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Leaching of Metals from Alkaline Wastes by Municipal Waste Leachate

C. W. Francis
M. P. Maskarinec

Environmental Sciences Division
Publication No. 2846

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ENVIRONMENTAL SCIENCES DIVISION

LEACHING OF METALS
FROM ALKALINE WASTES
BY
MUNICIPAL WASTE LEACHATE

C. W. Francis and M. P. Maskarinec*

Environmental Sciences Division
Publication No. 2846

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ABSTRACT

FRANCIS, C. W., and M. P. MASKARINEC. 1986. Leaching of metals from alkaline wastes by municipal waste leachate. ORNL/TM-10050. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 36 pp.

Four alkaline wastes were leached under anoxic conditions with a municipal waste leachate (MWL) to simulate the codisposal of the wastes in a municipal waste landfill. Two of the four wastes were wastewater treatment plant sludges from electroplating processes, and the other two wastes were resource recovery ashes. The electroplating wastewater sludges contained cadmium, and the resource recovery ashes contained lead at levels that were in excess of the present regulatory standards established by the Resource Conservation Recovery Act (RCRA) extraction test (EP).

The four wastes were extracted by the two media (extraction fluids No. 1 and No. 2) of the Toxicity Characteristic Leaching Procedure (TCLP) recently proposed by the U.S. Environmental Protection Agency* to replace the RCRA-EP leach test. The concentrations of lead, cadmium, nickel, and zinc in the extracts from the laboratory extractions (EP, TCLP No. 1, and TCLP No. 2) of the four wastes were compared with those concentrations observed in the leachates of the wastes after leaching with a municipal waste leachate. Concentrations of lead from the two resource recovery ashes were <1.4 and <0.4 mg/L compared with 6 and 12 mg/L, respectively, in the EP extracts. Concentrations of cadmium in the leachates of the electroplating wastes were 82 and 1 mg/L compared with 360 and 2.5 mg/L in the EP extracts. Concentrations of cadmium, lead, nickel, and zinc in the TCLP No. 2 extracts of the four wastes were similar to the corresponding concentrations in the EP extracts. The concentrations of cadmium,

*Federal Register Vol. 51, No. 114, June 13, 1986.

nickel, and zinc extracted from the four wastes by municipal waste leachate were approximated more closely by the TCLP No. 1 extracts than by either the EP or TCLP No. 2 extracts. The data from this study suggest that the TCLP with extraction medium No. 1 is much better than the alternative procedures tested for simulating the leaching of alkaline wastes by municipal waste leachate.

1. INTRODUCTION

The recently developed Toxicity Characteristic Leaching Procedure (TCLP) is being considered by the U.S. Environmental Protection Agency (USEPA) as a replacement for its existing waste leach test, the extraction test (EP) procedure (USEPA 1986). The EP is being used as a regulatory tool by the USEPA to determine the leachability of inorganic constituents from those wastes that might be codisposed of with municipal wastes in a municipal waste landfill (USEPA 1980). The codisposal of an industrial waste in a sanitary landfill (as a model) was selected as a reasonable worst-case mismanagement scenario because USEPA was concerned that potentially hazardous waste, if not brought under regulation by the Resource Conservation Recovery Act (RCRA), might be sent to a sanitary landfill, with a resulting high degree of leaching. The method used in conducting the EP (USEPA 1982) simulates leaching by acetic acid, the dominant carboxylic acid found in municipal waste leachate (MWL). The major limitation of the EP is that its ability to simulate a real-world disposal environment has never been tested.

The purpose for the development of the TCLP was to design a laboratory extraction procedure that accurately modeled the leaching of an industrial waste, with respect to both inorganic and organic constituents, codisposed of in a municipal waste landfill. To simulate the leaching of an industrial waste codisposed in a municipal waste landfill, industrial wastes were leached with MWL generated in a field lysimeter test facility (epoxy-resin-lined concrete cylinder 1.8 m in diameter and 3.6 m in height) containing municipal wastes. The leaching of the industrial wastes was conducted in two phases during the summers of 1983 and 1984, respectively. In Phase I four industrial wastes were leached, and in Phase II seven wastes were leached. Much of the data used to support the use of the TCLP have been based on this two-phased study reported by Francis et al. (1984) (Phase I) and Francis and Maskarinec (1986) (Phase II).

The objective of the experimental work was to determine the concentrations of inorganic and organic constituents in the industrial waste leachates at the field lysimeter site and then design a laboratory extraction procedure whose extract concentrations simulated those determined at the lysimeter. A total of 95 target constituents (57 organic and 38 inorganic) were identified in the lysimeter leachates. The laboratory extraction methods examined included two extraction procedures (a rotary batch and an upflow column), four extraction media [0.1 M sodium acetate pH 5 buffer, carbonic acid (carbon-dioxide-saturated deionized distilled water), deionized distilled water, and MWL at four liquid-to-solid ratios of 2.5, 5, 10, and 20:1].

A number of statistical approaches were used to compare laboratory extract concentrations with those target concentrations determined in waste leachates at the lysimeter using the criteria developed by Kimmell and Friedman (1986). The laboratory extraction procedure found best to simulate the lysimeter target concentrations was the 0.1 M sodium acetate pH 5 buffer conducted in a rotary-batch extractor at a liquid-to-solid ratio of 20:1. This procedure is much easier to perform than the presently used EP, because it does not require the periodic titration called for in the EP.

2. BACKGROUND

Analysis of the leaching data conducted by Francis et al. (1984) and Francis and Maskarinec (1986) revealed no significant differences between the TCLP proposed extraction medium (a pH 5, 0.1 M acetate buffer) and the EP to simulate field target concentrations for the metals Cd, Hg, Ni, and Zn. In Phase I nickel and zinc were leached from the electroplating waste, and in Phase II cadmium and mercury were leached from a settling sludge obtained from a waste impoundment, both wastes being generally alkaline (pH values of 9.5 and 8.1, respectively, for 100-g suspensions of electroplating waste and settling sludge in 1600 mL of distilled water). Lead, a toxic metal of major concern in the environment, was not included as one of the target metals. In other studies, alkaline wastes extracted with the proposed TCLP acetate buffer have shown extract concentrations of lead and cadmium on the order of 5 to 10 times lower than those concentrations in the EP extractions (Francis 1985). Other alkaline wastes, when extracted by the two extraction procedures, showed concentrations of lead in the EP extracts that were factors of 10 higher than that extracted by the 0.1 M NaOAc buffer (personal communication, September 1985, T. Kimmell and D. Friedman, Studies and Methods Branch, Office of Solid Waste and Emergency Response, USEPA, Washington, D.C.).

To evaluate in more detail the leaching characteristics of metals from alkaline wastes by MWL, four alkaline wastes known to contain levels of metals (two containing lead and two containing cadmium) in excess of present regulatory standards by the EP test were leached by the same MWL used in the studies reported in Francis et al. 1984 and Francis and Maskarinec 1986 and compared with metal concentrations in their EP and TCLP extractions.

3. METHODS AND MATERIALS

Two of the four wastes were wastewater treatment plant sludges from electroplating processes [plants A and B collected and sent to Oak Ridge National Laboratory (ORNL) by PEI Associates, Inc., Cincinnati, Ohio]. The other two wastes were composited resource recovery ash samples collected by a subcontractor for the California Waste Management Board at the Sumner County Resource Authority, Gallatin, Tennessee (called "Sumner County resource recovery ash" in this work) and the (NASA) refuse for steam facility at Hampton, Virginia (called "Hampton resource recovery ash" in this work). The latter two wastes were used in the Francis (1985) study. All four wastes were alkaline because pH of a 100-g suspension in 1600 mL of water was 8.35, 8.97, 10.3, and 10.0, respectively, for the PEI-A, PEI-B, Sumner County, and Hampton wastes. Their respective pH values, as determined by step 7.12 of the proposed TCLP leaching procedure, were 6.12, 6.84, 7.11, and 6.41 (USEPA 1986). Thus, all four wastes would require extraction with medium no. 2, an acetic acid solution whose pH is 2.88. This extraction solution was prepared by diluting 5.7 mL of glacial acid to 1 L as outlined in step 5.6.2 of the proposed TCLP procedure (USEPA 1986).

Each of the wastes was leached with MWL pumped directly from the field lysimeter test facility to the bottom and out the top of a 10-cm-diam column containing 200 g of waste. Flow rate was ~ 0.8 mL/min. Leachate was collected daily, volume and pH were recorded, and a 200-mL aliquot was acidified to pH < 2.0 from which the metals concentration was determined by inductively coupled plasma (ICP) spectroscopy. The pH of the anoxic MWL (taken immediately from a Tedlar bag) was 5.24, while that stirred overnight was ~ 5.7. Organic carbon content of the MWL ranged between 4000 and 4300 mg/L, and the calcium concentration was 790 mg/L, quite similar to the concentration in the MWL used in Phase II of the previous leaching study reported earlier. The sodium content of the MWL was 120 mg/L, ~ 100 mg/L lower than that used in the earlier Phase II leaching

study; however, the iron content was 450 mg/L, ~ 200 mg/L more concentrated than the Phase II MWL.

The field target concentrations (called AMC20 concentrations) are those average maximum concentrations measured in a 20:1 liquid-to-solid leaching interval that bracketed the MLC measured in the lysimeter leachates of the industrial wastes (see Kimmell and Friedman 1986). The method used to determine the AMC20 concentrations is illustrated in Fig. 1. The principle of AMC20 concentrations is based on the use of the liquid-to-solid ratio to define the quantity of leachate generated with respect to the quantity of waste used; that is, the liquid-to-solid ratio is the quantity of leachate collected in liters divided by the quantity of waste leached (liters per kilogram). For example, as a waste is leached, the leachate is collected, and the extent of leaching is expressed in units of liquid-to-solid ratio rather than time of leaching or volume of leachate collected. The concept of average maximum concentration (AMC) is centered around the liquid-to-solid ratio at which point the MLC in the field studies was obtained. For example, the AMC20 concentration from the field studies was determined from the quantity of target constituent leached over a 20:1 liquid-to-solid ratio centered on the MLC (i.e., a leaching interval at a liquid-to-solid ratio of ten on each side of the MLC). For further clarification, please refer to Kimmell and Friedman (1986) or Francis et al. (1984).

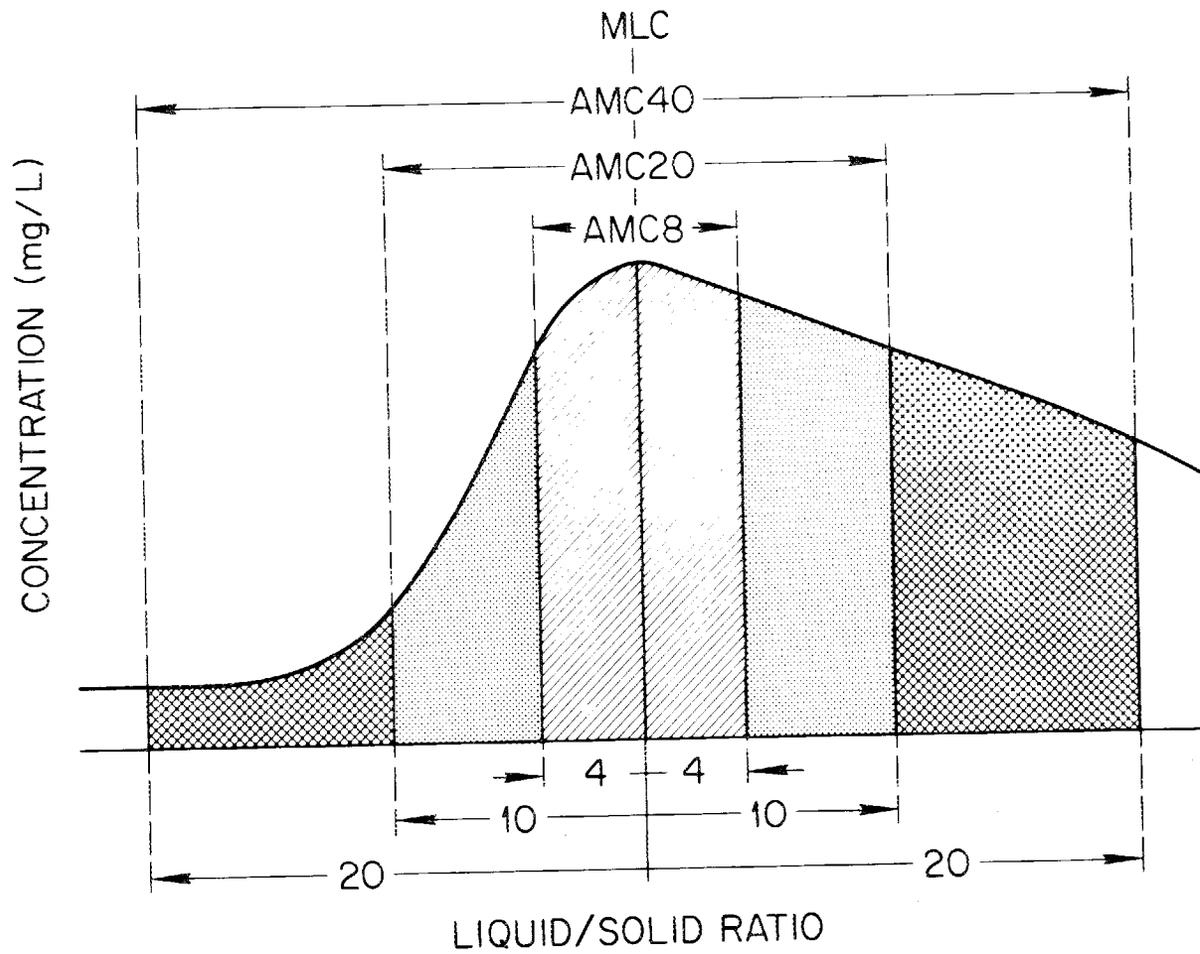


Fig. 1. Illustration of method to determine average maximum concentrations (AMC)

4. RESULTS AND DISCUSSION

4.1 LEACHATE CONCENTRATIONS OF METALS

The concentration of metals in each of the wastes' leachate sampled is presented in terms of the liquid-to-solid ratio (quantity of leachate collected in liters divided by kilograms of waste leached) in Tables 1-4. Mean concentrations of the metals in the leachate over the total leaching period are illustrated in Table 5 relative to the concentrations of the metals in the MWL. Mean concentrations were determined by dividing the total quantity of the metal measured in the leachate (in milligrams) by the volume of leachate generated (in liters). Concentrations of those metals below the ICP detection limit were estimated by dividing the detection level by 2. Using this approach, mean concentrations of B, Ca, Cd, Co, Cu, Mg, Mn, Mo, Na, Ni, Sb, Si, Sr, and Zn in the PEI-A waste leachate were observed to be greater than that measured in MWL. Of principal concern are the leaching of Cd, Ni, and Zn, for which the mean concentrations were quite high (e.g., 74, 38, and 91 mg/L, respectively). For the PEI-B waste, mean concentrations of Ca, Cd, Cu, Mg, Mn, Sb, Sr, V, and Zn were observed to be higher than that measured in the MWL used to leach the waste. The leaching of zinc (mean concentration of 229 mg/L) and cadmium (mean concentration of 0.72 mg/L) appear to be the major environmental concerns. The leachates from the resource recovery ashes contained low concentrations of Cd, Ni, and Zn, relative to those leachates collected from the PEI wastewater treatment sludges. The concentrations of these elements (Cd, Ni, and Zn), plotted with respect to the liquid-to-solid ratios for each of the four wastes, are illustrated in Figs. 2 and 3. The resulting pH of the leachate collected from each of the wastes is presented in Fig. 4.

4.1.1 Metal concentrations in laboratory extracts

Metal concentrations, by ICP spectroscopy, in the EP extracts and the 0.1 M acetate buffer (TCLP No. 1) are presented in Table 6. Analyses by atomic absorption spectroscopy of a single replicate

Table 1. Concentrations of metals in leachate from waste PEI-A^a

Element	Liquid-to-solid ratio (mg/L)							
	0.8	2.9	7.5	12.0	17.7	25.3	31.0	36.5
Ag	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30
Al	<1.20	<1.20	<1.20	<1.20	<1.20	<1.20	<1.2	<1.20
As	<0.60	<0.60	<0.60	<0.60	<0.60	<0.60	<0.60	<0.60
B	6.3	6	3.9	2.7	2.5	1.7	1.5	1.4
Ba	0.17	<0.12	0.13	0.19	0.21	0.26	0.25	0.29
Be	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Ca	770	1200	1200	1100	1100	1100	1000	1100
Cd	23	40	77	87	87	80	74	69
Co	0.099	0.13	0.26	0.29	0.28	0.29	0.26	0.27
Cr	0.32	0.31	0.26	<0.24	<0.24	0.28	0.27	0.29
Cu	2	2.8	3.4	3.3	3.2	2.9	2.5	2.3
Fe	63	60	180	290	350	440	440	480
Li	<1.20	<1.20	<1.20	<1.20	<1.20	<1.20	<1.20	<1.20
Mg	320	350	200	130	110	90	84	86
Mn	<1.20	6.3	12	13	13	13	13	13
Mo	<0.24	0.34	1.1	1.5	1.5	1.5	1.4	1.4
Na	580	290	140	130	130	130	130	140
Ni	5.8	17	38	42	45	40	39	38
P	8.5	7.7	10	11	11	11	10	11
Pb	<1.20	<1.20	<1.20	<1.20	<1.2	<1.2	<1.20	<1.20
Sb	<1.20	<1.20	1.6	2	1.9	2.2	2	2
Se	<1.20	<1.20	<1.20	<1.2	<1.20	<1.20	<1.20	<1.20
Si	24	31	41	44	46	48	48	49
Sr	3.6	4.6	3.1	2.2	1.9	1.4	1.2	1.1
Ti	<0.12	<0.12	<0.12	<0.12	<0.12	<0.12	<0.12	<0.12
V	0.5	0.51	0.34	0.26	0.2	0.2	0.18	0.19
Zn	11	25	77	110	110	110	99	98
Zr	<0.12	<0.12	<0.12	<0.12	<0.12	<0.12	<0.12	<0.12

^aTwo hundred grams of waste leached in an upflow column with MWL under anoxic conditions.

Table 2. Concentrations of metals in leachate from waste PEI-B^a

Element	Liquid-to-solid ratio (mg/L)					
	1.8	7.3	13.7	19.0	24.7	38.1
Ag	<0.30	<0.55	<0.55	<0.55	<0.55	<0.55
Al	<1.20	<2.20	<2.20	<2.20	<2.20	<2.20
As	<0.60	<1.10	<1.10	<1.10	<1.10	<1.10
B	0.53	<0.88	<0.88	<0.88	<0.88	<0.88
Ba	0.17	0.38	0.39	0.42	0.42	0.39
Be	<0.02	<0.03	<0.03	<0.03	<0.03	<0.03
Ca	660	1300	1400	1300	1200	1000
Cd	0.59	1.1	1	0.95	0.86	0.59
Co	<0.06	<0.11	<0.11	0.15	0.12	0.13
Cr	0.32	<0.44	<0.44	<0.44	<0.44	<0.44
Cu	0.6	0.49	0.26	0.31	0.33	0.25
Fe	41	210	270	280	340	450
Li	<1.20	<2.20	<2.20	<2.20	<2.20	<2.20
Mg	470	310	160	140	120	97
Mn	5	13	14	13	12	11
Mo	0.61	3.2	4.9	4.9	4.7	4.3
Na	1100	460	210	170	150	130
Ni	<0.36	<0.66	0.82	0.9	0.79	0.8
P	4.7	12	16	17	16	14
Pb	<1.20	<2.20	<2.20	<2.20	<2.20	<2.20
Sb	<1.20	<2.20	2.9	3.5	3.2	3.6
Se	<1.20	<2.20	<2.20	<2.20	<2.20	<2.20
Si	7.9	18	21	21	23	27
Sr	6.8	8.5	7	6.4	5.3	3.2
Ti	<0.12	<0.22	<0.22	<0.22	<0.22	<0.22
V	0.5	0.46	0.27	0.28	0.24	0.21
Zn	36	230	350	350	330	310
Zr	<0.12	<0.22	<0.22	<0.22	<0.22	<0.22

^aTwo hundred grams of waste leached in an upflow column with MWL under anoxic conditions.

Table 3. Concentrations of metals in leachate from
Summer County resource recovery ash^a

Element	Liquid-to-solid ratio (mg/L)						
	1.4	5.7	10.0	14.7	20.7	26.2	34.3
Ag	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30
Al	<1.20	<1.20	<1.20	<1.20	<1.20	<1.20	<1.20
As	<0.60	<0.60	<0.60	<0.60	<0.60	<0.60	<0.60
B	7.9	7.1	2.1	0.88	0.87	0.99	0.77
Ba	<0.12	<0.12	0.23	0.45	0.61	0.71	0.66
Be	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Ca	1500	1500	1600	1300	1100	1100	960
Cd	0.045	0.085	0.055	0.052	0.06	0.067	0.049
Co	<0.06	<0.06	0.092	0.1	0.095	0.078	0.089
Cr	<0.24	<0.24	<0.24	<0.24	<0.24	<0.24	<0.24
Cu	<0.12	0.36	0.43	0.41	0.51	0.42	0.35
Fe	0.36	54	55	200	350	400	420
Li	<1.20	<1.20	<1.20	<1.20	<1.20	<1.20	<1.20
Mg	88	130	93	72	71	74	67
Mn	1.3	15	22	16	15	13	12
Mo	<0.24	<0.24	<0.24	<0.24	<0.24	<0.24	<0.24
Na	760	140	130	120	110	120	110
Ni	<0.36	<0.36	0.41	<0.36	<0.36	<0.36	<0.36
P	<1.20	<1.80	<1.80	2	2.5	2.4	2.4
Pb	<1.20	<1.20	<1.20	<1.20	<1.20	<1.20	<1.20
Sb	<1.20	<1.20	<1.20	<1.20	1.4	1.3	1.4
Se	<1.20	<1.20	<1.20	<1.20	<1.20	<1.2	<1.20
Si	2	16	16	19	22	23	22
Sr	5.5	3.6	3.2	2.2	1.7	1.5	1.2
Ti	<0.12	<0.12	<0.12	<0.12	<0.12	<0.12	<0.12
Zn	1.1	7.9	9.4	10	12	9.2	9.9
Zr	<0.12	<0.12	<0.12	<0.12	<0.12	<0.12	<0.12

^aTwo hundred grams of waste leached in an upflow column with MWL under anoxic conditions.

Table 4. Concentrations of metals in leachate from Hampton resource recovery ash^a

Element	Liquid-to-solid ratio (mg/L)								
	3.0	8.9	15.0	20.8	26.5	32.6	38.6	44.7	50.9
Ag	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Al	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40
As	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
B	1.3	0.96	0.72	0.69	0.58	0.54	0.51	0.51	0.48
Ba	0.15	0.25	0.29	0.2	0.14	0.12	0.11	0.099	0.096
Be	0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Ca	1100	1000	930	910	840	820	820	820	730
Cd	0.11	0.077	0.059	0.052	0.042	0.035	0.025	0.023	0.039
Co	0.53	0.057	0.058	0.064	0.057	0.054	0.052	0.049	0.043
Cr	<0.08	<0.08	<0.08	0.19	<0.08	<0.08	<0.08	<0.08	<0.08
Cu	0.81	0.33	0.13	0.093	0.044	<0.04	<0.40	<0.04	<0.04
Fe	260	350	390	400	380	380	400	400	350
Li	0.74	0.55	0.46	0.45	<0.40	<0.40	<0.40	<0.40	<0.40
Mg	170	130	97	89	78	77	74	74	67
Mn	10	10	10	10	9.3	9.2	9.2	9.1	8
Mo	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08
Na	490	230	130	110	94	91	91	96	91
Ni	<0.12	<0.12	<0.12	0.17	<0.12	<0.12	<0.12	<0.12	<0.12
P	3.4	2.9	3.5	4.4	5.2	5.6	6.5	6.5	5.5
Pb	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40
Sb	0.5	0.58	0.6	0.57	0.59	0.58	0.57	0.53	0.56
Se	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40
Si	20	23	24	24	22	22	22	22	20
Sr	1.6	1.3	1.1	1	0.9	0.85	0.8	0.77	0.67
Ti	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Zn	12	8.7	7	7.1	5.6	5	4.5	3.9	2.9
Zr	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04

^aTwo hundred grams of waste leached in an upflow column with MWL under anoxic conditions.

Table 5. Mean concentrations of metals in waste leachate relative to those determined in MWL^a

Element	Wastes (mg/L)				MWL
	PEI A	PEI B	Sumner Co.	Hampton	
Ag	0.15	0.22	0.15	0.05	<0.30
Al	0.6	0.86	0.6	0.2	<1.2
As	0.3	0.43	0.3	0.1	<0.60
B	2.71	0.37	2.35	0.7	<0.48
Ba	0.21	0.31	0.47	0.16	0.3
Be	0.01	0.01	0.01	0.01	<0.012
Ca	1096	967	1216	884	790
Cd	74.1	0.72	0.06	0.06	0.031
Co	0.26	0.08	0.08	0.08	0.078
Cr	0.23	0.19	0.12	0.12	<0.24
Cu	2.89	0.3	0.38	0.18	<0.12
Fe	332	228	262	368	450
Li	0.6	0.86	0.6	0.35	<1.2
Mg	140	168	81.7	94.8	62
Mn	11.9	9.67	13.6	9.41	8.9
Mo	1.27	3.23	0.12	0.04	<0.24
Na	162	270	165	157	120
Ni	37.6	0.53	0.2	0.07	<0.36
P	10.4	11.3	1.9	4.85	14
Pb	0.6	0.86	0.6	0.2	<1.2
Sb	1.79	2.08	1.03	0.56	<1.2
Se	0.6	0.86	0.6	0.2	<1.2
Si	44.2	16.7	18.9	22.1	22
Sr	2.07	5.13	2.27	1	0.6
Ti	0.06	0.09	0.06	0.02	<0.12
V	0.26	0.26	^b	^b	0.14
Zn	91.6	229	9.17	6.26	1.9
Zr	0.06	0.09	0.06	0.02	<0.12

^aMean concentrations in waste leachate determined by dividing total milligrams of metal leached over the leaching period by the liters of leachate collected (concentrations below detection by ICP were estimated by dividing the detection limit by two). Values of metals in MWL are determined by ICP on a single sample taken during leaching of the wastes.

^bNot determined.

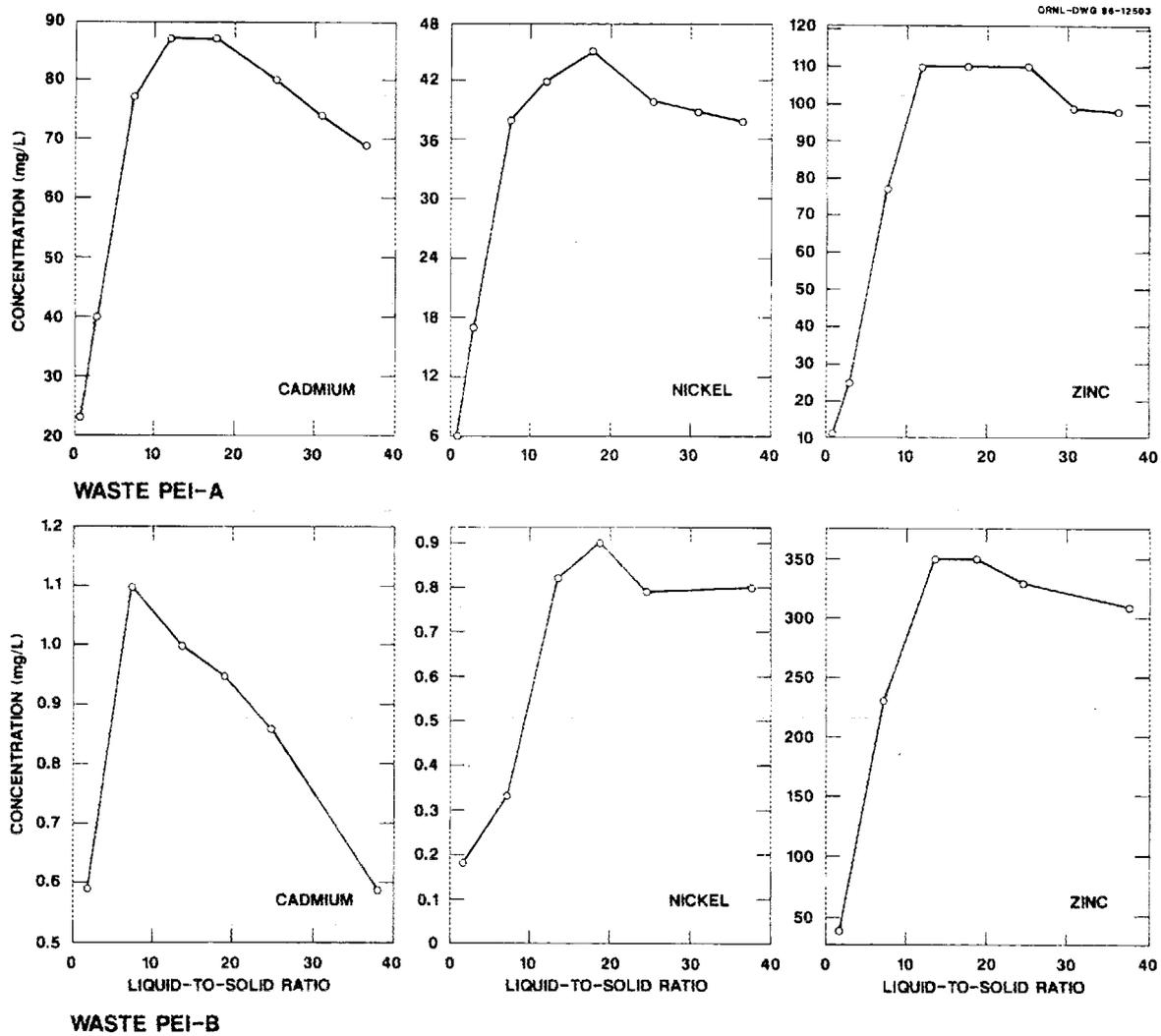


Fig. 2. Leaching of cadmium, nickel, and zinc from PEI-A and PEI-B waste by municipal waste leachate

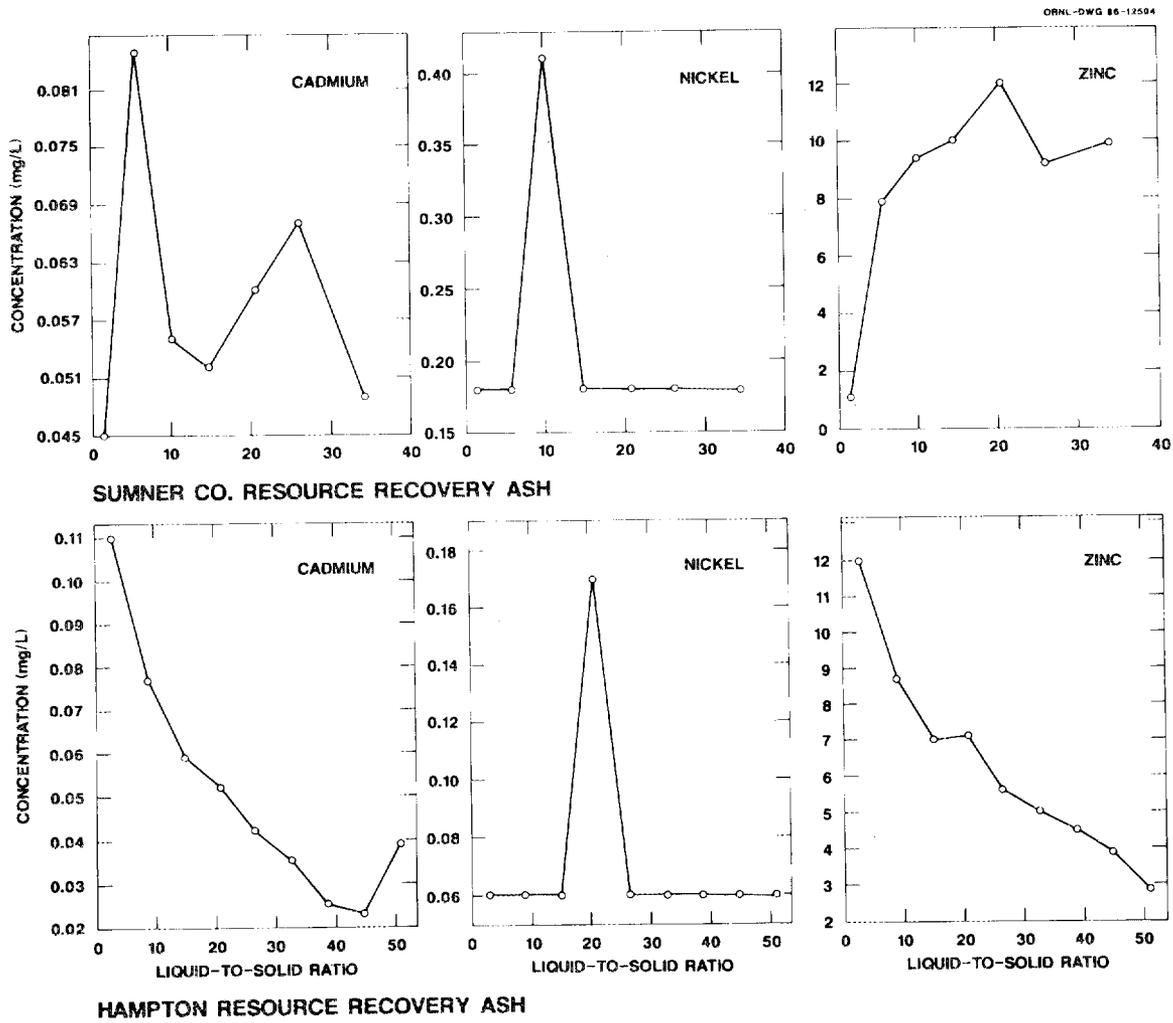


Fig. 3. Leaching of cadmium from Sumner County resource recovery ash by municipal waste leachate

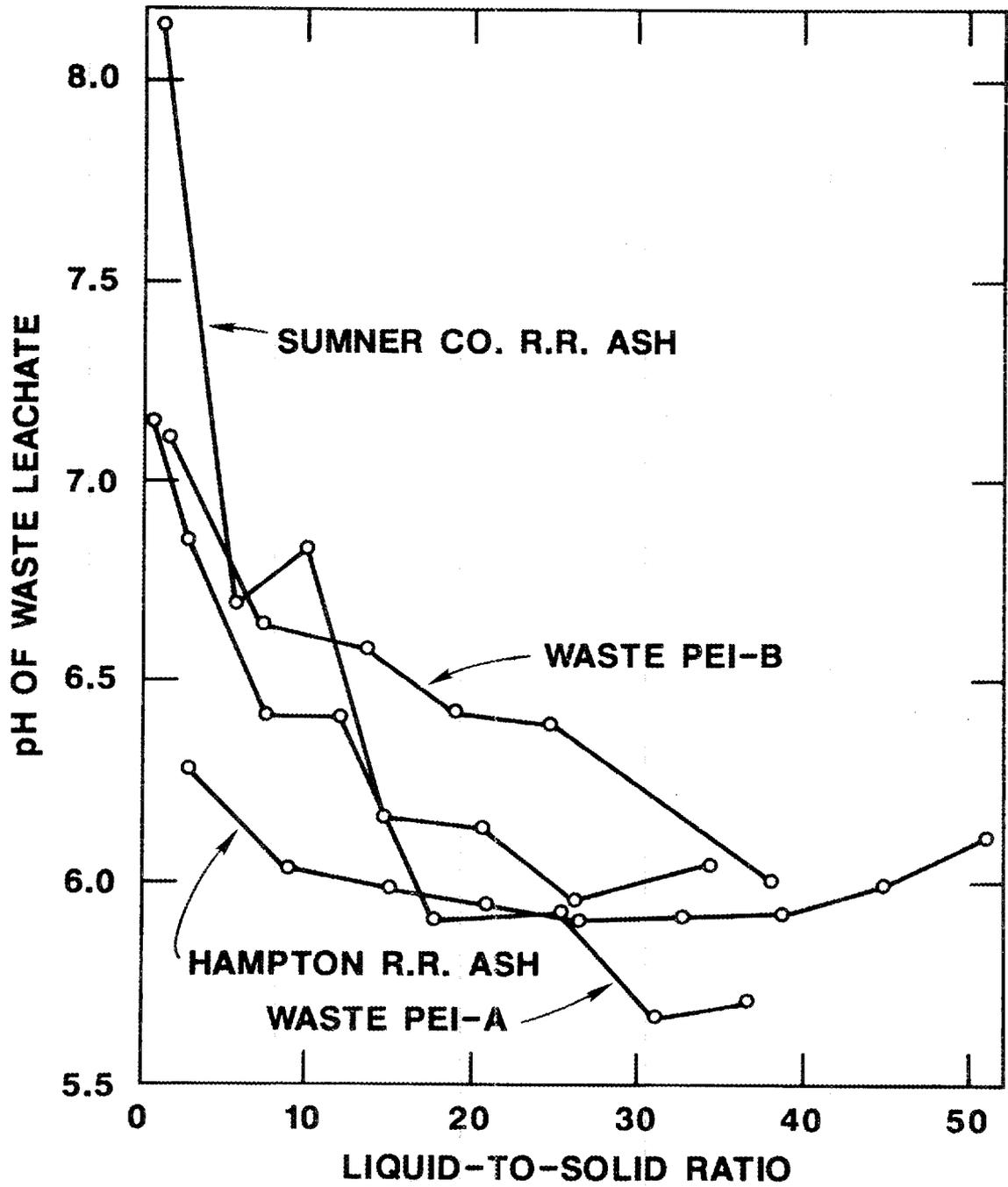


Fig. 4. pH of waste leachates

Table 6. Concentrations of metals in laboratory extracts^a

Element	Wastes (mg/L)											
	PEI A			PEI B			Summer Co.			Hampton		
	EP	TCLP No. 1	TCLP No. 2	EP	TCLP No. 1	TCLP No. 2	EP	TCLP No. 1	TCLP No. 2	EP	TCLP No. 1	TCLP No. 2
Ag	<1.1	<0.30	<1.10	<2.5	<0.30	<2.5	<0.18	<0.18	<0.10	<0.18	<0.18	<0.55
Al	<4.2	<1.2	<4.2	<10	<1.20	<10	92.3	<0.35	110	63.5	<0.35	85
As	<2.1	<0.60	<2.1	<5.1	<0.60	<5.1	n.d.	n.d.	n.d.	n.d.	n.d.	<1.1
B	4	2.8	3.9	<4.1	<0.48	<4.1	2.60	2.78	3.6	0.935	0.68	1.2
Ba	0.68	0.65	0.51	<1.00	0.45	1.1	0.168	<0.03	0.11	0.217	0.1	0.24
Be	0.065	<0.02	<0.04	0.13	0.013	<0.10	0.001	<0.01	<0.004	0.01	<0.01	<0.02
Ca	530	400	540	1000	440	880	956	1120	1600	847	839	1300
Cd	360	82	430	2.5	0.45	2.8	0.179	0.03	0.31	0.425	0.31	0.73
Co	0.34	0.09	<0.21	<0.51	<0.06	<0.51	0.071	<0.078	0.084	0.038	<0.08	<0.11
Cr	<0.84	<0.24	3.2	<2.00	<0.24	<2.0	0.464	<0.138	0.1	<0.09	<0.14	<0.44
Cu	14	0.69	26	<1.00	<0.12	<1.0	4.40	0.181	1.9	0.421	<0.19	<0.22
Fe	<0.63	<0.18	<0.63	<1.5	<0.18	<1.5	10.6	0.142	20	1.30	0.14	9
Li	<4.20	<1.2	4.2	<10	<1.2	<10	n.d.	n.d.	0.63	n.d.	1.04	<2.2
Mg	170	130	210	210	140	260	57.7	29.6	65	55.1	33.1	83
Mn	6.6	2.6	7.9	3.4	1.1	3.3	8.27	4.35	15	3.15	2.53	5.5
Mo	<0.84	<0.24	<0.84	<2.0	<0.24	<2.0	0.238	<0.16	<0.08	0.415	0.21	<0.44
Na	53	2000	61	270	1700	280	83.4	1620	110	71.9	790	99
Ni	120	29	150	<3.1	<0.36	<3.1	0.875	<0.66	0.83	0.134	<0.66	<0.66
P	18	<1.80	16	<15	<1.8	17	3.91	n.d.	4.6	n.d.	n.d.	5.6
Pb	<4.20	<1.20	<4.2	<10	<1.2	<10	5.83	<1.56	6.6	12.0	1.25	7.2
Sb	<4.20	<1.20	<4.2	<10	<1.2	<10	2.69	<1.2	<0.40	5.18	<1.2	<2.2
Se	<4.20	<1.20	<5.0	<10	<1.2	<10	n.d.	<2.58	<0.5	n.d.	<2.58	<2.2
Si	89	41	110	22	7.5	24	39.8	<0.72	52	17.9	<0.72	41
Sr	3.6	2.3	3.8	15	6.8	15	4.26	3.58	4.8	3.37	2.53	3.6
Ti	<0.42	<0.12	<0.42	<1.0	<0.12	<1.0	0.237	0.313	<0.04	0.196	0.31	<0.22
Zn	330	38	420	770	77	870	26	3.03	39	86.1	63.2	150
Zr	<0.42	<0.12	<0.42	<1.0	<0.12	<1.0	<0.06	<0.11	<0.04	<0.06	<0.11	<0.22

^aConcentrations determined by ICP. Concentrations for the EP and TCLP No.1 extractions of the resource recovery ashes are means from two replicated extractions; others represent only a single extraction.

(replicate no. 1) are presented in Francis (1985) for the resource recovery ashes. In general, there was a very good agreement between the two methods of analysis. The acetate buffer (TCLP No. 1) used for the resource recovery ashes was made using NaOAc and acetic acid (mean pH of 4.95 for the Sumner County waste and 4.92 for the Hampton waste) while the acetate buffer for the PEI wastes was made as prescribed in the proposed TCLP leaching procedure (USEPA 1986). The final pH of the laboratory extracts and milliliters of 0.5 N HOAc used in the EP extractions are presented in Table 7. From the standpoint of the EP, the PEI wastes A and B would be considered hazardous because of elevated cadmium levels (>1.0 mg/L), and both of the resource recovery ashes would be hazardous because of elevated levels of Pb (>5.0 mg/L).

4.1.2. Comparison of laboratory extracts with AMC20 concentrations

Values for AMC20 were determined for Cd, Ni, and Zn leached from the PEI-A waste, as well as Cd and Zn leached from the PEI-B waste and both of the resource recovery ashes (Table 8). Lead AMC20 values in the leachates of the resource recovery ashes would have been calculated except that lead concentrations were below ICP detection

Table 7. Final pH of laboratory extracts

Waste	EP mL of 0.5 N HOAc	pH	TCLP No. 1	TCLP No. 2
PEI A	345	5.18	6.70	5.02
PEI B	400	6.14	7.10	5.87
Sumner Co.	350	5.08	7.39	5.37
Hampton	275	5.06	6.46	5.18

Table 8. Comparison of metal concentrations in laboratory extracts and AMC20 values^a

Waste	Metal (mg/L)	AMC20 ^a (mg/L)	Laboratory (mg/L) extracts		
			EP	TCLP No. 1	TCLP No. 2
mg/L					
PEI-A					
	Cd	82	360	82	430
	Ni	40	120	29	150
	Zn	96	330	38	420
PEI-B					
	Cd	1.01	2.5	0.45	2.8
	Zn	267	770	77	870
Sumner Co. resource recovery ash					
	Cd	0.04	0.18	0.03	0.31
	Zn	8	26	3.0	39
Hampton resource recovery ash					
	Cd	0.05	0.42	0.31	0.73
	Zn	7.5	86	63	150

^aValues for AMC20 and AMC30 are equivalent except for Cd leached from the PEI Waste B; in this case, AMC30 value is 0.72 mg/L using the model $Y = ae^{1/x}$. See Table 9 and Figs. 5 and 6, which illustrate the cumulative leaching of the metals from the wastes.

levels (<1.2 and <0.4 mg/L for the Sumner County and Hampton ashes, respectively). Similarly, nickel concentrations in the leachates of PEI-B waste and the resource recovery ashes were <1.0 mg/L.

Except for cadmium leached from the PEI-A waste, AMC20 and AMC30 values are identical. This anomaly results as a consequence of small differences in the concentrations of metals in waste leachates at liquid-to-solid ratios between 10 and 15 beyond the liquid-to-solid ratio of the MLC. Or more simply, the cumulative leaching of metals from these wastes are directly related to the liquid-to-solid ratios. For example, regression analyses showed a strong statistical fit to a simple linear model (see Table 9 and Figs. 5-6). Among the four models used to fit the cumulative leaching of constituents in the wastes studied by Francis et al. (1984), the linear model gave the best fit, as measured by the coefficient of determination (R-squared) for all metals except the cadmium leached from the PEI-A waste (Table 9).

Examination of Table 8 reveals that concentrations of Cd, Ni, and Zn in EP extracts range from about 3 to >10 times higher than AMC20 concentrations. Extracts using the TCLP No. 2 medium generally contained higher concentrations of these metals than the EP extracts. On the other hand, concentrations of these metals in the extracts of the acetate buffer (TCLP No. 1) tended to be generally closer to the AMC20 values. It appears that the acetate buffer tends to underestimate AMC20 concentrations for zinc while the EP and the TCLP No. 2 extractions tend to overestimate the AMC20 concentrations. On the other hand, the acetate buffer did not underestimate zinc concentrations for the Hampton resource recovery ash nor for the zinc extracted from the electroplating waste used in Phase I of the research [in Francis et al. (1984), where the AMC20 value for zinc was 85 mg/L and the zinc concentration in the acetate extract was 215 mg/L compared with 430 mg/L for the EP].

Another indication that the EP and the TCLP No. 2 extraction procedures are overly aggressive in their simulation of metal AMC20 values is the "high" lead concentrations in the extracts of the resource recovery ashes relative to the lead concentrations in the leachates of these ashes on leaching with MWL. For example, lead

Table 9. Comparison of models to simulate the cumulative leaching of metals from alkaline wastes by MWL

Waste	Metal	Model ^a R-Squared			
		No. 1	No. 2	No. 3	No. 4
PEI-A					
	Cd	0.991	0.815	0.766	0.821
	Ni	0.992	0.846	0.736	0.810
	Zn	0.993	0.809	0.761	0.780
PEI-B					
	Cd	0.923	0.954	0.695	0.948
	Ni	0.973	0.872	0.790	0.828
	Zn	0.968	0.965	0.674	0.878
Sumner Co. resource recovery ash					
	Cd	0.993	0.903	0.778	0.858
	Ni	0.994	0.846	0.826	0.856
	Zn	0.995	0.935	0.724	0.787
Hampton resource recovery ash					
	Cd	0.964	0.860	0.856	0.958
	Ni	0.983	0.797	0.872	0.882
	Zn	0.977	0.838	0.875	0.939

^aModels used were as follows:

Model No. 1: $Y = a + bX$

Model No. 2: $Y = ae^{1/X}$

Model No. 3: $Y = ae^{bX}$

Model No. 4: $Y = a \ln X$

where Y = cumulative leaching of the metal in milligrams and
X = liquid-to-solid ratio, and a and b are constants.

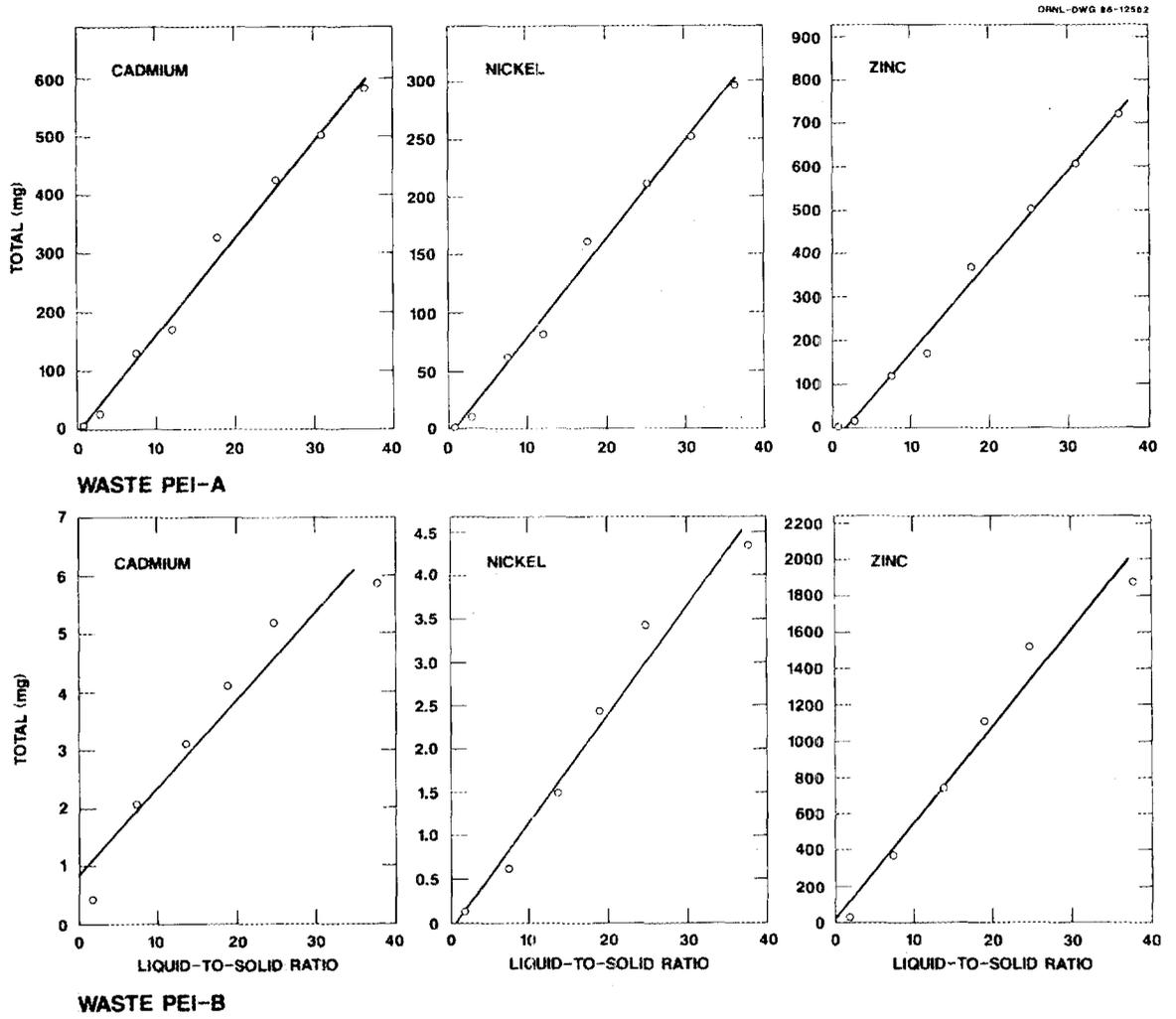


Fig. 5. Total cadmium, nickel, and zinc leached from PEI-A and PEI-B by municipal waste leachate

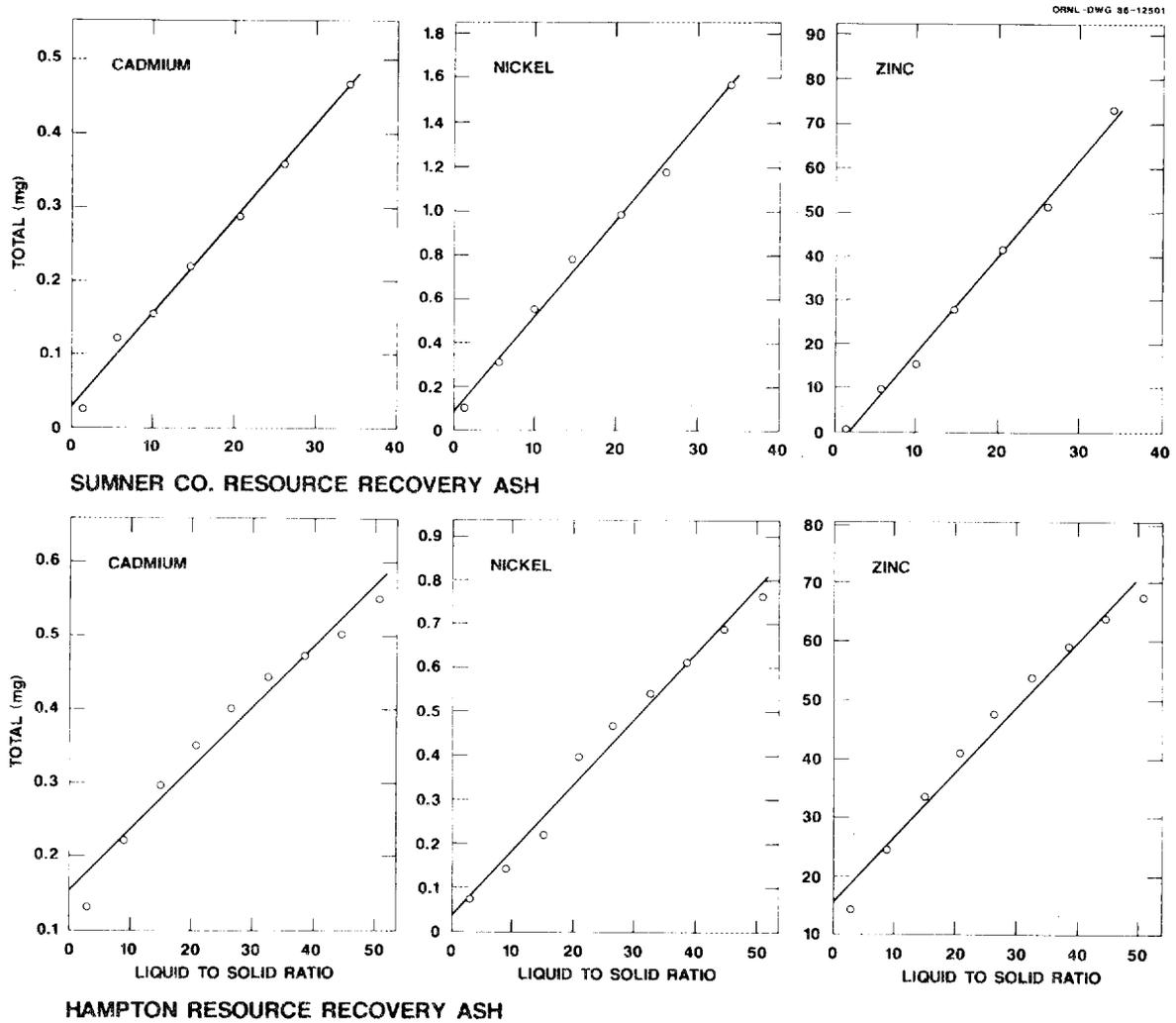


Fig. 6. Total cadmium, nickel, and zinc leached from Sumner County and Hampton resource recover ashes by municipal waste leachate

concentrations in the EP extracts of both ashes were in excess of the 5.0-mg/L RCRA limits (mean concentrations from two replicated extractions of 5.83 and 12.0 mg/L for the Sumner County and Hampton ashes, respectively). Concentrations of lead in the TCLP No 2 were also in excess of 5.0 mg/L (see Table 6). However, maximum concentrations in the leachates of these ashes by the MWL were never in excess of 1.2 and 0.4 mg/L (the detection levels for lead by ICP) for the Sumner County and Hampton ashes, respectively.

5. SUMMARY AND CONCLUSIONS

Three laboratory extractions (the RCRA, EP and the proposed RCRA-TCLP using extraction media No. 1 and No. 2) were compared with the AMC20 values for nine target metals using the "Comparison by Ratio" method described by Francis and Maskarinec (1986). In this method of comparison, the laboratory concentration is expressed as a ratio of the target concentration (the AMC20 concentration) as follows:

$$\text{Ratio} = \text{LC:TC} ,$$

where LC is the laboratory extract concentration (in milligrams per liter), and TC is the AMC20 target concentration (also in milligrams per liter) obtained by leaching the alkaline wastes with the municipal waste leachate. A ratio of 1.00 would indicate that the concentration in the laboratory extract was identical to the AMC20 value. Ratios >1.00 would represent laboratory concentrations in excess of the target concentration, and ratios <1.00 would represent laboratory concentrations that underestimate target concentrations. This ratio was then transformed to a log base to represent a lognormal population (Tornquist et al. 1985). Median ratios of 0.93, 4.25, and 5.89 were calculated for TCLP No. 1, EP, and TCLP No. 2, respectively. These data strongly indicate that the TCLP with extraction medium No. 1 simulates the leaching of alkaline wastes by MWL much better than either of the alternatives tested.

REFERENCES

- Francis, C. W. 1985. Leaching characteristics of resource recovery ash in municipal waste landfills. Final Report to California Waste Management Board, Sacramento, California. Environmental Sciences Division Publication No. 2456. Oak Ridge National Laboratory, Oak Ridge, Tennessee.
- Francis, C. W., M. P. Maskarinec, and J. C. Goyert. 1984. Mobility of toxic compounds from hazardous waste. ORNL-6044. Oak Ridge National Laboratory, Oak Ridge, Tennessee.
- Francis, C. W. and M. P. Maskarinec. 1986. Field and laboratory studies in support of a hazardous waste extraction test. ORNL-6247. Oak Ridge National Laboratory, Oak Ridge, Tennessee.
- Kimmell, T. A. and D. Friedman. 1986. Model assumptions and rationale behind the development of the EP-III. pp. 36-53. In J. K. Petros, W. J. Lacy, and R. A. Conway (eds.), Hazardous and Industrial Solid Waste Testing: Fourth Symposium. ASTM Special Technical Publication 886. Philadelphia, Pennsylvania.
- Tornquist, L., P. Vartia, and Y. O. Vartia. 1985. How should relative changes be measured? *Am. Stat.* 39(1):43-46.
- U.S. Environmental Protection Agency. 1986. Fed. Reg. 51(114):21648-21693.
- U.S. Environmental Protection Agency (USEPA). 1980. Identification Listing of Hazardous Waste. Environmental Protection Agency Hazardous Waste Management System. Title 40, Code of Federal Regulations, Part 261, Section 24.
- U.S. Environmental Protection Agency (USEPA). 1982. Test Methods for Evaluating Solid Wastes. Physical/Chemical Methods SW-846. 2nd ed. Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency, Cincinnati, Ohio.

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