ENVIRONMENTAL
Fact Sheet
NEW HAMPSHIRE DEPARTMENT OF Environmental Services

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Ion Exchange Treatment of Drinking Water

INTRODUCTION

Ion exchange (IE) is a water treatment method where one or more undesirable contaminants are removed from water by exchange with another non-objectionable, or less objectionable substance. Both the contaminant and the exchanged substance must be dissolved and have the same type (+,-) of electrical charge. One example of IE is the process called "water softening." Visit the fact sheets webpage at www.des.nh.gov/organization/commissioner/pip/factsheets/dwgb/index.htm and scroll to WD-DWGB-3-6 for an explanation of the removal of hardness from drinking water.

ONLY DISSOLVED CONTAMINANTS

When contaminants dissolve in water they typically form **ions**. Ions are electrically charged portions of a compound. There is a balance of positively and negatively charged ions in natural waters. When contaminants are dissolved in water, the water is typically crystal clear. If the water is cloudy or otherwise discolored it is likely that some, or all, of the contaminants are in a solid form. Solid particles are not intended to be removed by IE and solids will clog the treatment media.

The Exchange of Ions

The electrical charge on an ion can be either positive (+) or negative (-). Valence is the term that describes the category of the electrical charge on a dissolved ion such as **positive 2** or **positive 3**. If the contaminant has a positive charge, it would be called a **cation,** and would be removed by use of an IE media called **a cation exchange resin**. If the contaminant has a negative charge, **it would be called an anion,** and the appropriate treatment media would be called **an anion exchange resin**.

THE WATER SOFTENING PROCESS

A water softener at a private home typically has two or three tanks. The smaller tank contains the sodium or potassium salt used to regenerate the resin media while the taller tank(s) contains the purifying media called a "cation" exchange resin. During normal operations, raw water passes through the ion exchange resin media in the tall tank. The calcium (Ca^{++}), magnesium (Mg^{++}), iron (Fe^{++}), or manganese (Mn^{++}) ions in the water are typically "exchanged" for sodium (Na^{+}) or potassium (K^{+}) ions, which have been temporarily stored in the pores of the resin during the previous regeneration cycle. In fact, any contaminant ion of valence positive 2 or greater will be removed in a water softener.

As the softener removes hardness minerals from the water, sodium or potassium will be given back proportionally. Shown below is the concentration of either sodium or potassium that would be **added** to the **existing** raw water concentration if 10 mg/L of hardness is removed.

Hardness Removed	Na^{+} or K^{+} Added	
10 mg/L as $CaCO_3$	Sodium (Na+) added	= 4.6 mg/L
10 mg/L as $CaCO_3$	Potassium (K+) added	= 7.6 mg/L

If we think of atoms and balanced electrical charges: then if we have 10 atoms (ions) of hardness (calcium (++), magnesium (++)) we will be adding 20 atoms (ions) of sodium (+) or potassium (+).

CATEGORIZING HARDNESS

Water treatment professionals use different terminology to categorize hardness in drinking water, as shown below. DES uses the terminology used by sanitary engineers.

Worded Description	Sanitary Engineers (mg/L as $CaCO_3$)	Water Conditioning Industry (mg/L as $CaCO_3$)
soft water	0-75	0-50
somewhat hard water	76 to 150	51-100
hard water	151 to 300	101-150
very hard water	301 and up	151 and up

EXPRESSING THE AMOUNT OF HARDNESS IN WATER

There are two terms which are used by drinking water professionals to identify the concentration of hardness in drinking water. They are:

- Milligrams per liter, abbreviated as mg/L.
- Grains per gallon, abbreviated as gpg.

To convert a hardness concentration from one set of units to the other, use one of the following formulas:

- the concentration in milligrams per liter x $^1/_{17.2}$ = the concentration in grains per gallon.
- the concentration in grains per gallon x 17.2 = the concentration in milligrams per liter.

One milligram per liter (mg/L) equals 1 part per million (ppm) and 1 mg/L also equals 1,000 parts per billion (ppb), which can also be expressed as 1,000 micrograms per liter (ug/L).

Equivalent Concentration as $CaCO_3$

The concentration of hardness in water is normally **reported** as an equivalent concentration of calcium carbonate ($CaCO_3$). This laboratory calculation provides a common reference for the **reactive power** of various contaminants regardless of their atomic weight or valences. Thus, the typical laboratory units used for expressing hardness are “mg/L as calcium carbonate ($CaCO_3$).” The equivalent reactive concentrations for various cations are shown below.

Contaminate	Equivalent Weight
10 mg/L Calcium	24.97 mg/L $CaCO_3$
10 mg/L Magnesium	41.15 mg/L $CaCO_3$
10 mg/L Iron	17.92 mg/L $CaCO_3$
10 mg/L Manganese	18.22 mg/L $CaCO_3$

REGENERATION

Eventually the removal capacity of the IE resin becomes exhausted and the resin will need to be regenerated. The regeneration process typically begins by a **rapid** backwashing of the resin to remove fine particles that have been strained out of the water during the production (i.e. service) portion of the treatment cycle. This rapid backwash provides a physical cleaning of the outside of the media, but does not regenerate the resin's IE contaminant removal capability.

As the process continues the backwash flow rate is significantly reduced and brine (salt dissolved in water) is added to the backwash flow. The sodium or potassium from the brine permeates the resin pores and displaces the previously removed contaminants. After approximately 20 minutes, the remaining brine along with the concentrated, displaced contaminant ions are flushed out of the resin tank and disposed of into an approved dry well, septic tank, or sewer.

The control valve(s) then returns to the taller tank(s) to the service production run. In a single tall tank system the system backwashes late in the evening since raw water would enter the plumbing if there was customer demand. In a more modern "green" softener there are two treatment tanks so that one can be treating while the other is backwashed.

REDUCTION OF SALT USAGE

Being a good steward of the environment involves reducing **excessive** brine waste wherever possible. Salt brine can contaminate the general groundwater, and possibly that of **your own** well. Consequently, reducing salt usage while maintaining water softener effectiveness should be an important goal of all users of water softeners. In areas without sewers, reduction of salt discharge lessens the possibility of meaningfully contaminating groundwater.

Four methods can be used to reduce the amount of salt brine used when regenerating IE resin.

1. Initiation of the Regeneration Cycle

Older water softeners use a time clock to initiate the regeneration of the resin media. Modern softeners, however, regenerate usually by a meter that measures the **volume** of water already treated during the production cycle.

In either case, these modern methods of regeneration will be triggered based on actual exhaustion of the resin, rather than just triggered by the passage of time. This newer method is called "demand regeneration." In the historical case, a time clock backwashes a softener whether it needs regeneration or not, such as during a vacation period. This excessive backwashing needlessly increases salt use and the generation of waste brine.

When using demand regeneration, the IE device can begin regeneration at any time of the day even when water is being actively used in the home. When this happens, the IE device goes into a bypass mode, and untreated water must be used within the home. This untreated condition, although a disadvantage of the demand mode, is of short duration. In response to the bypass of treatment, some manufactures are now producing softeners with dual media tanks. While one tank is being regenerated the other is available to produce treated water.

2. Strength of Brine Used to Regenerate

The regeneration of a water softener can be carried out using different strengths of brine solution. This is achieved by installing the properly rated **venturi siphon insert** at the time the system is installed. From an environmental view point, those IE devices with a higher efficiency of contaminant removal, known as weaker brine regeneration, are the more appropriate to use.

The following summarizes the choice relative to the strength of brine versus the size of the treatment device.

a. **The weak brine regeneration alternative – recommended by DES**. This method uses approximately 6-7 pounds of salt to regenerate each cubic foot of IE resin media.

Advantage: Provides a higher efficiency of contaminant removal per pound of salt, approximately 7 percent efficiency compared to the 2 percent achieved with the strong brine alternative.

Disadvantage: Results in lower percent regeneration of the resin, and thus generally requires some enlarging of the size of the softener if the regeneration cycle durations are going to be comparable.

b. The strong brine regeneration alternative - not recommended by DES. This method uses approximately 12 pounds of salt to regenerate each cubic foot of softener resin media.

Advantage: Results in higher percentage of regeneration of resin media, and thus allow use of a minimum sized softener.

Disadvantage: Lower efficiency of contaminant removal per pound of salt, approximately 2 percent efficiency compared to the 7 percent achieved with the weak brine alternative.

3. Capture Last Part of Brine Backwash
This approach recognizes that the level of contaminants present at the end of the brine portion of the regeneration cycle is much less than at the beginning. Thus, the last portion of the brine regeneration solution is clean enough to reuse at the beginning of the next regeneration period. This method is generally not used at a private home because of the complex controls and “off line” brine holding required.

4. Partial Treatment (Split Flow)
In this method a portion of the raw water bypasses the treatment process. This typically requires throttling valves and meters on both the treatment and the by-pass plumbing lines. A hardness target concentration could be approximately 50-75 mg/L in the blended treated water. This approach is not practical where iron or manganese is present in high concentrations. This process reduces both waste brine and sodium levels in the finished water.

AVOIDANCE OF SODIUM
Sodium is not regulated as a drinking water health contaminant, and thus its presence is only of strict importance to those on a doctor-mandated **no-salt** diet.

If a source of untreated water with low sodium is desired in the home, untreated water can be provided to an additional faucet located at the kitchen sink. Sodium can also be avoided by use of potassium chloride to regenerate the unit or installation of a point-of-use RO.

DISPOSAL OF WASTES TO LEACHFIELD
There is often concern that septic tanks or disposal fields will be harmed by brine waste. Studies by the Water Quality Association (WQA) indicate that waste brine and purged contaminants do not injure leach fields or septic tanks. This WQA report is available from DES. If concern remains, a separate dry well can be constructed on the user’s property to dispose of the brine waste from the regeneration of the softener. There is no state regulation of this brine waste disposal system.

PREFERENCE SEQUENCE
1. Affinity Sequence for Cation and Anion Resins.
IE media have an affinity for certain contaminants over others. The strength of this selective affinity is governed by two factors.

a. **The principal factor affecting the strength of the affinity is the valence of the contaminant.** Thus, aluminum with a plus three valence will be more strongly held on the cation resin than calcium with a plus two valance. The higher the valence of the contaminant ion, the stronger the affinity of the media for that contaminant.

b. **The second and less strong affinity factor is approximated by the weight/size of the contaminant ion.** The higher the weight of the ion, the higher the affinity of the resin for that contaminant.

2. Manmade Modification of Affinity Selectivity
When the target contaminant is not the most preferred compared to another contaminant(s) in the water, it may be possible to reformulate an IE resin to better target the specific contaminant of interest. Nitrate selective resins are an example of such a modified resin. The capacity of these selective resins for nitrate will not be appreciably diminished by the presence of sulfate, which normally occurs for the most preferred cation. A down side to such selective resins is that a higher concentration of salt is needed to regenerate these resins.

3. Exception to the Affinity Sequence.
The affinity sequence holds for normal commercial grade IE resins at normal contaminant concentrations. When the contaminant is present at a much higher concentration, the affinity sequence will be affected, and the less preferred contaminant at high strength will be exchanged significantly. The regeneration step, using sodium (Na^+) or potassium (K^+), is the ultimate example of how a high concentration of a low affinity ion can override natural selectivity sequence of ions.

4. Dumping
Dumping is a serious limitation of an IE process. Dumping is related to the affinity sequence and to the relative concentration of the contaminant in the raw water. To illustrate the importance of dumping, suppose there are two contaminants that are both initially exchanged in the treatment process. As treatment continues, the more highly favored contaminant will be better attracted to the exchange sites of the resin than the less preferred ions presently there.

As the service cycle continues, this highest preference contaminant would push off other low affinity contaminants. As a result, the **lower** preference contaminant will be **dumped** and would increase its concentration in the finished water above the value in the **raw water** concentration. This concentration of the less preferred contaminant could exceed a water quality standard near the end of each service run.

Understanding the dumping phenomenon is critical when operating an IE system, and choosing which contaminants will govern the setting for the initiation of the regeneration step of the treatment process.

OTHER ION EXCHANGE TOPICS
1. **Broad Treatment.** IE is a very broad treatment technology, where numerous other contaminants are removed, as well as the target contaminant. Thus, beneficial contaminants may be removed and excess treatment, other than intended, is carried out.

2. **Solids Pretreatment.** Solids will clog an IE treatment media preventing efficient exchange of ions. Prefiltration may be needed to remove solids.

3. **Media Age.** Every time the IE media is regenerated the resin is subject to great chemical stress caused by the high concentration of brine. This constant compression and expansion weakens the IE resin with time. After many years, the resin may need to be replaced. The resin's remaining capability can be

evaluated by having a water treatment professional determine **the whole bead count** and the **percent of moisture** of the IE media.

4. **Anion Exchange Resin.** Earlier in this document, we illustrated the process for cation exchange. Many other contaminants occur as anion, such as nitrates (NO_3), sulfates (SO_4), and arsenic compounds. To remove multivalent anions, an anion rather than cation resin is used. Like the cation resin, the anion resin is regenerated by salt, although the actual regeneration is by the chloride ion rather than the sodium ion.

5**. Deionization**. In its more general form, IE for both + and **-** can also be called deionization. This treatment is a form of IE which typically targets sodium and chloride and other single valence ions from water. In these cases, acids (H^+) and bases (OH^-) are typically used as the regeneration chemicals. Any excess H^+ and OH^- converts to water. Deionization is used for medical and industrial situations requiring very pure water. Deionization is not necessarily for drinking water treatment, and would produce very **flat** tasting water. Strong acids and bases are dangerous chemicals to use in a residential home.

6. **Loss of Media.** If the rate of backwash of the device is too high, media may be washed out of the tank. This loss of media will reduce the effectiveness of the treatment. Temperature changes also affect the rate of backwash that can be used. In some fiberglass tanks, the media depth can be identified by shining a strong light through the tank in an otherwise darkened room, and noting the shadow that represents the depth of the remaining IE media.

SUMMARY

We suggest that you discuss this brine strength issue and long term salt savings with your equipment supplier. In general, DES does not recommend the use of softeners to treat only iron and manganese in non-sewered areas due to brine disposal concerns. Where hardness is above approximately 125-150 mg/L, or where there are multiple contaminants treatable by softening, an IE processes is supported. For detailed information concerning iron and manganese treatment, see DES fact sheet WD-DWGB-3-7.

FOR MORE INFORMATION

Please contact the Drinking Water and Groundwater Bureau and the New Hampshire Water Well Board at (603) 271-2513 or dwgbinfo@des.nh.gov or visit our website at http://www.des.nh.gov/organization/divisions/water/dwgb/index.htm. All of the bureau's fact sheets are on-line at http://www.des.nh.gov/organization/commissioner/pip/factsheets/dwgb/index.htm.

Note: This fact sheet is accurate as of September 2009. Statutory or regulatory changes or the availability of additional information after this date may render this information inaccurate or incomplete.