Ion Exchange System Selection Criteria: Design and Operational Considerations

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ABSTRACT

Ion exchange (IX) technology is considered Best Available Treatment Technology (BATT) for removal of many regulated inorganic compounds in municipal and industrial water streams. Developments in resin technology offer new treatment options, but the treatment system design can significantly impact operational costs, and ultimately, the system lifecycle costs.

Ion exchange systems can be classified into two broad categories; lead-lag or staggered bed. Each system design has its strengths from an operational perspective. Selection criteria should include influent water quality variability, primary and secondary treatment goals, as well as costs associated with regeneration chemicals and waste stream handling requirements. Waste stream disposal options also need to be further classified into onsite “pre-treatment” and final offsite disposition. Requirements for system operation and maintenance are also critical and needs to be accounted for in the overall lifecycle cost.

Many states now prescribed standardized IX system treatment approaches, but many now realize that these designs are not the most sustainable in the long run. Consequently, many regulatory agencies are now encouraging demonstration and implementation of IX systems that can significantly improve performance, lower costs and enhance sustainability. Since waste disposal can represent a significant portion of the operational cost, implementing an environmentally “greener” solution and lowering overall operating costs are not mutually exclusive.

Experience in design, implementation, and operation of IX systems is also critical when considering this treatment technology. End users should realistically assess whether they can operate these systems or develop a service relationship for long term reliability and cost control. Balancing treatment goals, technology solutions and operational considerations will result in a successful, cost effective IX system.

INTRODUCTION

Ion exchange (IX) is a widely accepted process for removal of targeted, typically inorganic compounds. Its ability to selectively target and remove recalcitrant compounds to very low levels makes it an ideal treatment technology for a broad range of applications. Since IX utilizes a regenerant and creates a waste stream, proper system design and operation is vital to long-term process reliability and cost effectiveness.

It is essential to consider all of a system’s operational and maintenance factors during the design phase. Almost any IX process can be adjusted to meet base requirements for treated water, but an integrated approach is required to avoid performance issues and excessive treatment costs. The system designer should look at overall system utilization, potential variations in raw water quality, long term waste handling options, and the financial dimensions of waste disposal, regenerant supply and property valuation. The ability of the designer to evaluate these factors on a cost-per-treated volume basis is critical to the optimal selection of an IX process.

Thorough knowledge of the operation and maintenance of IX systems is also necessary to ensure optimal performance throughout the project life. For example, in some locations a waste rate reduction as small as 0.1% can significantly reduce operational costs; this can be accomplished by fine-tuning the regeneration process and/or operating the unit to consistently meet minimal effluent treatment goals. With process controllers to closely monitor and adjust these parameters, operator attention is reduced on the process end and can be directed to routine system maintenance. Precise process adjustments made by experienced system operators can also help optimize system efficiency. Finally, advances in IX resin properties can create significant cost savings in cases where a media change-out is warranted to improve system performance. All of these factors can contribute to the ultimate goal:

providing an IX system that offers the lowest lifecycle cost to the customer.

ION EXCHANGE PROCESS

Ion exchange treatment is the exchange of ions between the aqueous solution and the ion exchange's fixed-charge counter ion. Ion exchange resin has a total capacity and an operating capacity, which are dependent on the following factors:

- Type of resin and total number of functional sites per unit of volume.
- Regenerant used
- Percent concentration of the regenerant
- Dosage (Lbs/CF)
- Empty Bed Contact Time (EBCT) or Total Regenerant Contact Time (TRCT).
- Ratio and affinity of ions in the feed stream to the resin

With perfect plug flow, the ions will partition based on their affinities for the ion exchange resin. In co-flow regenerated applications, these ions are pushed through the ion exchange resin in the same direction as the service flow. Since the regeneration process is not 100% effective, a heel of partially exhausted resin in a down flow system will be at the bottom of the vessel and cause leakage of these ions while the system is in service. The operating capacity of IX resin is typically 30-75% of the total capacity, depending on the factors listed above.

Counter-current regeneration pushes the ions out of the vessel in the opposite direction from which they came. With perfect plug flow the ion segregation is reversed, with the highest regenerated resin residing in the lower portion of the vessel, minimizing leakage of exhaustion ions. In reality, however, perfect plug flow is not possible on commercial systems; thus there is always some leakage, but the level is orders of magnitude lower in counter-current systems (typically 10-100 times less).

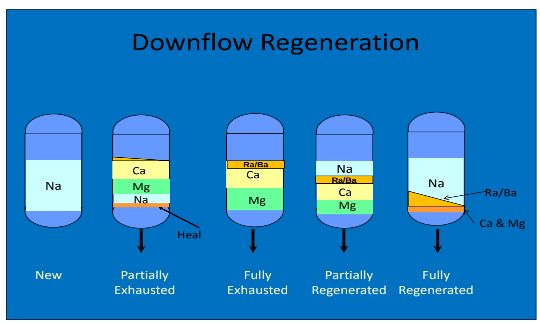
ION EXCHANGE TREATMENT

The feed water quality and the valence of the contaminant will determine which type of resin is selected to treat the water. Contaminate ions can be in the form of elements or compounds. Many elements form oxyanionic species in water, such as arsenate $(AsO_3)^{-2}$, molybdate $(MoO_4)^{-2}$, chromate $(CrO_4)^{-2}$. nitrate $(NO_3)^{-1}$, and sulfate $(SO_4)^{-2}$ are other examples of oxygenated compounds of the element. Chloride $(Cl)^{-1}$, calcium $(Ca)^{+2}$, sodium $(Na)^{-1}$ and magnesium $(Mg)^{+2}$ are examples of elemental ions.

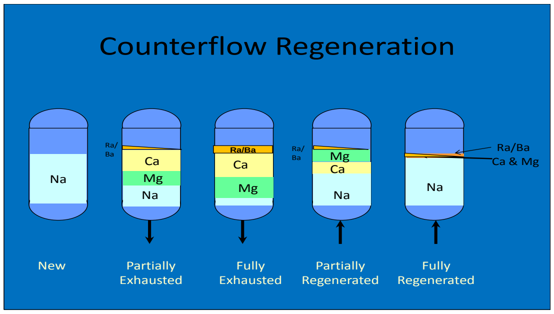
The valance (charge) and size of the ion determine the affinity of the ion to the functional site of the resin. The higher affinity ions bond more tightly to the resin and determines the order (under plug flow) they are adsorbed within the resin bed. For example, the nitrate $(NO_3)^{-1}$ ion is anionic; however, sulfate $(SO_4)^{-2}$ has a higher valance and is an interfering ion. The sulfate's higher affinity for a type I anion resin results in the nitrate ion being pushed progressively farther down through the resin bed. The alkalinity and chloride-to-nitrate ratio also affect performance. The resin is in the chloride form. In co-current regenerated systems, the chloride ion concentration is used to push the nitrate and sulfate through the vessel. This typically requires >10 lbs. of brine per cubic foot (cf) of resin. Consequently, regenerations with only 5-8 lbs/cf will leave sulfates and some nitrate in the resin bed.

In co-current systems, regenerant ion concentration is used to push the contaminant through the vessel in the same direction as it was adsorbed. This drives all the contaminants through the entire vessel and any remaining contaminants stay in the bottom of the vessel. These contaminants are then released when the system goes back into adsorption, creating contaminant "leakage" from the bottom of the vessel. In order to reduce this leakage, the regenerant dose must be increased beyond the typical, efficient level.

Below is an illustration of this theory using a water softener as an example.



Counter-current regenerated systems will have a similar resin capacity but operate at 20% to 50% better regeneration efficiency (i.e. salt usage) with a lower leakage. Improvements include better salt utilization, a reduction in rinse water volume required, better distribution design, and packing the resin to prevent bed re-characterization (i.e. mixing) and maintain the wave fronts (chromatographic separation). Consequently, the leakage rate is significantly lower for the exhaustion ions until the wave front reaches the lower portion of the vessel. The breakthrough curve is exponential versus a more linear breakthrough curve of conventional down flow regenerated systems. Below is a graphic example of the theory:



The balancing of the factors above and the acceptable leakage rate will determine the actual capability of the counter-current regenerated system. Optimum salt usage to determine the throughput, leakage rates and low lifecycle cost is established during validation studies on the water in question.

Counter current regeneration along with the staggering of vessels allows an individual vessel to go beyond the normal breakpoint, increasing operating capacity. Segregation of the regeneration elution fractions allow for the cascading or reclaim of brine, which reduces regenerant chemical usage and waste volume. The blending effect of multiple vessels and reuse of brine increases the operating capacity another 15-30% versus conventional co-current systems. We have seen total increases in the 30-40+% range versus co flow modeling, depending on feed water quality.

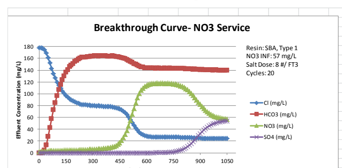
SYSTEM OPTIONS

Ion exchange treatment systems can be classified into two broad categories; lead-lag or staggered bed. Lead-lag systems are simply serial treatment with two or more vessels in series. This allows the lead vessel to become fully exhausted while producing a very good (i.e. low contaminant level) effluent quality. Depending on the total influent ion concentration, one typically runs the lead vessel to 20-50% contaminant breakthrough before removing it from service and moving the lag vessel(s) up in the treatment order. A typical limitation is overall pressure drop, which practically limits the number of vessels the designer can put into service. A key advantage is that the lag vessel(s) are typically considered a guard bed and provide additional process security in the event of influent process upset.

Staggered bed operation is a parallel common feed header flow pattern utilizing two or more vessels. The "staggering" comes from each vessel being operated at various points on the capacity exhaustion curve. The most basic design is an independent parallel system, where the number of vessels typically is equal to the number required for normal flow (2-3 vessels). Each vessel's regeneration is based on throughput or time in service, and is only staggered by the duration of an individual vessel's regeneration. This system design is commonly referred to as "N" design where "N" equals the number of vessels required for flow.

An upgrade to the above is the N+1 design in which N vessels are for flow and an additional vessel remains in either regeneration or standby mode. This design allows the vessels to maintain staggered gaps on the exhaustion curve.

Advanced staggered system or carousel IX systems typically consist of eight or more treatment vessels that operate in parallel treatment. This results in a blended effluent water quality which can be easily predicted and controlled. Since the system has multiple vessels treating the influent water, one or more vessels can be totally exhausted (i.e. 100% contaminant breakthrough) or beyond that point while still maintaining the required effluent water quality (see Figure 1). Parallel treatment provides the benefit of reduced media pressure drop while still maintaining required hydraulics and volumetric flow parameters. Typically, a staggered bed system will operate at a higher target contaminant level than a lead-lag system under the same process conditions.



BV Set Point	615															
NO3 Goal (mg/L)	28															
Vessels On Line	13															
BV Split	47.30769231															
	Vessel 1	Vessel 2	Vessel 3	Vessel 4	Vessel 5	Vessel 6	Vessel 7	Vessel 8	Vessel 9	Vessel 10	Vessel 11	Vessel 12	Vessel 13	Vessel 14	Vessel 15	Vessel 16
BV Operating Point	615	568	520	473	426	378	331	284	237	189	142	95	47	0	0	0
NO3 Contrib (mg/L)	115.99	100.72	65.35	25.61	11.23	7.61	6.54	5.70	4.92	4.45	4.09	3.72	2.98	1.75	1.75	1.75
NO3 Contrib (mg/L)	115.99	100.72	65.35	25.61	11.23	7.61	6.54	5.70	4.92	4.45	4.09	3.72	2.98	0.00	0.00	0.00
NO3 Effluent (mg/L)	27.6															
NO3 Goal Met	Goal Met															
Waste Rate (%)	0.21%															

Figure 1- Example of vessel staggering in nitrate service

Many states now accept the staggered bed design (see Figure 2) as an equivalent to lead-lag in terms of process safety due to the blending effect of multiple vessels. Essentially, treatment redundancy is accomplished by the multiple beds versus a single guard bed.

As can be seen above (Fig. 1), even though the IX vessels are allowed to reach full exhaustion (116 ppm NO_3), the blended effect with counter current regeneration results in an effluent of 27.6 ppm NO_3, lower than the treatment goal of 28.0 ppm NO_3 (6.5 ppm as N) and well below the MCL limit of 43.3 ppm NO_3 (10 ppm as N) for U.S. municipal drinking water systems.

Figure 2- Advanced staggered bed system utilizing fixed bed design

Resin selection is an important part of the system design and can enhance system performance. Selection is based on the target contaminant, total ion load (either anion or cation), salt usage versus waste rate tradeoff, and waste profile considerations. Today, there are many selective type resins available on the market. These resins are tailored for specific applications and process conditions, but offer additional properties that can improve system performance. For example, a steep breakthrough curve limits the ability to overrun the beds in a staggered bed design; conversely a shallow breakthrough curve can improve its function. Another resin selection factor is the selectivity of other ions relative to the target contaminant. To avoid concentrating other ions in the waste (e.g. chrome), you want a lower selectivity relative to the target contaminant selectivity. This allows the target contaminant to displace the other ions, keeping it from being concentrated in the waste stream. These more subtle process options can dramatically affect life cycle costs. Examples of these factors will be shown in the case study section.

DESIGN CONSIDERATIONS

There are many factors that drive system design decisions, but the key factors that affect life cycle costs include:

- Required vs. desired treated water quality
- Stability of influent water quality over time
    - Regenerable or replaceable (i.e., single pass) resin
    - Waste rate produced on a per volume basis
    - Waste handling options
        - Municipal Sewer system
        - Evaporation lagoon
        - Trucking
        - Hazardous waste
    - Regenerant consumption on a per volume basis
    - Total throughput per unit of volume versus operating capacity (Regeneration)
- Infrastructure requirements
- Capital Costs
- Operator availability and skill to operate the IX treatment plant

The factors listed above are critical in the project financial analysis and selection of IX systems. This analysis should include a life cycle cost analysis for the entire project, including both capital and operating/ maintenance (O/M) costs over a term of 5-10 years. Treatment project duration and equipment life may well exceed this period, but the unknown factors (i.e. chemical costs, regulatory changes, utilities, etc.) are difficult to predict beyond this time frame and may negatively skew the decision-making process. Typically, capital investment costs are dwarfed by O/M costs over a 10-year period when considering items such as waste removal and disposal or salt usage. However, this is highly dependent on physical location and varies from state to state.

The first step in the design process is to model and determine optimum points for resin adsorption and regeneration parameters. This includes variations in regenerant (salt) doses to obtain the breakthrough curves typically expressed in terms of Bed Volumes. (Bed Volume is a unit-less term that allows us to define the process without being concerned with physical vessel size or system flow rate. A bed volume is the amount of resin that is contained in each vessel.) Determining the BV throughput and the regeneration process will define the overall system waste rate. Waste Rate (%)= BV of waste/ BV adsorption set point X 100%. For example, for a high efficiency, staggered bed nitrate treatment system operating with a 425 BV set point, and assuming 1.3 BV of waste, the waste rate would be 1.3/425 X 100%= 0.306% overall waste rate. Increasing the salt dosage could extend BV adsorption and potentially cause a slight increase in waste volume, but would likely reduce the overall waste rate. There is a point, however, of diminishing return; in addition to an increased salt dose, the rinse volumes required would also have to change to achieve acceptable salt removal. Computer modeling allows us to quickly evaluate these points based on the IX treatment system options being considered.

Design of the regeneration process is as critical as the sizing of the IX system itself. Regeneration affects the waste rate, system throughput, and stability of the treated water effluent water quality. The regeneration process is broken up into the following general steps:

- Backwash
- Chemical Addition - 1 or 2 times
- Contact time(s)
- Rinse- Slow (displacement) and fast (final and media setting)

Regeneration is either co-current or counter-current relative to the adsorption flow direction. The advantage of counter-current regeneration is lower initial contaminant leakage as the IX vessel is put on line versus the lower capital cost associated with co-current regeneration design. This difference becomes important when considering staggered bed versus lead-lag design, as the initial contaminant leakage affects the blending effect of the multiple vessels. This tradeoff becomes relevant when one is looking at project life cycle costs, since the capital investment for a staggered vessel IX system is higher than a conventional lead-lag.

A subtle issue of staggered bed design is the overall regeneration cycle time relative to the adsorption cycle. As one vessel comes off line, another vessel needs to take its place to maintain hydraulic loading and EBCT. Since the vessels operate in parallel at various stages of adsorption, the regeneration cycle time must be closely designed to finish before the next vessel is removed from service. For example, if you have 10 vessels on line and the regeneration cycle is 90 minutes per vessel, the adsorption cycle must be at least 810 minutes in duration. (90*(10-1) = 810 minutes.) If the regeneration cycle is too long the vessels will begin to stack, waiting for regeneration, and create the potential for operational problems during peak system loads. Lead-lag systems do not typically have this issue, as each vessel contains more resin and the adsorption cycle time is much greater than the regeneration time.

It is also important to look at water quality trends over time for well treatment applications. This includes annual and seasonal trends for the contaminant of concern. As well usage increases, contaminants from neighboring aquifers can be pulled into the treated well aquifer. Conversely, during off-peak demand periods, intrusion from neighboring aquifers is diminished. Even annual rainfall can greatly affect contaminant loading. For example, one shallow well in Southern California sees a 75% increase in NO3 level during wet “El Nino” years. While this requires them to have a treatment system on line, the system may only see substantial use every 3-5 years.

Finally, utility and infrastructure requirements must be considered. Collection and disposition of the waste stream is the first consideration. Since waste disposal can represent 60% of overall operating cost, it is vital to determine how it will be handled. Typically, the waste is sent to an industrial sewer connected to a publicly owned treatment works (POTW), collected and trucked to a waste disposal facility, or put into an evaporation pond. The life cycle cost should consider all available options, including land valuation in the case of an evaporation pond. Even POTW treatment has a cost associated with the treatment of the liquid, whether it is owned by the end-use client or not.

In order to determine which options are viable, the regenerant waste composition should be either modeled or characterized as part of a pilot test. The key concern here is that other ions, having been concentrated as part of the IX process, may constitute a hazardous (Federal, State, or Local) waste. (IX process can increase concentration by 100X to 2500X depending on the application.) Many times, entities receiving the waste will have tighter standards for these compounds which will typically increase system operating costs. Changes in IX process parameters or resin type can address some of these issues.

Salt usage and the associated delivery costs typically account for 30% to 50% of IX system operating costs. The IX process parameters and equipment selection will determine salt usage on a throughput basis. A significant portion of the salt costs, however, arise from transportation and delivery of the salt to the site. Salt for larger IX units is delivered in bulk loads and is “blown” into the briner (regenerant) system. The most economical salt delivery is 25 tons, which is the maximum load allowed on most US roads. This means the salt briner should be sized to accept at least 25 tons; optimally as large as practically possible, but no bigger than 60 days of salt storage capacity. The larger brine tank will accommodate full salt deliveries and allow for long weekend operation without requiring additional deliveries. Typically, you want to size the salt briners to hold between 36 and 41 tons of bulk salt. On smaller systems or one with lower utilization, the designer may choose to go with smaller briners to avoid long periods of salt storage which may result in salt bridging or bacteria formation.

OPERATIONAL CONSIDERATIONS

Operational costs represent 30% to 70% of the overall life cycle cost of the IX treatment system. In order to minimize this cost, proper operation and ongoing maintenance of the system is critical. Proper operation includes monitoring of process indicators, trend analysis of influent and effluent parameters, and verification of regeneration process steps such as step sequence times and volumetric totals. Maintenance goes beyond instrumentation calibration and repair of broken components; it should include routine overall process review for potential cost savings. This would include process changes due to influent quality variations, system optimization to operate consistently at process limits, and resin performance monitoring to ensure reasonable operating capacity. Experienced operators with the close support of process engineering are necessary to achieve this level of operation and maintenance.

Routine operations represent the largest part of the operating costs. Of these costs, waste handling and salt usage are the major factors. Maintaining and operating the system under design conditions will minimize these expenses, but these costs are driven by the open market. Service companies that operate these types of systems can provide these items at reduced rates due to the volume handled on an annual basis. They are also more efficient in salt deliveries and waste hauls (if applicable) as they will move full loads and minimize trip charges. When using an outside service company, it is important to exactly specify the type of salt supplied and how the waste is characterized, manifested, and ultimately disposed of. These seemingly minor details can result in poor process operation (in the case of salt quality) or in large waste disposal costs (in the case of waste classification). A service company with in-house technical support capability or working closely with consulting engineers can help mitigate these types of issues.

Performance trending is key to ensuring consistent water quality at the lowest operating cost. Knowledge of trends allows the operator to monitor real time performance and foresee equipment or process problems before they result in system shutdowns. The following minimum process conditions should be recorded and trended:

- Pressure- Influent, effluent, and through various regeneration steps
- Flow- Influent, effluent, and regenerate/ rinse flows
- Conductivity- Influent, effluent, waste
- Contaminant concentration (If device available) - Influent and effluent. Additional sample port for spot process checks.
- Cycle times- Adsorption and regeneration process steps

This data, along with outside water quality analysis, allows operations to run the IX unit consistently at the effluent target level. It is critical that operations run the unit as close to the target level as practical to minimize costs. The ability to run at the optimized treated water quality is a function of both operator attention and the type of IX system used, and can result in significant operational savings. For example, trimming the waste rate by 0.1% on a 1000 GPM system would reduce the waste volume by more than 525,000 gallons annually with a cost savings of $105,120 (assuming $0.20/gallon waste disposal).

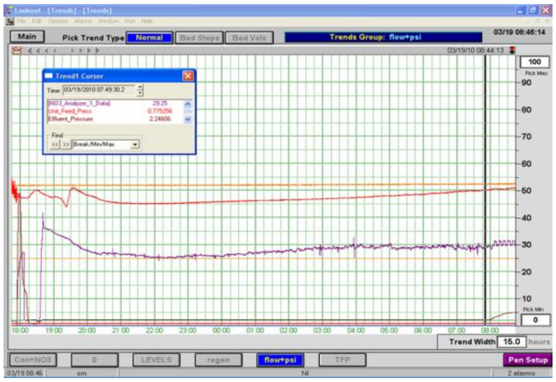


Figure 3 - Example of trending screen showing flow, pressure, and effluent NO3 level.

Effective monitoring of the IX system requires higher end process controllers and sufficient external disk space to capture the data. Ideally, this data is communicated back to operations where it can retrieved and analyzed. Today, smart phones work well to communicate, monitor, and provide prompt notification if the IX system goes into warning or alarm conditions. This requires a communication link between the IX system and the outside world. We recommend the customer install a “hard line” to ensure uninterruptable service and the ability to upload or download information to the process controller.

CASE STUDIES

The following case studies are based on operational drinking water plants. These plants have service contracts which allow us to closely monitor performance over an extended period. Operational examples with results are shown to support the issues discussed above.

CASE 1 – Case 1 is a municipal water plant, treating perchlorate, located in southern CA. The customer was considering both a lead-lag and a staggered bed design. Using the breakthrough curve, perchlorate leakage from each vessel is added based on the stagger set by the BV set point (i.e., 205,000/12= 17,083). The table shown below (Figure 4) provides an example of this BV set point and the relative ClO_4 contribution for each vessel. This process setting would result in < 4 µg/L (actually 3.82 µg/L) of perchlorate in the treated water.

The lead-lag design set point is calculated based on loading the resin to 99.7% of its 18 meq/L capacity. (It is unlikely we will be able to load up the resin beyond this capacity in a lead-

Effluent ClO4 Goal (ppb)	4.00												
Vessels on line	12	11	10	9	8	7	6	5	4	3	2	1	0
BV Set point	205000												
		Vessel 1	Vessel 2	Vessel 3	Vessel 4	Vessel 5	Vessel 6	Vessel 7	Vessel 8	Vessel 9	Vessel 10	Vessel 11	Vessel 12
BV Setpoint Differential	17083	205,000	187,917	170,833	153,750	136,667	119,583	102,500	85,417	68,333	51,250	34,167	17,083
ClO4 Contrib/ Bed		10.801	9.820	8.677	6.811	4.819	2.906	1.411	0.503	0.123	0.030	0.020	0.019
Effluent ClO4 (ppb)	3.82	10.801	9.820	8.677	6.811	4.819	2.906	1.411	0.503	0.123	0.030	0.020	0.019
Target Met	GOOD												
	BV's	ClO4 (ppb)											
Lead-Lag Set point	157,106	3.983											
BV Gain	47,894												
BV % Gain	30.49%												
Resin Cost (FT3)	$175.00												
Flow Rate (GPM)	4500												
Flow Production (AF/Yr)	7,259		2365200000										
		Lead-Lag	Staggered Bed										
BV Size (Gal)		3,172	187										
BV's (annual)		745,762	12,648,128										
BV Size (FT3)		424	25										
Resin Consumed (FT3)		2,013	1,542		470								
Change Out Freq (days)		307.6	118.3										
Resin Replacement Price ($/Yr)		$352,218.00	$269,929.57										
Resin Replacement costs ($/AF)		$48.52	$37.19										
Initial Resin Load (FT3)		3,392	2,600										
1st year savings- After Resin Reload			$82,288.43		23.36%								
1st year Savings/ AF- After Resin Reload			$11.34										

BV's Gained from Staggered Bed Design

Annual Resin Savings

Annual Resin Savings based on $175/ FT3 resin price

Figure 4 - Proforma financial analysis showing benefit of staggered bed design.

lag process mode without significant leakage to the lag bed.) This high loading is achievable due to the resin’s high selectivity coefficient of perchlorate over other anions including nitrate. The optimum loading will be to run the lag vessel to approximately 75,000 BVs and then switch it to the lead position. This will allow the lead bed to completely exhaust while maintaining an average perchlorate leakage at less than 4 µg/L from any one lead-lag pair. Extending the bed life beyond 157,106 BVs would result in a vessel pair leakage exceeding the 4 ppb requirement. The actual results may vary slightly due to operational conditions and water quality changes; especially increases in nitrate levels.

The staggered bed design will result in a 30% gain in BVs over a lead-lag design. This equates to 470 FT^3 less resin consumed annually. The actual savings would be based on the resin and disposal costs incurred over the life of the project. Following is an example where the resin cost ($175/ FT^3) and disposal cost ($10/ FT^3 including labor) is used over a 10-year project life using a 1% inflation rate and a 4% cost of money.

		Yr 0	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8	Yr 9	Yr 10	Project Total
Lead Lag		$0.00	$372,344.75	$376,068.19	$379,828.87	$383,627.16	$387,463.44	$391,338.07	$395,251.45	$399,203.96	$403,196.00	$407,227.96	$3,895,549.87
Staggered		$0.00	$285,354.12	$288,207.66	$291,089.73	$294,000.63	$296,940.64	$299,910.04	$302,909.14	$305,938.23	$308,997.62	$312,087.59	$2,985,435.40
Project Savings		$0.00	$86,990.63	$87,860.54	$88,739.14	$89,626.53	$90,522.80	$91,428.03	$92,342.31	$93,265.73	$94,198.39	$95,140.37	$910,114.46
NPV		$707,515.07											

Figure 5- Proforma financial analysis showing annual cost savings.

This would result in a savings of $0.71 MM in current dollars based on this time period. There are additional minor costs that may increase overall O&M costs for either system. The savings shown here, however, would increase over an extended project duration, for annual inflation rates greater than 1%, or for an increase in resin usage based on changes in water quality.

The capital and O&M costs are used to determine lifecycle costs. For this example we will use capital costs for both systems and estimated installation costs. The lead-lag system proposal included delivery and erection of eight vessels, face piping to interconnect the vessels, and electrical work to route signals back to the customer's SCADA system. We estimated the construction cost at $150K. The cost associated with the installation of the staggered bed systems, covering the same portion of the construction, will require $70K. This assumes that a single Ethernet cable will be routed to their SCADA system. Using these numbers, we determined the following lifecycle cost based on the same assumption used above.

Inflation (%)	1.00%												
COC (%)	4.00%												
		Yr 0	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8	Yr 9	Yr 10	Project Total
Lead Lag		$2,460,000.00	$372,344.75	$376,068.19	$379,828.87	$383,627.16	$387,463.44	$391,338.07	$395,251.45	$399,203.96	$403,196.00	$407,227.96	$6,355,549.87
Staggered		$1,465,000.00	$285,354.12	$288,207.66	$291,089.73	$294,000.63	$296,940.64	$299,910.04	$302,909.14	$305,938.23	$308,997.62	$312,087.59	$4,450,435.40
Project Savings		$995,000.00	$86,990.63	$87,860.54	$88,739.14	$89,626.53	$90,522.80	$91,428.03	$92,342.31	$93,265.73	$94,198.39	$95,140.37	$1,905,114.46
NPV		$1,664,245.64											

Figure 6- CAPEX assumptions for comparison between processes.

This represents a $1.66 MM project savings in current dollars based on this time period. The savings would increase over a longer project duration, annual inflation rates greater than 1%, an increase in resin usage based on changes in water quality, or if higher installation costs for the lead-lag system are encountered.

CASE 2 – Case 2 is a municipal water plant treating nitrate, located in AZ. This plant was using a staggered bed system, but began to experience build-up of chrome (Cr) in the wastewater. The waste chrome level averaged 3-4 mg/L but would vary with influent Cr levels, sometimes resulting in a RCRA waste stream.

Computer modeling of the process using a nitrate selective resin clearly showed the problem. The nitrate curve broke in front of the chromate curve so the resin would retain the chrome, which would be released in the regeneration step.

The only way to reduce the overall concentration was to "over rinse" the system, thereby reducing the total chrome concentration in the system. This increased the waste ratefrom 0.299% to 0.686%, resulting in an increase of 3,400 gallons of additional daily waste at a cost of $678/day. In order to reduce waste disposal

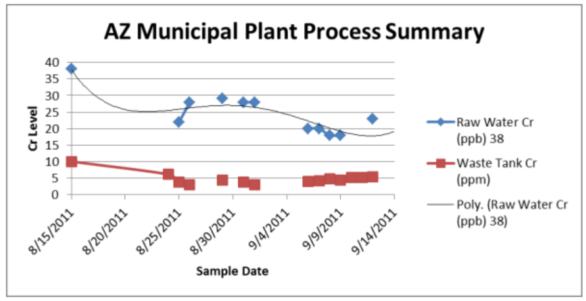


Figure 7- Example of trending screen showing flow, pressure, and effluent NO3 level.

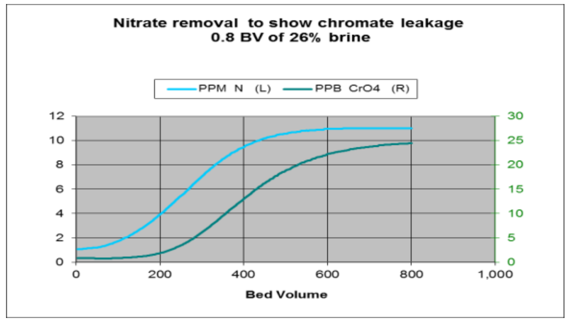


Figure 8- Breakthrough curve of NO3 and CrO4 on nitrate selective resin.

costs, several options were considered.

Reviewing the current waste profile, chrome segregation appeared to have potential. It is well known that chromate comes off rapidly and sharply from anion resins. This creates the potential to capture and treat a small volume of the waste stream, keeping the chrome out of the bulk waste solution. This effect is shown on the graph below (Figure 9).

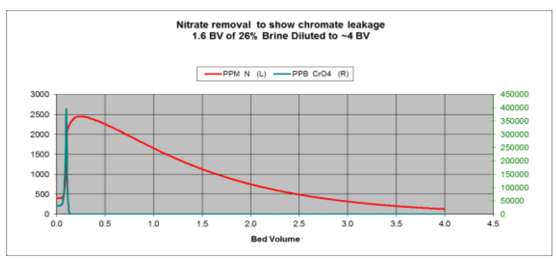


Figure 9- Regeneration curve showing sharp CrO4 removal peak.

Capturing the chrome is the first 0.5 BVs (~94 gallons), and sequestering it for additional Cr removal treatment, including precipitation or adsorption on Cr selective resin, was a viable option. This would allow the waste rate to return to the desired level and create a manageable waste stream. The down side of this approach was adding a secondary process and the required permitting necessary to “treat” this waste stream.

Another option was to evaluate other resins that would preferentially select nitrate over chromate and thereby leave the low levels of chrome in the treated water. This process would not only eliminate the issue with chrome but reduce the waste below the historic level. Our approach here was to use a perchlorate-selective resin in place of the nitrate-selective resin. The model results are shown below (Figure 10).

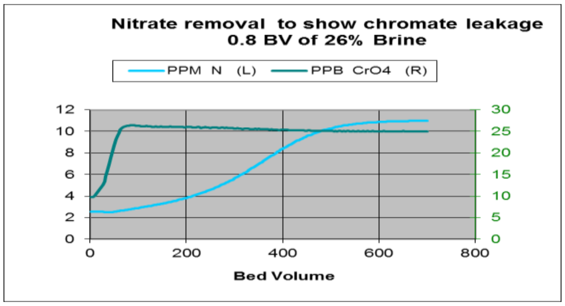


Figure 10- Breakthrough curve of NO3 and CrO4 on perchlorate selective resin.

In this case, the chrome is adsorbed and then displaced by nitrate back into the treated water. This chromatographic peaking (i.e. dumping) would potentially be an issue with a lead-lag unit, but is blended out with a staggered bed design. Performance of this resin is similar to the nitrate-selective resin, so the adsorption set point remained the same. However, since the rinse rate would now be lower than even originally set, the waste rate was reduced to 0.22% or 694 gallons/day, resulting in $139/day savings. Resin change-out costs were approximately $90,000, which is ~3 month return on investment.

CASE 3 – Case 3 is a municipal water plant, treating arsenic (11-13 ppb), located in WI. The initial evaluation was between coagulation filtration (CF) and high efficiency ion exchange. Both technologies were piloted side by side over a two week period. The influent water quality testing indicated a significant portion of the arsenic was in the reduced state (9-10 ppb). In addition, there was a moderate level of iron (300 ppb), but not enough to bind all of the arsenic. Both systems were able to treat the arsenic below the treatment target of 5 ppb (10 ppb is the MCL). The site did not have a sewer line and a new sewer line was not going to be added to the project. Therefore, all waste volume would need to be trucked the treatment plant.

Based on the piloting results, an economic value and life cycle cost evaluation was performed by the consulting engineer. The capital costs were projected to be similar. Since the site would not have a sewer line, the trucking disposal cost was a significant factor. The IX system was projected to produce less waste volume than the CF system. In addition, the chemical costs were project to be slightly more expensive for the CF system than the IX system. Consequently, the consulting engineer and community decided that the IX system would be a better fit for them.

This plant uses a counter current staggered bed design with brine reclaim. In addition, the system has an air and chlorine oxidation system to convert the arsenic to the oxidized state, and a bag filtration system (5 micron) to remove particulate. The IX system is a N+1 design with three vessels where N is equal to the number of vessels required for proper IX flow parameters (gpm/ft^2 and gpm/ft^3). The initial BV setting for this system was 2,550 BV which produces < 0.14% waste rate. The effluent arsenic level from the system was consistently, 2 ppb by field test and certified analytical tests.

Since the treatment plant operators are also the road maintenance, wastewater treatment plant, and building maintenance staff. The Original Equipment Manufacturer (OEM) recommended a long term service contract to support them in the maintenance and a technical support of the water treatment system, but the client decided to not pursue this option.

After about 1 year of service, the arsenic level increased to > 5 ppb from the system. The operators at that time noticed the regeneration steps were not occurring to the same length of time as previously and flow meter readings at the PLC were too high.

Upon investigation by the OEM’s service group, it was determined; a major electrical storm had damaged the electrical supply system tied to the treatment plant. The PLC battery backup maintained plant operation, but had affected the electromagnetic flow meter calibration. Unfortunately, the municipal operators did not notice the issue until the arsenic leakage was > 5 ppb. In addition to the major issue above, it was determined the operators had reduced the amount of air into the system, and were inconsistent in the monitoring of the chlorination and de-chlorination levels.

During the OEM’s service call, high iron content was measured in the brine recovery tank. The tank was dumped, flushed and new brine reclaim volume was made from the addition of salt and treated water. After resetting the system, air scouring the system and double regenerating the vessels, the arsenic leakage was still inconsistent.

Resin samples from the top and bottom of a vessel were obtained for analysis, field testing for arsenic of filtered samples indicated the arsenic leakage was due to particulate iron-arsenate (see Figure 11). The soluble arsenic (1 um filtered) was still less then <2 ppb. Samples were also collected for analysis in the lab.

Results:	Feed water	Effluent "B"
As unfiltered (ppb)	N/A	35
As after 1 µm (ppb)	N/A	<2

Figure 11 - Field arsenic test results

Since air scouring was ineffective to remove the amount of iron captured within the bed, the resin was cleaned with Hydrochloric acid, and further regenerated with salt. This returned the system to normal operation.

During this evaluation, it was determined that at the current setting for the oxidation system was < 11 scfm air and 0.08 ± 0.01 ppm free chlorine. Under these operating conditions, the 5 micron bag filter system was not removing the particulate iron. Upon further investigation, the iron appears to be colloidal at <3 micron in size (See Figure 12).

The OEM recommended the following three items:

1. Replace chlorine analyzers with models that would control chlorine levels to 0.15 to 0.20 mg/L free chlorine
2. Change pre-filtration filters to a 1 micron absolute fiber, bag filter
3. Obtain a service contract to assist plant operations in trouble shooting and maintaining the iX plant

These recommendations were NOT implemented. Approximately, six (6) months later the client contacted the OEM stating they needed to frequently backwash and scour the system. At the request of the Consulting Engineer, the OEM contacted the municipality and was told that the bag filters were not removing any iron. In addition, the chlorine level was measured 0.08 ppm free chlorine at the sample point.

Results:	Feed water	Effluent "B"
As unfiltered (ppb)	15	5
As after 3 µm (ppb)	14	5
As after 1 µm (ppb)	12	5
As after 0.2 µm (ppb)	12	5
Fe unfiltered (ppb)	160	20
Fe after 3 µm (ppb)	120	20
Fe after 1 µm (ppb)	30	10
Fe after 0.2 µm (ppb)	<5	10

Figure 12- Filtering test results for As and Fe using site feed water.

Subsequently, a 1 micron nominal (0.25 ppm Fe leakage), a 1 micron absolute (ND Fe leakage), and a 3 micron absolute (0.1 ppm Fe leakage) filter bags were tested. This testing confirmed the previous laboratory work, but the municipality returned to the original 5 micron nominal filters as they did not like the required change out frequency of the new filters.

The BV set point was reduced to 1,800 BV's to reduce the iron loading on the vessels for each adsorption cycle. Their current goal is to balance the frequency of air scouring with the frequency of bag filter change outs. The client has not purchased the proper chlorine analyzers, but states they are maintaining the proper levels. The plant is in operation now and meeting the treatment requirements.

Key lessons learned in this case are the following:

1. OEM needed to provide stronger justification to the Consulting Engineer for selection of the proper equipment that is outside OEM's scope.
2. Particle size analysis should be part of the water quality analysis for the design of proper pretreatment for counter-current systems with limited vessel head space for backwashing.

3. OEM and Consulting Engineer needs to be more cognizant of the municipality's operators capabilities and, if the situation is warranted, should strongly advocate pursuing a long term service support agreements to keep the system in proper operating condition.

CONCLUSIONS

System selection should include both design and operational considerations for reliable, long-term operation. Although initial system cost is an important consideration, evaluation on a life cycle basis provides a far more realistic treatment cost estimate and is necessary to properly calculate the overall cost for treated water. Waste disposal costs represent a large portion of the O/M costs to operate an IX treatment plant. Finally, skill and experience operating an IX plant, combined with a proactive maintenance plan, will help control costs and lead to further opportunities for system optimization.

The required treatment goal will determine the best system design. It is important to look at historical water quality data to develop realistic influent conditions. The treatment goal needs to consider both system and overall objectives to properly size and select the unit type. Staggered bed designs typically provide a very consistent effluent water quality at a higher efficiency, but at a higher, overall contaminant leakage level. Lead-lag systems have larger variations in effluent water quality and operate at a lower efficiency, but provide a lower overall contaminant leakage. Resin selection is typically driven by the overall ion concentration versus the trace contaminants typically targeted for treatment. It is still critical to look at ALL contaminants ionic and particulate to ensure the treatment goal can be achieved and the waste properly handled. In some cases, control of the waste profile will dictate the process resulting in a less than optimal IX process. Experience in both design and operation is key to identifying these issues and determining the best process conditions to satisfy all the requirements.

Long term service agreements with the OEM can benefit the consulting engineer and the end use client by keeping the system at peak operating conditions, and resolving any technical issues that may arise during the life of the system. With performance guarantees for controllable operating expenses associated with the treatment system, it should be viewed as a small insurance policy towards system sustainability and performance.