

Improving Drinking Water Plant Performance and Regulatory Compliance via Chemical Control Optimization

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Most conventional and membrane water treatment facilities are dependent upon chemical treatment, including coagulants and polymers, to operate effectively. Misapplication of these products can diminish the potential performance of these systems. This performance includes clarifier operation, filter efficiency, total organic carbon (TOC) removal, disinfection byproduct (DBP) compliance, lead and copper compliance, and cost. Providing proper chemical control optimization can not only improve the efficiency of the system and regulatory compliance but also provide a rapid potential pay back.

Coagulant Selection and Performance

There are a variety of different coagulants in the marketplace, including aluminum sulfate (alum), ferric chloride, ferric sulfate, polyaluminum chloride (PACl), and aluminum chlorhydrate (ACH). Each of these products possesses varying acidity, performance, and cost. It is difficult, if not impossible, to predict the performance of any coagulant on a specific water source; therefore, jar testing is recommended.

The photo with four jars demonstrates results after 20 parts per mil (ppm) dose of four different coagulants. Although it ap-

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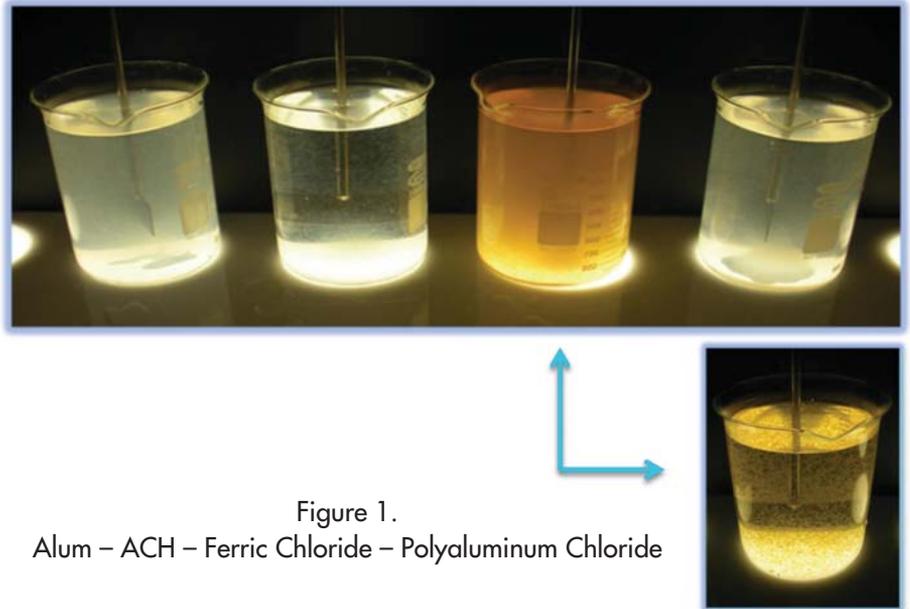


Figure 1.
Alum – ACH – Ferric Chloride – Polyaluminum Chloride

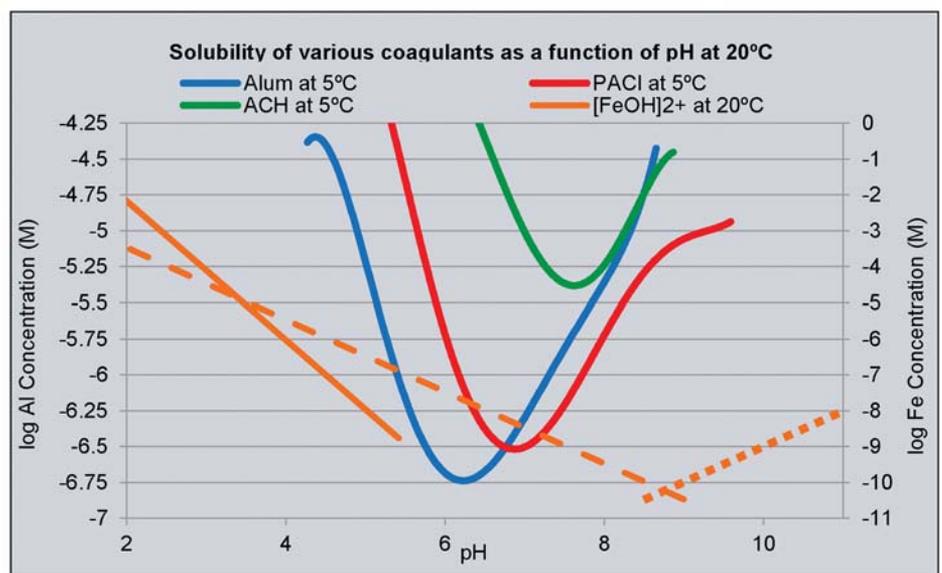


Figure 2. Shown are pH Precipitation Points for Alum (blue), PACl (red), ACH (green), and Ferric Chloride (orange – 2 targets)

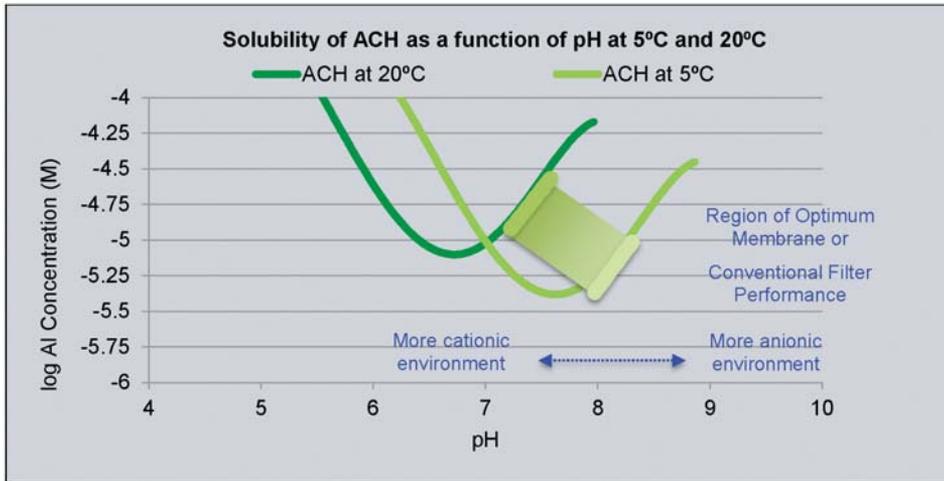


Figure 3. Optimum pH Precipitation Point for ACH While Compensating for Temperature

Table 1. Coagulant Selection

Coagulant	Acidity	TOC Removal	Cost
Ferric Chloride	Very High	Very Good	Low
Ferric Sulfate	High	Good to High	Low
Aluminum Sulfate	High	Fair to Poor	Very Low
Polyaluminum Chloride	Low	Good	High
Aluminum Chlorhydrate	Very Low	Very Good	High

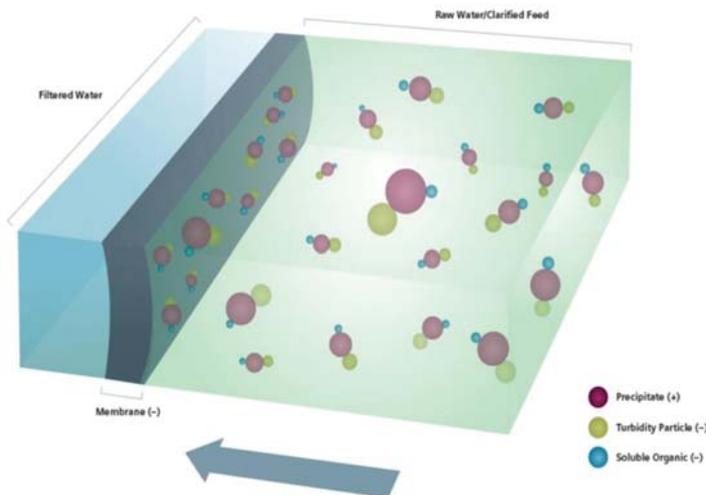


Figure 4. Floc Precipitate (red) Attracts Turbidity (green) and Soluble Organic Ions (blue)

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pears the jar second from the left (ACH) provided the best results in terms of floc precipitation and settling, it is only because the optimum pH precipitation point for ACH aligns best on this particular water sample. Floc precipitation can be improved on the other samples by adjusting pH to the point of least solubility for that particular coagulant. Keep in mind that all of these coagulant samples possess different optimum pH precipitation points.

Floc Precipitation Affected by Temperature

Figure 2 shows established optimum points of floc precipitation for various coagulants.

Temperature Effects on Flocculation

Although it is important to maintain an optimum pH value, there are two additional points to consider: water temperature changes and floc particle charge. Raw water temperature changes can affect the precipitation of floc particulates. The lower the water temperature, the higher the optimum pH value (Figure 3). This temperature decrease will also affect particle charge.

Temperature Effects on Particle Charge

All of the coagulant samples described are “acidic” and therefore precipitate as a “cationic” particle charge. This particle charge is offset by natural ion charges in the raw water (example: turbidity particles carry an “anionic” charge). Therefore, turbidity offset by coagulant in theory produces a “net zero zeta potential” or “neutral” charge. When coagulant doses exceed that which is required to neutralize turbidity, the precipitated particle charges possess a stronger and stronger “cationic” charge. This occurs when employing enhanced coagulation. Coagulant dose exceeding turbidity charges will result in higher removal of soluble organic carbon ions. Particle charge moves from cationic towards anionic as the water temperature decreases.

Raw Water pH and Alkalinity Effects on Coagulation Selection

Raw water sources around the country vary widely in terms of pH and alkalinity.

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Generally, softer waters with low alkalinity will possess a low pH value as well. Higher alkalinity waters will generally possess a high pH value. This is important when selecting the proper coagulant. A range of coagulants vary in terms of acidity, TOC removal, and price (Table 1).

Coagulant performance is dependent on water quality. It is difficult to predict performance for any source and it is recommended to perform jar testing before selecting a coagulant. Although ACH and PACl are more expensive than commodity

coagulants, such as alum and ferric chloride, they are becoming more popular due to lower coagulant dose, lower sludge generation, and higher TOC removal, and less dependent on alkalinity adjustment as they are prehydrolyzed with an alkalinity base.

Particle Charge Neutralization: Net Zero Zeta Potential

Traditionally, coagulants have been utilized primarily to mitigate incoming turbidity. Unchecked, turbidity, which does not possess the “weight” to settle, will pass

through a sedimentation unit or clarifier, accumulate in the filter, and ultimately break through. A primary coagulant can “attract” and “grab” these particles via particle charge neutralization. Turbidity particles carry an “anionic (-)” or negative charge. An acidic or coagulant floc particle carries an opposing “cationic (+)” or positive charge. As opposites attract, the precipitated coagulant floc particle can accumulate turbidity particles via charge neutralization.

Turbidity mitigation via coagulation can normally be achieved with a low coagulant dose; however it is important to keep in mind that all coagulants provide better performance at lower doses when operating near the optimum point of pH “insolubility,” which fluctuates depending on water temperature (see Figures 2 and 3).

For example, a raw water supply possesses a pH of 8.2; dosing ferric chloride at 10 ppm depresses the pH to 7.6. The ideal point of pH insolubility is 6.3 at 20°C. Unless pH is depressed from 7.6 to 6.3, precipitation, turbidity mitigation, and settling will be poor. It is possible to overfeed ferric to the point where saturation will eventually precipitate enough floc to provide mitigation; however, soluble iron will elevate and coagulant cost will increase.

Electrostatic Particle Attraction Onto Filter Surface With Membrane or Conventional Filter

Even the most efficient sedimentation or clarifier systems will allow floc particles to pass to the filter. Most drinking water

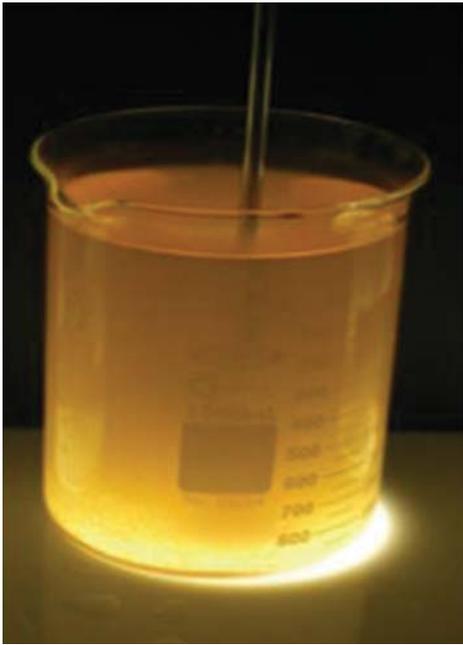


Figure 5. Uncontrolled pH

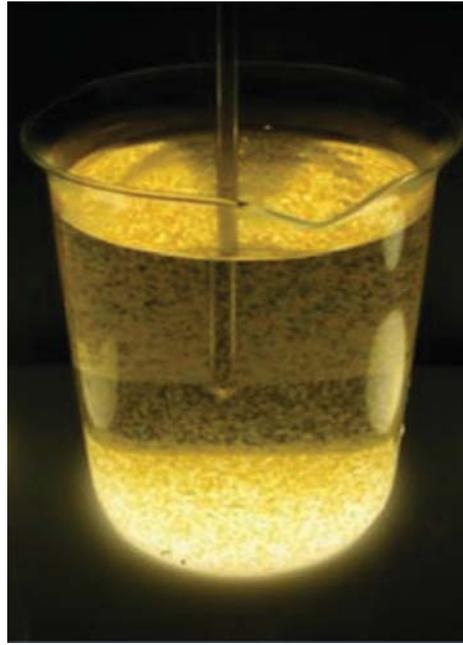


Figure 6. Controlled pH



Figure 7. Sedimentation, Uncontrolled pH



Figure 8. Sedimentation, Controlled pH

treatment plants are categorized as either “conventional floc–sed–filter,” with the filter comprising of various grades of media (multimedia) or ultrafiltration membranes. Both conventional and membrane filters can operate with or without sedimentation as pretreatment. In either case, whether incorporating presedimentation or not, pre-

cipitated floc particles that pass through to the filter can decrease performance. For conventional filters, the issue is filter run time versus particle breakthrough. For membrane systems, the performance issue is “fouling.” As coagulant particles precipitate as a cationic or (+) charge, the corresponding filter media or membrane

element possesses an opposing negative (-) charge. Similar to charge neutralization for turbidity mitigation, these precipitated floc particles will attract or stick to the filter via electrostatic attraction. This reaction will decrease the performance of either filter.

Filter Performance With and Without Particle Charge Control

By controlling particle charge and neutralizing the charge attraction, filter performance increase can be dramatic.

Depicted in Figures 13 and 14, a ultra-violet (UF) membrane plant with two separate filter skids conducted a test to demonstrate the effectiveness of particle charge control. Coagulant was dosed in a direct feed mode (no clarification). Poly-aluminum chloride (PACl) coagulant was dosed upstream into a common line. Both UF filter skids UF Filter 1 (Figure 13) and UF Filter 2 (Figure 14) received this same dose. A controlled dose of liquid caustic soda was dosed ahead of UF Filter 2 skid (Figure 14) and there is a dramatic difference. The red trend lines depict trans membrane pressure (TMP) rise and the blue lines depict permeability decline. There is a significant difference between Skid 1 and Skid 2.

Chemical Control Effects Regarding Regulatory Compliance

Major regulatory issues that relate to chemical treatment in a drinking water plant include TOC, DBPs, haloacetic acids (HAA), total trihalomethanes (TTHM), lead and copper, and arsenic. The TOC and DBPs are in many instances intertwined. As DBPs form when soluble organics, which pass through a filter, react with chlorine, they increase with detention and are compounded by temperature. The higher the water temperature, the faster the formation; therefore, by reducing soluble organic load, there is a twofold effect on reduction: 1) lower soluble organic content will reduce formation when reactive with chlorine, and 2) lower soluble organic content will require less chlorine. Lower organic content with lower chlorine dose will further decrease DBP formation. So in these cases, soluble organic removal potential will direct operations to consider superior performing coagulant options when regulatory compliance is at issue.

Additionally, operations must consider additional parameters that require attention,

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Figure 9. Precipitated Floc Particle Accumulation via “Electrostatic Attraction” With 20 ppm ACH



Figure 10. Precipitated Floc Can be Rinsed With Low Water Pressure



Figure 11. 20 ppm ACH With pH and Particle Charge Control With no Particulate Accumulation



Figure 12. Electrostatic Particle Accumulation (ferric) on UF Elements

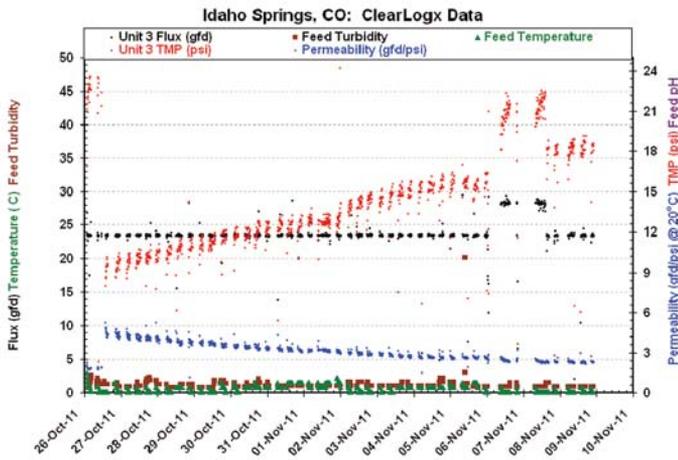


Figure 13. UF 20 ppm ACH, no Charge Control

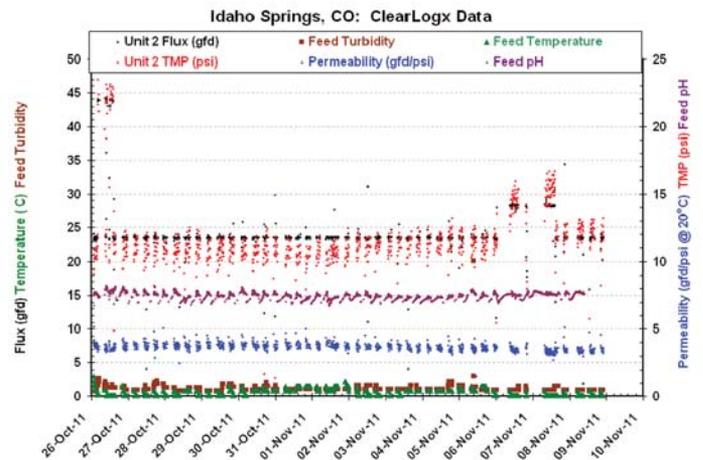


Figure 14. UF 20 ppm ACH, no Charge Control

Langelier Saturation Index								
Sample	Coagulant Dose (ppm)	pH	Temperature (°C)	Calcium Hardness as CaCO ₃ (mg/L)	Alkalinity as CaCO ₃ (mg/L)	TDS (mg/L)	LSI	Significance
Historic Max	0	0					---	---
Historic Avg	51.7	6.1					---	---
Historic Min	0	0					---	---
Raw Sample	0						---	---
LMF							---	---
Alum/LMF (coagulant)	30	7.5	25	8	6	7.7	-1.85	Mild Corrosion
(coagulant)	30	7.5	10	8	6	7.7	-2.18	Moderate Corrosion
(coagulant)							---	---
(coagulant)							---	---
(coagulant)							---	---
(coagulant)							---	---

Figure 15. Langelier Saturation Index (LSI) Calculator

Chloride to Sulfate Mass Ratio (CSMR) Calculator															
These calculations assume a contribution of 0.405 mg/L sulfate ion per 1 mg/L aluminum sulfate, and 0.656 mg/L chloride ion per 1 mg/L ferric chloride, based on contributions of the sulfate and chloride counterions to the molar masses of the coagulants. PACI is assumed to contribute 0.075 mg/L sulfate ion and 0.27 mg/L chloride ion per 1 mg/L PACI; based on University of Waterloo's research (http://hdl.handle.net/10012/4229)															
Background Levels		Alum-limited				Ferric-limited				CSMR					
Raw Sulfate (mg/L)		Alum Dose (ppm v/v)	Alum % w/w Strength	Alum Specific Gravity	Alum Dose (mg/L)	Maximum Ferric Dose for CSMR < 0.2 (ppm v/v)	Maximum Ferric Dose for CSMR < 0.5 (ppm v/v)	Ferric Dose (ppm v/v)	Ferric % w/w Strength	Ferric Specific Gravity	Ferric Dose (mg/L)	Minimum Alum Dose for CSMR < 0.2 (ppm v/v)	Minimum Alum Dose for CSMR < 0.5 (ppm v/v)	CSMR at specified alum and ferric dosages	
2	20	20	48.6%	1.33	12.9	8.18	28.50	20	40.0%	1.42	11.4	104.13	N/A	0.37	
Background Levels		PACI				CSMR									
Raw Sulfate (mg/L)		PACI Dose (ppm v/v)	PACI % w/w Strength	PACI Specific Gravity	PACI Dose (mg/L)	CSMR at specified PACI dosage									
2	20	10	50.0%	1.29	6.45	0.18									

Figure 16. Chloride-to-Sulfate Mass Ratio (CSMR) Calculator

Projected Return on Operations Investment											
Clean-in-Place (CIP) Tracking											
	2, 1 Cell #1 Train 1 and 2	2, 1 Cell #2 Train 1 and 2	2, 1 Cell #3 Train 1 and 2	2, 1 Cell #4 Train 1 and 2	2, 1 Cell #5 Train 1 and 2	2, 1 Cell #6 Train 1 and 2	2, 1 Cell #7 Train 1 and 2			Current CIP's/yr without Cleaning	Estimated CIP's/yr with Cleaning
HCl CIPs (#/yr)	26	26	26	26	26	26	26			182	100
Phosphoric CIPs (#/yr)	26	26	26	26	26	26	26			182	100
Hypochlorite CIPs (#/yr)	26	26	26	26	26	26	26			182	100
Clean-in-Place (CIP) Cost Variables											
Volume of HCl Acid (gal/CIP)	12	9	\$2.70	\$8.84	259	136	\$0.14	7	8		
Volume of Phosphoric (gal/CIP)											
HCl Acid Cost (\$/gal)											
Phosphoric Cost (\$/gal)											
Average Energy for Heating/Washing with CIP's (kWh/CIP)											
Average Energy for Heating/Washing with Chlorine (kWh/Chlorine-CIP)											
Energy Cost (\$/kWh)											
Volume of Bleach for Neutralization (gal/CIP)											
Volume of NaOH for Acid Neutralization (gal/CIP)											
Bleach Cost (\$/gal)	\$1.29	\$2.01	0	\$0.00	0	\$0.00	0	\$	15,774.34		
NaOH Cost (\$/gal)											
Total Volume for Disposal (gal/CIP)											
Disposal Cost (\$/gal)											
Labor (hrs/CIP)											
Labor Cost (\$/hr)											
Number of Operators Required (#/CIP)											
Savings on Reduced CIP's/yr (Saved/year)											
Average Heating Energy Usage accounting for Seasonal Variation in Water Temperature (mini-calculator)											
Average Energy Usage for Heating cleans (kWh/clean)											
Number of Summer cleans											
Average Energy Usage for Heating cleans (kWh/clean)											
Number of Winter cleans											
Average Energy Usage for Heating cleans (kWh/clean)											
Phosphoric CIPs	240	182	266	0	240.0	<--- Use this number in the appropriate boxes above					
Chlorine CIPs	120	0	160	0	#DIV/0!	<--- Use this number in the appropriate boxes above					
Maintenance Wash (MW)											
Volume of Chlorine (gal/MW)	11	\$1.05				7	\$1.29			255	1277
Chlorine Cost (\$/gal)											
Average Energy Usage for Heating (kWh/MW)											
Average Energy Usage for Washing (kWh/MW)											
Energy Cost (\$/kWh)											
Volume of Bleach for Neutralization (gal/MW)											
Bleach Cost (\$/gal)											
Total Volume for Disposal (gal/MW)											
Disposal Cost (\$/gal)											
Current MW's/yr without Cleaning											
Estimated MW's/yr with Cleaning											
Savings on Reduced MW's/yr (Saved/year)											\$ 11,540.34
Water Pump Energy											
Percent of Time Operating in Suction Mode (%)	0%	45	MGD	1440	2	70%	91%	97%			
Instantaneous Flow per Feed Pumps											
Instantaneous Flow Rate ("gal/min" or "MGD")											
Total Operation Time (min/day)											
Total Number of Feed Pumps (#)											
Efficiency of Feed Pump (%)											
Efficiency of Feed Pump Motor (%)											
Efficiency of Feed Pump WFD (%)											
Head Loss in Pipe (ft)	0	0	6	4	2112.0	\$0.14	\$	107,922.51			
Chlorine Requirements out of Sulfite (ft)											
Current Average TMP (ft)											
Estimated Average TMP with Cleaning (ft)											
Energy Savings for Pump (kWh/day)											
Average Energy Cost (\$/kWh)											
Savings on Reduction in TMP by Cleaning (Saved/yr)											
Estimated Total Return on Operations Investment (\$ saved/year)											
\$135,237.19											

Figure 17. Drinking Water Facility Return on Investment (ROI) Calculator

Continued from page 10 including iron and manganese, color, taste and odor, and corrosion control.

Corrosion Control: Langelier Saturation Index Versus Chloride-to-Sulfite Mass Ratio

Although corrosion control is not a regulatory compliance issue in itself, lead and copper compliance is, and is directly related to the corrosivity of the water that enters the distribution system. Over the years, the standard measurement regarding the corrosivity of a water supply is the LSI Index (Langelier Saturation Index). This index takes into consideration a water sample's pH, calcium hardness, alkalinity, total dissolved solids value, and temperature.

Another measurement has recently been introduced, which relates water's corrosivity to its chloride-to-sulfate mass balance ratio (CSMR). The thought is when the chloride level exceeds sulfate by a cer-

tain ratio, there is an appreciable acceleration in corrosion. This is important regarding coagulant selection as it would assume that chloride-based coagulants, such as ferric chloride, PACl, and even ACH, would exceed the optimum ratio.

Before making this assumption, values should be entered into a CSMR calculator. It is feasible that chloride-based coagulants, if they outperform other options in terms of organic removal, could still be utilized. A chemical control logic could monitor dose versus the effect on CSMR.

For example, an operator at a large drinking water plant wants to dose ferric chloride as it has proven to achieve the highest soluble organic removal when compared to other coagulant via jar testing. There may be concern that this coagulant will exceed the recommended CSMR. When the operator inputs the raw water chloride and sulfate levels, as well as coagulant dose, it is confirmed that the ratio is exceeded. However, when the operator inputs a "co-

dose" of aluminum sulfate at a certain dose, the desired ratio is achieved. Additionally, in this case, the less expensive alum maximizes soluble organic removal with a lower overall ferric chloride demand.

Chemical Control Regarding Overall Plant Operating Cost: Return on Investment

One of the first issues arising regarding installation of an automated control system for chemical feed will be the initial capital cost. Based on the issues raised in this article, it is very feasible that there can be a rapid return on investment (ROI) in as little as one year or less according to the following:

- Reduced overall chemical demand
- Reduced chemical sludge generation and disposal
- Power savings
- Workforce savings
- Water conservation