detergent consumption and can cause scaling problems on household heating appliances, distribution pipes, and industrial cooling equipment. There are various approaches to soften hard water or prevent scale formation at the centralized and the household scale. In order to choose the best treatment for a specific set of conditions, an appropriate technology evaluation is necessary. Prior research have tested single technology or compared two or three technologies with respect to their performance. Not many papers have compared all available technologies using the same assessment criteria. At the household scale, point-of-entry (POE) devices are commonly used. Among these, ion exchange is the most widely applied POE device in Canada, though it has two major disadvantages: high sodium concentration in softened water and high chloride content in the brine which is often discharged into the sewer. Hence, there is an increasing interest in adopting salt-free treatment technology. Template assisted crystallization (TAC) is a relatively new household scale prevention technology. TAC media transforms free calcium (Ca²⁺) and magnesium (Mg²⁺) ions into insoluble microcrystals. TAC technology has the potential to be an alternative to ion exchange, but there is very little published journals about this technology.

Key words: Hard water, has a hardness ≤ 120 mg/L CaCO_3 , point-of-entry (POE), template assisted crystallization (TAC), prevention technology, TAC media transforms free calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions into insoluble microcrystals, TAC technology.

INTRODUCTION

Hardness in drinking water is defined as the total concentrations of dissolved metallic polyvalent cations. Primarily, hardness is the sum of calcium and magnesium ions. Other ions can also contribute to water hardness such as iron, manganese, strontium, aluminum, and zinc (World Health Organization, 2010). Hardness is expressed as equivalent calcium carbonate concentrations. There are two types of hardness: carbonate hardness refers to the concentration of polyvalent ions that contribute to alkalinity such as carbonate and bicarbonate (Crittenden et al., 2012). In addition, non-carbonate hardness represents the concentration of polyvalent ions associated with non-alkalinity anions such as sulphate and chloride (Crittenden et al., 2012). In water treatment studies, total water hardness is the sum of carbonate and non-carbonate hardness. [1]

There are four drinking water hardness levels characterized: soft water has a concentration level from 0 to 60 mg/L CaCO_3 ; medium soft water has a concentration level from 60 mg/L to 120 mg/L CaCO_3 ; hard water has a concentration level from 120 mg/L to 180 mg/L CaCO_3 ; very hard water has a concentration level of over 180 mg/L (Environmental Canada, 1977).

Surface water, such as lakes and rivers, as well as groundwater, are two major sources of drinking water. In Ontario, the average drinking water hardness supplied by surface water sources is 95 mg/L with the range from 3.7 mg/L to 296 mg/L (Health Canada, 2009). The average drinking water hardness supplied by groundwater sources is 294 mg/L, with the range from 40 mg/L to 1300 mg/L (Health Canada, 2009). [2]

The primary natural source of water hardness is soil and sedimentary rocks that contain calcium and magnesium components. The inorganic chemical industry and mining industry are the two main industrial sources of water hardness (Biesecker & George, 1966). Groundwater generally has a higher hardness level compared to surface water.

Hard water causes problems such as scale deposition in plumbing pipes and heat-transfer appliances, costly breakdown of industry boilers and cooling towers, high consumption of detergents, high consumption of sequestering agents used in cooling water (Greenleaf et al., 2006), membrane fouling (Greenleaf et al., 2006) as well as problems of deterioration of fabrics (Crittenden et al., 2012). [3]

Softening processes which remove calcium, magnesium, as well as other dissolved hardness minerals, are indispensable to domestic and industrial water supply and are also crucial as a pretreatment of brackish water and seawater desalination (Fang & Wang, 2014). Regarding the drinking water softening processes application, in this chapter, softening technologies will be classified into two categories: centralized softening and household softening.

The objective of this chapter is to review and compare different softening technologies on a centralized scale and household scale.[4]

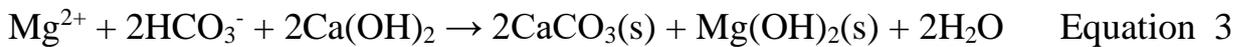
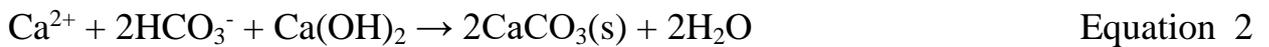
Centralized softening technologies.

Centralized water softening approaches treat hard water in a “central” location, which is generally a part of the drinking water treatment plant, then softened water is distributed to the community via pipelines and channels. In this section, four centralized water softening technologies are discussed: lime softening, pellet softening, nanofiltration, and ion exchange.

Lime softening.

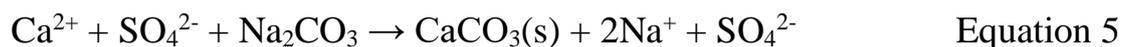
Lime softening is the earliest applied drinking water softening method, which is also a chemical softening method. General treatment procedure includes: raise pH to 11 for Mg precipitation; recarbonate to pH=10 for Ca precipitation; finally, adjust pH to about 8 for distribution.

For calcium carbonate hardness removal, lime is the commonly used chemical. Reaction equations are listed below:

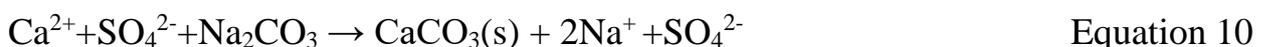
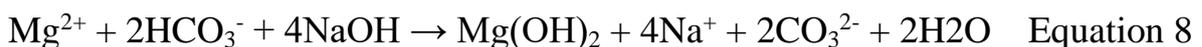
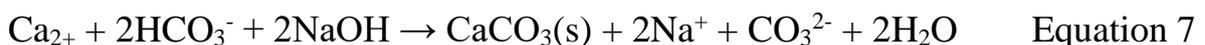


When lime (Ca(OH)_2) is added to water, it reacts with CO_2 first and forms the calcium carbonate (CaCO_3) precipitate (Equation 1). This step does not remove hardness (from water). The second stage is the conversion of bicarbonate species to carbonate species (Equation 2), which requires a pH around 9.3 (Crittenden et al., 2012). For magnesium hardness removal, a pH of at least 10.5 is required for an effective Mg(OH)_2 precipitation according to practical experience (Equation 3) (Crittenden et al., 2012). Equation 4 represents that non-carbonate hardness is also removed in this process. [5,6]

Lime-soda softening is an alternative to use lime exclusively during the softening process. Soda ash (Na_2CO_3) is added when the source water does not have enough carbonate alkalinity (HCO_3^-) to react with lime. This method can remove both carbonate and noncarbonate hardness (Crittenden et al., 2012).



Caustic Soda softening is another alternative to lime softening. Caustic soda (NaOH) is added when the source water does not have enough carbonate hardness to react with lime.



Recarbonation is a common final step for all kinds of lime softening approaches. The main purpose of this step is to adjust the pH of the finished water

and to prevent the precipitation of carbon scale on the filter sand or piping of the distribution system (Wang et al., 2005). Carbon dioxide addition also converts carbonate to bicarbonate ions to stabilize the finished water. [7]

Conventional lime softening process can reduce the water hardness level. Therefore, it can decrease the scale forming tendency and reduce the consumption of cleaning agents. The efficiency of lime softening in water hardness removal is relatively high, and the softened water has the residue hardness level around 40 mg/L CaCO_3 (Wang et al., 2005). Lime softening also aids to remove radium 226/228, arsenic, uranium, and heavy metals (McNeill & Edwards, 1997; Clifford, 1990; Sorg, 1990). Also, lime softening removes some organics and reduces the total organic carbon level. Fulvic acid, humic acid, organophosphate, phosphonate can be effectively removed by lime softening as well (Liao & Randtke, 1986). In addition, lime softening process assists in iron, manganese, and some heavy metals removal as well (Crittenden et al., 2012). Besides, some carboxylic acids and phenols can be removed by absorbing onto CaCO_3 precipitate (Liao & Randtke, 1986). Chemicals used in lime softening are relatively easy to purchase and safe to use. [8,9]

With the high efficiency, lime softening is a popular centralized softening technology used in the United States and other countries. However, there are disadvantages and concerns associated with lime softening. First of all, it produces a large quantity of wet sludge which has a very high concentration of CaCO_3 and $\text{Mg}(\text{OH})_2$ mixture, and usually with a relatively high pH. A large city in Iowa state, which relies mainly on lime softening to treat hard water produces about 32,000 tons (dry weight) of lime sludge annually (Jones, 2011). Wet sludge is difficult and costly to dispose. The lime sludge is generally disposed into a municipal solid waste landfill or use lagoons to store the wet sludge from the water plant. However, the transportation, dewatering processes, landfill leachate control is expensive. The sludge disposal cost for a city can be as high as US \$600,000 per year (Jones, 2011). Sludge might also contain colloidal coagulation residues as

well as some unreacted lime (American Water Works Association, 1981). Wet sludge can be stored and dewatered in lagoons, can be treated via gravity thickening or sludge palletization, and can go through landfill (American Water Works Association, 1981). In order to make the sludge residual treatment more cost-effective, possible usage of dry sludge is worthwhile to be considered. Lime sludge can potentially be used to apply in agriculture, to control SO_x generated in power plant, to neutralize wastewater and also can be used as road construction materials (Jones, 2011; Shannon et al., 1997; Watt & Angelbeck, 1977). [10,11]

Another disadvantage is that the pH adjustment process as a post-treatment is needed for softened water because of the high pH after being treated by the softening process. As discussed previously, this step is to add CO₂ to stabilize the finished water and prevent further precipitation in the distribution system.

The third drawback is that the lime softening process requires extensive land use (Bergman, 1995), and its initial installation cost is relatively high as well. The construction of lime softening treatment needs a separate land space for lagoon, which is used to store wet sludge generated. Because of the continuously high demand of chemical input as well as the further sludge treatment, the maintenance cost is relatively high as well. [12,13,14,15]

The last concern is that when soda is added in lime soda or caustic soda softening as presented in Equations 5-10, it might increase sodium levels in the finished water as well.

Generally, lime softening is a well-developed centralized technology and is commonly applied currently. The knowledge gap is not significant for this treatment approach; the next step would be the optimization of sludge treatment and cost reduction.

Recommendations for future work are as follows:

- Future research work could perform scale test according to DVGW W512 standard test using a flow through system. This is to provide more supportive

information for TAC technology by testing different source waters, in addition to Fox et al. (2014) report.

- Water samples collected for this study were taken right after the TAC unit. According to the theory, the microcrystals formed were supposed to serve as nucleation surfaces for further CaCO_3 precipitation as the water flows through pipes. Therefore, future studies could design a setup to test the unit performance after the water has been transported a certain distance i.e. had a certain contact time after TAC treatment in a flow-through system.

- Although the contact time of the media of only five seconds is supposed to be sufficient for crystal formation, the flow rate could be controlled in future work to test if longer contact times such as several minutes would improve performance.

- Future studies could also do some media analysis, to ascertain differences in media surfaces in brand new media and exhausted media.

- Further development of the simplified scale test would be appropriate because it gave different results than the standard DVGW W512 test which is designed for a flowthrough system.

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