

**INVESTIGATION OF METAL
HYDROXIDE SOLUBILITY FROM
SLUDGE IN ACIDIC MINE WATER
CONDITIONS**

AT-1

This project was prepared for
CANMET, Energy Mines and Resources Canada, Canada Centre for Mineral Energy
Technology
By
NB Coal Limited

March 1997

**INVESTIGATION OF METAL HYDROXIDE
SOLUBILITY FROM SLUDGE IN
ACIDIC MINE WATER CONDITIONS**

FINAL REPORT

March, 1997

Prepared for:

CANMET Contract

23440-4-1196

Serial No. 41196-01SQ

Energy Mines and Resources Canada

Canada Centre for Mineral and Energy Technology

555 Booth Street

Ottawa, Ontario

K1A 0G1

Submitted by:

NB Coal Limited

P.O. Box 520

Minto, New Brunswick

E0E 1J0



March 11, 1997

VIA-5019

N.B. Coal Limited
P.O. Box 520
Minto, NB
E0E 1J0

Attention: Michele Coleman

Michele;

Please find enclosed 7 copies of a final report entitled, "Investigation of Metal Hydroxide Solubility from Sludge in Acidic Mine Water Conditions" relating to amended CANMET Contract #23440-4-1196/01-SQ and your purchase order # N900-0525-95.

Thank you for your participation on this project.

Yours truly,

A handwritten signature in cursive script that reads 'T. Whalen'.

T. Whalen, EIT
Project Coordinator

TJW/nms
attachment

TABLE OF CONTENTS

1.0 INTRODUCTION	Page 1
2.0 OBJECTIVES	Page 1
3.0 EXPERIMENTAL RESULTS	Page 2
3.1 Initial Solids Sampling & Characterization	Page 2
3.2 Laboratory Generated Sludge Characterization	Page 4
3.3 Test Reactor Leachate Production, Sampling and Analysis	Page 4
4.0 CONCLUSIONS & RECOMMENDATIONS	Page 20
APPENDIX A	Leach Cycle Procedures
APPENDIX B	Photographs

LIST OF TABLES

TABLE 1	Initial Solids Characterization	Page 3
TABLE 2	Comparison of Other Measured Parameters	Page 8
TABLE 3	Comparison of Soluble Metal Concentrations	Page 9
TABLE 4	Soluble Metal Concentrations Progressive Situations 1 & 2 Composite Samples	Page 10
TABLE 5	Mass Solids Added and Removed	Page 11
TABLE 6	Final Solids Characterization	Page 13
TABLE 7	Comparison of Initial and Final Cell Contents	Page 14
TABLE 8	Summary of Metals Removed in Reactors 1,2 & 3	Page 15
TABLE 9	Summary of Metals Removed in Reactors 4,5 & 6	Page 16
TABLE 10	Percentage of Metals Removed	Page 17
TABLE 11	Potential Cost Savings	Page 18
TABLE 12	Variations In Solids Chemistry	Page 19

LIST OF FIGURES

FIGURE 1	Reactor Trends - Mine Water pH	Page 5
FIGURE 2	Reactor Trends - Mine Water Conductivity	Page 6

1.0 INTRODUCTION

This investigation will pursue an aggressive leach of fresh and aged samples of wastewater treatment plant solids from NB Coal Ltd.'s Fireroad hydrated lime neutralization facility using acid mine water collected from the site to monitor the leachability of iron, aluminum and other minor metal hydroxides contained in the solids. This investigation will use samples of relatively fresh (< 2 months) and also aged (1 to 3 years) solids. Each sample will be batch leached with acidic mine water. A total of 10 two week leach cycles will be conducted in triplicate using 3 reactors containing fresh solids and 3 reactors containing aged solids. In addition, 2 reactors monitoring progress of solid amendments in the water will be investigated. These sensitivity cases will monitor the effect of the newly generated sludge from the mine water and the behaviour of the solids when it is reintroduced into the acidic mine water after treatment to pH 8.5.

2.0 OBJECTIVES

The current investigation has been initiated to address concerns related to the solubility of metal hydroxides in the hydrated lime neutralization solids in acidic leach conditions. More specifically, however, the investigation will address the following concerns:

- 1) To what extent will the metal hydroxides contained in the solids dissolve in acidic mine water ?
- 2) What will be the effect on the demand of hydrated lime required to neutralize the mine water which has been in contact with the relocated solids ?

3.0 EXPERIMENTAL RESULTS

3.1 INITIAL SOLIDS SAMPLING & CHARACTERIZATION

Sludge samples were collected from recent and aged sedimentation ponds for the test program and eight reactors have been set up using the solids collected as follows:

Reactors 1,2 & 3	Fresh Solids (Triplicate)
Reactors 4,5 & 6	Aged Solids (Triplicate)
Reactor 7	Sensitivity Case 1 (Fresh Solids)
Reactor 8	Sensitivity Case 2 (Fresh Solids)

The leach cycle procedures for all reactors are included in Appendix A.

The volumes of solids introduced into each reactor were based on tests conducted to determine the quantity of solids required to raise the solution pH to 5 after mixing for approximately 10 minutes. Approximately 64 g of fresh solids and 51 g of aged solids were added to reach the target pH of 5. Based on this information, it was concluded that 50 g of solids should be added to each of the 8 reactors for the test program.

Color photographs of the bench scale reactors and their contents have been included in Appendix B for cycles 1 and 10.

The solids collected were also subjected to detailed initial characterization of % moisture, total sulfur, sulfate sulfur, neutralization potential and analysis of Al, Ca, Cu, Fe, Mg, Mn & Zn after nitric acid digestion. These results are presented in Table 1.

The data collected for the fresh and aged solids in Table 1 indicate that these solids are predominantly composed of calcium sulfate, lime, aluminum hydroxide and iron hydroxide. In addition, the fresh solids appear to have a slightly higher theoretical lime content, which would indicate that the fresh solids should be capable of neutralizing more mine water. It should also be noted that significantly higher levels of aluminum, iron, manganese and zinc were present in the aged

TABLE 1
Initial Solids Characterization

Sample Number	Sample Description	Moisture Content (%)	Total Sulfur (%)	Total Sulfur (After HCl) (%)	Sulfate Sulfur (%)	Theoretical CaSO4 Content (lb/Ton)	Theoretical CaSO4 Content Dry (%)	Theoretical CaSO4 Content As Received (%)	Acid Consumption (lb/ton)	Theoretical CaO Content Dry (wt %)	Theoretical CaO Content As Received (wt %)
V1A-5019-FS-01	Fresh Solids	88.40	1.87	<0.05	1.87	158.81	7.94	0.92	434	12.41	1.44
V1A-5019-FS-02	Fresh Solids	88.80	1.96	<0.05	1.96	166.46	8.32	0.93	422	12.07	1.35
V1A-5019-FS-03	Fresh Solids	90.00	2.25	<0.05	2.25	191.09	9.55	0.96	413	11.81	1.18
Average	Fresh Solids	89.07	2.03	<0.05	2.03	172.12	8.61	0.94	423	12.09	1.32
V1A-5019-AS-01	Aged Solids	86.80	4.55	0.09	4.46	378.77	18.94	2.50	353	10.09	1.33
V1A-5019-AS-02	Aged Solids	86.70	4.18	0.05	4.13	350.75	17.54	2.33	356	10.18	1.35
V1A-5019-AS-03	Aged Solids	87.00	4.44	0.07	4.37	371.13	18.56	2.41	363	10.38	1.35
Average	Aged Solids	86.83	4.39	0.07	4.32	366.88	18.34	2.41	357	10.22	1.35

Sample Number	Sample Description	Moisture Content (%)	Metals Analysis of Digested Solids Samples													
			Al		Ca		Cu		Fe		Mg		Mn		Zn	
			(ug/g)	%	(ug/g)	%	(ug/g)	%	(ug/g)	%	(ug/g)	%	(ug/g)	%	(ug/g)	%
V1A-5019-FS-01	Fresh Solids	87.90	33828	3.38	59528	5.95	13.18	0.001	18880	1.89	12980	1.30	12534	1.25	324	0.03
V1A-5019-FS-02	Fresh Solids	90.90	40747	4.07	89890	8.99	23.93	0.002	20991	2.10	12326	1.23	15318	1.53	398	0.04
V1A-5019-FS-03	Fresh Solids	90.00	38802	3.88	64253	6.43	12.67	0.001	19696	1.97	11130	1.11	13573	1.36	352	0.04
Average	Fresh Solids	89.60	37792	3.78	71224	7.12	17	0.002	19856	1.99	12145	1.21	13808	1.38	358	0.04
V1A-5019-AS-01	Aged Solids	86.20	127748	12.77	86831	8.68	57.78	0.006	40286	4.03	10116	1.01	22235	2.22	1338	0.13
V1A-5019-AS-02	Aged Solids	86.70	146728	14.67	86129	8.61	58.08	0.006	46564	4.66	10881	1.09	24376	2.44	1483	0.15
V1A-5019-AS-03	Aged Solids	86.20	133188	13.32	83128	8.31	59.89	0.006	44292	4.43	10415	1.04	25673	2.57	1375	0.14
Average	Aged Solids	86.37	135888	13.59	85363	8.54	59	0.006	43714	4.37	10471	1.05	24095	2.41	1399	0.14

solids which would indicate the presence of more metal hydroxides, in addition to higher levels of calcium sulfate. Based on these factors, it may be safe to assume that the fresh solids would be more effective in reducing the acidity of the mine water. This will be confirmed later in the report based on other data collected during the test program.

3.2 LABORATORY GENERATED SLUDGE CHARACTERIZATION

A lab generated sludge was produced from a 1L mine water sample (based on the pre-determined acidity) after treatment with powdered hydrated lime to produce a typical solid waste product. The powdered hydrated lime (0.80 g) was slurried with 200 mL of mine water taken from the 1L sample and mixed for 15 minutes. The lime slurry was subsequently injected into the mine water and agitated for approximately 35 minutes in order to achieve a final treated effluent with a pH of 8.4. After allowing the solids to settle and compact for a period of 16 hours, 120 mL of solids was produced. The solids produced were also analyzed for moisture content and a portion of the solids were retained and digested for determination of calcium and iron fractions as follows:

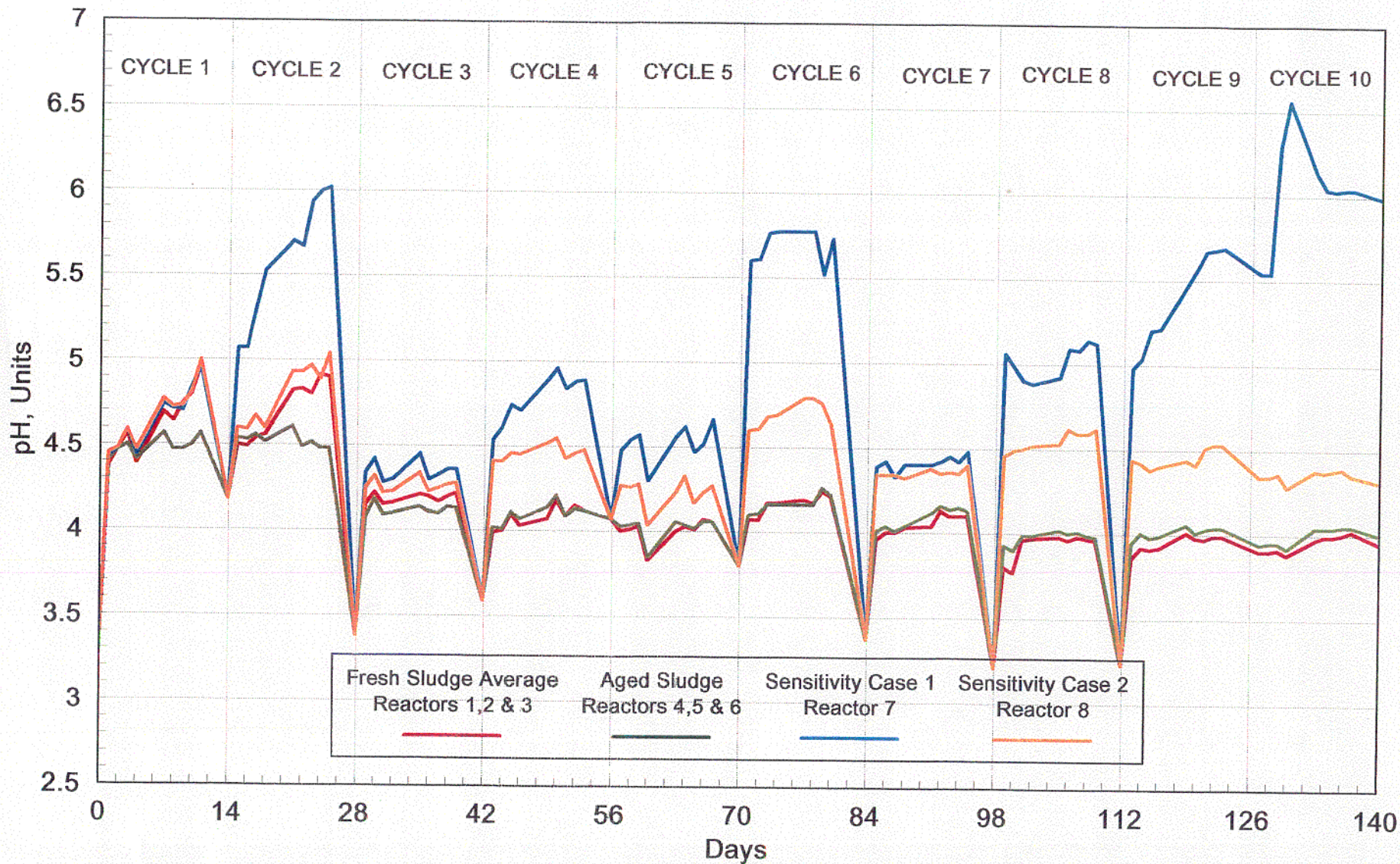
Moisture Content:	91.5%
Ca Fraction:	88720 $\mu\text{g/g}$
Fe Fraction:	2670 $\mu\text{g/g}$

3.3 TEST REACTOR LEACHATE PRODUCTION, SAMPLING AND ANALYSIS

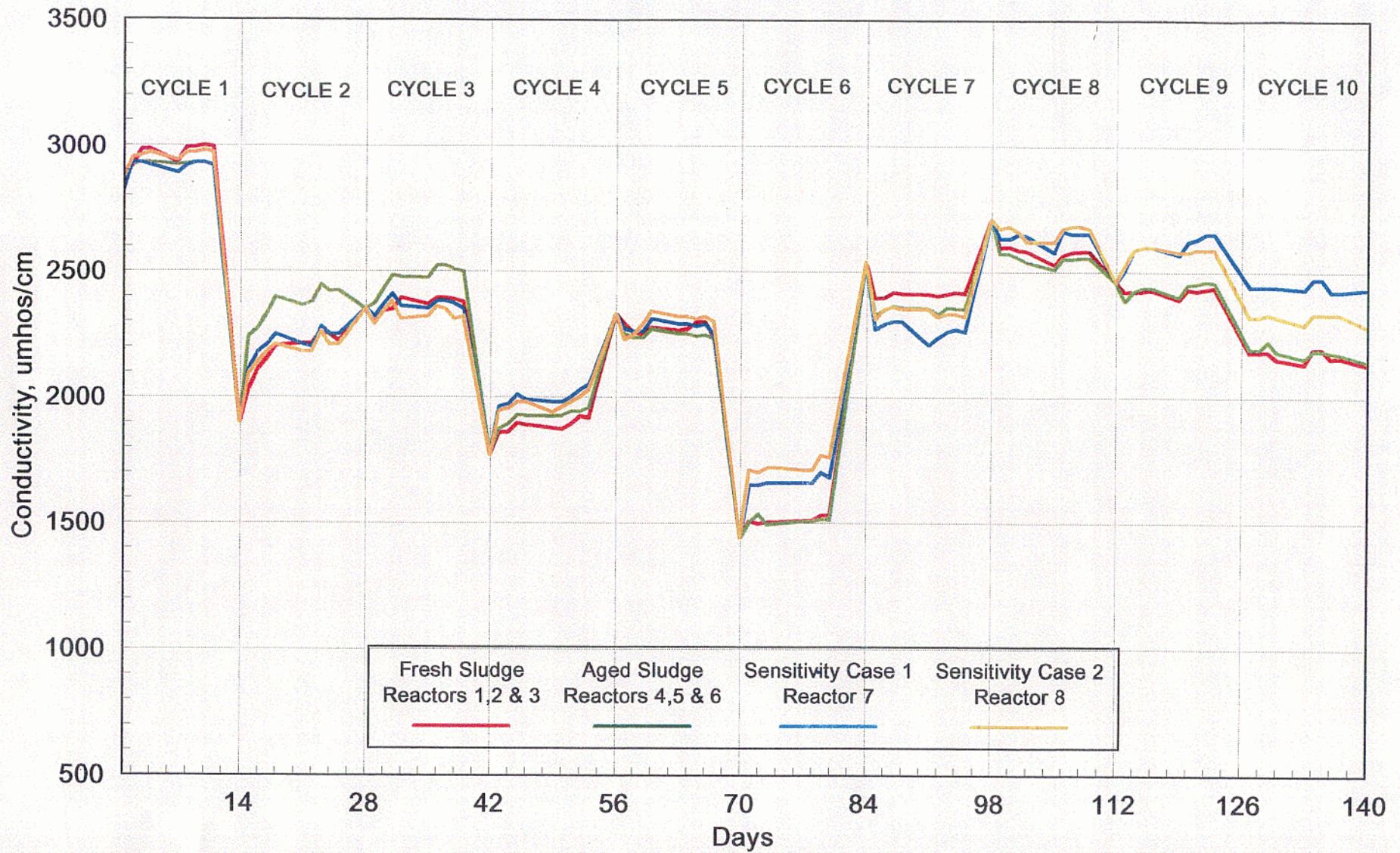
The pH and conductivity of the mine water added to each of the reactors has been measured on a daily basis for 10 complete 2 week leach cycles. These results are presented in Figures 1 and 2 respectively. Based on the information collected, the pH in all reactors has remained above pH 2 of the mine water added at the start of each leach cycle.

The mine water added to each reactor at the start of each leach cycle and the leachate removed at the completion of each cycle has also been analyzed for pH, Eh, acidity, conductivity,

REACTOR TRENDS
FIGURE 1 - MINE WATER pH



REACTOR TRENDS
FIGURE 2 - MINE WATER CONDUCTIVITY



sulfate concentration and soluble metal concentrations which include Al, Ca, Cu, Fe, Mg, Mn & Zn. These results are presented in Tables 2 and 3. The results in Table 2 indicate that most of the available alkalinity contained in the neutralization solids has been removed after 5 complete leach cycles as the acidities remain lower than the original mine water samples added at the start of each cycle for the period. Following the removal of the available alkalinity contained in the solids, the reported acidity levels within the leachate collected at the end of each cycle essentially remain the same as the acidity of the mine water added at the start of each leach cycle.

The results in Table 3 indicate that a portion of the metals (ie. calcium, magnesium, manganese and zinc) have dissolved during the first 4 leach cycles to some extent based on a slight increase in the soluble metal concentrations. However, the soluble iron concentrations have remained significantly lower in the leachate collected at the completion of each cycle in comparison to the mine water added at the start of each leach cycle.

Table 4 presents the soluble metal concentrations found in the composite samples collected during the program for the progressive situations (reactors 7 and 8). The supernatant collected from both reactors exhibits extremely low concentrations of soluble Al, Cu, Fe and Zn which is typical of a lime treated mine water sample. The relatively high concentrations of Ca and Mg (approximately 500 mg/L and 85 mg/L respectively) are also typical due to dissolving of the inherent calcium sulfate and magnesium hydroxide present in the waste water treatment plant solids found at the Fireroad Mine Site. The levels of soluble manganese (on the order of 25 mg/L) are also consistent with the fact that the manganese (present in the mine water) does not precipitate well as a metal hydroxide and thus would continue to remain in solution.

Table 5 presents the quantities of solids originally added to each reactor and the subsequent quantity removed from each reactor at the completion of the test program. As the results indicate, the mass removed from each of the reactors is slightly higher for reactors 1 thru 6 and significantly higher for reactors 7 and 8 as follows:

TABLE 2
Comparison of Other Measured Parameters

Description	Parameter	Cycle									
		1	2	3	4	5	6	7	8	9	10
Minewater	pH (units)	3.28	4.18	3.38	3.59	4	3.8	3.37	3.21	3.23	3.48
	Eh (mV)	560	447	520	407	366	522	565	584	487	434
	Cond. (umhos/cm)	2860	1900	2350	1770	2330	1440	2540	2710	2460	2270
	SO4 (mg/L)	2103	1288	1398	1398	1715	856	1715	4384	1938	3163
	Acidity as CaCO3 to pH 8.5	849	305	801	611	839	290	724	828	837	574
Fresh Sludge Reactors 1,2 &3	pH (units)	5.32	5.53	4.27	4.23	4.15	4.14	4	4.05	4.03	3.98
	Eh (mV)	223	308	404	469	467	374	447	453	479	474
	Cond. (umhos/cm)	2913	2223	2303	1903	2227	1525	2340	2520	2363	2143
	SO4 (mg/L)	1939	1274	1837	1456	2104	975	2730	2221	3726	1362
	Acidity as CaCO3 to pH 8.5	33	23	397	543	583	284	716	837	723	612
Aged Sludge Reactors 4,5 & 6	pH (units)	4.73	4.62	4.18	4.19	4.16	4.16	4.06	4.1	4.06	4
	Eh (mV)	385	371	446	448	482	434	478	467	488	480
	Cond. (umhos/cm)	2837	2430	2433	1947	2270	1520	2317	2480	2400	2170
	SO4 (mg/L)	1993	1308	1835	1518	1539	995	2343	2161	3724	1517
	Acidity as CaCO3 to pH 8.5	147	85	560	594	623	279	704	839	676	644
Reactor 7	pH (units)	5.67	6.02	4.58	5.8	4.62	5.23	4.34	5.6	5.84	5.85
Reactor 8	pH (units)	5.21	5.38	4.31	4.61	4.32	4.43	4.13	4.71	4.49	4.29

TABLE 3
Comparison of Soluble Metal Concentrations

Description	Soluble (mg/L)	Cycle									
		1	2	3	4	5	6	7	8	9	10
Minewater	Al	126	35.1	107	87.2	98	28.9	112	130	119	109
	Ca	332	295	300	241	296	205	333	330	322	284
	Cu	0.052	0.02	0.035	0.035	0.034	<0.007	0.036	0.038	0.028	0.03
	Fe	7.21	0.293	4.33	2.12	3.68	0.258	4.22	11.8	2.9	2.62
	Mg	119	52.8	95.7	78.3	95.9	44.7	102	111	108	92.5
	Mn	62.2	24.5	43.1	33.6	43.5	13.3	56.8	59.8	42.8	41.1
	Zn	1.66	0.705	1.57	1.21	1.57	0.402	2.02	2.58	1.92	1.76
Fresh Sludge Reactors 1,2 & 3	Al	2.61	0.4	54.8	79.8	128	45.5	126	145	134	93.1
	Ca	549	433	404	242	334	194	312	334	311	235
	Cu	<0.007	<0.006	0.011	0.01	0.018	0.011	0.032	0.035	0.042	0.038
	Fe	0.018	0.013	0.084	0.111	0.161	0.059	0.177	0.22	0.186	0.181
	Mg	164	65.9	110	80	106.3	48.3	106	124	107.3	75.6
	Mn	69.8	23.6	50.1	40.3	50.1	22.9	58.6	71.4	55.9	46.7
	Zn	0.71	0.21	2.1	1.91	2.36	1.01	2.29	2.69	2.28	1.75
Aged Sludge Reactors 4,5 & 6	Al	11.3	7.89	79.1	85.3	126	44.4	120	145	137	106
	Ca	505	536	448	275	317	202	307	338	316	262
	Cu	<0.007	<0.006	0.011	0.008	0.017	0.006	0.019	0.02	0.034	0.028
	Fe	0.027	0.027	0.102	0.144	0.124	0.053	0.148	0.167	0.178	0.157
	Mg	165	75	101	79.5	98.7	46.4	101	120.7	109.3	83.1
	Mn	78.2	34.4	49	41.9	41.2	22.8	57.6	69.5	60.1	45.9
	Zn	1.59	1.13	3.34	2.45	1.78	1.31	2.55	2.96	2.62	1.87

TABLE 4
Soluble Metal Concentrations
Progressive Situations 1 & 2 Composite Samples

Parameter	Reactor 7 (mg/L)	Reactor 8 (mg/L)
Al	<0.032	0.121
Ca	488	491
Cu	<0.007	<0.007
Fe	<0.010	<0.010
Mg	85.7	83.2
Mn	22.2	23.9
Zn	0.012	0.08

TABLE 5
Mass of Solids Added and Removed

Reactor #	Type of Solids	Initial Mass of Solids Added (As Received) (g)	Initial Moisture Content (%)	Initial Mass of Solids Added (Dry Basis) (g)	Final Mass of Solids Removed (Dry Basis) (g)
1	Fresh	50	89.07	5.47	5.6
2	Fresh	50	89.07	5.47	5.5
3	Fresh	50	89.07	5.47	5.6
Average		50	89.07	5.47	5.57
4	Aged	50	86.83	6.59	6.8
5	Aged	50	86.83	6.59	7.1
6	Aged	50	86.83	6.59	6.8
Average		50	86.83	6.59	6.90
7	Fresh	50	89.07	5.47	10.6
8	Fresh	50	89.07	5.47	10.4

Reactors 1,2&3	Increase of approximately 2%
Reactors 4,5&6	Increase of approximately 5%
Reactor 7	Increase of approximately 93%
Reactor 8	Increase of approximately 90%

As expected, the net result of adding the solids to the mine water (based on reactors 1 thru 6) has resulted in an increase of solids based on the fact that more solids were formed from precipitation than solids dissolved during the test program. The significantly higher increase of solids found in reactors 7 and 8 is consistent with the fact that the solids produced from the treatment of the supernatant at the end of each leach cycle were subsequently added back to the reactors.

Table 6 presents final characterization of the reactor solids for calculation of theoretical calcium sulfate and lime present in the samples. The difference in the amounts of these compounds are summarized in Table 7.

The decrease in the amount of calcium sulfate found in reactors 1 thru 6 can be attributed to dissolving of the inherent calcium sulfate originally found in the solids. The decrease in the amount of theoretical lime found is consistent with the fact that the excess lime contained in the solids has reacted with the soluble metals found in the leachate to form insoluble metal hydroxides.

The increase in the theoretical calcium sulfate content of the solids collected from reactors 7 and 8 is consistent with the fact that the solids produced from the lime treatment to pH 8.5 would contain calcium sulfate and are subsequently added back to the reactors. In addition, the smaller decrease in the theoretical lime content in these reactors can be explained by the presence of unreacted lime found in the returned solids which would be present based on the reaction time of 15 minutes (rather than the 30 minutes which would be required to fully utilize the lime added during the treatment).

TABLE 6
Final Solids Characterization

Sample Number	Sample Description	Total Sulfur (%)	Total Sulfur (After HCl) (%)	Sulfate Sulfur (%)	Theoretical CaSO ₄ Content (lb/Ton)	Theoretical CaSO ₄ Content Dry (%)	Acid Consumption (lb/ton)	Theoretical CaO Content Dry (wt %)
V1A-5019-R-01	Fresh Solids	1.18	0.10	1.08	91.72	4.59	93	2.66
V1A-5019-R-02	Fresh Solids	1.04	0.06	0.98	83.23	4.16	88	2.52
V1A-5019-R-03	Fresh Solids	1.26	0.05	1.21	102.76	5.14	87	2.48
Average	Fresh Solids	1.16	0.07	1.09	92.57	4.63	89	2.55
V1A-5019-R-04	Aged Solids	3.88	0.08	3.80	322.72	16.14	89	2.54
V1A-5019-R-05	Aged Solids	3.42	0.20	3.22	273.46	13.67	86	2.45
V1A-5019-R-06	Aged Solids	3.76	0.17	3.59	304.89	15.24	69	1.96
Average	Aged Solids	3.69	0.15	3.54	300.36	15.02	81	2.32
V1A-5019-R-07	Fresh Solids	2.38	0.10	2.28	193.63	9.68	283	8.09
V1A-5019-R-08	Fresh Solids	2.95	0.07	2.88	244.59	12.23	290	8.29

TABLE 7
Comparison of Initial and Final Cell Contents

Reactor #'s	Theoretical Dry CaSO ₄ Content (%)		% Diff.	Theoretical Dry CaO Content (%)		% Diff.
	Initial	Final		Initial	Final	
1,2&3	8.61	4.63	- 46 %	12.09	2.55	- 79 %
4,5&6	18.34	15.02	- 18 %	10.22	2.32	- 77 %
7	8.61	9.68	+ 13 %	12.09	8.09	- 33 %
8	8.61	12.23	+ 42 %	12.09	8.29	- 31 %

After 10 complete leach cycles, the solids contained in each reactor have been subjected to the same detailed analysis undertaken at the start of the test program. The data collected during this study have provided results to determine the following:

- I) The percentage of each metal removed from each reactor during the leach cycles are summarized with comments below in Tables 8 and 9. Detailed results are presented in Table 10:

TABLE 8
Summary Of Metals Removed - Reactors 1,2 & 3

Reactors 1, 2 & 3 (Fresh Solids)		
Parameter	Difference (+/- %)	Comments
Al	+ 61 %	-Due to the precipitation of Al. -Confirmed by reduction of Al in leachate during first 4 cycles.
Ca	- 98 %	-Due to dissolving of CaSO ₄ . -Confirmed by increase in Ca in leachate during first 4 cycles.
Cu	+ 77 %	-Due to the precipitation of Cu. -Confirmed by reduction of Cu in leachate during first 4 cycles.
Fe	+102 %	-Due to the precipitation of Fe. -Confirmed by reduction of Fe in leachate during all cycles.
Mg	- 80 %	-Due to dissolving of Mg(OH) ₂ . -Confirmed by increase in Mg in leachate for most cycles.
Mn	- 17 %	-Due to dissolving of some of the Mn. -Confirmed by increase in Mn in leachate for most cycles.
Zn	- 42 %	-Due to dissolving of Zinc Hydroxide. -Confirmed by increase in Zn in leachate for most cycles.

TABLE 9
Summary Of Metals Removed - Reactors 4,5 & 6

Reactors 4, 5 & 6 (Aged Solids)		
Parameter	Difference (+/- %)	Comments
Al	+ 29 %	- Due to the precipitation of Al. - Confirmed by reduction of Al in leachate during first 4 cycles. - Less than reactors 1,2 & 3 due to less theoretical lime available for neutralization.
Ca	- 97 %	- Due to dissolving of CaSO ₄ . - Confirmed by increase in Ca in leachate during first 4 cycles. - Approximately the same as reactors 1,2 & 3.
Cu	+ 51 %	- Due to the precipitation of Cu. - Confirmed by reduction of Cu in leachate during first 4 cycles. - Less than reactors 1,2 & 3 due to less theoretical lime available for neutralization.
Fe	+ 69 %	- Due to the precipitation of Fe. - Confirmed by reduction of Fe in leachate during all cycles. - Less than reactors 1,2 & 3 due to less theoretical lime available for neutralization.
Mg	- 77 %	- Due to dissolving of Mg(OH) ₂ . - Confirmed by increase in Mg in leachate for most cycles. - Approximately the same as reactors 1,2 & 3.
Mn	- 36 %	- Due to dissolving of some of the Mn. - Confirmed by increase in Mn in leachate for most cycles. - Higher than reactors 1,2 & 3 due to a larger amount of Mn present in aged solids.
Zn	- 57 %	- Due to dissolving of Zinc Hydroxide. - Confirmed by increase in Zn in leachate for most cycles. - Higher than reactors 1,2 & 3 due to a larger amount of Zn present in aged solids.

TABLE 10
Percentage of Metals Removed

Metal	Reactors 1,2&3 (Fresh Solids)						
	Ci (ug/g)	Mi (g)	CiMi (mg)	Cf (ug/g)	Mf (g)	CfMf (mg)	% Diff. (+/-)
Al	37792	5.47	207	59799	5.57	333	61
Ca	71224	5.47	390	1632	5.57	9.09	-98
Cu	16.59	5.47	0.09	29	5.57	0.16	78
Fe	19856	5.47	109	39489	5.57	220	103
Mg	12145	5.47	66.4	2375	5.57	13.2	-80
Mn	13808	5.47	75.5	11298	5.57	62.9	-17
Zn	358	5.47	1.96	204	5.57	1.14	-42

Metal	Reactors 4,5&6 (Aged Solids)						
	Ci (ug/g)	Mi (g)	CiMi (mg)	Cf (ug/g)	Mf (g)	CfMf (mg)	% Diff. (+/-)
Al	135888	6.59	896	167179	6.90	1154	29
Ca	85363	6.59	563	2302	6.90	15.88	-97
Cu	58.58	6.59	0.39	85	6.90	0.59	52
Fe	43714	6.59	288	70541	6.90	487	69
Mg	10471	6.59	69.0	2281	6.90	15.7	-77
Mn	24095	6.59	158.8	14765	6.90	101.9	-36
Zn	1399	6.59	9.22	574	6.90	3.96	-57

- II) The equivalent neutralization costs to treat mine water at the start and end of each leach cycle.

The equivalent neutralization costs can be calculated assuming a mine water volume of 10L and the cumulative acidities of the mine water, fresh solids leachate and aged solids leachate presented in Table 2.

Based on the cumulative mine water acidity, 6658 mg of CaCO₃ would be required to raise the pH of 10L of mine water to 8.5. In addition, mine water in contact with fresh and aged solids would require 4751 mg and 5151 mg respectively. A summary of the data and associated costs are included in Table 11 below.

TABLE 11
Potential Cost Savings

	Mine Water	Fresh Solids Leachate	Aged Solids Leachate
Theoretical Lime Required (mg)	6658 mg	4751 mg	5151 mg
Neutralization Costs (\$) (assuming \$100/mg CaCO ₃)*	\$665,800	\$475,100	\$515,100
Cost Savings (\$)	-	\$190,700	\$150,700
Cost Reduction (%)	-	29%	23%

Note: *Hypothetical values used for illustration purposes.

Based on the data collected during this program, it should be noted that there is expected to be a reduction in treatment cost associate savings in lime consumed in addition to the savings associated sludge disposal and subsequent handling. The volumes of mine

water to sludge (1L:0.05L or 20:1) used for this program indicate that a potential savings should exist due to the consumption of almost 30% and 25% less lime when the fresh and aged solids respectively are added to the mine water.

- III) The variation in the solids chemistry (calcium and iron) after neutralization of the decant water from each leach cycle. These results are presented in Table 12 below.

TABLE 12
Variation In Solids Chemistry

Cycle	Reactors 1,2 &3		Reactors 4,5 & 6	
	Ca	Fe	Ca	Fe
	($\mu\text{g/g}$)	($\mu\text{g/g}$)	($\mu\text{g/g}$)	($\mu\text{g/g}$)
1	IS	IS	IS	IS
2	IS	IS	IS	IS
3	55370	1680	55300	2470
4	44240	2735	25860	1730
5	37940	1580	41360	2057
6	51790	2387	71380	2259
7	62100	4210	103160	2580
8	71520	1450	66150	1600
9	92800	2010	87300	2700
10	110730	2250	81850	3500

Note: IS - Insufficient sample available for digestion.

These results are typical and appear to be consistent with the quality of the mine water treated.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be made based upon the results of the bench reactor studies:

- Precipitated wastewater treatment plant solids can be reintroduced into the acidic mine water without redissolving of significant metals.
- Solids reinjection would not have a detrimental effect on either lime consumption in the treatment plant or the quality of effluent treated.
- Upon reinjection into the acidic mine water, the neutralized lime content in the precipitated solids produced at the Fireroad site will assist with the neutralization process.
- From a utilization viewpoint, the fresh solids provided more neutralizing potential than the aged solids collected from the Fireroad site.
- The predominant compounds present in the precipitated solids were calcium sulfate, lime, aluminum hydroxide and ferric hydroxide.

APPENDIX A

LEACH CYCLE PROCEDURES

Main Program (in Triplicate - 6 Reactors)*

1. Characterize sludges as described in Table 1.
2. Inject sludge into mine water by pouring down along inside of reactor.
3. Characterize mine water as described in Table 2.
4. Add 1L mine water to reactor.
5. Monitor pH and conductivity of each reactor daily for 2 weeks.
6. After 2 weeks, remove and measure the supernatant volume collected.
7. Analyze each aliquot of supernatant for parameters outlined in Table 2.
8. A composite of all three supernatants will be prepared and a sample withdrawn and treated with powdered hydrated lime to achieve a simulated treated effluent with a pH of 8.5. the quantity of lime added will be based on the preceding acidity determination. The treated leachate will then be allowed to settle and the volume of solids will be recorded. The supernatant will be filtered and analyzed for parameters in Table 2. The sludge produced will be filtered, weighed, dried and digested for subsequent determination of calcium and iron fractions.
9. All sludges will be qualitatively described and photographed.
10. Repeat steps 3 through 9 for 10 complete leach cycles.
11. Repeat Step 1 at completion of program.

* Three reactors will contain fresh sludge and three reactors will contain aged sludge.

Progressive Situation - (Sensitivity Case -1 Reactor)

Objective: This situation monitors the impact on the mine water and sludge quality by continuous additions of sludge to the mine as could be anticipated from a continuous sludge deposition program.

1. Characterize sludge as described in Table 1.
2. Inject sludge into test reactor.
3. Characterize mine water as described in Table 2.
4. Add 1L mine water to reactor.
5. Monitor pH and conductivity of reactor daily for 2 weeks.
6. Add powdered hydrated lime to the reactor to achieve a simulated treated effluent of pH 8.5 and record amount added.
7. Allow sludge to settle, remove and measure the supernatant volume collected and retain 100 mL for composite sample to be analyzed at completion of the test program for parameters outlined in Table 2.
8. Sludge will be qualitatively described and photographed.
9. Repeat steps 3 through 8 for 10 complete leach cycles.
10. Repeat Step 1 at completion of program.

Progressive Situation 2 -(Sensitivity Case - 1 Reactor)

Objective: This situation monitors the impact on the mine water and sludge quality by continuous additions of sludge to the mine as could be anticipated from a continuous sludge deposition program.

1. Characterize sludge as described in Table 1.
2. Inject sludge into test reactor.
3. Characterize mine water as described in Table 2.
4. Add 1L mine water to reactor.
5. Monitor pH and conductivity of reactor daily for 2 weeks.
6. Allow sludge to settle, remove and measure the supernatant volume collected.
7. Add powdered hydrated lime to the supernatant to achieve a simulated treated effluent of pH 8.5 and record amount shown.
8. Allow sludge to settle, remove and measure the supernatant volume collected and retain 100 mL for composite sample to be analyzed at completion of the test program for parameters outlined in Table 2.
9. Sludge will be qualitatively described and photographed.
10. Add new sludge produced in Step 6 to the reactor.
11. Mixed sludge will be qualitatively described and photographed.
12. Repeat steps 3 through 11 for 10 complete leach cycles.
13. Repeat Step 1 at completion of program.

TABLE 1: SLUDGE CHARACTERIZATION

% Moisture	Net Neutralization Potential
Total Sulfur	SO ₄ Sulfur
Metals after Nitric Acid Digestion	
Al	Mg
Ca	Mn
Cu	Zn
Fe	

TABLE 2: MINE WATER CHARACTERIZATION

pH, Eh	Conductivity
Acidity	SO ₄ Concentration
Soluble Metals	
Al	Mg
Ca	Mn
Cu	Zn
Fe	

APPENDIX B

PHOTOGRAPHS



Figure B1 - Experimental Set Up



Figure B2- Reactors 1,2 &3 (week 0)

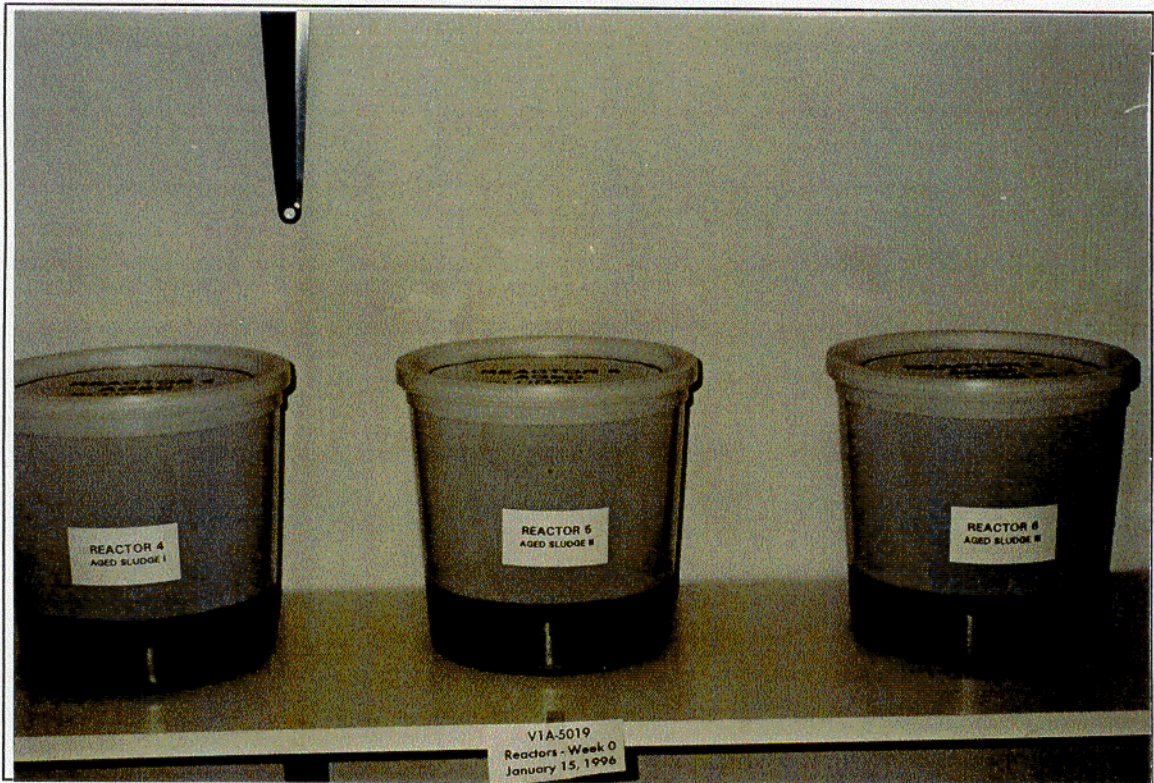


Figure B3 - Reactors 4,5 & 6 (Cycle 0)



Figure B4 - Reactors 7 & 8 (Cycle 0)



Figure B5 - Reactor 1 Contents (Cycle 1)

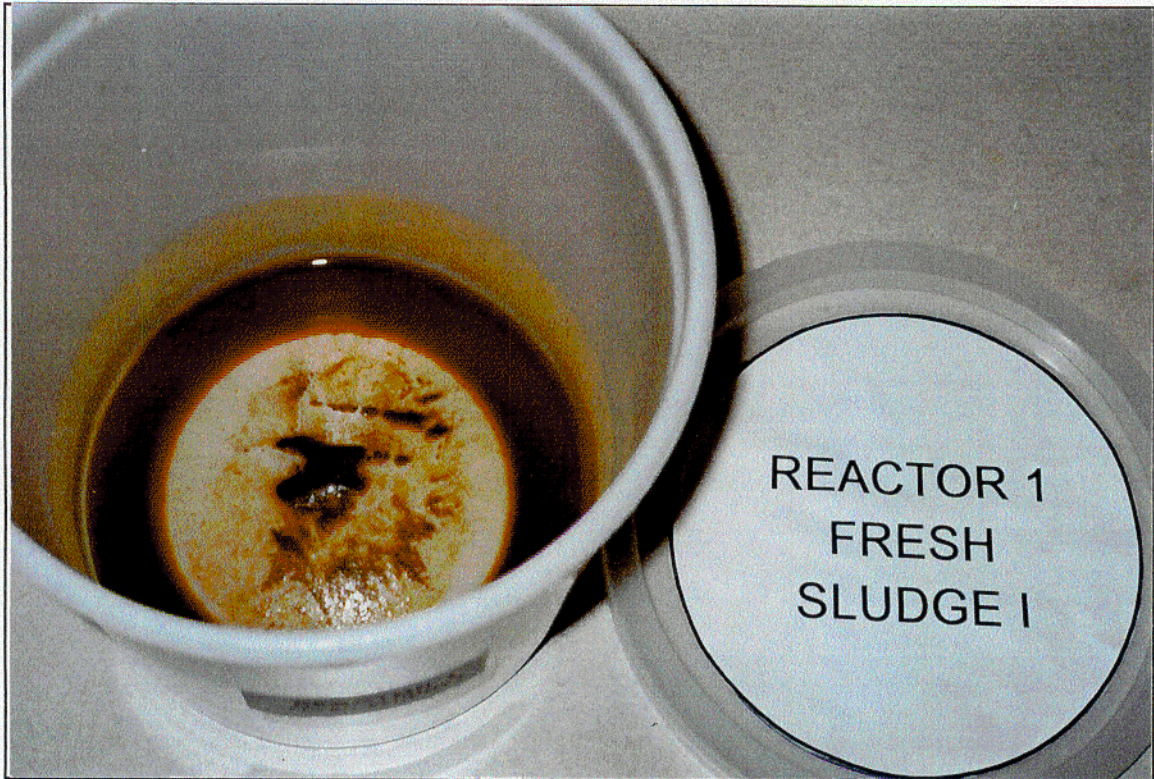


Figure B6 - Reactor 1 Contents (Cycle 10)

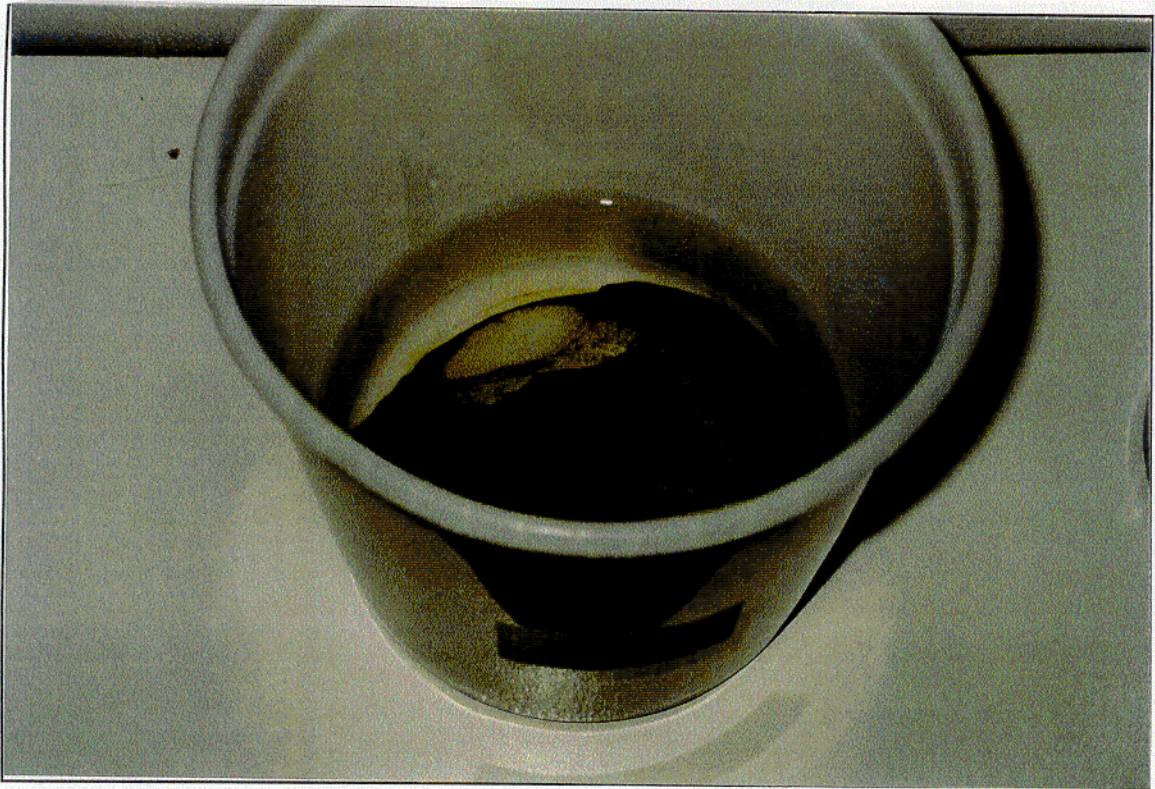


Figure B7 - Reactor 2 Contents (Cycle 1)

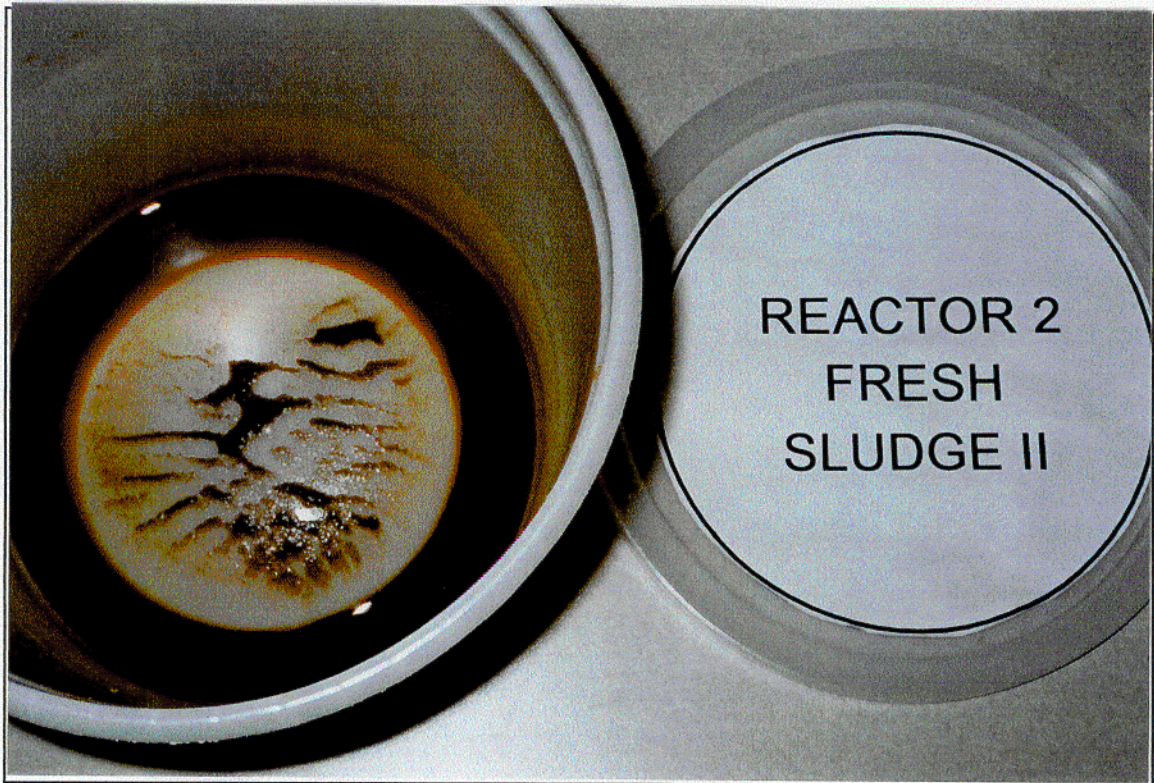


Figure B8 - Reactor 2 Contents (Cycle 10)



Figure B9 - Reactor 3 Contents (Cycle 1)

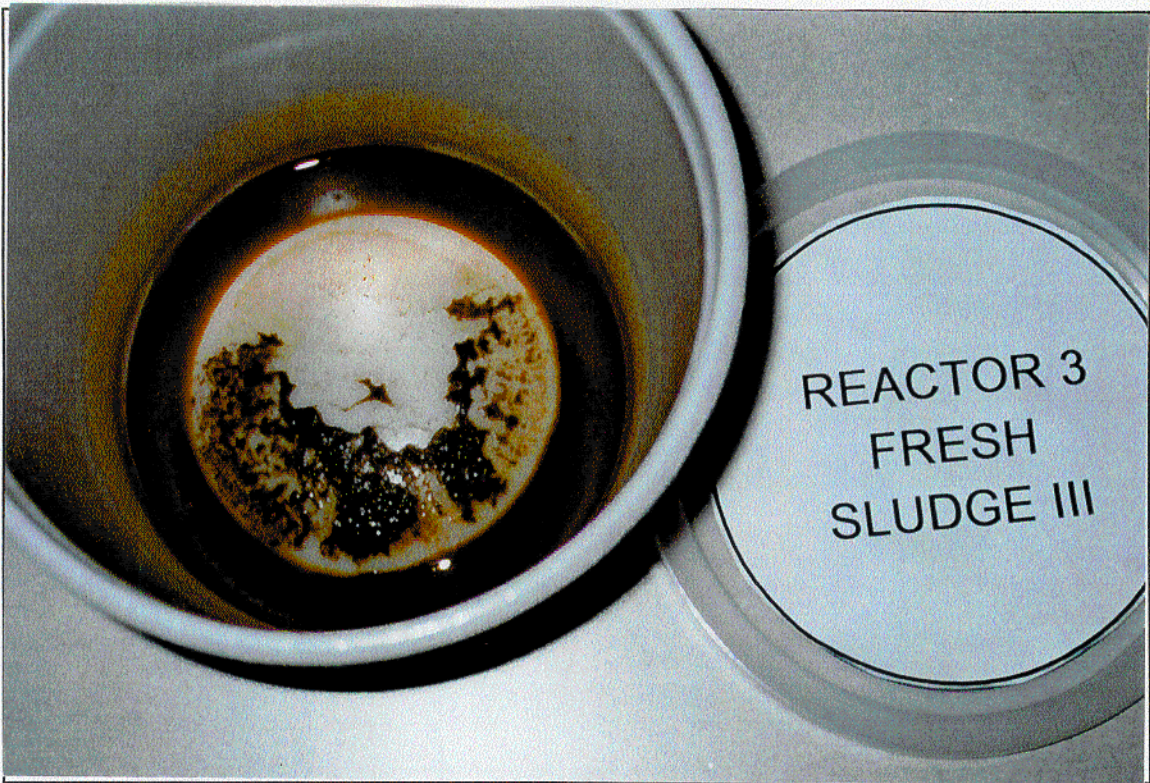


Figure B10 - Reactor 3 Contents (Cycle 10)

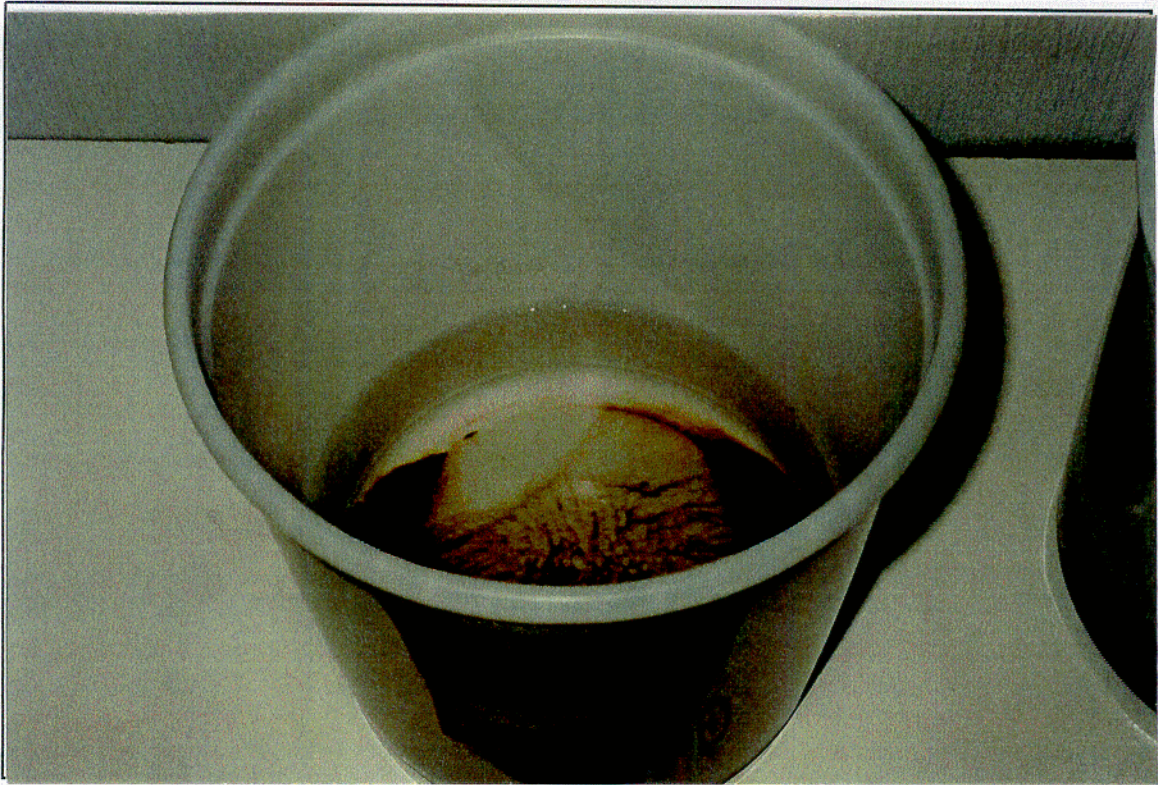


Figure B11 - Reactor 4 Contents (Cycle 1)

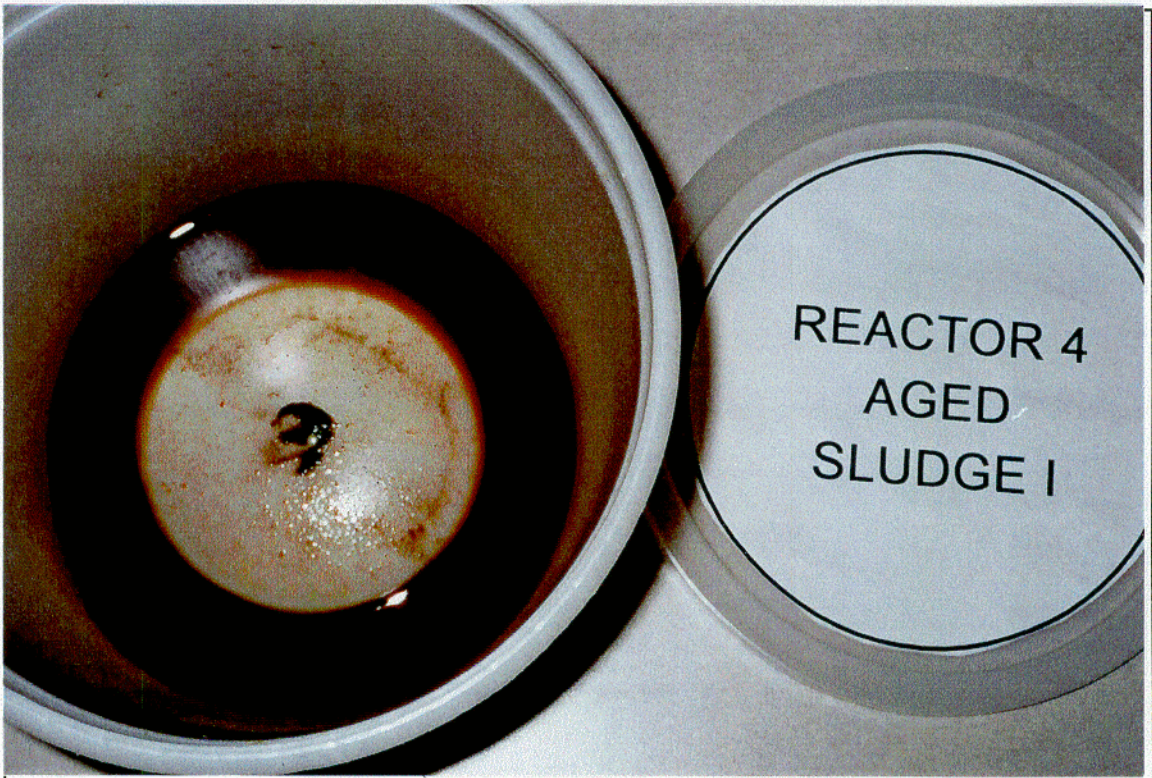


Figure B12 - Reactor 4 Contents (Cycle 10)



Figure B13 - Reactor 5 Contents (Cycle 1)

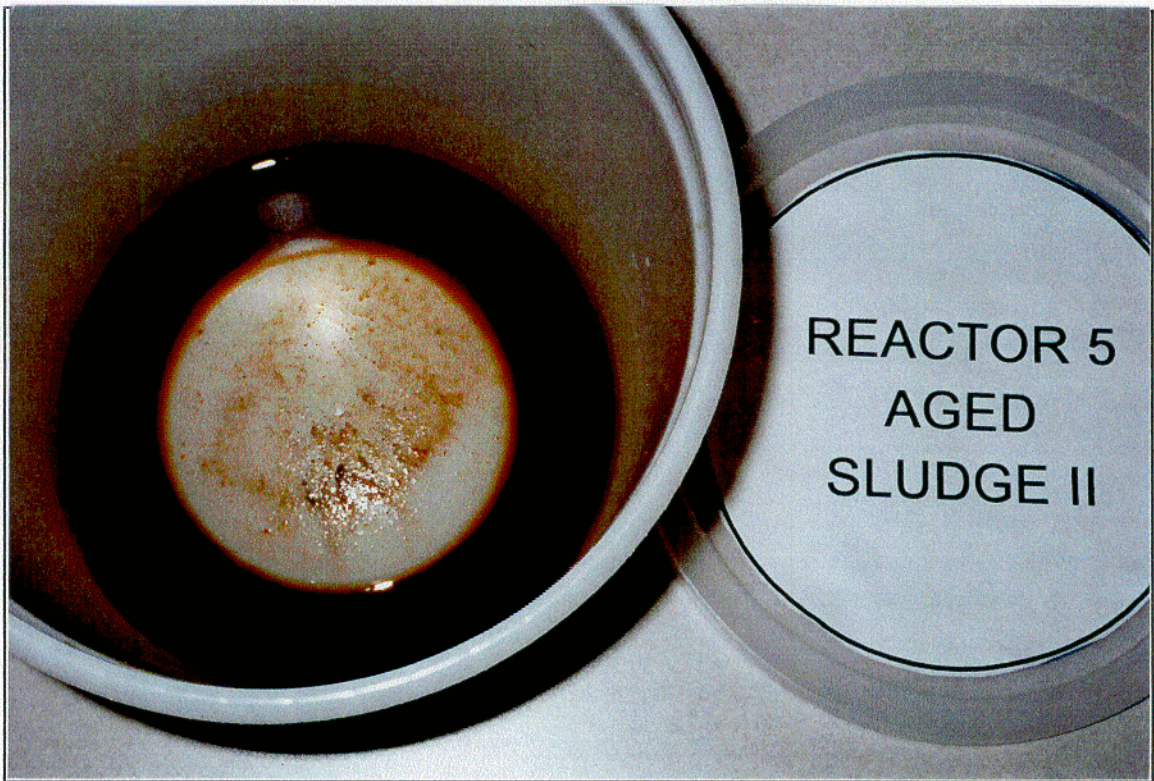


Figure B14 - Reactor 5 Contents (Cycle 10)



Figure B15 - Reactor 6 Contents (Cycle 1)

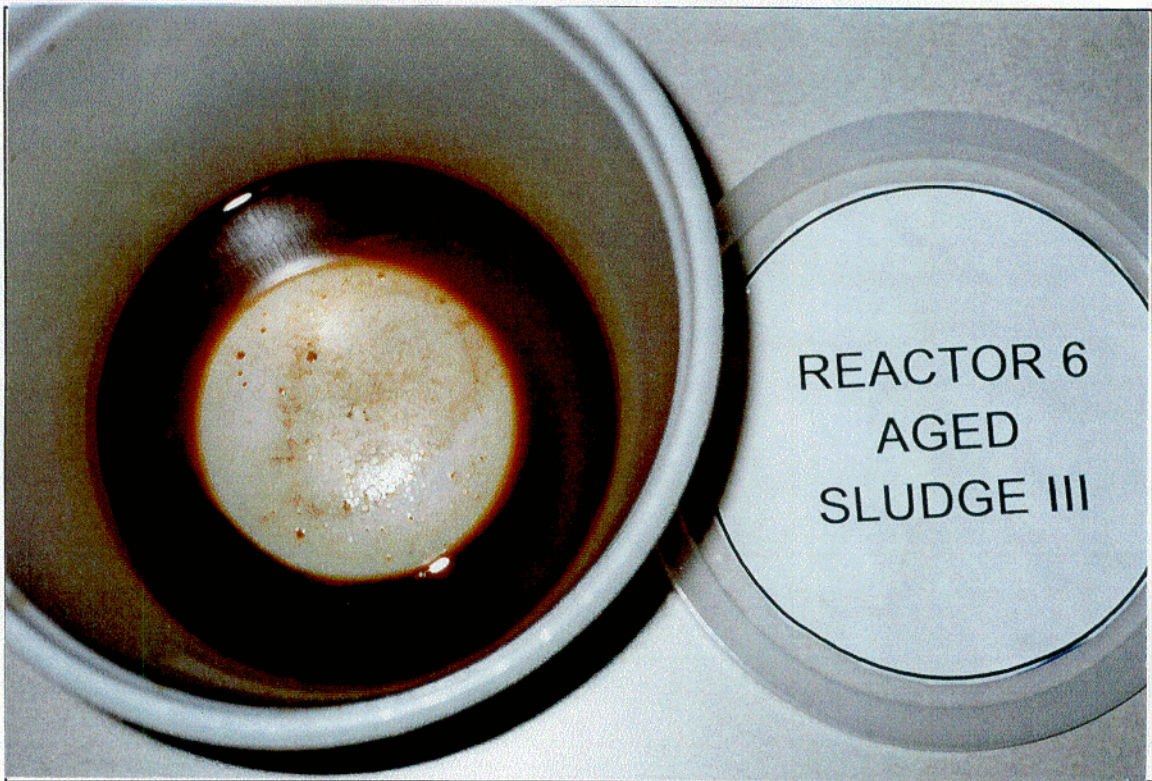


Figure B16 - Reactor 6 Contents (Cycle 10)

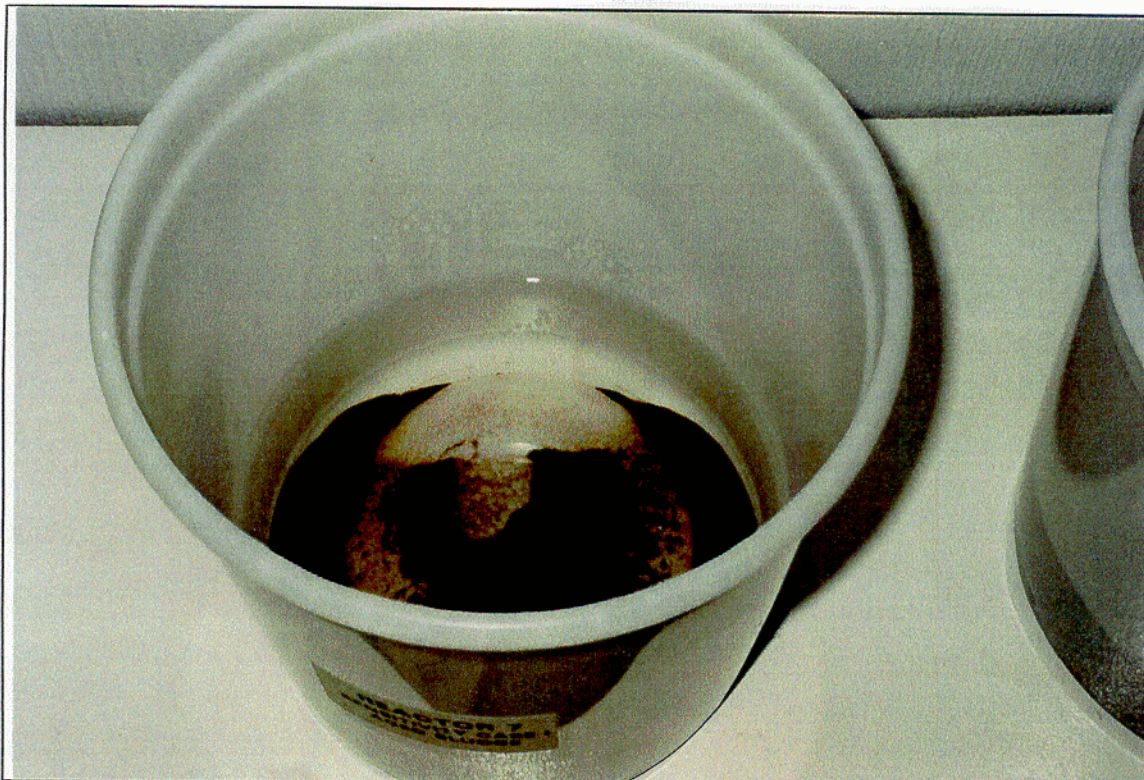


Figure B17 - Reactor 7 Contents (Cycle 1)

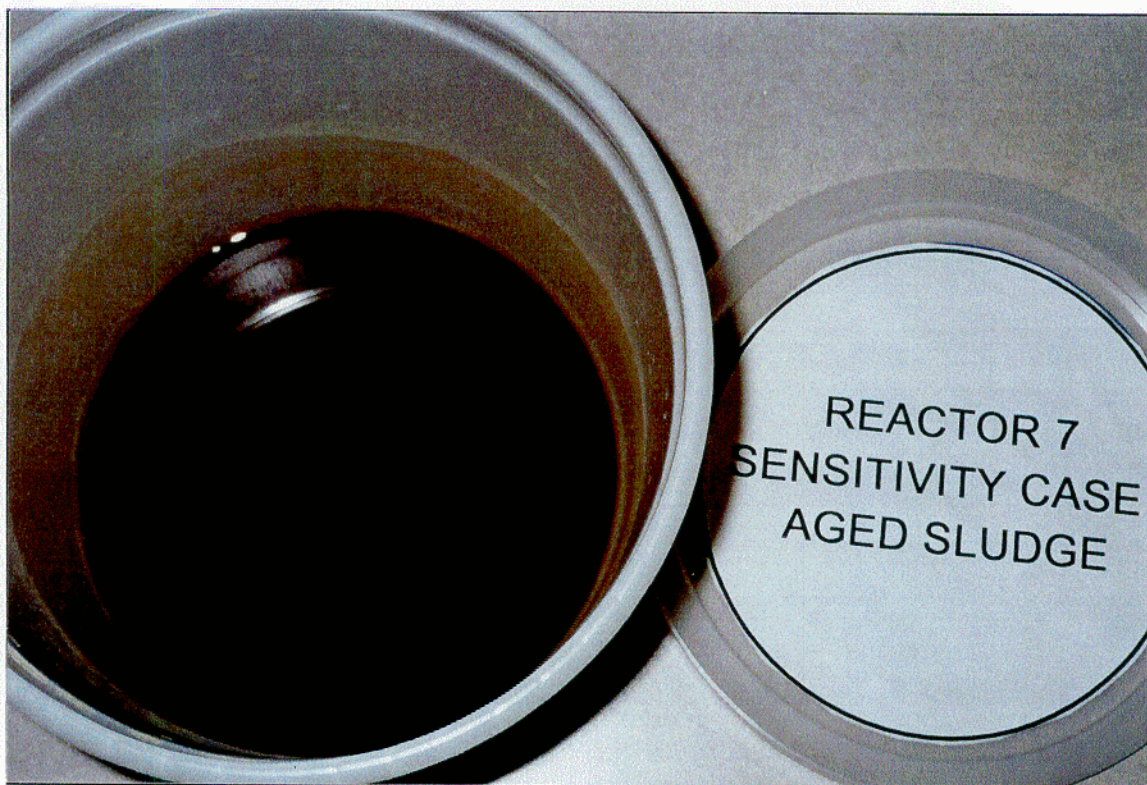


Figure B18 - Reactor 7 Contents (Cycle 10)

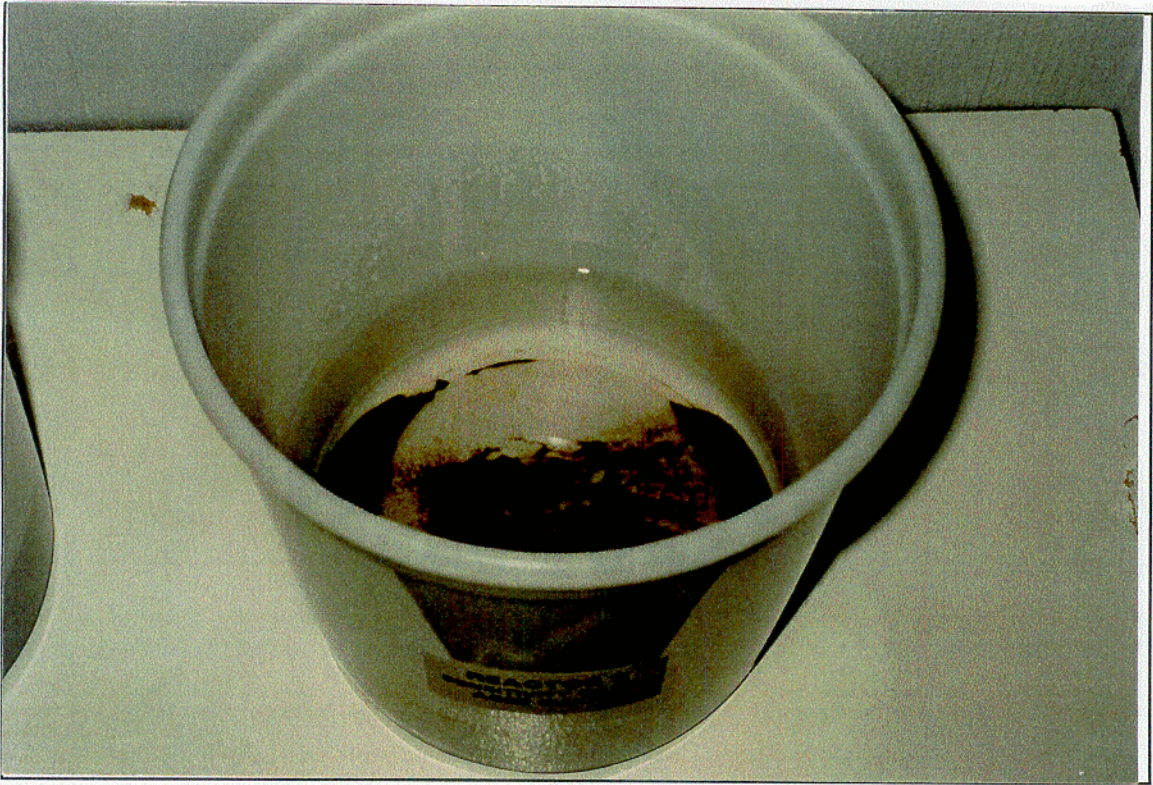


Figure B19 - Reactor 8 Contents (Cycle 1)

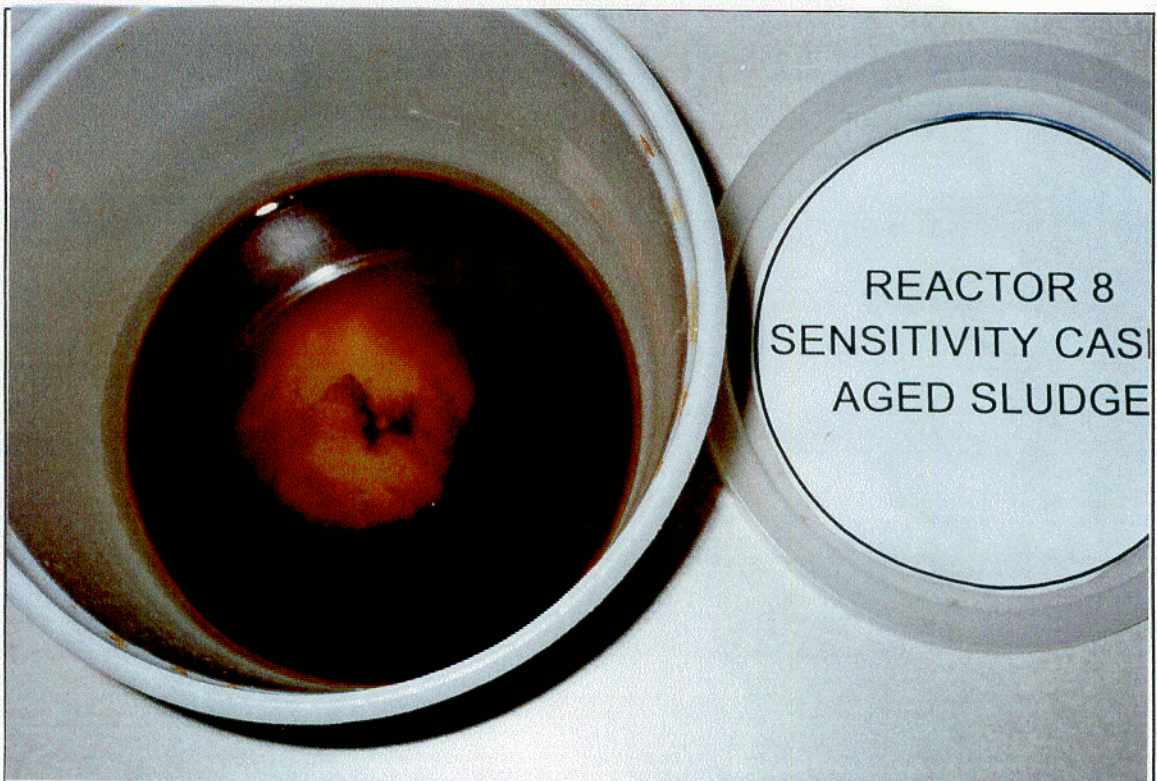


Figure B20 - Reactor 8 Contents (Cycle 10)