Case Study: The Coagulation/Filtration Process for Groundwater Arsenic Removal

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View from Cattletrack looking Southeast

Paradise Valley Arsenic Removal Facility
ADMINISTRATION BUILDING

Abstract

As a result of the 2006 arsenic MCL change, Arizona American Water (AAW) was required to construct several arsenic removal facilities within the Phoenix, Arizona metropolitan area. Coagulation filtration (C/F) was the treatment technology selected for AAW's two largest centralized facilities. The new facilities, which were designed by Damon S. Williams Associates (DSWA), treat a combined maximum flow of approximately 28 million gallons per day (MGD).

The arsenic removal facilities are unique, both because they are some of the largest C/F arsenic removal facilities in the southwest, and because of process equipment selection and design considerations imposed by local conditions. In addition, multiple pilot and full-scale C/F tests were conducted to validate the process design, which allows for comparisons to be made between performance values reported in the literature and data obtained at pilot scale and full-

scale. As such, the data presented herein can help to bridge the gap between theoretical and observed C/F arsenic removal results.

Project Summary

In March 2001, the United States Environmental Protection Agency promulgated new rules in response to legislation lowering the arsenic MCL from 50 ppb to 10 ppb. As a result, water service providers began working to identify the best available technologies for removal of arsenic from systems affected by the new regulation. AAW determined that centralized C/F treatment facilities were the most cost-effective option for arsenic removal in both the Paradise Valley and Sun City West districts. Preliminary bench and pilot scale testing identified process operating ranges and performance objectives for the facilities. Following conceptual design, AAW conducted a competitive bidding process and selected the design/build team of DL Norton and DSWA to deliver the project.

Because of the timeframe for implementation, the projects were placed on an accelerated project schedule. The use of the design/build method allowed for early procurement of long lead items and helped to familiarize the builder with the project prior to construction. During the preliminary design phase slight modifications were made to the design to reduce the cost of construction. A second series of pilot studies was conducted during the detailed design phase of the project to confirm design process operating ranges and process equipment sizing. Following design completion, construction permits were granted, and construction phase was underway by May of 2005. Following substantial completion of the arsenic removal system, a series of process performance and facility start-up tests were conducted to verify that the full-scale facility was meeting design objectives.

Treatment Process Description

Before construction of the arsenic removal facilities, groundwater supplies were pumped to a central storage facility where chlorine was added prior to pumping into the distribution system. The arsenic removal facilities were installed upstream of the finished water storage reservoirs. Since the C/F process is capable of achieving high arsenic removal efficiency, a portion of the raw water from the wells can bypass the treatment system and recombine with the low arsenic supplies exiting the treatment system, to produce a blended supply that still meets the MCL. The C/F facilities constructed during this project have been designed to meet a finished water arsenic goal of 8 ppb, which provides a factor of safety to ensure that the facilities comply with the 10 ppb MCL.

The portion of the flow that is routed to the treatment system is dosed with ferric chloride under high mixing energy to achieve good dispersion. Chlorine may be added to ensure that the arsenic is oxidized to the arsenate state. Sulfuric acid is added at one of the facilities to help reduce the pH of the water to optimize coagulation. During coagulation, arsenate adsorbs to the surface of the ferric hydroxide particles and is co-precipitated. Following coagulation, solids flocculate and then are removed by horizontal dual media pressure filters. Treated water recombines with the treatment bypass stream prior to storage and subsequent distribution to the local potable water supply system. The filters are backwashed periodically to remove accumulated iron solids. Following backwashing, the solids are settled and

thickened prior to disposal. Figure 1 presents a simplified block flow diagram of the C/F process.
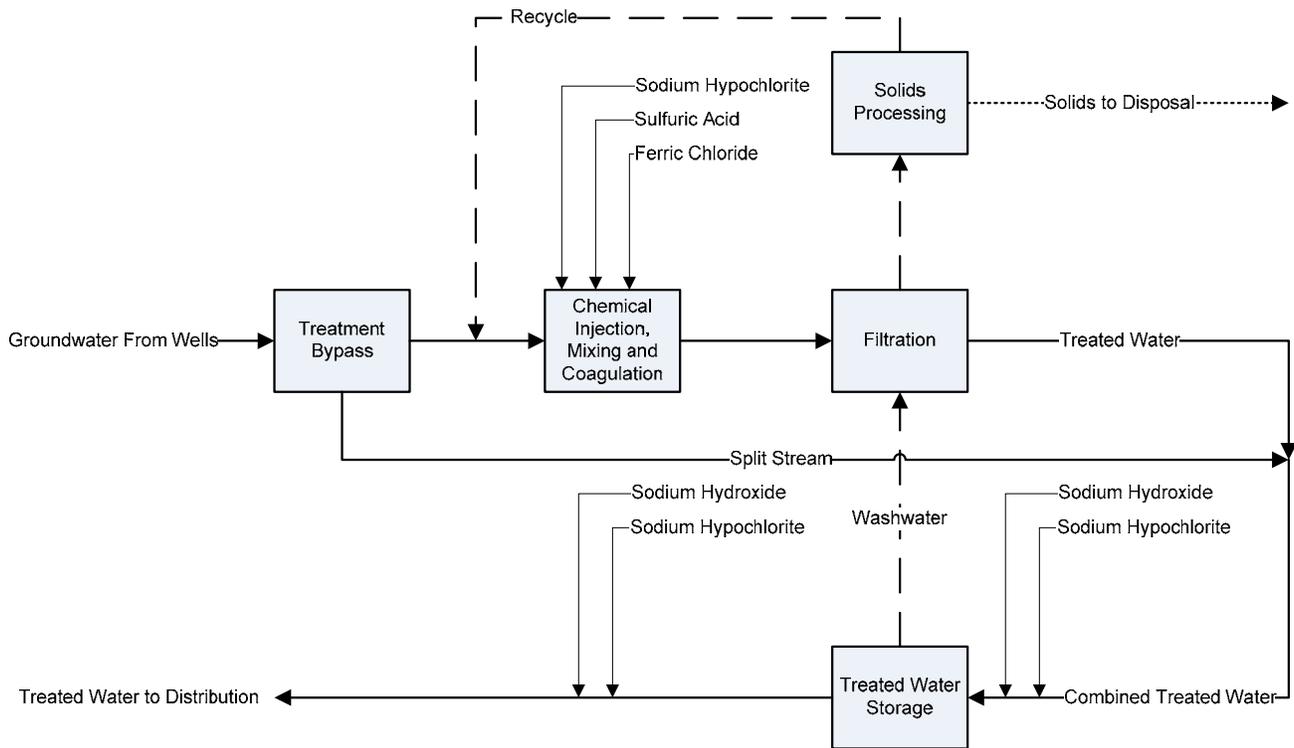
Figure 1   Simplified C/F Process Block Flow Diagram

Process Performance Objectives

The Sun City West Arsenic Removal Facility (SCWARF) and Paradise Valley Arsenic Removal Facility (PVARF) have been designed with similar treatment objectives. Both facilities are designed to achieve a treated water arsenic concentration of not more than 8 ppb. The PVARF has been designed to treat a maximum hydraulic flow of 21 MGD with a reliable production capacity of 18 MGD and average raw water arsenic concentration of 17 ppb. The SCWARF has been designed to treat a maximum hydraulic flow of 7.5 MGD with reliable production capacity of 6 MGD and average arsenic concentration of 36 ppb. The groundwater chemistry at the SCWARF is somewhat more alkaline than that of the PVARF. Differences in water chemistry resulted in slight modifications to the designs and subtle differences in operation of the two facilities.

Treatment Bypass

As mentioned previously, the high arsenic removal efficiency of the C/F process allows for blending of treated and untreated water while maintaining treated water arsenic concentrations below the MCL. The use of a spilt stream, to bypass the C/F process with a fraction of the flow, allows for smaller process equipment, lower treatment costs and reduced space requirements. Bypass flow is controlled through the use of a flow control valve that is

automatically adjusted by the plant control computer. Split stream flow percentage can be determined from an arsenic mass balance through the facility to maintain a fixed percentage of treated and untreated water. Differences in average raw water arsenic concentration between the SCWARF and PVARF allow the bypass percentage to be much greater at the PVARF than at the SCWARF.

Pretreatment Chemical Addition

Both the SCWARF and PVARF facilities use a jet mixing system, which was designed to provide significant mixing energy for pretreatment chemical dispersion. This system was selected to provide consistent high energy mixing over a wider range of treatment stream flow rates. Ferric chloride is injected into a side stream of raw water that is drawn off of the main treatment plant supply line by a centrifugal pump and re-injected back into the flow stream through a small diameter orifice nozzle. Sodium hypochlorite is also applied at the jet mixer at each plant, both to oxidize arsenic and to provide a disinfectant residual to prevent biological growth within the treatment facility and distribution system. Although arsenic in many groundwater supplies is already present in an oxidized or arsenate (As^{5+}) form, hypochlorite is added upstream of the treatment process to ensure that the arsenic has been oxidized because the C/F arsenic removal process is much less effective at removing arsenic that is in the reduced arsenite (As^{3+}) form.

The pH of the groundwater supplies entering the PVARF averages in the range of 7.8, whereas the pH entering the SCWARF is in the range of 8.2. Arsenic adsorption to iron diminishes rapidly as the pH approaches 8.0 standard units. Since addition of ferric chloride lowers the pH, the system can be placed into an efficient pH range with larger doses of ferric chloride and the larger dose provides more iron for adsorption. Thus this seemingly minor difference in raw water pH, coupled with the higher concentration of arsenic in the SCWARF supplies, would mean that significantly higher dosages of ferric chloride would be required to achieve similar arsenic removal performance as at the PVARF. Therefore, a sulfuric acid feed system was included in the design of the SCWARF to allow for reduced coagulant addition, which in turn would result in lower residuals production and associated handling costs. Carbon dioxide was also considered for pH adjustment, particularly because of the benefits it would provide relative to pH buffering. However, it was determined that sulfuric acid would be substantially more cost-effective than carbon dioxide.

Coagulation and Flocculation

During the coagulation process, metal salt coagulants dissociate, react with water and precipitate. Precipitated solids adhere to each other during flocculation to form particles of sufficient size that can be effectively removed via granular media filtration. Although alum can be used for arsenic removal, iron based coagulants are generally preferred because they are more effective for arsenic removal due to arsenic's natural affinity for iron. Of the iron based coagulants, ferric chloride is used most often for arsenic removal.
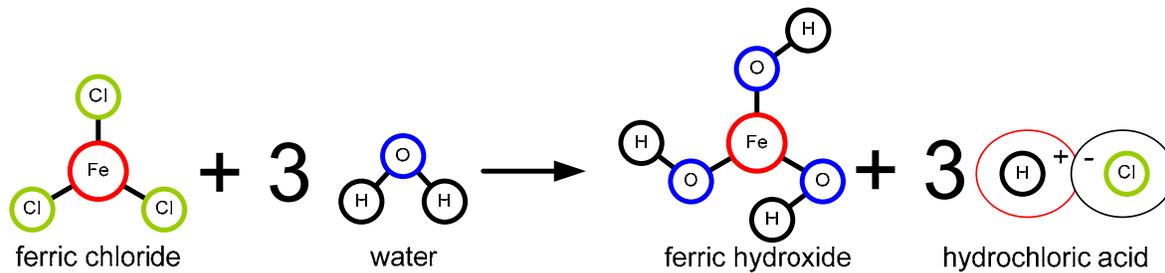
Figure 2   Overall Ferric Chloride Coagulation Reaction

During flocculation, arsenic bonds to the surface of the floc and is removed with the filtered solids. The efficiency of the arsenic removal process is directly related to the ability of the arsenic to find and bond to surface sites during coagulation and flocculation. For this reason, high mixing energy (G greater than 1000 s^{-1}) is provided for dispersion of the coagulant. Flocculation of the precipitated solids requires low level mixing energy because of the relatively weak bonds that may be sheared apart under high mixing energy. At the PVARF and SCWARF, flocculation occurs as the coagulated water mixes while it flows through the filter face piping assemblies and passes through the pressure vessel distribution headers.

Filtration

Direct dual media pressure filtration is used for removal of arsenic-bearing ferric hydroxide precipitates. The use of pressure filter vessels is beneficial because the water can be treated through the arsenic removal system and conveyed to the above-ground treated water storage reservoirs without an additional pumping step. Although many types of filtration can be used for floc removal in the C/F process, including, granular media filtration and membrane micro-filtration, dual media filtration was selected for use at the PVARF and the SCWARF because it was the most cost-effective.

At the PVARF and SCWARF, the dual media filters consist of 18 inches of anthracite on top of 12 inches of sand. The hydraulic loading range on the filter beds is 3 to 7.5 gallons per minute per square foot (gpm/sf) of filter bed. A filter-aid polymer feed system is provided in the event enhanced particle removal is necessary. Finished water turbidity is used as an indicator of the passage of iron (and associated arsenic) through the filter bed, and can be used to determine when filters are in need of backwashing.

Post Treatment Chemical Addition

Finished water from the arsenic removal system blends with the bypass stream prior to post treatment chemical injection. During post treatment chemical addition, sodium hydroxide is provided to re-establish the pH of the finished water to a level that will not be corrosive to distribution piping materials. Additional sodium hypochlorite can be added if necessary to raise the disinfectant residual to an acceptable level for disinfection.

Filter Backwashing

During filtration, solids will accumulate within the filter bed, which will lead to a gradual rise in head loss over the course of the filter run cycle. Filter backwashing is necessary before head loss gets to high or before turbidity (particles) begins to "breakthrough" the filter.   Filter

backwashing consists of air scour, water washing and filter-to-waste cycles. The air scour helps to loosen up the filter media and detach particles from the surface of the media. A drain down cycle is provided as part of the air scour step to prevent media from being washed out of the vessel. A centrifugal blower provides air for the air scour and air assisted drain down portion of the filter washing cycle.

Following air scour, the filter bed is backwashed by passing finished water upwards through the filter bed to waste. The wash cycle consists of a low flow rate wash followed by a high flow rate wash, and then a second low flow rate wash. The first low flow rate wash gradually fills the filter vessel with water. The high flow rate wash fluidizes and expands the media bed to release the trapped particulates so that they can be washed out of the vessel. The final low flow rate wash is provided to settle the filter media into stratified layers. Of importance is the fact that water viscosity affects fluidization of the filter media. The warm groundwater temperatures experienced in the region therefore require that higher flow rates and larger volumes of water be used for filter backwashing than would occur at many other granular filtration installations. Following the filter washing cycle, a filter-to-waste cycle is initiated to allow for the filter ripening process to occur. The duration of the filter to waste cycle is determined by passage of a minimum number of filter volume replenishments and filtered water turbidity.

Solids Handling
Backwash wastewater is collected in a batch clarification tank where it is allowed to settle. The supernatant is recycled back to the treatment process and the settled solids are thickened prior to subsequent sewer disposal or onsite dewatering. Clarifying and recycling backwash water significantly reduces the volume of waste and the costs associated with disposal. The backwash settling basins collect a predetermined number of filter wash cycles before initiating a settling timer. A floating decanter is then used to decant clarified backwash water from the surface of the settling basin for subsequent recycling to the head of the arsenic removal system. Multiple fill/decant cycles take place until the solids storage portion of the basin is full.

Once the bottom portion of the basin is full of solids, the settled solids are pumped to a lamella thickener. Polymer is added to help further thicken the sludge solids, and the separated water is returned to the backwash clarifiers. Thickened sludge is transferred from the lamella thickener to a sludge holding tank prior to sewer disposal or dewatering.

The SCWARF is designed to discharge the thickened solids to the local sanitary sewer system, which is served by a wastewater reclamation facility owned and operated by AAW. Sewer disposal was not available at the PVARF, so an onsite dewatering system was provided. Thickened solids from the sludge holding tank are pumped into a recessed plate and frame filter press. The dewatered solids discharge into a roll-off storage bin that is subsequently hauled offsite for landfill disposal.

Lessons Learned
During facility design and pilot testing, a few important C/F process relationships were identified. These relationships tie together the use of pH adjustment during coagulation, the

amount of solids that the filters can retain prior to filter turbidity breakthrough, and the impact of increased hydraulic loading rate on filter performance.

Facility design was completed under the premise that the arsenic removal objective would be met by feeding higher doses of coagulant until the performance objective was achieved. A series of bench and pilot tests were conducted to confirm the dose of ferric chloride required to reliably meet treatment system arsenic removal goals. The tests confirmed that 10 mg/L of ferric chloride, which lowered the pH of the treatment stream to approximately 7.5 standard units, achieved 90% removal. During the tests, jar testing and a series of filter runs were conducted using pH adjustment in combination with lower coagulant doses. The filter runs confirmed that 5 mg/L of ferric chloride coagulant with pH adjusted to 7.5 during coagulation produced similar arsenic removal results to the 10 mg/L ferric chloride dose without pH adjustment.

The pilot tests were also designed to test the impact of increased HLR on filter performance. HLR tests were conducted over a range of 4 to 7.5 gallons per minute per square foot of filter surface area. The mass of solids removed prior to turbidity breakthrough was determined for each filter run. The test results indicated that turbidity breakthrough was a direct function of the mass of solids applied to the bed and was not significantly affected by the hydraulic loading rate over the ranges of hydraulic loading rate experienced by the full scale facility. Mass fed prior to breakthrough was consistently in the range of 110 to 120 grams of ferric chloride per square foot of filter surface area. Since the amount of retained solids was fairly consistent, the filter run length could be estimated based on coagulant dose and flow. By using pH adjustment to lower coagulant dose, filter solids loading rates could be reduced, which in turn reduced backwash frequency and sludge production. Specifically, with pH adjustment, filter run times could be extended by 50% and waste residuals volumes could be reduced by 50%.

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About the Authors
Robert Boysen served as an engineer during the design and construction portion of this project. Mr. McCandless served as principal in charge and project manager of the design portion of the project. Mr. Keenan served as the design engineer for American Water throughout the entire project. Finally, Ms. Close served as project engineer during the design phase of the project and project manager during the construction phase of the project.

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