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SafeGuard™ H2O Arsenic Removal Treatment System  
Demonstration Report

City of Alamosa Water District, CO

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# SafeGuard™ H2O Arsenic Removal Demonstration Report

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## June 2023

This report summarizes the performance results of Aqua Metrology Systems' intelligent SafeGuard™ H2O arsenic removal treatment system and details the technology's ability to mitigate arsenic contamination in drinking water at the City of Alamosa in Colorado.

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# Executive Summary

## Overview

While the current maximum contaminant level (MCL) for arsenic is 10 parts per billion (ppb), the U.S. Environmental Protection Agency (EPA) is reviewing its MCL recommendations for this toxic contaminant. This is leading utilities across the U.S. to prepare for the possibility of a more stringent federal regulation and evaluate the efficacy of their existing arsenic removal treatment systems.

Since 2008, the City of Alamosa in Colorado, like many other utilities across the U.S. needing to treat for arsenic contamination, has been operating an arsenic removal system based on the use of bulk ferric chloride as a coagulant. This reagent is dosed into raw water at a rate of 17-19 milligrams per liter (mg/L). Following coagulation, the treated water is passed through a ZeeWeed® ultrafiltration (UF) membrane to remove the ferric-arsenic coagulant. The filters are backwashed periodically, and the backwash is discharged to the city's sewerage system. This process reduces arsenic from an influent value of  $\geq 35$  ppb to an effluent below 10 ppb. Since its start-up the plant's performance has been regularly monitored by an AMS at line arsenic water quality analyzer to ensure system compliance. The city's drinking water treatment plant has a maximum flow rate capacity of 5.25 million-gallons-per-day (mgd). The facility blends source water obtained from five wells across the region. Source water contains naturally occurring arsenate [As(V)] and other inorganic contaminants.

While the city's existing treatment scheme can achieve greater arsenic removal efficiency, it would require additional chemicals and an increased ferric chloride dose of 25-40 mg/L to reduce arsenic to 5 ppb or less.

Concerned with having to increase reliance on bulk chemicals to meet a lower arsenic MCL and a number of associated operational issues, the City of Alamosa evaluated the SafeGuard™ H2O arsenic removal treatment system, manufactured by Aqua Metrology Systems (AMS), to replace the use of bulk ferric chloride.

The SafeGuard™ H2O technology uses a non-toxic, certified reagent precursor material (low carbon steel) and an in-situ electrolytic generator to create a ferrous reagent onsite and on-demand. SafeGuard™ H2O features automatic dosing and incorporates proprietary continuous, real-time monitoring of contaminant levels at the influent and effluent to ensure optimal treatment and compliance with regulatory and operational targets 24/7/365. As with any water treatment system, high frequency continuous water quality monitoring of contaminants such as arsenic and iron at critical treatment process steps supports process automation, optimization, reliability, and can give remote visibility of system performance for the utility and their customers.

The SafeGuard™ H2O evaluation was completed via bench-scale testing and subsequent pilot demonstration.



The bench-scale test in 2022 characterized the efficacy of the technology and the coagulation filtration requirements. The demonstration from Jan. 14 to Feb. 3, 2023, was initiated to show the ability of SafeGuard™ H2O to provide effective and reliable arsenic removal below the MCL, evaluate the purity of the in-situ generated ferrous reagent compared to bulk ferric chloride and study the impact of both reagents on UF membrane health.

## Results

The bench scale demonstration of the SafeGuard™ H2O in-situ electrogenerated ferrous reagent treatment technology at the City of Alamosa in 2022 has shown the in-situ generated reagent can achieve arsenic removal below 10 ppb; proving the efficacy of the technology. The electrogenerated ferrous reagent achieved reliable arsenic removal below 5 ppb with a ferrous dose of 6.5-8 mg/L.

For the SafeGuard™ H2O demonstration, a treatment system with a capacity of 100 milliliters per minute (ml/min) [0.016 gal/sq ft/min] that uses all the essential components for a full-scale installation was designed to mimic the key plant conditions and parameters including treatment reagent (coagulant) dose, water/coagulant contact time, coagulation pH, the flowrate through UF module and UF membrane backwashing schedule.

The SafeGuard™ H2O demonstration system consisted of two treatment trains, one for the electrolytic ferrous reagent and another for bulk ferric chloride, that were run in parallel to ensure a side-by-side comparison of the two treatment approaches. Each treatment train shared a similar process flow and identical arsenic coagulation/filtration modules, they differed only in the reagent used.

During the operation period of Jan. 14 to Feb. 3, 2023, the influent arsenic levels, specifically As(V), were  $\geq 35$  ppb. Total arsenic levels in the permeate obtained from the electrolytic ferrous reagent were consistently lower than that in the permeate obtained from the bulk ferric chloride.

These findings were confirmed by laboratory and field tests. The results demonstrate that the SafeGuard™ H2O arsenic removal treatment technology can effectively reduce arsenic in the drinking water source to below the 10 ppb MCL level.



Conclusions from the demonstration of the SafeGuard™ H2O technology include:

- The SafeGuard™ H2O arsenic removal technology demonstrated the ability to remove high levels of influent arsenic to below 5 ppb under tightly controlled treatment process conditions.
- The electrolytically generated ferrous reagent provides a higher efficiency in arsenic removal compared to bulk ferric chloride. The SafeGuard™ H2O electrolytically generated reagent demonstrated high arsenic treatment performance using a ferric coagulant dose 27% lower than that with a bulk ferric chloride reagent.
- The purity of the in-situ ferrous reagent precursor is of a higher quality than bulk ferric chloride.
- The high purity of the in-situ ferrous reagent resulted in lower manganese levels in the treatment reagent as well as in the treated water and waste. The low manganese content in the electrolytic ferric reagent relative to the bulk ferric reagent caused minimal impact on the treated water quality.

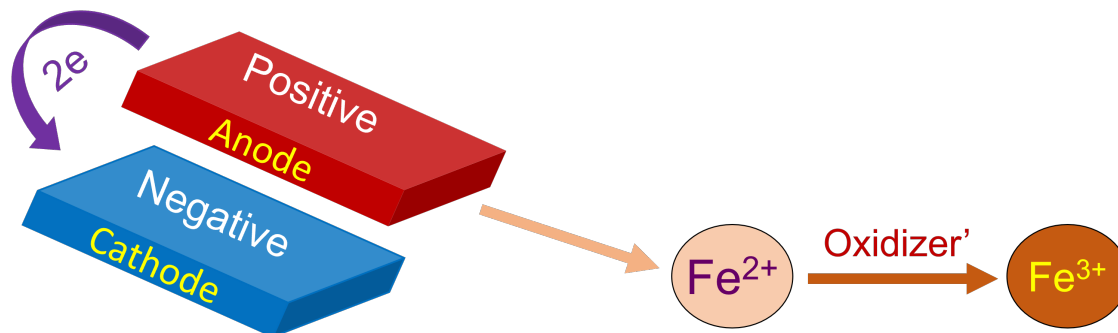


## Demonstration Technology

### SafeGuard™ H2O Arsenic Removal Treatment System

The SafeGuard™ H2O in-situ electrogenerated ferrous reagent treatment technology is a novel approach to arsenic treatment. The SafeGuard™ H2O system generates a ferrous reagent in-situ via an electrolytic process.

The technology produces a controlled amount of ferrous ions in-situ and on-demand (Figure 1). This is accomplished through the process of electrolysis, where an iron metal precursor (anode) corrodes under controlled conditions producing a ferrous reagent in-situ.



**Figure 1. SafeGuard™ H2O Electrolytic Ferrous Reagent Generation Process**

Freshly generated ferrous ions oxidize into the ferric form and are then used in the SafeGuard™ H2O arsenic removal process. A certified steel precursor is used for ferrous reagent generation, the high-purity material has defined contaminants (metal and non-metal) which have minimal and predictable effects on treated water quality.

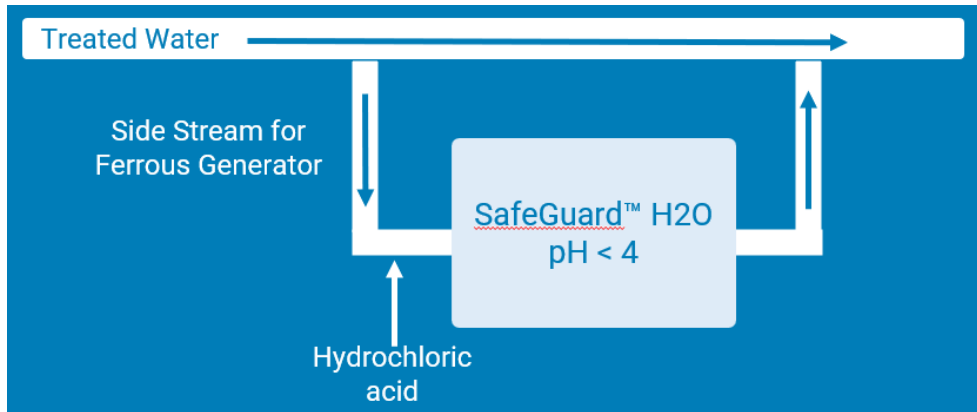
SafeGuard™ H2O also features automatic dosing and incorporates proprietary, continuous, real-time monitoring of contaminant levels (arsenic and iron) at the influent and effluent to ensure optimal treatment and compliance with regulatory and operational targets 24/7/365. Data generated from the onboard arsenic monitoring system helps drive a highly accurate remediation process by ensuring reliable reagent dosing control through manipulation of site-specific process parameters.

Unlike some traditional treatment systems, which cannot operate unattended, the fully autonomous in-situ system can be controlled, monitored and optimized remotely. The need of personnel on site for supervision is minimal, further reducing operating costs. Depending on treatment size needs and site requirements, a SafeGuard™ H2O system can be designed to operate unattended for several weeks.



The SafeGuard™ H2O arsenic removal installation schematic (Figure 2) for City of Alamosa details how the ferrous generator is fed by the side stream, less than 1 %, that is taken from the treated water flow. The electrolytic ferrous reagent produced is then re-injected into the treated water flow at a pre-determined rate to maintain the required coagulant dose.

To ensure high electrolytic reagent quality and stability, the ferrous generator stream pH is maintained in the acidic range by injecting hydrochloric acid into the generator stream. Flexible and tight control of both the electrolytic reagent concentration and pH is beneficial for treatment process tuning and optimization.



**Figure 2. SafeGuard™ H2O Arsenic Removal Technology Schematic**

A high efficiency of ferrous ion generation ensures accurate reagent dose in a broad concentration range. With the SafeGuard™ H2O system’s proprietary control (Figure 3), generation of a ferrous ion reagent can be easily adjusted in real time, based on changing treatment process conditions. Moreover, the ferrous ion generator can be terminated immediately simply by switching the power off, and restored as soon as power is switched on, making it highly suitable for stop-and-run operation modes associated with wells that do not run continuously.



**Figure 3. SafeGuard™ H2O Arsenic Removal System Control Panel**





# Demonstration Set-up & Operation

## Demonstration Site & Treatment Process

The City of Alamosa's drinking water treatment plant has a maximum flow rate capacity of 5.25 mgd and obtains source water from five wells across the region that is then blended at the facility. Source water contains naturally occurring arsenate and other inorganic contaminants (Table 1). The city receives raw well water with elevated arsenic levels above the 10 ppb MCL and requires arsenic remediation treatment to achieve regulatory compliance.

**Table 1. City of Alamosa Water Quality Parameters**

Parameter	Value
Arsenate	≥ 35 ppb
pH	≥ 8.7
Alkalinity	≥ 87 ppm
Silica	≥ 87 ppm
Manganese	< 6 ppb

Since 2008, the City of Alamosa has been using a coagulation assisted UF arsenic removal treatment process to address elevated levels of the contaminant in their drinking water supply.

A bulk ferric chloride solution (39-42%) is used as an arsenic removal coagulant with a ferric dose of 17-19 mg/L to reduce arsenic from an influent value of ≥ 35 ppb to an effluent value below 10 ppb. Typical residual arsenic levels in the city's treated water range from 6-8 ppb.

At the start of the treatment process, the bulk ferric chloride solution is added and then rapidly mixed with the raw water before it enters a reaction tank (contactor) where it remains for a contact time of 15 minutes so it can form a large enough floc needed for effective filtration. Alamosa's source water contains high levels of silica (Table 1) and, as a result, a relatively long contact time of 15 minutes is required since silica is proven to interfere with the ferric hydroxide coagulation process. The pH of the water in the contactor is reduced from initial levels of 8.7-8.8 to the range 7.45-7.55 with the addition of acidic ferric chloride, no additional pH adjustment is used to optimize the coagulation process.

After passing the contactor, the coagulant is filtered through ZeeWeed® UF membranes supplied by Veolia (following the acquisition of Suez- Water Technologies & Solutions) and then the treated water undergoes chlorination before it is pumped into the distribution system without any pH adjustment. The UF membranes are backwashed in a prescheduled manner to remove any coagulant precipitate from the membrane surface and the backwash cycle averages 30 minutes. The backwash water is sent to the sewage system without any further treatment. Additionally, the UF membranes are periodically treated with citric acid to maintain their performance.



Operators at Alamosa’s Water Treatment Plant are concerned with:

- Increasing the use and reliance of hazardous bulk ferric chloride chemicals;
- The quality of bulk ferric chloride chemicals and their varying iron content and reagent pH, insoluble matter, as well certain heavy metal co-contaminants, especially manganese;
- The fact that multiple variables associated with the ferric chloride reagent may significantly affect the quality of arsenic removal and the stability of the treatment equipment (UF membranes), as well as add undesirable contaminants into the treated water.
- The security of the ferric chloride reagent supply as well as its cost stability.

### Demonstration Materials – Bulk Ferric Chloride & Electrogenerated Ferrous Reagent

The 39% bulk ferric reagent and the electrogenerated ferrous reagent materials used in the demonstration of the SafeGuard™ H2O arsenic removal technology at the City of Alamosa were analyzed by SDC Laboratory located in Alamosa, CO. Results are summarized in Table 2.

**Table 2. Laboratory Analysis Results of 39% Bulk Ferric Chloride Reagent And Electrogenerated Ferrous Reagent Material Used In The SafeGuard™ H2O Arsenic Removal Demonstration**

Parameter	Bulk Ferric Chloride Reagent (mg/L)	Electrogenerated Ferrous Reagent (mg/L)
Antimony	0.378	0.0008
Beryllium	0.002	< 0.0006
Copper	112.91	2.56
Iron	> 14000	2865.35
Lead	< 0.001	< 0.001
Manganese	951.48	5.789
Molybdenum	8.092	1.159
Nickel	21.546	0.841
Selenium	0.094	0.004
Silver	0.122	0.006
Thallium	< 0.0002	< 0.0002
Zinc	28.8	0.97

Source: Analytical Results conducted by SDC Laboratory located at Tierra Del Sol Industrial Park, 2329 Lava Lane, P.O. Box 642, Alamosa, CO 81101



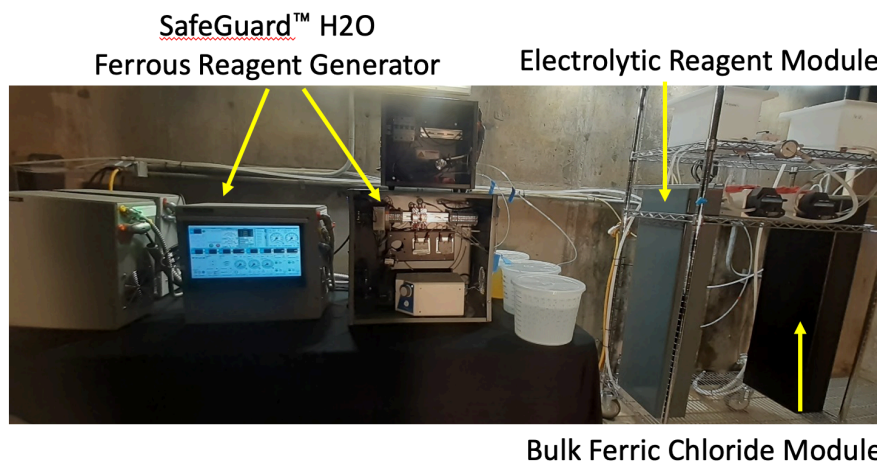
The steel supplier has provided a certificate of analysis for the low carbon steel material used for the SafeGuard™ H2O electrolytic ferrous reagent process is detailed in Table 3.

**Table 3. Certificate of Analysis For The Steel Electrode Used In The SafeGuard™ H2O Process**

C	Mn	P	S	Si	Al	Cu	Ni
0.05	0.18	0.006	0.004	0.022	0.027	0.08	0.03
Cr	Mo	V	Nb	Ti	N	B	
0.04	0.01	0.001	0.001	0.001	0.0071	0.0001	

### Demonstration System Configuration and Operation Mode

To evaluate the performance and arsenic removal efficiency of the electrolytic ferrous reagent versus the bulk ferric chloride reagent, AMS designed and built a full-scale demonstration system (Figure 4) that included all the essential components characteristic to Alamosa’s existing coagulation assisted UF arsenic removal treatment process.

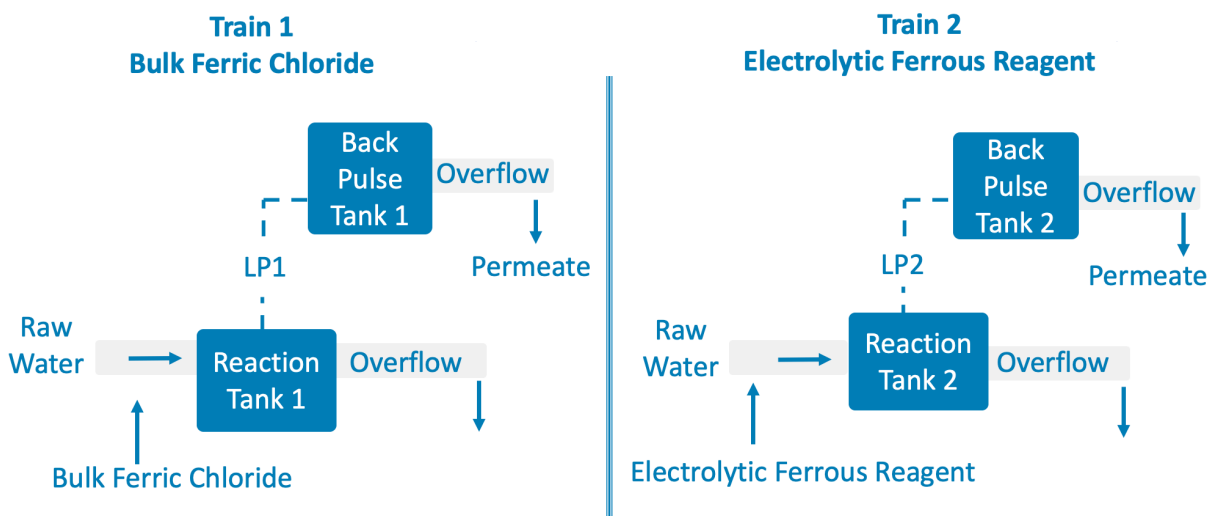


**Figure 4. Ferrous Reagent Treatment Demonstration System Installed at City of Alamosa**

Additionally, the demonstration system was operated under the same key treatment process parameters, such as reagent dose, influent/reagent contact time, treatment pH, UF membrane hydraulic load, and UF membrane backwash cycle and conditioning.



The demonstration system consisted of two separate trains (Figure 5), one for the bulk ferric chloride reagent (Train 1) and another for the in-situ electrolytic ferrous reagent (Train 2) that were run in parallel to ensure a side-by-side comparison of the treatment approaches. Each treatment train shared a similar process flow and identical arsenic coagulation/filtration modules, they differed only in the reagent used — bulk ferric chloride vs. electrolytic ferrous reagent.



**Figure 5. Schematic Of Arsenic Removal Demonstration System Installed at City of Alamosa**

Each train comprised of the Reaction Tank (30 L) with immersed ZeeWeed® UF module, Back Pulse Tank (6 L), and Liquid Pump (LP). Each Reaction Tank contained a ZeeWeed® UF module (2.5 ft sq) that was fed with one of the evaluated streams, bulk ferric chloride or the electrolytic ferrous reagent.

The inlet into Train 1 used a side stream from the plant treatment system that was tapped off just downstream from the ferric chloride reagent injection (5.9 parts per million (ppm) as Iron). This 2 L/min stream entered the 30 L Reaction Tank 1 with a 15 min water/reagent contact time (identical to the contact time currently used in Alamosa's treatment process). An overflow from the Reaction Tank discharged to drain. An outlet of ZeeWeed® cartridge was connected to inlet of the peristaltic Liquid Pump (LP1) which was set to a 100 ml/min flowrate (0.016 gal/sq ft/min). An outlet of the LP 1 (UF membrane permeate) fed into Pulse Tank 1. The overflow from Pulse Tank 1 was manually sampled, preserved, and analyzed for Total arsenic and other constituents by certified laboratory. Also, the permeate from the Pulse Tank 1 was used for the periodic UF membrane backwashing by reversing liquid pump direction (BW flow). Air was purged through the Reaction Tank 1 during the backwashing process to accelerate particle removal according to the membrane manufacturers' recommendations (not shown in Figure 4).



Train 2 comprised of the same key components as Train 1 and only differed in the arsenic reducing reagent used, batches of an electrolytic ferrous reagent concentrate (4.2 L, 3000 ppm ferric) were produced at line by the SafeGuard™ H2O ferrous reagent generator (Figure 3). A 3,000 ppm ferrous reagent concentrate was fed into the 2.0 L/min raw water stream with a dosing flowrate of 3.3 ml/min (5.0 ppm ferrous reagent dose). The effectiveness of the 5.0 ppm electrolytic ferrous reagent dose to reliably reduce raw water arsenic below 10 ppb was demonstrated in previous bench-scale testing performed by AMS at the City of Alamosa in 2022.

The overflow samples from each Reaction Tank (Reaction Tank 1 and Reaction Tank 2) were collected during the backwashing procedure and analyzed for total arsenic and other contaminants by a certified laboratory. Also, split daily permeate samples were tested onsite via a total arsenic bench top analyzer.

Each train operated independently, however all key process parameters, such as reagent dose, treatment pH, backwash cycle and more were maintained as close as possible to the city's coagulation assisted UF arsenic removal treatment process.

The demonstration period was from Jan. 14 to Feb. 3, 2023.



## Demonstration Results

### Treatment Objective

The main objective of the SafeGuard™ H2O technology demonstration at the City of Alamosa was to show the effectiveness of electrolytically generated ferrous reagent to provide accurate and reliable arsenic removal from source water with elevated levels of arsenic contamination to the levels below 10 ppb.

Other objectives included:

- To demonstrate the high flexibility of the SafeGuard™ H2O arsenic removal system to control key water treatment parameters: reagent dose, treatment pH;
- To demonstrate the high purity of the electrolytically generated ferrous reagent and its impact on treated effluent quality.

### Grab Sampling and Laboratory Analysis

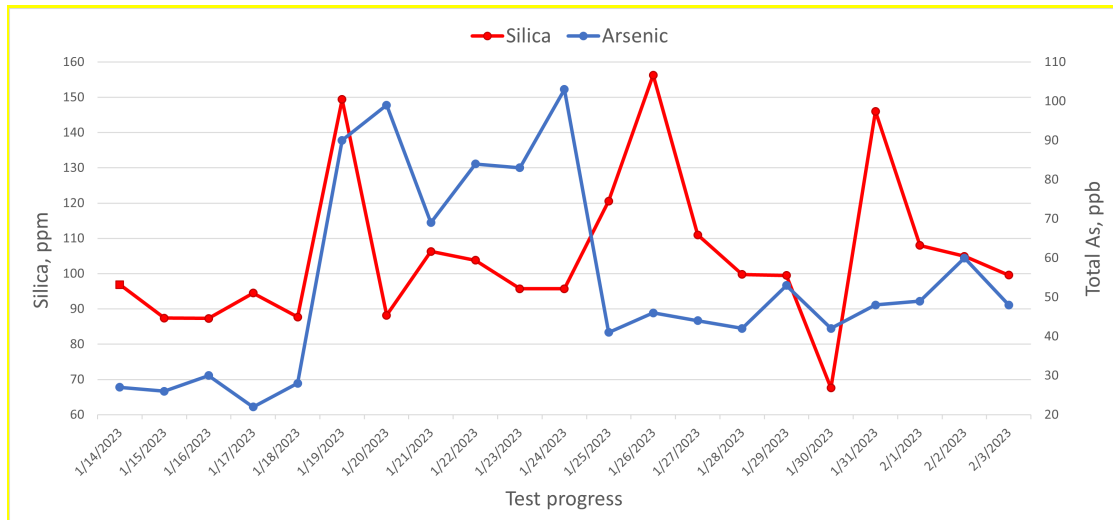
Manual grab samples were collected daily by City of Alamosa Water Treatment Plant personnel, preserved and analyzed for multiple constituents by a certified laboratory (SDC Laboratory).

### Results and Discussion

#### Raw Water Quality Parameters

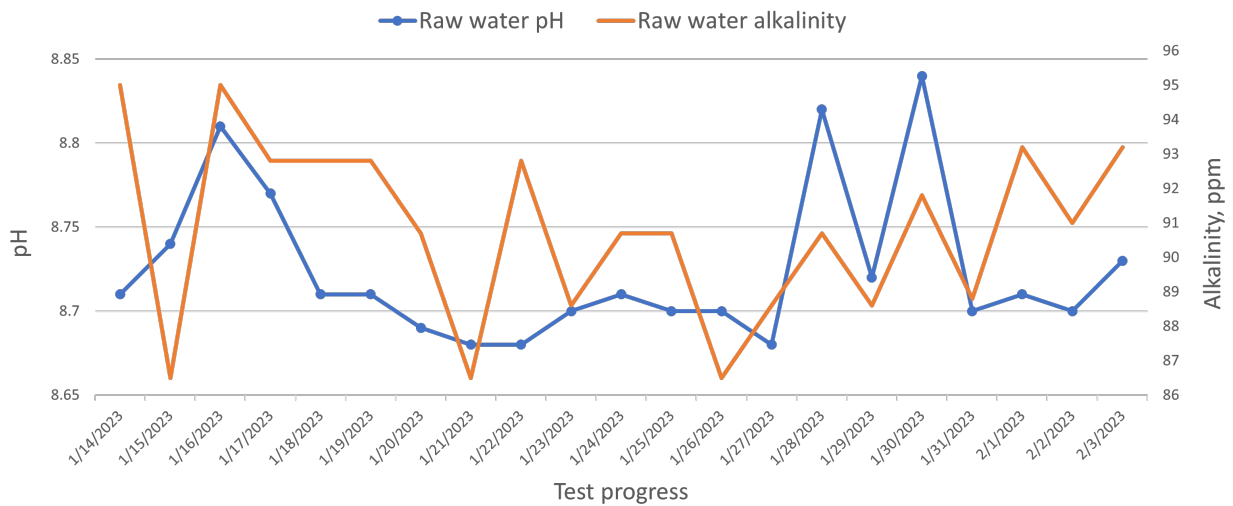
Key raw water quality parameters that are essential for the performance of the arsenic removal process such as arsenic and silica levels, pH and alkalinity were monitored daily during the demonstration period (Jan. 14 to Feb. 3, 2023) by manual sampling followed by laboratory analysis. Laboratory results for these water constituents are detailed in Figures 6 and 7.

Figure 6 demonstrates both total arsenic and silica results during from the demonstration period. Raw water arsenic levels sharply increased from the initial 30 ppb range to about 100 ppb between Jan. 18 – 26, 2023 and then reduced and stabilized at range of 40-60 ppb. Silica levels demonstrated three major spikes from the base line level of 90 ppm, reaching approximately 150 ppm on Jan. 19, Jan. 26 and Feb. 1, 2023. There is a correlation between arsenic and silica levels between Jan. 14 and Jan.21, 2023; however, after Jan. 21, 2023, there is no clear correlation between these parameters.



**Figure 6. Total Arsenic and Silica Values in Raw Water at City of Alamosa**

Figure 7 demonstrates raw water pH and alkalinity during the demonstration period. Raw water pH remained within the 8.68-8.84 range and alkalinity levels varied between 86-96 ppm. No correlation between pH and alkalinity can be seen.



**Figure 7. pH And Alkalinity Values in Raw Water at City of Alamosa**

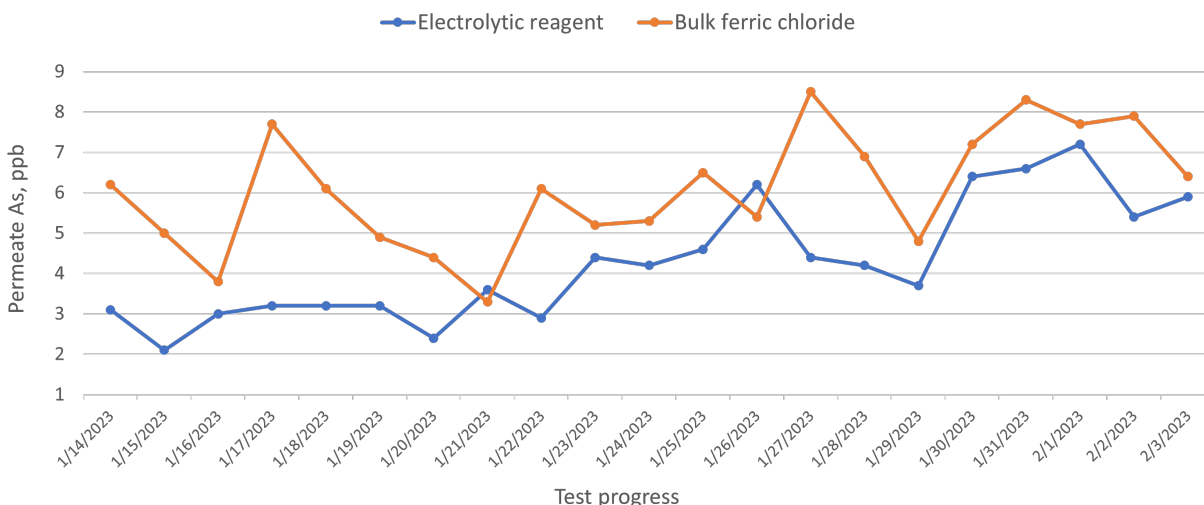


**Permeate Water Quality Sample Results**

Total arsenic values obtained in the permeates from the bulk ferric chloride and electrolytic ferrous reagent treatment trains are detailed in Figure 8. Arsenic residuals in the Train 2 permeate (electrolytic ferrous reagent) are consistently lower than those with bulk ferric chloride (Train 1), except for two data points (Jan. 21 and Jan. 26, 2023).

During the demonstration, Train 1 arsenic results displayed multidirectional trends (Figure 8). The highest arsenic residual levels in the Train 1 permeate (bulk ferric chloride) were observed in the first, second and third week of the demonstration with peak values of 7.7, 8.5 and 8.3 ppb respectively.

During the first week of the demonstration (Jan. 14 – Jan. 20, 2023) Train 2 had the lowest residual arsenic levels in the permeate, varying between 2.1 and 3.2 ppb. Between Jan. 21 and Feb. 3, 2023, Train 2 arsenic permeate (electrolytic ferrous reagent) levels demonstrated a gradual increase with maximum arsenic levels between Jan. 30 to Feb. 1, 2023 (Figure 8).

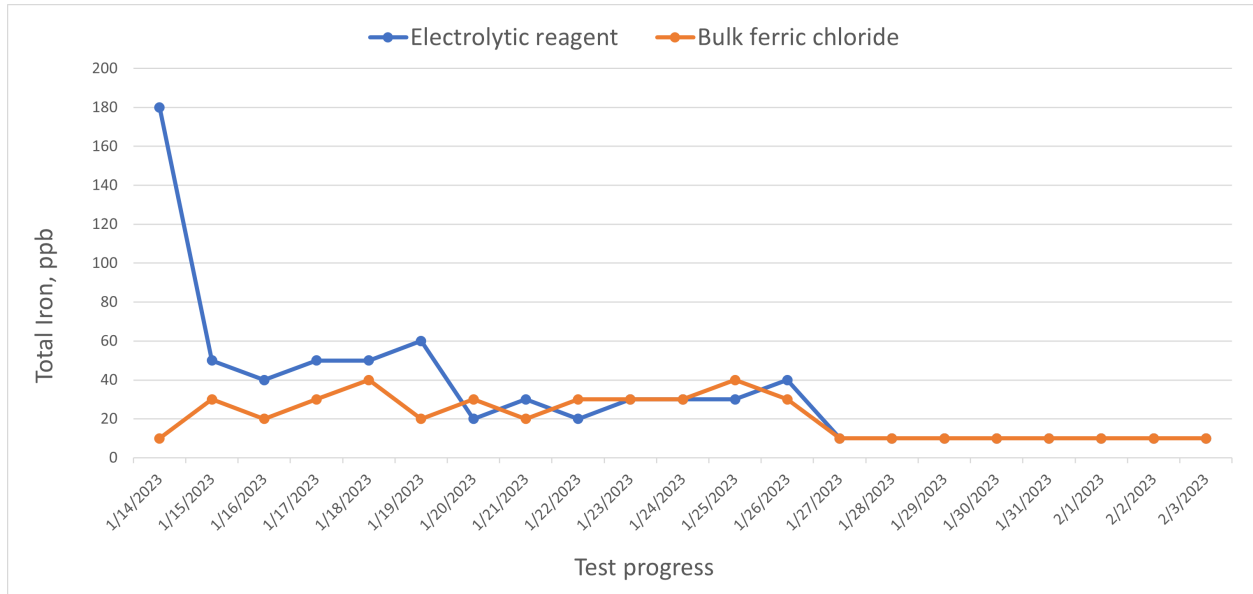


**Figure 8. Total Arsenic in Train 1 (Bulk Ferric Chloride) and Train 2 (Electrolytic Ferrous Reagent) Permeates**

Total iron values obtained in the permeates from the bulk ferric chloride and electrolytic ferrous reagent treatment trains are detailed in Figure 9. Total iron levels in the permeates in both Train 1 (bulk ferric chloride) and Train 2 (electrolytic ferrous reagent) are significantly below iron MCL (300 ppb) and generally follow similar trends.

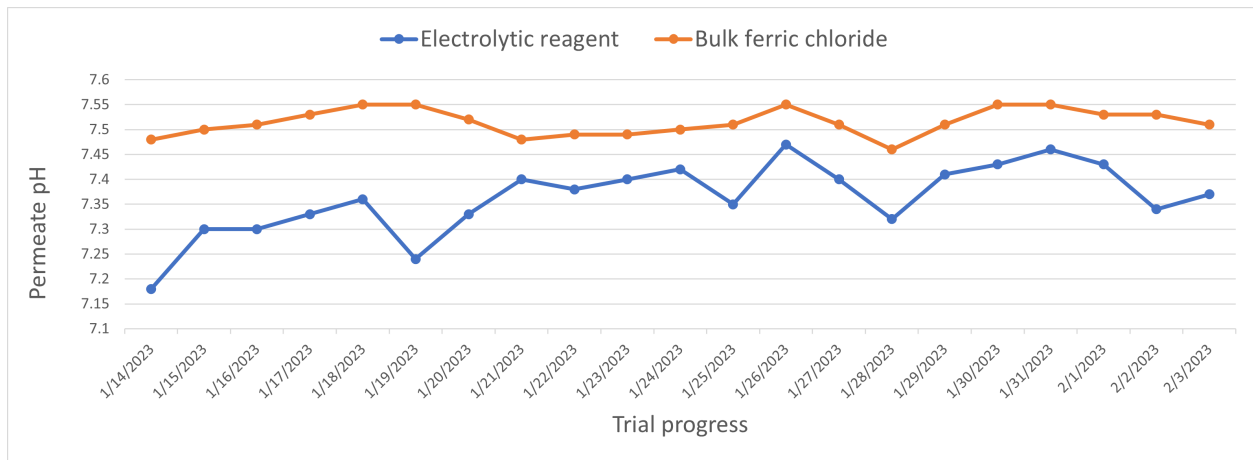
On Jan. 14, 2023, the iron level in Train 2 (electrolytic ferrous reagent) spiked to 180 ppb and then stabilized within 20-60 ppb while the Train 1 (bulk ferric chloride) iron levels fluctuated within 10-40 ppb. Between Jan. 21 to Feb. 3, 2023, iron levels in the permeate of Train 1 and Train 2 demonstrated relatively low (10-40 ppb) residual iron levels which is indicative of a high coagulant removal efficiency (99-99.8%). Such a high treatment coagulant removal efficiency indicates that arsenic residuals found in the permeates are due to insufficient arsenic adsorption during the arsenic/coagulant contact time.





**Figure 9. Total Iron in Train 1 (Bulk Ferric Chloride) and Train 2 (Electrolytic Ferrous Reagent) Permeates**

The pH values obtained in the permeates from the bulk ferric chloride and electrolytic ferrous reagent treatment trains are detailed in Figure 10. The pH levels in the Train 1 permeate (bulk ferric chloride) were higher than corresponding pH levels in the Train 2 permeate (electrolytic ferrous reagent) during the demonstration. The pH levels in the Train 1 permeate (bulk ferric chloride) varied within 7.45 -7.55 showing repeatable weekly trends. The pH levels in the Train 2 permeate (electrolytic ferrous reagent) demonstrated the lowest values (7.18-7.35) during the first week of the demonstration (Jan. 14 to Jan. 20, 2023). Between Jan. 21 to Feb. 3, 2023, the pH levels in the Train 2 permeate (electrolytic ferrous reagent) varied within 7.3 -7.45.



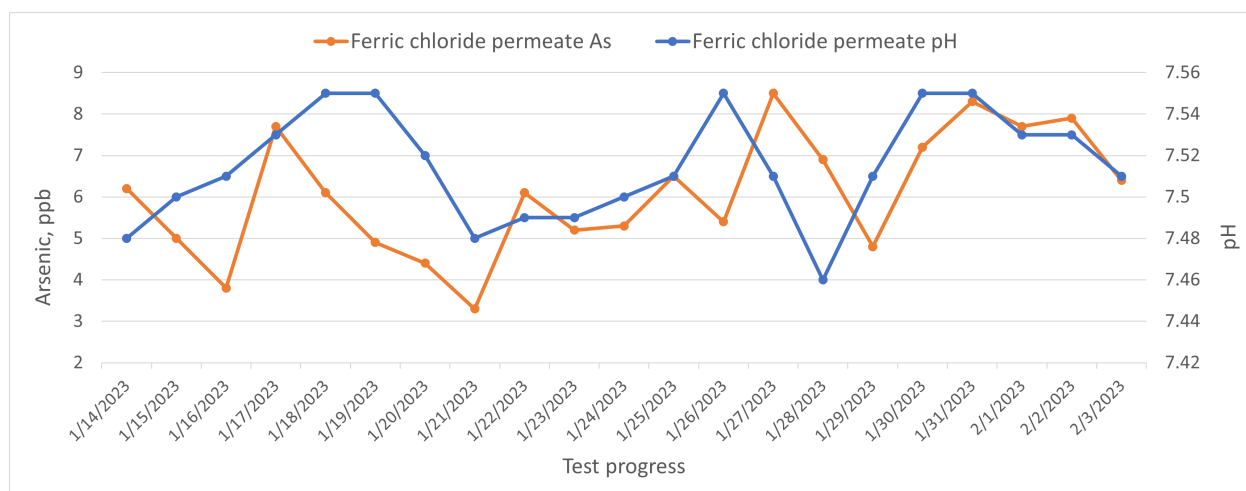
**Figure 10. pH in Train 1 (Bulk Ferric Chloride) and Train 2 (Electrolytic Ferrous Reagent) Permeates**



In the flocculation/ultrafiltration treatment approach used at the City of Alamosa, the first step is arsenic adsorption onto colloidal ferric hydroxide [1]. The driving force of this arsenic/coagulant interaction is an electrostatic attraction between positively charged colloidal iron hydroxide complexes ( $Fe(OH)^{+}_2$ ) and negatively charged arsenate oxyanions ( $HAsO^{2-}_4$ ) [2]. It has been demonstrated in multiple studies that coagulant surface charge and its sorption capacity are strongly influenced by treated water pH [2,3].

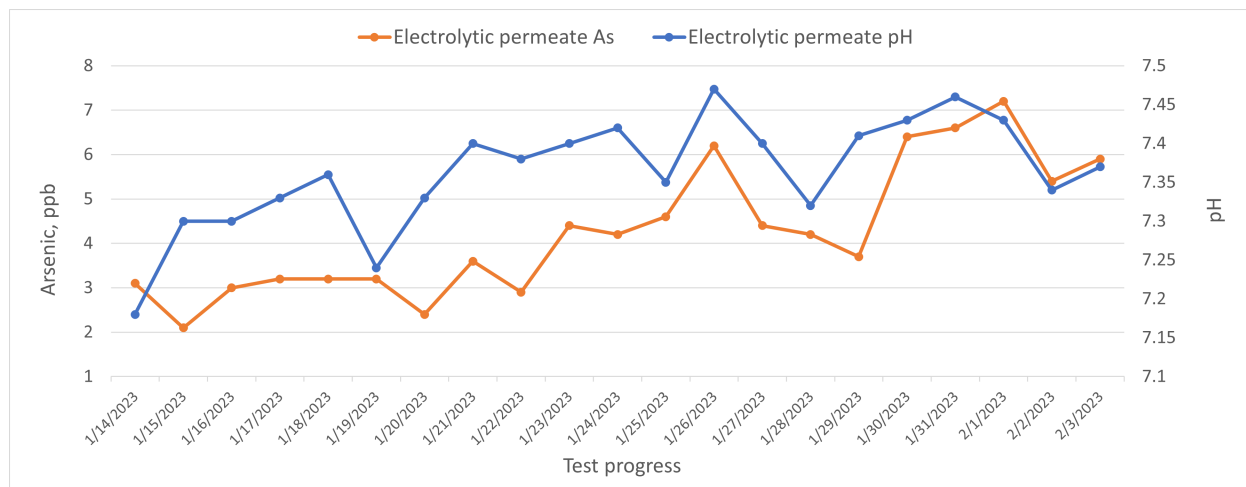
It should be noted that arsenic adsorption onto a coagulant surface is a highly complex process which depends on multiple treated water constituents such as pH, competitive ions, organics, water ionic strength, and more. However, pH control is one of most critical factors in arsenic removal process optimization and control because of its very strong effect on both arsenic adsorption and the coagulation process; and the fact of the constant need to control pH levels throughout the treatment process. Therefore, the effect of pH on arsenic removal using either the electrolytic ferrous reagent or the bulk ferric chloride reagent was reviewed and arsenic levels in the permeates were plotted against corresponding pH levels (Figures 11-12).

The correlation between both permeate pH and arsenic levels in the Train 1 permeate (bulk ferric chloride) are detailed in Figure 11. The Train 1 permeate arsenic levels follow the pH trends whereby an increase in water pH causes a proportional increase in residual arsenic levels.



**Figure 11. Train 1 (Bulk Ferric Chloride) Permeate Arsenic Results Plotted vs pH**

The correlation between both permeate pH and arsenic levels in the Train 2 permeate (electrolytic ferrous reagent) are detailed in Figure 12. There is very strong correlation between treated water pH and residual arsenic levels in Train 2 permeate (electrolytic ferrous reagent). In fact, the lowest arsenic levels (2-3 ppb range) were achieved during the first week of the demonstration where the permeate pH range was the lowest between 7.18-7.38. During the second and third weeks of the demonstration pH levels increased to 7.35-7.45 which caused a corresponding increase in arsenic residuals.



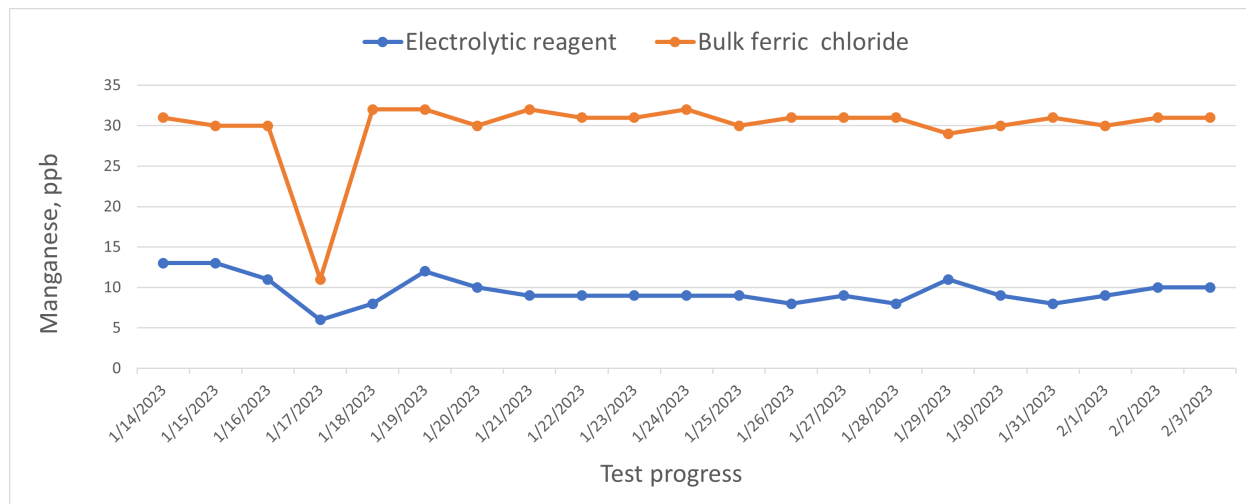
**Figure 12. Train 2 (Electrolytic Ferrous Reagent) Permeate Arsenic Results Plotted vs pH**

The electrolytic ferric reagent was produced in batches and its pH was adjusted manually to match water pH in Train 2 and Train 1 (plant process pH). It is obvious, that some discrepancy has occurred during the pH adjustment process between the two demonstration treatment trains. It should be noted that results obtained during this demonstration trial are in very strong correlation with results reported in [1]. In this work, arsenic removal from Alamosa well water based on coagulation and microfiltration was investigated. Both ferric chloride and ferric sulfate bulk reagents have been evaluated as coagulants. It was demonstrated that the best arsenate removal (over 90 %) can be achieved at pH levels below 7, while at pH levels 7.6 and above arsenic removal reduced dramatically to 80% or below [1].

Also, a higher quality effluent using the electrolytic ferrous reagent was achieved using a much lower dose of the coagulant; 4.8 ppm of the electrolytic ferrous reagent vs 5.9 ppm of bulk ferric chloride. With the SafeGuard™ H2O electrolytic reagent approach the iron dose and pH were controlled independently (Figure 9). By contrast, it is not possible to achieve the independent control of iron dose and pH using bulk ferric chloride. In fact, in order to keep treatment pH at an optimal level (7.2-7.3) using a ferric chloride reagent, the dose would need to be increased from 5.9 to 6.5 ppm or higher. This would result in excessive reagent dosing and costs, more frequent membrane backwashing and use of associated chemicals and greater waste generation and discharges. The only alternative to that would have been to incur the lifetime costs of installing, managing and monitoring an additional acid dosing module of sufficient scale to impact the overall pH of the bulk reagent. By contrast, the electrolytic ferrous reagent generation approach allows for optimization of key process parameters within tight operational parameters, materials and cost savings and overall process automation.



The manganese values from the Train 1 (bulk ferric chloride) and Train 2 (electrolytic ferrous reagent) permeates are detailed in Figure 13.



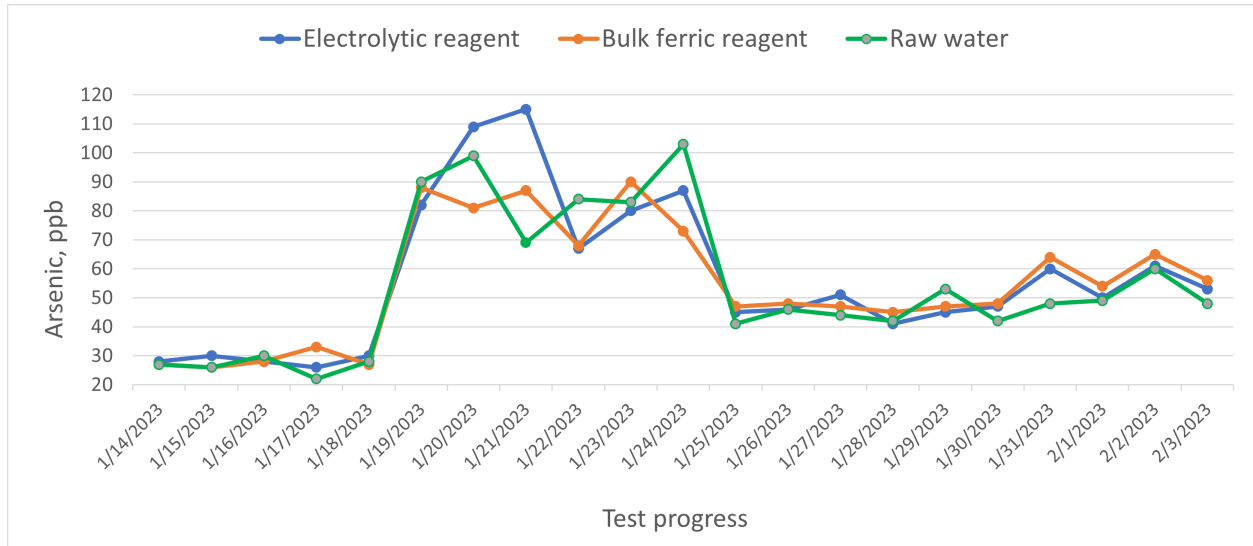
**Figure 13. Manganese Levels in Train 1 (Bulk Ferric Chloride) and Train 2 (Electrolytic Ferrous Reagent) Permeate Streams**

The raw water manganese levels were measured by the certified laboratory to be under 6 ppb. The permeate manganese levels in Train 2 (electrolytic ferrous reagent) are significantly lower than those in Train 1 (bulk ferric chloride). This is due to a much lower relative manganese content in the electrolytic ferrous reagent than in the bulk ferric chloride reagent (Figure 2). Based on the steel anode certificate data (0.18% Mn, Figure 3) and laboratory data on electrolytic reagent (Figure 2), the electrolytic reagent contribution to manganese permeate levels is expected at the level of 9.3 ppb. The Train 2 permeate (electrolytic ferrous reagent) manganese levels varied between 8-13 ppb. On the contrary, the Train 1 permeate (bulk ferric chloride) demonstrated significantly higher permeate manganese levels 29-32 ppb typical (except for an outlier on Jan. 17, 2023).

Laboratory analysis has shown that bulk ferric chloride reagent has a manganese level of 0.56% which is significantly higher than the 0.2 % manganese level in the electrolytic ferrous reagent. Therefore, any bulk ferric reagent dose increase will contribute to a proportional permeate manganese level increase. In commodity bulk ferric chloride reagents, manganese values can vary significantly from 0.5-1.5% which poses a risk of exceedance of the Secondary Maximum Contaminant Limit for manganese of 50 ppb.

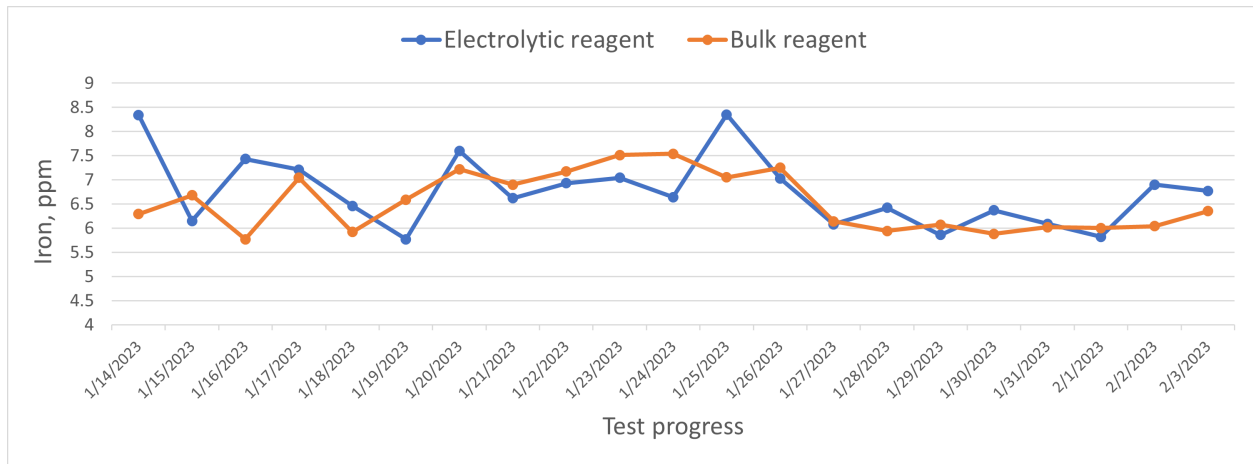
**Reaction Tank Water Quality Sample Results**

In addition to daily permeate samples from Train 1 and Train 2, samples from the Reaction Tanks were taken during the back wash step and analyzed by the certified laboratory (Figure 14). Total arsenic results in both Reaction Tanks (Reaction Tank 1- bulk ferric chloride and Reaction Tank 2- electrolytic ferrous reagent) are in good agreement with each other and correlate well with raw water trends (Figure 6).



**Figure 14. Total Arsenic Results In Reaction Tank 1 (Bulk Ferric Chloride) and Reaction Tank 2 (Electrolytic Ferrous Reagent) During Backwash Step And in Raw Water.**

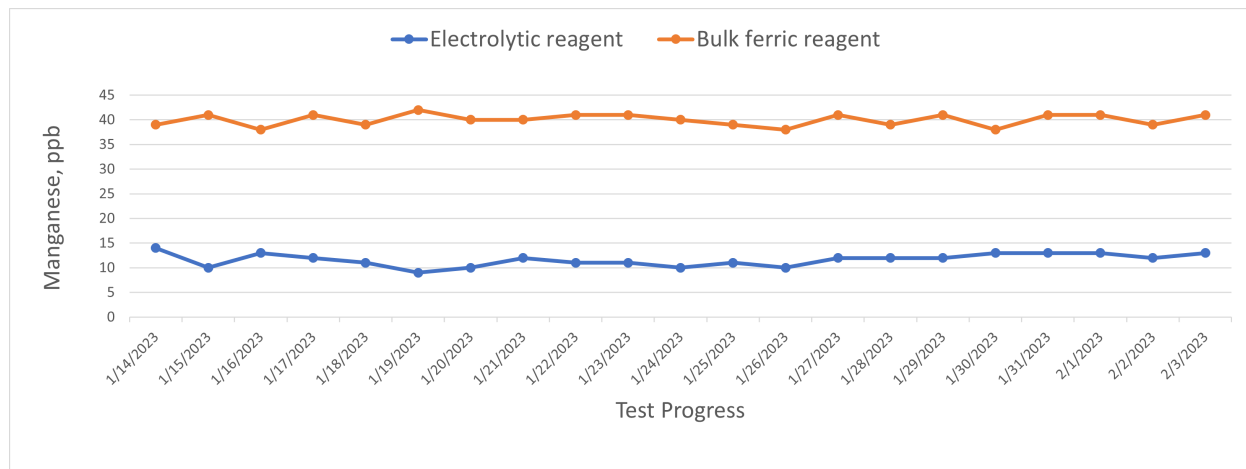
Figure 15 shows total iron results in both Reaction Tank 1 (bulk ferric chloride) and Reaction Tank 2 (electrolytic ferrous reagent) during the back wash. Total iron levels in both reaction tanks reflect iron reagent doses applied for arsenic removal: 5 ppm of electrolytic ferric and 5.9 ppm of bulk ferric chloride reagent. The results indicate that in both treatment trains particle removal is highly efficient, this is confirmed by external laboratory results detailed Figure 9.



**Figure 15. Total Iron Results In Reaction Tank 1 (Bulk Ferric Chloride) and Reaction Tank 2 (Electrolytic Ferrous Reagent) During Backwash Step**



Figure 16 demonstrates manganese results in both Reaction Tank 1 (bulk ferric chloride) and Reaction Tank 2 (electrolytic ferrous reagent) during the backwash step. Manganese levels correlate well with permeate manganese levels and manganese contamination levels in the electrolytic ferrous reagent and bulk ferric chloride reagent.



**Figure 16. Total Manganese Results In Reaction Tank 1 (Bulk Ferric Chloride) and Reaction Tank 2 (Electrolytic Ferrous Reagent) During Backwash Step**

### Conclusions

Since 2008, the City of Alamosa has been using ultrafiltration filtration and a ferric dose of 16-19 mg/L to successfully reduce arsenic from 35-45 ppb (influent) to below 10 ppb (effluent).

Concerned with having to increase their reliance on bulk ferric chloride to meet a lower arsenic MCL and the associated inherent concerns, the city evaluated the novel SafeGuard™ H2O arsenic removal technology from AMS that generates a ferrous reagent in-situ via an electrolytic process and eliminates the reliance on hazardous bulk chemicals.

The bench scale demonstration of the SafeGuard™ H2O in-situ electrogenerated ferrous reagent treatment technology at the City of Alamosa in 2022 showed how the in-situ generated reagent can achieve arsenic removal below 10 ppb; proving the efficacy of the technology. The electrogenerated ferrous reagent was shown to achieve reliable arsenic removal below 5 ppb with a ferrous dose of 6.5-8 mg/L.



The technology demonstration evaluated the purity of the in-situ electrogenerated ferrous reagent compared to bulk ferric chloride and studied the impact of both reagents on membrane health.

Conclusions from a SafeGuard™ H2O demonstration include:

- The SafeGuard™ H2O arsenic removal technology, a full-scale 100 ml/min system (0.016 gal/sq ft/min), demonstrated the ability to remove high levels of influent arsenic to below 5 ppb under tightly controlled treatment process conditions.
- The electrolytically generated ferrous reagent provides a higher efficiency in arsenic removal compared to bulk ferric chloride. The SafeGuard™ H2O electrolytically generated reagent demonstrated high arsenic treatment performance using ferric coagulant dose 27% lower than that with bulk ferric chloride reagent.
- The purity of the in-situ ferrous reagent precursor is of a higher quality than bulk ferric chloride.
- The high purity of the in-situ ferrous reagent resulted in lower manganese levels in the treatment reagent as well as in the treated water and waste. The low manganese content in the electrolytic ferric reagent relative to the bulk ferric reagent caused minimal impact on the treated water quality.

Arsenic is one of the most difficult inorganic contaminants to remove. Historically, arsenic treatment technologies have struggled to economically treat at the 10 ppb standard, let alone the lower 5 ppb or 3 ppb limits that are under consideration by the EPA.

The chemical, physical, and biological process treatment systems to date have failed to provide a reliable, economical, simple to operate arsenic removal solution, capable of achieving regulatory compliance without incurring high initial investment and operating costs.

The validation of SafeGuard™ H2O technology to generate a ferrous reagent in-situ via an electrolytic process shows great promise for utilities looking to remove arsenic to low levels and eliminate reliance on hazardous bulk chemicals.



The most significant benefits of the in-situ electrogenerated ferrous reagent treatment approach over traditional bulk reagents include:

- Electrogenerated ferrous ions are produced from a certified iron metal precursor therefore the reagent does not contain unexpected impurities (inorganic and organic) which may be present in bulk ferric chloride chemical solutions and interfere with the treatment process.
- Electrogenerated ferrous ions are non-toxic in nature. While bulk ferric solutions are highly concentrated acidic, toxic and corrosive, a ferrous ion reagent is produced in-situ using highly inert iron metal. As opposed to dangerous and corrosive ferric chloride concentrates, the electrolytic ferrous ion generation process does not require special complex infrastructure or safety protocols.
- The electrolytic approach to ferrous ion generation offers a more economical alternative to bulk ferric solutions. In fact, this method uses inexpensive and readily available resources – mild steel metal and electricity. Another highly important advantage of electrolytic approach to generation of ferrous ions on demand is scalability of the electrogeneration system.
- The integration of online, real-time water quality monitoring of arsenic in raw and treated water and iron in treated water into the SafeGuard H2O treatment system provides for continuous control and system optimization.





## **Acknowledgements**

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