Ferrate Treatment
TECHNOLOGIES

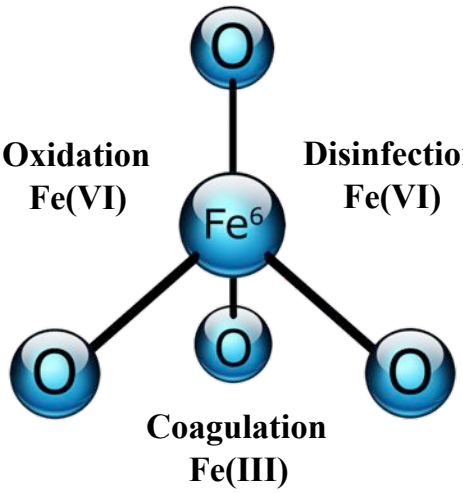
FTT Treatment Data

Case Studies by Market Application

Wastewater Treatment

Industrial Effluents

Drinking Water Treatment



Summer 2013 Handouts

Ferrate Treatment TECHNOLOGIES

Sample Wastewater Treatability Test Results

A Ferrate Laboratory Treatability Test incorporates proprietary Ferrate (Iron VI) Treatment System chemistries into a bench test under controlled conditions that are designed to meet treatment objectives specified by the client. The chemical modification or removal of target constituents is achieved by a combination of chemical reactions that can include oxidation, disinfection, complexation, or coagulation followed by the manipulation of one or more operational parameters such as pH adjustment, sedimentation, filtration and mixing.

Case Study 1

Objective: Disinfect plant effluent for fecal coliform (FC) to <14 CFU/100 mL, and reduce CDBM (Dibromochloromethane), caused by chlorination of plant effluent, to below 34 µg/L at an East Coast Florida Wastewater Plant.

Parameter	Chlorinated Plant Effluent	Raw Un-Chlorinated (Control)	3-ppm Ferrate Dose	Reduction
CDBM	123 µg/L	0.88 µg/L	1.39 µg/L	99%
FC (CFU/ 100 mL)	NA	1857	3.7	3-log

Results: At a dose of 3-ppm, not only was Ferrate Treatment able to meet the disinfection target, it also reduced the CDBM concentration down to 1.39 µg/L.

Case Study 2

Objective: Disinfect for fecal coliform to meet high level disinfection standards for reclaimed water systems while remaining within total trihalomethane (TTHM) regulatory standards at a Southwest Florida Wastewater Plant.

Results: Several effluent samples were collected from the plant's treatment system. A Ferrate dose of as little as 1-ppm was effective in disinfecting for fecal coliform (FC) to the high-level regulatory limit of <1 CFU/100 mL. A 2-ppm dose was equally effective for all the samples tested. This was achieved with minimal or no TTHM formation. Samples were also collected on different days to evaluate total phosphorus (TP) removal using Ferrate. A dose of 1-ppm reduced TP by 77% to 0.14 mg/L in one sample. Slightly higher dosages were even more effective in reducing TP to below 0.1 mg/L.

Parameter	Raw	1-ppm Ferrate	2-ppm Ferrate	3-ppm Ferrate
Fecal Coliform – CFU/100 mL	1,133.3	<1	<1	N/A
TTHMs (µg/L)	U (0.27)	I (0.31)	0.60	N/A
Fecal Coliform – CFU/100 mL	200	68	N/A	<1
TTHMs (µg/L)	U (0.37)	U (0.37)	N/A	I (0.92)
Fecal Coliform – CFU/100 mL	200	12	N/A	<1
TTHMs (µg/L)	U (0.37)	U (0.37)	N/A	I (0.94)

Parameter	Raw	1-ppm Ferrate	3-ppm Ferrate	5-ppm Ferrate
Total Phosphorus (mg/L)	1.4	0.27	0.19	0.080
Total Phosphorus (mg/L)	0.79	0.50	0.15	0.064
Total Phosphorus (mg/L)	0.60	0.14	I (0.025)	N/A
Total Phosphorus (mg/L)	0.86	0.20	0.12	N/A

N/A = Not Analyzed

U = Indicates that the compound was analyzed for but not detected. The Method Detection Limit is shown in parentheses.

I = The reported value, shown in parentheses, is between the laboratory Method Detection Limit (MDL) and the Practical Quantitation Limit (PQL).

Cutting-Edge Environmentally Friendly Water Treatment

Case Study 3

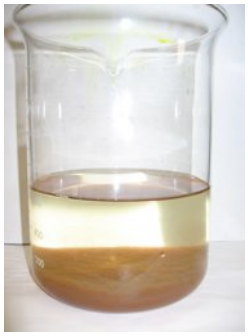
Objective: To reduce extremely high color and disinfect for Total Coliform (TC) without exceeding regulated disinfection byproduct (DBP) standards at a Tennessee Wastewater Treatment Plant. This facility's high effluent color is due in large part, but not exclusively, to a single industrial contributor.

Results: Ferrate treatment at a dose of 15-ppm was able to reduce effluent color to 25 Platinum Cobalt Units (PtCoU), lower TC numbers to none detected (<1 CFU/100 mL), and to meet the DBP standards applicable to drinking water. Ferrate treatment at the same 15-ppm dose was still able to reduce effluent color to 25 PtCoU, even with this industrial source being contributed to the influent wastewater.

Sample	TC (CFU/100 mL)	TTHM (µg/L)	HAA5 (µg/L)	Color (PtCoU)
Raw Effluent w/o Industrial Contribution	TNTC	1.90	27.46	>120
Treated Sample 15-ppm Ferrate	<1	1.59	42.38	25
Reduction	99.99%	-	-	>79.17%
Raw Effluent with Industrial Contribution	N/A	N/A	N/A	>120
Treated Sample 15-ppm Ferrate	N/A	N/A	N/A	25

Total Trihalomethanes (TTHM) – Primary Drinking Water Standard <80 µg/L
Haloacetic Acids (HAA5) – Primary Drinking Water Standard <60 µg/L
TNTC = Too Numerous to Count N/A = Not Analyzed

Effluent without Industrial contribution



Ferrate treatment at 15-ppm

Case Study 4

Objective: Achieve high-level disinfection of effluent (<1 CFU/100 mL), and meet primary drinking water DBP standards (TTHM and HAA5) at a Florida Wastewater Plant. Samples were collected and tested from two points in the existing treatment train.

Results: The sample from the secondary clarifier was disinfected to the high-level standard using only 3-ppm of Ferrate. The disinfection byproducts were 1.11 µg/L of TTHM and 12.84 µg/L of HAA5, well below primary drinking water standards. An effluent sample collected after filtration was disinfected to the same standard using only 1-ppm of Ferrate. Analyses for DBPs were conducted using the 3-ppm Ferrate treated jar. The DBPs were 4.40 µg/L for TTHM and 18.80 µg/L for HAA5, well below primary drinking water standards.

Secondary Clarifier	Coliform Bacteria per 100 mL	TTHM (µg/L)	HAA5 (µg/L)
Raw	3,333.33	NA	NA
1-ppm Ferrate	77.77	NA	NA
3-ppm Ferrate	<1	1.11	12.84

After Filtration	Coliform Bacteria per 100 mL	TTHM (µg/L)	HAA5 (µg/L)
Raw	1,666.68	NA	NA
1-ppm Ferrate	<1	NA	NA
3-ppm Ferrate	<1	4.40	18.80

Total Trihalomethanes (TTHM) – Primary Standard <80 µg/L
Haloacetic Acids (HAA5) – Primary Standard <60 µg/L
NA = Not Analyzed

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Case Study 5

Objective: Tests were conducted at a wastewater treatment facility located in Georgia for phosphorus removal and disinfection. The samples were taken from the Primary Influent in front of the bar screens prior to chemical addition (ferric chloride), and taken after a Secondary Clarifier.

Results: A 7 ppm Ferrate (VI) dose (and pH adjustment with ferric sulfate) reduced ortho-phosphate in the Primary Influent from 13.3 mg/L to 0.41 mg/L, for a reduction rate of 97%. A Ferrate dose of 3 ppm (and pH adjustment) reduced ortho-phosphate after the Secondary Clarifier by up to 75% and completely disinfected it (even with just a 2 ppm dose of Ferrate).

Sample	Total Coliform (CFU/100 mL)	Ortho-Phosphorus (mg/L)
Raw Primary Influent		13.3
Treated Sample 7 ppm Ferrate		0.41
Reduction		97%
Secondary Clarifier	600	0.08
Treated Sample 3 ppm Ferrate	<1	0.02
Reduction	99.8%	75%

Case Study 6

Objective: Tests were conducted at a wastewater treatment plant in Alabama for removal of total phosphorus, in order to prepare for their future nutrient limit of 0.043 mg/L (43 ppb).

Results: A Ferrate(VI) dose of only 2 ppm (with pH adjustment) was able to reduce the total phosphorus from their clarifier from 3.84 parts per million to <13 parts per billion (below lab detection), for a removal rate of >99.7%, and well within their future limit.

Clarifier Effluent	Total Phosphorus (parts per billion)
Raw	3,840
2 ppm Ferrate	<13(**U**)

U indicates that the compound was analyzed for but not detected

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Ferrate Treatment TECHNOLOGIES

Sample Industrial Wastewater Treatability Test Results

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Case Study 1 – Agricultural Stormwater

Objective: To reduce Total Phosphorus to the lowest achievable concentration, using the smallest dose of Ferrate.

Results: The raw water sample received was highly colored, and had a Total Phosphorus concentration estimated to be approximately 3 ppm (3,000 ppb). A Ferrate dose of 5 ppm with ferric chloride for pH adjustment reduced Total Phosphorus to <8 ppb (the private laboratory method's analytical detection limit).

	Raw Phosphorus	Ferrate Dose	Initial pH	Ferric Chloride Dose	Treated pH	Treated Total Phosphorus
Run 1	2.4 ppm	5 ppm	12.18	103 ppm	4.86	**<0.008 ppm**
Run 2	2.4 ppm	5 ppm	12.26	109 ppm	5.19	**0.21 ppm**

Case Study 2 – Lead Smelter

Objective: Reduce Lead (Pb) and Cadmium (Cd) concentrations to acceptable levels (≤ 10 ppb for Lead and ≤ 5 ppb for Cadmium).

Results: A Lead Smelter sample with 30.3 ppb Lead and 320 ppb Cadmium was reduced to 2.62 ppb Pb and 2.74 ppb Cd with a Ferrate dose of 10 ppm and pH adjustment to 10.3 – 10.4 This is 90% of their initial concentrations and a level well below reported discharge limits of 10 ppb Pb and 5 ppb Cd to meet compliance. Soluble concentrations for both metals were below 1 ppb.

Parameter	Raw	Ferrate Dose 10 ppm
Total Lead (Pb) – ppb	30.3	2.62
Total Cadmium (Cd) – ppb	320.0	2.74
Soluble Lead (Pb) – ppb	1.8	0.19
Soluble Cadmium (Cd) – ppb	7.2	0.64
% Removal – Lead (Pb)	---	**91.4**
% Removal – Cadmium (Cd)	---	**99.1**

Cutting-Edge Environmentally Friendly Water Treatment

Case Study 3 – Cyanide Production Facility

Objective: Reduce the Total Cyanide concentration from 6.6 ppm to <1 ppm in the plant effluent.

Results: Ferrate was able to reduce the Total Cyanide concentration in the effluent to levels acceptable for environmental discharge, and could in fact reduce Cyanide levels to below detection if needed.

Ferrate Dose (ppm)	Final pH	Total Cyanide (ppm)
0	12.5	6.6
35	6.5	1.5
50	6.5	0.065
75	6.5	<0.0038 (U)

Case Study 4 – Peru Acid Mine Drainage

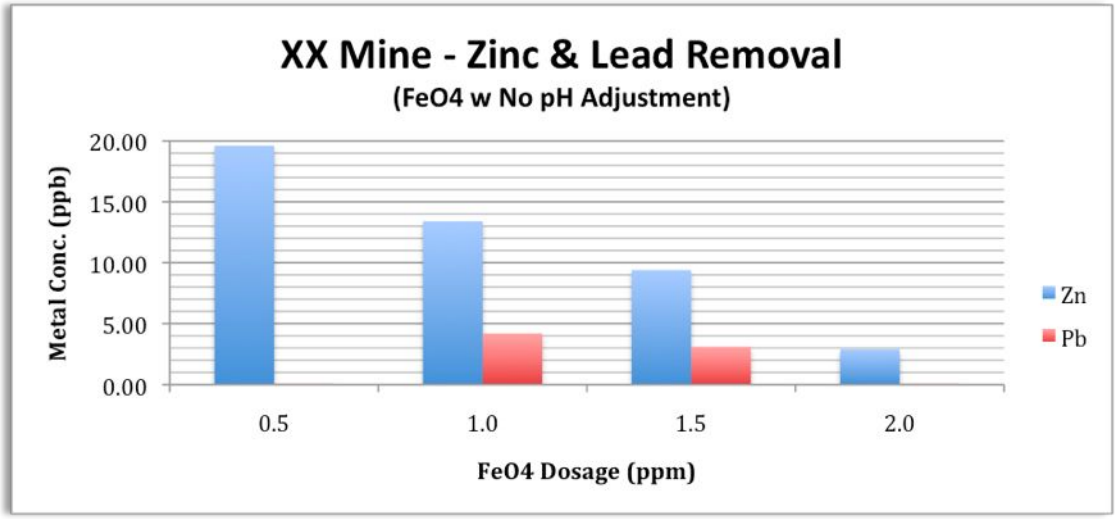
Objective: Reduce the concentrations of organics and metals including aluminum, iron, manganese, and nickel.

Results: With a dose of 2 ppm, Ferrate(VI) treatment was able to destroy >98% of the organic carbon (measured as UV_{254} absorbance), reduce turbidity to 0.3 NTU, and residual Al & Fe were reduced by greater than 99.7%, while Ni & Mn were reduced by 65% & 43%. The acid was neutralized by Ferrate's caustic.

Case Study 5 – Mining Wastewater

Objective: Verify Ferrate's ability to remove (via co-precipitation) toxic heavy metals; specifically Zinc (Zn) and Lead (Pb) from the wastewater to "extremely" low levels, so that the effluent would not pose any environmental or health risk. A useful standard for comparison would be the *World Health Organization's Drinking Water Standards: Zn = 3,000 ppb, and Pb = 10 ppb.*

Results: Ferrate reduced Zn by > 99.8% down to < 3 ppb, and Pb by > 99.9% down to < 0.1 ppb with a dose of 2 ppm or less. *This represents a water quality level equal to 1/1000 of the Zn standard and 1/100 of the Pb standard for drinking water.*



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Case Study 6 – Lake Clean-up (Dredge Return Water)

•***Objective:*** Treat the liquid fraction of dredged sediments that are harming ecology
• Remove ammonia and phosphorus from this dredge return water.

Ferrate Dose (ppm)	TP* (mg/L)	TN* (mg/L)
0	4.178	403.6
5	0.034	0.034
% Removal	99.2	98.5

* Average Value (from 12/12/12 - 3/22/13) after deleting anomalous records

Results: The pilot demonstration was conducted from 12/28/12 through 3/22/13, and after deleting anomolous records, the average total phosphorus removal was 99.2%, and the total nitrogen removal was 98.5%, using a Ferrate dose of 5 ppm with ferric chloride for pH adjustment. The average total phosphorus (TP) was 34 ppb; the TP nutrient criterion for the lake is 55 ppb. The field test kit found no detections of ammonia during the pilot demo

Case Study 7 – Pennsylvania Acid Mine Drainage

Objective: Reduce the concentrations of metals including iron, manganese, and aluminum.

Results: The raw water had 49.7 mg/L iron (Fe), 1.72 mg/L manganese (Mn), and 8.63 mg/L aluminum (Al). Water treatment using Ferrate(VI) in doses ranging from 1 ppm to 35 ppm were able. Water treatment using a Ferrate(VI) dose of only 3 ppm and adjusting the pH with ferric sulfate to a pH of 7.5 was able to reduce iron (Fe) by 99.97%, manganese (Mn) by 97.81%, and aluminum (Al) by 99.13%.

Ferrate Dose (ppm)	Iron (mg/L)	Manganese (mg/L)	Aluminum (mg/L)
0	49.7	1.72	8.63
3	0.014	0.0376	0.075
% Removal	99.97	97.8	99.13

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Sample Drinking Water Treatability Test Results

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Case Study 1

Objective: Odor Removal at North Florida Drinking Water Treatment Plant.

Results: A full scale Ferrate Treatment demonstration was conducted providing treated water for public consumption. Sulfide was reduced from an average concentration of 3 mg/l to below the laboratory detection limit of <0.010 mg/l by a Ferrate dose of 6 ppm. A comparison of current operating costs showed that the cost of Ferrate Treatment is offset by replacing the existing chemicals used for treatment. Ferrate Treatment met or exceeded all performance expectations for sulfide removal and for treated water Disinfection By-Product (DBP) concentrations.

Case Study 2

Objective: Removal of organic precursors and prevention of regulated disinfection byproducts with from well water in an Alabama Drinking Water Treatment Plant.

Results: Tests were conducted a Water Treatment Plant in Alabama. The samples were taken before the existing activated carbon filters and were relatively clear in color. Water treatment using Ferrate(VI) in doses ranging from 0.5 ppm to 5 ppm were able to reduce the Total Organic Carbon in all of the samples tested. Using a Ferrate(VI) dose of 1 ppm at a pH of 7.5 to treat the raw water had approximately 47.0% reduction of TOC, 78% reduction of turbidity, and a 89% reduction of Total Trihalomethanes (TTHM).

Parameter	TOC (mg/L)	UV_{254}	TTHM Potential
Raw	1.7	0.840	58.1
1 ppm Ferrate (and $Fe_2(SO_4)_3$)	0.9	0.047	5.89
Percentage Reduction	47%	94.4%	89.9%

Case Study 3

Objective: Replacement of ozone and reverse osmosis with Ferrate as a lower cost solution to reducing high color and iron levels as well as DBP precursors (UV_{254}) from well water in a South Florida Drinking Water Treatment Plant.

Results: At a Ferrate dose of 5-ppm, color was reduced by 91.7% from 120 PtCo Units to 10 PtCo Units. Iron was reduced by 98.5% from 4 mg/L to 0.06 mg/L. The same Ferrate dose lowered potential DBP precursor levels, as indicated by UV_{254}, by 78.6% from an absorbance of 0.640 units down to 0.137 units.

Parameter	Color Units	Iron (mg/L)	UV_{254} (abs)
Raw Sample (Control)	120	4	0.640
5-ppm Ferrate (and $FeCl_3$)	10	0.06	0.137
Percentage Reduction	91.7%	98.5%	78.6%

Raw Water Control

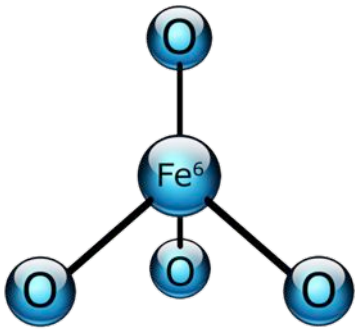
Water treated with 5-ppm Ferrate

Case Study 4

Objective: Removal of color, organics, and prevention of DBPs for an East Coast Florida surface water sourced Drinking Water Treatment Plant.

Results: A Ferrate dose of 5-ppm with a ferric chloride ($FeCl_3$) dose of 13.5 mg/L reduced color from >240 units to <10, reduced UV_{254} by 91%, and reduced Total Organic Carbon by 75%. This treated sample was then dosed with 4 mg/L chlorine and kept at room temperature for eight days to simulate the time water may remain in a distribution system, resulting in TTHM formation of only 0.3 µg/L and HAA5 formation of only 7.19 µg/L.

Parameter	Color Units	UV_{254}	TOC (mg/L)
Raw	>240	0.963	22
5-ppm Ferrate (and $FeCl_3$)	<10	0.087	5.5
Percentage Reduction	>96%	91%	75%



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Case Study 5

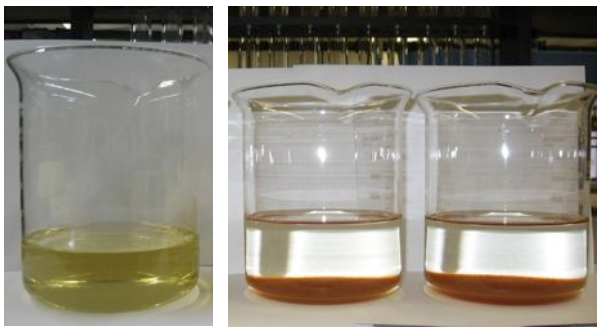
Objective: Removal of organic precursors and prevention of regulated disinfection byproducts with from surface water for an Alabama Drinking Water Treatment Plant.

Results: Tests were conducted at a Surface Water Treatment Plant (WTP) in Alabama to determine Ferrate's effectiveness in reducing the organic precursors in the sample water, based on UV_{254} data. The samples were taken from the raw water before the primary clarifier and were relatively clear in color. A Ferrate(VI) dose of only 0.5 ppm with a final pH of 7.0 to 8.0 was able to reduce the UV_{254} by almost 60%.

Parameter	UV_{254} (abs)	Iron (mg/L)
Raw Sample (Control)	0.109	0.09
0.5 ppm Ferrate (and $Fe_2(SO_4)_3$)	0.044	0.01
Percentage Reduction	60%	98.5%

Case Study 6

Objective: Color and organics removal without formation of DBPs at a Florida Drinking Water Treatment Plant.



Blended Raw Water | Treated 7-ppm Ferrate | Treated 10-ppm Ferrate

Results: At a dose of 7-ppm, Ferrate treatment was able to reduce color by >87.5%, from >120 Platinum Cobalt Units (PtCo Units) in a blended raw water sample down to 15 PtCo Units. At a dose of 10-ppm, Ferrate treatment was able to reduce color by >91.7%, from >120 PtCo Units down to 10 PtCo Units. In addition, the 7-ppm dose of Ferrate reduced Total Organic Carbon (TOC) by 70.1%, down from 14.4 mg/L in a blended raw water to 4.31 mg/L. Various forms of organics can act as precursors to the creation of disinfection byproducts. And the 10-ppm dose of Ferrate reduced TOC by 72.5%, down to 3.96 mg/L.

Parameter	Blended Raw Sample (Control)	7-ppm Ferrate Dose	Reduction	10-ppm Ferrate Dose	Reduction
Color (PtCo Units)	>120	15	>87.5%	10	>91.7%
TOC (mg/L)	14.4	4.31	70.1%	3.96	72.5%

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