A SunCam online continuing education course

Ion Exchange for Water Treatment

by

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Course Outline:

Overview of Ion Exchange

Ion exchange is a water treatment process that can remove several contaminants and help to produce high-quality drinking water. It works by exchanging harmless ions on the surface of resin for undesirable ions in the water. These undesirable ions adsorb to the surface of the resin until being removed by regeneration.

Ion exchange was first utilized for water treatment in the 1930s. During the twentieth century, ion exchange technology was refined for the purpose of water softening and deionization, each of which is explained below. In the twentieth century, ion exchange resins have been specialized for removing toxins like arsenic and PFAS.

Water Softening

Softening refers to a reduction in water hardness. Hardness is the concentration of calcium (Ca^{2+}) and magnesium (Mg^{2+}) in the water, often expressed as the concentration of calcium carbonate ($CaCO_3$). One problem with hard water is that once heated, such as in a water heater, calcium carbonate can form hard deposits and scale. These can reduce the equipment life, lower the efficiency for heating water, and clog pipes.

Soft water is commonly considered as having a hardness of less than 17 mg/L of $CaCO_3$. See Table 1 for common descriptions for water hardness/softness.

Table 1: Hardness of Water

Water Hardness Description	Hardness as $CaCO_3$ (mg/L)(~ppm)
Soft	< 17
Slightly hard or normal	17 to 60
Moderately hard	60 to 120
Hard	120 to 180
Very Hard	> 180

The acceptable level of hardness is debatable and often a personal preference. Many public water treatment systems target a hardness of below 60 mg/L. Groundwater typically has a hardness of more than 60 mg/L, as shown in Figure 1. Therefore, a treatment process is commonly used to remove calcium and magnesium and thereby soften the raw water. Ion exchange with cation type resin and lime softening are two common approaches for reducing hardness.

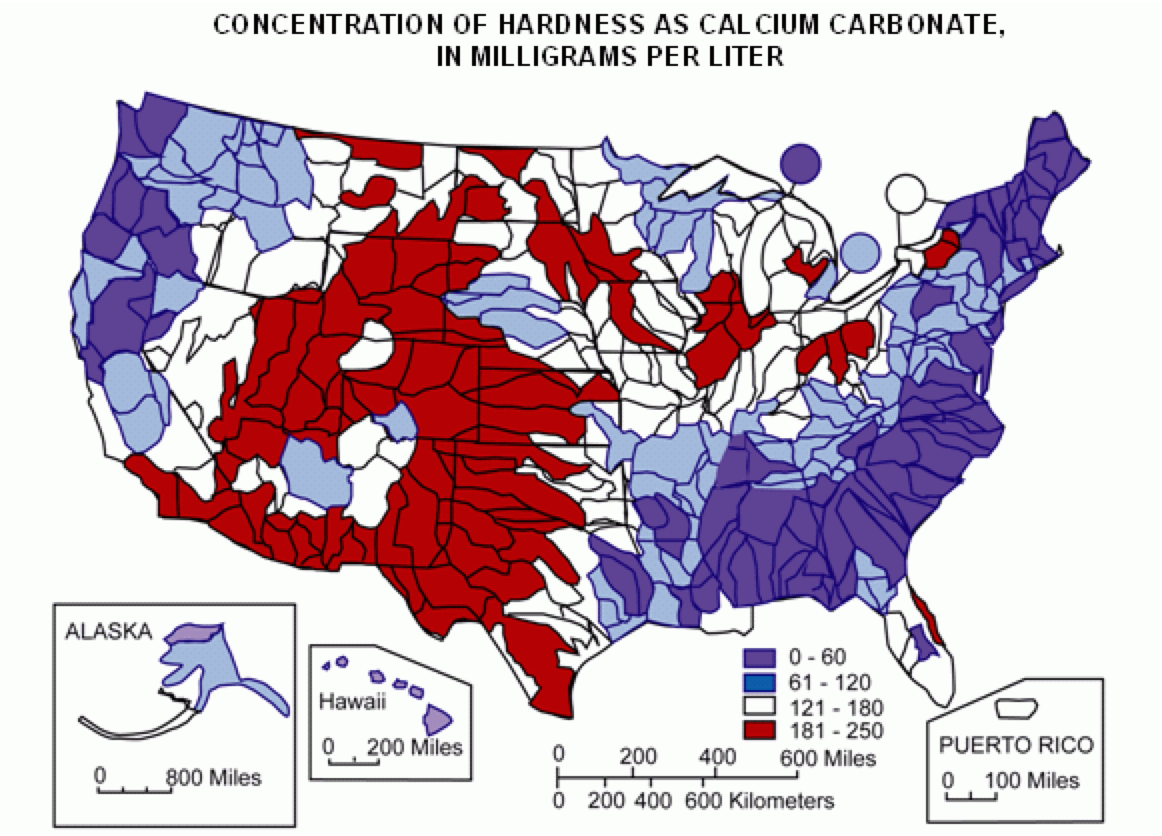


Figure 1: Typical hardness of groundwater throughout the United States.

Source: https://www.usgs.gov/media/images/map-water-hardness-united-states (public domain)

Deionization:
Deionization is also called demineralization, desalting, or deashing. It involves the removal of cations (positively charged ions) and anions (negatively charged ions) to purify the water. Common ions removed are as follows:

- Cations: Ca^{2+}, Fe^{3+}, K^{+}, Mg^{2+}, Mn^{2+}, Na^{+}
- Anions: CO_3^{2-}, HCO_3^{-}, Cl^{-}, NO_3^{-}, SO_4^{2-}, SiO_2

Ion exchange processes produce deionized water. Partial deionization systems only remove cations or anions, while complete deionization systems remove both cations and anions.

Deionized water is similar to distilled water. Distillation boils the water and then condenses the steam back into a liquid to remove impurities and minerals. The distillation process is much more costly than deionization, although it can remove both ionic and non-ionic impurities.

Recent Advances
Ion exchange (IX) continues to be used for a variety of water softening and deionization applications. However, in the last two centuries, ion exchange systems have been developed for more advanced purposes, including removal of the following contaminants:

- Alkalinity
- Arsenic
- Barium
- Boron
- Chlorides
- Color
- Disinfection byproduct (DBP) precursors
- Fluorides
- Hardness (water softening)
- Nitrates
- Organics
- Perchlorate
- Per- and Polyfluorinated Substances (PFAS)
- Radium
- Silica
- Sulfates
- Total Dissolved Solids (TDS)
- Toxic metals
- Uranium

Ion exchange is also used to treat wastewater, especially for industrial streams that require the removal of ammonia, fluoride, inorganic ions, heavy metals, nitrate, nitrite, phosphorus, or radioactive elements. This course focuses on ion exchange systems for drinking water applications.

Ion exchange membranes are semi-permeable membranes that allow most ions to pass through in a concentrate stream while blocking neutral molecules that continue as the purified water. Ion exchange membranes are used in electrodialysis or diffusion dialysis processes, often in industrial applications such as special food and beverage productions and for wastewater treatment.

Cation Exchange

Cation exchange is used for both water softening and deionization of cation contaminants. Cation resins are designed to attract cations, which are contaminants having a positive charge. The resin starts with hydrogen ions (H^+) on the surface. When water passes through the resin, cations will attract and adhere to the resin surface, thereby releasing (exchanging) the hydrogen ions. See Figure 2.

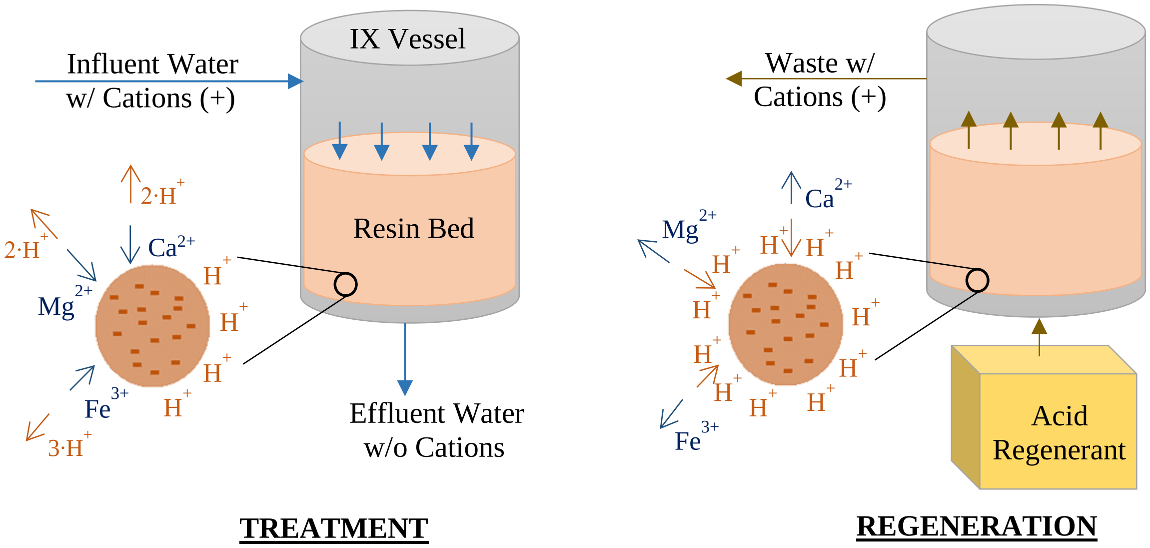


Figure 2: Schematic of a cationic fixed-bed IX system during treatment (left) and regeneration (right). The cation resin beads are negatively charged and attract positive ions such as calcium, magnesium, and iron, which are exchanged with hydrogen ions (H^+). During regeneration, the hydrogen ions are restored to the resin surfaces.

Source: Author

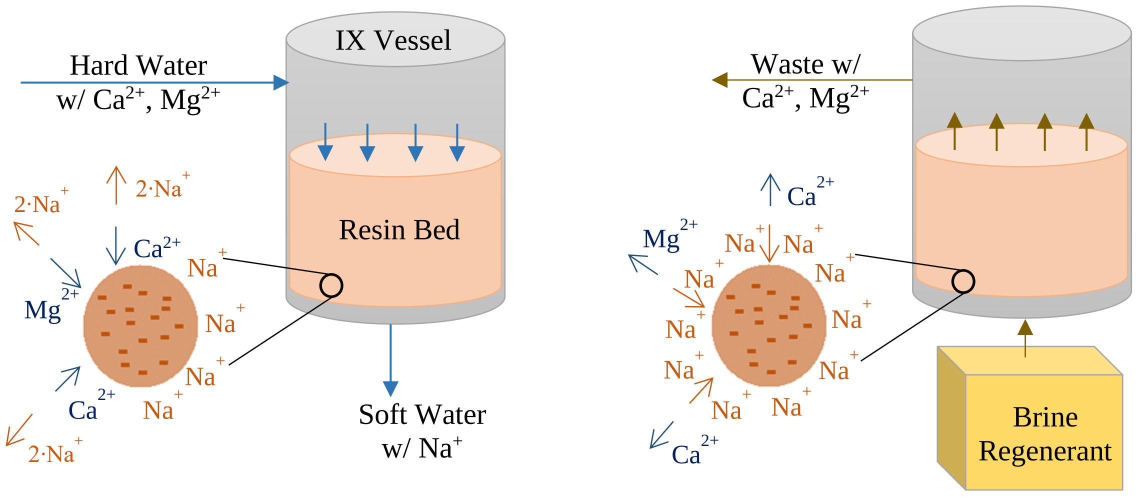
The treatment process is always occurring as water flows continuously through the IX vessel. However, once the resin is essentially full of cations, a breakthrough of contaminants starts to occur. At this point, the resin should be regenerated by soaking it in acid, such as sulphuric or hydrochloric acid. The acid has the chemical drive to strip off the cations from the resin and exchange back the hydrogen ions. It is common to have multiple vessels in parallel to allow for one vessel to be out of service during regeneration while the remaining vessels continue treatment.

Common cationic contaminants removed by IX include:

- Calcium (Ca^{2+})
- Iron (Fe^{3+})
- Magnesium (Mg^{2+})
- Manganese (Mn^{2+})
- Potassium (K^{+})
- Sodium (Na^{+})

Salt-based Water Softeners

Salt-based water softeners target the removal of calcium and magnesium to soften the water. Instead of hydrogen ions, sodium or potassium ions cover the resin and are used for exchange. This allows regeneration with a brine solution ($NaCl + H_2O$), which is lower cost and safer to handle than an acid solution. See Figure 3 for typical arrangements.



TREATMENT **REGENERATION**

Figure 3: Schematic of a salt-based IX system during treatment (left) and regeneration (right). The cation resin beads are negatively charged and attract calcium and magnesium, which are exchanged with sodium ions (Na^{+}). During regeneration, a brine solution restores the sodium ions to the resin surfaces.

Source: Author

Salt-based water softeners are common for home treatment systems with a private well with hard water. See Figure 4 for a typical softening system. They produce a salty wastewater that is discharged to drain, which can negatively impact septic systems, wastewater treatment plants, and groundwater. For this reason, salt-based water softeners are banned by some communities in the states of California, Connecticut, Massachusetts, Michigan, and Texas. Some communities offer rebates if homeowners replace or upgrade their existing salt-based water softeners.

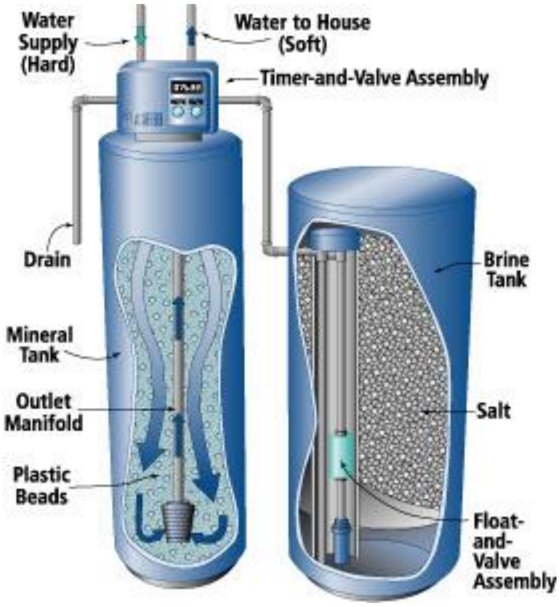


Figure 4: Typical residential water softener system.

Source: https://basc.pnnl.gov/resource-guides/water-softeners

Cation Resins

Resin facilitates the exchange of ions. Resin is a collection of small insoluble beads, nodules, or granules. The most common resin is small organic polymer beads (0.25 to 1.43 mm radius) that are yellow or orange. The beads can be porous to provide a greater surface area. See Figure 5 for examples.

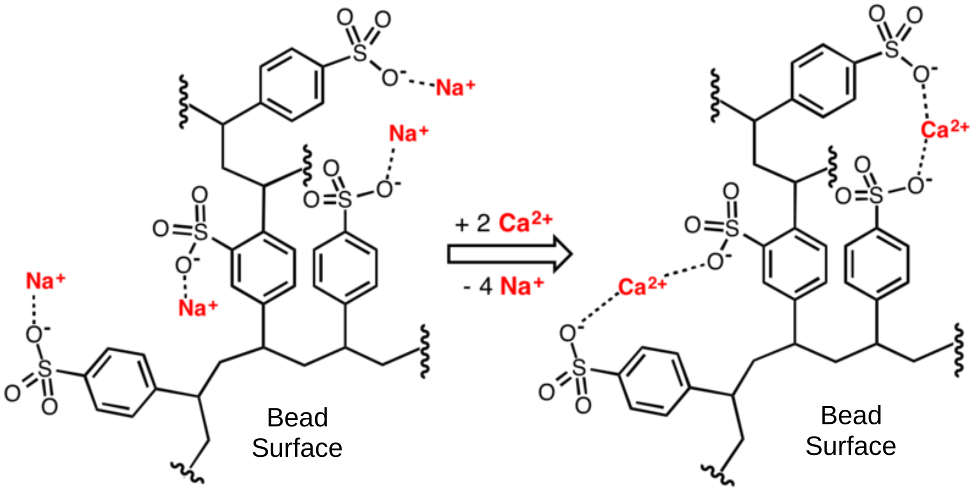
Figure 5: Examples of resin beads.

Source: https://commons.wikimedia.org/wiki/File:Orange_resin.JPG (public domain)

Cation resins may be either strongly or weakly acidic:

- Strongly acidic: Commonly include sulfonic acid groups, such as sodium polystyrene sulfonate or polyAMPS. Most commercial resins are made of polystyrene sulfonate.
- Weakly acidic: Commonly include carboxylic acid groups.

The beads are manufactured so the surfaces have weak bonds with hydrogen or sodium ions. During treatment, these bonds release and stronger bonds form with cation contaminants such as calcium, magnesium, and iron. See Figure 6 for a chemical depiction of a bead surface.



Before Treatment **After Treatment**

Figure 6: Skeletal structure of a cation bead surface, before treatment (left) with sodium ions on the surface, and after treatment (right) with calcium ions on the surface.

Source: https://commons.wikimedia.org/wiki/File:CationExchCartoon.png, Smokefoot, CC-BY-SA-3.0

For cation resin, the following is the order of preference, from greatest to least:

- Barium (Ba^{2+})
- Lead (Pb^{2+})
- Mercury (Hg^{2+})
- Calcium (Ca^{2+})
- Nickel (Ni^{2+})
- Cadmium (Cd^{2+})
- Copper (Cu^{+})
- Zinc (Zn^{2+})
- Iron (Fe^{3+})
- Magnesium (Mg^{2+})
- Potassium (K^{+})
- Ammonia (NH_4^{+})
- Sodium (Na^{+})
- Hydrogen (H^{+})

Chelating Resins

Chelating resins are cation resins that are manufactured to have a higher-than-normal selectivity towards removing heavy metal cations, including the following:

- Barium (Ba^{2+})
- Cadmium (Cd^{2+})
- Cobalt (CO^{2+})
- Copper (Cu^{+})
- Chromium (Cr^{3+})
- Lead (Pb^{2+})
- Manganese (Mn^{2+})
- Nickel (Ni^{2+})
- Zinc (Zn^{2+})

With a normal cation resin, calcium will be bonded before most heavy metals, which results in frequent regeneration and unwanted pass-through of heavy metals. With a chelating resin, the heavy metals will bond before calcium.

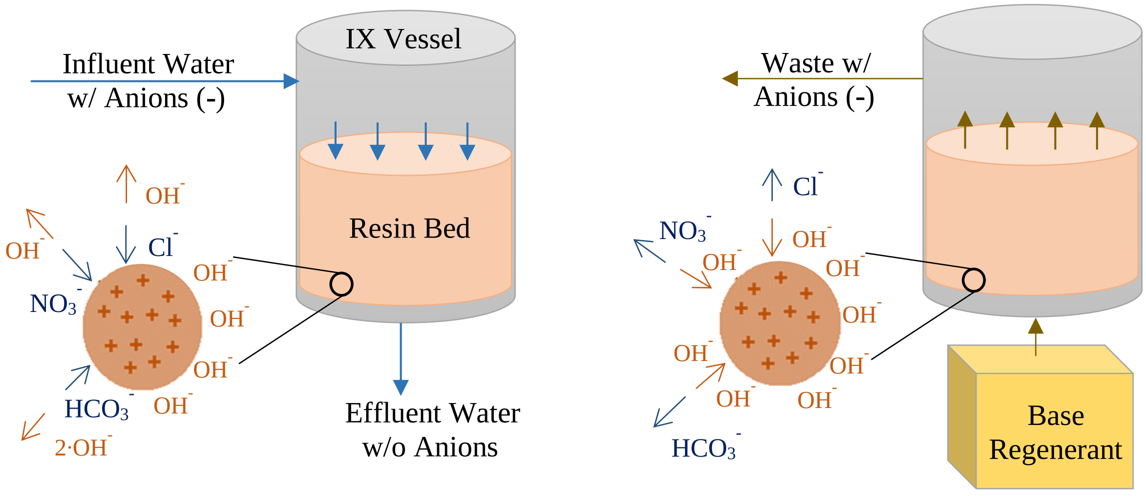
Chelating resins come in the following forms:

1. Sodium form: Starts with sodium ions on the resin surface and is regenerated with brine. This is the most common form and has the greatest selectivity for heavy metals.
2. Hydrogen form: Starts with hydrogen ions on the resin surface and is regenerated with acid. Regeneration is very effective because heavy metals easily release at low pH when the acid solution is introduced.

A drawback to chelating resins is the cost is approximately double of other cation resins.

Anion Exchange

Anion exchange is used to remove a variety of anion contaminants. Anion resins are designed to attract anions, which are contaminants having a negative charge. The resin starts with hydroxide (OH^-) on the surface. When water passes through the resin, anions will attract and adhere to the resin surface, thereby releasing (exchanging) the hydroxide ions. See Figure 7.



TREATMENT **REGENERATION**

Figure 7: Schematic of an anionic fixed-bed IX system during treatment (left) and regeneration (right). The anion resin beads are positively charged and attract negative ions such as chlorides, nitrates, and bicarbonate, which are exchanged with hydroxide ions (OH^-). During regeneration, the hydroxide ions are restored to the resin surfaces.

Source: Author

The resin should be regenerated by soaking it in a strongly basic solution, such as sodium hydroxide. The base has the chemical drive to strip off the anions from the resin and exchange back the hydroxide ions.

Common anionic contaminants removed by IX include:

- Alkalinity/Carbonate (CO_3^{2-}, HCO_3^-)
- Chloride (Cl^-)
- Nitrate (NO_3^-)
- Sulfate (SO_4^{2-})
- Silica (SiO_2)
- Color
- Total Organic Carbon (TOC)
- Per- and Polyfluorinated Substances (PFAS)

Anion Resins

Anion resins are similar in size and texture to cation resins.

Anion resins may be either strongly or weakly basic:

- Strongly basic: Commonly include quaternary amino groups, for example, trimethylammonium groups, such as polyAPTAC.
- Weakly basic: Commonly include primary, secondary, and/or tertiary amino groups, such as polyethylene amine.

The beads are manufactured so the surfaces have weak bonds with hydroxide ions. During treatment, these bonds release and stronger bonds form with anion contaminants such as chlorides, nitrates, and sulfates.

For anion resins, the following is the order of preference, from greatest to least:

- Perchlorate (ClO_4^-)
- Iodide (I^-)
- Sulfate (SO_4^{2-})
- Nitrate (NO_3^-)
- Bisulfite (HSO_3^-)
- Bromine (Br^-)
- Chloride (Cl^-)
- Cyanide (CN^-)
- Bicarbonate (HCO_3^-)
- PFAS (various)
- Acetate ($CH3COO^-$)
- Hydroxide (OH^-)
- Fluoride (F^-)

Resin manufacturers

The following is a list of manufacturers for both cation and anion resins:

- DuPont de Nemours
- IXOM Watercare Inc., formerly Orica Watercare Inc.
- Lanxess
- Mitsubishi Chemical
- Novasep Holding
- Purolite Corporation
- ResinTech Inc.
- Samyang
- Thermax Limited

Magnetic Resins

Magnetically enhanced anion resin consists of polyacrylic beads with magnetic iron oxide particle inclusions. The beads are 2 to 5 times smaller than conventional anion resins. The small size and magnetic inclusions allow the magnetic resin to be used in completely mixed and suspended-bed applications, in which the resin is continuously being recycled and regenerated.

This process is called magnetic ion exchange and given the abbreviation MIEX®, which is a registered trademark of IXOM, formerly Orica Australia. IXOM has patents for several magnetic resins. Magnetic resins are significantly more expensive than standard anion resins.

System Configurations

The following tables provide a summary of common IX system configurations.

Fixed-Bed IX Single Stage	
Unique Features	**Options**
Cylindrical vessels (columns) packed with resin. Commonly include upper & lower manifolds, gravel underdrain, regenerant distributor, and air scour grid. Most common configuration.	• Cation or Anion • Upflow or Downflow • Air Scour • Auto or Manual Valves • Co-current or Counter-current Backwash

Figure 8: Four fixed-bed ion exchange vessels in blue with piping and valves to allow for treatment and backwash cycles.

Source: https://commons.wikimedia.org/wiki/File:Cation_anion_ion_exchange.jpg, Z22, CC-BY-SA-4.0

Fixed-Bed IX
Multi-Stage

Unique Features	Options
Cation vessel followed by an anion vessel. Acid or brine regenerant for the cation exchanger, and base regenerant for the anion exchanger.	• Upflow or Downflow • Air Scour • Auto or Manual Valves • Co-current or Counter-current Backwash • Bypass for Either Vessel

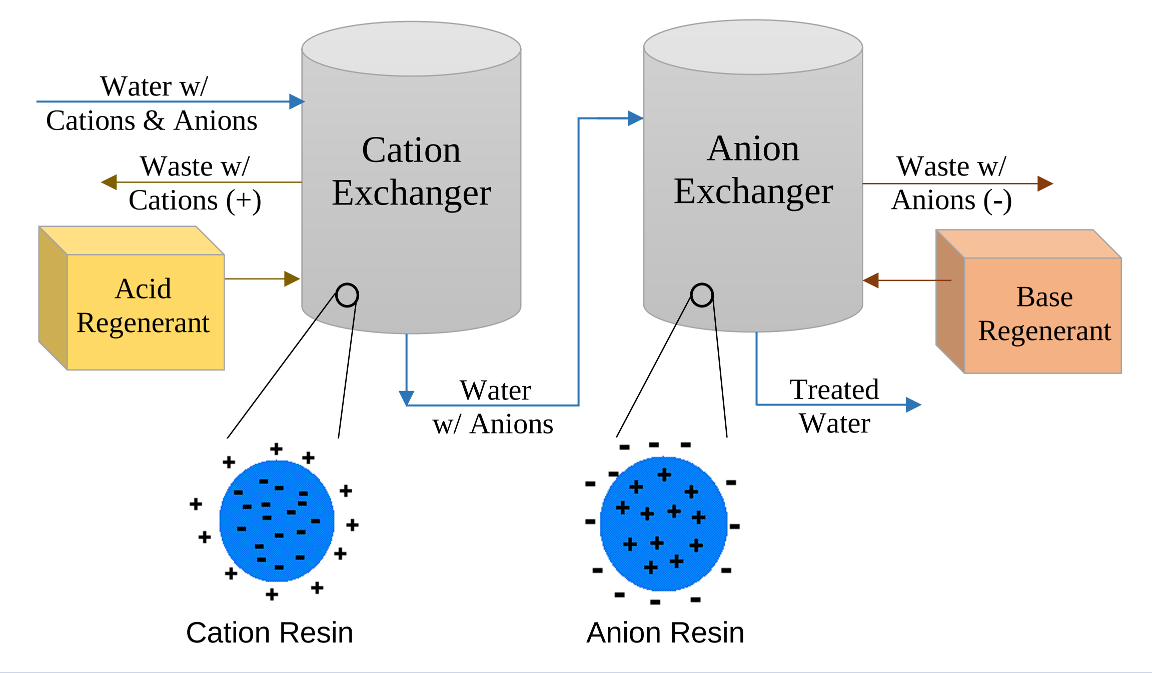


Figure 9: Schematic of a two-stage ion exchange system with cation and anion exchangers in series.

Source: Author

Fixed-Bed IX Mixed-Bed	
Unique Features	**Options**
Cation resin and anion resin are mixed in a single vessel. An upflow backwash separates the resins with the lighter anions floating to the top. The base is added to the top for anion regeneration, and acid is added to the bottom for cation regeneration, with the waste drained between the two kinds of resins.	• Upflow or Downflow • Air Scour • Auto or Manual Valves • Disposable Cartridges

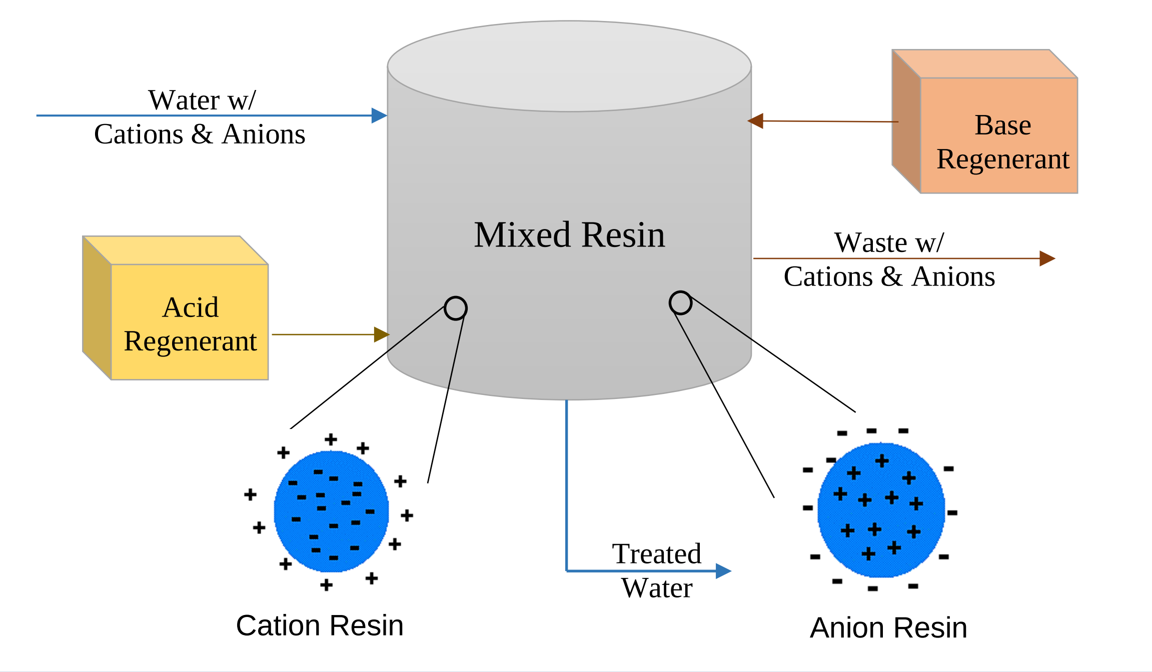


Figure 10: Schematic of a mixed-bed ion exchange system with both cation and anion resins in a single vessel.

Source: Author

Moving-Bed / Suspended IX	
Unique Features	**Options**
The resin is suspended in the water through continuous mixing in a treatment chamber, vessel, or column. The resin can be recycled and regenerated through a sidestream.	• Batch or Continuous • Cation or Anion • Plug Flow or Continuous Mixed

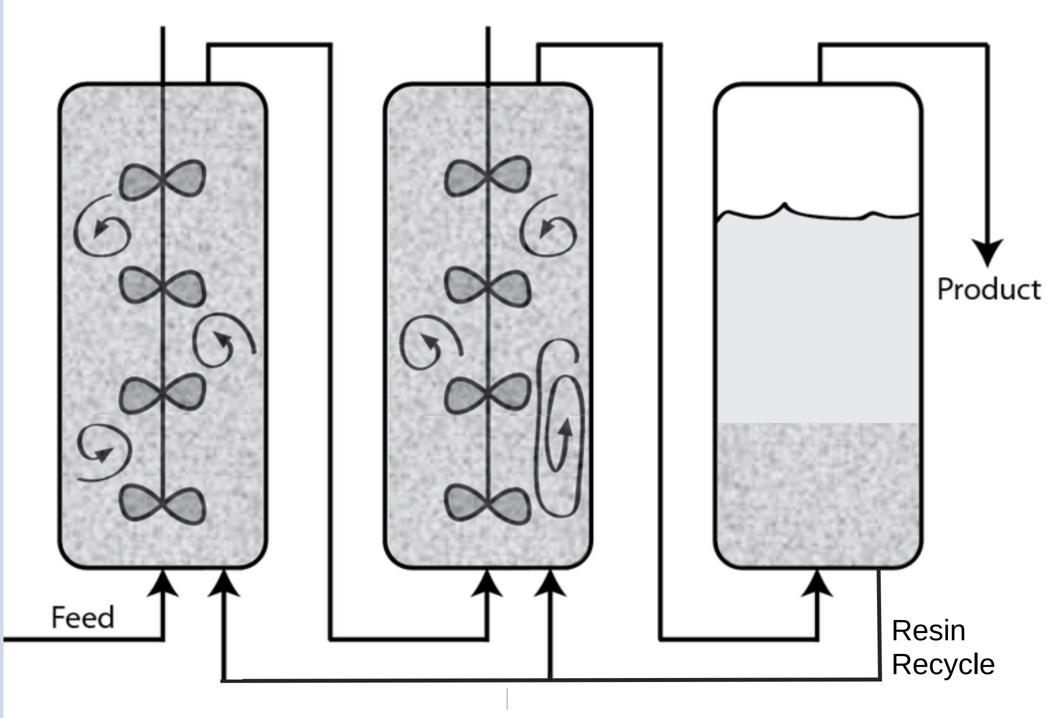


Figure 11: A suspended IX system with three vessels. The first two are near plug flow columns with IX resin. The last vessel settles out any carryover resin for recycling.

Source: https://commons.wikimedia.org/wiki/File:Back_Mixing_and_Digester.png (modified), Brazosport College, CC-BY-SA-3.0

Magnetic IX (MIEX®)	
Unique Features	**Options**
Magnetically enhanced anion resin is suspended in the water through continuous mixing in a tank or vessel. Resin is continuously removed, regenerated, and recycled.	• Raw water treatment without pre-filtration • Concrete Tanks or Steel/FRP Vessels • Aeration • Pre-chlorination • Special removals: ○ Bromide ○ Color ○ Dissolved Organic Carbon (DOC) ○ Perfluorinated alkyl substance (PFAS) ○ Sulfate

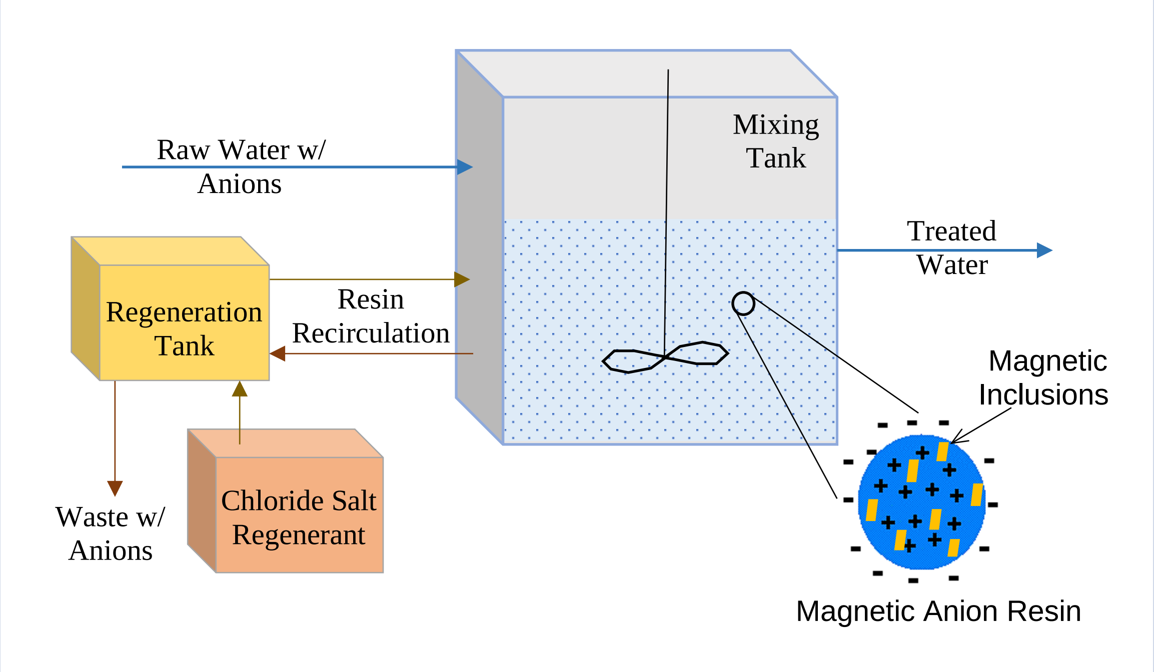


Figure 12: Schematic of a magnetic ion exchange system.

Source: Author

Biological (BIEX)	
Unique Features	**Options**
Biological IX is similar to anion fixed-bed IX except bacterial growth is encouraged on the surface of the resin beads, thereby allowing additional removal of dissolved organics.	• Bioaugmentation • Biotic condition controls • Special Removals: ○ Dissolved Organic Carbon (DOC) ○ Natural Organic Matter (NOM)

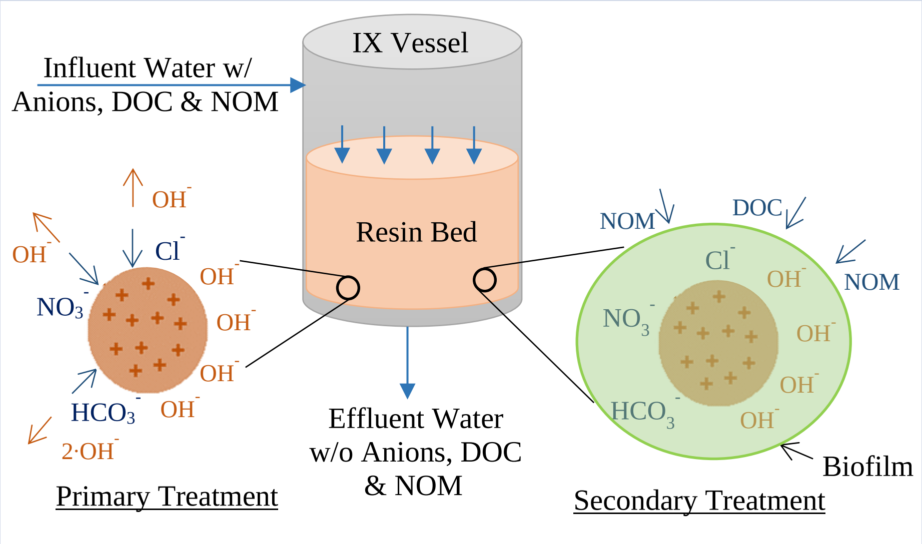


Figure 13: Schematic of a biological IX system, which performs both primary treatment for anions (left) and secondary treatment for organic removal (right). The resin attracts negative ions and, after growing a biofilm, attracts organic material such as dissolved organic carbon (DOC) and natural organic matter (NOM). Regeneration removes the contaminants and biofilm and restores the hydroxide ions to the resin surfaces.

Source: Author

Summary of Configurations

Table 2: Comparison of IX Configurations

Configuration	Anion or Cation	Pre-Filters	Prevalence	Water Applications	Capital Cost	Lifecycle Cost
Fixed Bed, Single Stage	Either	Common	Very Common	• Residential, commercial, industrial softening • Large municipal plants • Targeted contaminants	Average	Lowest
Fixed Bed, Multi-Stage	Both	Common	Common	• High purity water for food, beverage, and medical • Deionized water • Large municipal plants	High	Average
Fixed-Bed, Mixed Bed	Both	Common	Common	• Polishing of treated water • Condensate polishing • Disposable cartridges • Nuclear power • Steam generator blowdown	High	Average
Moving Bed / Suspended	Either	Optional	Uncommon	• Large municipal plants • Industrial applications	Average	High
Magnetic	Anion	Optional	Uncommon	• Large municipal plants	Average	Highest
Biological	Anion	Optional	Very Uncommon	• Pilot plants and studies	Unknown	Unknown

Field Testing

Field testing is essential for the design of an ion exchange system. Water has a unique combination of water quality parameters and contaminants for each application. Small changes in these parameters have a large influence on the resin's effectiveness and life span. For this reason, actual field test results are utilized to select the proper resin and to size the resin bed.

Field testing can be called jar testing, bench-scale testing, laboratory testing, demonstration testing, or pilot testing. See Figures 14 and 15 for field test pictures.

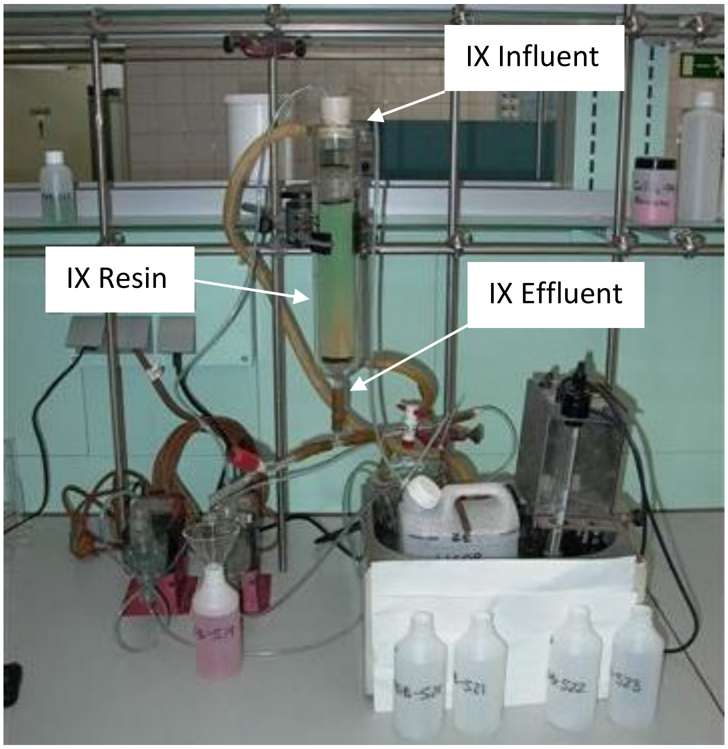


Figure 14: Bench-scale test for demonstrating IX resin performance.

Source: wiki.biomine.skelleftea.se/wiki/index.php/Image:Ion_Exchange_laboratory_test_work.jpg, Francisco Sánchez

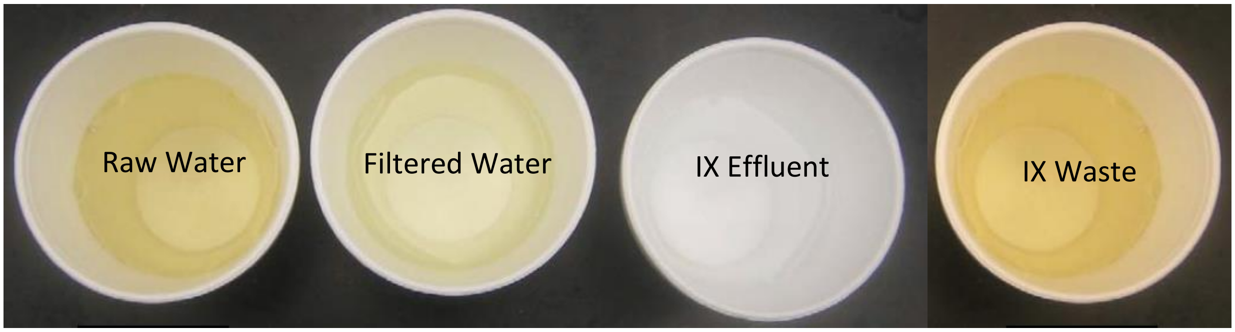


Figure 15: Test results showing the color of the water. Raw Water is before filtration (pre-conditioning). Filtered Water is after filtration and is the IX Influent. IX Effluent is after IX treatment. IX Waste represents the IX backwash and regeneration waste.

Example Problem 1

Engineer Randy is designing an ion exchange system for the removal of organics and color. Randy performed jar testing with three different anion resins, with the results summarized in Table 3. Which resin performed better for this application?

Table 3: Test Results for Example Problem 1

Parameter	**Units**	**IX Influent**	**IX Effluent**			**Permit Limits**
			Resin A	**Resin B**	**Resin C**	
Alkalinity	mg/L as $CaCO_3$	250	205	185	190	-
Chloride	mg/L	68	60	102	120	250
Color	C.U.	48	4	1	2	15
Total Hardness	mg/L as $CaCO_3$	280	220	204	205	-
Iron	mg/L	0.8	0.3	0	0.1	0.3
pH	-	7.4	7.3	7.4	7.2	6.5-8.5
Sulfate	mg/L	20	1	1	0	250
Total Dissolved Solids (TDS)	mg/L	380	420	400	505	500
Temperature	℃	26.0	26.0	25.5	25.8	-
Total Organic Carbon (TOC)	mg/L	18	4	3	6	25

Solution:
Randy reviews the data. To simplify the comparison, he removes the rows for non-targeted parameters in which all resins met the permit limits. See Table 4. For the two targeted parameters (color and TOC), Randy highlights in **green** the best results, which both belong to Resin B. He highlights in **red** any effluent values that exceed the permit limits, which in iron for Resin A and TDS for Resin C.

Table 4: Test Results for Key Parameters for Example Problem 1

Parameter	**Units**	**IX Influent**	**IX Effluent**			**Permit Limits**
			Resin A	**Resin B**	**Resin C**	
Chloride	mg/L	68	60	102	120	250
Color	C.U.	48	4	**1**	2	15
Iron	mg/L	0.8	**0.3**	0	0.1	0.3
pH	-	7.4	7.3	7.4	7.2	6.5-8.5
Sulfate	mg/L	20	1	1	0	250
Total Dissolved Solids (TDS)	mg/L	380	420	400	**505**	500
Total Organic Carbon (TOC)	mg/L	18	4	**3**	6	25

Resin B provided for the greatest removal of color and organics and was the only resin to meet all the permit limits. Therefore, **Resin B** performed the best in the test.

Design Criteria

During the planning stage, it is important to identify the goals of the IX system. At the beginning of the design stage, these goals are translated into specific design criteria. These design criteria form the basis of the design. The criteria are based on field test results and can be revised as the design progresses. See Table 5 for an example.

Table 5: Example Ion Exchange Design Criteria

Description	Criteria	Units
IX Configuration	Fixed Bed, Single Stage Anion Exchange	-
Flow rate range (min. to max.)	2.0 to 6.0	MGD
Flow direction	Downwards	-
Resin type	Strong-base Type I	-
Organics absorbing capacity	6,000	gal/ft^3
Regeneration Frequency	3 to 5	days
Number of vessels (total)	6	no.
Vessel diameter	12	ft
Bed depth	4	ft
Resin volume, per vessel	450	ft^3
Treatment rate (average)	6	gpm/ft^2
Treatment rate (two vessels out of service, regenerating, or backwashing)	9	gpm/ft^2
Max. pressure drop (clean bed)	5	psi
Max. pressure drop (dirty bed)	8	psi
Underdrain type	Gravel	-
Materials of construction	Epoxy coated steel	-
Regeneration solution	Brine (sodium chloride)	-
Air scour source	Existing compressed air	-

Process Flow Diagrams

In the planning stage, it is important to make a block flow diagram of the overall treatment process. Block flow diagrams show the main processes as rectangles or circles with lines and arrows for the main flow paths. See Figure 16 for an example of an ion exchange treatment process for treating drinking water.

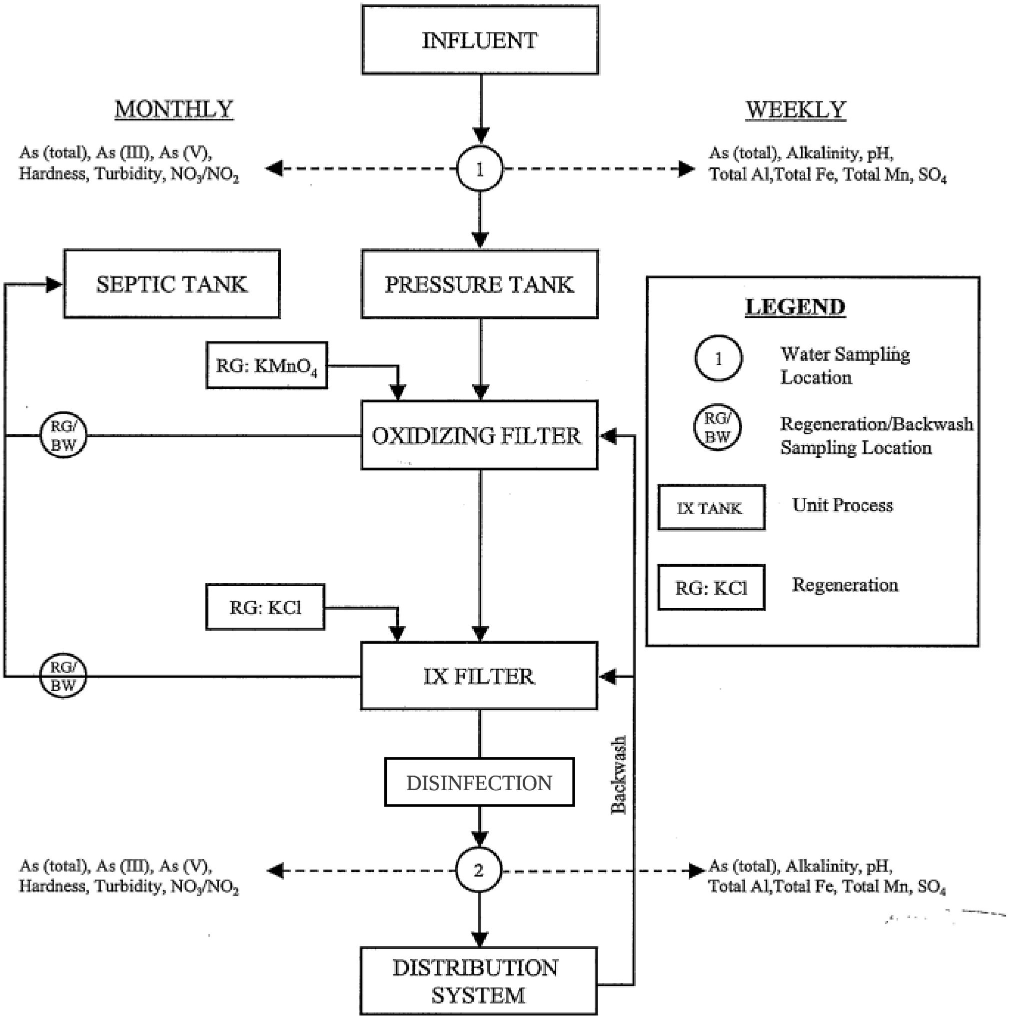


Figure 16: Block flow diagram with an ion exchange system labeled “IX FILTER”. The cation resin is regenerated with a potassium chloride (KCl) brine solution. The waste goes to a septic tank. The “OXIDIZING FILTER” removes sulfates, and thereby allows the ion exchange system to provide a higher removal of the targeted contaminant, arsenic (As^{5+}). The OXIDIZING FILTER also converts As^{3+} to As^{5+}.

Source: “Arsenic Removal from Drinking Water by Ion Exchange and Activated Alumina Plants”, EPA 600/R-00/088

In the design stage, process flow diagrams (PFDs) should be created. A PFD is a drawing with symbols for major components such as pumps, tanks, mixers, and flow meters. Lines with flow direction arrows represent piping between the components.

As the design develops, more details should be added to the PFD in CAD software. Ideally, all major components should be identified, including instrumentation. Manual operated valves are not required, however important isolation valves and control valves should be identified. Pipe fittings do not need to be identified. It is helpful to label pipes and to show sizes of pipes and tanks, if known.

See Figures 17 through 19 for examples. PFDs are often given to electrical and controls engineers to create instrumentation and controls diagrams (P&IDs). P&IDs include symbology for the controls features, such as instrumentation and communications.

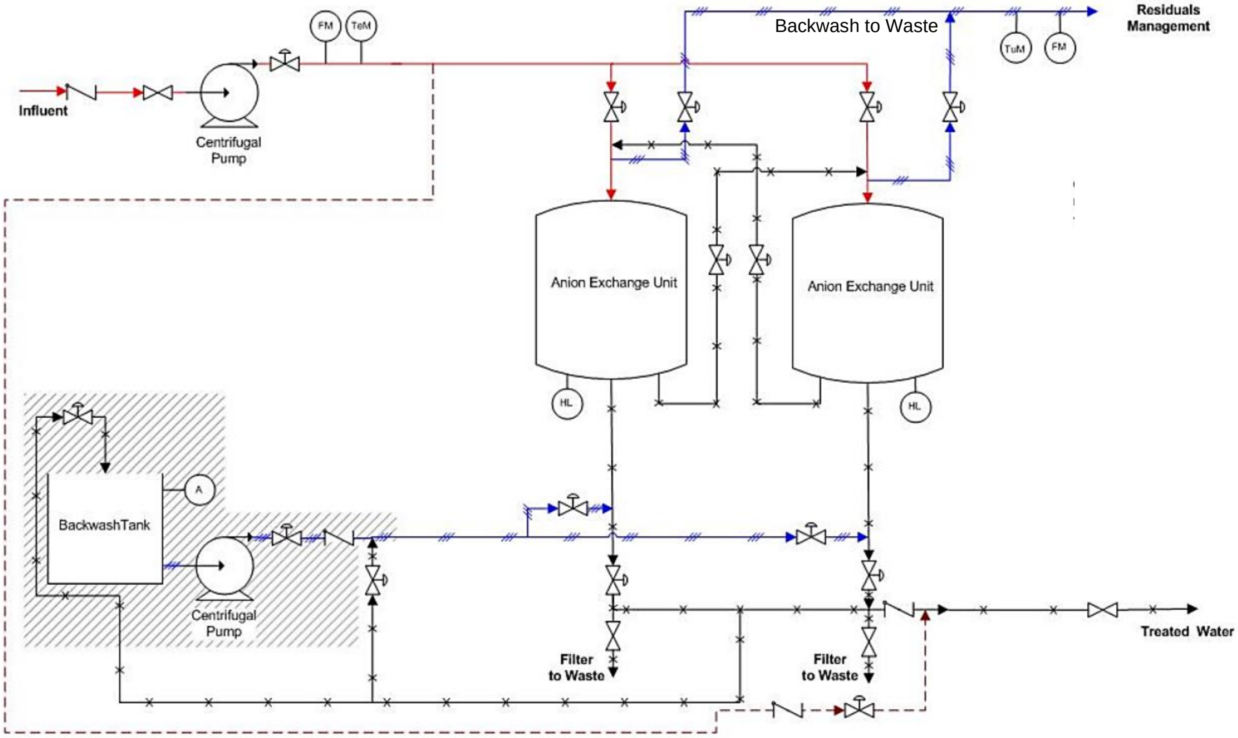


Figure 17: Example PFD for a fixed-bed ion exchange system with two vessels. The piping arrangements can be complex with the pipes entering and exiting the vessels serving different purposes during the treatment, backwash, and regeneration cycles.

Source: www.epa.gov/sites/default/files/2019-07/documents/wbs-ixclo4-documentation-june-2019.pdf (public domain)

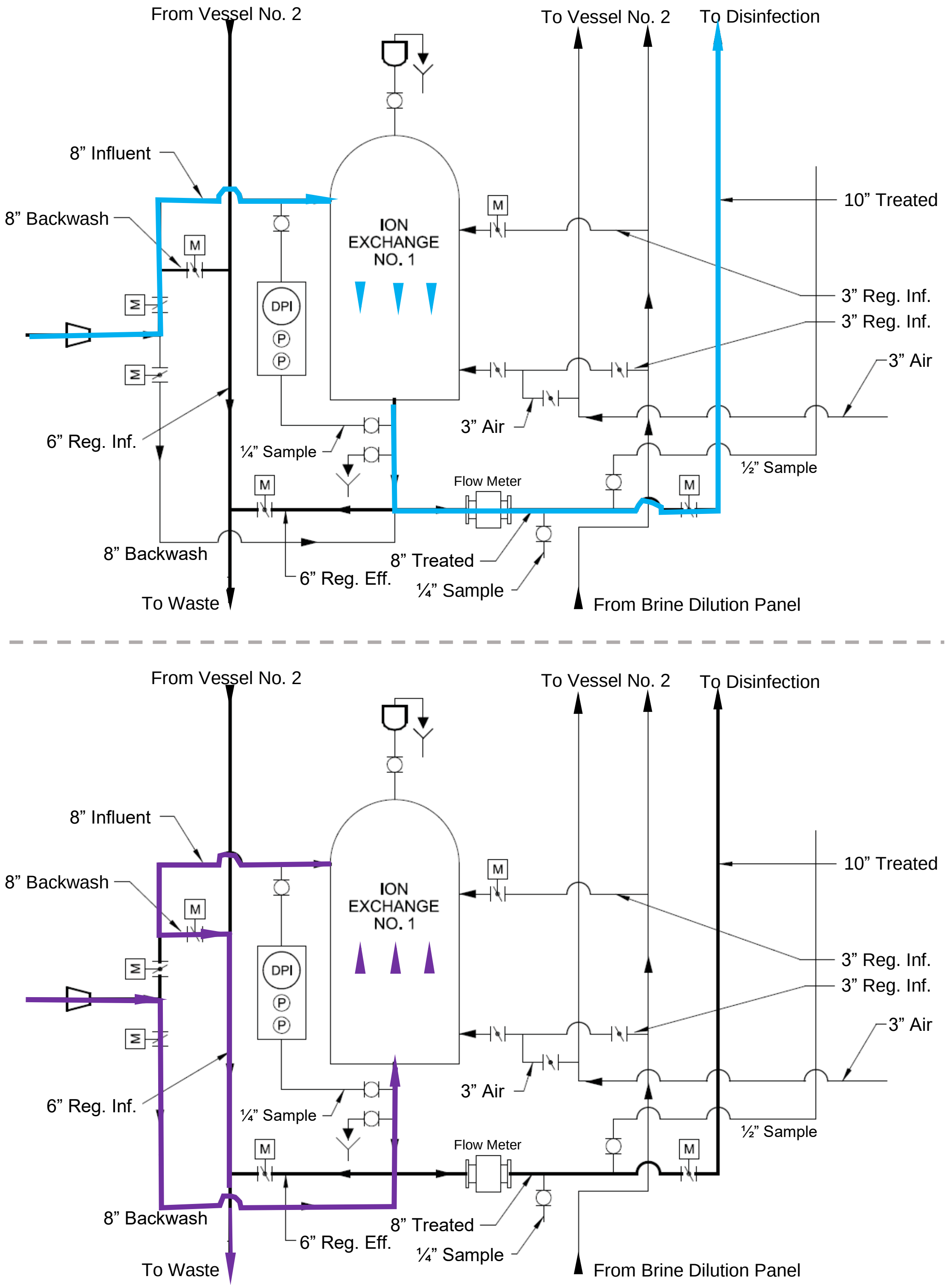


Figure 18: PFD with treatment flow in blue (top) and backwash flow in purple (bottom).

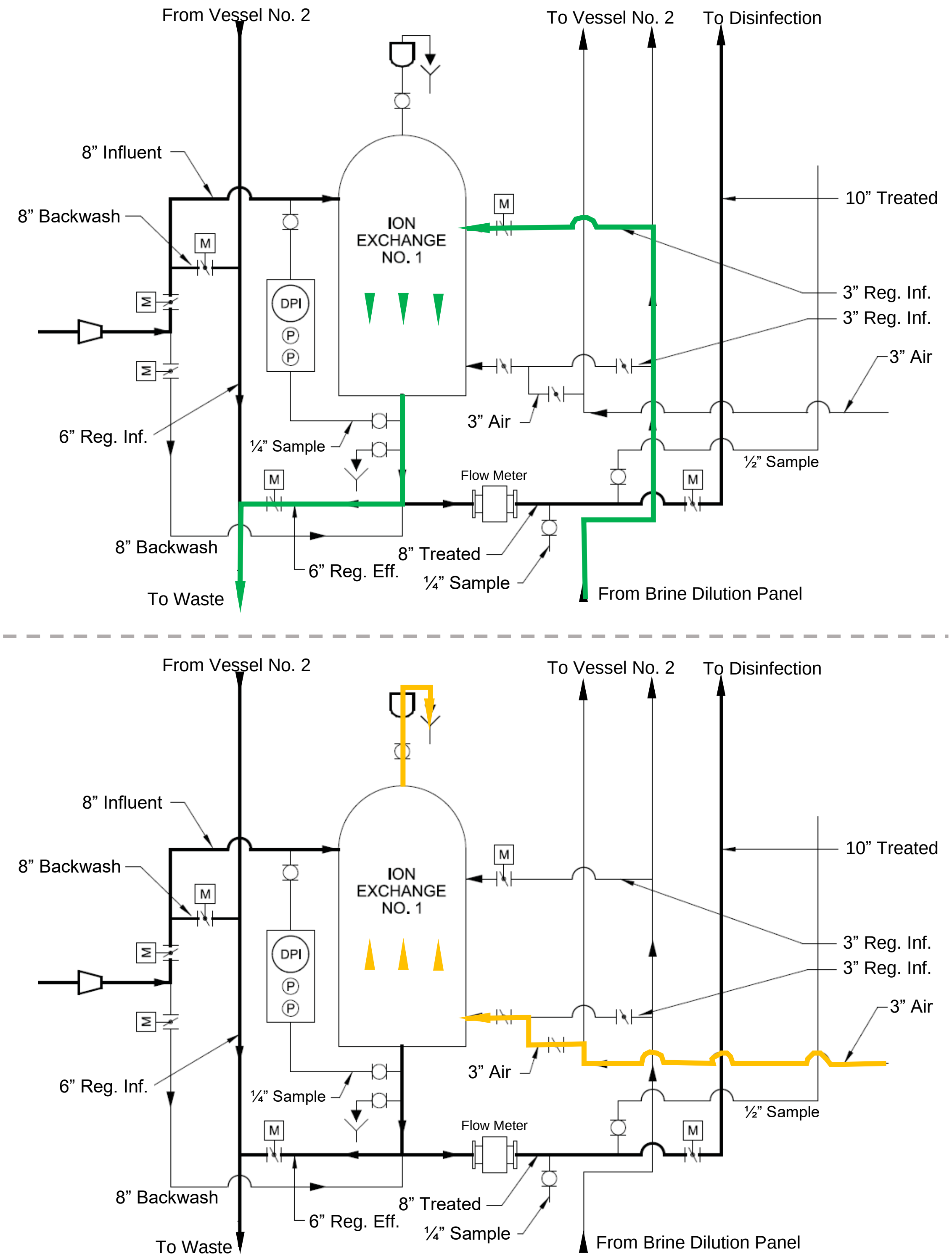


Figure 19: PFD with regeneration flow in green (top) and air scour flow in orange (bottom).

The plan view or site plan is also important to develop early in the design process, as the physical layout impacts other disciplines. See Figure 20 for an example.

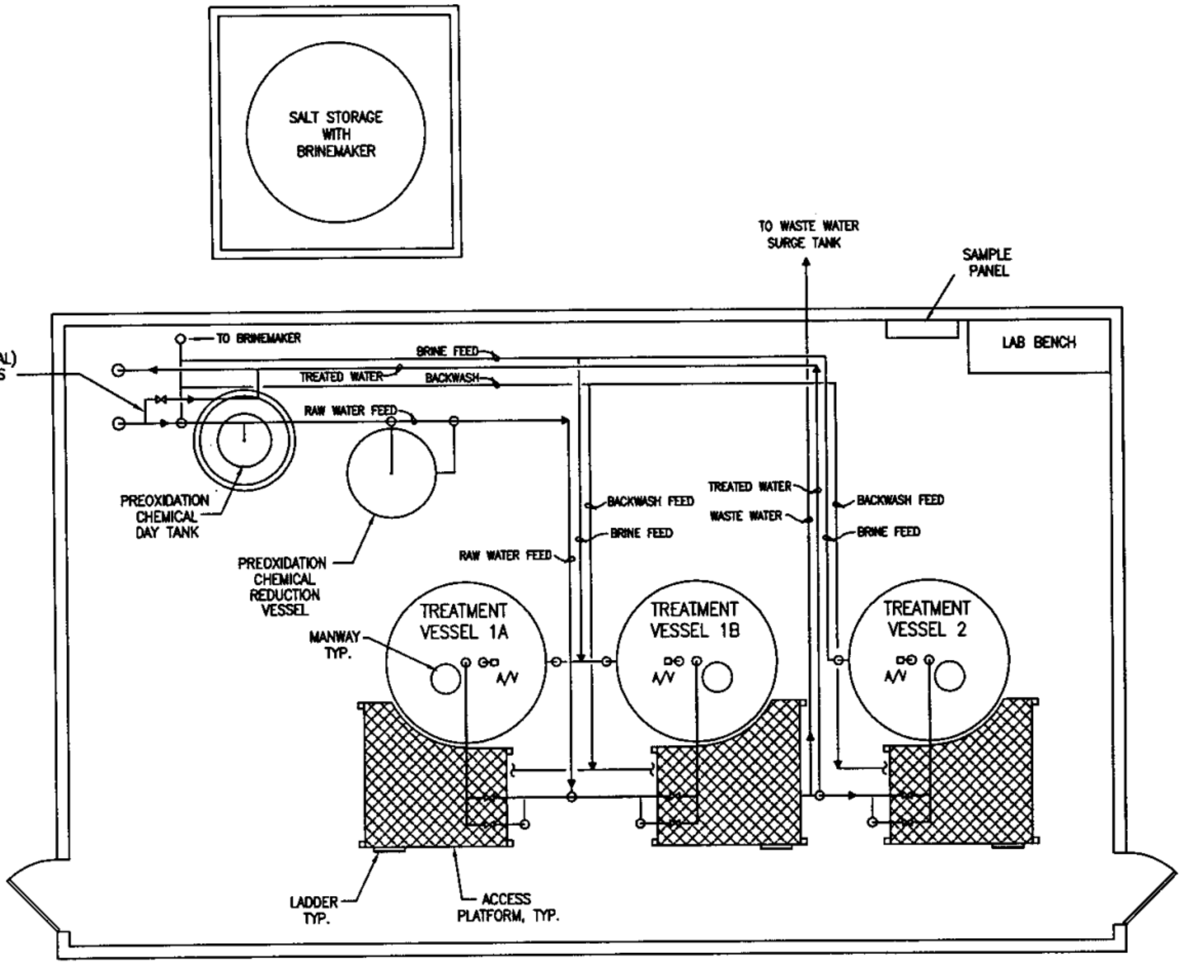


Figure 20: Preliminary plan view for a fixed-bed IX system with brine regeneration.

Source: “Design Manual: Removal of Arsenic from Drinking Water by Ion Exchange”, EPA/600/R-03/080

An isometric drawing shows the piping and tanks in a 3-dimensional layout. See Figure 21 for an example. Isometrics are particularly helpful for ion exchange systems since there is a complex arrangement of piping and valves at each vessel. Often plan and section views are insufficient for a Contractor to perform a proper installation.

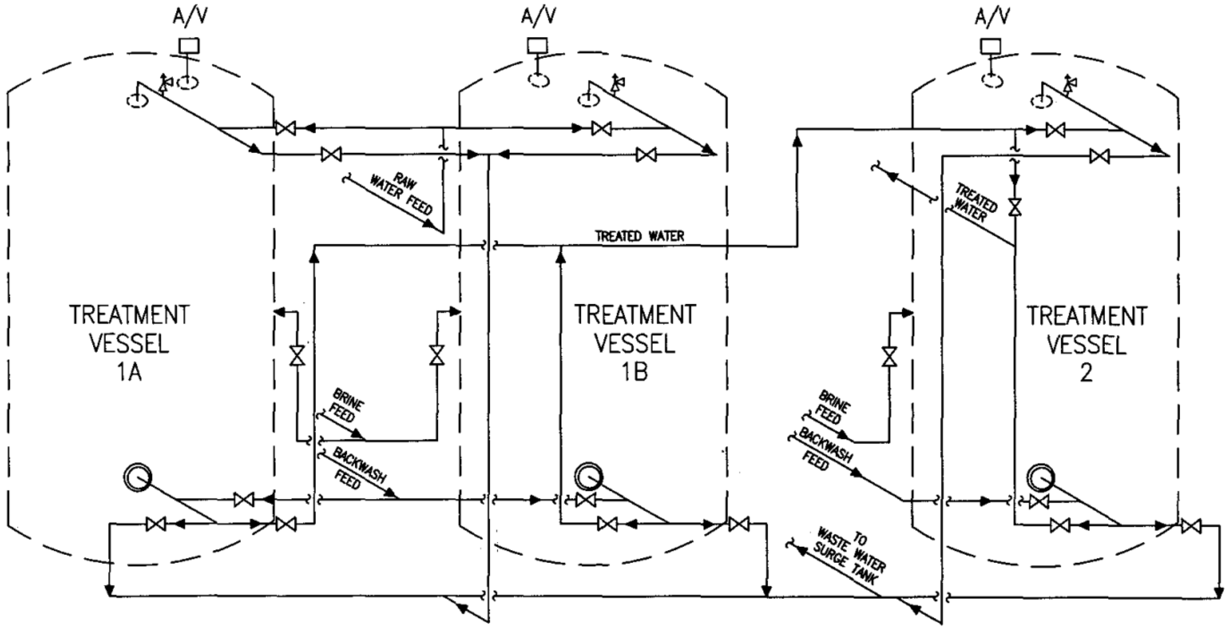


Figure 21: Isometric showing the piping arrangement at three IX vessels.

Source: “Design Manual: Removal of Arsenic from Drinking Water by Ion Exchange”, EPA/600/R-03/080

Lifecycle Cost

Since ion exchange systems include substantial operations and maintenance costs, it is appropriate to estimate the lifecycle cost in addition to the capital cost. Lifecycle cost refers to the total cost of ownership over the life of an asset. This whole-life costing includes costs incurred after an asset has been constructed, such as maintenance, resin replacement, energy usage, operation, and disposal costs.

The lifecycle cost can be calculated using the present worth approach. The formula is as follows:

$$Lifecycle\ Cost = Capital\ Cost + Annual\ Maintenance * PWF - Salvage\ Value$$

where: $PWF = Present\ Worth\ Factor = \frac{(1+i)^T - 1}{i*(1+i)^T}$

$i = interest\ rate$

$T = number\ of\ years$

IX system installation costs for municipal drinking water applications range from $3,000 to $10,000 per gpm of design flow.

The resin media is a significant portion of the cost. And some resin is lost over time due to carry-over, meaning that new resin needs to be purchased every few years to replenish the lost resin. Common resin costs are as follows:

- <u>Cation resin</u> for household softening can cost **$200** per ft^3.
- <u>Anion resin</u> can cost **$500** per ft^3, or $350 per gpm of design flow.
- <u>Chelating or magnetic resin</u> can cost **$1,000** per ft^3.

Example Problem 2:
Engineer Zara needs to calculate the 20-year lifecycle cost of an ion exchange system, rounded to the nearest $1,000. The interest rate is 5%. The salvage value at 20 years is 20% of the capital costs. Capital costs are provided in Table 6 and maintenance costs are in Table 7.

Table 6: Capital Costs for Example Problem 2

Item	Unit	No. of Units	Unit Cost ($)	Total Cost ($)
IX Vessels	Item	4	80,000	240,000
Specialty Resin	Ft^3	1000	800	800,000
Valves	Item	24	10,000	240,000
Piping	Feet	800	100	80,000
Instrumentation	Sum	1	30,000	30,000
Electrical and Controls	Sum	1	80,000	80,000
Contractor Overhead, Profits, Warranty, etc.	Sum	1	250,000	250,000

Table 7: Annual Maintenance Costs for Example Problem 2

Item	Unit (/yr)	No. of Units	Unit Cost ($)	Total Cost ($/yr)
Resin Replacement with Delivery	Ft^3	200	800	160,000
Maintenance Labor	Hrs	600	60	36,000
Maintenance Materials	Sum	1	10,00	10,000
Electrical Power	kWH	70,000	0.10	7,000

Solution:
Zara sums the capital costs in Table 6, which add to \$1,720,000. She sums the maintenance costs in Table 7, which add to \$213,000 per year.

Next, Zara calculates the present worth factor, PWF:

$$PWF = \frac{(1+0.05)^{20}-1}{0.05*(1+0.05)^{20}} = \frac{1.65}{0.13} = 12.46$$

Now, Zara calculates the lifecycle cost:

$$Lifecycle\ Cost = Capital\ Cost + Annual\ Maintenance * PWF - Salvage\ Value$$

$$Lifecycle\ Cost = \$1{,}720{,}000 + \$213{,}000 * 12.46 - 0.2 * \$1{,}720{,}000 = \$4{,}029{,}980$$

$$Lifecycle\ Cost = \$\mathbf{4,030,000}\ \ \text{(rounded)}$$

Helpful References

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