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LABORATORY STUDY OF SUBMERGED METAL-MINE TAILINGS 1: EFFECT OF SOLID-LIQUID CONTACT TIME AND AERATION ON CONTAMINANT CONCENTRATIONS

by

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ABSTRACT

The dissolution of metals from various metal-mine tailings has been studied through a series of submerged tailings batch tests at U.S. Bureau of Mines laboratories. Tailings selected for this study included both reactive (as determined by column leaching studies) and benign tailings. Metal mobilization in aerated (97 pct saturated with oxygen) samples appeared to be consistently greater than metal dissolution from stagnant (79 pct or 70 pct saturated with oxygen) waters. In the early weeks of the study, sulfate concentrations increased with solid-liquid contact time, while calcium dissolution remained nearly constant. Metal concentrations varied in relation to solid-liquid contact time and aeration. Leachate pH appeared to be nearly independent of solid-liquid contact time for basic tailings. Reactive tailings having both a submerged and a surface component demonstrated increased metal mobility.

INTRODUCTION

During mining operations, minerals are exposed to oxidizing environments that accelerate weathering. The oxidation of iron disulfides, in particular marcasite and pyrite, is a major cause of acid mine drainage (Caruccio et al., 1977; Potter and Nordstrom, 1977), which is initiated either by simple dissociation of iron pyrite or by the oxidation of pyrite (Singer and Stumm, 1970). In a sulfate and iron-rich acidic solution having a pH of about 3, the oxidation of ferrous iron is extremely slow, whereas the oxidation of pyrite by ferric ion is rapid. Once this propagation cycle is in motion, the initiation reaction is no longer significant (Singer and Stumm, 1968).

Another factor that affects the rate of acid formation is a group of bacteria that includes Thiobacillus ferrooxidans, Ferrobacillus ferrooxidans, and other related species (Silverman, 1967). T. ferrooxidans was significant in acid formation in soil samples having a plentiful supply of oxygen and water, but it had little effect on acid production in soils where oxygen was limited (Kleinmann et al., 1978).

Previous investigations (Doepker, 1988; Doepker, 1989) reported that enhanced metal dissolution was not apparent in water-saturated tailings where solid-liquid contact times extended over 2 to 3 months, presumably because oxidation is so slow. Case studies, such as those in Shasta County, CA (Potter and Nordstrom, 1977; Nordstrom, 1985), point to major oxidation in the capillary zone of tailings impoundments and, to a much lesser extent, in the submerged tailings found in the creeks of the area (Fillpek et al., 1987). Similar results were found during a study at Elliot Lake, Ontario (Dave et al., 1986).

The purpose of the present study is to examine those parameters that influence metal dissolution from submerged tailings, particularly contact time and aeration.

MATERIALS AND METHODS

Waste

Tailings from two lead mines and a copper mine were selected for this initial study. Both lead mine tailings were composed essentially of dolomite [$CaMg(C0_3)_2$] with trace amounts of sphalerite (ZnS), pyrite (FeS_2), galena (PbS), microcline ($KAlSi_30_8$), and crystobalite (SiO_2). The mineral analysis of lead mine A tailings showed that the pyrite grains were of uniform size and ranged from 5 to 25 micrometers in diameter. Cubic galena crystals were generally smaller than crystals of the other sulfide minerals in the sample and averaged 2 to 3 micrometers in cross section. The pyrite and sphalerite were 90-pct liberated; the galena was 70-pct liberated. A similar mineral characterization for lead mine B tailings is not available at this time. The abbreviated results of the "maximum leachability assay" (a nondestructive, mixed HCl-$HN0_3$ assay) (Kuryk et al., 1985) for tailings from lead mines A and B and copper mine A are given in Table 1.

Copper mine A tailings contained abundant free pyrite, and grain size ranged from 20 to 50 micrometers. Magnetite (Fe_30_4) and ilmenite ($FeTiO_3$) were present in relatively significant amounts. Chalcopyrite ($CuFeS_2$) occurred in minor amounts, usually locked with gangue particles. Gangue was predominantly quartz (SiO_2) and orthoclase ($KAlSi_30_8$). Several other minerals identified in the sample included pyromorphite [$(PbCl)Pb_4(P0_4)_3$]; an iron-zinc silicate, POSSIBLY danalite; and a lead-copper-antimony phase identified as either bournonite ($PbCuSbS_3$) or a lead-bearing tetrahedrite ($3Cu_2S.Sb_2S_3$), which occurred as inclusions in the iron-zinc silicate.

The tailings samples used in this study were air dried in the laboratory and crushed to the original size range, mixed well, and stored in plastic containers.

Chemicals

All chemicals in this study were commercially available, analyticalgrade reagents used without further purification. The deionized water was produced in ~he laboratory through distillation (Barnstead glass still) and then deionized with a Barnstead NANOpure II Demineralizer[1] (18.3 Mohm/cm).

Batch Test Equipment and Method

In one series, 2 kg of lead mine A tailings were slurried with 2 L of deionized water and poured into a 4-L, wide-mouth, polyethylene bottle. An additional 1.5 L of deionized water was added to each of seven identical samples, yielding a solid-to-liquid ratio of 0.57. Three bottles were equipped with fish-tank aeration systems, three were loosely covered with perforated plastic wrap, and one was capped. Fifty-cubic-centimeter solution samples (for analyses) were taken at table 1 approximately 4-day intervals over the first 3 weeks prior to aeration. Pumps were activated after 20 days to permit a sufficient number of samplings to obtain baseline metal concentrations that would ensure the significance of any differences among aerated and nonaerated samples. Samples were then taken every other week. After each sampling, 50 cm3 of deionized water was added to the bottle to replace the amount withdrawn.

In another series with the same tailings, two 25-g, 50-g, and 75-g samples were slurried with 125 cm^3, 120 cm^3, and 110 cm^3 of deionized water, respectively, and transferred to six 130-cm^3 glass vials. All tailings were completely submerged. Twenty-cubic-centimeter samples were withdrawn for metal analysis and replaced with 20 cm^3 of deionized water. All six vials remained closed with rubber stoppers except during sample withdrawal.

Three acrylic columns 1.5 m and 15 mm in outside diameter (OD) were fitted with cemented couplings and bushings. A 5-cm-diameter perforated Nalgene plate was installed near the bottom of each column. Qualitative, medium-pore filter paper was placed on the perforated plate and covered with approximately 3 in of coarse silica sand. The purpose of the sand was to reduce clogging of the paper during sampling. Sampling ports were mounted into the walls of the column at 9-in intervals starting 7 in above the bottom plate. The bottom of the column was equipped with a valve as an additional sampling port. Five kilograms of lead mine A tailings was slurried with 5 L of deionized water and poured into each column, which contained 10 L of deionized water. An additional 8 L of deionized water was added to each column, producing a column of approximately 8 in of sand and tailings topped with 4 ft of water. One column was aerated at a depth of 0.9 m and a second at 40 mm, while the third was left open. Fifty-cubic-centimeter samples were withdrawn from the bottom of the tailings, within the tailings (the bottommost column port), and in the supernatant liquid above the tailings (five remaining column ports).

During additional tests, six l-kg samples of copper mine A tailings were slurried with 3 L of deionized water and placed in six 4-L, wide-mouth bottles. Three were again outfitted with aeration equipment while three were fitted with perforated plastic wrap covers. The pH of these slurries was found to be approximately 3.0. Each of the six l-kg samples was mixed with 3 g of calcium oxide (lime), slurried, and handled in the same manner as the six previous samples. Slurry pH varied from 11 to 5 in the lime-treated samples, but averaged nearly 7. All 12 systems were sampled on a normal 2-week cycle by withdrawing 50 cm^3 of leachate from each container. Total volume was maintained through subsequent addition of deionized water.

Six 333-g samples of lead mine B tailings were placed into 2-L, polyethylene, rectangular, wide-mouth bottles. Two liters of deionized water were poured into each bottle, with three receiving aeration and three exposed to the atmosphere. Fifty-cubic-centimeter samples were taken for analysis and replaced with deionized water.

Previous column leaching experiments have demonstrated that metal mobilization is enhanced in unsaturated tailings. Incorporation of unsaturated tailings into a submerged tailings system suggested the design of the experimental apparatus and test protocol described below.

A Plexiglass open-top tank 280 x 1220 x 250 mm was constructed with a partition 75 mm from one end (fig. 1) to make two chambers, one 250 x 75 x 241 mm (inside dimensions) and one 10 by 44 by 9.5 in. Three 1/2-in openings at the bottom of the partition were restricted with a small quantity of glass wool. Six kilograms of silica sand was laid over the bottom of the large chamber to a depth of approximately 12.5 mm and then covered with 7.5 kg of dry tailings. In the small chamber, 800 g of sand was covered with 5.5 kg of tailings. Twenty-five liters of deionized water was then dripped into the large chamber. To reduce the compactness of the tailings and allow better interaction between the solid material and the atmosphere, an additional 400 g of tailings was mixed with 400 g of sand and added to the small chamber. The water level in the large chamber reached a height of 10 mm above the base of the tank, and the

TABLE 1. MAXIMUM LEACHABILITY ASSAY

	Element, mg/g-waste											
Tailings	Al	Ba	Ca	Co	Cu	Fe	Mg	Mn	Ni	Pb	S	Zn
Lead mine A...	0.20	0. 00	81.1	0.04	0.25	17.5	54.2	1.41	0.06	1.56	17.1	0.74
Lead mine B...	0.16	0.0	61. 8	0.04	0.07	13.2	40.0	2.00	0.02	0.49	3.84	0.42
Copper mine A. . .	5.40	0.04	4.46	0.0	0.74	11.9	4.54	0.13	0.01	0.19	10.1	0.35

depth of the tailings in the small chamber was 215 mm. Capillary action wetted all the tailings in the small chamber. Three sampling ports were fitted to the tank, one at the bottom of the small chamber (port 1), one into the tailings at the end of the large chamber (port 2), and the third above the second port but into the supernatant liquid (port 3). Aeration to the main "pond" water was supplied through a fish-tank air pump.

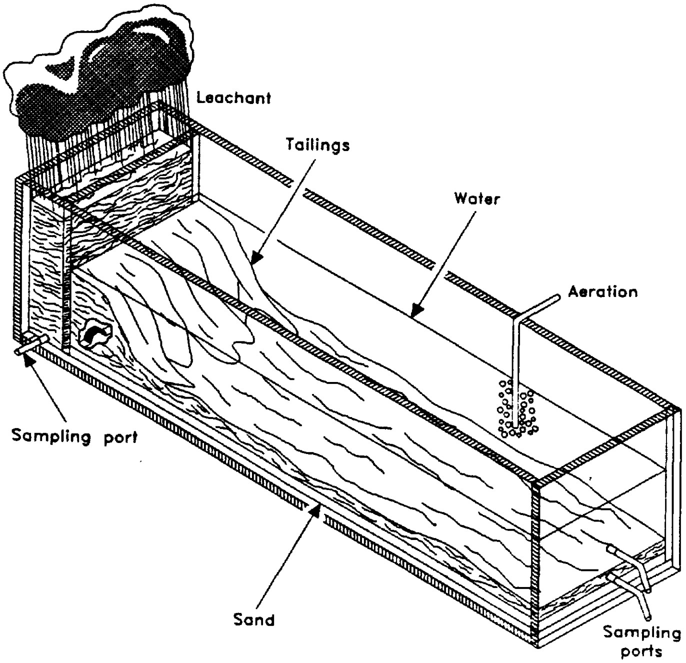

Figure 1. Plexiglass tank model showing relationships of exposed and submerged tailings.

Sixty-cubic-centimeter solution samples were removed from each port for analysis. In order to reduce evaporation, plastic wrap was used to cover the open top of the tank. Water was sprinkled periodically on the damp exposed tailings in the small chamber to maintain a near-constant volume. Thus, water entering the main "pond" area first percolated downward through the exposed tailings and then moved upward through the submerged tailings under the main "pond."

Analytical Equipment

Electrical conductivity and pH were measured on each sample collected. The unfiltered samples were then split, with one portion acidified with nitric acid for metal analysis and the other left for anion analysis. Metal analyses were carried out with the aid of a Perkin-Elmer Plasma II ICP spectrometer and anion analyses with a Dionex 4000i ion chromatograph (I C) .

RESULTS AND DISCUSSION

Even though lead mines A and B are both located in the same mining district, column leaching experiments demonstrated different results. Unsaturated tailings from lead mine A underwent oxidation, producing enhanced metal dissolution (Doepker, 1989), while tailings from lead mine B did not appear to show the same sensitivity. On the other hand, both tailings demonstrated constant dissolution from columns of saturated tailings.

Table 2 shows that leachate pH from aerated and nonaerated samples of lead mine A tailings were equivalent throughout the test period, while total ion conductivity and sulfate increased with contact time. Boron and barium, which are not shown in table 2, as well as manganese, all decreased over the sampling period. The average values of the dissolved oxygen were measured at 90 pct, 80 pct, and 71 pct of saturation for aerated bottles, nonaerated bottles, and stagnant bottles, respectively. More important was that when aeration was inlroduced (at 20 days into the experiment), the rate of sulfate production was greater in the aerated samples than in the stagnant samples. These results indicate that oxidation had occurred and that presumably oxygen was involved in the rate-determining reaction channel. Nickel and coba]t appear to be good indicators of oxidation in column leaching experiments and concentrations were seen to increase with aeration in this study. Dilution effects in this test protocol were about 1.5 pct after each sampling.

An examination of the effect of the solid-to-liquid ratio (Table 3) shows that initial concentrations of calcium, barium, cobalt, magnesium, manganese, nickel, lead, sulfur, and zinc all increased with increasing solid-to-liquid ratios. This solid-to-liquid-ratio effect was nearly eliminated with seven dilutions (17 pct per sampling) and a contact time of 87 days.

Results obtained from the samples from the 4-L bottles and 130-mL vials were similar to the results obtained from the three 23-L columns (Table 4), except that aeration (either shallow or deep) did not appear to greatly affect contaminant concentrations, especially nickel, cobalt, and sulfate. This was most likely due to the smaller waste surface-to-solution volume ratio for the columns (0.021 in^{-1}) compared to the 4-L-bottles (0.17 in $^{-1}$) To maintain constant volume, the dilution effect for the 23-L columns was about 1.1 pct per sampling, compared with 1.5 pct for the samples from the 4-L bottles.

Sulfate, boron, and magnesium concentrations were greater from samples taken within the tailings than from samples in solution or drawn from below the tailings. Concentrations of nickel and cobalt, although always low, were highest in the solution phase, while the concentrations of barium, manganese, and zinc were found to be greatest in the sample extracted from below the tailings. Concentrations of aluminum, calcium, copper, lead, and iron appeared to be independent of sampling location. Dissolved oxygen within the solution phase averaged from 99 to 96 pct of saturation. The leachate drawn from within the tailings produced oxygen saturation values of 70 pct of saturation, while pore leachate collected from below the tailings gave values from 46 to 50 pct of saturation.

Results from the open-top tank experiment are summarized in Table 5. Metal concentrations from the "pond" water (port 3) and from under 12.5 mm of tailings (port 2) were very similar, indicating near-equilibrium of the pond tailings pore water and the bulk pond water. However, samples taken from port 1 below the exposed tailings produced high concentrations of sulfate, calcium, magnesium, and manganese. This situation reflects both a backflow of pond water, which is the result of a combination of capillary flow and evaporation, and downleaching of the tailings when replenishment water was added. Metal concentrations from samples taken at port 1 were less than were anticipated on the basis of earlier column leaching experiments (Doepker, 1989). It is expected that over a longer time, the influence of oxidation on the exposed tailings will greatly affect the quality of the pond water.

TABLE 2 - EFFECTS OF SOLID-LIQUID CONTACT TIME ON LEACHATE CONCENTRATION OF SUBMERGED LEAD MINE A TAILINGS

Contact time, days	pH	SO_4	Cond. mmho	Aℓ	Ca	Co	Cu	Fe	Mg	Mn	Ni	Pb	Zn
				Element, mg/L									
						AERATED							
28	7.46	684	1.504	0.51	243	0.10	0.07	0.27	70.2	0.271	0.10	0.18	0.95
42	7.61	719	1.574	.32	244	.14	.08	.45	76.4	.199	.16	.21	1.13
70	7.43	818	1.779	.76	262	.19	.10	.32	86.0	.107	.20	.22	1.35
86	7.54	870	1.751	.48	230	.17	.09	.34	76.3	.089	.16	.17	1.27
113	7.74	933	1.845	.54	248	.22	.10	.61	92.0	.058	.21	.12	1.10
143	7.64	933	1.827	.45	254	.20	.09	.56	86.2	.052	.25	.08	1.21
156	7.51	898	1.803	.67	261	.23	.11	1.03	88.7	.050	.28	.16	1.26
						OPEN							
Initial	7.24	NA	1.088	.58	172	.20	.06	.78	41.8	.455	.17	.23	1.04
4	7.33	622	1.369	.42	211	.20	.09	.71	61.6	.465	.18	.34	1.21
8	7.30	701	1.466	.23	261	.18	.07	.38	75.3	.407	.15	.20	1.05
17	7.49	554	1.273	.35	251	.21	.08	.59	62.0	.495	.19	.21	1.30
28	7.33	654	1.442	.14	223	.14	.10	.31	61.5	.363	.13	.13	1.22
42	7.44	633	1.444	.32	229	.12	.09	.45	65.2	.300	.11	.16	.94
70	7.36	718	1.610	.76	238	.12	.09	.33	68.7	.226	.09	.19	.80
86	7.55	768	1.585	.45	201	.09	.08	.26	69.4	.230	.05	.23	.81
113	7.72	805	1.660	.54	213	.15	.08	.59	82.1	.168	.15	.11	.85
143	7.80	830	1.701	.43	213	.13	.09	.58	76.4	.145	.19	.12	.96
156	7.71	820	1.703	.66	231	.17	.08	1.10	92.0	.169	.25	.12	1.10
						CLOSED							
Initial	7.20	NA	0.836	.59	125	.11	.05	.89	33.9	.391	.10	.32	.70
4	7.29	460	1.095	.42	158	.14	.09	.72	51.4	.375	.12	.28	.90
8	7.41	565	1.262	.23	227	.12	.04	.37	67.0	.315	.12	.28	.75
17	7.54	445	1.084	.35	192	.10	.07	.54	51.2	.324	.09	.15	.92
28	7.32	603	1.350	.11	198	.09	.07	.25	63.9	.225	.07	.06	.75
42	7.21	579	1.366	.30	194	.07	.09	.46	65.1	.237	.05	.21	.67
70	7.21	680	1.550	.77	209	.06	.10	.31	71.6	.193	.07	.22	.75
86	7.29	739	1.577	.44	218	.06	.07	.27	72.8	.193	.05	.17	.77
113	1.62	782	1.626	.54	244	.10	.09	.59	85.5	.180	.10	.12	.82
143	8.00	826	1.670	.44	203	.11	.09	.63	82.0	.171	.13	.06	.79
156	7.71	805	1.680	65	226	.16	.09	1.09	110.0	.222	.22	.21	1.05

NA No analysis

TABLE 3. EFFECTS OF SOLID-TO-LIQUID RATIO VERSUS CONTACT TIME ON LEACHATE CONCENTRATIONS OF SUBMERGED LEAD MINE A TAILINGS

Contact time, days	pH	Aℓ	Ca	Fe	Mg	Mn	Ni	Pb	S	Zn
		Element, mg/L								
					25 g/125 ml					
Initial	7.41	0.34	91.1	0.73	27.1	0.286	0.07	0.20	105.0	0.69
6	6.87	.35	125.0	1.30	31.0	.292	.06	.28	117.0	.72
17	6.99	.12	98.2	.35	24.8	.154	.02	.18	93.2	.39
31	7.14	.29	88.7	.45	27.8	.109	.04	.18	85.3	.36
45	7.61	.76	81.6	.64	25.6	.070	.05	.15	79.1	.28
60	7.54	.52	75.9	.62	25.2	.054	.04	.16	72.3	.28
75	7.46	.39	60.6	.17	22.6	.025	.05	.09	58.3	.28
87	7.54	.45	59.0	.54	22.8	.040	.06	.09	54,9	.31
102	7.04	NA	54.3	NA	20.9	.033	.07	.08	52.3	.17
116	7.66	.46	59.8	.70	20.5	.032	.08	.12	47.0	.26
132	7.71	.43	51.8	.59	18.9	.022	.06	.07	38.6	.27
					50 g/120 ml					
Initial	7.34	.36	225.0	.78	56.2	.648	.21	.39	232.0	2.08
6	6.99	.42	209.0	2.17	52.3	.521	.17	.26	207.0	1.64
17	7.04	.18	166.0	1.38	47.8	.257	.08	.32	179.0	.91
31	7.13	.30	157.0	,45	43.7	.203	.05	.23	144.0	.62
45	7.61	.30	144.0	.51	43.8	.160	.08	.29	155.0	.46
60	7.44	.52	114.0	.63	36.1	.101	.05	.21	115.0	.33
75	7.36	.45	89.3	.34	31.2	.132	.05	.20	93.6	.39
87	7.57	.46	82.0	.55	30.1	.061	.05	.15	83.3	.28
102	7.12	NA	80.1	NA	28.5	.055	.05	.11	74.9	.23
116	7.23	.47	74.9	.73	26.4	.047	.07	.27	66.9	.27
132	7.65	.45	61.6	.62	22.0	.032	,05	,09	51.0	.25
					75 g/110 ml					
Initial	7.47	.32	374.0	.67	84.6	1.040	.33	.40	374.0	3.41
6	7.09	.36	321.0	.69	83.4	.536	.14	1.41	333.0	1.86
17	7.11	.10	203.0	.25	55.7	.331	.09	.24	224.0	1.05
31	7.16	.32	207.0	.47	62.6	.220	.08	.21	213.0	.65
45	7.62	.39	188.0	.47	63.1	.169	.06	.15	215.0	.57
60	7.46	.52	151.0	.63	47.2	.112	.04	.23	163.0	.39
7s	7.43	.40	127.0	.77	42.0	.084	.03	.17	140.0	.33
87	7.50	.44	78.8	.52	29.6	.053	.01	.10	93.3	.24
102	7.24	NA	81.4	NA	26.3	.080	.06	.11	113.0	.25
116	7.48	.46	86.9	.68	30.1	.064	.07	.12	78.6	.29
132	7.73	.43	72.5	.58	24.8	.045	.04	.11	64.9	.24

NA No analysis

TABLE 4. EFFECTS OF SOLID LIQUID CONTACT TIME ON LEACHATE CONCENTRATIONS OF SUBMERGED LEAD MINE A TAILINGS IN COLUMNS.

Contact time, days	With aeration						Without aeration					
			Element, m/L						Element, mg/L			
	pH	SO_4	Ca	Mg	Mn	Zn	pH	SO_4	Ca	Mg	Mn	Zn
						IN TAILINGS						
Initial	7.74	244	113	35.0	0.040	1.05	7.82	267	125	28.9	0.580	1.05
7	7.48	271	113	40.5	.037	.17	7.59	294	109	40.5	.037	.11
21	7.54	306	114	46.1	.066	.12	8.11	319	132	49.7	.040	.16
35	7.58	310	131	55.2	,032	.19	7.64	332	120	50.5	.029	.19
49	7.73	295	113	52.0	.030	.11	7.08	310	151	63.8	.029	.12
91	6.88	364	108	47.7	<.003	<.01	7.47	350	123	55.5	<.003	<.01
122	7.35	286	83	41.9	.024	.11	7.74	318	104	52.6	.028	.08
135	7.58	279	98	39.9	.019	.13	7.56	297	92	38.8	.017	.10
					122	BELOW TAILINGS						
21	6.58	37	62	4.6	.168	1.36	6.34	35	144	11.1	.489	10.00
35	7.82	123	111	10.7	.230	.58	6.89	86	205	25.0	.628	4.77
49	6.73	144	122	14.3	.235	1.12	6.84	109	211	33.5	.534	3.20
65	6.36	165	165	20.8	.305	1.22	6.61	140	254	43.9	.572	2.85
91	6.72	231	115	18.0	.156	.31	6.82	225	165	38.0	.237	.82
122	7.77	212	96	26.9	.286	.80	6.83	209	156	49,9	.331	1.23
135	6.48	216	101	22.9	.192	.54	6.79	212	128	35.7	.188	.16
						ABOVE TAILINGS						
Initial	7.16	273	121	28.9	.958	3.39	7.12	296	128	31.2	.164	.48
7,	7.29	294	113	27.8	.247	.32	6.97	309	121	29.5	.140	.31
21	7.10	275	110	26.3	.119	.32	7.14	304	135	31.9	.146	.34
35	7.44	276	117	28.3	.125	.41	7.44	314	137	33.5	.149	.40
49	7.00	273	116	28.8	.115	.38	7.1	308	137	35.0	.135	.33
65	7.28	281	135	31.0	.137	.55	7.24	303	133	35.1	.142	.45
91	7.13	342	97	22.7	.053	<.01	7.45	359	132	31.2	.068	<.01
122	7.17	265	82	26.3	.079	.38	7.34	298	87	30.2	.122	.48
135	7.36	279	89	23.9	.072	.41	7.15	286	86	23.9	.084	.36

TABLE 5 - EFFECTS OF EXPOSED AND SUBMERGED LEAD MINE A TAILINGS ON "POND" WATER QUALITY

Contact time, days	Sat. O_2, pct	pH	SO_4	Cond. mmho	Element, mg/L Al	Ca	Co	Cu	Fe	Mg	Mn	Ni	Pb	Zn
							PORT 1							
Initial.	NA	6.76	2960	4.89	0.44	771	1.56	0.08	0.75	502.0	4.300	1.02	0.19	0.81
14.....	NA	6.94	2700	4.28	.57	487	.15	.09	.86	283	.948	.12	.12	.40
30.....	NA	7.20	6980	9.21	.39	431	<.03	.06	2.33	1210	.663	.01	.16	.13
42.....	94	7.88	3110	4.88	.52	408	<.03	.10	1.01	399	.317	<.01	.03	.08
57.....	NA	6.40	1730	2.80	<.0.2	459	<.03	.08	NA	51.7	.162	.01	<.05	<.01
71.....	96	6.93	1550	2.65	.54	359	<.03	.16	.96	36.2	.171	.01	.05	.13
87.....	84	7.15	1670	2.80	.48	507	.01	.10	1.05	69.5	.131	.01	.10	.16
100....	90	7.28	1640	2.92	.69	641	.02	.11	1.35	138	.229	.01	.08	.13
115....	90	7.05	1760	3.09	.52	305	.05	.17	7.83	136	.250	.10	.08	.61
127....	92	7.33	1520	2.89	.68	547	<.03	.10	1.27	63.7	.157	.03	.11	.14
142....	92	7.68	1570	2.99	.59	355	<.03	.10	.87	59.2	.144	<.01	1.49	.17
155....	90	7.77	1520	2.62	.56	343	.02	.14	.10	>110	.162	.01	.03	.06
							PORT 2							
Initial.	NA	7.18	194	.581	.44	88.5	.05	.03	.82	28.6	.134	.05	.29	.29
14.....	NA	6.94	505	1.109	.53	166	.08	.09	1.01	48.2	.189	.12	.35	.86
30.....	NA	7.53	710	1.522	.40	196	.09	<.01	.90	75.1	.141	.15	.33	.61
42.....	94	7.36	859	1.834	.46	190	.11	.08	.80	77.4	.089	.14	.14	.57
57.....	NA	6.93	1290	2.40	.27	354	.25	.22	NA	236	.128	.29	.35	2.49
71.....	96	7.42	1210	2.26	.47	220	.20	.15	.74	131	.089	.25	.08	.75
87.....	84	7.75	1210	2.28	.45	269	.21	.09	.83	129	.100	.31	.11	.95
100....	90	7.51	1200	2.37	.75	413	.47	.16	3.28	262	.459	.69	.97	1.97
115....	90	7.17	1270	2.35	.50	151	.37	.40	.57	185	2.190	.52	.28	1.47
127....	92	7.39	1260	2.56	1.04	496	.29	.24	20.60	217	1.560	.52	2.69	2.81
142....	92	7.47	1300	2.62	.95	307	.31	.21	12.50	263	1.500	.51	2.46	2.25
155....	90	7.69	1370	2.54	.56	260	.42	.17	.68	>110	.110	.63	.43	1.57
							PORT 3							
Initial.	NA	7.14	166	.537	.41	77.5	.03	.05	.68	24.2	.082	.03	.15	.28
14.....	NA	6.76	439	1.076	.52	146	.09	.08	.73	41.1	.112	.12	.24	.92
30.....	NA	7.59	674	1.516	.39	203	.09	.02	.20	68.9	.007	.16	.18	.63
42.....	94	7.49	840	1.857	.46	176	.12	.07	.83	83.4	.062	.18	.15	.72
57.....	NA	7.39	1050	2.10	.03	184	.19	.11	NA	115	.052	.20	.08	.77
71.....	96	7.41	1180	2.23	.47	160	.16	.15	4.46	127	.050	.26	.33	.83
87.....	84	7.86	1220	2.26	.44	248	.23	.12	.64	126	.035	.33	.09	.90
100....	90	7.72	1190	2.38	.64	416	.38	.09	1.17	119	.071	.45	.25	1.26
115....	90	7.27	1270	2.46	.49	128	.40	.22	1.33	200	.089	.56	.35	1.37
127....	92	7.49	1270	2.56	.49	300	.32	.10	<.01	146	.047	.41	.14	1.01
142....	92	7.50	1290	2.62	.57	309	.35	.11	.34	195	.588	.52	.33	1.26
155....	90	7.81	1340	2.64	.54	231	.65	.22	.09	>110	.053	.73	2.61	1.61

NA - No analysis

TABLE 6. EFFECTS OF SOLID-LIQUID CONTACT TIME ON LEACHATE CONCENTRATIONS OF SUBMERGED COPPER MINE A TAILINGS.

Contact time, davs	Sat. °2' pct	pH	SO4	Cond. mmho	Al	Ca	Co	Element, mg/L Cu	Fe	Mg	Mn	Ni	Zn
				NEUTRAL, AERATED									
Initial	NA	7.27	1120	2.09	0.43	352	0.01	4.91	2.12	44	1.98	0.03	2.59
11	NA	5.73	1400	2.38	.30	456	.32	9.12	.66	78	3.41	.05	4.67
22	96	5.30	1620	2.59	.69	372	.51	15.60	.07	91	4.09	.12	7.19
36	97	5.25	1740	2.58	.64	459	.05	17.40	.75	123	5.64	.13	7.54
50	93	5.23	1780	2.75	1.48	542	.42	18.40	.77	107	4.64	.14	6.73
67	91	4.75	1830	2.69	4.43	475	.47	23.60	1.23	164	7.77	.16	9.03
78	94	5.21	1760	2.61	1.53	425	.37	17.90	.24	125	6.19	.13	6.65
				NEUTRAL, STAGNANT									
Initial	NA	8.22	1010	2.22	.62	328	.01	1.00	.57	48	1.65	.02	1.70
11	NA	7.78	1200	2.12	.06	453	.15	.75	.05	65	2.37	.03	1.61
22	81	6.68	1490	2.33	.25	416	.24	1.47	.06	98	4.12	.05	3.54
36	84	6.38	1490	3.32	<.02	424	.01	2.28	.61	104	4.95	.08	3.54
50	84	6.08	1560	2.45	.20	503	.29	3.77	.57	105	4.59	.08	4.60
67	82	5.30	1610	2.51	.51	510	.39	6.68	.29	132	6.82	.11	6.14
78	84	5.39	1650	2.50	.48	414	.35	6.00	.13	122	6.73	.10	5.13
		NONACIDIFIED, AERATED AND STAGNANT											
Initial	NA	3.00	2330	3.35	14.10	377	.04	57.90	38.80	152	8.12	.18	15.10
11	NA	2.84	2250	3.51	19.70	538	.90	78.00	44.60	199	9.91	.24	18.50
22	95/791	2.84	2460	3.54	23.10	399	1.29	99.90	3.49	278	15.70	.40	30.60
36	95/791	3.02	2460	3.38	32.20	424	.35	128.00	2.96	399	29.90	.76	41.70
50	93/771	2.98	2550	3.42	26.10	355	1.06	92.40	2.10	248	15.90	.42	24.70
67	92/751	3.62	2460	3.46	31.60	454	1.31	103.00	1.54	253	16.40	.50	25.30
78	92/781	3.91	557	1.05	4.78	112	.26	19.80	.34	47	3.20	.10	5.03

NA No analysis.

[1] Pct O_2 saturation, aerated sample/stagnant sample.

[2] 2 L leachate withdrawn, followed by addition of 2 L of deionized water 2 weeks before sampling.

Copper mine A tailings were found to produce acidic column leachates with high concentrations of dissolved metals. Two results from the supernatant water above these 12 samples are reported in Table 6. Neutralization with lime prior to slurrying decreased metal concentrations (except for calcium and boron) in the leaching water; however, most metal concentrations increased with contact time in both neutralized and unneutralized systems. In general, metal concentrations were increased through aeration. The pH of the leachate decreased with increasing contact time for the neutralized samples. Oxygen consumption in the nonaerated sample can be inferred from the lower percentage of oxygen saturation. It would appear that the dissolution rate of metals from these tailings was greatly enhanced by the presence of oxygen. In an as-yet unpublished study[2], metal dissolution from columns of copper mine A tailings could not be substantially reduced even when the surrounding atmosphere contained only 1 pct oxygen.

Results from the 2-L samples of aerated and nonaerated lead mine B tailings also showed that contaminant concentrations increased with contact over a 56-day period as observed for the tailings from lead mine A. However, constituent concentrations in aerated and nonaerated samples were within 10 pct of each other. These values will be described in a later report. The observations agree with results from column leaching experiments in that little enhanced metal dissolution was seen in unsaturated lead mine B tailings.

SUMMARY AND CONCLUSIONS

Although this report has been limited to tailings samples from only three mines and contact times were short, it is apparent that oxygen plays an important role in metal dissolution in submerged mine tailings. Dissolution behaviour as determined from column leaching studies (wet-dry cycle and solid-liquid time effects) can be used to qualitatively predict contact time and aeration influences on submerged tailings. Dissolution from submerged tailings depends on contact surface area, leachate exchange rates (dilution effects), and dissolved oxygen, as well as the nature of the tailings themselves. Neither biological activity nor naturally occurring organic water contaminants were addressed in this study, but these factors are either presently being investigated or studies are being planned.

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[1] Reference to specific equipment or trade names does not imply endorsement by the Bureau of Mines.

[2] Investigations in progress at the Spokane Research Center, U.S. Bureau of Mines.