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MAGNETICALLY ENHANCED HYDROSEPARATOR STUDY

by

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MAGNETICALLY ENHANCED HYDROSEPARATOR STUDY

September 6, 2005

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Summary

The hydroseparator is extensively used in the taconite industry to remove fine gangue from the taconite concentrate. The amount of gangue removed is limited by the carry-over of fine magnetite if the rise velocity gets too high. The use of a low-strength magnetic field has been shown in the laboratory and on a small pilot scale to reduce the carry-over of fine magnetite. The purpose of this test program was to run semi-continuous tests in the plant to confirm the previous results and to determine if the buildup of magnetite on the magnet grid reached equilibrium. A six-foot diameter thickener was used for the tests. A magnetic grid assembly with 12-inch square openings was constructed using 1.5-inch wide by ¼-inch thick magnetic strips. This produced a field strength at the center of each grid of between 40 and 60 gauss.

The unit was installed on Line 7 at Minntac. A portion of the plant hydroseparator feed was diverted to the test unit. Tests were run with and without the magnet assembly in place. For all of the tests, the average test unit overflow rate was essentially the same for the tests with and without magnets. Use of the magnets reduced the average magnetic iron content in the overflow by about 22 percent. However, when the test overflows are compared to the plant overflows, the magnetic iron content of the plant overflows was significantly higher when the magnets were installed. The difference between the test unit and the plant magnetic iron content for the tests without magnets was 0.61 compared with 0.10 for the tests with the magnets installed.

The tests showed that the magnetite build-up did reach equilibrium and, although the field strength did decrease with the magnetite build-up, there was no indication of diminished performance.

Introduction

The majority of the taconite plants utilize hydroseparators in their concentrators. The hydroseparator is usually used to treat cyclone overflow from the final stage of grinding. Hydroseparator underflow is generally upgraded by magnetic separation, while the overflow product is tailings. The hydroseparator is essentially an elutriation column where the rise velocity is maintained to allow fine gangue to rise while allowing fine magnetite to settle. To improve the settling characteristics of the fine magnetite, hydroseparator feed is magnetically flocculated. If the rise velocity could be increased without the loss of fine magnetite, then additional gangue removal could be accomplished. In addition, at higher rise velocities, more higher specific gravity silicates could be removed.

In principle, magnetite losses to the overflow could be greatly reduced by applying a magnetic field within the hydroseparator to capture the fine magnetite going to the overflow at higher rise velocities. This principle was tested by Roe[1)] in 1953 using a 46 mm diameter laboratory tube with a dc electromagnet coil near the top of the tube. The magnetic field strength at the internal tube wall was varied from 5 to 300 gauss. His work demonstrated that high silica middlings as well as free silica particles could be removed without excessive iron losses by careful control of magnetic field and water supply. While electro magnets are useful in the laboratory, they are not practical for commercial application. Ersayin and Iwasaki[2)] utilized a grid of magnetic material within the hydroseparator to develop a relatively uniform field within the hydroseparator. Initial tests were conducted in a 4-inch diameter tube with follow up tests being conducted in a pilot scale 3-ft diameter by 4-ft deep Door-Oliver Siphon Sizer. In the pilot scale tests, the magnet grid had a square pattern with 6-inch openings and field strength in the grid centers of between 45 and 65 gauss. Test results indicated substantially reduced iron losses even at high rise velocities. During testing, it was noted that magnetite tended to build up on the magnetic grid and there was a slight decrease in field strength with the buildup. It was thought that the build-up of magnetite on the magnets would reach a steady state condition where flocculated magnetite falling from the magnets would equal the new magnetite attachment. However, the tests were not run long enough for steady state conditions to develop. Therefore, a proposal was submitted to and accepted by the Iron Ore Cooperative Research Committee to conduct tests using a 6-foot diameter thickener with a magnetic grid being fed a slip stream from a plant's hydroseparator feed. This report describes the test conditions and results.

Test Set Up

A Denver six-foot diameter thickener with a sloping bottom and a sidewall of approximately 6 feet was used for the tests. A steel support structure was welded about 4-inches below the overflow lip of the thickener, Figure 1. On top of these supports, the magnet assembly was placed. The magnet assembly consisted of steel strips welded into a grid pattern with about 12-inch square openings. On top of the metal strips, two layers of 1.5-inch wide by ¼-inch thick layers of magnetic material were positioned and held in place by plastic ties. Figure 2 shows the sections of magnet assembly awaiting insertion into the test hydroseparator. Figure 3 shows the magnet assembly installed in the test unit. The grid pattern is shown schematically in Figure 4. Also shown in Figure 4 are the gauss readings in the center of each grid. The readings ranged from 39 to 65 gauss. To control the underflow discharge, a sludge layer sensor, a Variable Frequency Drive (VFD) and a pump were purchased. The objective was to maintain a layer of settled solids in the bottom and use the sensor to control the pump speed. The system was assembled at the Coleraine Minerals Research Laboratory (CMRL) and tested. The system appeared to work in that the sensor detected changes in sludge height and sent the appropriate signal to the VFD to change pump.

Once the system had been tested it was shipped to Minntac for installation on Line 7 in the concentrator. A tap was made in the bottom of a "boil box" that was used to feed the plant hydroseparator on Line 7. The tap was after the magnetic block; therefore, the feed was magnetically flocculated. Figure 5 shows the piping from the boil box. Provisions were made for plant water to be used for cleaning out the pipe and sample point. Figure 6 is a closer view of the sample point and shows the location of the flow meter that was used to set the feed rate to the test unit. The boil box is suspended from the bottom of the third floor and the test unit is located in the basement. The installed test unit is shown in Figure 7. The test unit overflow was collected in a single pipe and discharged to plant sewer. The discharge point could be manually sampled. The underflow was pumped into one of the plant pump sumps so that the iron units would not be lost. Figure 8 shows the discharge pump and the diagonal pipe carrying the overflow. Figure 9 shows the VFD and sludge level sensor.

Test Program

The initial tests were run with the magnets in the test unit. Once the underflow density had built up, the system was sampled. Sample points were the feed, test unit overflow (timed sample), test underflow, plant hydro overflow and plant hydro underflow. Three samples at each point were taken 45 minutes apart and composited, with the exception of the overflow samples, which were kept separate. The samples were taken back to Coleraine where the sample wet weighs were recorded, the samples were filtered and dried, and the dry weight was recorded. After the dry weights were recorded, the overflow samples were composited and splits were taken for chemistry and size structure. After several days of operation, it became apparent that the sludge level sensor was not sensitive enough to be utilized for controlling the pump speed to maintain a uniform density in the underflow. Therefore, the pump was switched to manual control, and the underflow density was controlled from Marcy Cup measurements on the underflow pump discharge. After several weeks of running with the magnets in the test unit, the magnets were removed and the unit was operated as a normal hydro. After several weeks of operation without the magnets, the magnet assembly was re-installed and additional tests were run.

Test Results and Discussion

The results for the tests with the magnet assembly installed are given in Appendix I, and the results for the tests without the magnets are given in Appendix II. The average results for the tests with and without magnets are given in Table I below.

Table I – Average Results for Tests With and Without Magnets

Average Results Without Magnets					
Sample	% solids	Overflow, gpm	Satmagan Iron, %	Total Iron, %	Silica, %
Feed	31.68		50.76	55.89	17.88
Test Underflow	56.92		53.01	57.66	16.06
Test Overflow	2.97	85.03	1.50	16.54	60.28
Plant Underflow	66.28		54.18	58.85	14.66
Plant Overflow	2.64		0.89	15.95	60.63
Average Results With Magnets					
Feed	28.05		50.22	56.52	17.64
Test Underflow	54.72		52.58	58.61	15.21
Test Overflow	2.49	86.83	1.17	16.64	63.94
Plant Underflow	65.57		54.15	59.84	13.82
Plant Overflow	2.42		1.07	16.35	64.82

Since the average overflow rate (gpm) was essentially the same for the tests with and without the magnets, the rise velocity should be essentially the same. Therefore, differences in the magnetic iron content in the overflow should be related to the presence or absence of the magnet assembly. On the average, the magnetic iron content of the overflows without magnets was 28 percent higher (1.50 vs 1.17 %). Plotting the magnetic iron content in the overflows versus the overflow rate, Figure 10, indicates little significant difference; however, there is also a significant difference in the magnetic iron content in the plant overflow between the two test conditions. The average magnetic iron content of the plant overflow was 20 percent higher for the tests with magnets than during the tests without magnets (1.07 vs 0.89 %). Therefore, plotting the difference between the test unit and the plant overflows versus the test overflow rate is a better indication of the differences. This plot is shown in Figure 11. This figure shows that magnetic iron content of the test overflow is consistently lower when the magnets were in place. Plotting the magnetic iron content of the overflows with and without magnets along with the corresponding magnetic iron content of the plant overflow, Figure 12, shows that the test overflows without magnets are consistently higher than the plant overflows, while the magnetic iron contents of the overflows with the magnets installed are sometimes lower than the plant overflows.

The screen analyses for all the samples are given in Appendix III. The percent minus 270 mesh in the feed is plotted on Figure 13, which shows fairly high variability on a daily basis, with the minus 270 mesh content ranging from about 55 to 75 percent. The tests without the magnets had the coarsest feed; however, the feed size did not appear to have affected the overflow minus 270 mesh content, Figure 14. A comparison of the percent minus 500 mesh in test and plant overflows is shown in Figure 15. Again, it appears that the test unit was producing a finer overflow than the plant and that the presence or absence of the magnets did not have a measurable effect on the size in the overflow.

Another part of the test program was to determine if the use of magnets in the hydroseparator had an impact on the silica grade of the underflow. Unfortunately, there were serious problems in handling the underflow at high (>60 %) solids. The underflow discharge line kept sanding. Therefore, most of the tests had to be run at lower than plant percent solids in the underflow, which probably resulted in higher silica in the test underflows than in the plant underflows. Before we could modify the discharge system, there was an upset in the plant and the plant coarse tailings classifier had to be dumped, which buried the test unit in slurry. Some of the slurry got into the VFD, shorting out the unit. It was not possible to get the VFD repaired within the time constraints of the contract. However, comparing the average difference in the test underflow silicas with the plant underflow silicas indicates no difference between having magnets or not having magnets (difference of 1.39 vs 1.40 percent silica).

Other than the problems with the underflow line sanding, there were few problems with the operation. Over the weeks of testing with the magnets, there was a build-up of magnetite on the magnet grid, Figure 16. The build-up appeared to reach equilibrium quickly and did not cause any problems. However, gauss readings taken when the test unit was drained indicated a decrease in the field strength of up to 40 percent. There was no detectable loss in performance with time. This loss in field strength was noted in previous work[2].

Conclusions and recommendations

The test program has shown that a magnetic grid can be installed in a hydroseparator and operated over a relatively long period of time without an excessive build-up of magnetite on the magnets. The use of magnets reduced the magnetic iron losses in the overflow by at least 25 percent without affecting the underflow grade. With the magnets installed, the magnetic iron losses were relatively insensitive to up flow velocity.

Additional testing with percent solids in the underflow would help to determine if there is any silica benefit to having the magnets in the hydroseparator. Also, because of the loss of field strength, a higher initial field strength (more layers of magnetic material) needs to be tested.

References

1. Roe, L.A., "The Magnetic Reflux Classifier," Mining Engineering, Vol. 5, No. 3, 1953, pp. 312-315.
2. Ersayin, S. and Iwasaki, I., "Magnetically Enhanced Hydroseparator," Minerals and Metallurgical Processing, Vol. 19, No. 4, November 2002, pp.187-191.

Figure 1 – Steel Supports for Magnet Assembly

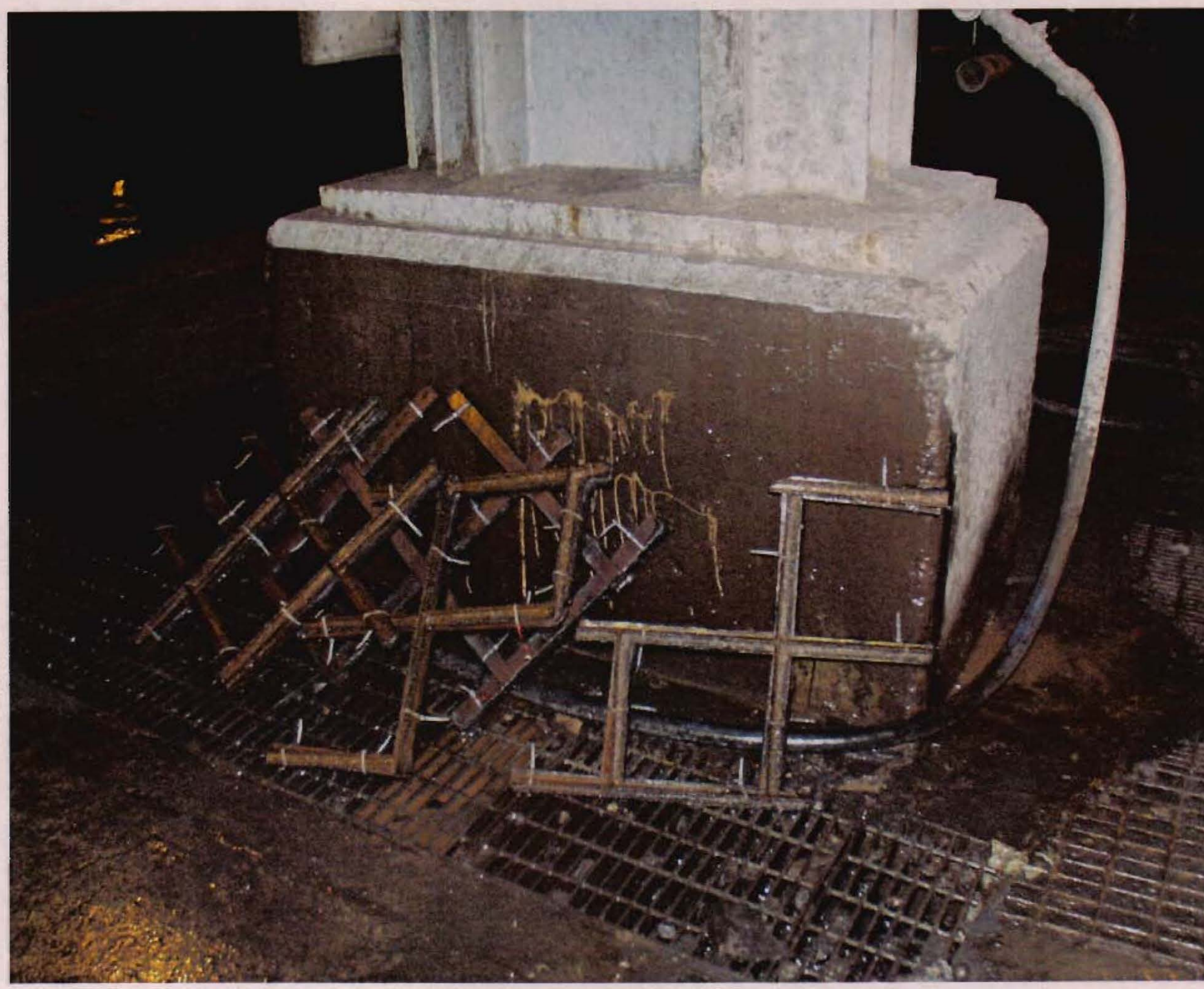


Figure 2 – Sections of Magnet Assembly Awaiting Installation into Test Unit

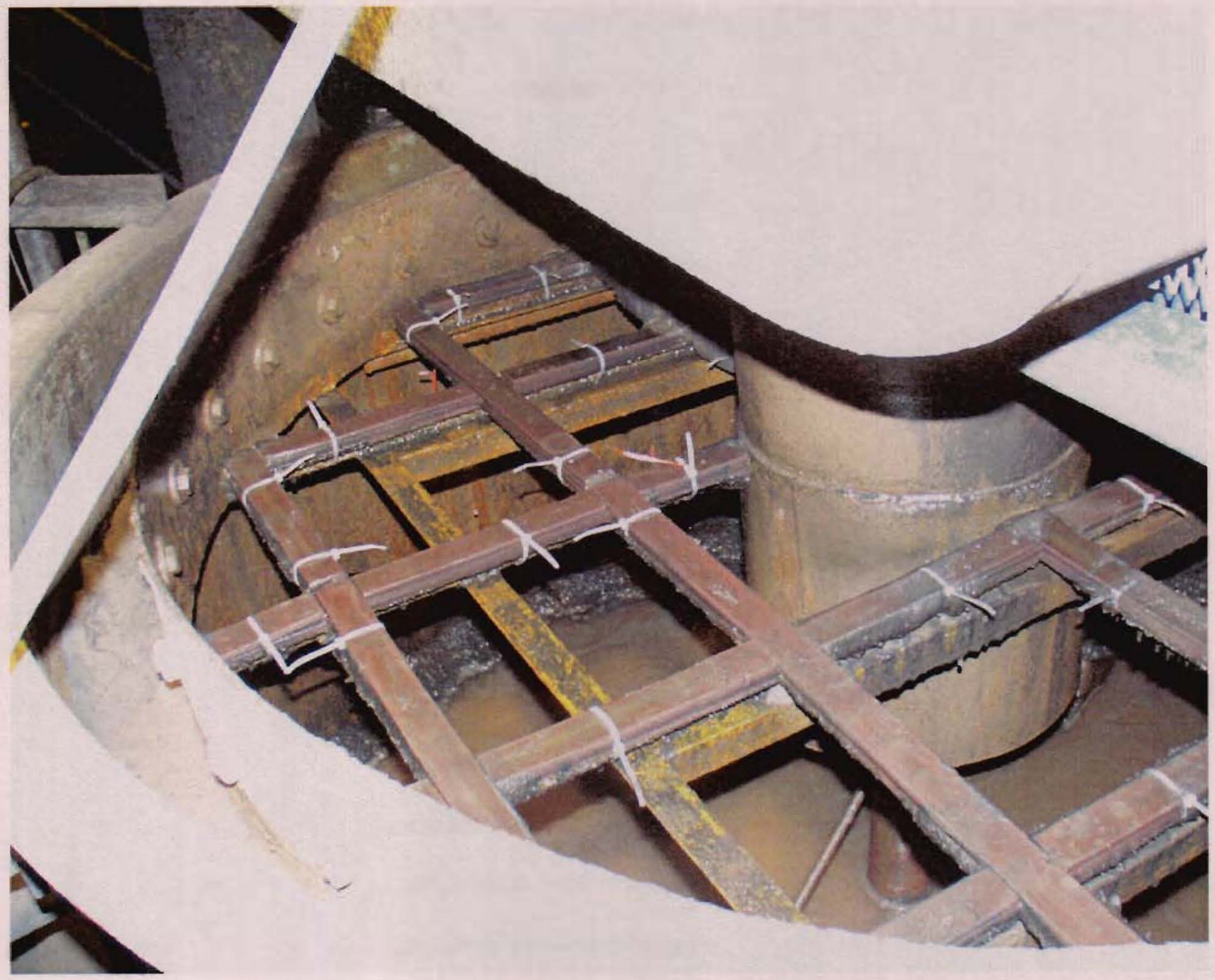


Figure 3 – Magnet Assembly Installed in Test Unit

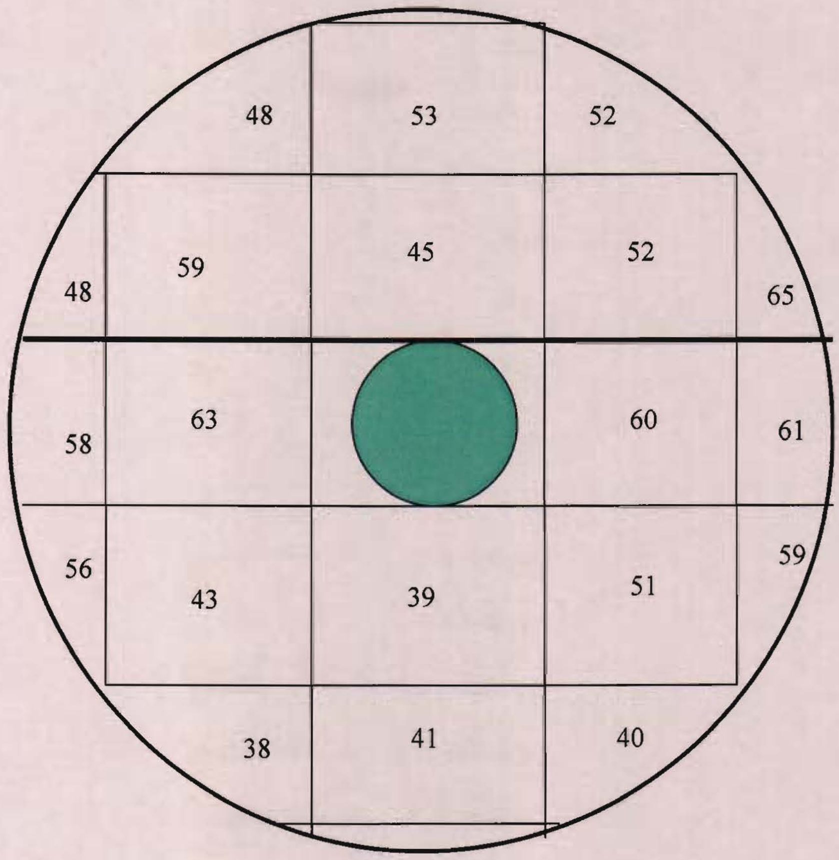


Figure 4 - Schematic of Magnet Grid Inside Test Hydroseparator

Figure 5 – Feed Line Showing Plant Sample Point and Wash Water Piping

Figure 6 – Close up of Feed Sample Point and Flow Meter

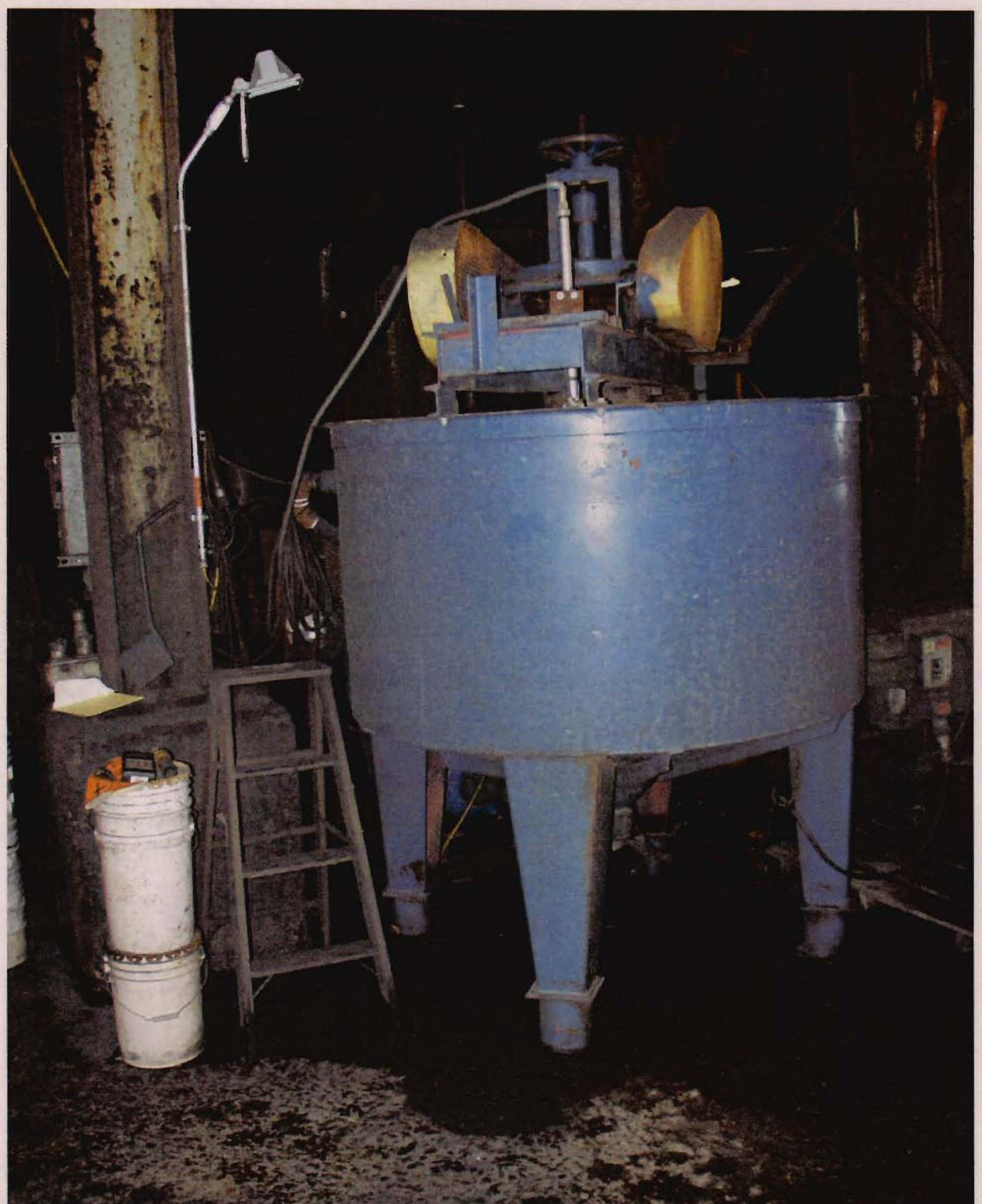


Figure 7 – Test Unit as Installed on Line 7 at Minntac

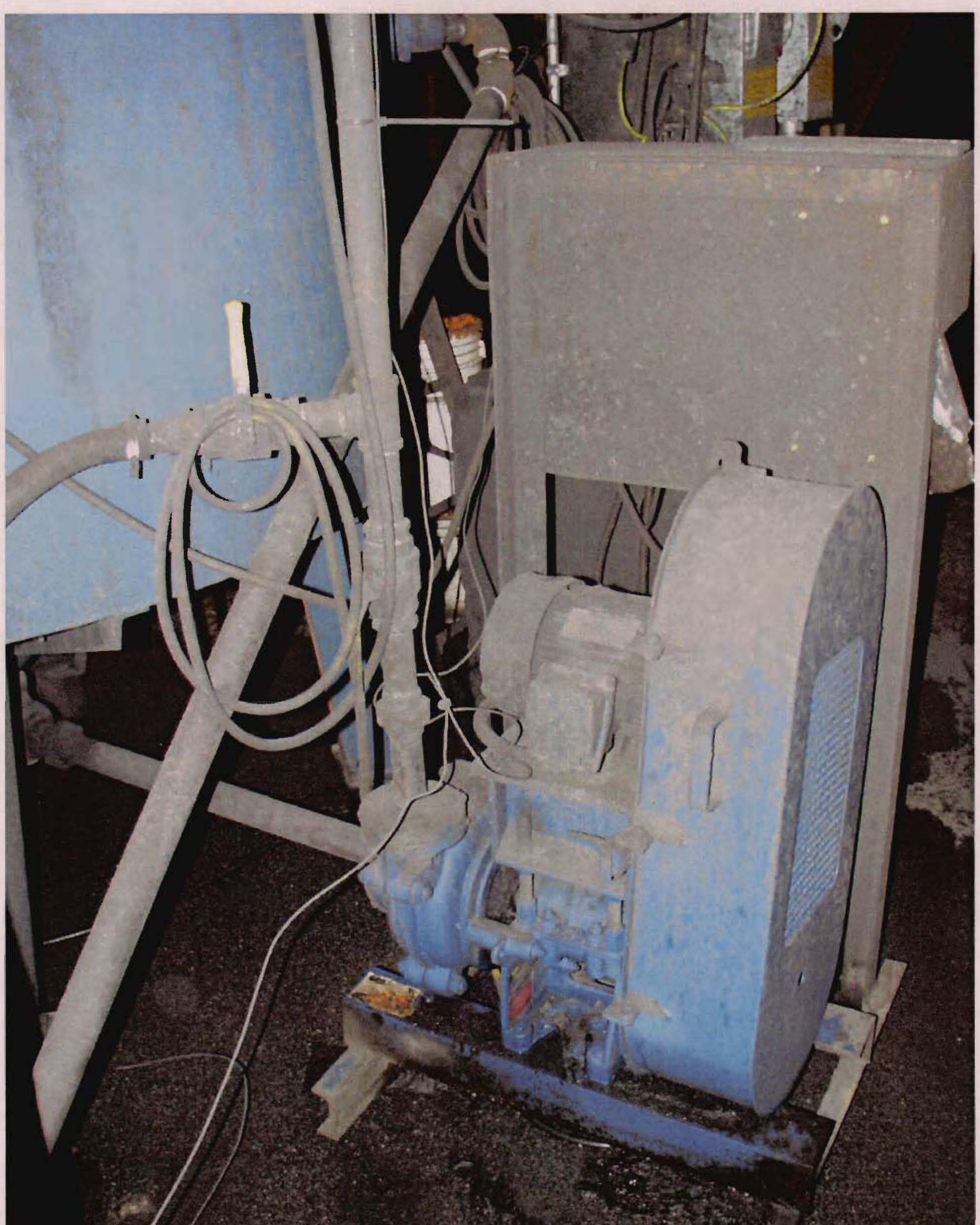


Figure 8 – Underflow Pump

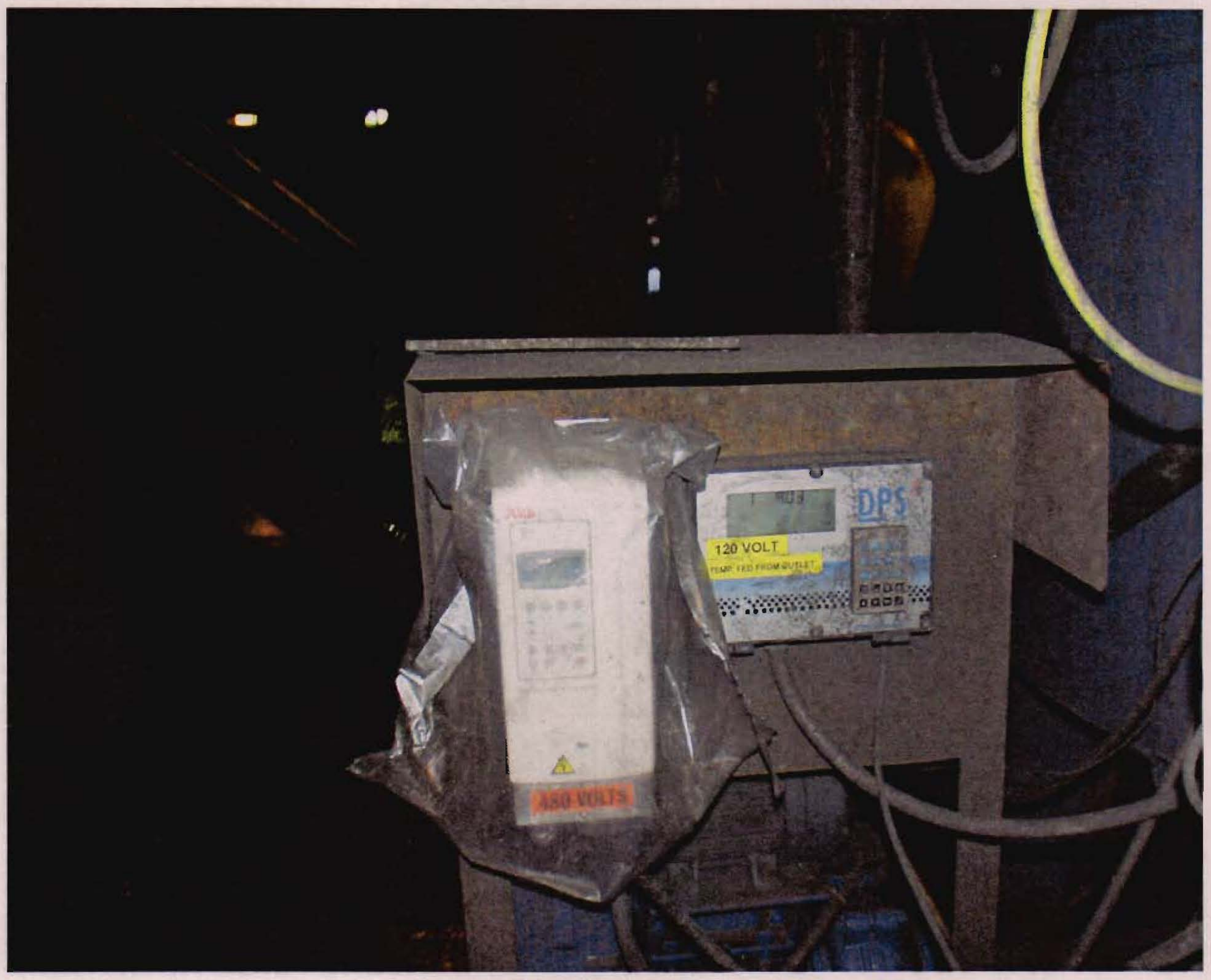


Figure 9 – Sludge Level Sensor Control and VFD

Figure 10 - Effect of Overflow gpm on Mag Fe Content

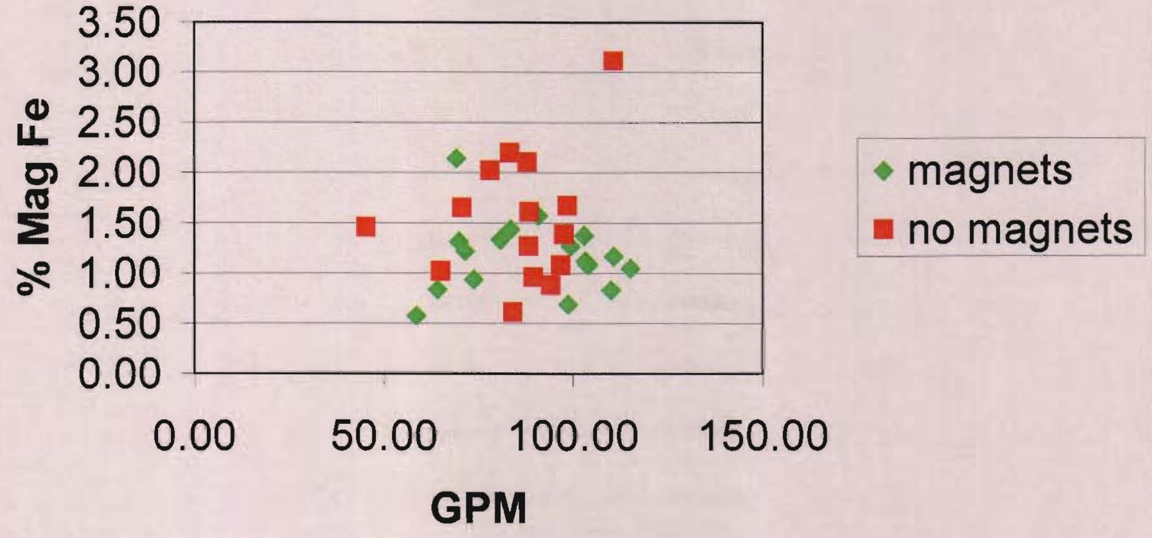


Figure 11 - Difference between Test Unit and Plant Mag Fe vs Overflow gpm

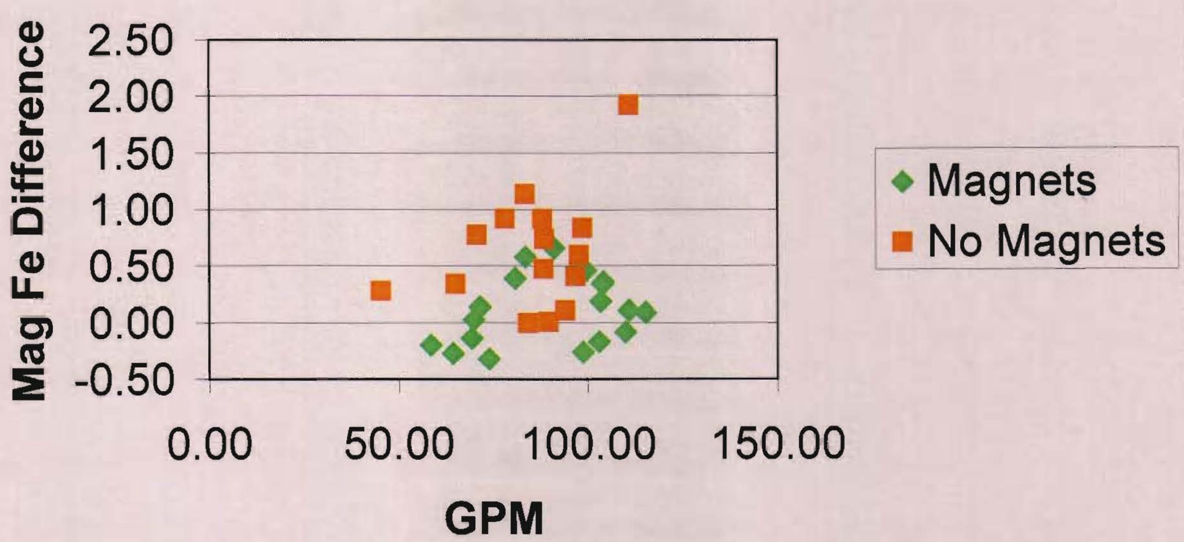


Figure 12 - Comparison of Plant and Test Overflow Mag Fe

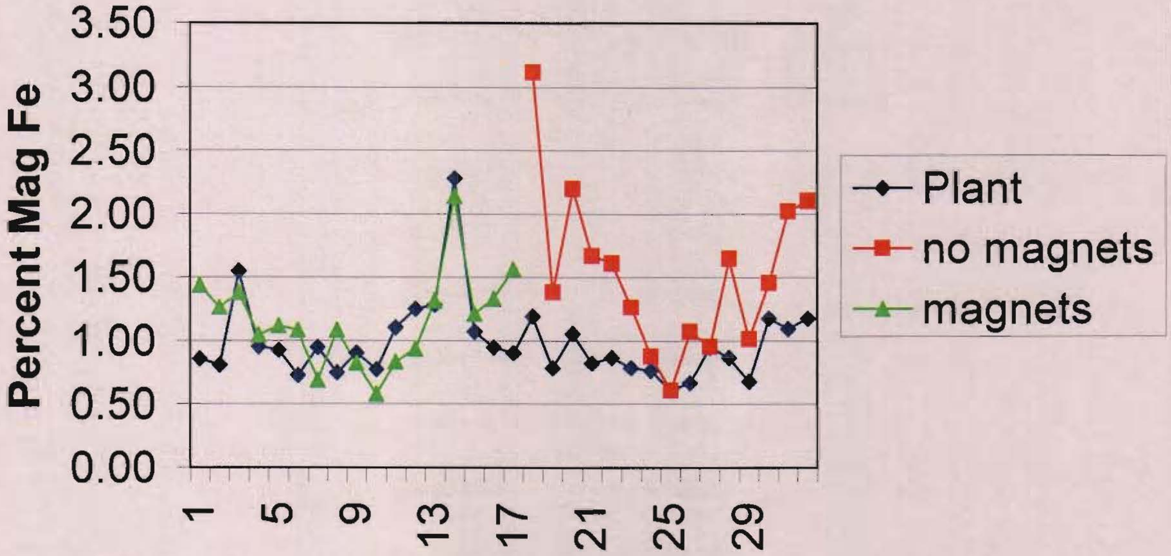


Figure 13 - Percent minus 270 Mesh in Feed

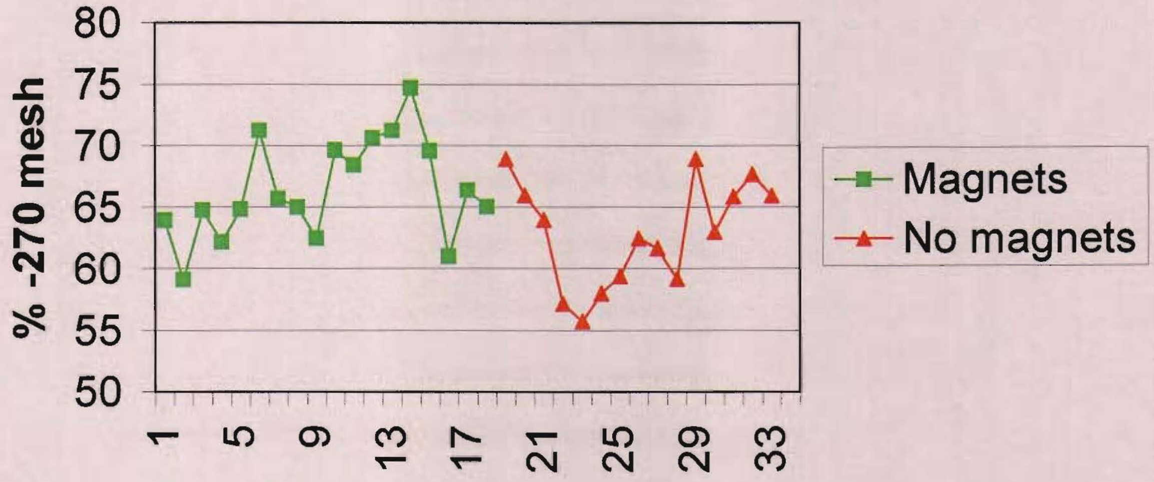


Figure 14 - Comparison of % -270 mesh in Overflows

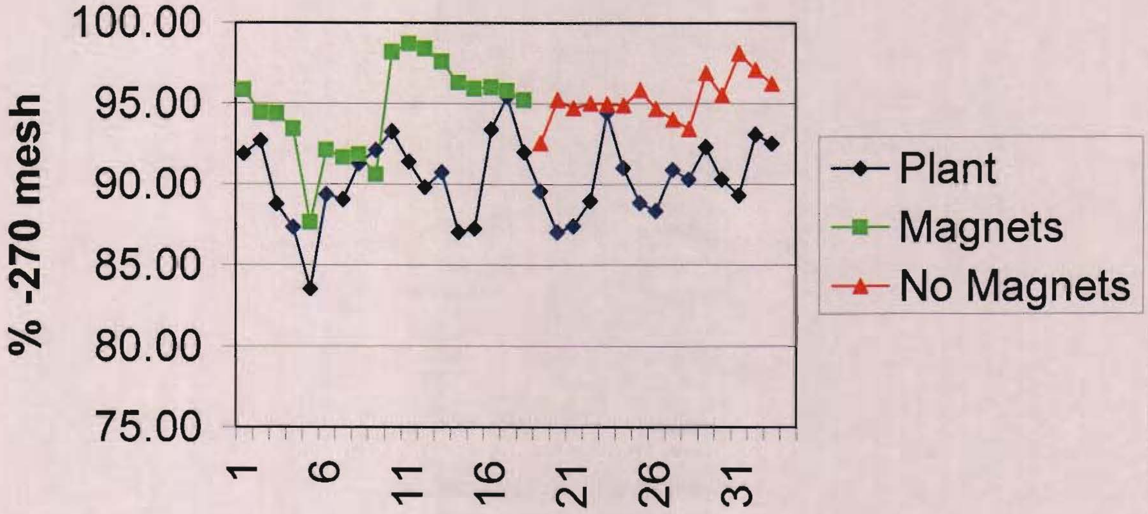
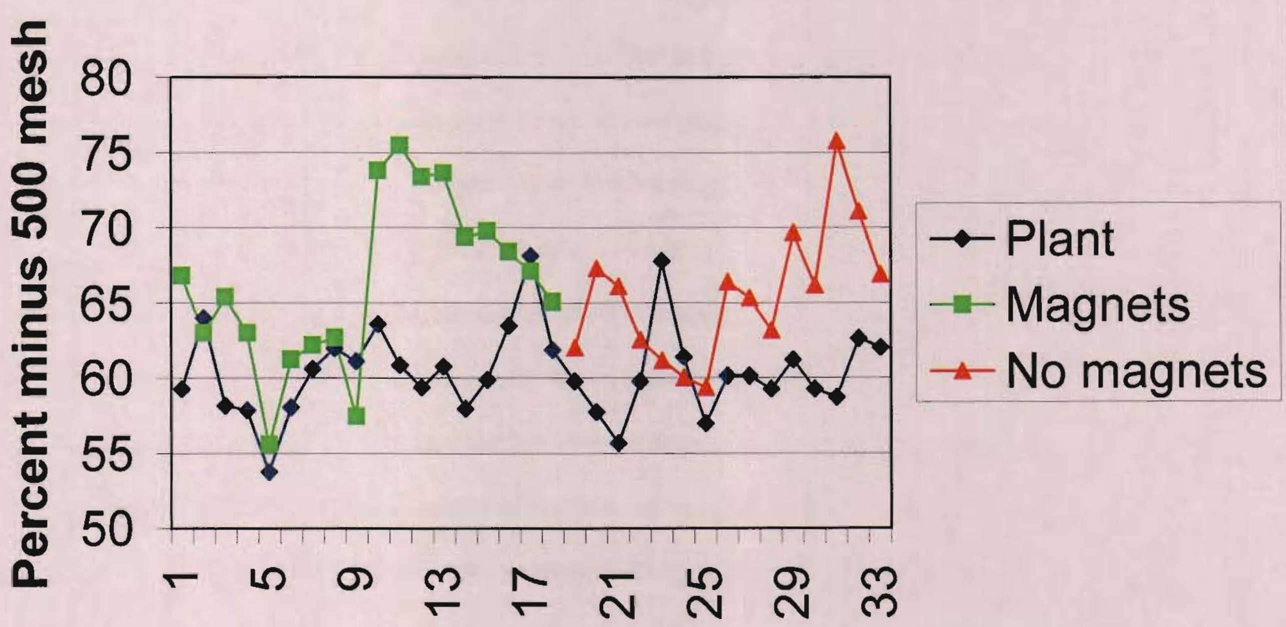


Figure 15 - Comparison of Plant and Test % - 500 mesh in Overflow



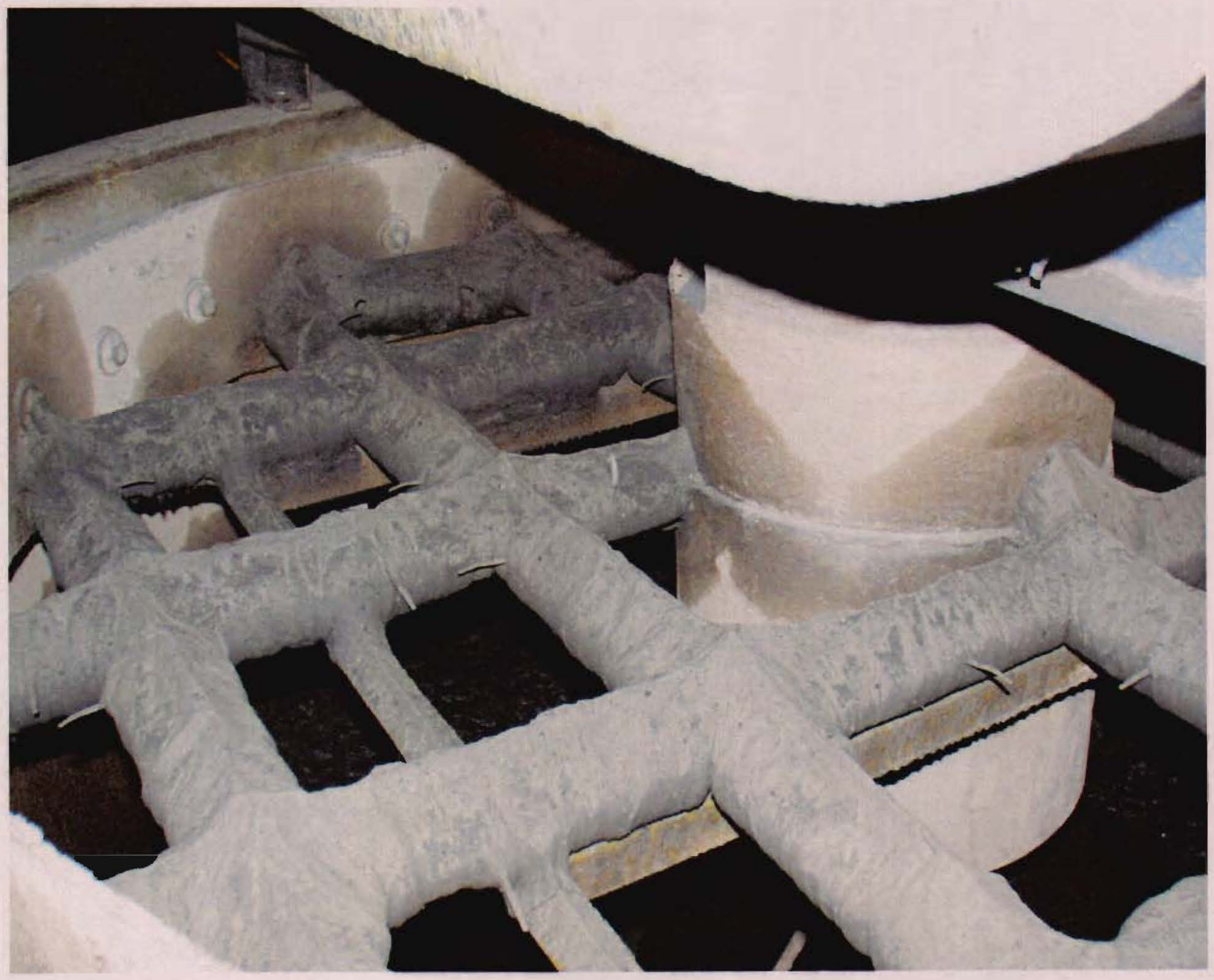


Figure 16 – Magnet Assembly Loaded with Magnetite

APPENDIX I

RESULTS OF TESTS WITH MAGNETS INSTALLED

Appendix I - Results of Tests with Magnets Installed						
Date	Sample	% solids	gpm	Sat Mag	Fe	SiO2
2/21/05	Hydro Feed	25.41		48.14	55.40	18.90
	Mag Hydro Underflow	50.20		51.62	58.30	15.61
	Mag Hydro Overflow	2.52	83.50	1.44	16.80	65.92
	Plant Underflow	67.73		52.81	59.20	14.52
	Plant Overflow	2.68		0.86	16.30	65.25
2/22/05	Hydro Feed	28.22		49.14	55.60	19.39
Test 1	Mag Hydro Underflow	58.16		52.24	58.20	16.64
	Mag Hydro Overflow	2.78	99.39	1.27	16.50	63.56
	Plant Underflow	65.66		53.46	59.40	14.49
	Plant Overflow	2.38		0.81	16.10	63.01
2/23/05	Hydro Feed	27.49		49.78	56.30	17.37
Test 1	Mag Hydro Underflow	49.43		51.94	58.60	14.25
	Mag Hydro Overflow	2.48	102.88	1.38	17.40	60.56
	Plant Underflow	66.44		52.95	59.70	13.92
	Plant Overflow	2.58		1.55	17.30	60.99
Test 2	Hydro Feed	28.62		48.25	55.10	18.12
	Mag Hydro Underflow	57.81		50.49	57.60	15.15
	Mag Hydro Overflow	2.83	115.06	1.05	16.60	60.22
	Plant Underflow	65.55		51.87	58.30	14.41
	Plant Overflow	2.60		0.96	16.40	60.03
2/25/05	Hydro Feed	27.90		50.32	55.90	16.71
Test 1	Mag Hydro Underflow	52.88		53.7	58.90	13.98
	Mag Hydro Overflow	2.65	103.32	1.12	15.70	61.85
	Plant Underflow	66.09		54.63	59.60	12.66
	Plant Overflow	2.42		0.93	15.20	64.11
Test 2	Hydro Feed	27.39		49.75	55.70	16.79
	Mag Hydro Underflow	59.24		53.1	58.60	13.83
	Mag Hydro Overflow	2.79	104.02	1.09	15.70	61.81
	Plant Underflow	65.77		53.80	58.90	13.62
	Plant Overflow	2.50		0.73	15.00	65.11
2/28/05	Hydro Feed	30.57		52.68	56.30	17.78
Test 1	Mag Hydro Underflow	63.14		56.85	58.90	15.19
	Mag Hydro Overflow	2.96	98.66	0.69	14.50	67.68
	Plant Underflow	65.48		58.24	60.20	13.44
	Plant Overflow	3.00		0.95	14.90	72.65

Test 2	Hydro Feed	24.61		54.36	57.00	16.89
	Mag Hydro Underflow	54.74		56.25	59.20	14.00
	Mag Hydro Overflow	2.62	103.86	1.09	14.60	70.94
	Plant Underflow	65.00		59.10	60.60	12.41
	Plant Overflow	2.39		0.75	14.20	70.78
3/1/05	Hydro Feed	31.77		50.04	55.60	20.63
	Mag Hydro Underflow	64.28		52.2	58.20	16.89
	Mag Hydro Overflow	3.00	109.94	0.83	16.40	74.42
	Plant Underflow	65.08		52.72	58.40	16.30
	Plant Overflow	2.71		0.91	16.90	69.06
3/22/05	Hydro Feed	25.34		51.06	56.70	17.98
	Mag Hydro Underflow	48.99		53.36	58.70	15.70
	Mag Hydro Overflow	1.91	58.61	0.58	16.00	67.31
	Plant Underflow	66.55		56.32	60.70	13.63
	Plant Overflow	2.06		0.78	15.70	68.71
3/23/05	Hydro Feed	30.43		50.6	57.00	17.26
Test 1	Mag Hydro Underflow	51.04		51	58.10	16.08
	Mag Hydro Overflow	2.13	64.38	0.84	16.80	58.87
	Plant Underflow	66.18		53.25	59.80	14.10
	Plant Overflow	2.38		1.11	16.70	59.44
Test 2	Hydro Feed	28.49		49.7	56.90	17.86
	Mag Hydro Underflow	50.50		51.74	58.40	15.45
	Mag Hydro Overflow	2.51	73.90	0.94	16.40	58.82
	Plant Underflow	66.94		53.73	60.10	13.47
	Plant Overflow	1.64		1.26	16.70	59.82
3/24/05	Hydro Feed	31.02		50.87	57.30	16.56
	Mag Hydro Underflow	47.47		53.84	59.20	14.56
	Mag Hydro Overflow	1.92	69.97	1.32	15.80	62.58
	Plant Underflow	55.91		55.82	61.00	12.56
	Plant Overflow	2.19		1.29	15.30	64.42
3/28/05	Hydro Feed	25.81		53.28	59.20	14.82
	Mag Hydro Underflow	43.66		53.87	60.20	14.04
	Mag Hydro Overflow	1.88	69.34	2.14	18.50	63.60
	Plant Underflow	64.43		56.14	62.30	11.69
	Plant Overflow	2.22		2.28	18.20	64.12
3/29/05	Hydro Feed	26.87		51.3	58.40	15.74
	Mag Hydro Underflow	60.86		52.02	59.10	14.90
	Mag Hydro Overflow	2.30	71.55	1.22	16.80	63.50
	Plant Underflow	67.22		54.19	60.60	13.40
	Plant Overflow	2.60		1.08	16.50	65.16

3/30/05	Hydro Feed	30.54		47.37	56.20	18.38
Test1	Mag Hydro Underflow	59.99		49.63	58.20	15.66
	Mag Hydro Overflow	2.57	80.88	1.34	19.10	61.48
	Plant Underflow	67.75		51.02	59.20	14.51
	Plant Overflow	2.57		0.95	18.40	63.65
Test 2	Hydro Feed	26.34		47.16	56.20	18.64
	Mag Hydro Underflow	57.89		50.09	58.00	16.56
	Mag Hydro Overflow	2.54	66.85	1.57	19.20	63.84
	Plant Underflow	66.85		50.49	59.20	15.88
	Plant Overflow	2.23		0.91	18.20	65.69

APPENDIX II

RESULTS OF TESTS WITHOUT MAGNETS INSTALLED

Appendix II - Results of Tests Without Magnets Installed						
Date	Sample	% solids	gpm	Sat Mag	Fe	SiO2
3/2/05	Hydro Feed	27.57		50.85	57.20	17.01
	Test Hydro Underflow	50.42		55.21	60.10	13.37
	Test Hydro Overflow	2.27	110.78	3.12	17.30	62.00
	Plant Underflow	65.04		55.91	61.00	11.92
	Plant Overflow	2.03		1.20	15.40	63.78
3/4/05	Hydro Feed	29.28		51.45	55.60	17.15
Test 1	Test Hydro Underflow	56.23		54.80	58.00	14.91
	Test Hydro Overflow	2.69	97.59	1.39	16.40	59.20
	Plant Underflow	65.39		53.98	57.70	15.86
	Plant Overflow	2.81		0.79	16.00	62.31
Test 2	Hydro Feed	31.61		53.45	57.10	15.99
	Test Hydro Underflow	49.12		55.27	58.90	14.34
	Test Hydro Overflow	2.04	83.39	2.20	17.40	59.71
	Plant Underflow	64.30		58.12	61.20	11.77
	Plant Overflow	2.23		1.06	16.10	61.62
3/8/05	Hydro Feed	30.86		49.15	55.30	20.01
	Test Hydro Underflow	56.61		51.34	57.10	18.14
	Test Hydro Overflow	3.02	98.47	1.67	16.60	61.92
	Plant Underflow	67.01		52.75	58.50	16.15
	Plant Overflow	2.91		0.83	15.90	69.07
3/10/05	Hydro Feed	31.18		49.94	54.50	19.61
Test 1	Test Hydro Underflow	55.38		51.29	55.70	18.42
	Test Hydro Overflow	3.03	88.44	1.61	16.60	61.68
	Plant Underflow	66.42		54.13	58.50	14.95
	Plant Overflow	2.62		0.89	16.50	62.72
Test 2	Hydro Feed	32.89		51.33	55.50	17.91
	Test Hydro Underflow	59.94		52.70	56.50	16.78
	Test Hydro Overflow	2.85	88.24	1.27	16.40	58.78
	Plant Underflow	66.42		53.42	58.00	15.93
	Plant Overflow	2.60		0.79	15.80	59.64
3/11/05	Hydro Feed	33.96		48.72	53.90	19.47
Test 1	Test Hydro Underflow	67.07		52.80	57.30	16.09
	Test Hydro Overflow	3.31	94.05	0.88	16.40	61.28
	Plant Underflow	66.84		52.92	57.30	15.85
	Plant Overflow	3.44		0.77	16.50	61.70

	Appendix II- Continued					
Test 2	Hydro Feed	36.53		48.85	54.50	18.59
	Test Hydro Underflow	65.69		51.78	56.60	16.62
	Test Hydro Overflow	3.36	84.02	0.61	16.20	61.40
	Plant Underflow	67.70		52.10	57.20	16.30
	Plant Overflow	2.77		0.61	16.60	60.70
3/14/05	Hydro Feed	35.70		51.48	55.90	18.28
Test 1	Test Hydro Underflow	65.64		54.84	58.40	15.70
	Test Hydro Overflow	3.01	96.80	1.08	14.50	52.48
	Plant Underflow	67.82		55.33	58.40	15.22
	Plant Overflow	2.99		0.67	14.40	65.32
Test 2	Hydro Feed	36.39		53.33	57.00	16.75
	Test Hydro Underflow	63.49		55.54	58.00	15.63
	Test Hydro Overflow	2.82	89.60	0.96	15.10	64.72
	Plant Underflow	66.84		55.59	59.10	14.73
	Plant Overflow	2.82		0.95	14.90	63.86
3/15/05	Hydro Feed	27.45		50.99	56.40	17.26
Test 1	Test Hydro Underflow	50.63		52.94	58.10	15.42
	Test Hydro Overflow	2.22	70.62	1.65	16.00	61.64
	Plant Underflow	65.24		54.87	59.40	13.43
	Plant Overflow	2.18		0.87	15.10	62.60
Test 2	Hydro Feed	30.94		50.65	55.90	17.93
	Test Hydro Underflow	58.46		51.74	57.00	16.57
	Test Hydro Overflow	2.46	65.02	1.02	15.70	60.74
	Plant Underflow	67.29		53.56	58.30	14.84
	Plant Overflow	2.73		0.68	15.00	62.18
3/16/05	Hydro Feed	30.52		50.53	56.90	16.89
	Test Hydro Underflow	48.38		50.74	57.80	16.13
	Test Hydro Overflow	1.98	45.28	1.46	18.00	57.38
	Plant Underflow	66.04		53.06	60.00	13.39
	Plant Overflow	2.42		1.18	17.30	29.92
3/17/05	Hydro Feed	28.66		49.91	56.70	17.43
	Test Hydro Underflow	49.79		51.18	57.80	16.76
	Test Hydro Overflow	2.26	78.06	2.02	19.00	60.92
	Plant Underflow	65.58		52.84	59.30	14.86
	Plant Overflow	2.40		1.10	17.80	63.34

APPENDIX III

SCREEN ANALYSES FOR THE OVERFLOWS AND FEED

Appendix III - Screen Analyses for the Overflows and Feed						
	2/21/05			2/22/05		
Mesh	Mag Oflo	Plant Oflo	Feed	Mag Oflo	Plant Oflo	Feed
100	0.03	0.00	2.72	0.00	0.00	4.29
150	0.07	0.00	7.03	0.16	0.07	7.37
200	0.34	0.37	10.79	0.36	0.56	12.21
270	3.70	7.71	15.52	5.08	6.63	16.98
325	4.18	6.69	7.71	5.85	5.48	9.06
400	7.68	8.54	6.94	7.99	7.26	6.97
500	17.19	17.39	13.26	17.55	15.98	9.56
-500	66.80	59.29	36.03	63.01	64.03	33.55
	2/23/2005-1			2/23/2005-2		
Mesh	Mag Oflo	Plant Oflo	Feed	Mag Oflo	Plant Oflo	Feed
100	0.00	0.00	2.76	0.00	0.00	3.34
150	0.00	0.00	6.59	0.00	0.00	7.56
200	0.54	1.41	10.47	0.51	2.01	11.30
270	5.07	9.81	15.46	6.07	10.65	15.62
325	5.01	6.46	7.92	5.63	7.02	7.99
400	7.43	7.78	8.32	7.81	7.22	7.82
500	16.55	16.33	14.48	17.00	15.21	13.99
-500	65.40	58.21	34.02	62.99	57.89	32.37
	2/25/2005-1			2/25/2005-2		
Mesh	Mag Oflo	Plant Oflo	Feed	Mag Oflo	Plant Oflo	Feed
100	0.03	0.00	2.40	0.00	0.00	3.24
150	0.00	0.00	6.90	0.00	0.00	6.76
200	0.81	1.34	9.87	0.64	1.15	9.92
270	7.49	9.57	15.15	7.46	7.55	15.10
325	6.11	5.39	6.38	6.07	5.01	5.89
400	7.89	8.34	7.28	7.78	7.97	7.38
500	15.45	14.71	10.68	15.35	16.31	10.57
-500	62.21	60.65	41.34	62.69	62.00	41.14
	2/28/2005-1			2/28/2005-2		
Mesh	Mag Oflo	Plant Oflo	Feed	Mag Oflo	Plant Oflo	Feed
100	0.00	0.00	4.06	0.00	0.00	2.14
150	0.06	0.00	7.51	0.03	0.00	5.59
200	1.17	2.50	9.66	0.70	1.08	7.48
270	11.11	13.98	13.97	7.11	9.57	13.55
325	6.12	6.62	3.86	5.09	5.93	4.76
400	10.37	8.86	9.26	10.18	8.89	9.72
500	15.55	14.23	11.32	15.68	16.44	13.36
-500	55.62	53.81	40.36	61.21	58.09	43.40

Appendix III Continued						
	3/1/05			3/22/05		
Mesh	Mag Oflo	Plant Oflo	Feed	Mag Oflo	Plant Oflo	Feed
100	0.00	0.00	3.34	0.00	0.00	2.16
150	0.06	0.03	8.37	0.00	0.00	5.71
200	0.83	0.53	11.07	0.16	0.67	8.13
270	8.49	7.31	14.75	1.64	6.04	14.37
325	3.83	3.34	6.48	1.15	5.20	6.53
400	12.07	10.68	5.80	5.92	7.55	8.17
500	17.25	17.01	11.71	17.27	16.95	13.41
-500	57.46	61.11	38.47	73.85	63.59	41.52
	3/23/2005-1			3/23/2005-2		
Mesh	Mag Oflo	Plant Oflo	Feed	Mag Oflo	Plant Oflo	Feed
100	0.00	0.00	2.46	0.00	0.00	1.81
150	0.00	0.00	6.12	0.00	0.00	5.46
200	0.20	0.82	8.36	0.20	1.17	8.07
270	1.10	7.73	14.61	1.40	9.02	14.00
325	1.60	4.28	4.67	1.50	4.51	4.69
400	5.20	9.70	9.53	6.30	9.52	9.78
500	16.40	16.61	12.09	17.20	16.36	12.40
-500	75.50	60.86	42.16	73.40	59.43	43.79
	3/24/05			3/28/05		
Mesh	Mag Oflo	Plant Oflo	Feed	Mag Oflo	Plant Oflo	Feed
100	0.00	0.00	2.08	0.00	0.00	1.10
150	0.00	0.00	4.83	0.10	0.00	4.07
200	0.20	0.77	8.04	0.40	2.79	6.53
270	2.20	8.46	13.78	3.20	10.16	13.60
325	1.90	4.04	5.89	2.30	3.39	7.60
400	6.40	9.42	8.57	7.90	9.96	8.67
500	15.60	16.54	13.68	16.70	15.74	13.88
-500	73.70	60.77	43.14	69.40	57.97	44.54
	3/29/05			3/30/2005-1		
Mesh	Mag Oflo	Plant Oflo	Feed	Mag Oflo	Plant Oflo	Feed
100	0.00	0.00	2.25	0.00	0.00	3.93
150	0.00	0.00	5.68	0.10	0.00	7.99
200	0.60	2.47	7.79	0.50	0.41	11.22
270	3.47	10.27	14.67	3.40	6.19	15.83
325	3.42	6.57	4.70	4.40	5.13	5.46
400	6.14	6.83	10.35	7.50	8.05	8.09
500	16.60	13.92	13.17	15.70	16.70	11.14
-500	69.77	59.94	41.39	68.40	63.52	36.34

Appendix III Continued						
	3/30/2005-2			3/31/05		
Mesh	Mag Oflo	Plant Oflo	Feed	Mag Oflo	Plant Oflo	Feed
100	0.00	0.00	2.30	0.00	0.00	2.95
150	0.10	0.00	6.57	0.10	0.00	7.31
200	0.60	0.33	9.75	0.50	0.62	10.04
270	3.50	4.24	14.96	4.20	7.37	14.70
325	5.50	4.39	4.91	4.10	5.81	5.15
400	6.90	6.46	9.44	8.20	7.49	8.35
500	16.30	16.43	11.41	17.80	16.84	11.72
-500	67.10	68.16	40.66	65.10	61.88	39.79
		No Magnets				
	3/2/05			3/4/2005-1		
Mesh	Non Mag	Plant Oflo	Feed	Non Mag	Plant Oflo	Feed
100	0.00	0.00	2.69	0.00	0.00	3.36
150	0.10	0.00	5.94	0.05	0.04	6.84
200	1.03	1.55	8.42	0.49	2.14	9.53
270	6.30	8.88	14.02	4.25	10.76	14.32
325	5.37	5.82	5.57	5.24	7.15	5.77
400	8.15	7.56	8.11	5.43	6.20	8.15
500	17.03	16.40	12.66	17.24	15.90	12.73
-500	62.02	59.79	42.58	67.29	57.81	39.30
	3/4/2005-2			3/11/2005-1		
Mesh	Non Mag	Plant Oflo	Feed	Non Mag	Plant Oflo	Feed
100	0.00	0.04	3.73	0.00	0.00	6.41
150	0.05	0.04	7.18	0.00	0.00	9.79
200	0.45	1.70	10.19	0.19	1.05	12.17
270	4.80	10.78	14.93	4.82	9.97	14.40
325	5.65	7.99	6.48	4.18	5.59	4.45
400	5.96	6.00	6.51	11.20	8.74	7.05
500	17.01	17.75	12.27	17.05	14.86	9.85
-500	66.08	55.70	38.70	62.57	59.79	35.88
	3/11/2005-2			3/14/2005-1		
Mesh	Non Mag	Plant Oflo	Feed	Non Mag	Plant Oflo	Feed
100	0.00	0.00	6.93	0.00	0.00	6.02
150	0.00	0.00	10.43	0.03	0.00	9.30
200	0.16	0.20	12.61	0.30	0.73	11.99
270	4.89	5.33	14.27	4.80	8.23	14.67
325	4.57	3.89	5.06	5.54	3.47	5.28
400	11.25	7.38	6.32	10.90	9.87	7.20
500	17.92	15.37	9.68	18.35	16.27	10.38
-500	61.21	67.83	34.69	60.08	61.43	35.16

Appendix III Continued						
	3/14/2005-2			3/8/05		
Mesh	Non Mag	Plant Oflo	Feed	Non Mag	Plant Oflo	Feed
100	0.00	0.00	4.41	0.00	0.00	4.65
150	0.00	0.00	8.75	0.04	0.00	7.81
200	0.17	0.97	11.81	0.32	1.25	10.57
270	4.00	10.18	15.61	4.96	10.38	14.48
325	6.00	6.14	4.89	4.56	5.09	6.23
400	10.91	9.37	8.37	8.39	9.42	7.18
500	19.52	16.32	10.20	15.33	13.71	11.43
-500	59.40	57.03	35.95	66.40	60.15	37.63
	3/10/2005-1			3/10/2005-2		
Mesh	Non Mag	Plant Oflo	Feed	Non Mag	Plant Oflo	Feed
100	0.03	0.06	4.54	0.03	0.03	4.77
150	0.12	0.00	8.53	0.10	0.03	9.09
200	0.56	0.93	11.24	0.57	1.41	12.27
270	5.29	8.11	14.00	5.84	8.20	14.65
325	4.49	4.78	6.50	5.08	4.37	5.58
400	8.29	9.07	5.91	8.48	9.67	6.68
500	15.88	16.90	11.04	16.71	17.01	11.00
-500	65.34	60.16	38.24	63.18	59.28	35.94
	3/15/2005-1			3/15/2005-2		
Mesh	Non Mag	Plant Oflo	Feed	Non Mag	Plant Oflo	Feed
100	0.00	0.00	2.19	0.00	0.00	4.16
150	0.00	0.00	6.39	0.00	0.00	7.90
200	0.50	0.50	8.56	0.60	0.83	9.68
270	2.60	7.15	13.90	3.90	8.83	15.29
325	3.60	5.66	6.01	4.20	5.83	5.81
400	6.50	7.65	8.72	6.00	8.83	7.45
500	17.10	17.80	12.40	19.10	16.33	12.06
-500	69.70	61.23	41.83	66.20	59.33	37.65
	3/16/05			3/17/2005-1		
Mesh	Non Mag	Plant Oflo	Feed	Non Mag	Plant Oflo	Feed
100	0.00	0.00	3.08	0.00	0.00	2.18
150	0.00	0.00	6.82	0.00	0.00	6.16
200	0.20	1.50	9.30	0.30	0.33	9.15
270	1.70	9.18	14.95	2.60	6.58	14.83
325	2.60	6.01	5.38	1.40	4.77	4.88
400	4.40	7.18	8.16	7.20	8.72	9.40
500	15.30	17.36	12.24	17.40	16.94	12.87
-500	75.80	58.76	40.07	71.10	62.66	40.53

Appendix III Continued						
	3/17/2005-2					
Mesh	Non Mag	Plant Oflo	Feed			
100	0.00	0.00	2.59			
150	0.00	0.00	6.81			
200	0.50	0.74	9.67			
270	3.30	6.70	14.99			
325	3.80	3.72	5.58			
400	7.60	9.93	8.44			
500	17.90	16.87	12.13			
-500	66.90	62.03	39.78			