EFFECTS OF ADDING ACID PLANT SULFUR

ON HEAP LEACHING

By
Jibin George

Approved:

Jim Henry
Professor of Chemical Engineering
(Director of Thesis)

Frank Jones
Professor of Chemical Engineering
(Committee Member)

Douglas Kutz
Professor of Chemistry
(Director of Thesis)

William H. Sutton
Dean of the College of Engineering
and Computer Science

A. Jerald Ainsworth
Dean of the Graduate School

EFFECTS OF ADDING ACID PLANT SULFUR ON HEAP LEACHING

By

Jibin Jacob George

A Thesis
Submitted to the Faculty of the
University of Tennessee at Chattanooga
in Partial Fulfillment of the Requirements
for the Degree of Master of Science
in Chemical Engineering

The University of Tennessee at Chattanooga
Chattanooga, Tennessee

March 2012

ABSTRACT

Mining industry is heavily invested in mining various precious metals from their natural ore deposits. Copper ore deposits are found across the world and heap leaching of copper has been implemented effectively for years. The ore is broken down to copper ions and elemental sulfur in the heap. Acid plants are used in mines to replenish the raffinate leaching the heaps which consists of sulfuric acid. Molten sulfur carried in rail cars to the acid plant is often accidentally spilled on the ground. The contaminated sulfur cannot be added to the acid plant and has been disposed of as hazardous waste at a high cost.

This study tests the effects of adding waste sulfur to the leaching heaps to observe any inhibitory effects or even potential benefits towards bioleaching that occurs within the heap. The study done examines the behavior of the waste sulfur within columns used to simulate mine heap conditions. Shake flask tests were also run to observe the potential effects with increased aeration. The study concluded that there were no harmful effects observed towards leaching with the addition of the waste sulfur. This project has been useful to the company to recommend the final placement of the acid plant sulfur and the potential for acid generation if placed in the heap.

TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION

The consistent global demand of copper has ensured a steady growth in the field of copper mining. There are many companies invested in mining reserves all over the world with copper deposits that are predicted to last up to sixty years. Ore is the natural state the valuable metal is found in. Copper ore is collected from blasting sites and then crushed to the required size using a sequence of multiple crushers. The crushed ore is stacked into heaps upon which a raffinate solution consisting of dilute sulfuric acid is poured in a recycle loop. The raffinate solution dissolves the copper from the ore and flows down through the heap. The copper is separated from the raffinate solution collected from the heaps by using various methods of solvent extraction. The copper extracted is then electroplated into copper cathodes which are shipped to be manufactured.

Kennecott mining company first patented the use of a specific strain of bacteria, *Thiobacillus ferrooxidans* in 1958 [1]. Biomining is the process where bacteria or fungi are used to aid in mining metals from their ores. *T. ferrooxidans* oxidize the ferrous ions to ferric form which in turn is useful to liberate the copper from its sulfide ore. The elemental sulfur is then converted to sulfuric acid by the bacterial species, *T. thiooxidans* which is then collected in the raffinate solution. Heap bioleaching is now widely practiced around the world to extract copper from its secondary copper ores, chalcocite (Cu_2S) and covellite (CuS) [1]. Biomining has been proven to increase the amount of copper extracted, and regulation of environmental factors for the bacteria within the heap can increase bacterial growth. Figure 1 further illustrates this process that is patented by BHP Billiton mining company. The chemical reactions are listed and discussed in theory.

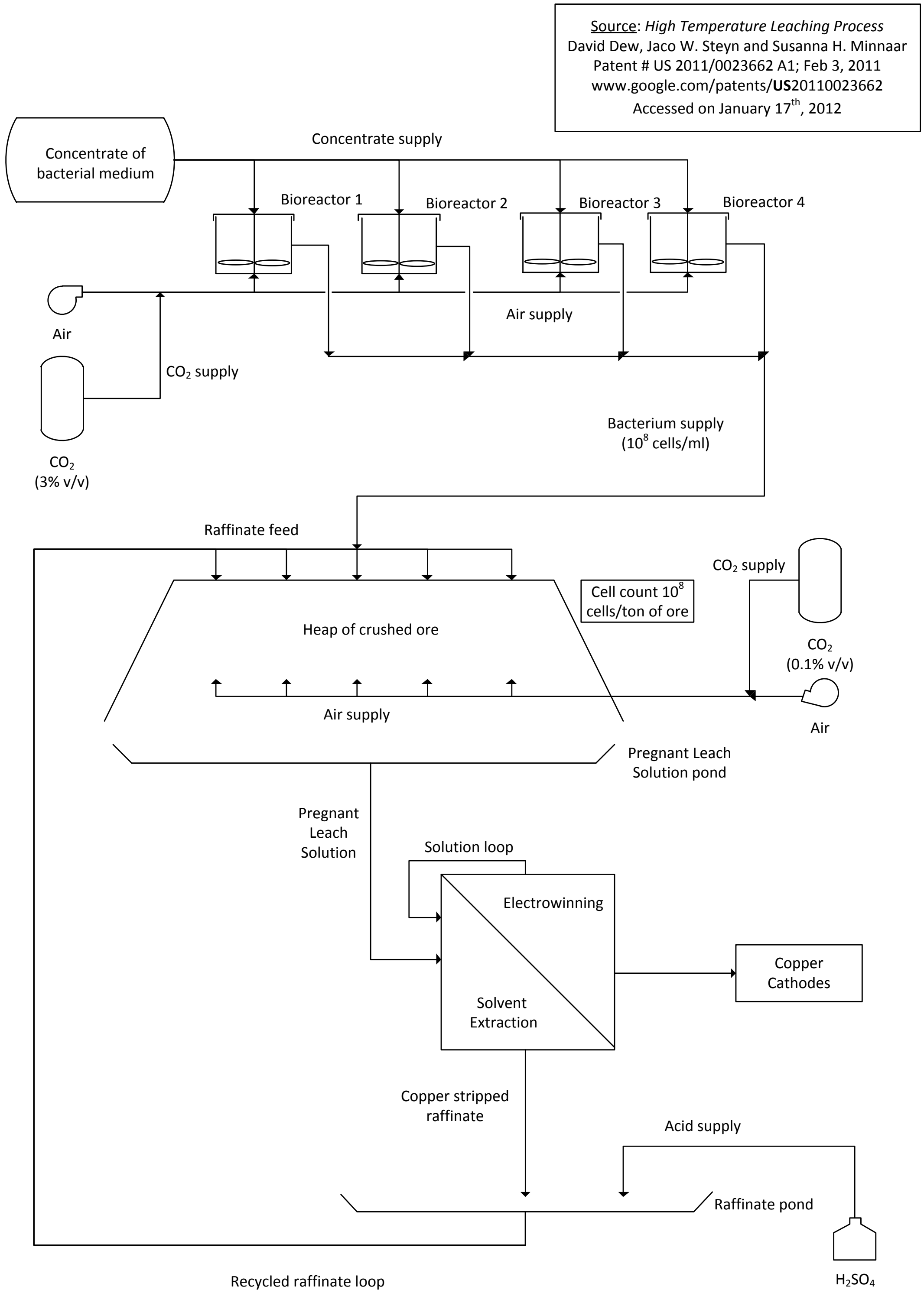

Figure 1

Bacterial assisted leaching of copper

Company X is a copper mining company that also uses biomining techniques. Molten sulfur is transferred from rail cars to their acid plant where it is converted to sulfuric acid before it is dumped on heaps for leaching. During the process some molten sulfur is lost to the ground. After contact with the ground the sulfur can no longer be fed to the acid plant and therefore must be disposed of as hazardous waste. This waste removal process is quite expensive when comparing the amount of waste site sulfur collected. However, there is compelling evidence that this sulfur could be added to the leach stockpile without detriment and could possibly be proven beneficial. The shake flask/column test will explore on a lab scale the metallurgical impact of the sulfur to the heap by utilizing conditions to simulate the factors present in the heap. The experiment is designed to specifically detect any potential interference with the extraction of copper due to the presence of the sulfur additive. In conjunction to investigating copper extraction performance, the program will also analyze the sample for potential harm against bioleaching.

Theory

The bacterial activity inside the heap has been proven vital for the process of extraction of copper. The bacteria were first found to form naturally within the heap. However, now through research, the mining industry has been able to manipulate bacterial growth and in turn manipulate copper extraction levels. The major biochemical reactions taking place inside the heap are shown below: [3]

1. $CuFeS_2 + 4\,Fe^{3+} \rightarrow Cu^{2+} + 5\,Fe^{2+} + 2\,S^0$ (Spontaneous)
2. $4\,Fe^{2+} + O_2 + 4H^+ \rightarrow 4\,Fe^{3+} + 2H_2O$ (*T. ferrooxidans*)
3. $2\,S^0 + 3\,O_2 + 2\,H_2O \rightarrow 2\,SO_4^{2-} + 4\,H^+$ (*T. thiooxidans*)

Net Reaction: $CuFeS_2 + 4\,O_2 \rightarrow Cu^{2+} + Fe^{2+} + 2\,SO_4^{2-}$

The first reaction takes place spontaneously when the chalcopyrite ($CuFeS_2$) found in the copper ore reacts with the ferric ions present in the raffinate. This produces ferrous and copper ions along with elemental sulfur. The *T. ferrooxidans* species converts the ferrous ions back to ferric ions under aerobic conditions. This bacterial activity ensures enough ferric ions present to break down more chalcopyrite creating a continuous process. The elemental sulfur produced gets converted by the *T. thiooxidans* species into sulfuric acid. The reaction is also aerobic and it takes up the water produced in step (2) as a reactant for step (3). Both bacterial reactions are aerobic, and therefore an air supply is vital within the heap for the leaching process. The net reaction describes the overall process in step (4).

The sulfur carried in the rail cars is in molten form from the company's acid plant. The sulfur is in its elemental state. Some sulfur is often accidentally spilled on the ground where it solidifies. Touring the site revealed clumps of solid yellow sulfur all along the rail road at the transfer point. The sulfur mixed with the dirt on the ground is then scooped up and dumped into large barrels. These barrels are then shipped off for disposal under EPA regulations. The hypothesis proposed suggests that the sulfur collected can be dumped on top of the heap without any harmful effects towards leaching. The assumption is made considering that the only contaminant is dirt and since the heap is made of copper ore which is basically dirt and chalcopyrite compound, the waste site sulfur should not be detrimental. However, the sample needs to be analyzed to determine any additional detrimental components such as gasoline that could hinder the bioleaching process. This along with running experiments to simulate heap conditions, would help confirm the hypothesis that any possible inhibition towards bioleaching should be noted and recorded, as it could inadvertently inhibit copper production.

CHAPTER II

METHODOLOGY

Equipment

- Multisizer 4 COULTER COUNTER

  - Manufacturer: Beckman Coulter Item # A63076

  - Offers highly accurate and reliable particle counting and sizing

  - Sizing range of 0.4 µm to 1600 µm using Digital Pulse Processor [2]

  - Dimensions: Width: 64 cm (25 in), Depth: 61 cm (24 in), Height: 51 cm (20 in)

Figure 2 Multisizer 4 Coulter Counter [2]

- Heap simulation columns

  - Eight porcelain columns

  - Simulates a 15 ft lift

  - Pump feeds raffinate at 0.0025 gpm/ft^2 compared to heap raffinate feed rate of 1.5-2 gpm/ft^2

  - Leach cycle of 120 days

  - Dimensions: Height : 5 ft, Width: 6 inches

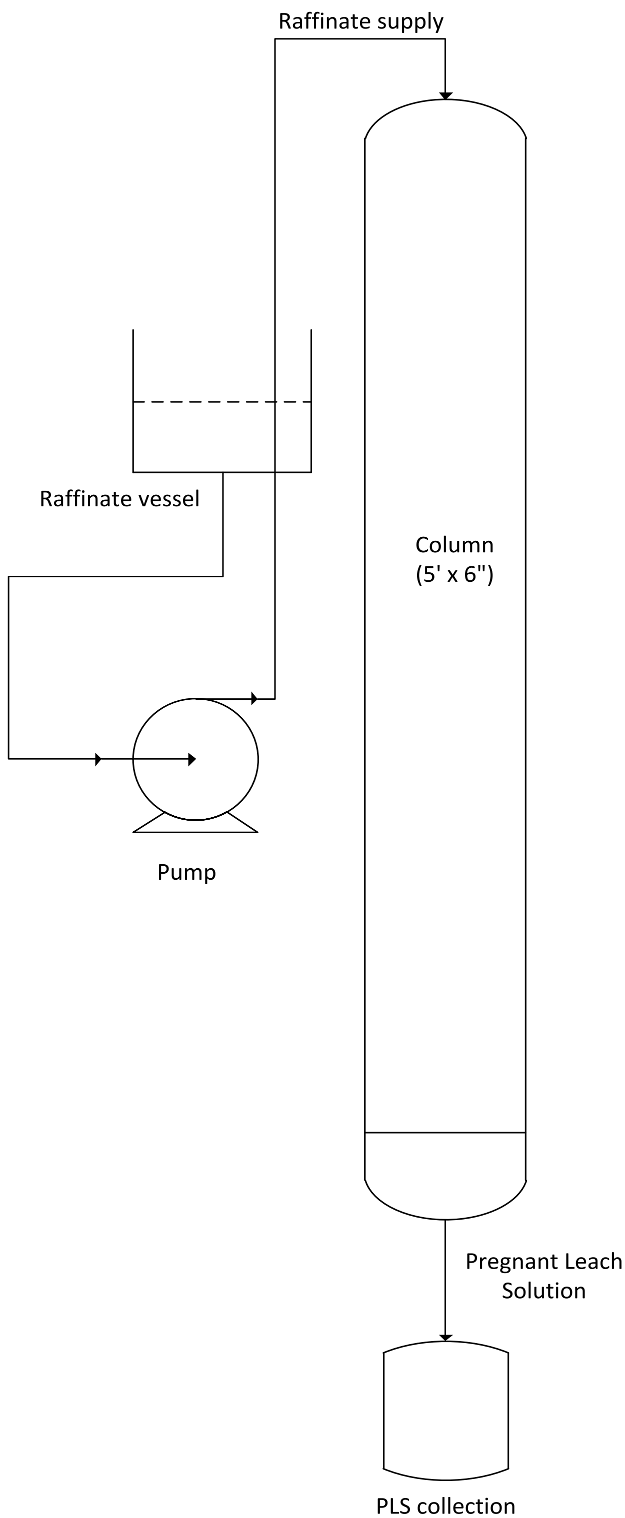

Figure 3

Column diagram

Procedure

The molten sulfur spilled near the acid plant was collected in barrels after it solidified. This sample was then crushed to 1 inch or less and blended with the cure where it is agglomerated with the acid. One sample was set aside for mineralogical and analytical analysis. The analyses performed were used to investigate the total sulfur, impurities and any hydrocarbons present in the sample. These tests include:

- Inductively Coupled Plasma sweep of 27 elements: 25 g of (-) 400 mesh
- X-ray diffraction with Rietveld: 25 g of (-) 400 mesh
- Sulfur Hydrocarbon analysis at; 130 g of 1 inch top size
    1. 80/15-AZ: Gas range (C_6 to C_{10})
    2. 80/15-D: Diesel range (C_{10} to C_{22}) and Oil range (C_{23} to C_{32})

The rest of the collected sulfur was used in both the shake flask and column tests.

Shake Flask Test Work

The shake flask sulfur material was further crushed to a size of -400 mesh.

A total of 18 shake flasks were tested as listed in Table 1. The study investigates the reactivity of the acid plant sulfur under: ideal conditions, actual raffinate conditions with bacteria inoculation and also with raffinate with no bacteria inoculation. Inoculation is the process by which bacteria is added to the sample. The shake flasks tests help investigate any potential inhibitory effects towards the bacterial activity so vital in the mining of copper. The tests were also run to identify any effects under both mesophilic and moderate conditions for inoculation to observe variations for temperature within the heap. The test matrix in Table 1 is listed below.

Table 1

Test matrix for shake flasks test

Shake Flask ID	Solution MKM/RMKM (180 ml)	Inoculum (5 ml)	Acid Plant Sulfur Weight (g)	Temperature conditions to inoculate
148	MKM	Heap Culture	10	Mesophilic
149	MKM	Heap Culture	10	Mesophilic
150	MKM	Heap Culture	10	Mesophilic
151	MKM	Heap Culture	10	Moderate
152	MKM	Heap Culture	10	Moderate
153	MKM	Heap Culture	10	Moderate
154	RMKM	Heap Culture	10	Mesophilic
155	RMKM	Heap Culture	10	Mesophilic
156	RMKM	Heap Culture	10	Mesophilic
157	RMKM	Heap Culture	10	Moderate
158	RMKM	Heap Culture	10	Moderate
159	RMKM	Heap Culture	10	Moderate
160	RMKM	-	10	Mesophilic
161	RMKM	-	10	Mesophilic
162	RMKM	-	10	Mesophilic
163	RMKM	-	10	Moderate
164	RMKM	-	10	Moderate
165	RMKM	-	10	Moderate

RMKM – Raffinate Modified Kelly’s Medium   MKM – Modified Kelly’s Medium

The shake flasks were filled with 180 ml of solution mediums modified Kelly’s medium, MKM and raffinate modified Kelly’s medium, RMKM as specified in Table 1, with 5 ml of the inoculum added where specified. These mediums are supplied to provide a base for the bacteria to grow on. Typical bacterial nutrients were added at the rates of 0.4 g/L ammonium sulfate, 0.4

g/L magnesium sulfate and 0.04 g/L potassium sulfate. The MKM was adjusted to a pH of 3.08 using 10N H_2SO_4. The bacterial genus of *Thiobacillus* grows under the moderate and mesophilic temperature ranges which is specified within 68°F (20°C) and 113°F (45°C). Inclusion of the temperature comparison ensures that both *thiooxidans* and *ferrooxidans* species are encouraged to grow in the natural environment.

The shake flasks were run for a period of three weeks. During this time, bacteria counts, pH and oxidation reduction potential levels were recorded for each flask daily. Final solutions upon the completion of the test period were submitted to Analytical for H_2SO_4 analysis. Final residues were then vacuum filtered and final dry weights were recorded. Each set of three flasks for each feed were combined, blended and submitted to mineralogy for X-ray diffraction analysis.

Column Program

Chemical and Mineralogical Characterization:

Analysis was performed on the column test samples in the following tests categories;

- Total copper content
- Mole fraction of copper
- Quick Leach Test
- Iron content
- Total Acid Consumed
- Net Acid Consumed
- Inductively Coupled Plasma sweep (27 elements)
- X-ray Diffraction with Rietveld

Sample Collection/Preparation

Ore mined by company X was utilized as feed material for this study. The ore material shall be used “as is” with no additional crushing. The material was blended with the agglomerate and split into eight column charges (approximately 90 lbs per column). Each charge received the designated sulfur according to the test matrix listed in Table 2. Each column charge was agglomerated using a 50 lb/ton cure (agglomeration with acid) with a 3 day rest period and it received an additional 30 lb/ton acid in the raffinate.

Column Test Work

A total of eight (5 ft x 6 inches) columns were tested with various concentrations of sulfur collected from the acid plant. The columns are listed below:

Table 2

Test Matrix for Column Leaching

Column ID	Waste site sulfur [lbs]	Nutrients[NH_4SO_4] (g/day)	Biomass (%)
168	-	-	-
169	-	-	-
170	0.5	-	-
171	1	-	-
172	5	-	-
173	5	1.63	-
174	5	-	1
175	5	1.63	1

Columns were scaled to simulate a 15 foot lift with a leach solution feed rate of 0.0025 gallons per minute/ft^2. Raffinate was used for all columns acidified to apply 30 lb/ton acid. The leach cycle was run for a total of 120 days. Samples were taken every Monday, Wednesday and Friday and sent for analysis for Total Copper, Total Iron and Fe (II) and H_2SO_4 concentrations. The pH, oxidation reduction potential and bacteria counts were recorded from these samples. Screen and analytical samples were taken from each column residue upon completion of the leach cycle. Chemical analysis was again done for Total Copper, Iron and Sulfur concentrations.

CHAPTER III

RESULTS

The initial tests run on the waste site sulfur sample produced the following results. The Inductively Coupled Plasma sweep conducted on the waste site sulfur sample revealed 30 ppm concentration of phosphorus. Molybdenum was detected up to 10 ppm while all other minerals were found to be less than 5 ppm. The X-ray diffraction analysis of the waste site sulfur sample detected sulfur as the only crystalline phase present. The hydrocarbon analysis of the waste site sulfur identified up to 130 mg/kg of hydrocarbons C_{10} to C_{32} as o-Terphenyl and 5 m/kg of hydrocarbons C_6 to C_{10}. This could be attributed to gasoline leakage from the rail cars or truck tankers where the said sample is gathered.

The shake flask data was first reported with a shorter test period of just three weeks. The bacteria counts, pH and oxidation reduction potential values collected throughout the test were then graphed. The graphs compared three shake flasks at a time with similar inoculation temperature conditions. The graphs plotted are shown below in the following figures:

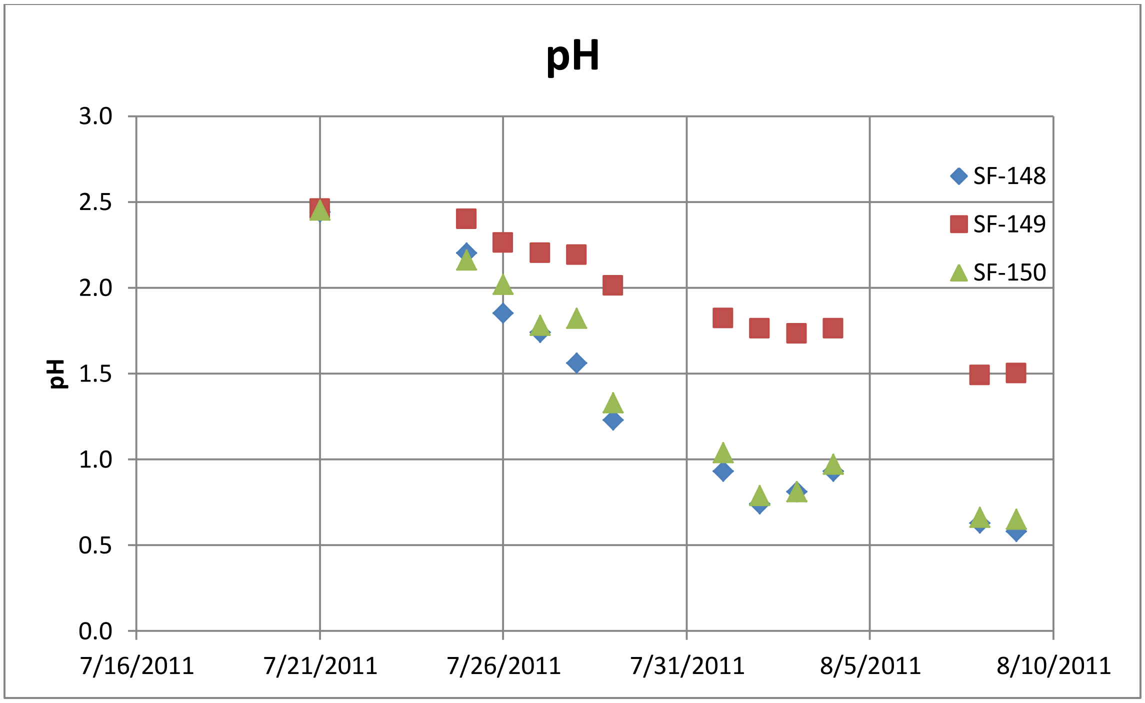

Figure 4: Shake flask 148-150 pH levels

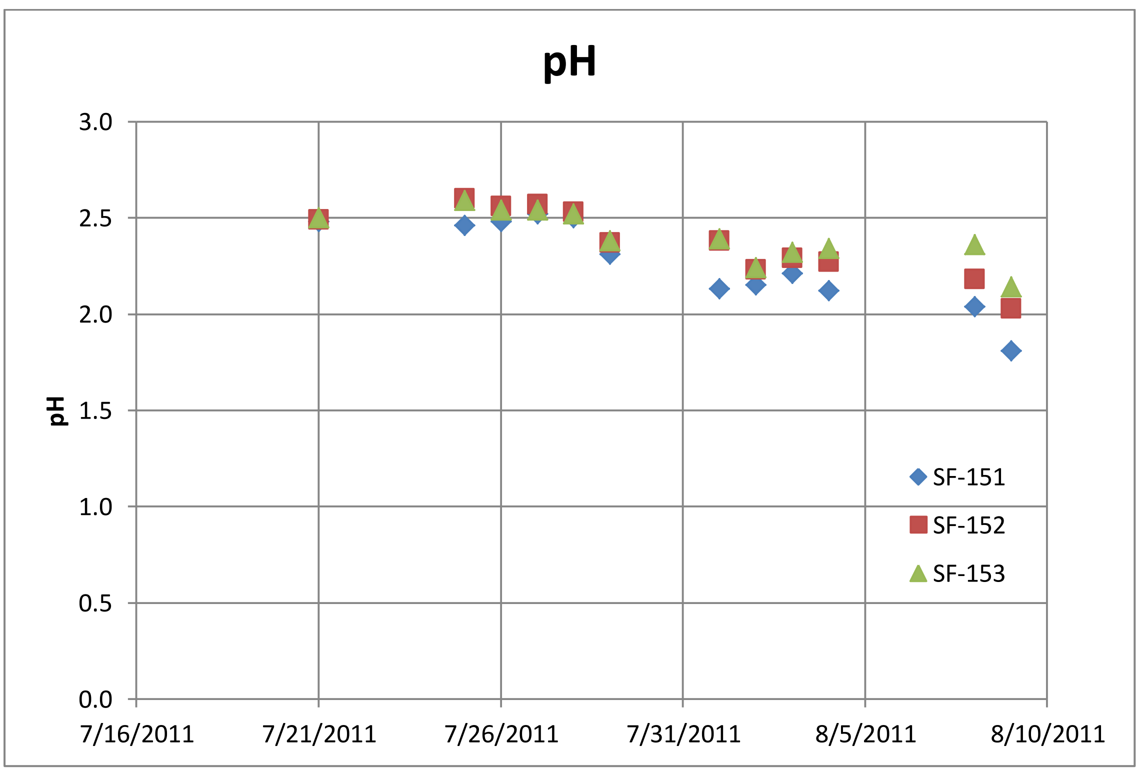

Figure 5: Shake flasks 151-153 pH levels

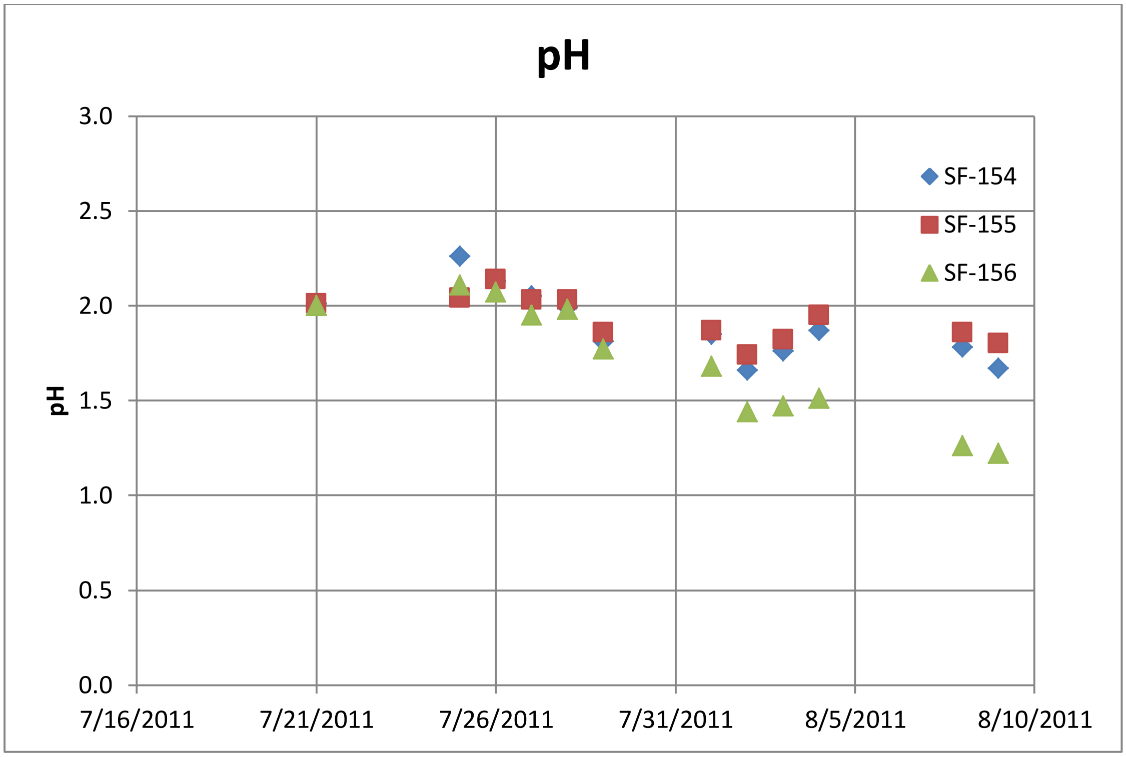

Figure 6: Shake flasks 154-156 pH levels

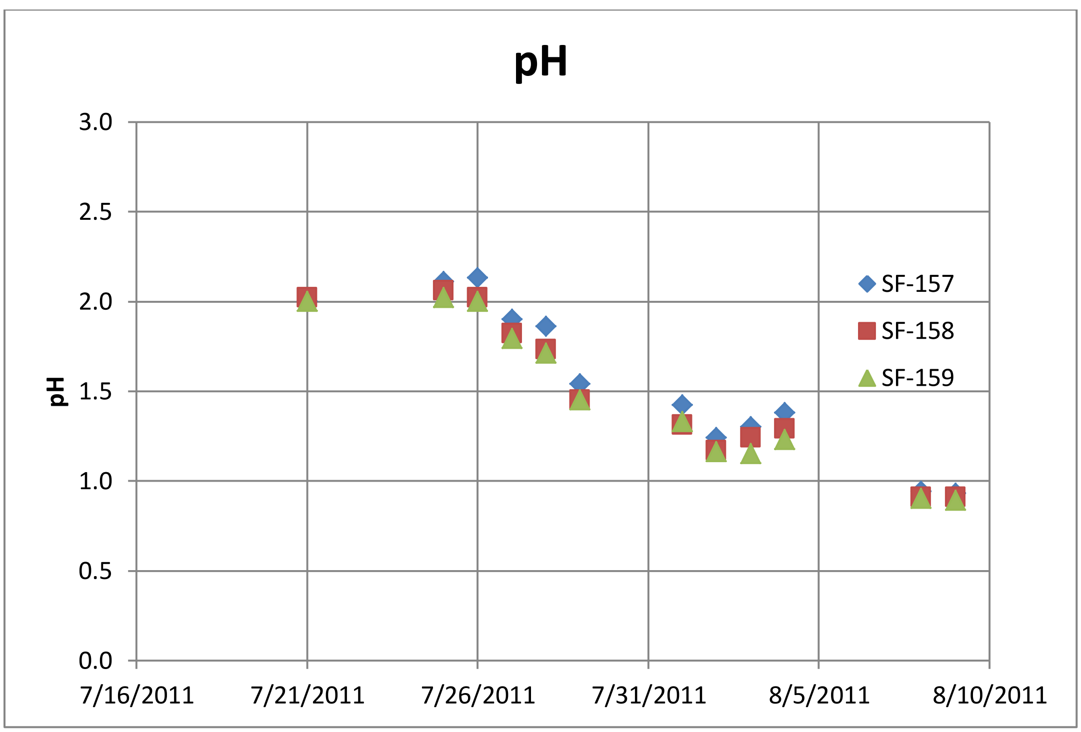

Figure 7: Shake flasks 157-159 pH levels

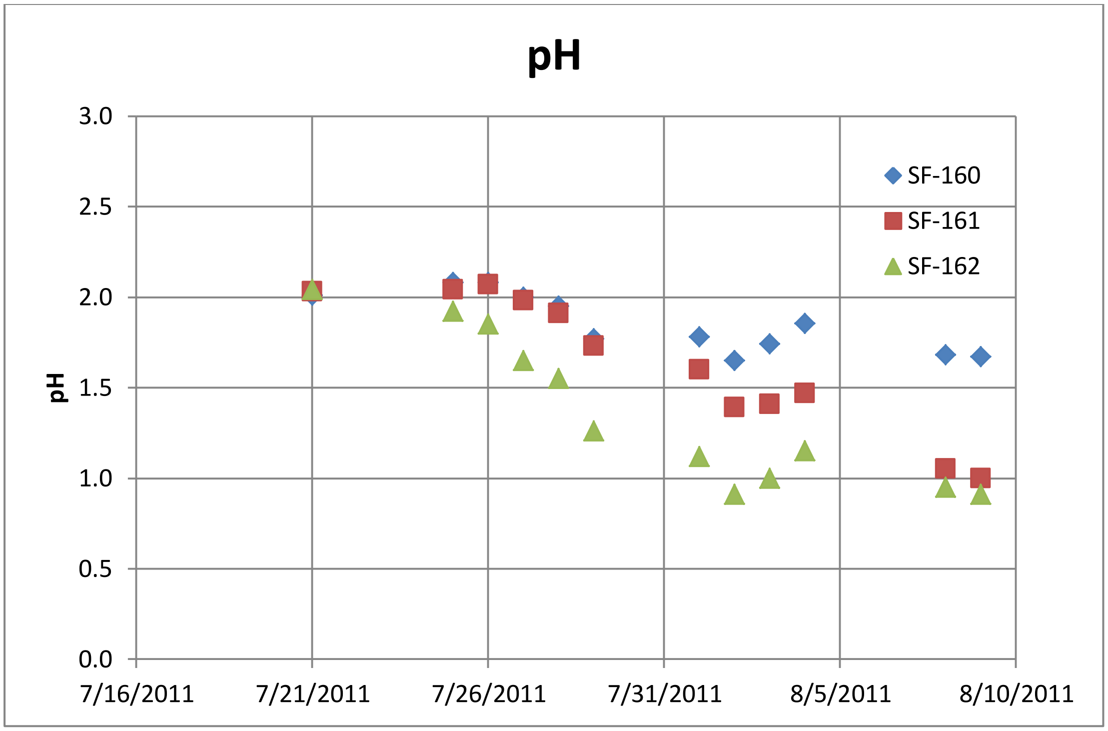

Figure 8: Shake flasks 160-162 pH levels

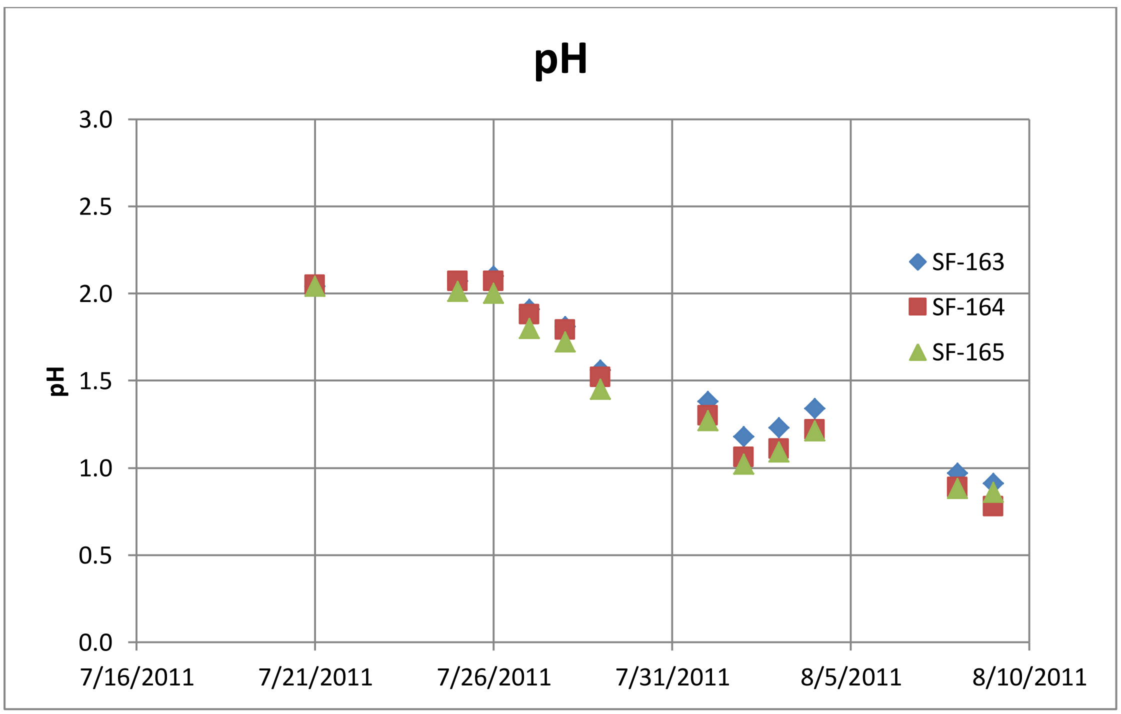

Figure 9: Shake flasks 163-165 pH levels

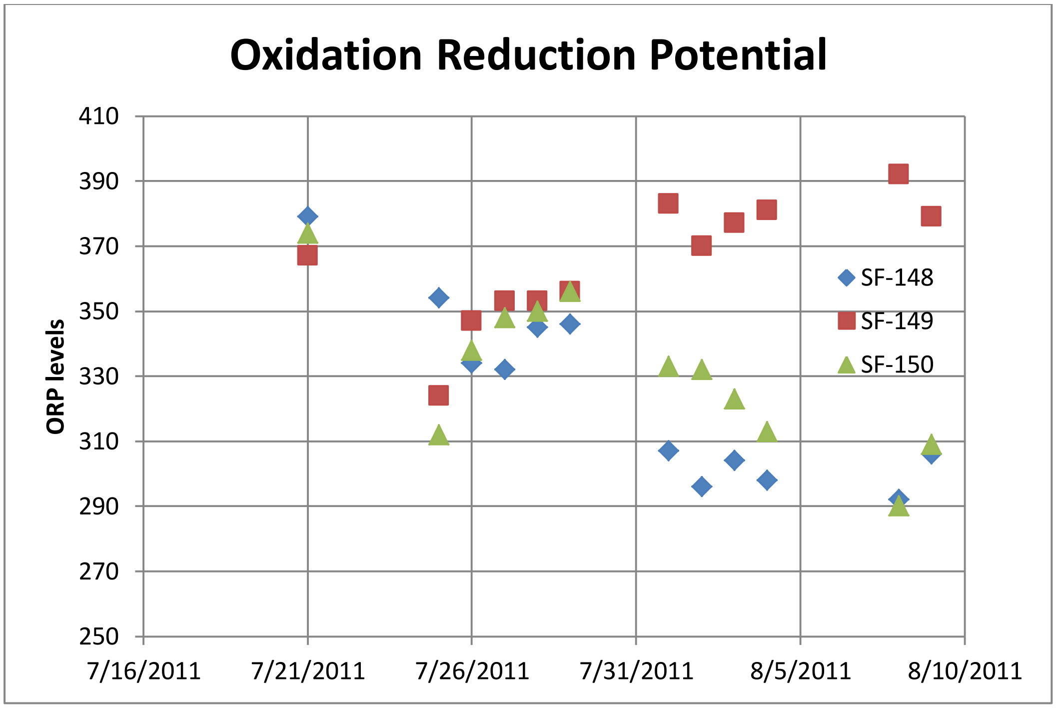

Figure 10: Shake flasks 148-150 ORP levels

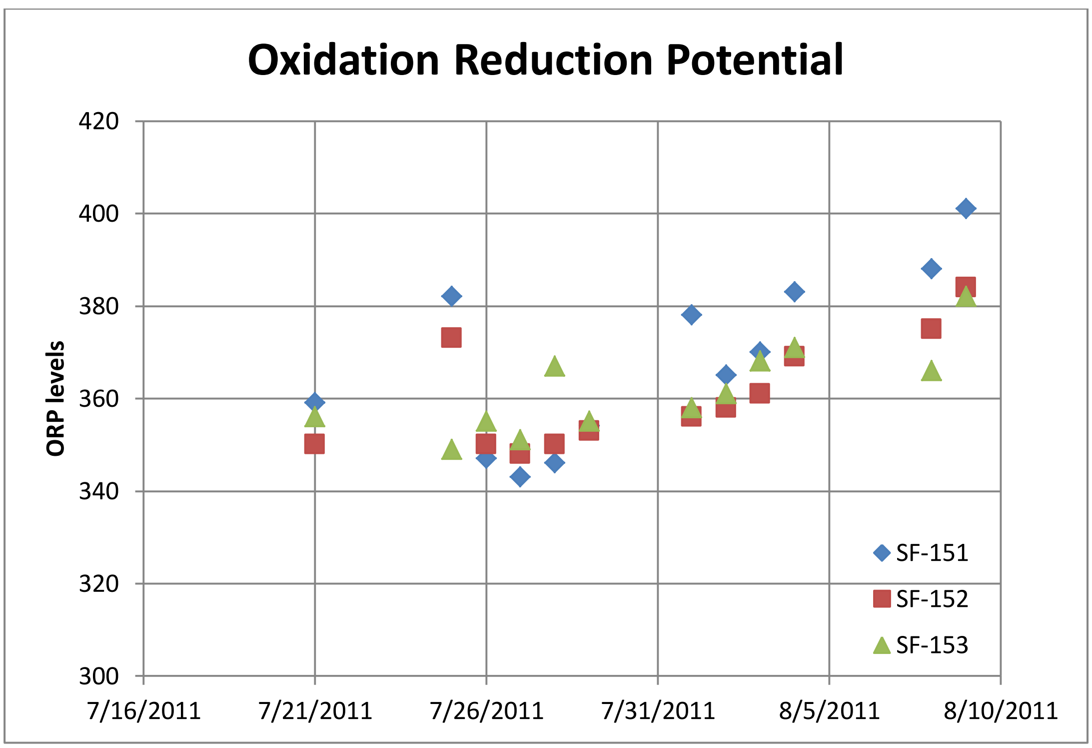

Figure 11: Shake flasks 151-153 ORP levels

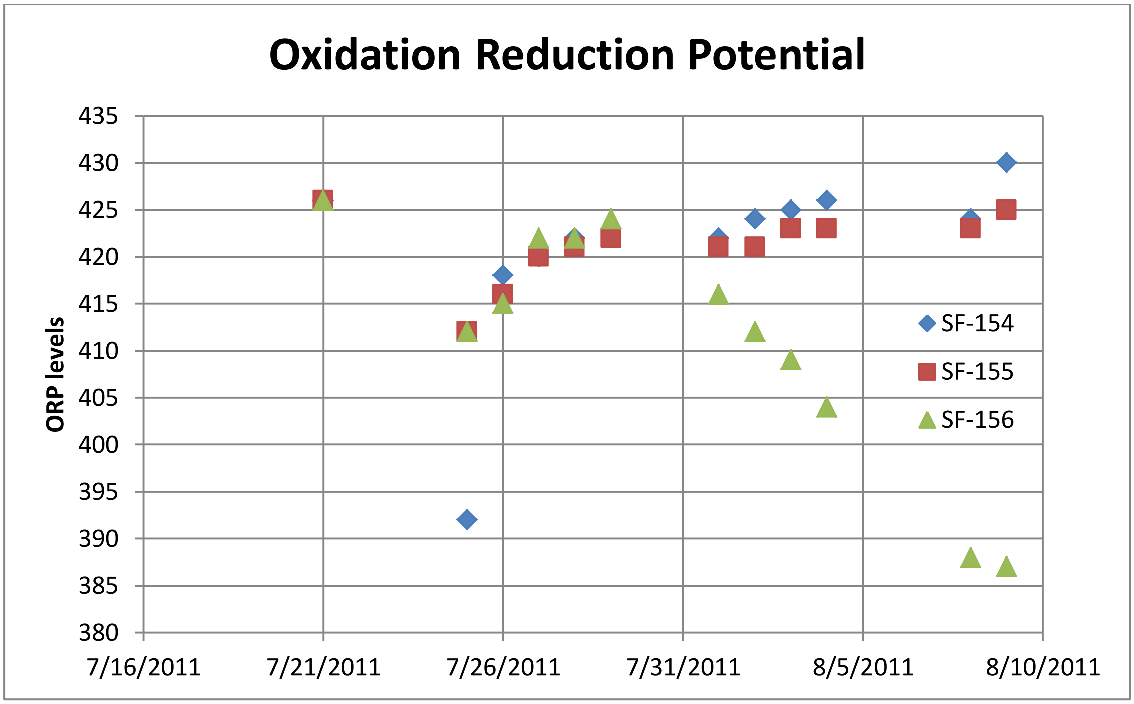

Figure 12: Shake flasks 154-156 ORP levels

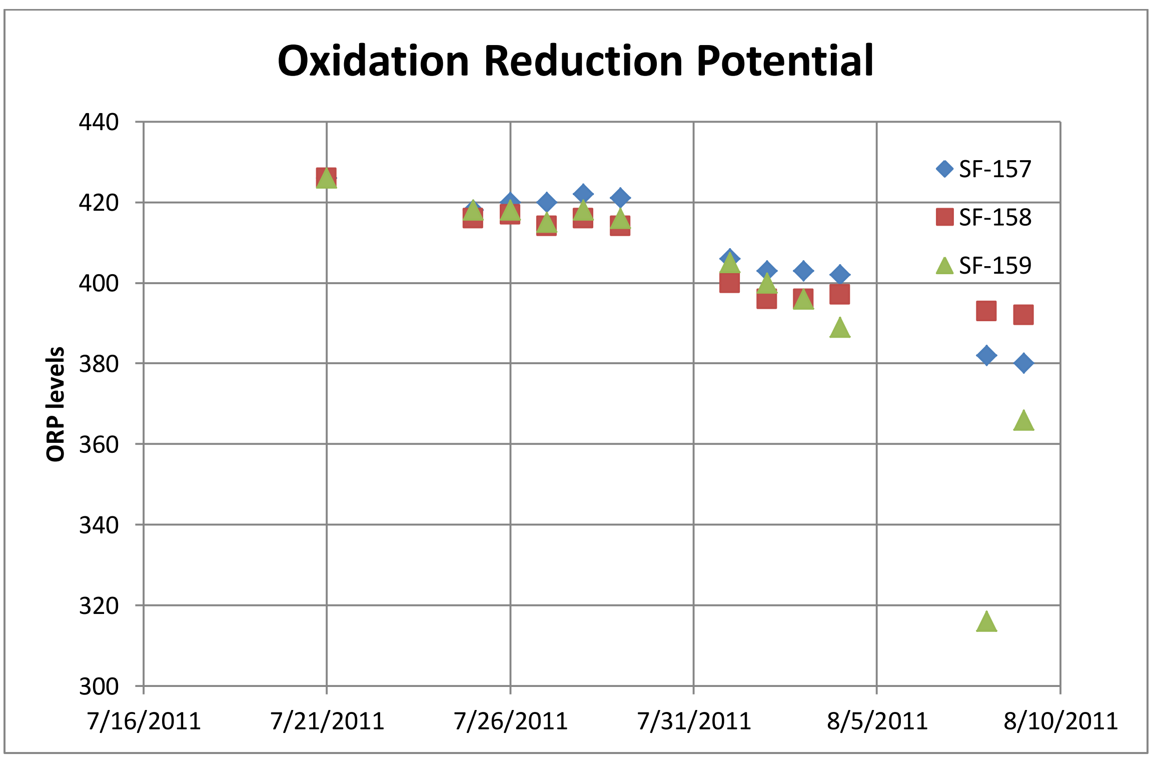

Figure 13: Shake flasks 157-159 ORP levels

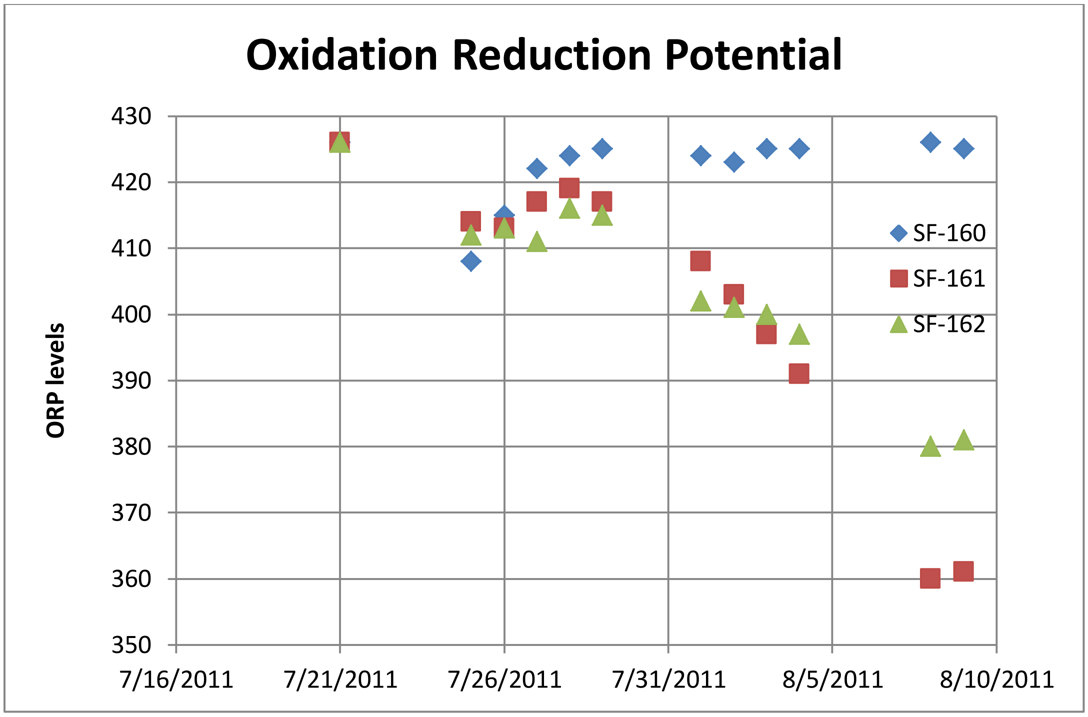

Figure 14: Shake flasks 160-162 ORP levels

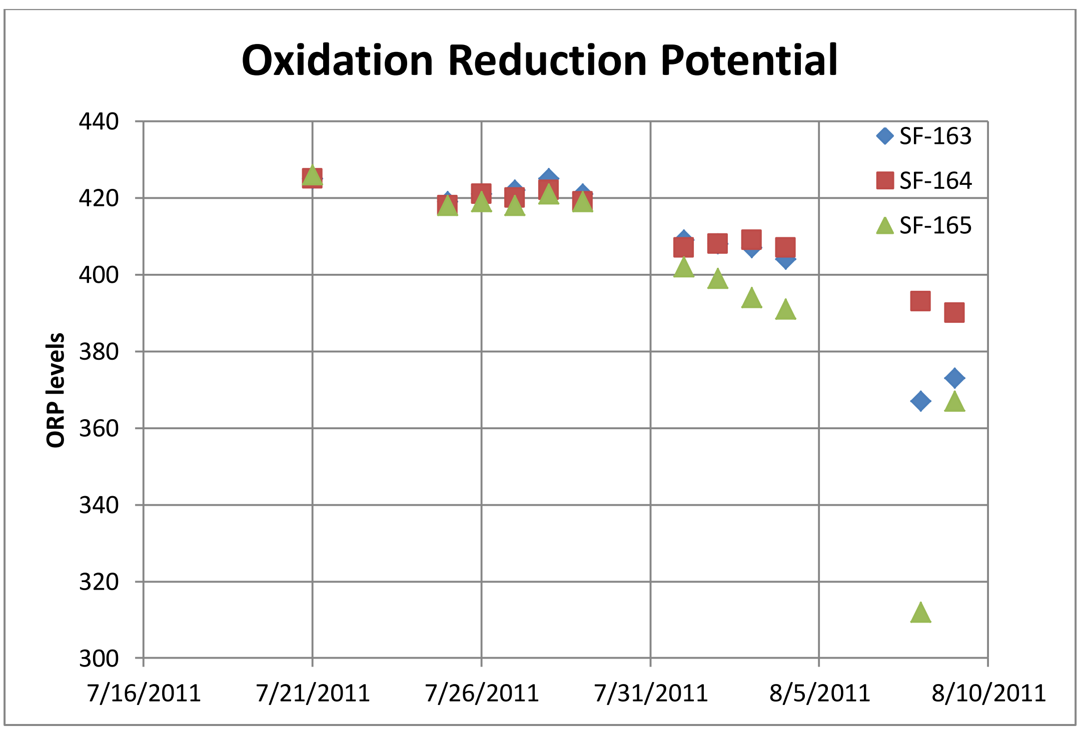

Figure 15: Shake flasks 163-165 ORP levels

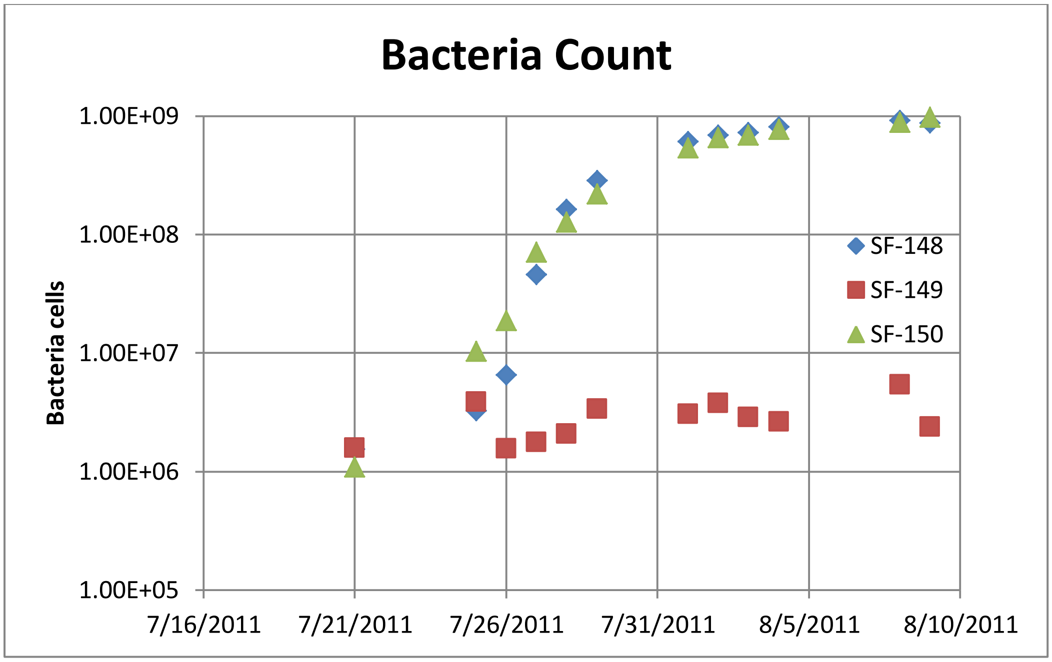

Figure 16: Shake flasks 148-151 Bacteria Count levels

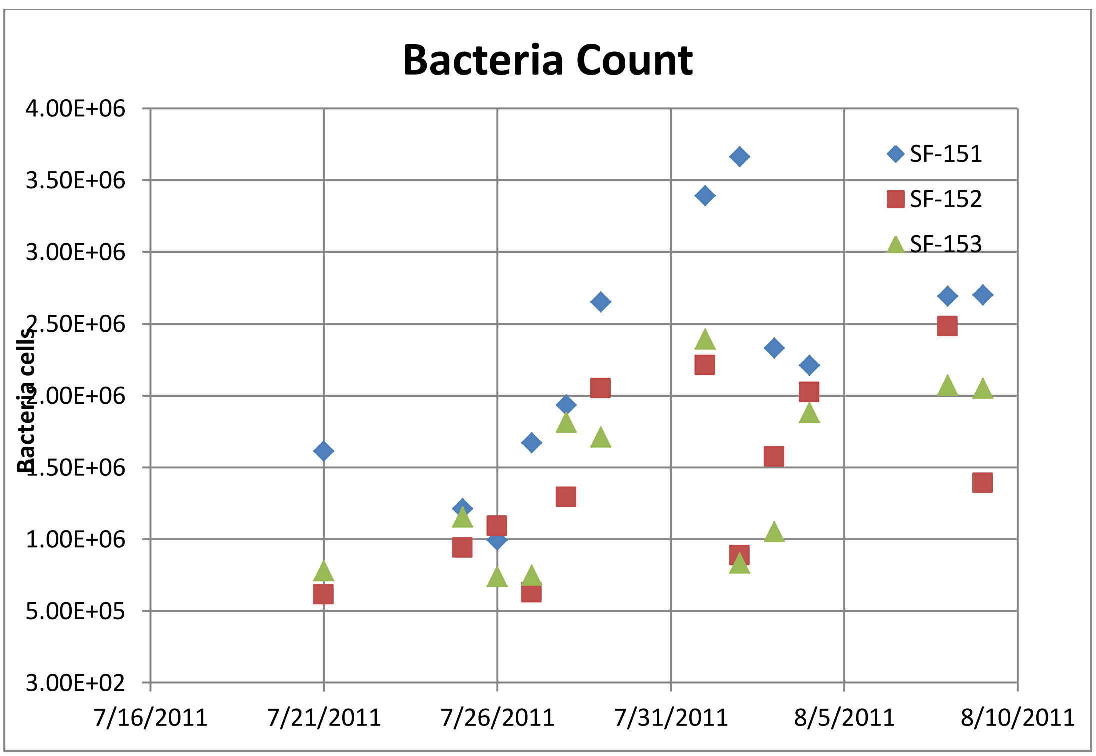

Figure 17: Shake flasks 151-153 Bacteria Count levels

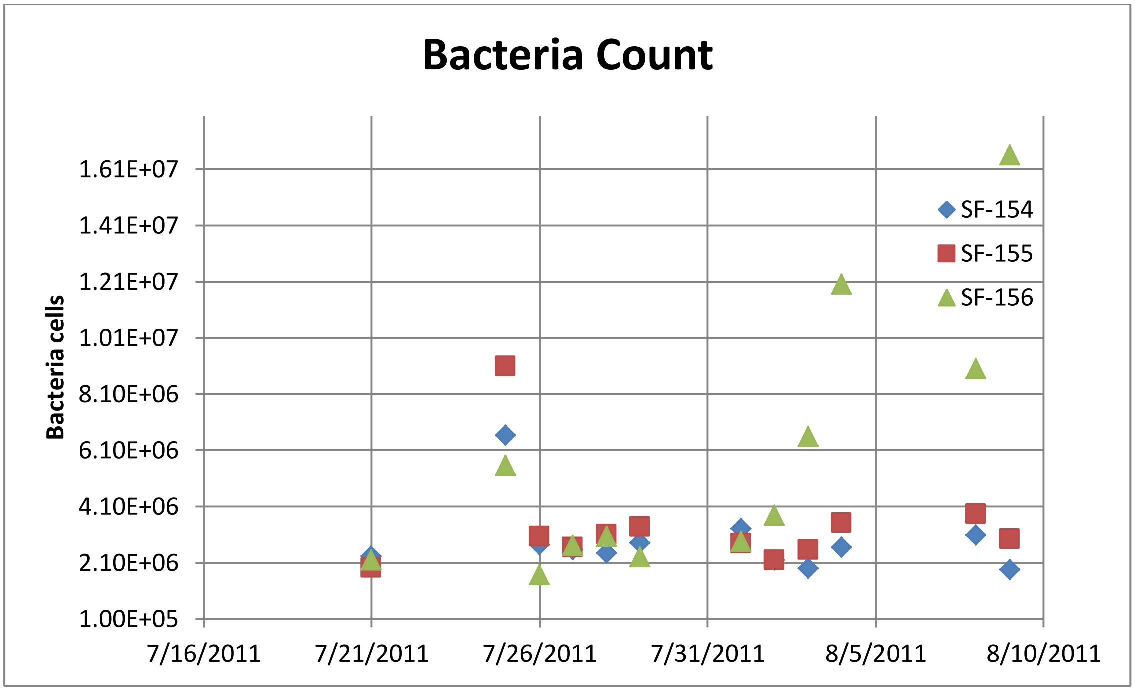

Figure 18: Shake flasks 154-156 Bacteria Count levels

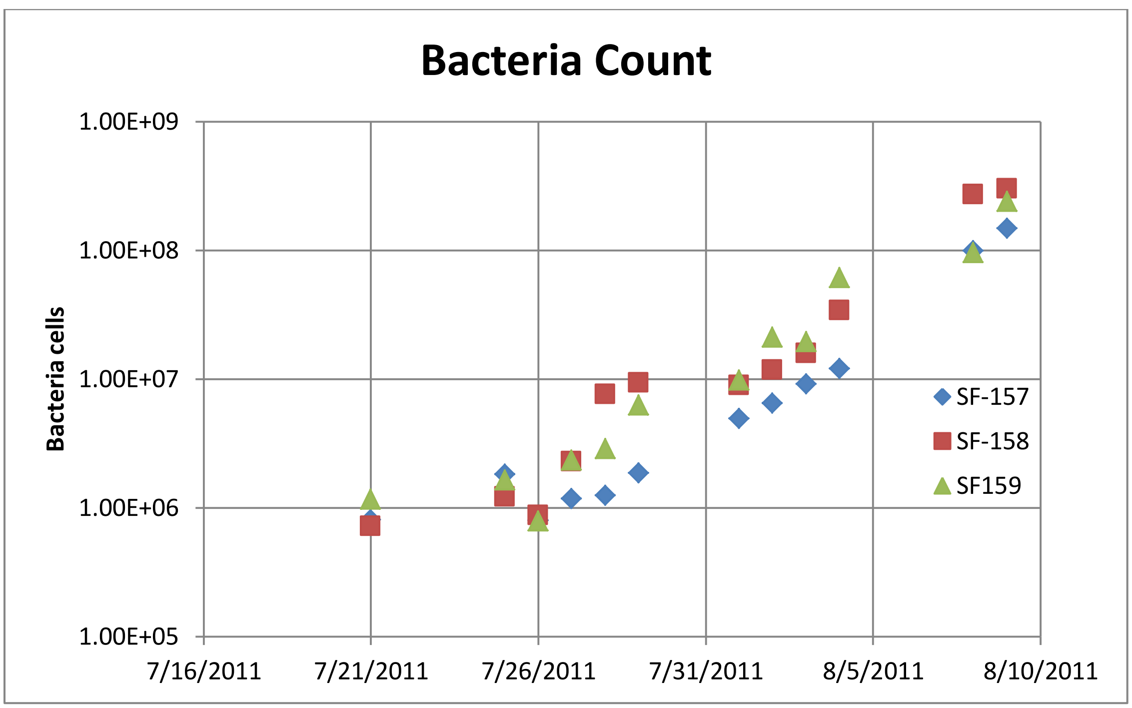

Figure 19: Shake flasks 157-159 Bacteria Count levels

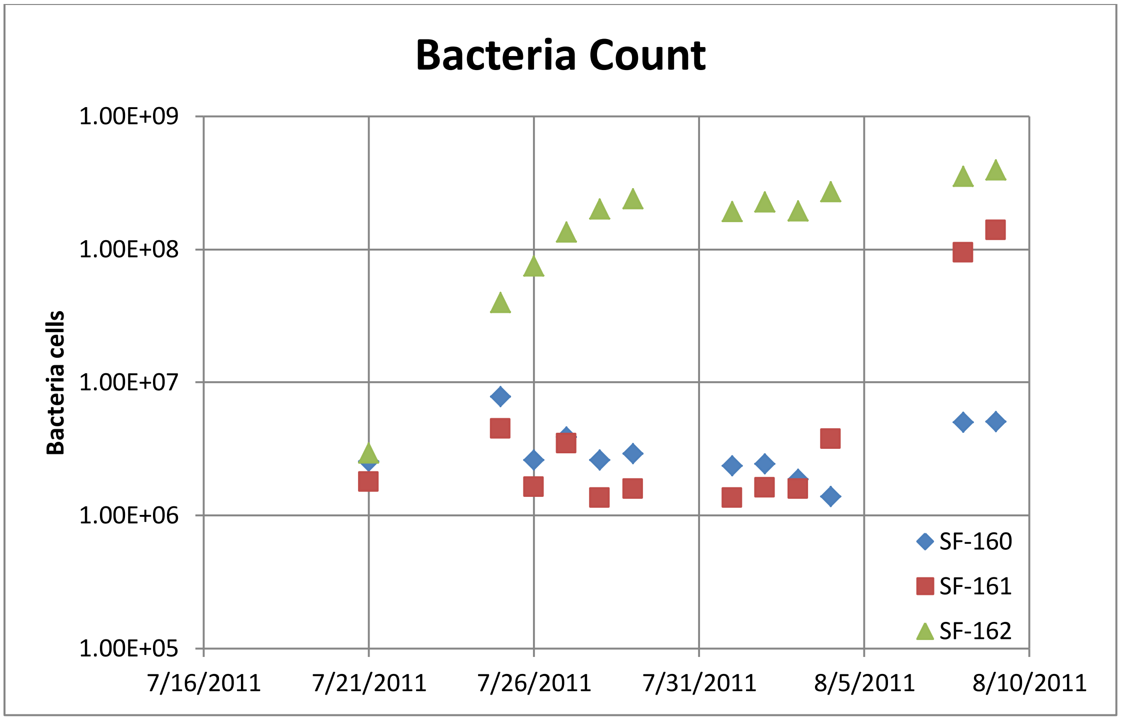

Figure 20: Shake flasks 160-162 Bacteria Count levels

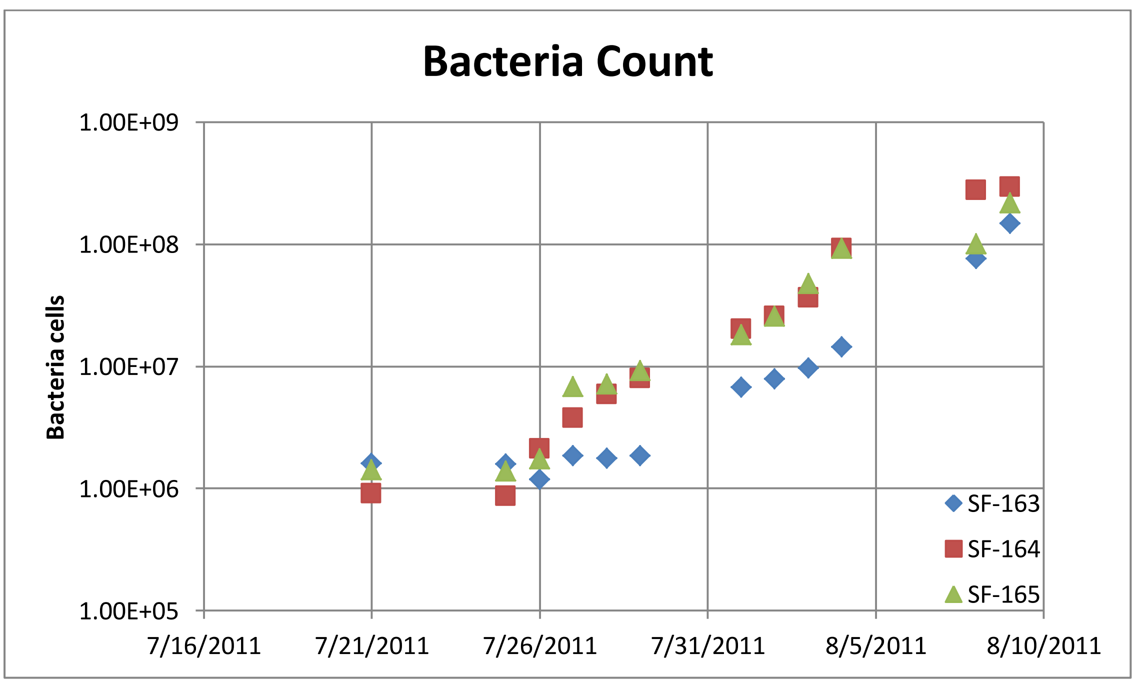

Figure 21: Shake flasks 163-165 Bacteria Count Levels

CHAPTER IV

DISCUSSION

The graphs of the shake flask tests can be used to observe the effects of the waste site sulfur on the two relevant bacteria strains found in the heap. These tests encompass various conditions present in the heap such as the two temperature variations (moderate and mesophilic), two mediums (standard and raffinate modified), etc by calculating bacteria counts, oxidation reduction potentials and pH levels. Reviewing figures 4-9, the pH levels can be seen to drop consistently throughout the shake flasks. This shows that sulfuric acid is being formed to drop the pH levels. Sulfuric acid is only formed when the reactions proceed successfully. Figures 10-15 compares the oxidation reduction potential levels recorded over three weeks. The oxidation reduction potential levels are seen to decrease showing that the two species of bacteria are carrying out their oxidation reactions. Figures 16-21 illustrates the bacteria count recorded. The shake flasks show how the waste site sulfur does not affect the bacterial growth inside the heap. The bacterial activity is heavily involved in the bioleaching process and any detrimental effect could be harmful in the process of leaching copper.

Column tests graphs

The data from the eight columns were tabulated in the report by the technicians at Company X. The report data were then used to construct the following plots.

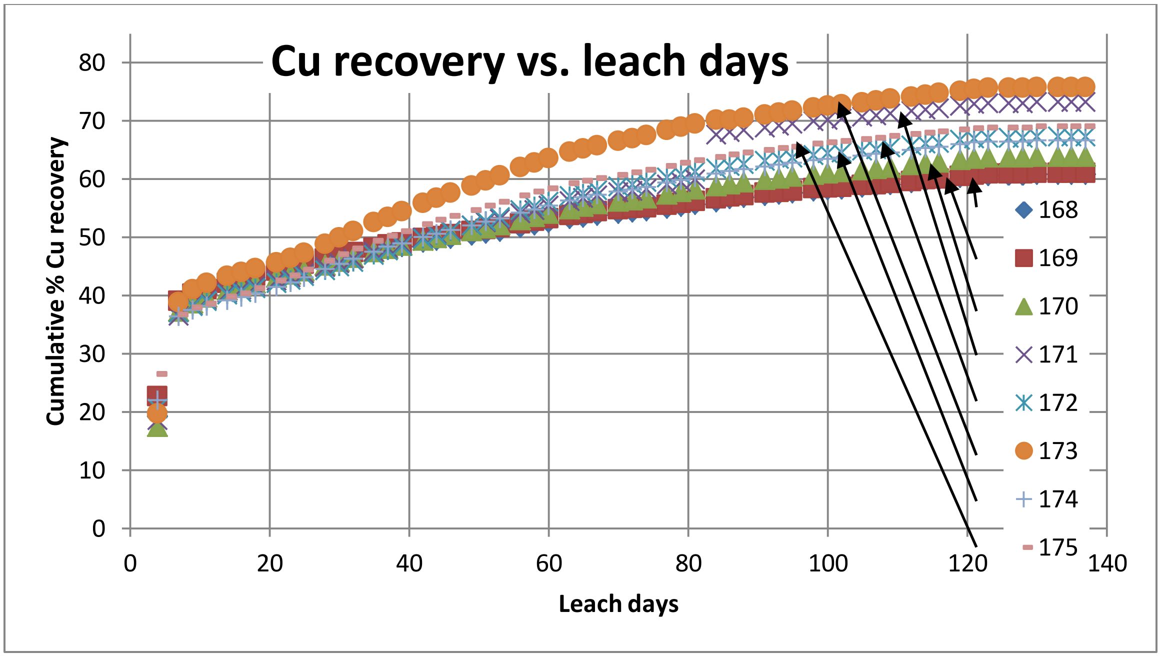

Figure 22: Columns 168-175 Copper Recovery

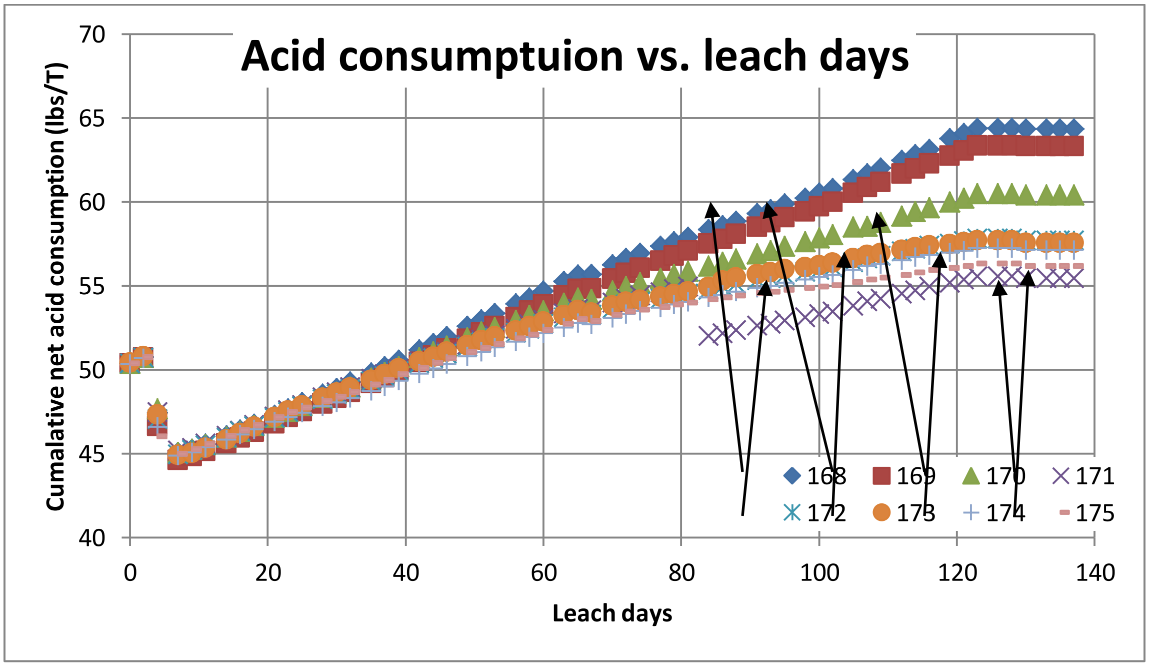

Figure 23: Columns 168-175 Acid Consumption

The column test results are depicted in Figures 22-24. The cumulative percentage of copper recovery reported was plotted against the number of days of leaching in Figure 22. The two control columns, 168-9 without any waste site sulfur, are shown to have the lowest copper recovery out of all the columns. The columns 173 is shown to have the highest percentage copper recovery throughout the test. This column contains 5 pounds of waste sulfur along with 1.63 g/day of nutrients added. The columns with waste site sulfur added appear to have a higher copper recovery than the columns without.

Figure 23 depicts a graph of cumulative acid consumption against the number of days of leaching. This graph shows the reverse of the results mentioned above where the control columns appear to consume the most acid.

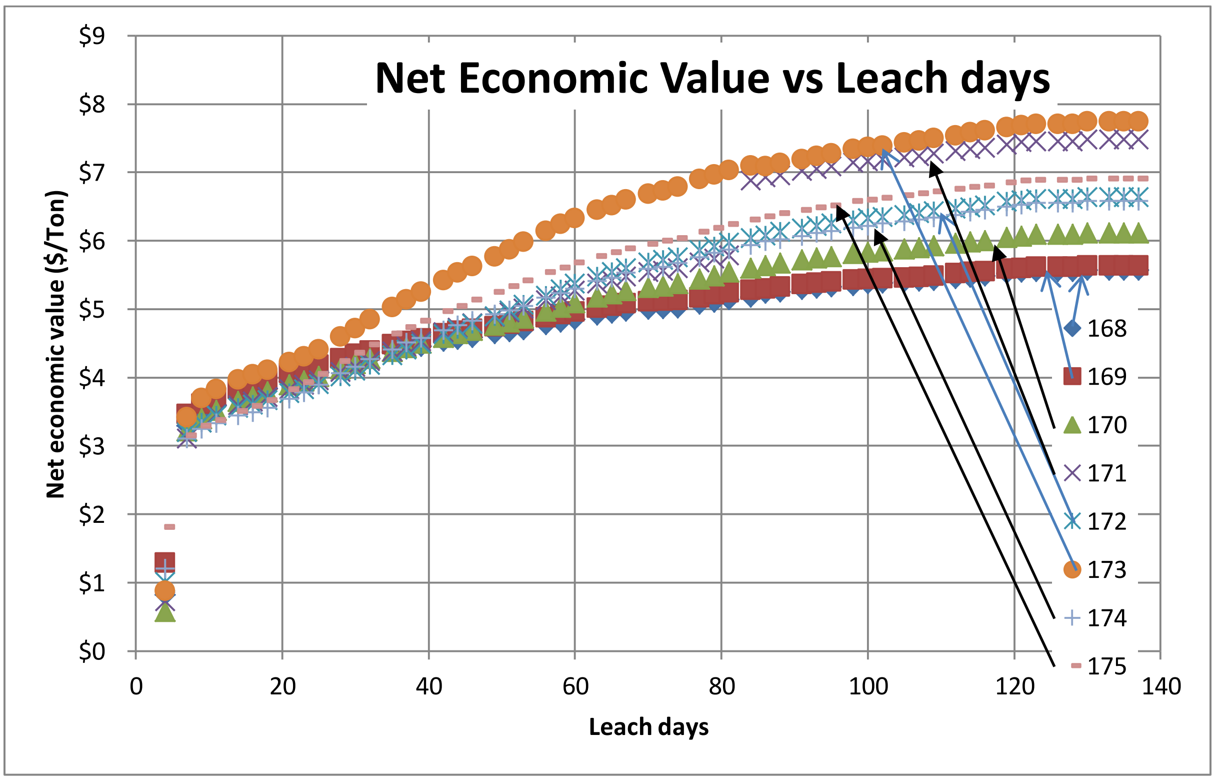

Figure 24: Columns 168-175 Net Economic Value

The last figure shows the net economic value which is the difference of copper recovered and acid consumed reported in price per ton of copper ore leached. This graph shows the same observation as reported for Figure 22.

CHAPTER V

CONCLUSION

The Inductively Coupled Plasma, X-ray Diffraction and hydrocarbon analysis identified sulfur as the major crystalline phase element in the sample with trace amounts of molybdenum, phosphorus, o-terphenyl and gasoline. The shake flask confirms that the sulfur sample does not affect the bacterial activity. The strains showed growth when compared under different conditions with the sample.

The column test compared the addition of sulfur under heap conditions. The columns showed higher copper recovery with lower acid consumption when the sulfur sample is added. This resulted in higher net economic value with an ultimate difference of up to $2/ton of copper ore processed when compared to the control column. This is rather large when considering a mining process which processes on average 40,000 tons of copper ore in a heap. This profit is additional to the savings from avoiding the EPA regulated disposal fees. When considering 10 barrels of waste sulfur disposed weekly, the annual cost adds up to over $150,000.

The experiments conducted in this test support the hypothesis that there are no detrimental effects from adding waste sulfur to the heap towards the production of copper through bioleaching. The results show a beneficial effect instead. Therefore, based on the studies performed a recommendation is made to add waste site sulfur to the heaps for bioleaching of copper.

REFERENCES CITED

(1) African mining brief. Accessed on August 16, 2011. http://www.ambriefonline.com/april_may11%20suppl2.html

(2) Beckman coulter. Accessed on August 16, 2011. https://www.beckmancoulter.com/wsrportal/wsr/industrial/products/coulter-counter-analyzers/multisizer-4/index.htm

(3) Copper Range Company: The story of man's oldest and newest metal. Boyd, James. The Newcomen society, New York. 1970

(4) Copper: The next fifteen years. A United Nations study. 1979. Gluschke, Wolfgang, Shaw, Joseph, Varon, Bension. D. Reidel Publishing Company. Holland.

(5) Extractive metallurgy of copper. Schlesinger, King, Sole and Davenport. 2011. 5th edition. Elsevier Ltd. Oxford, UK.

(6) Massachussets government. Accessed on March 22, 2012. http://www.mass.gov/dep/recycle/reduce/fac53c1.pdf

APPENDIX A

COLUMN 168 DATA SHEET FROM LABORATORY

SMALL COLUMN TEST DATA SHEET

Column I.D.:	EC-168	**Test:**	Comparison of waste sulfur effects	**QLT%:**	65%
Column Size:	6" x 5'	**Agglomeration:**	Yes	**Feed Assay (%Cu):**	0.54
Material Size:	As Received	**Cure:**	50 lbs/ton	**Calculated Feed (%Cu):**	
Raffinate:	Mine	**Target/Actual Appl. Rate:**	0.00250/0.00083 gpm/sqft	**Column Charge (lbs):**	75.8
Leach Cycle:	120	**Air Injection:**	No	**Contained Cu (gms):**	184.4

		RAFFINATE						PLS						
Date	Leach Days	Liters	gpl Cu	ORP	gpl H2SO4	gpl Total Fe	gpl Fe+++	Liters	pH	ORP	gpl Cu Gross	gpl H2SO4	gpl Total Fe	gpl Fe+++
26-Jul-11		1.20	0.02	509	716.3	0.38	0.38							
1-Aug-11	0													
3-Aug-11	2	1.78	0.04	526	3.60	0.64	0.64							
5-Aug-11	4	1.78	0.02	509	4.45	0.38	0.38	1.16	1.99	327	30.79	8.82	9.34	1.36
8-Aug-11	7	2.66	0.05	474	4.50	0.46	0.45	2.70	2.85	285	12.76	0.00	3.25	0.16
10-Aug-11	9	1.78	0.02	481	4.38	0.36	0.31	1.48	3.29	290	1.96	0.00	0.52	0.09
12-Aug-11	11	1.78	0.00	501	4.40	0.41	0.38	1.66	3.39	283	1.00	0.00	0.29	0.05
15-Aug-11	14	2.66	0.00	496	4.35	0.43	0.43	2.54	3.30	341	0.81	0.00	0.17	-0.03
17-Aug-11	16	1.78	0.03	429	4.39	0.45	0.34	1.55	3.33	329	0.69	0.00	0.22	0.03
19-Aug-11	18	1.78	0.01	504	4.43	0.39	0.38	1.70	3.33	336	0.69	0.00	0.20	0.05
22-Aug-11	21	2.66	0.05	492	4.43	0.41	0.39	2.45	3.20	354	0.75	0.00	0.01	-0.12
24-Aug-11	23	1.78	0.02	508	4.51	0.45	0.44	1.54	3.11	359	0.68	0.00	0.14	-0.01
26-Aug-11	25	1.78	0.03	447	4.43	0.45	0.38	1.69	3.14	378	0.69	0.00	0.22	0.14
29-Aug-11	28	2.66	0.03	504	4.21	0.40	0.38	2.41	3.14	392	0.72	0.00	0.25	0.20
31-Aug-11	30	1.78	0.03	488	4.19	0.40	0.38	1.49	3.12	429	0.73	0.00	0.33	0.30
2-Sep-11	32	1.78	0.01	512	4.48	0.39	0.37	1.52	3.08	425	0.66	0.00	0.20	0.19
5-Sep-11	35	2.66	0.05	507	4.45	0.41	0.37	2.45	3.12	468	0.68	0.00	0.20	0.20
7-Sep-11	37	1.78	0.02	510	4.45	0.37	0.37	1.54	3.09	475	0.63	0.00	0.29	0.29
9-Sep-11	39	1.78	0.05	498	4.49	0.43	0.42	1.62	3.08	476	0.52	0.00	0.27	0.27
12-Sep-11	42	2.66	0.01	498	4.48	0.38	0.37	2.45	3.02	482	0.54	0.00	0.27	0.27
14-Sep-11	44	1.78	0.04	439	4.46	0.43	0.35	1.62	3.04	454	0.48	0.00	0.39	0.39
16-Sep-11	46	1.78	0.01	498	4.49	0.41	0.40	1.65	2.94	497	0.40	0.00	0.29	0.29
19-Sep-11	49	2.66	0.05	497	4.49	0.37	0.36	2.49	2.99	502	0.43	0.00	0.36	0.36
21-Sep-11	51	1.78	0.03	455	4.46	0.39	0.34	1.63	2.97	509	0.46	0.00	0.44	0.44
23-Sep-11	53	1.78	0.06	512	4.37	0.37	0.35	1.53	2.93	512	0.49	0.11	0.50	0.50
26-Sep-11	56	2.66	0.06	515	4.41	0.38	0.38	2.52	2.94	519	0.54	0.13	0.54	0.54
28-Sep-11	58	1.78	0.01	518	4.44	0.39	0.38	1.51	2.90	469	0.52	0.23	0.50	0.50
30-Sep-11	60	1.78	0.02	515	4.56	0.36	0.36	1.56	2.88	512	0.53	0.00	0.58	0.58
3-Oct-11	63	2.66	0.02	510	4.54	0.41	0.41	2.47	2.91	518	0.47	0.31	0.49	0.49
5-Oct-11	65	1.78	0.02	523	4.57	0.36	0.36	1.51	2.90	490	0.41	0.28	0.48	0.48
7-Oct-11	67	1.78	0.02	515	0.88	0.37	0.37	1.63	2.95	435	0.36	0.00	0.50	0.50
10-Oct-11	70	2.66	0.04	515	4.59	0.42	0.41	2.51	2.91	529	0.31	0.42	0.43	0.43
12-Oct-11	72	1.78	0.10	521	3.97	0.64	0.64	1.69	2.89	525	0.30	0.37	0.58	0.57
14-Oct-11	74	1.78	0.11	516	3.75	0.64	0.63	1.61	2.85	526	0.31	0.43	0.62	0.62
17-Oct-11	77	2.66	0.07	518	3.81	0.68	0.67	2.45	2.82	520	0.44	0.68	0.77	0.77
19-Oct-11	79	1.78	0.08	502	3.86	0.63	0.61	1.50	2.83	511	0.53	0.55	0.74	0.74
21-Oct-11	81	1.78	0.10	507	3.80	0.61	0.58	1.63	2.80	510	0.50	0.75	0.69	0.69
24-Oct-11	84	2.66	0.11	506	3.88	0.61	0.61	2.48	2.75	521	0.43	0.61	0.77	0.77
26-Oct-11	86	1.78	0.07	502	3.77	0.64	0.62	2.38	2.80	524	0.43	0.61	0.86	0.86
28-Oct-11	88	1.78	0.10	499	3.69	0.71	0.69	1.59	2.79	519	0.41	0.57	0.73	0.73
31-Oct-11	91	2.66	0.10	447	3.71	0.76	0.69	2.55	2.73	518	0.36	0.58	0.69	0.69
2-Nov-11	93	1.78	0.07	494	3.62	0.60	0.58	1.62	2.70	515	0.35	0.79	0.73	0.73
4-Nov-11	95	1.78	0.08	492	3.83	0.60	0.58	1.66	2.74	510	0.34	0.44	0.68	0.68
7-Nov-11	98	2.66	0.08	506	3.42	0.67	0.67	2.55	2.77	507	0.32	0.74	0.73	0.73
9-Nov-11	100	1.78	0.12	503	3.77	0.65	0.65	1.61	2.72	511	0.33	0.79	0.71	0.71
11-Nov-11	102	1.78	0.10	501	3.75	0.64	0.62	1.58	2.70	511	0.28	0.86	0.64	0.64
14-Nov-11	105	2.66	0.11	397	4.69	0.83	0.58	2.90	2.68	506	0.29	0.94	0.71	0.71
16-Nov-11	107	1.78	0.10	397	4.72	0.81	0.52	1.57	2.65	507	0.32	1.02	0.76	0.76
18-Nov-11	109	1.78	0.11	396	4.34	0.89	0.59	1.75	2.71	506	0.35	0.92	0.88	0.88
21-Nov-11	112	2.66	0.11	397	4.46	0.85	0.57	2.54	2.63	505	0.37	1.06	0.81	0.81
23-Nov-11	114	1.78	0.09	403	4.52	0.77	0.66	1.62	2.65	502	0.38	1.10	0.74	0.74
25-Nov-11	116	1.78	0.11	396	4.53	0.75	0.50	1.78	2.62	505	0.33	0.97	0.76	0.76
28-Nov-11	119	2.66	0.09	396	4.42	0.72	0.52	3.07	2.64	506	0.33	0.00	0.52	0.52
30-Nov-11	121	1.78	0.10	398	4.36	0.55	0.42	1.75	2.59	504	0.32	1.03	1.03	1.03
2-Dec-11	123	1.78	0.11	402	4.30	1.10	1.03	1.68	2.59	501	0.33	0.98	0.96	0.96

APPENDIX B

SHAKE FLASKS DATA SHEET FROM LABORATORY

Date	Sample ID	pH
7/20/2011	Safford RMKM	2.01
7/20/2011	MKM	3.12
7/21/2011	ES-1	2.17
7/21/2011	ES-2	2.15
7/21/2011	ES-3	2.42
7/21/2011	ES-4	2.42
7/21/2011	SF-148	2.44
7/21/2011	SF-149	2.46
7/21/2011	SF-150	2.45
7/21/2011	SF-151	2.48
7/21/2011	SF-152	2.49
7/21/2011	SF-153	2.50
7/21/2011	SF-154	2.01
7/21/2011	SF-155	2.01
7/21/2011	SF-156	2.00
7/21/2011	SF-157	2.00
7/21/2011	SF-158	2.02
7/21/2011	SF-159	2.00
7/21/2011	SF-160	2.01
7/21/2011	SF-161	2.03
7/21/2011	SF-162	2.04
7/21/2011	SF-163	2.04
7/21/2011	SF-164	2.05
7/21/2011	SF-165	2.04
7/25/2011	ES-1	1.43
7/25/2011	ES-2	1.46
7/25/2011	ES-3	2.36
7/25/2011	ES-4	2.41
7/25/2011	SF-148	2.20
7/25/2011	SF-149	2.40
7/25/2011	SF-150	2.16
7/25/2011	SF-151	2.46
7/25/2011	SF-152	2.60
7/25/2011	SF-153	2.59
7/25/2011	SF-154	2.26
7/25/2011	SF-155	2.04
7/25/2011	SF-156	2.11
7/25/2011	SF-157	2.11
7/25/2011	SF-158	2.06
7/25/2011	SF-159	2.02
7/25/2011	SF-160	2.08
7/25/2011	SF-161	2.04
7/25/2011	SF-162	1.92
7/25/2011	SF-163	2.07
7/25/2011	SF-164	2.07
7/25/2011	SF-165	2.01
7/26/2011	ES-1	1.35
7/26/2011	ES-2	1.31
7/26/2011	ES-3	2.25

Date	Sample ID	ORP
7/20/2011	Safford RMKM	433
7/20/2011	MKM	412
7/21/2011	ES-1	395
7/21/2011	ES-2	404
7/21/2011	ES-3	383
7/21/2011	ES-4	388
7/21/2011	SF-148	379
7/21/2011	SF-149	367
7/21/2011	SF-150	374
7/21/2011	SF-151	359
7/21/2011	SF-152	350
7/21/2011	SF-153	356
7/21/2011	SF-154	426
7/21/2011	SF-155	426
7/21/2011	SF-156	426
7/21/2011	SF-157	426
7/21/2011	SF-158	426
7/21/2011	SF-159	426
7/21/2011	SF-160	426
7/21/2011	SF-161	426
7/21/2011	SF-162	426
7/21/2011	SF-163	425
7/21/2011	SF-164	425
7/21/2011	SF-165	426
7/25/2011	ES-1	374
7/25/2011	ES-2	405
7/25/2011	ES-3	374
7/25/2011	ES-4	368
7/25/2011	SF-148	354
7/25/2011	SF-149	324
7/25/2011	SF-150	312
7/25/2011	SF-151	382
7/25/2011	SF-152	373
7/25/2011	SF-153	349
7/25/2011	SF-154	392
7/25/2011	SF-155	412
7/25/2011	SF-156	412
7/25/2011	SF-157	418
7/25/2011	SF-158	416
7/25/2011	SF-159	418
7/25/2011	SF-160	408
7/25/2011	SF-161	414
7/25/2011	SF-162	412
7/25/2011	SF-163	419
7/25/2011	SF-164	418
7/25/2011	SF-165	418
7/26/2011	ES-1	336
7/26/2011	ES-2	397
7/26/2011	ES-3	389

Date	Sample ID	Bac Count
7/20/2011	Safford RMKM	2.87E+06
7/20/2011	MKM	3.72E+05
7/21/2011	ES-1	5.31E+07
7/21/2011	ES-2	3.98E+07
7/21/2011	ES-3	1.69E+07
7/21/2011	ES-4	1.56E+07
7/21/2011	SF-148	1.53E+06
7/21/2011	SF-149	1.57E+06
7/21/2011	SF-150	1.09E+06
7/21/2011	SF-151	1.61E+06
7/21/2011	SF-152	6.11E+05
7/21/2011	SF-153	7.76E+05
7/21/2011	SF-154	2.32E+06
7/21/2011	SF-155	1.91E+06
7/21/2011	SF-156	2.19E+06
7/21/2011	SF-157	7.98E+05
7/21/2011	SF-158	7.16E+05
7/21/2011	SF-159	1.16E+06
7/21/2011	SF-160	2.53E+06
7/21/2011	SF-161	1.78E+06
7/21/2011	SF-162	2.93E+06
7/21/2011	SF-163	1.61E+06
7/21/2011	SF-164	9.17E+05
7/21/2011	SF-165	1.42E+06
7/25/2011	ES-1	1.02E+09
7/25/2011	ES-2	1.32E+09
7/25/2011	ES-3	1.37E+07
7/25/2011	ES-4	1.99E+07
7/25/2011	SF-148	3.26E+06
7/25/2011	SF-149	3.87E+06
7/25/2011	SF-150	1.03E+07
7/25/2011	SF-151	1.21E+06
7/25/2011	SF-152	9.36E+05
7/25/2011	SF-153	1.15E+06
7/25/2011	SF-154	6.64E+06
7/25/2011	SF-155	9.08E+06
7/25/2011	SF-156	5.55E+06
7/25/2011	SF-157	1.81E+06
7/25/2011	SF-158	1.21E+06
7/25/2011	SF-159	1.64E+06
7/25/2011	SF-160	7.78E+06
7/25/2011	SF-161	4.44E+06
7/25/2011	SF-162	3.98E+07
7/25/2011	SF-163	1.59E+06
7/25/2011	SF-164	8.70E+05
7/25/2011	SF-165	1.39E+06
7/26/2011	ES-1	5.86E+08
7/26/2011	ES-2	6.01E+08
7/26/2011	ES-3	4.56E+06

Sample ID	Tare Weight (g)	Final Weight (g)
SF-148	2.29	11.23
SF-149	2.39	11.66
SF-150	2.32	11.25
SF-151	2.47	10.80
SF-152	2.41	11.82
SF-153	2.28	11.01
SF-154	2.42	11.91
SF-155	2.32	13.92
SF-156	2.34	12.40
SF-157	2.42	12.82
SF-158	2.48	12.24
SF-159	2.33	12.27
SF-160	2.38	12.72
SF-161	2.34	13.13
SF-162	2.32	12.51
SF-163	2.43	12.64
SF-164	2.43	12.09
SF-165	2.35	13.10

7/26/2011	ES-4	2.36
7/26/2011	SF-148	1.85
7/26/2011	SF-149	2.26
7/26/2011	SF-150	2.02
7/26/2011	SF-151	2.48
7/26/2011	SF-152	2.56
7/26/2011	SF-153	2.54
7/26/2011	SF-154	2.13
7/26/2011	SF-155	2.14
7/26/2011	SF-156	2.07
7/26/2011	SF-157	2.13
7/26/2011	SF-158	2.02
7/26/2011	SF-159	2.00
7/26/2011	SF-160	2.08
7/26/2011	SF-161	2.07
7/26/2011	SF-162	1.85
7/26/2011	SF-163	2.10
7/26/2011	SF-164	2.07
7/26/2011	SF-165	2.00
7/27/2011	ES-1	1.12
7/27/2011	ES-2	1.09
7/27/2011	ES-3	2.45
7/27/2011	ES-4	2.47
7/27/2011	SF-148	1.74
7/27/2011	SF-149	2.20
7/27/2011	SF-150	1.78
7/27/2011	SF-151	2.52
7/27/2011	SF-152	2.57
7/27/2011	SF-153	2.54
7/27/2011	SF-154	2.05
7/27/2011	SF-155	2.03
7/27/2011	SF-156	1.95
7/27/2011	SF-157	1.90
7/27/2011	SF-158	1.82
7/27/2011	SF-159	1.79
7/27/2011	SF-160	2.00
7/27/2011	SF-161	1.98
7/27/2011	SF-162	1.65
7/27/2011	SF-163	1.91
7/27/2011	SF-164	1.88
7/27/2011	SF-165	1.80
7/28/2011	ES-1	1.16
7/28/2011	ES-2	1.20
7/28/2011	ES-3	2.25
7/28/2011	ES-4	2.36
7/28/2011	SF-148	1.56
7/28/2011	SF-149	2.19
7/28/2011	SF-150	1.82
7/28/2011	SF-151	2.50
7/28/2011	SF-152	2.53
7/28/2011	SF-153	2.52
7/28/2011	SF-154	1.99
7/28/2011	SF-155	2.03
7/28/2011	SF-156	1.98
7/28/2011	SF-157	1.86
7/28/2011	SF-158	1.73
7/28/2011	SF-159	1.71
7/28/2011	SF-160	1.95
7/28/2011	SF-161	1.91
7/28/2011	SF-162	1.55
7/28/2011	SF-163	1.81
7/28/2011	SF-164	1.79
7/28/2011	SF-165	1.72
7/29/2011	ES-1	0.94
7/29/2011	ES-2	0.96
7/29/2011	ES-3	2.12
7/29/2011	ES-4	2.20
7/29/2011	SF-148	1.23
7/29/2011	SF-149	2.01
7/29/2011	SF-150	1.33

7/26/2011	ES-4	370
7/26/2011	SF-148	334
7/26/2011	SF-149	347
7/26/2011	SF-150	338
7/26/2011	SF-151	347
7/26/2011	SF-152	350
7/26/2011	SF-153	355
7/26/2011	SF-154	418
7/26/2011	SF-155	416
7/26/2011	SF-156	415
7/26/2011	SF-157	420
7/26/2011	SF-158	417
7/26/2011	SF-159	418
7/26/2011	SF-160	415
7/26/2011	SF-161	413
7/26/2011	SF-162	413
7/26/2011	SF-163	421
7/26/2011	SF-164	421
7/26/2011	SF-165	419
7/27/2011	ES-1	341
7/27/2011	ES-2	395
7/27/2011	ES-3	367
7/27/2011	ES-4	362
7/27/2011	SF-148	332
7/27/2011	SF-149	353
7/27/2011	SF-150	348
7/27/2011	SF-151	343
7/27/2011	SF-152	348
7/27/2011	SF-153	351
7/27/2011	SF-154	420
7/27/2011	SF-155	420
7/27/2011	SF-156	422
7/27/2011	SF-157	420
7/27/2011	SF-158	414
7/27/2011	SF-159	415
7/27/2011	SF-160	422
7/27/2011	SF-161	417
7/27/2011	SF-162	411
7/27/2011	SF-163	422
7/27/2011	SF-164	420
7/27/2011	SF-165	418
7/28/2011	ES-1	411
7/28/2011	ES-2	379
7/28/2011	ES-3	412
7/28/2011	ES-4	375
7/28/2011	SF-148	345
7/28/2011	SF-149	353
7/28/2011	SF-150	350
7/28/2011	SF-151	346
7/28/2011	SF-152	350
7/28/2011	SF-153	367
7/28/2011	SF-154	422
7/28/2011	SF-155	421
7/28/2011	SF-156	422
7/28/2011	SF-157	422
7/28/2011	SF-158	416
7/28/2011	SF-159	418
7/28/2011	SF-160	424
7/28/2011	SF-161	419
7/28/2011	SF-162	416
7/28/2011	SF-163	425
7/28/2011	SF-164	422
7/28/2011	SF-165	421
7/29/2011	ES-1	380
7/29/2011	ES-2	375
7/29/2011	ES-3	384
7/29/2011	ES-4	384
7/29/2011	SF-148	346
7/29/2011	SF-149	356
7/29/2011	SF-150	356

7/26/2011	ES-4	7.81E+06
7/26/2011	SF-148	6.54E+06
7/26/2011	SF-149	1.55E+06
7/26/2011	SF-150	1.88E+07
7/26/2011	SF-151	9.90E+05
7/26/2011	SF-152	1.09E+06
7/26/2011	SF-153	7.36E+05
7/26/2011	SF-154	2.74E+06
7/26/2011	SF-155	3.04E+06
7/26/2011	SF-156	1.67E+06
7/26/2011	SF-157	7.88E+05
7/26/2011	SF-158	8.70E+05
7/26/2011	SF-159	7.82E+05
7/26/2011	SF-160	2.59E+06
7/26/2011	SF-161	1.62E+06
7/26/2011	SF-162	7.48E+07
7/26/2011	SF-163	1.19E+06
7/26/2011	SF-164	2.12E+06
7/26/2011	SF-165	1.74E+06
7/27/2011	ES-1	4.71E+08
7/27/2011	ES-2	4.18E+08
7/27/2011	ES-3	1.05E+07
7/27/2011	ES-4	8.13E+06
7/27/2011	SF-148	4.59E+07
7/27/2011	SF-149	1.77E+06
7/27/2011	SF-150	7.09E+07
7/27/2011	SF-151	1.67E+06
7/27/2011	SF-152	6.27E+05
7/27/2011	SF-153	7.48E+05
7/27/2011	SF-154	2.55E+06
7/27/2011	SF-155	2.64E+06
7/27/2011	SF-156	2.72E+06
7/27/2011	SF-157	1.17E+06
7/27/2011	SF-158	2.27E+06
7/27/2011	SF-159	2.32E+06
7/27/2011	SF-160	3.88E+06
7/27/2011	SF-161	3.45E+06
7/27/2011	SF-162	1.34E+08
7/27/2011	SF-163	1.86E+06
7/27/2011	SF-164	3.78E+06
7/27/2011	SF-165	6.87E+06
7/28/2011	ES-1	5.90E+08
7/28/2011	ES-2	7.52E+08
7/28/2011	ES-3	5.52E+06
7/28/2011	ES-4	7.24E+06
7/28/2011	SF-148	1.63E+08
7/28/2011	SF-149	2.07E+06
7/28/2011	SF-150	1.27E+08
7/28/2011	SF-151	1.93E+06
7/28/2011	SF-152	1.29E+06
7/28/2011	SF-153	1.81E+06
7/28/2011	SF-154	2.44E+06
7/28/2011	SF-155	3.11E+06
7/28/2011	SF-156	3.03E+06
7/28/2011	SF-157	1.24E+06
7/28/2011	SF-158	7.60E+06
7/28/2011	SF-159	2.85E+06
7/28/2011	SF-160	2.60E+06
7/28/2011	SF-161	1.35E+06
7/28/2011	SF-162	2.01E+08
7/28/2011	SF-163	1.78E+06
7/28/2011	SF-164	5.95E+06
7/28/2011	SF-165	7.14E+06
7/29/2011	ES-1	6.90E+08
7/29/2011	ES-2	7.47E+08
7/29/2011	ES-3	7.78E+06
7/29/2011	ES-4	7.18E+06
7/29/2011	SF-148	2.84E+08
7/29/2011	SF-149	3.38E+06
7/29/2011	SF-150	2.19E+08

7/29/2011	ES-1	0.94
7/29/2011	ES-2	0.96
7/29/2011	ES-3	2.12
7/29/2011	ES-4	2.20
7/29/2011	SF-148	1.23
7/29/2011	SF-149	2.01
7/29/2011	SF-150	1.33
7/29/2011	SF-151	2.31
7/29/2011	SF-152	2.37
7/29/2011	SF-153	2.38
7/29/2011	SF-154	1.81
7/29/2011	SF-155	1.86
7/29/2011	SF-156	1.77
7/29/2011	SF-157	1.54
7/29/2011	SF-158	1.45
7/29/2011	SF-159	1.45
7/29/2011	SF-160	1.77
7/29/2011	SF-161	1.73
7/29/2011	SF-162	1.26
7/29/2011	SF-163	1.56
7/29/2011	SF-164	1.52
7/29/2011	SF-165	1.45
8/1/2011	ES-1	0.98
8/1/2011	ES-2	1.00
8/1/2011	ES-3	2.14
8/1/2011	ES-4	2.25
8/1/2011	SF-148	0.93
8/1/2011	SF-149	1.82
8/1/2011	SF-150	1.04
8/1/2011	SF-151	2.13
8/1/2011	SF-152	2.38
8/1/2011	SF-153	2.39
8/1/2011	SF-154	1.85
8/1/2011	SF-155	1.87
8/1/2011	SF-156	1.68
8/1/2011	SF-157	1.42
8/1/2011	SF-158	1.31
8/1/2011	SF-159	1.33
8/1/2011	SF-160	1.78
8/1/2011	SF-161	1.60
8/1/2011	SF-162	1.12
8/1/2011	SF-163	1.38
8/1/2011	SF-164	1.30
8/1/2011	SF-165	1.27
8/2/2011	ES-1	0.68
8/2/2011	ES-2	0.69
8/2/2011	ES-3	1.97
8/2/2011	ES-4	2.09
8/2/2011	SF-148	0.74
8/2/2011	SF-149	1.76
8/2/2011	SF-150	0.79
8/2/2011	SF-151	2.15
8/2/2011	SF-152	2.23
8/2/2011	SF-153	2.24
8/2/2011	SF-154	1.66
8/2/2011	SF-155	1.74
8/2/2011	SF-156	1.44
8/2/2011	SF-157	1.24
8/2/2011	SF-158	1.17
8/2/2011	SF-159	1.16
8/2/2011	SF-160	1.65
8/2/2011	SF-161	1.39
8/2/2011	SF-162	0.91
8/2/2011	SF-163	1.18
8/2/2011	SF-164	1.06
8/2/2011	SF-165	1.02
8/3/2011	ES-1	0.73
8/3/2011	ES-2	0.74
8/3/2011	ES-3	2.11
8/3/2011	ES-4	2.20

7/29/2011	ES-1	380
7/29/2011	ES-2	375
7/29/2011	ES-3	384
7/29/2011	ES-4	384
7/29/2011	SF-148	346
7/29/2011	SF-149	356
7/29/2011	SF-150	356
7/29/2011	SF-151	354
7/29/2011	SF-152	353
7/29/2011	SF-153	355
7/29/2011	SF-154	423
7/29/2011	SF-155	422
7/29/2011	SF-156	424
7/29/2011	SF-157	421
7/29/2011	SF-158	414
7/29/2011	SF-159	416
7/29/2011	SF-160	425
7/29/2011	SF-161	417
7/29/2011	SF-162	415
7/29/2011	SF-163	421
7/29/2011	SF-164	419
7/29/2011	SF-165	419
8/1/2011	ES-1	343
8/1/2011	ES-2	350
8/1/2011	ES-3	378
8/1/2011	ES-4	366
8/1/2011	SF-148	307
8/1/2011	SF-149	383
8/1/2011	SF-150	333
8/1/2011	SF-151	378
8/1/2011	SF-152	356
8/1/2011	SF-153	358
8/1/2011	SF-154	422
8/1/2011	SF-155	421
8/1/2011	SF-156	416
8/1/2011	SF-157	406
8/1/2011	SF-158	400
8/1/2011	SF-159	405
8/1/2011	SF-160	424
8/1/2011	SF-161	408
8/1/2011	SF-162	402
8/1/2011	SF-163	409
8/1/2011	SF-164	407
8/1/2011	SF-165	402
8/2/2011	ES-1	346
8/2/2011	ES-2	356
8/2/2011	ES-3	385
8/2/2011	ES-4	367
8/2/2011	SF-148	296
8/2/2011	SF-149	370
8/2/2011	SF-150	332
8/2/2011	SF-151	365
8/2/2011	SF-152	358
8/2/2011	SF-153	361
8/2/2011	SF-154	424
8/2/2011	SF-155	421
8/2/2011	SF-156	412
8/2/2011	SF-157	403
8/2/2011	SF-158	396
8/2/2011	SF-159	400
8/2/2011	SF-160	423
8/2/2011	SF-161	403
8/2/2011	SF-162	401
8/2/2011	SF-163	408
8/2/2011	SF-164	408
8/2/2011	SF-165	399
8/3/2011	ES-1	343
8/3/2011	ES-2	354
8/3/2011	ES-3	371
8/3/2011	ES-4	365

7/29/2011	ES-1	6.90E+08
7/29/2011	ES-2	7.47E+08
7/29/2011	ES-3	7.78E+06
7/29/2011	ES-4	7.18E+06
7/29/2011	SF-148	2.84E+08
7/29/2011	SF-149	3.38E+06
7/29/2011	SF-150	2.19E+08
7/29/2011	SF-151	2.65E+06
7/29/2011	SF-152	2.05E+06
7/29/2011	SF-153	1.71E+06
7/29/2011	SF-154	2.81E+06
7/29/2011	SF-155	3.37E+06
7/29/2011	SF-156	2.30E+06
7/29/2011	SF-157	1.86E+06
7/29/2011	SF-158	9.33E+06
7/29/2011	SF-159	6.23E+06
7/29/2011	SF-160	2.91E+06
7/29/2011	SF-161	1.57E+06
7/29/2011	SF-162	2.38E+08
7/29/2011	SF-163	1.86E+06
7/29/2011	SF-164	8.02E+06
7/29/2011	SF-165	9.30E+06
8/1/2011	ES-1	8.97E+08
8/1/2011	ES-2	9.95E+08
8/1/2011	ES-3	4.98E+06
8/1/2011	ES-4	5.13E+06
8/1/2011	SF-148	6.07E+08
8/1/2011	SF-149	3.05E+06
8/1/2011	SF-150	5.38E+08
8/1/2011	SF-151	3.39E+06
8/1/2011	SF-152	2.21E+06
8/1/2011	SF-153	2.39E+06
8/1/2011	SF-154	3.31E+06
8/1/2011	SF-155	2.78E+06
8/1/2011	SF-156	2.84E+06
8/1/2011	SF-157	4.88E+06
8/1/2011	SF-158	8.93E+06
8/1/2011	SF-159	9.73E+06
8/1/2011	SF-160	2.35E+06
8/1/2011	SF-161	1.34E+06
8/1/2011	SF-162	1.91E+08
8/1/2011	SF-163	6.76E+06
8/1/2011	SF-164	2.03E+07
8/1/2011	SF-165	1.82E+07
8/2/2011	ES-1	9.38E+08
8/2/2011	ES-2	9.66E+08
8/2/2011	ES-3	4.41E+06
8/2/2011	ES-4	5.98E+06
8/2/2011	SF-148	6.91E+08
8/2/2011	SF-149	3.78E+06
8/2/2011	SF-150	6.56E+08
8/2/2011	SF-151	3.66E+06
8/2/2011	SF-152	8.84E+05
8/2/2011	SF-153	8.32E+05
8/2/2011	SF-154	2.19E+06
8/2/2011	SF-155	2.18E+06
8/2/2011	SF-156	3.79E+06
8/2/2011	SF-157	6.44E+06
8/2/2011	SF-158	1.17E+07
8/2/2011	SF-159	2.09E+07
8/2/2011	SF-160	2.43E+06
8/2/2011	SF-161	1.60E+06
8/2/2011	SF-162	2.27E+08
8/2/2011	SF-163	7.93E+06
8/2/2011	SF-164	2.57E+07
8/2/2011	SF-165	2.59E+07
8/3/2011	ES-1	9.14E+08
8/3/2011	ES-2	1.04E+09
8/3/2011	ES-3	4.85E+06
8/3/2011	ES-4	4.74E+06

8/2/2011	SF-163	1.18
8/2/2011	SF-164	1.06
8/2/2011	SF-165	1.02
8/3/2011	ES-1	0.73
8/3/2011	ES-2	0.74
8/3/2011	ES-3	2.11
8/3/2011	ES-4	2.20
8/3/2011	SF-148	0.81
8/3/2011	SF-149	1.73
8/3/2011	SF-150	0.81
8/3/2011	SF-151	2.21
8/3/2011	SF-152	2.29
8/3/2011	SF-153	2.32
8/3/2011	SF-154	1.76
8/3/2011	SF-155	1.82
8/3/2011	SF-156	1.47
8/3/2011	SF-157	1.30
8/3/2011	SF-158	1.24
8/3/2011	SF-159	1.15
8/3/2011	SF-160	1.74
8/3/2011	SF-161	1.41
8/3/2011	SF-162	1.00
8/3/2011	SF-163	1.23
8/3/2011	SF-164	1.11
8/3/2011	SF-165	1.09
8/4/2011	ES-1	0.85
8/4/2011	ES-2	0.86
8/4/2011	ES-3	1.97
8/4/2011	ES-4	2.13
8/4/2011	SF-148	0.93
8/4/2011	SF-149	1.76
8/4/2011	SF-150	0.97
8/4/2011	SF-151	2.12
8/4/2011	SF-152	2.27
8/4/2011	SF-153	2.34
8/4/2011	SF-154	1.87
8/4/2011	SF-155	1.95
8/4/2011	SF-156	1.51
8/4/2011	SF-157	1.38
8/4/2011	SF-158	1.29
8/4/2011	SF-159	1.23
8/4/2011	SF-160	1.86
8/4/2011	SF-161	1.47
8/4/2011	SF-162	1.15
8/4/2011	SF-163	1.34
8/4/2011	SF-164	1.22
8/4/2011	SF-165	1.21
8/8/2011	ES-1	0.80
8/8/2011	ES-2	0.72
8/8/2011	ES-3	2.02
8/8/2011	ES-4	2.14
8/8/2011	SF-148	0.63
8/8/2011	SF-149	1.49
8/8/2011	SF-150	0.66
8/8/2011	SF-151	2.04
8/8/2011	SF-152	2.18
8/8/2011	SF-153	2.36
8/8/2011	SF-154	1.78
8/8/2011	SF-155	1.86
8/8/2011	SF-156	1.26
8/8/2011	SF-157	0.94
8/8/2011	SF-158	0.91
8/8/2011	SF-159	0.90
8/8/2011	SF-160	1.68
8/8/2011	SF-161	1.05
8/8/2011	SF-162	0.95
8/8/2011	SF-163	0.97
8/8/2011	SF-164	0.89
8/8/2011	SF-165	0.88
8/9/2011	ES-1	0.70

8/2/2011	SF-163	408
8/2/2011	SF-164	408
8/2/2011	SF-165	399
8/3/2011	ES-1	343
8/3/2011	ES-2	354
8/3/2011	ES-3	371
8/3/2011	ES-4	365
8/3/2011	SF-148	304
8/3/2011	SF-149	377
8/3/2011	SF-150	323
8/3/2011	SF-151	370
8/3/2011	SF-152	361
8/3/2011	SF-153	368
8/3/2011	SF-154	425
8/3/2011	SF-155	423
8/3/2011	SF-156	409
8/3/2011	SF-157	403
8/3/2011	SF-158	396
8/3/2011	SF-159	396
8/3/2011	SF-160	425
8/3/2011	SF-161	397
8/3/2011	SF-162	400
8/3/2011	SF-163	407
8/3/2011	SF-164	409
8/3/2011	SF-165	394
8/4/2011	ES-1	340
8/4/2011	ES-2	348
8/4/2011	ES-3	370
8/4/2011	ES-4	374
8/4/2011	SF-148	298
8/4/2011	SF-149	381
8/4/2011	SF-150	313
8/4/2011	SF-151	383
8/4/2011	SF-152	369
8/4/2011	SF-153	371
8/4/2011	SF-154	426
8/4/2011	SF-155	423
8/4/2011	SF-156	404
8/4/2011	SF-157	402
8/4/2011	SF-158	397
8/4/2011	SF-159	389
8/4/2011	SF-160	425
8/4/2011	SF-161	391
8/4/2011	SF-162	397
8/4/2011	SF-163	404
8/4/2011	SF-164	407
8/4/2011	SF-165	391
8/8/2011	ES-1	323
8/8/2011	ES-2	323
8/8/2011	ES-3	359
8/8/2011	ES-4	358
8/8/2011	SF-148	292
8/8/2011	SF-149	392
8/8/2011	SF-150	290
8/8/2011	SF-151	388
8/8/2011	SF-152	375
8/8/2011	SF-153	366
8/8/2011	SF-154	424
8/8/2011	SF-155	423
8/8/2011	SF-156	388
8/8/2011	SF-157	382
8/8/2011	SF-158	393
8/8/2011	SF-159	316
8/8/2011	SF-160	426
8/8/2011	SF-161	360
8/8/2011	SF-162	380
8/8/2011	SF-163	367
8/8/2011	SF-164	393
8/8/2011	SF-165	312
8/9/2011	ES-1	340

8/2/2011	SF-163	7.93E+06
8/2/2011	SF-164	2.57E+07
8/2/2011	SF-165	2.59E+07
8/3/2011	ES-1	9.14E+08
8/3/2011	ES-2	1.04E+09
8/3/2011	ES-3	4.85E+06
8/3/2011	ES-4	4.74E+06
8/3/2011	SF-148	7.26E+08
8/3/2011	SF-149	2.86E+06
8/3/2011	SF-150	6.85E+08
8/3/2011	SF-151	2.33E+06
8/3/2011	SF-152	1.57E+06
8/3/2011	SF-153	1.05E+06
8/3/2011	SF-154	1.90E+06
8/3/2011	SF-155	2.55E+06
8/3/2011	SF-156	6.58E+06
8/3/2011	SF-157	9.09E+06
8/3/2011	SF-158	1.58E+07
8/3/2011	SF-159	1.94E+07
8/3/2011	SF-160	1.86E+06
8/3/2011	SF-161	1.58E+06
8/3/2011	SF-162	1.94E+08
8/3/2011	SF-163	9.71E+06
8/3/2011	SF-164	3.68E+07
8/3/2011	SF-165	4.78E+07
8/4/2011	ES-1	9.51E+08
8/4/2011	ES-2	1.03E+09
8/4/2011	ES-3	6.06E+06
8/4/2011	ES-4	5.11E+06
8/4/2011	SF-148	8.06E+08
8/4/2011	SF-149	2.64E+06
8/4/2011	SF-150	7.72E+08
8/4/2011	SF-151	2.21E+06
8/4/2011	SF-152	2.02E+06
8/4/2011	SF-153	1.88E+06
8/4/2011	SF-154	2.65E+06
8/4/2011	SF-155	3.50E+06
8/4/2011	SF-156	1.20E+07
8/4/2011	SF-157	1.20E+07
8/4/2011	SF-158	3.39E+07
8/4/2011	SF-159	6.09E+07
8/4/2011	SF-160	1.37E+06
8/4/2011	SF-161	3.73E+06
8/4/2011	SF-162	2.71E+08
8/4/2011	SF-163	1.45E+07
8/4/2011	SF-164	9.26E+07
8/4/2011	SF-165	9.24E+07
8/8/2011	ES-1	1.08E+09
8/8/2011	ES-2	1.16E+09
8/8/2011	ES-3	6.18E+06
8/8/2011	ES-4	6.41E+06
8/8/2011	SF-148	9.14E+08
8/8/2011	SF-149	5.40E+06
8/8/2011	SF-150	8.80E+08
8/8/2011	SF-151	2.69E+06
8/8/2011	SF-152	2.48E+06
8/8/2011	SF-153	2.07E+06
8/8/2011	SF-154	3.08E+06
8/8/2011	SF-155	3.84E+06
8/8/2011	SF-156	9.00E+06
8/8/2011	SF-157	9.82E+07
8/8/2011	SF-158	2.69E+08
8/8/2011	SF-159	9.48E+07
8/8/2011	SF-160	4.97E+06
8/8/2011	SF-161	9.39E+07
8/8/2011	SF-162	3.53E+08
8/8/2011	SF-163	7.61E+07
8/8/2011	SF-164	2.79E+08
8/8/2011	SF-165	1.01E+08
8/9/2011	ES-1	1.04E+09

8/8/2011	SF-160	1.68
8/8/2011	SF-161	1.05
8/8/2011	SF-162	0.95
8/8/2011	SF-163	0.97
8/8/2011	SF-164	0.89
8/8/2011	SF-165	0.88
8/9/2011	ES-1	0.70
8/9/2011	ES-2	0.66
8/9/2011	ES-3	1.77
8/9/2011	ES-4	2.01
8/9/2011	SF-148	0.58
8/9/2011	SF-149	1.50
8/9/2011	SF-150	0.65
8/9/2011	SF-151	1.81
8/9/2011	SF-152	2.03
8/9/2011	SF-153	2.14
8/9/2011	SF-154	1.67
8/9/2011	SF-155	1.80
8/9/2011	SF-156	1.22
8/9/2011	SF-157	0.93
8/9/2011	SF-158	0.91
8/9/2011	SF-159	0.89
8/9/2011	SF-160	1.67
8/9/2011	SF-161	1.00
8/9/2011	SF-162	0.91
8/9/2011	SF-163	0.91
8/9/2011	SF-164	0.78
8/9/2011	SF-165	0.86

8/8/2011	SF-160	426
8/8/2011	SF-161	360
8/8/2011	SF-162	380
8/8/2011	SF-163	367
8/8/2011	SF-164	393
8/8/2011	SF-165	312
8/9/2011	ES-1	340
8/9/2011	ES-2	361
8/9/2011	ES-3	383
8/9/2011	ES-4	370
8/9/2011	SF-148	306
8/9/2011	SF-149	379
8/9/2011	SF-150	309
8/9/2011	SF-151	401
8/9/2011	SF-152	384
8/9/2011	SF-153	382
8/9/2011	SF-154	430
8/9/2011	SF-155	425
8/9/2011	SF-156	387
8/9/2011	SF-157	380
8/9/2011	SF-158	392
8/9/2011	SF-159	366
8/9/2011	SF-160	425
8/9/2011	SF-161	361
8/9/2011	SF-162	381
8/9/2011	SF-163	373
8/9/2011	SF-164	390
8/9/2011	SF-165	367

8/8/2011	SF-160	4.97E+06
8/8/2011	SF-161	9.39E+07
8/8/2011	SF-162	3.53E+08
8/8/2011	SF-163	7.61E+07
8/8/2011	SF-164	2.79E+08
8/8/2011	SF-165	1.01E+08
8/9/2011	ES-1	1.04E+09
8/9/2011	ES-2	1.08E+09
8/9/2011	ES-3	3.29E+06
8/9/2011	ES-4	5.07E+06
8/9/2011	SF-148	8.75E+08
8/9/2011	SF-149	2.37E+06
8/9/2011	SF-150	9.72E+08
8/9/2011	SF-151	2.70E+06
8/9/2011	SF-152	1.39E+06
8/9/2011	SF-153	2.05E+06
8/9/2011	SF-154	1.84E+06
8/9/2011	SF-155	2.94E+06
8/9/2011	SF-156	1.66E+07
8/9/2011	SF-157	1.48E+08
8/9/2011	SF-158	3.00E+08
8/9/2011	SF-159	2.38E+08
8/9/2011	SF-160	5.05E+06
8/9/2011	SF-161	1.38E+08
8/9/2011	SF-162	3.92E+08
8/9/2011	SF-163	1.49E+08
8/9/2011	SF-164	2.94E+08
8/9/2011	SF-165	2.19E+08

VITA

Jibin George was born in Abu Dhabi, UAE, to the parents of Payattuvilayil and Jayamani George. He is the youngest of three children, an older sister and brother. He attended school in Abu Dhabi till the third grade and then moved to India with his family where he attended St. Mary's Residential School in Pathanapuram, Kerala. He immigrated with his family to Chattanooga, TN and continued his high school education at Ooltewah High School in Ooltewah, TN. After graduation, he attended the University of Tennessee at Chattanooga for a Bachelor's of Science degree in chemistry with a minor in biology. He returned to the same university to complete a Master's of Science degree in Chemical Engineering. Jibin worked for a mining company as an intern for a year where he was able to work on various projects that introduced him to the industry. He was able to use his biology background to investigate bacterial activity in copper mining. Jibin is currently reviewing a few job opportunities in the mining and petroleum industries.