Disinfection Byproducts Control with Ion Exchange

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Abstract

Reduction of TOC prior to chlorination is an effective way to control the formation of Disinfection Byproducts (DBP). Use of brine regenerable ion exchange resins for TOC removal is an established and cost effective technology. Minimizing brine discharges to the environment is now very important in arid states as more municipal water treatment plants require the waste water from brine regenerable ion exchange systems be hauled away for disposal. Operating costs for such systems are now 4 to 6 times higher than for comparable systems with onsite brine disposal facilities. This presentation gives an overview of current technologies and explores a multiple reuse strategy for the spent brine from ion exchange systems, thereby reducing waste and reducing operating cost for the process.

Keywords: Disinfection byproducts, TOC, ion exchange, brine reuse

1.0 Introduction

Ion exchange resins occupy a unique and prominent position among technologies for potable and ground water treatment. Their capacity for trace contaminant removal and their ability to be regenerated and reused for hundreds of cycles are main contributors to their comparatively low operating costs versus other technologies. It is not surprising therefore that ion exchange resins are used for a host of purification applications, including the removal of hardness, arsenic, nitrate, uranium, perchlorate and organic matter (TOC) from potable water.

Disinfection of water containing TOC with oxidants such as chlorine and ozone can result in the formation of disinfection products (DBPs) such as trihalomethanes, haloacetic acid and bromate at levels exceeding their current maximum contaminant levels (MCLs) of 80 ppb, 60 ppb, and 10 ppb respectively. The recent promulgation of the Stage 2 DBP rule by the US EPA tightens operator control over pathogens (e.g. bacteria, cryptosporidium and giardia) as well as DBPs by requiring additional monitoring at individual points in the water distribution system. Consequently, organic matter control prior to the point of oxidant dosing has become even more critical.

2.0 Reducing TOC

A variety of methods are currently being used for TOC reduction from drinking water including:

- Coagulation / Filtration
- Granular Activated Carbon (GAC)
- Coagulation / Filtration + GAC
- Microfiltration (MF) + Coagulant Feed
- MIEX pretreatment
- Brine Regenerable Strong Base Anion Exchange Resins with option for brine reuse

A typical treatment scheme using coagulation / filtration followed by polishing with granular activated carbon is shown in Figure 1 below.

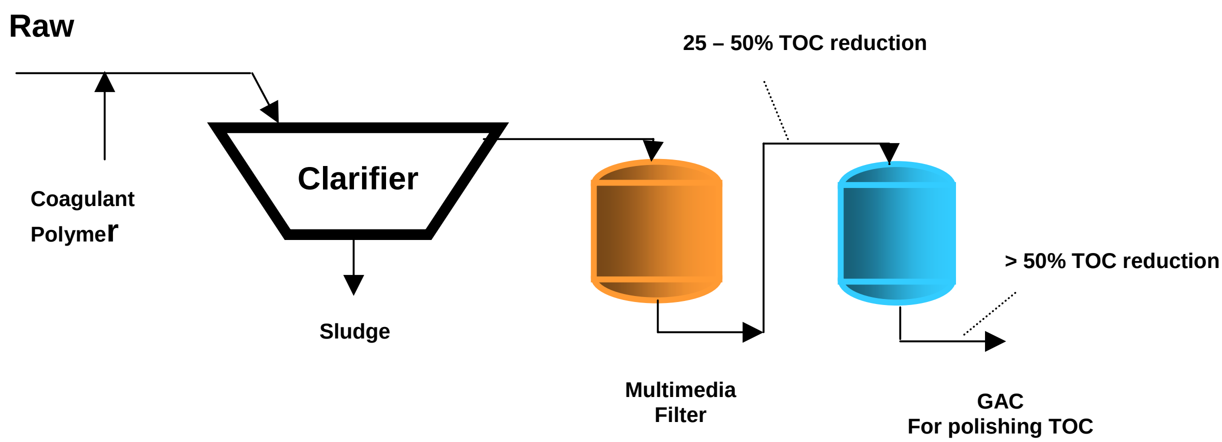

Figure 1. Typical Coagulation / Filtration + GAC Scheme

Clarification typically removes about 25% to 50% of the TOC depending on the characteristics of the TOC, while the addition of GAC as a polisher usually improves on this further.

Microfiltration (MF) coupled with the dosing of a suitable coagulant upstream of the MF unit has become popular in recent years. However, TOC removal claims vary widely, ranging from 10% to90%, with typical values more likely to be in the range of 10% to 30%. Figure 2 shows a typical treatment scheme.

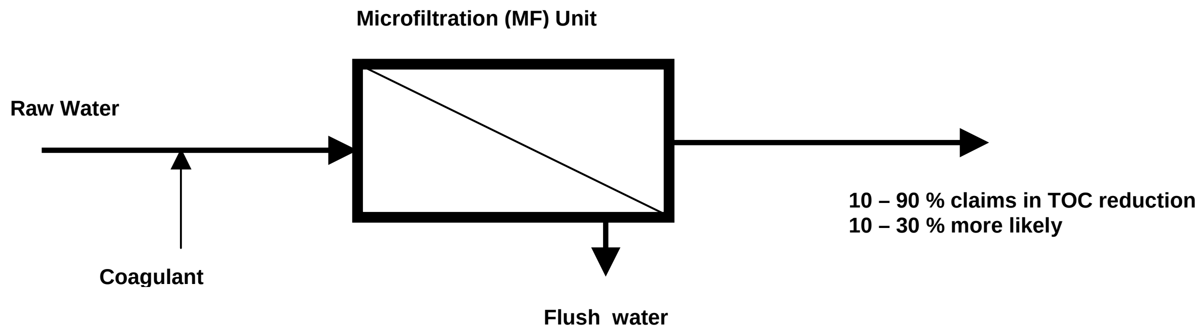

Figure 2. Typical Microfiltration (MF) + Coagulant Treatment Scheme

TOC removal using a variety of anion exchange resins has been used for many years. It is possible to get reliable and predictable results if the ion exchange plants incorporating such resin are properly designed and operated. Such ion exchange plants are relatively easy to operate and require only a simple brine solution to regenerate the resin. The ability to use the same standard fixed bed ion exchange equipment and controls as those used for softening, and the ability to efficiently regenerate these resins makes them very cost-effective options for control of organic matter. Typical operating conditions are shown in Figure 3 below.

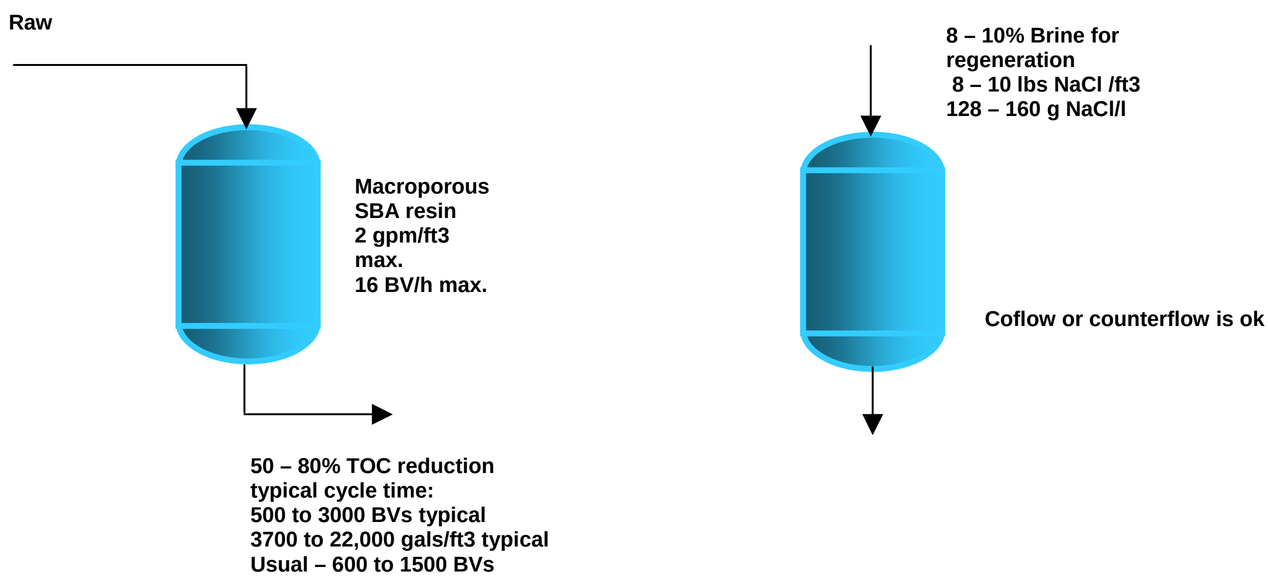

Figure 3. Strong Base Anion Exchange Resin – typical operating conditions

A relatively new ion exchanged based process called MIEX has also gained recognition in recent years in the US. This ion exchange based process uses an iron-infused strong base anion resin for TOC removal in a custom designed treatment process as shown in Figure 4.

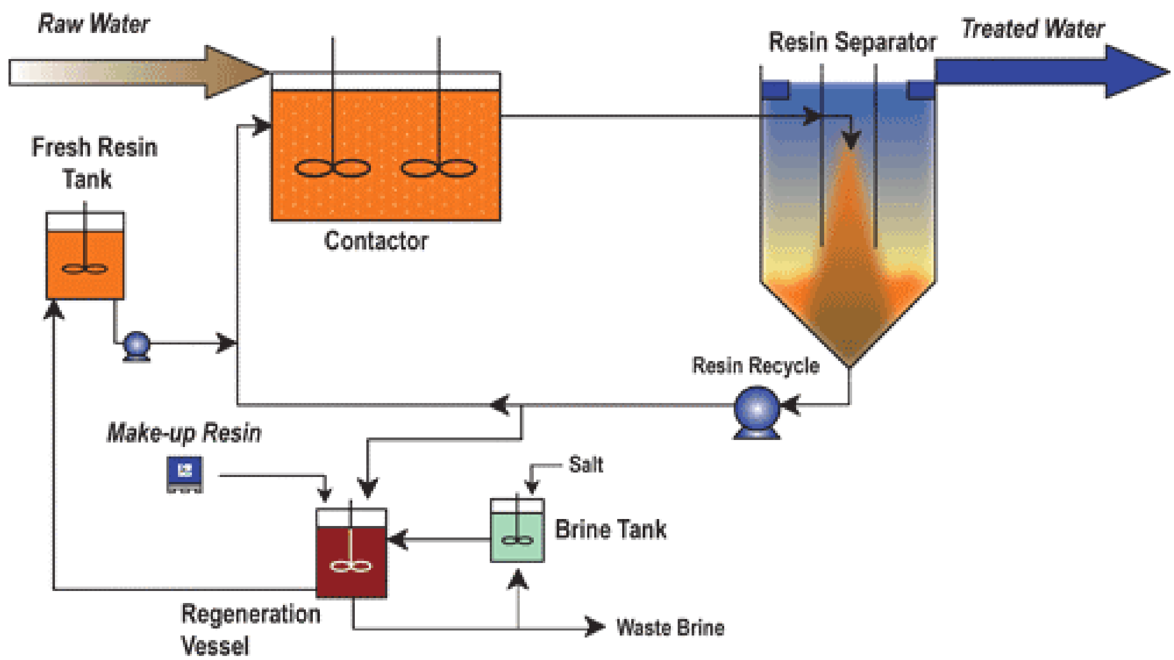

Figure 4. Typical MIEX Treatment Scheme (Courtesy MIEX)

The major difference from the standard ion exchange process is the use of relatively small iron-infused resin beads in a fluidized environment, with typical diameters raging from 150 to 180 microns as compared to the standard process which uses a Gaussian distribution of beads with diameters ranging from 300 to 1200 microns. The water and beads are mixed together in an open contactor tank, allowing quicker adsorption of the organic matter on the smaller beads. The beads are then separated from the treated water, taking advantage of the higher density caused by the iron infusion, then they are routed for regeneration with brine regeneration before being returned to the contactor tank. Fresh resin is continually added to make up for losses in resin volume due to the higher rate of bead attrition arising from the constant movement and impacts.

2.1 Design Considerations for Ion Exchange Systems

The extent of TOC removal by ion exchange depends on the nature of the organic matter in the water to be treated and the chemical characteristics of the resin itself. Both styrenic and acrylic type resins can be used. Naturally occurring organic matter (NOM) is comprised to a large extent of humic, fulvic and tannic acids. The majority of compounds tend to be non-polar and hydrophobic and can be adsorbed by either carbon or hydrophobic type resins[1].

The rest, or the polar fraction of the NOM is characterized as being non-adsorbable on carbon and are thought to be composed of low molecular weight compounds (< 1000) that are "water-loving" or hydrophilic in nature. Since strong base anion resins possess both adsorption and ion exchange properties, these resins can pick up both the polar and non-polar compounds. This is a fundamental difference and advantage compared to activated carbon picks up very little of the polar compounds.

More importantly, from a DBP control standpoint, research has shown that the compounds in raw water that can later form trihalomethanes (THM precursors) are evenly split between polar and non-polar fractions. This means that both polar and non-polar compounds must be removed before oxidation to assure complete control over DBP formation. Ion exchange resins therefore offer a more comprehensive solution for both types of organic matter.

In selecting a regenerable resin, good organic adsorption characteristics must be matched with good efficiency of release during regeneration. Hydrophobic styrenic resins form strong bonds with non-polar organics that are difficult to break during regeneration. They are especially susceptible to fouling by high molecular weight organic compounds. Acrylic resins, on the other hand, can pick up both polar and non-polar organic compounds. The hydrophilic nature of acrylic resins results in easier release of the organics during regeneration and is the preferred choice in many cases.

Good design rules are equally important to get the maximum benefits from the system. Most drinking water systems are designed to use just brine for regeneration, using about 8 to 10 pounds of salt per cubic foot of resin (or 128 to 160 grams NaCl per liter of resin) and typical service flow rates of 1.5 to 2 gpm/ft3 (12 to 16 BV/h). Regeneration in co-flow or counterflow modes are both acceptable. For difficult jobs, adding a small amount of caustic (where permitted) will generally help with the smoother release of the organics from the resin matrix, but the impact on the chemistry of the treated water must first be assessed.

2.2 Field Pilot Results for Brine Reuse:

Recovery and reuse of the spent brine for subsequent regenerations has been well documented in previous studies[3] for TOC removal, with successful reuse of the brine for as many as eight times before disposal. Thus the current fieldwork explores the use of this technique for a specific water chemistry and verifies regeneration efficiency from cycle to cycle in terms of residual TOC on the resin.

In attempting to recover and reuse the spent brine from such systems, it is important to understand the role of the brine in regenerating off TOC from the resin. Since the organic matter is adsorbed onto the resin matrix by both adsorption and ion exchange mechanisms, the brine serves two purposes. In one instance the brine simply displaces the relatively bulky organic molecule from the resin matrix by shrinking the volume of the resin bead, and in the other instance, the chloride content of the brine displaces the organic matter components that are bonded to the resin by the ion exchange mechanism. Thus the concentration of brine, the quantity of brine used and the TOC present in the brine will determine the effectiveness of regeneration.

Figure 5 shows the capacity and breakthrough results for the recent pilot using a macroporous acrylic anion resin. One cubic foot of resin (28 liters) was used with a flowrate of 2 gallons per minute (16 BV/h). Organic matter in the supply water was quite high at an average of 11.3 ppm measured as total organic carbon (TOC). The test pilot was operated for approximately 40 days with roughly a 50% on-time factor. The cumulative percentage leakage is also shown. After approximately 4,000 bed volumes of capacity (30,000 gallons per cubic foot of resin), the percentage removal of TOC was still higher than 80%.

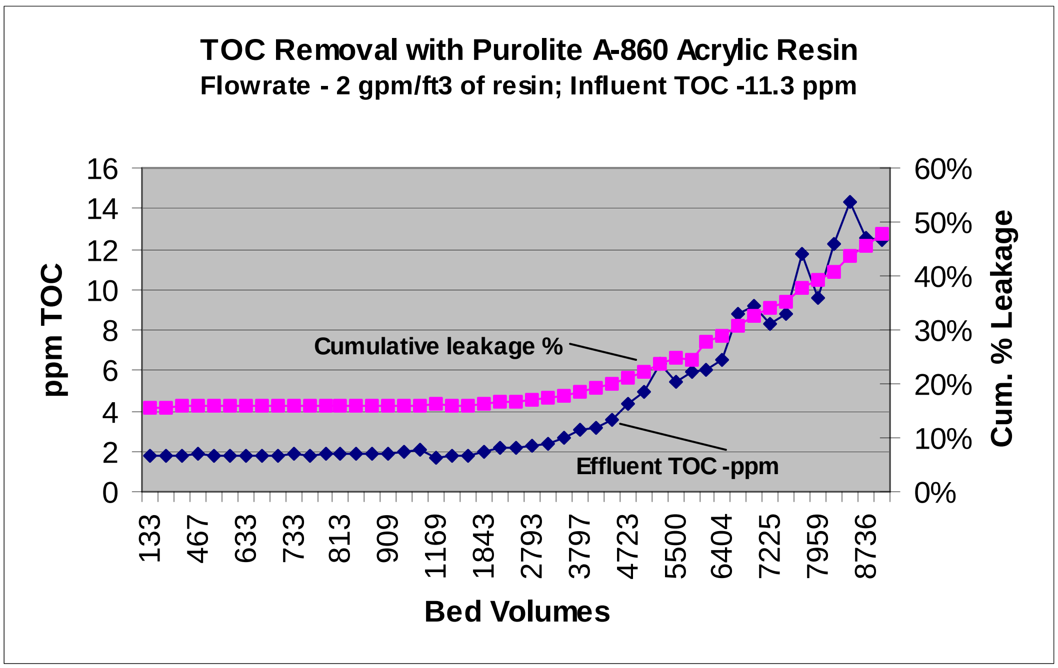

Figure 5. Typical Removal Efficiency of Acrylic SBA Resin

2.3 Brine Reuse

For the brine reuse evaluation, the pilot run was repeated using fresh resin for a service period of 5 weeks corresponding to the first breakpoint as discussed above, treating a total of 4076 bed volumes of water. The resin sample was then thoroughly mixed to achieve homogeneity and then separated into six equal fractions. Two regenerants were evaluated (a) 10% NaCl and (b) 10% NaCl + 2% NaOH. Three of the resin fractions were reserved for coflow regeneration with 1.3 bed volumes of 10% NaCl while the other three were reserved for coflow regeneration with 1.3 bed volumes 10% NaCl + 2% NaOH, both at a flow rate of 2 bed volumes per hour. For each set of resin fractions, the waste regenerant from the first fraction was subsequently used to regenerate the second resin fraction and the waste regenerant from the second used to subsequently regenerate the third fraction of resin. On each reuse of the regenerant, the first 25% of the regenerant was discarded and replaced by an equal volume of fresh regenerant in preparation for the next regeneration.

The initial and final TOC content of the resin fractions were measured and used as the measure of efficiency of regeneration of the resin. Initial TOC loaded on the resin was determined to be 31.3 mg as Carbon per dry gram of resin. Results are shown in Figure 6. Regeneration efficiency for both regenerants and for all regenerations ranged from approximately 87% for the first regeneration to approximately 82% for the third regeneration. Compared to regeneration efficiency for other common ion exchange processes which can typically range from 60% to 75%, all regeneration efficiency values obtained here are considered as excellent. The moderate reduction in efficiency from cycle to cycle indicates a good stabilization after three regenerations and it is deduced that the 25% regenerant "top-up" that was done in preparation for the next regeneration cycle was adequate to maintain the regeneration efficiency at these high levels. As a result, it is concluded that the brine reuse in conjunction with the "top-up" procedure used above can be easily extended to a minimum of five cycles before the regenerant must be considered for replacement. Also for this water quality, the lower cost option of regenerating with a simple 10% brine solution is adequate. Based on the above reuse strategy, the dosage of salt was reduced from 10 lbs/ft3 (160 g/l) for single use regeneration to a much lower value of 2.6 lbs/ft3 (42 g/l), amounting to approximately 75% savings in regenerant costs and environmental impact.

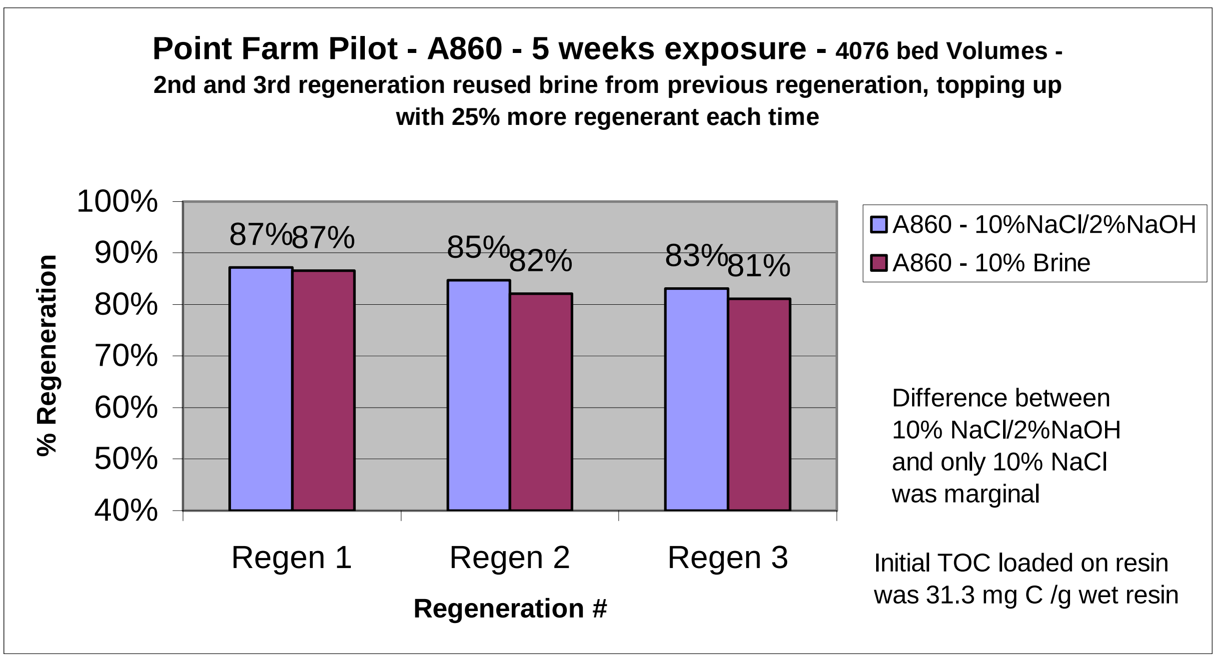

Figure 6. Brine Reuse using 10% NaCl or 10% NaCl + 2% NaOH

3.0 Cost Estimates

To complete the picture, an estimate of the operating cost for a single versus multiple brine use ion exchange system is needed. If a general resin price of $200 per cubic foot ($7/liter) is assumed along with a useful resin life of 5 years, the allocated cost of the resin to treat 1000 gallons (or 1m^3) of water can be estimated. For example, assume a flowrate of 100 gpm (22.7m3/h) and a daily water production of 72,000 gallons (273 m^3). Resin volume needed at 2 gpm/ft^3 (16 BV/h) would be 50 cubic feet (1.4m^3), with allocated resin cost to treat the water estimated at approximately $0.04 per 1000 gallons ($0.01 per m^3). Assuming a salt cost of $0.05 per lb ($0.11/kg), a salt dosage of 8 lbs per cubic foot of resin (128g/l), and a working resin capacity of 8,000 gallons per cubic of resin (1069 BVs), the operating cost for salt would amount to $0.05 per 1000 gallons of water ($0.013 per m^3) for the single brine use system. For the multiple brine reuse system, the salt cost for the same condition would equate to $0.0125 per 1000 gallons of water ($0.0033/m^3). Table 1 compares the cost of salt and the amortized cost of the resin for the single use versus multiple use of the brine.

Table 1. Comparing Cost of Single Brine Use to Multiple Brine Reuse for TOC Removal

	Single Brine Use $ / 1000 Gals treated	Single Brine Use ($ / m3)	5 Reuses of Brine with 25% top-up /regeneration $ / 1000 Gals treated	5 Reuses of Brine with 25% top-up /regeneration ($ / m3)
Resin cost (5 yr life)	0.04	0.01	0.04	0.01
Salt Cost ($0.05 /lb $0.11/kg)	0.05	0.013	0.0125	0.0033
Total salt & resin cost (No bypass)	0.09	0.023	0.053	0.013

Table 2 attempts to show how ion exchange compares to other technologies, using cost data available from various sources. In the case of ion exchange, only the cost of salt and resin is shown.

Table 2. Comparing TOC Removal Cost by Various Technologies

	TOC Removal %	Capital Cost $	Operating Cost $/m3	Operating Cost $ / 1000 Gals
Acrylic SBA with brine reuse	> 50	N/A	0.013 (salt & resin only)	0.053 (salt & resin only)
MIEX [2]	> 50	$ 19 MM	0.026 – 0.04	0.10 – 0.15
GAC [2] Based on $1/lb GAC	25 - 50	$ 17 MM	0.095	0.36
MF + Coag.	10 - 25	N/A	0.09	0.35

4.0 Summary:

In summary, ion exchange technology provides a simple and cost effective method of controlling the formation of disinfection byproducts by efficiently removing organic matter before the point of disinfection of the water.

While single use of the brine regenerant is competitive for cases where brine discharges are still allowed, multiple recovery and reuse of the brine regenerant is efficient and can reduce operating cost for salt by over 75%.

If waste brine must be hauled away for disposal, multiple reuse of the brine before disposal can significantly reduce overall operating cost for TOC removal.

References:

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