

Public Works and Government Services Canada

Giant Mine Bench Scale Testing Report

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Appendix D	ALS Laboratory Group Analytical Reports
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Appendix F	Veolia – Jar Test Report

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1. Introduction

1.1 Background

Giant Mine is a former gold mine located in the Northwest Territories near Yellowknife that was closed in 2004 after 56 years of operation. In 2005, the Government of the Northwest Territories and the Government of Canada agreed to cooperate to remediate, care for, and maintain the site. Part of this remediation and maintenance involves directing a portion of the contaminated water from the site to a new treatment system. To assist in optimizing and complementing the preliminary design report (PDR) of the treatment system, bench scale testing was recommended.

1.2 Scope

The existing treatment plant used hydrogen peroxide for arsenic oxidation, ferric sulphate for arsenic and solids coagulation and precipitation, and lime for metals precipitation. A dike separates the settling pond and polishing pond, which are used for solid-liquid separation. Sludge samples taken from the settling pond and polishing pond were sent to an accredited laboratory (ALS Edmonton) for analysis.

The recommended treatment process, described in the PDR consists of arsenic oxidation, arsenic and solids coagulation and precipitation, metals precipitation via lime addition and pH adjustment with carbon dioxide followed by filtration. Polymer is also added for enhanced coagulation. The bench scale program attempted to recreate the treatment process on a basic level, and a series of tests were performed to confirm the choice of chemicals. Aliquot samples from the testing were submitted to an accredited laboratory for analysis.

A mixed raw water sample was also sent to an equipment manufacturer. The manufacturer used various chemical combinations to validate the efficiency of their proposed equipment for arsenic removal and provide an estimate of the average arsenic concentration in the treated effluent. AECOM reviewed the procedures and results of the equipment manufacturer for due diligence and quality assurance purposes.

The purpose of this report is to summarize the results of the sludge testing and the bench scale testing program performed by AECOM, and to provide discussion on the implications of the results obtained. In addition, a brief discussion on the results of the equipment manufacturer's independent testing is provided.

A short summary of the bench scale tests and its conclusions and recommendations can also be found in the preliminary design report.

2. Bench Scale Testing

2.1 Introduction

Because the future wastewater is expected to be a mixture of mine groundwater, mine infiltration and tailings area runoff, it was not possible to obtain a representative sample from one source. Thus, water was collected from multiple sources in the mine and mixed in the lab to obtain a representative sample of the expected future water quality. A target mixed water dissolved arsenic concentration of 60 to 75 mg/L was selected. This range was selected to obtain a representative Arsenic concentration, both realistic and challenging to the proposed treatment configuration. Average concentrations identified in the preliminary design report (Sample points SNP 43-17 and SNP 43-21 identified in PDR tables 13 and 14) range between 33.6 and 76.8 mg/l.

On March 8, 2012, initial raw water samples were collected from two locations within the mine (from pumps UG-WS-1 and UG-WS-2 at the 750 ramp, and from pumps UG-WS-3 and UG-WS-4 at the 712 shop) to determine the dissolved arsenic concentrations. The results of these dissolved arsenic concentration testing were subsequently used to determine the appropriate mixing ratio for the raw water to be used during the bench scale testing.

The raw water samples for the bench scale testing were collected on March 15, 2012 at the mine site by Nuna Logistics, and shipped in 23 litre food grade pails to Edmonton for mixing and testing. Ten pails were collected from pumps UG-WS-1 and UG-WS-2 at the 750 ramp, and five pails were collected from pumps UG-WS-3 and UG-WS-4 at the 712 shop. Upon collection, sample containers were filled with a minimal amount of headspace, sealed and labelled. The samples were kept from freezing during transport and storage.

The raw water was blended at the laboratory in Edmonton in a 7:3 ratio from ~3.5 mg/L (dissolved arsenic) water sampled from UG-WS-1 and UG-WS-2 (at the 750 ramp) and ~240 mg/L (dissolved arsenic) water from UG-WS-3 and UG-WS-4 (at the 712 shop), respectively. The target arsenic concentration of the blended water was 60 to 75 mg/L (total As).

Bench tests were performed at the Edmonton Waste Management Centre located at 13111 Meridian (1st) Street NE, Edmonton, Alberta. Testing was conducted in an area isolated from other laboratory activities in order to reduce the possibility of contamination.

2.2 Purpose

The purpose of the bench scale testing program was to optimize, verify the choice of chemicals for, and provide more accurate chemical consumption estimates for the recommended water treatment plant concept at Giant Mine. The bench scale testing program consisted of sampling, a series of laboratory tests, verification steps and the production of a laboratory report. The treatment steps being simulated include chemical oxidation, coagulation, pH adjustment with lime, filtration, and pH depression with hydrochloric acid. Hydrochloric acid was selected as a replacement for carbon dioxide due to equipment availability.

2.3 Equipment

The jar testing equipment used consisted of the following:

- Deionised water
- Mechanical mixer, 6 paddle
- 6 – 2000 mL jars
- Digital thermometer

- Turbidimeter
- pH meter
- Filter paper (25 µm)
- Miscellaneous laboratory supplies (pipettes, burettes, beakers, funnels, etc.)
- Appropriate safety equipment

2.4 Chemicals

Chemicals used to perform the jar testing included the following:

- Hydrogen peroxide
- Potassium permanganate
- Ferric chloride
- Ferric sulphate
- Calcium hydroxide (Lime)
- Hydrochloric acid

Table 1 outlines general characteristic of each chemical. Copies of the MSDS Sheets can be found in Appendix A.

Table 1. General Chemical Properties

Chemical	Chemical Formula	Concentrate Concentration	Specific Gravity	Working Solution Concentration
Hydrogen Peroxide	H ₂ O ₂	29 %	1.11	10 g/L
Potassium Permanganate	KMnO ₄	97-100 % (Dry)	2.70	10 g/L
Ferric Chloride	FeCl ₃	39.5 %	1.37	100 g/L
Ferric Sulphate	Fe ₂ (SO ₄) ₃	69.5 %	1.485	100 g/L
Calcium Hydroxide (Lime)	Ca(OH) ₂	92-100 % (Dry)	2.3-2.4	100 g/L
Hydrochloric Acid	HCl	37.25%	1.194	10 g/L

2.5 Testing Procedures

A copy of the Standard Operating Procedure (SOP) can be found in Appendix B. Deviations from the SOP were noted on the Jar Test Report Sheets, which can be found in Appendix C.

2.5.1 Raw Water Collection, Transportation and Preparation

2.5.1.1 Purpose

The purpose of the raw water collection, transportation and preparation was to collect water samples from two locations within the mine (one with high arsenic concentration and one with low arsenic concentration), transport the samples to the testing facility, and mix the samples to achieve a uniform water concentration that would be representative of the expected raw water conditions at the proposed plant.

2.5.1.2 Test Procedure and Deviations from SOP

In general, the procedures followed for the performance of the raw water preparation can be found in the SOP in Appendix B. However, the following deviation was taken from the SOP during the transportation and sample preparation period:

- Raw water samples were not kept at the recommended holding temperature of 1-7°C during transportation. The samples arrived at a higher temperature that was not recorded. They were cooled back down in the lab refrigerator overnight before testing began.

2.5.2 Effect of Varying Oxidant Dosage

2.5.2.1 Purpose

The purpose of the oxidant testing was to compare the effectiveness of potassium permanganate and hydrogen peroxide at oxidizing the arsenite [As(III)] to arsenate [As(V)] at various chemical dosages.

2.5.2.2 Test Procedure and Deviations from SOP

In general, the procedures followed for the performance of the oxidation testing can be found in the SOP in Appendix B. However, the following deviation was taken from the SOP during the testing period:

- Photos were not taken of the hydrogen peroxide testing.
- The initial set of potassium permanganate samples remained a dark purple after the testing. This indicated that the potassium permanganate dose was excessive for the oxidation of the arsenic. Four more potassium permanganate samples were prepared at lower doses (5 mg/L, 10 mg/L, 25 mg/L and 50 mg/L) to see if a more appropriate dose could be determined visually. Each of these samples remained purple/pink as well. The 5 mg/L sample was a very light pink, so it was decided that this dose would be used for the subsequent testing. Aliquots from each of these four samples were sent to the accredited laboratory for arsenic speciation testing.

2.5.3 Effect of Varying Coagulant Dosage

2.5.3.1 Purpose

The purpose of the coagulant testing was to compare the effectiveness of ferric sulphate and ferric chloride at varying doses on the removal of contaminants.

2.5.3.2 Test Procedure and Deviations from SOP

In general, the procedures followed for the performance of the coagulation testing can be found in the SOP in Appendix B. However, the following deviation was taken from the SOP during the testing period:

- The SOP called for the addition of 105 mg/L of potassium permanganate. Because of the low level of oxidation determined in the oxidation testing, only 5 mg/L of potassium permanganate was added.
- Arsenic speciation testing was not performed on these samples, as it should be equivalent to the arsenic speciation established following the 5 mg/L potassium permanganate addition in the oxidation testing.

2.5.4 Effect of pH Adjustment with Lime and Filtration

2.5.4.1 Purpose

The purpose of the pH adjustment with lime testing was to determine the appropriate lime dose to raise the pH of the water to 10.5, post coagulation, and determine the effect on the removal of contaminants. Following this, the test was performed a second time and the overlaying water filtered to determine the effect of filtration on the removal of contaminants from the pH-adjusted samples.

2.5.4.2 Test Procedure and Deviations from SOP

In general, the procedures followed for the performance of the pH adjustment with lime testing can be found in the SOP in Appendix B. However, the following deviation was taken from the SOP during the testing period:

- The SOP called for the addition of 105 mg/L of potassium permanganate. Because of the low level of oxidation determined in the oxidation testing, only 5 mg/L of potassium permanganate was added.
- The SOP indicated that this testing was to be repeated for both ferric sulphate and ferric chloride, however only the samples treated with ferric sulphate were used.
- Raw water and chemical volumes were increased by 10% over those requested in the SOP to account for sludge accumulation and still provide adequate overlaying water for the sample aliquots being sent to the accredited laboratory.
- To ensure rapid reaction of chemical in the test samples during lime titration, the mixer was set to 90 rpm as opposed to 30 rpm outlined in the SOP.
- The SOP requested that the pH of the samples be recorded for every 10 mg/L of lime added. Because of the high concentration of lime required to adjust the pH, pH was instead recorded at 100 mg/L and 25 mg/L intervals.
- Arsenic speciation testing was not performed on the unfiltered or filtered samples, as it should be equivalent to the arsenic speciation established following the 5 mg/L potassium permanganate addition in the oxidation testing.

2.5.5 Effect of pH Adjustment with Hydrochloric Acid

2.5.5.1 Purpose

The purpose of the pH adjustment with hydrochloric acid testing was to determine the appropriate hydrochloric acid dose to depress the pH of the water to 8.5, post-lime addition and filtration.

2.5.5.2 Test Procedure and Deviations from SOP

In general, the procedures followed for the performance of the oxidation testing can be found in the SOP in Appendix B. However, the following deviation was taken from the SOP during the testing period:

- The SOP called for the addition of 105 mg/L of potassium permanganate. Because of the low level of oxidation determined in the oxidation testing, only 5 mg/L of potassium permanganate was added.

- Because no samples were required to be sent from this test to the accredited laboratory for analysis, only 1500 mL of raw water was used per beaker, as opposed to the 2000 mL outlined in the SOP, and the chemical doses were adjusted accordingly.
- To achieve rapid reaction of chemical in the test samples during lime titration, the mixer was set to 60 rpm as opposed to 30 rpm outlined in the SOP.
- The SOP requested that the pH of the samples be recorded for every 10 mg/L of hydrochloric acid added. Because of the small concentration of acid required to adjust the pH, pH was instead recorded at 1 mg/L and 0.5 mg/L intervals.

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3. Results and Discussions

The Jar Test Data Sheets completed during the performance of the tests can be found in Appendix C, and the analytical reports from the accredited laboratory can be found in Appendix D.

3.1 Raw Water Sampling Results

Table 2 outlines the results of the initial raw water samples that were collected on March 8, 2012. The results of these arsenic concentration testing results were subsequently used to determine the appropriate mixing ratio for the raw water to be used during the bench scale testing.

Table 2. Raw Water Testing Results

Parameter	Units	UG-WS-1	UG-WS-2	UG-WS-3	UG-WS-4
Arsenic (As)-Dissolved (by Flame AA)	mg/L	3.7	3.5	241	242
Arsenic (As)-Dissolved (by ICPMS (Low))	mg/L			265	
Arsenic (As)-Total	mg/L			244	
Chloride (Cl)	mg/L			16.3	
Nitrate and Nitrite (as N)	mg/L			0.897	
Copper (Cu)-Total	mg/L			<0.20	
Copper (Cu)-Dissolved	mg/L			<0.12	
Lead (Pb)-Total	mg/L			<0.020	
Lead (Pb)-Dissolved	mg/L			<0.020	
Nickel (Ni)-Total	mg/L			0.044	
Nickel (Ni)-Dissolved	mg/L			0.0030	
Zinc (Zn)-Total	mg/L			<0.80	
Zinc (Zn)-Dissolved	mg/L			1.09	
Total Suspended Solids	mg/L			21.0	
Total Dissolved Solids	mg/L			1030	
pH				6.73	

Based on the results of this testing, a 7:3 ratio from ~3.6 mg/L (dissolved As) water sampled from the 750 ramp and ~241 mg/L (dissolved As) water from the 712 shop, would be required to obtain the target blended water arsenic concentration of 60 to 75 mg/L. As noted later on in section 0, the dissolved arsenic concentration in the mixed water was found to be 70.4 mg/L.

3.2 Bench Scale Testing

For the jar testing, a number of samples were tested with a variety of chemical combinations. Table 3 outlines the sample IDs, the chemical being tested, the doses, and the step in the treatment process that the sample was intended to mimic.

Table 3. Sample Identification

Sample ID	Treatment Step	Oxidant	Oxidant Dose	Coagulant	Coagulant Dose	Lime Dose	Caustic Dose
Raw	Raw Water	None	0 mg/L	None	0 mg/L	0 mg/L	0 mg/L
H2O2 25	Oxidation	H ₂ O ₂	25 mg/L	None	0 mg/L	0 mg/L	0 mg/L
H2O2 35	Oxidation	H ₂ O ₂	35 mg/L	None	0 mg/L	0 mg/L	0 mg/L
H2O2 45	Oxidation	H ₂ O ₂	45 mg/L	None	0 mg/L	0 mg/L	0 mg/L
KMnO4 5	Oxidation	KMnO ₄	5 mg/L	None	0 mg/L	0 mg/L	0 mg/L
KMnO4 10	Oxidation	KMnO ₄	10 mg/L	None	0 mg/L	0 mg/L	0 mg/L
KMnO4 25	Oxidation	KMnO ₄	25 mg/L	None	0 mg/L	0 mg/L	0 mg/L
KMnO4 50	Oxidation	KMnO ₄	50 mg/L	None	0 mg/L	0 mg/L	0 mg/L
KMnO4 80	Oxidation	KMnO ₄	80 mg/L	None	0 mg/L	0 mg/L	0 mg/L
KMnO4 105	Oxidation	KMnO ₄	105 mg/L	None	0 mg/L	0 mg/L	0 mg/L
KMnO4 130	Oxidation	KMnO ₄	130 mg/L	None	0 mg/L	0 mg/L	0 mg/L
Ox-Blank	Oxidation	None	0 mg/L	None	0 mg/L	0 mg/L	0 mg/L
FC-1000	Coagulation	KMnO ₄	5 mg/L	FeCl ₃	1000 mg/L	0 mg/L	0 mg/L
FC-1300	Coagulation	KMnO ₄	5 mg/L	FeCl ₃	1300 mg/L	0 mg/L	0 mg/L
FC-1600	Coagulation	KMnO ₄	5 mg/L	FeCl ₃	1600 mg/L	0 mg/L	0 mg/L
FS-1200	Coagulation	KMnO ₄	5 mg/L	Fe ₂ (SO ₄) ₃	1200 mg/L	0 mg/L	0 mg/L
FS-1600	Coagulation	KMnO ₄	5 mg/L	Fe ₂ (SO ₄) ₃	1600 mg/L	0 mg/L	0 mg/L
FS-2000	Coagulation	KMnO ₄	5 mg/L	Fe ₂ (SO ₄) ₃	2000 mg/L	0 mg/L	0 mg/L
FS-1200-Lime	pH adjustment with lime	KMnO ₄	5 mg/L	Fe ₂ (SO ₄) ₃	1200 mg/L	425 mg/L	0 mg/L
FS-1600-Lime	pH adjustment with lime	KMnO ₄	5 mg/L	Fe ₂ (SO ₄) ₃	1600 mg/L	600 mg/L	0 mg/L
FS-2000-Lime	pH adjustment with lime	KMnO ₄	5 mg/L	Fe ₂ (SO ₄) ₃	2000 mg/L	650 mg/L	0 mg/L
FS-1200-Fil	Filtration following lime addition	KMnO ₄	5 mg/L	Fe ₂ (SO ₄) ₃	1200 mg/L	425 mg/L	0 mg/L
FS-1600-Fil	Filtration following lime addition	KMnO ₄	5 mg/L	Fe ₂ (SO ₄) ₃	1600 mg/L	600 mg/L	0 mg/L
FS-2000-Fil	Filtration following lime addition	KMnO ₄	5 mg/L	Fe ₂ (SO ₄) ₃	2000 mg/L	650 mg/L	0 mg/L
FS-1200-HCL	pH adjustment with HCl	KMnO ₄	5 mg/L	Fe ₂ (SO ₄) ₃	1200 mg/L	425 mg/L	3 mg/L
FS-1600-HCL	pH adjustment with HCl	KMnO ₄	5 mg/L	Fe ₂ (SO ₄) ₃	1600 mg/L	600 mg/L	3.5mg/L
FS-2000-HCL	pH adjustment with HCl	KMnO ₄	5 mg/L	Fe ₂ (SO ₄) ₃	2000 mg/L	650 mg/L	0 mg/L

3.2.1 Turbidity and Floc Formation

The turbidity of the blended raw water and each of the test samples was recorded in the lab on the jar test report sheets. In addition, a visual characterization of the floc formation was noted following coagulant addition. Table 4 outlines the recorded observations.

Table 4. Turbidity and Floc Formation Observations

Sample ID	Turbidity	Floc Formation	Additional Comments
Raw (Pail 1)	3.69	Not Applicable	Clear, some settled solids
Raw (Pail 2)	3.37	Not Applicable	[No comments noted]
Raw (Pail 3)	2.29	Not Applicable	Clear, homogenous
Raw (Pail 4)	2.43	Not Applicable	Mainly clear, some sediment visible
Raw (Pail 5)	4.47	Not Applicable	Mainly clear, some sediment visible
Raw (Pail 6)	1.31	Not Applicable	Clear, very slight sedimentation
Raw (Pail 7)	2.14	Not Applicable	Clear, some sediment on bottom of pail
H2O2 25	6.06	Nil	Water looks the same as it did before chemical addition and mixing
H2O2 35	6.07	Nil	Water looks the same as it did before chemical addition and mixing
H2O2 45	6.57	Nil	Water looks the same as it did before chemical addition and mixing
KMnO4 5	9.25	Nil	Light pink
KMnO4 10	10.2	Nil	Light/medium pink
KMnO4 25	9.57	Nil	Medium pink
KMnO4 50	8.26	Nil	Medium/dark pink
KMnO4 80	11.4	Nil	Very purple
KMnO4 105	9.34	Nil	Very very purple
KMnO4 130	10.3	Very slight	Very very purple, small amount of precipitate formed
Ox-Blank	3.47	Nil	[No comments noted]
FC-1000	32.6	Good	Very very slight pink colour noted
FC-1300	41.2	Okay	[No comments noted]
FC-1600	29.2	None	One jar seems clearer than the second
FS-1200	87.0	Excellent	Slight pink/peach colour, cloudy
FS-1600	41.4	Excellent	Very very slight peach colour, slight cloudiness
FS-2000	23.8	Very good	No pink visible, clear
FS-1200-Lime	1.86	Very good	Dark orange in colour, water very clear
FS-1600-Lime	0.80	Very good	Dark orange in colour, water very clear
FS-2000-Lime	0.55	Very good	Dark orange in colour, water very clear
FS-1200-Fil	0.43	Excellent	[No comments noted]
FS-1600-Fil	0.42	Excellent	[No comments noted]
FS-2000-Fil	0.87	Excellent	[No comments noted]
FS-1200-HCL	Not recorded	(filtered)	Very clear, colourless water
FS-1600-HCL	Not recorded	(filtered)	Very clear, colourless water
FS-2000-HCL	Not recorded	(filtered)	Very clear, colourless water

3.2.2 pH

The pH of each sample was recorded in the lab during testing, and the pH of a number of samples was confirmed by the accredited laboratory. Figure 1 illustrates the pH values recorded.

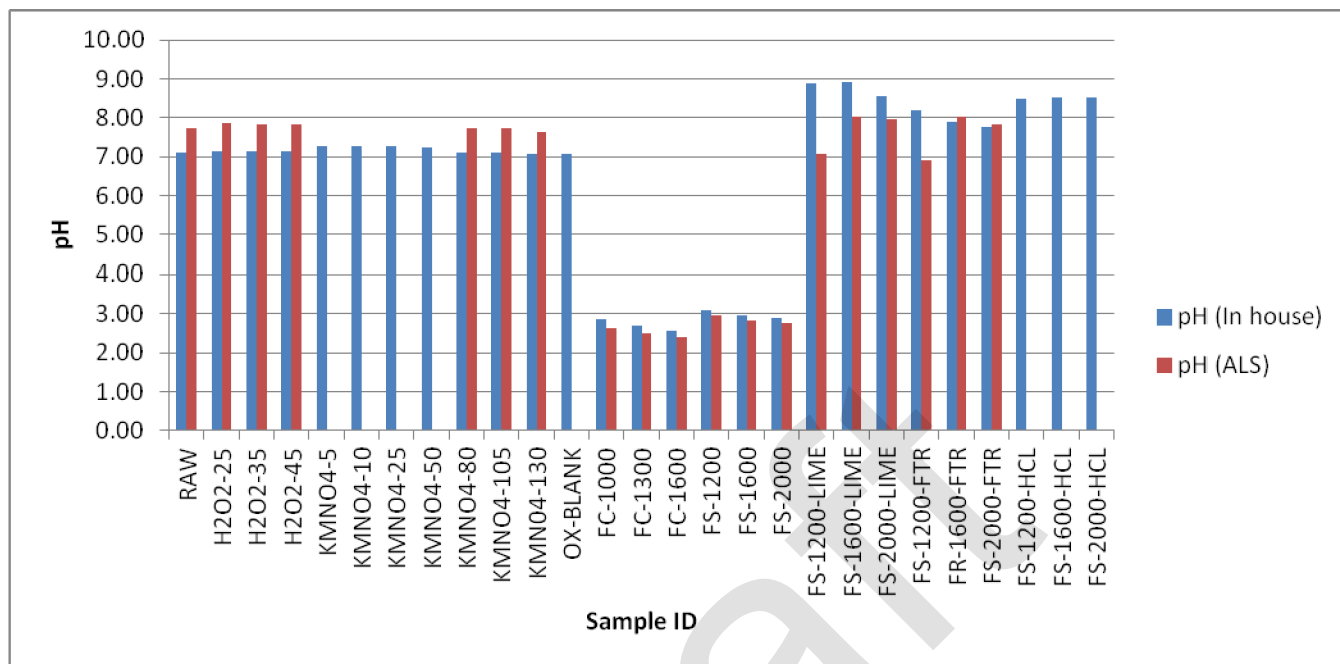


Figure 1. pH Results

The pH of samples KMnO4-5, KMnO4-10, KMnO4-25, KMnO4-50 and OX-BLANK was not requested from the accredited laboratory. These samples were only performed to determine the effects of oxidation on the arsenic speciation. Samples FS-1200-HCl, FS-1600-HCl, FS-2000-HCl were also not sent to the accredited laboratory, as they were simply used to determine the amount of acid addition required to depress the pH of the finished water.

In the lime addition step, a titration with lime was performed to determine the appropriate lime dose required to raise the sample pHs to 10.5. Figure 2 illustrates the pH at each lime dose for the three ferric sulfate doses.

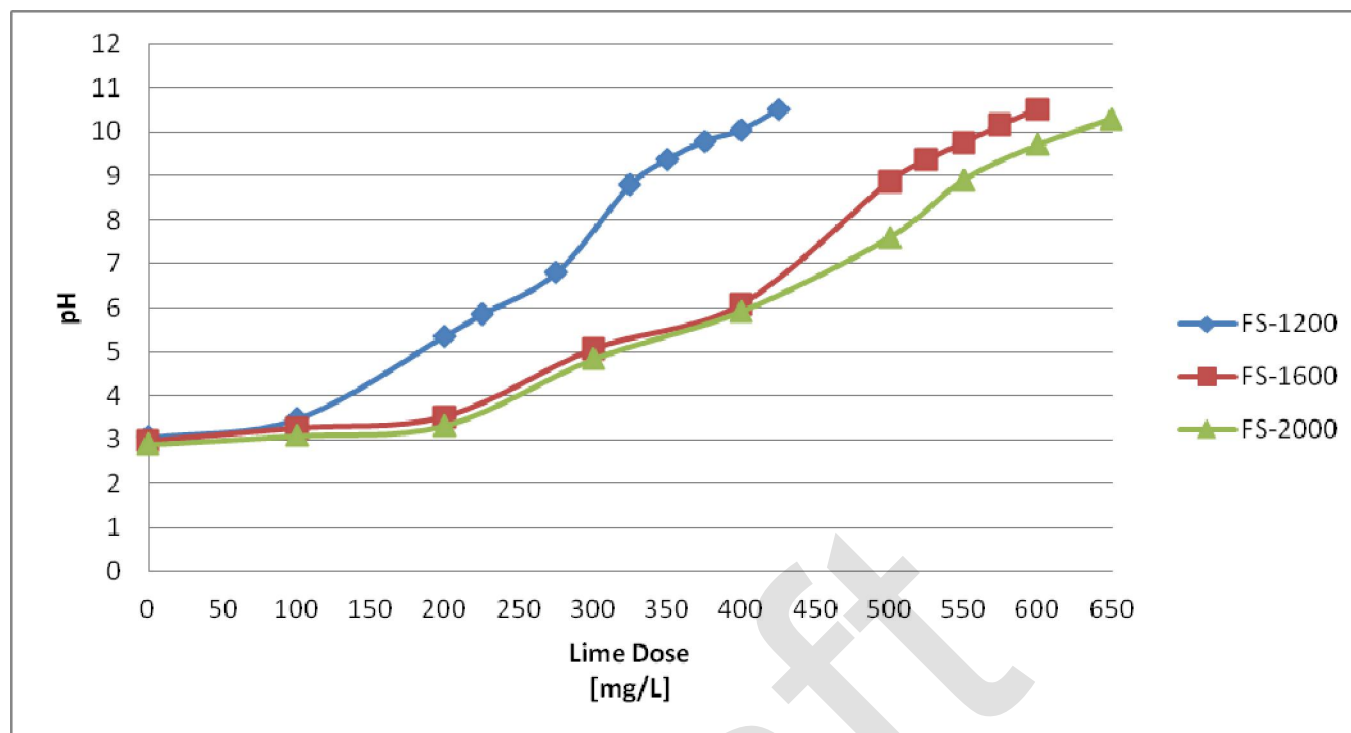


Figure 2. pH Adjustment with Lime

In the hydrochloric acid addition step, a titration with HCl was performed to determine the amount of acid required to depress the sample pH to 8.5. Table 5 illustrates the pH at each lime dose for the three ferric sulfate doses.

Table 5. pH Adjustment with HCl

FS-1200-HCL		FS-1600-HCL		FS-2000-HCL	
HCl Dose [mg/L]	pH	HCl Dose [mg/L]	pH	HCl Dose [mg/L]	pH
0	8.98	0	9.00	0	8.53
1	8.88	1	8.94		
2	8.73	2	8.80		
3	8.48	3	8.65		
		3.5	8.53		

These results demonstrate that the pH drops from the pH of 10.5 after lime addition to about 8.5-9.0 without any chemical addition, following settling and filtration. Very little acid was required to depress the pH further.

Note: Compared with the manufacturer's test report we did find a discrepancy regarding the pH adjustment with acid. Although the pH adjustment was only carried out over a small pH range (i.e. pH 9 to 8.5), we found a lower relative acid consumption than the equipment manufacturer. We have tried to investigate this discrepancy, but could not find the cause at this stage. We would have to repeat the titration with a new water sample.

3.2.3 Arsenic

3.2.3.1 Arsenic Speciation (III, V)

To determine the amount of arsenic (III) that would be oxidized to arsenic (V), arsenic speciation testing was performed on the raw water, as well as after the various oxidation tests. One single sample mimicking the oxidation testing without chemical addition was also performed to determine the effect of the aeration on arsenic speciation. The results of the speciation testing are outlined in Table 6.

Table 6. Arsenic Speciation Results

Sample ID	As(III) [mg/L]	As(V) [mg/L]
RAW	<1.000	53.800
H2O2-25	<1.000	54.000
H2O2-35	<1.000	53.500
H2O2-45	<1.000	55.400
KMNO4-5	<1.000	55.500
KMNO4-10	<1.000	54.300
KMNO4-25	<1.000	54.500
KMNO4-50	<1.000	53.300
KMNO4-80	<1.000	59.400
KMNO4-105	<1.000	53.100
KMNO4-130	<1.000	52.900
OX-BLANK	<1.000	54.600

These results indicate that the arsenic is already nearly entirely in the arsenic (V) form. Thus, oxidation may not be required to assist in arsenic removal.

3.2.3.2 Arsenic Concentrations

The arsenic concentration is high in the raw water, and ferric chloride appears to have little effect. There was a significant drop in arsenic recorded with the addition of ferric sulphate, with the 1200 mg/L ferric sulphate dose displaying the highest level of removal. Following lime precipitation and filtration, a total arsenic concentration of 0.0530 mg/L was achieved. This demonstrates a total arsenic removal of over 99.9%.

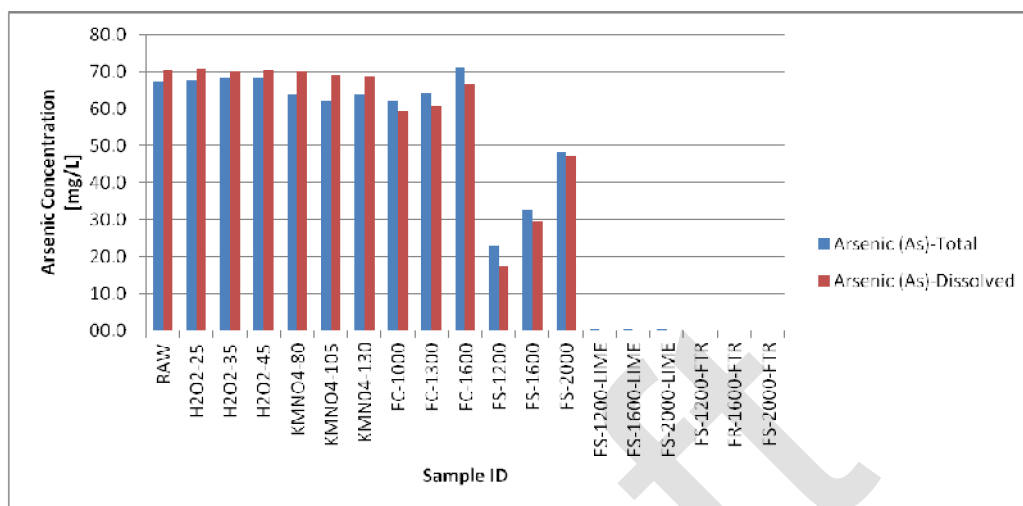


Figure 3. Arsenic Concentration

3.2.4 Chloride

Chloride levels remained consistent throughout the treatment process with two exceptions. The addition of ferric chloride increased chloride concentrations, as would be expected. Chloride readings in the lime samples were below the detection limits, but reappeared following the filtration steps. This suggests an anomaly in the lime precipitation test samples tested at the accredited laboratory. Figure 4 illustrates the chloride concentration results.

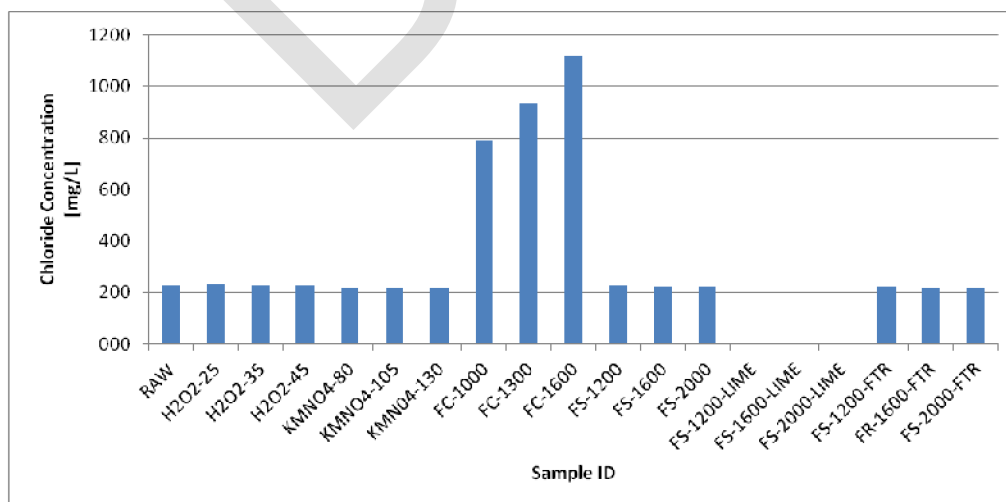


Figure 4. Chloride Concentration

3.2.5 Phosphorus

The total phosphorus concentrations indicated that potassium permanganate at high doses provided a small reduction in total phosphorus, as did ferric chloride at higher doses. As in the chloride testing, the phosphorus readings in the lime samples were below the detection limits, but reappeared following the filtration steps. This again suggests an anomaly in the lime precipitation test samples tested at the accredited laboratory. Figure 5 illustrates the total phosphorus concentration results.

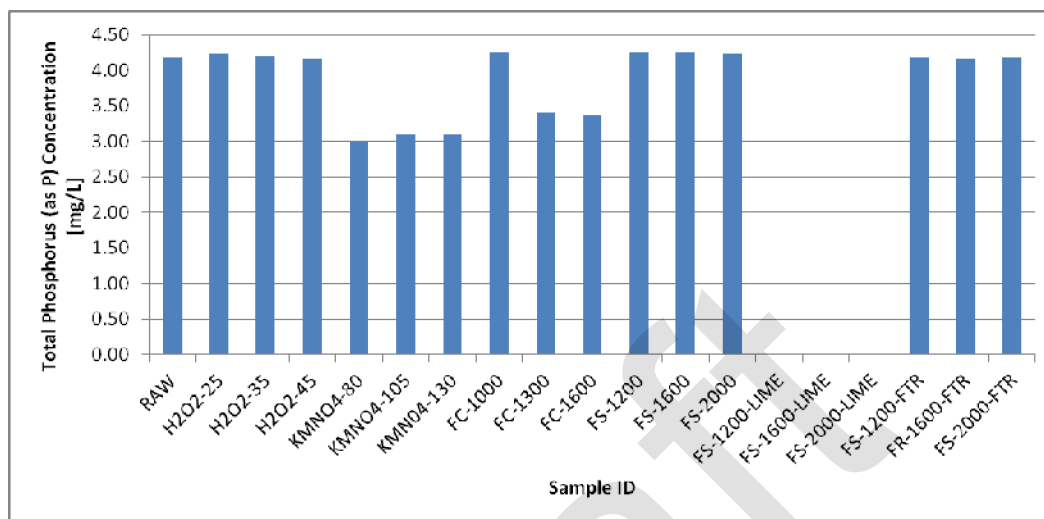


Figure 5. Total Phosphorus Concentration

3.2.6 Cyanide

A 20% removal was achieved even at the low concentrations. Figure 6 illustrates the cyanide concentration results.

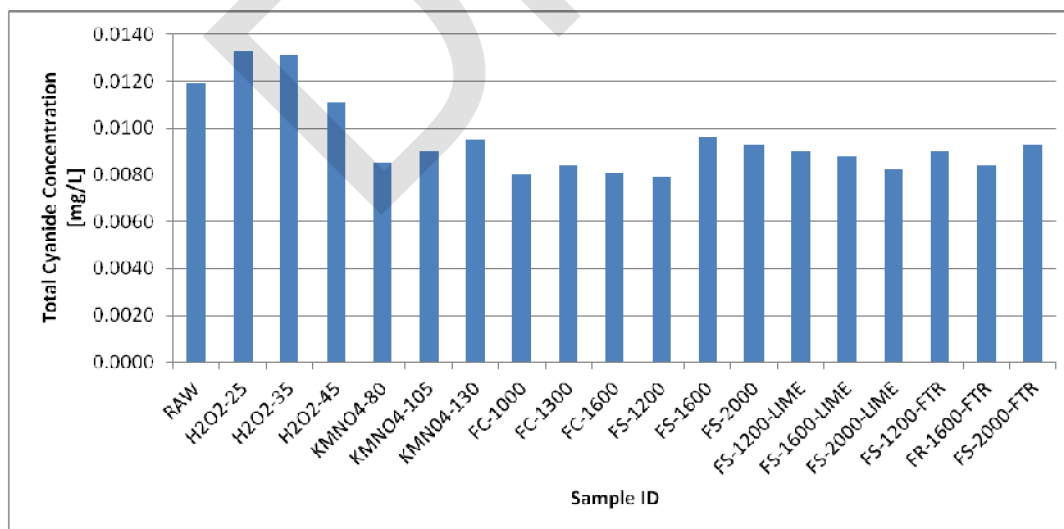


Figure 6. Total Cyanide Concentration

3.2.7 Additional Metals (Total and Dissolved)

3.2.7.1 Copper

There appeared to be a spike in copper concentration in the ferric chloride samples, and another smaller spike in the ferric sulfate samples. The reason for these spikes is unknown. Figure 7 illustrates the copper concentration results.

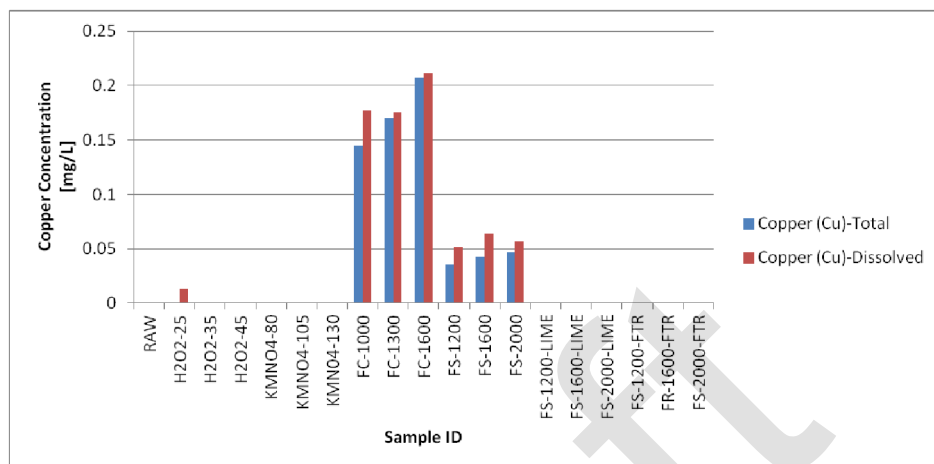


Figure 7. Copper Concentration

3.2.7.2 Lead

There appeared to be a spike in lead concentration in the ferric chloride samples. The reason for this spike is unknown. Figure 8 illustrates the lead concentration results.

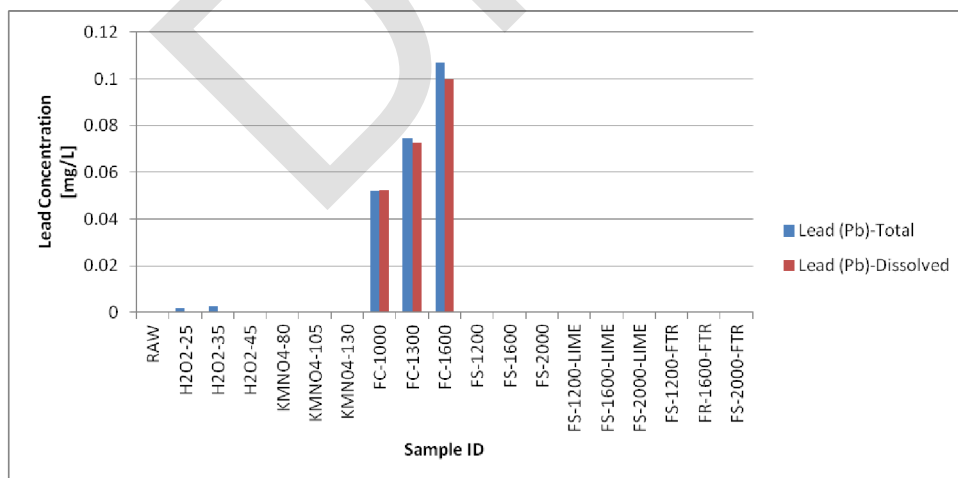


Figure 8. Lead Concentration

3.2.7.3 Nickel

All post-lime addition and post-filtration samples were below the detection limit of 0.004 mg/L for total nickel and 0.002 mg/L for dissolved nickel, with the exception of the FS-2000 samples. These samples were approximately 0.007 mg/L. These results demonstrate a removal greater than 80%. Figure 9 illustrates the nickel concentration results.

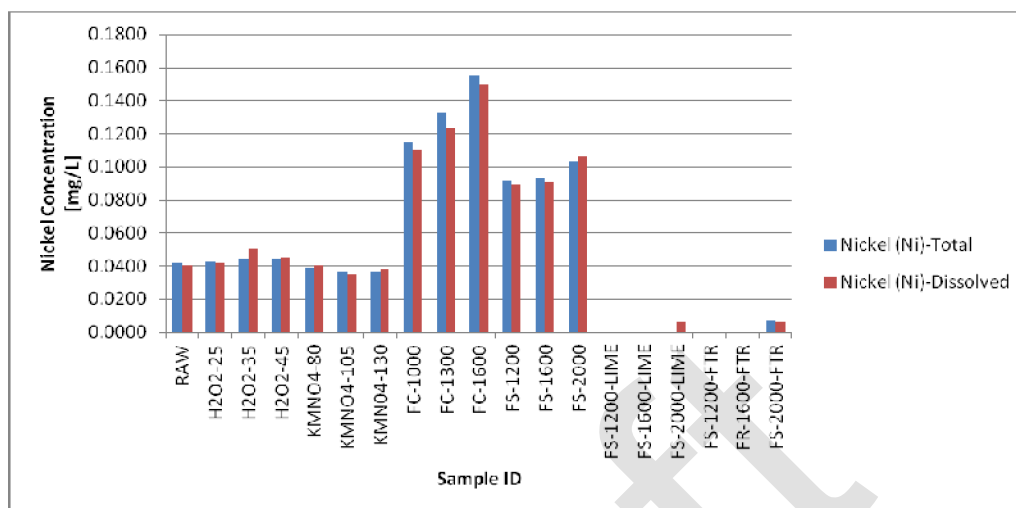


Figure 9. Nickel Concentration

3.2.7.4 Zinc

All post-lime addition and post-filtration samples were below the detection limit of 0.08 mg/L for total zinc and 0.02 mg/L for dissolved zinc. These results demonstrate a removal greater than 35%. Figure 10 illustrates the zinc concentration results.

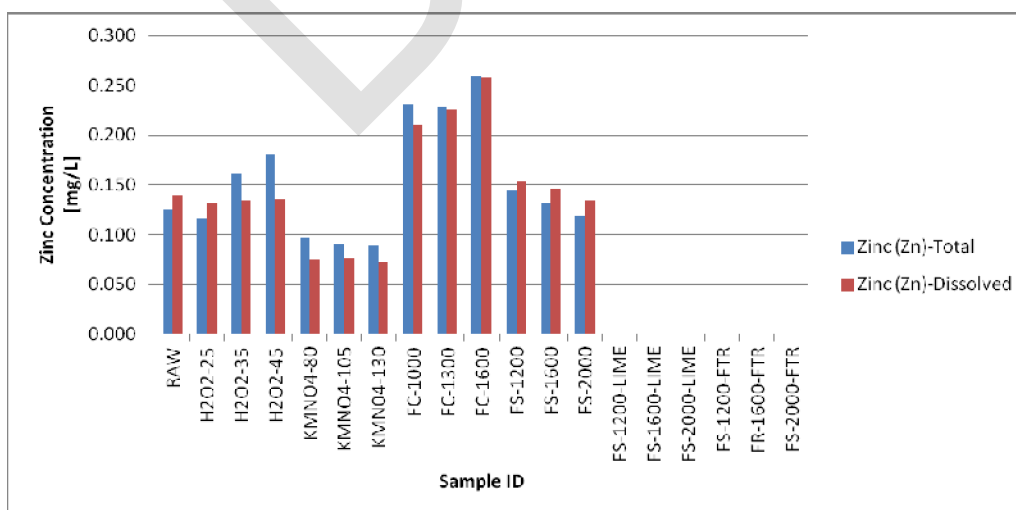


Figure 10. Zinc Concentration

3.2.8 Ammonia

The existing effluent treatment plant (ETP) was operating under the conditions identified in its expired water license (N1L2-0043), which included a maximum average concentration of 12 mg/L discharge of total ammonia. Ammonia will be included as treatment parameters in anticipation of a similar requirement in the new WTP's licence. The samples tested found the ammonia in the raw water to be about 0.1 mg/L, which is well below the anticipated limit.

The anticipated water treatment system is not expected to remove ammonia, and this is demonstrated by the results of the jar testing. Figure 11 illustrates the total ammonia concentration results.

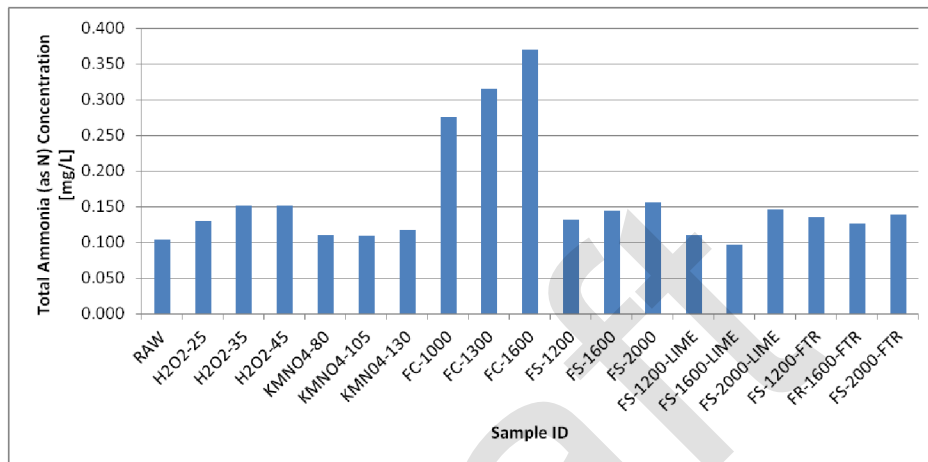


Figure 11. Total Ammonia Concentration

3.2.9 Nitrate and Nitrite

The anticipated water treatment system is not expected to remove nitrate and nitrite, and this is demonstrated by the results of the jar testing. Figure 12 illustrates the total Nitrate and Nitrite concentration results.

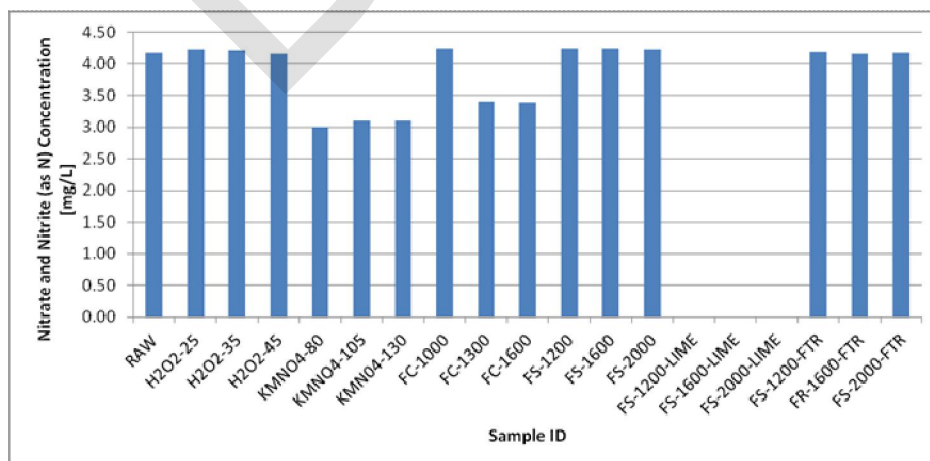


Figure 12. Total Nitrate and Nitrite Concentration

3.2.10 Oil and Grease

The expired license for the existing ETP included a discharge limit of 5 mg/L maximum concentration from any grab sample for oil and grease. Thus, it is anticipated that this same restriction for discharge of oil and grease will be included as a requirement in the new WTP's licence. The bench testing found the oil and grease to be below the detection limit of 1 mg/L in each of the samples tested.

3.2.11 Radium 226

Figure 13 illustrates the results of the radium-226 testing. These results indicate that even at these low radium concentrations, removals in excess of 75% are achievable.

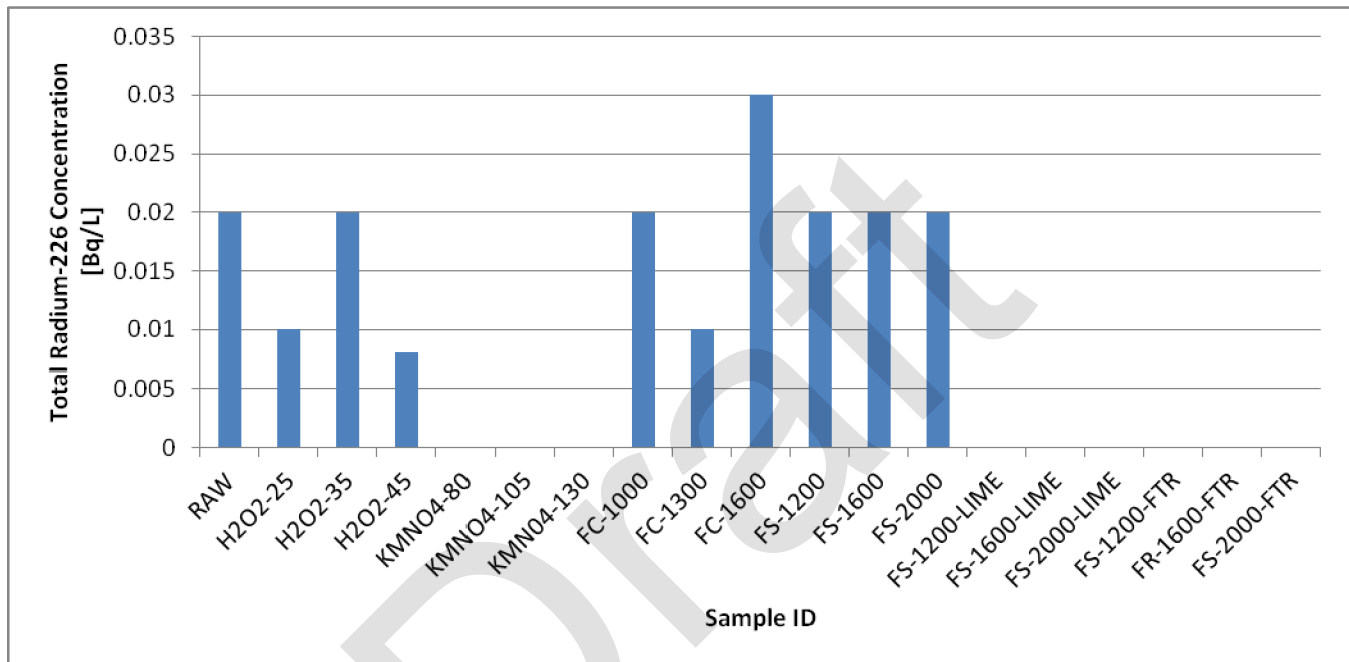


Figure 13. Total Radium-226 Concentration

3.2.12 Total Dissolved Solids

The anticipated treatment system is not designed for the removal of total dissolved solids (TDS). Figure 14 illustrates the results of the TDS testing. An increase in TDS occurs after each chemical addition, and because this constituent is dissolved, the filtration step does not have an effect.

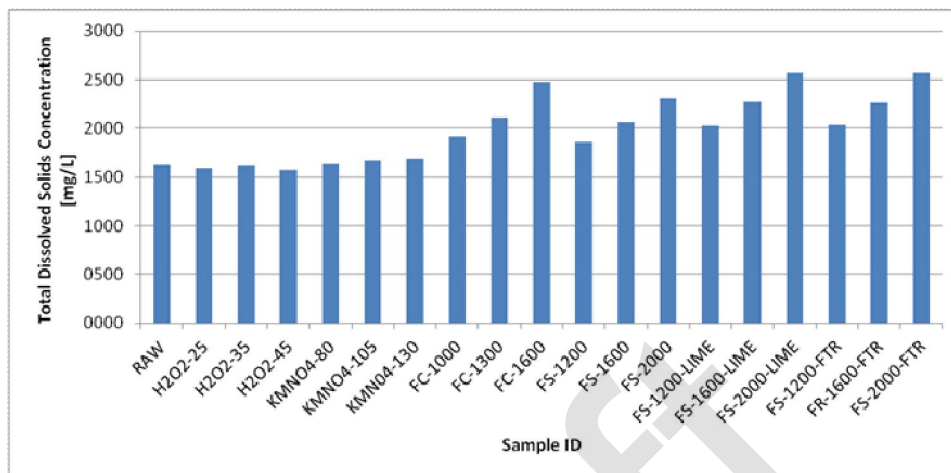


Figure 14. Total Dissolved Solids Concentration

3.2.13 Total Suspended Solids

The raw water sample had a total suspended solids (TSS) concentration of 11 mg/L. and an increase was seen following the addition of the coagulants. This increase would have been due to the floc produced that did not settle in the allotted time. The lime addition and settling aided in the removal of TSS, and reduced it to less than 14 mg/L. The filtration step further reduced the TSS to less than 6 mg/L. Figure 15 illustrates the results of the TSS testing.

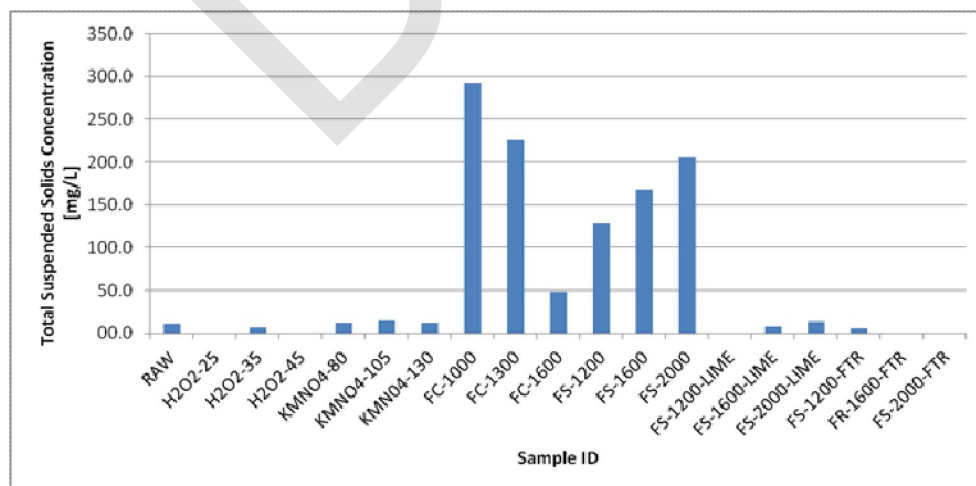


Figure 15. Total Suspended Solids Concentration

3.3 Residuals Testing Results

On March 13, 2013, sludge samples were taken from two locations in the existing sludge ponds for analysis. The analytical results for these samples are outlined in Table 7.

Table 7. Residuals Testing Results

Parameter	Units	S.P. 1	S.P. 2
Arsenic (in soil)	mg/kg	17400	22700
Copper (in soil)	mg/kg	12400	23300
Iron (in soil)	mg/kg	114000	150000
Lead (in soil)	mg/kg	206	169
Nickel (in soil)	mg/kg	503	970
Zinc (in soil)	mg/kg	479	1160
Arsenic (leachable)	mg/L	0.23	<0.20
Copper (leachable)	mg/L	<0.50	<0.50
Iron (leachable)	mg/L	<5.0	<5.0
Lead (leachable)	mg/L	<0.50	<0.50
Nickel (leachable)	mg/L	1.11	0.93
Zinc (leachable)	mg/L	<5.0	<5.0
Percent Solids	%	64.5	54.9

The chemical characteristics of the sludge in the settling pond were assessed by Golder Associates Ltd. in 2001¹. The arsenic content of the sludge sample was about 1% (by weight) and the iron content was about 6% (by weight). Samples were again taken in 2006 with an average arsenic concentration of 2.4% (by weight) and an average iron concentration of 12.1% (by weight). The samples taken on March 13, 2012 found arsenic concentrations of about 1.7-2.2% (by weight) and iron concentrations of about 11-15% (by weight). These values are in the same order as the 2001 and 2006 samples. The slight variation noted between 2001, 2006 and 2012 may be due to differences in the exact location of the sampling, and/or the depth the sample was taken.

The solubility of the arsenic in the 2006 samples was found to be 0.26 mg/L. This is again similar to the findings of the March 13, 2012 samples.

¹ Giant Mine Remediation Project – Environmental Assessment EA0809-001, October 2010

3.4 Equipment Manufacturer's Independent Testing

An 80 L mixed water sample was sent to an equipment manufacturer for independent testing. The intent of this testing was for the manufacturer to validate the efficiency of their equipment for arsenic removal and provide a more accurate estimate of the average arsenic concentration in the treated effluent. A copy of the manufacturer's laboratory study is included in Appendix F.

3.4.1 Objectives

The objectives of the equipment manufacturer's testing were to determine the following:

- The treatment performance of the manufacturer's proprietary equipment
- The optimal coagulation pH
- The optimal coagulant dosage
- The optimal oxidant dosage (KMnO₄)
- The optimal polymer dosage
- Determine the most appropriate treatment chain to achieve the treatment criteria

3.4.2 Methodology

The jar test program was designed in order to simulate the manufacturer's proprietary ballasted flocculation technology combined with high rate clarification. The trials were mainly completed at a simulated hydraulic retention time equivalent to a rise rate of 40 m/h and analyses were conducted below 3°C. Detailed materials and methods used may be found in the the manufacturer's laboratory study included in Appendix F.

3.4.3 Conclusions

The tests demonstrated that arsenic can be consistently removed from the Giant Mine water sample received using a two step treatment chain using the manufacturer's proprietary ballasted flocculation clarifiers. Either Option 1 (oxidation followed by lime precipitation) or Option 2 (lime precipitation followed by oxidation) can be used and will give similar results. Option 2 seems to be the lowest operating cost process since the potassium permanganate dosages are much lower in the second step of the treatment chain.

4. Conclusions and Recommendations

The bench testing showed that the proposed treatment configuration is able to reduce the arsenic concentration of the treated water. During the bench scale tests, treated water total arsenic levels of below 0.1 mg/l were obtained.

Minimal potassium permanganate (< 5 mg/L) was required to oxidize the arsenic from As(III) to As(V) since nearly no As(III) was present in the raw water tested.

The 1200 mg/L ferric sulphate solution dose showed the greatest level of arsenic removal prior to lime addition and filtration. Figure 16 illustrates the arsenic removal at the optimum chemical doses found.

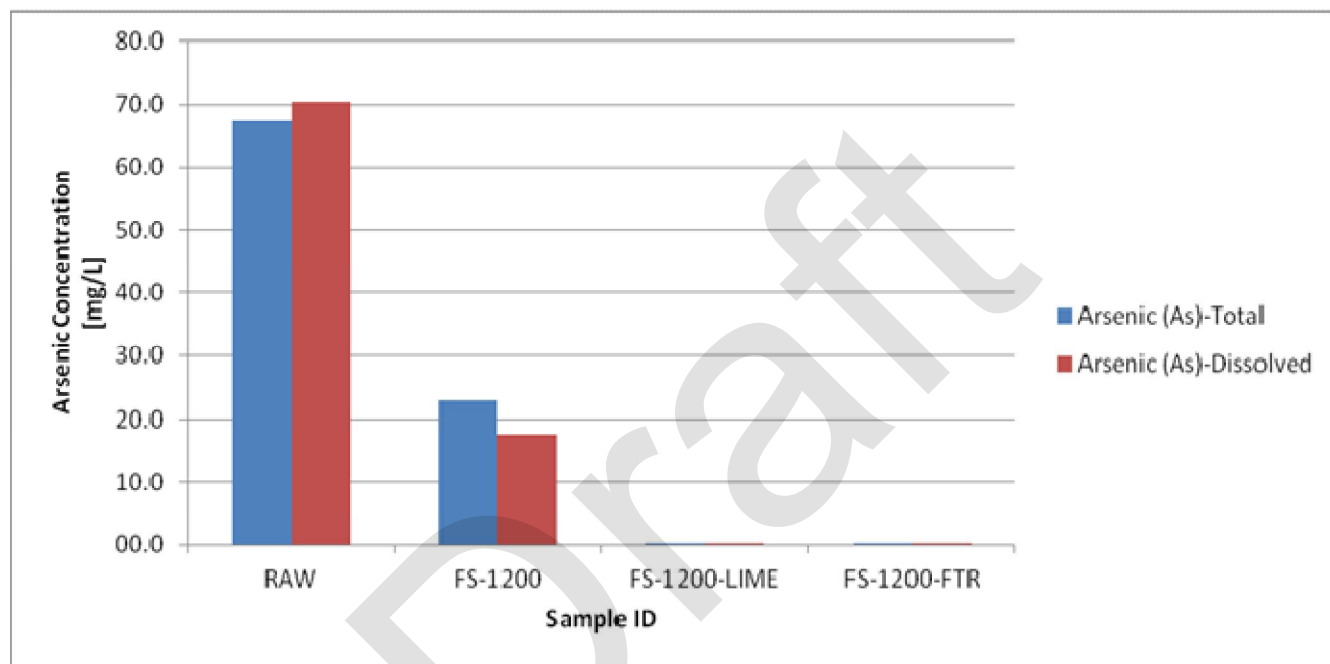


Figure 16. Arsenic Removal at Optimum Chemical Doses – Arsenic in mg/L

4.1 Comparison to Manufacturer's Results

Table 8 outlines the various chemical doses calculated and found by testing from AECOM's preliminary design report (2011), AECOM's bench scale testing, and the manufacturer's test results.

Table 8. AECOM Preliminary Design Report - Calculated Doses

	Chemical Units	KMnO ₄ mg/L	Coagulant (Fe-sulfate)		Polymer mg/L	Lime mg/L	CO ₂ mg/L	HCl mg/l	H ₂ SO ₄ Mg/l
			mg/L (12% Solution)	mg/L (Fe)					
AECOM Preliminary Design Report	Dose	89	2340	281	1.26	555	25		
AECOM Bench Scale testing results (oxidation – lime precipitation)	Dose	5	1200	144	-	425		1 -3.5 ¹	
Manufacturers results (Option 1 – lime precipitation - oxidation)	Dose	5 -	456	56.7	3	300			250 ¹
Manufacturers results (Option 2 – oxidation - lime precipitation)	Dose	50	775	94.5	3	400			250 ¹

Note 1: Compared with the manufacturer's test report we did find a discrepancy regarding the pH adjustment with acid. Although the pH adjustment for this report was only carried out over a small pH range (i.e., pH 9 to 8.5; refer to Table 5 Section 3.2.2.), we found a lower relative acid consumption than the equipment manufacturer. We have tried to investigate this discrepancy, but could not find the cause at this stage. We suggest repeating the titration with a new water sample.

The manufacturer's proprietary ballasted flocculation system appears to require lower chemical doses than the traditional clarification/flocculation system replicated by AECOM's bench scale testing. In particular, the results indicate that Option 1 (lime precipitation and coagulant addition prior to oxidation and coagulant addition) can achieve high levels of arsenic removal from the raw water provided at lower total chemical doses.

With reference to the preliminary design configuration, it would be prudent to design the treatment equipment to allow lime and oxidant dosing prior to each high rate clarifier in the ballasted flocculation system to allow operational flexibility should water conditions change over the life of the new treatment system.

4.2 Recommendations for Additional Testing

To help confirm and improve on the results obtained during from the bench scale testing, the following additional testing is recommended during the detailed design phase:

- Test arsenic speciation at each sampling location in the mine to rule out the possibility that the arsenic was oxidized during travel and to investigate if arsenic oxidation already occurs within the mine
- Test additional ferric sulfate doses for optimization
- Repeat acid titration for pH adjustment (refer to footnote on this page)
- Run a pilot of the proposed treatment plant in the detailed design stage to obtain more representative results for full scale operation and chemical dose estimations
- Perform testing, including dewatering testing, on the residuals created by the pilot program for more representative results

Appendix A

Material Safety Data Sheets (MSDS)

Draft

Appendix B

Giant Mine Bench Scale Testing Standard Operating Procedure (SOP)

Draft

Appendix C

Jar Test Report Sheets

Draft

Appendix D

ALS Laboratory Group Analytical Reports

Draft

Appendix E

Bench Test Photographs

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Appendix F

Veolia Report

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