Well Water

Ion Exchange to Remove High Nitrate Levels in Drinking Water Supplies

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Summary: Nitrates are a recurring problem for water treatment dealers, particularly those that specialize in we II water applications. An understanding of ion exchange selectivity can help tremendously in diagnosing a solution. The issue is revisited here.

The dangers of high nitrate levels in drinking water are only now being fully realized. Nitrates have been linked to several adverse health effects, including blue baby syndrome, miscarriage and cancer. Several government agencies are aware of the dangers of high nitrate levels. Ni tra tes are usually in trod uced into water supplies through commercial fertilizers, animal waste, leaching from septic tanks and sewage. This means that high levels of nitrates are most commonly found in rural areas, particularly in well waters, which may be unregulated. Residents of these households should become educated aboutthe dangers of high-nitrate drinking water and put systems in place that will successfully rid their drinking water of nitrates.

Harmful effects

For several decades, nitrates have been linked to a serious and sometimes fatal condition known as methenoglobinemia or "blue baby syndrome." Upon an infant's ingestion of nitrate-contaminated water, the bacteria of the digestive system converts the nitrate into nitrite. The nitrite reacts with hemoglobin to form methemoglobin, which cannot transport oxygen through the body. As a result, developing organs in an infant's body are deprived of needed oxygen. The infant can suffer from diarrhea, lethargy, coma and even death.

In addition, the *Indianapolis Star/ News* reported a link between high-nitrate well water and miscarriages.[1] Between 1991 and 1994, four Indiana women living in the same geographical area miscarried in their eighth week of pregnancy, some of them experiencing multiple miscarriages. Three of these women lived within a mile of a hog farm, and the fourth had a septic tank on her property that was leaching into her well water. Analysis of their residential wells showed high levels of nitrate contamination. Once the polluted drinking water source changed, they delivered healthy children.

Nitrates also can lead to the formation of carcinogenic nitrosamines. In fact, the U.S. Environmental Protection Agency (USEPA) has found enough associative evidence between nitrates and human cancer to recommend that nitrate be listed as a Group A oncogen.

Acceptable detection levels

Standards for potable water are governed by the Safe Drinking Water Act (SDWA), which was revised in 1996. In this act, the USEPA established maximum level of nitrates for drinking water as 10 mg/L as nitrogen. However, the SDWA applies only to public water systems and systems that have at least 15 service connections or regularly serve at least 25 individuals. In 1998, $725 million was allocated under the Safe Drinking Water Revolving Load Fund to help communities upgrade deteriorating drinking water systems and provide safer drinking water.[2] However, this funding would not provide any assistance for those using residential wells.

Most home water conditioning equipment companies do not test for nitrates when evaluating a water source for treatment options. Detection of nitrates in the water laboratory is simple and can be measured on a color disk. Using this method, a pre-measured amount of reagent, supplied in a "powder-pillow/[7] is added to an amount of water. After a specific amount of time has elapsed, the color of the solution can be compared to a color disk. Other more sophisticated methods, such as spectrophotometry, are also available.[3]

Nitrate removal methods

For point-of-use/point-of-entry (POU/POE), there are few options for effectively removing nitrates from the water supply. While preventing nitrate from entering the water supply at the source or switching to a municipal water source would be the most preferred routes, these often aren't viable options.

Reverse osmosis (RO) systems have been considered for home water treatment and use high-pressure pumps to force water through a semipermeable membrane that doesn't allow passage of charged ions—like nitrate. The reject volume for treating water with RO is high, making it quite expensive to apply solely for nitrate reduction when compared to other technologies.

A well-known technology for effectively removing nitrates from drinking water is ion exchange, which has been used successfully by both homeowners and municipalities for years. The basic principles of nitrate removal using ion exchange is similar to removing hardness from water with a water softener, but with slightly different chemistry.

Nitrate removal v. softening

In the water softening process, the resin starts the service cycle in the sodium form. Cations—positively charged ions such as calcium and magnesium—are removed from the water and exchanged with sodium on the resins. The exchange reaction looks as follows:

Figure 1. Softening process[a]

$$2\bullet_C\text{-Na} + Ca^{2+} \Leftrightarrow \bullet_C\text{-Ca} + 2Na^{+}$$

Ca, or calcium, is interchangeable in this formula for Mg, or magnesium, as minerals <W> exchanged with sodium (Na) in the <W> of removing hardness from water.

The $\bullet_C$ above represents an exchange site on the cation exchange n resin. The exchange reaction proceeds \ because the resin is more selective for calcium than sodium, as shown in Figure 1 and Figure 2:

Figure 2. Cation resin selectivity

Most Selective $Ca^{2+} > Mg^{2+} > Na^{+} > H^{+}$ Least Selective

Once the resin is exhausted with calcium and magnesium, the reaction can be reversed by contacting the resin with high concentrations of sodium ions in the form of brine (NaCl). This reverse reaction is termed regeneration.

In comparison, nitrate (NO_3) is an anion, since it is negatively charged. Anions are removed using an anion exchange resin, which has very different chemistries than cation exchange resins. In the nitrate removal process, chloride ions on the resin are exchanged for nitrate ions in the raw water, as represented by the exchange reaction in Figure 3:

Figure 3. Nitrate removal

$$\bullet_A\text{-Cl} + NO_3^{-} \Leftrightarrow \bullet_A\text{-}NO_3 + Cl^{-}$$

In the above reaction, $\bullet_A$ represents an exchange site on the anion exchange resin. Brine regeneration reverses the reaction, restoring the resin back to the chloride form.

Ion exchange & nitrate

The design and use of an ion exchange nitrate removal system is as simple as the design and use of a water softening system. Water conditioning equipment distributors can simply use the same equipment for water softening systems. Just as with softening, after a pre-determined time, the system can cycle through a regeneration using the same brine and rinse. Since anion resins are lighter than cation softening resins, an adjustment must be made to the backwash flow rate to prevent resin loss down the drain. Normally, about 40 percent of the backwash flow rate is needed for anion resins.

Because a standard water softening system can easily be adapted for nitrate removal, ion exchange is the easiest and least expensive way to design and implement a nitrate removal system. For the homeowner, costs would be comparable to the cost of owning and operating the water softening system.

Selective resins

Choosing an anion exchange resin that is sufficient for nitrate removal means choosing a resin that is more selective for nitrates. As mentioned above with water softening, the cation resins favor the divalent ions, such as Ca^{2+} and Mg^{2+} over Na^{+}. Similarly, standard anion exchange resins generally prefer divalent sulfate ions (SO_4^{2-}) over nitrate ions (NO_3^-):

Figure 4. Anion resin selectivity
Most Selective $SO_4^{2-} > NO_3^- > Cl^- > HCO_3^- > OH^-$ Least Selective

The concern of using standard anion exchange resins is that if the unit is overrun, nitrates that have concentrated on the resins will begin to leak first (see *Figure* 2). This would cause the concentration of nitrates in the effluent to be actually higher than the original influent. To counter this problem, nitrate selective resins are available specifically for nitrate removal. The advantage of using a nitrate selective resin is that the selectivity for divalent sulfate and nitrate is reversed:

Figure 5. Nitrate-selective resin
Most Selective $NO_3^- > SO_4^{2-} > Cl^- > HCO_3^- > OH^-$ Least Selective

Using this approach, sulfate would be the first ion that would leak from the unit, giving the home user a "safety cushion" to regenerate the system before experiencing health risks from high nitrates (see *Figure* 3).

Nitrate selectivity is not the only factor in choosing the optimal anion exchange resins. Total operating capacity for removing nitrate is also important. Resins with a greater total operating capacity will provide higher throughput and longer run times. The resin also should be specially manufacture and purified for use in non-industrial application.

Conclusion

In spite of the health risks of high-nitrate drinking water, not enough is being done to educate the homeowners about nitrates and nitrate removal. As in any case, knowing is half the battle to implementing and successfully using a nitrate removal system.

Beyond educating homeowners about the statistics of high-nitrate water, water conditioning equipment distributors can make sure that the water tests they offer examine the nitrate levels of water supplies. Together with an informed discussion of high nitrate levels, these tests will act as tools for the distributor to create a greater awareness of nitrates. And by using ion exchange resins specially created for nitrate removal, water conditioning equipment distributors can offer high quality nitrate removal systems, giving residents a renewed sense of health, security and well-being. □

References

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