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Comparison of Three Waste Leaching Tests

Executive Summary

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COMPARISON OF THREE WASTE LEACHING TESTS

Executive Summary

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DISCLAIMER

This Executive Summary has been reviewed by the Industrial Environmental Research Laboratory, the Municipal Environmental Research Laboratory and the Office of Solid Waste, U.S. Environmental Protection Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

The selection or design of any leachate test will ultimately be decided by a number of practical, rather than theoretical, considerations. The classification of whether or not a waste is hazardous, via a leaching test, must assume less than ideal disposal conditions, in order that, its potential for causing environmental harm can be minimized. It is recognized that a single test will not be optimal for all disposal conditions. Nevertheless from a regulatory point of view, developing different tests for each different waste and disposal option is clearly impractical and probably unworkable.

This Executive Summary is published with the intent of providing quick and concise information on the results and findings of this project.

FOREWORD

This research effort is a combined response to an environmental need by two Office of Research and Development Laboratories. The Edison, New Jersey office of the Industrial Environmental Research Laboratory assisted the Municipal Environmental Research Laboratory in this effort.

The Industrial Environmental Research Laboratory-Cincinnati develops cost effective techniques to prevent, control, or abate multi-media (air, water, solid wastes, etc.) pollutional impacts associated with the extraction, transportation, processing, benefication, conversion, and use of mineral resources and with industrial processing and manufacturing. The Municipal Environmental Research Laboratory develops new and improved technology and systems for preventing, treating, and managing waste water and solid and hazardous waste pollutant discharges from municipal and community sources, for preserving and treating public drinking water supplies, and for minimizing the adverse economic, social, health, and aesthetic effects of pollution. The related pollutional impacts on our environment and the interplay between its components require a concentrated and integrated attack on the problem.

This report deals with the investigation of three leaching tests as reliable predictors of the potential environmental effects of the disposal of thirteen industrial wastes. The advantages and disadvantages of each test based on the leaching characteristics of the thirteen wastes and the usefulness of each procedure as a standard test are analyzed and compared. The report will provide data for decision makers of both government and industry alike contemplating residue leachate control from industrial sludge impoundment/municipal landfill co-disposal operations.

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ABSTRACT

A comparison of three leaching tests was performed with thirteen industrial wastes to evaluate the potential of each test for use as a standard leaching test procedure. Such a procedure could be used to assess the leaching characteristics of industrial wastes for land disposal. The study was done in conjunction with a background study on the development of a standard leaching test. The advantages and disadvantages of each test based on the leaching characteristics of the thirteen wastes and the usefulness of each procedure as a standard test are analyzed and compared. Finally, comments are provided on the need for careful interpretation of test results.

This report was submitted in partial fulfillment of Grant No. R-804773-01 by the Department of Civil and Environmental Engineering, University of Wisconsin-Madison. The work was completed July 1978.

CONTENTS

FIGURES

TABLES

SECTION 1

INTRODUCTION

Developing awareness of the potential of landfilled industrial wastes to pollute groundwater has led to an interest in a standardized test to discern the relative leaching potential of a waste. A background study on such a test has been done by the authors for the U.S. Environmental Protection Agency (EPA) (1). During this background study a leaching test was developed, called the SLT. In order to evaluate the SLT, and other leaching tests which might be used as the standard test, a comparison of three leaching tests was made by running the tests on a wide variety of industrial wastes and comparing the relative ease, practicality and amount of information obtained in each of the tests. The results of the test comparison are given in this report. The test comparison also serves as a practical evaluation of the SLT.

This report constitutes an Executive Summary of the complete report of the study as submitted to EPA (2).

SECTION 2

SUMMARY AND CONCLUSIONS

Certain features of an ideal standard leaching test following the concepts discussed in Section 4 are given in Table 1. An ideal leaching test is defined herein as a standardized procedure which works on all wastes and is able to predict quickly and with accuracy the potential water quality degradation within a landfill represented by the landfill disposal of a particular waste. It does not evaluate any changes in leachate quality arising from passage through soils or dilution. The major abilities and limitations of each test used in this study with regard to these features are given in Table 2. Column tests are not included in the concept of an ideal leaching test because of the difficulty of using a column test on a wide variety of wastes.

TABLE 1. SOME FEATURES OF AN IDEAL STANDARD LEACHING TEST*

1. Use of leaching media corresponding to liquids likely to be in contact with the waste in the landfill (such as use of both an acid synthetic municipal landfill leachate and distilled water leaching solutions for modeling leaching in actively decomposing and stabilized municipal landfills, respectively).

2. Incorporates procedures to indicate both concentration and release of parameters likely to be leached from a waste.

3. Use of multiple elutions so secondary effects can be observed.

4. Use of an effective agitation procedure which does not unnaturally or unnecessarily abrade waste particles.

5. Use of a solid/liquid ratio high enough to minimize analytical and sampling errors, yet low enough to allow rapid determination of critical concentration and release information for most parameters.

6. Use of convenient, yet justifiable, elution times and numbers of elutions.

*It is assumed that any useable test would incorporate sampling procedures and sufficient replicates to gain statistical reliability.

TABLE 2. ABILITIES AND LIMITATIONS OF EACH TEST IN COMPARISON TO AN IDEAL TEST*

SLT

Positive aspects:

1. Use of two separate procedures to allow prediction of both concentration and release of parameters from waste.
2. Flexibility of leaching media selection such as the use of both acid synthetic municipal landfill leachate and distilled water as leaching solutions to model co-disposal with muncipal solid waste.
3. Use of an effective, yet gentle, agitation technique.
4. Use of multiple elutions.
5. Use of an intermediate solid/liquid ratio which lessens the chance of analytical errors of the Minn. test while generally allowing more rapid evaluation of release characteristics than does the IUCS test.
6. Incorporates procedures which allowed its direct use on all the wastes tested in this study.

Limitations:

1. Use of an oxygen sensitive leachate, required for proper modeling of leachate generated in actively decomposing municipal solid waste landfills.
2. The laboratory procedures and the amount of information obtained, especially if both concentration and release results are desired, require more laboratory effort and interpretive care.

IUCS TEST

Positive aspects:

1. Use of a generally effective agitation technique.
2. Use of multiple elutions.
3. Use of a high solid/liquid ratio gives relatively high concentrations of many parameters.

(continued)

*i.e., Table 1

TABLE 2 (continued)

4. Use of a relatively straightforward laboratory procedure.

Limitations:

1. Use of only a distilled water leachate.
2. Lack of a procedure to evaluate the maximum concentration of a parameter in leachate.
3. Use of an elution time and number such that work needs to be continued over weekends.
4. Required adaptations on a waste by waste basis to allow some wastes to be tested.
5. The fewer numerical results require more careful interpretation and extrapolation of data than the SLT to apply the results to actual landfill situations.

MINNESOTA TEST

Positive aspects:

1. Use of both acid and distilled water leachates.
2. Simple and rapid to perform.

Limitations:

1. Acetate buffer models only one aspect of municipal solid waste leachate affecting its leaching aggressiveness.
2. Low solid/liquid ratio emphasizes subsampling, weighing, and analytical errors.
3. Use of only one elution gives much less information than either of the other two tests. No information is provided regarding the approach to stable results, the rate at which such stability is reached, or possible secondary effects.
4. Agitation technique allows significant concentration gradients in the bulk solution, slowing the time needed to approach equilibrium and reducing the reproducibility of the results.
5. Required adaptations on a waste by waste basis to allow some wastes to be tested.

(continued)

TABLE 2 (concluded)

6. Neither concentration nor release information can be obtained with confidence because it is not known how close the results are, after one elution, to maximum values attainable or to practical values reached in actual landfills. Application of test results to actual landfills is difficult to justify.

A number of different tests could be designed which meet the criteria of Table 1 and, yet, have considerable differences between them. Thus, once a standard leaching test has been designed, interpretation of the test results becomes a crucial factor in determining the applicability of the test. A standard leaching test provides a reproducible set of numbers that are a function of the interaction of a waste with a specific leaching solution under a specific set of conditions. It is up to the decision maker to evaluate those numbers and make a prediction regarding the behavior of the waste in a landfill. Unfortunately, the multiplicity of factors affecting the wastes' leaching characteristics, both in the test and in the landfill, and the variability of landfill conditions, dictate that interpretation be done with care and with consideration of the waste and landfill characteristics. Tests results should not be interpreted rigidly; i.e., a certain concentration of a given parameter in the test leachate should not be taken to indicate automatically that the waste is hazardous in the landfill. Rather, consideration should be given to such factors as the amount of waste to be disposed, the annual net infiltration of water or movement of groundwater through the landfill, the factors affecting the leaching of the waste (as far as can be determined from the test results), possible waste-leachate interactions, and the fate of the landfill leachate after it leaves the waste and passes through additional wastes or soil.

As an example of the need for careful interpretation, consider the distilled water leachates from the $CuO-Na_2SO_4$ sludge. These leachates contained low concentrations of copper (<1 mg/l), yet, very high concentrations of Na (~10,000 mg/l in the SLT Elution 1 leachates). With regard to Na, the leachate is probably not very hazardous, at least no more hazardous than sea water which has approximately the same Na concentration. Yet, in a landfill or in the soil underneath, the high ionic strength could solubilize potentially hazardous trace metals through ion exchange mechanisms. Thus, the leachate itself may not be hazardous, but it may solubilize hazardous materials in landfill environments. Likewise, several wastes released large amounts of unidentified organic compounds, as evidenced by the very high COD values in the distilled water leachates. The potential hazard of these wastes may not come from the organic compounds released by the waste, if these are not hazardous, but from the ability of the released organics to solubilize otherwise insoluble hazardous compounds such as PCBs, chlorinated organic pesticides, or heavy metals. On the other hand, a waste may release small amounts of hazardous materials which will most likely be removed from the leachate by passage through the soil under the landfill. The waste might appear to be hazardous due to the release of this material in a leaching test, while in the landfill it would actually be of no practical concern. Several wastes which released trace metals in low concentrations might fall into this category. It should be noted that leaching modeled by the test in one or two days may simulate years of leaching in the field. During this time, bacteria may convert hazardous compounds into innocuous ones, or vice versa, or they may completely alter the leaching characteristics of a waste through their action on the waste matrix.

When interpreting test results, it is important to consider the physical condition of the landfilled waste. For example, a waste which is landfilled in large stable chunks or with a stable impervious coating would most likely behave far differently in a landfill than in a test in which it were ground. The test results need to be interpreted with regard to particle surface area both in the test and in the landfill and in light of the stability of the chunks of waste or coatings on the waste in the landfill.

An evaluation of the hazardous nature of a waste must include an evaluation of the landfill environment. A waste's hazardous nature is a situation specific characteristic. A waste may be hazardous to an organism under one set of environmental conditions, yet, completely innocuous under a different set of conditions. Furthermore, its hazard may be organism specific; i.e., it may be hazardous to one organism and not to another under the same set of conditions. Thus, a determination of the hazardous nature of a waste must include an evaluation of its hazardousness to specific organisms under specific conditions.

The limitations of a standard leaching test and the care needed in interpreting the results do not mean that a standard test is not worth developing and using. A standard test should provide a rapid evaluation of the parameters that are likely to be leached from a waste, and an indication of their maximum concentrations in the leachate and the total amount to be released per unit weight of waste. That the test is not perfect in predicting the long term leaching pattern of a waste or the precise concentration of a particular parameter in a particular landfill, means that the test results need to be interpreted with care to avoid unnecessary expenditures for control of wastes that are not actually hazardous in a particular landfill, or to avoid unexpected environmental degradation from improper land disposal of a waste.

In summary, of the three tests compared in this study, the SLT gave the most information in the shortest amount of time. The IUCS test could be improved if several modifications were incorporated, such as use of an acidic synthetic municipal landfill leachate when co-disposal of the waste being tested with municipal solid waste is possible, and if a procedure for measuring maximum concentration were added. The Minn. test would require several modifications in order to be a widely applicable standard test.

Whatever standard test is used, interpretation of test results is the crucial factor in determining the test's ultimate value in predicting whether a waste is hazardous when placed in a landfill. Virtually any leaching test which is properly interpreted would be more useful in making such a prediction than would be a well designed leaching test which is poorly interpreted.

SECTION 3

EXPERIMENTAL PROCEDURES

LEACHING TESTS USED

The two tests used in addition to the SLT were selected by EPA as being among the best tests currently available and as having some variety in the test conditions. The tests used were the SLT, an IU Conversion System modified 48-hour shake test (the IUCS test) and a test developed by the Minnesota Pollution Control Agency (the Minn. test). There are several IUCS shake tests available, so particular care should be taken to specify the test conditions when discussing the test. A summary and comparison of the test conditions is given in Table 3. Note that the IUCS test uses fresh leaching media for each elution, as does the SLT test procedure R (see note in Table 3).

In addition to the tests mentioned above, a municipal leachate was used as a leaching medium, using a modified SLT procedure R. The difficulty in working with highly air sensitive real leachate necessitated the modifications. The purpose of the real leachate test (RLT) was not to verify the accuracy of the synthetic leachate used in the SLT, as might be supposed, but rather to obtain an idea of the leaching ability of a real leachate sample. The leachate was not as aggressive as the leachate upon which the synthetic leachate was modeled, and so cannot be used as a verification of the synthetic leachate.

WASTES USED AND SAMPLE PREPARATION

Fourteen wastes were used in the test comparison. The wastes and the tests they were used in are listed in Table 4. Since the intent of the comparison was to evaluate the tests themselves, the sample preparation procedure was kept the same for all tests. This preparation included a solid/liquid separation procedure that is recommended for sample preparation in the SLT background study. This technique is not included in either the IUCS or Minn. tests. Both of these tests, however, were designed for solid or semi-solid wastes rather than for predominantly liquid wastes. As many of the wastes used in the test comparison were predominantly liquid, the designers of both the IUCS and Minn. tests were asked how to prepare predominantly liquid wastes for their tests. Both agreed that a solid/liquid separation might be one approach to sample preparation, although both emphasized that their tests were not designed for such wastes, and that a solid/liquid separation might not be the approach they would use to prepare predominantly liquid wastes for their tests.

TABLE 3. A SUMMARY OF THE LEACHING TESTS USED IN THE TEST COMPARISON

	SLT	IUCS Test	Minnesota Test
Leaching Solution	Synthetic Leachate† H_2O§	H_2O§	Acetate Buffer‡ H_2O§
Solid/Liquid Ratio	1:10 (Proc. R)* Varied (Proc. C)	1:4	1:40
Time per Elution	24 hrs	48 hrs	24 hrs
Number of Elutions	3 or more	5	1
Temperature	Room	Room	Room
Shaking Technique	Slow Tumbling (rotating)	Back and Forth Shaking (reciprocal)	1 min. shake, 24 hr rest (separatory funnel)

*Two procedures used, in one of which the solid-liquid ratio is varied, replacing the waste with fresh waste in successive elutions (C), while in the other it is kept constant, replacing the leaching media in successive elutions (R), maximizing concentration (C) and release (R), respectively.

†A synthetic municipal landfill leachate, with a pH of 4.5 and composed as follows:

0.15M Acetic Acid
0.15M Sodium Acetate
0.050M Glycine
0.008M Pyrogallol
0.024M Ferrous Sulfate

‡pH of 4.5.

§Distilled, deionized water used.

TABLE 4. WASTES USED IN THE TEST COMPARISON

	Waste	Waste Abbreviation	Test Used in	
1.	Adhesive Waste #1		SLT, Minn, IUCS	
2.	Ink & Paint Waste	I.P.W.	STL, Minn, IUCS	
3.	Coal Tar Waste		SLT, Minn, IUCS	
4.	Health and Beauty Care Waste	H.B.C.	SLT, Minn, IUCS	
5.	Food Grade Waste		SLT, Minn, IUCS	
6.	Adhesive Waste #6		SLT, Minn, IUCS	
7.	Petrochemical Industry-Water/ Oil Sludge	Petrochemical Sludge	SLT, Minn, IUCS	
8.	Grain Process-ing Lipids and Fats	Grain Fats	SLT, Minn, IUCS	
9.	Food Wastes, Clay		SLT, Minn, IUCS	
10.	Marble Wash		SLT, Minn, IUCS	
11.	Copper Oxide-Sodium Sulfate Sludge	$CuO-Na_2SO_4$ Sludge	SLT, Minn, IUCS	RLT
12.	Electroplating Sludge	EPS	SLT, Minn, IUCS	RLT
13.	Wastewater Treat-ment Sludge	WTS	SLT, Minn,	RLT
14.	Papermill Sludge, EPA	PMS-EPA	SLT	

RELEASE CALCULATIONS

The release of a parameter per unit mass waste for each of the tests was calculated using the equation given below:

$$\text{Release}_{\text{elution}(i)} \quad \frac{\sum_{i=1}^{N} (\text{conc}(i),\ \text{mg/L})(\text{leachate volume, mL})(1\ \text{L}/1000\ \text{mL})}{(\text{dry weight of solid in test, g})(1\ \text{kg}/1000\text{g})}$$

where i is the elution number and N the total number of elutions. Leachate volume and dry weight of solid is constant for each test, except for SLT procedure C. Since the purpose of procedure C is to evaluate maximum concentration, release using this procedure was not calculated. Except for unusual release patterns, release in procedure R will be greater than or equal to that in procedure C.

SECTION 4

TEST COMPARISON

In order to compare results of the different test procedures and leaching media, a comparison can be made of the concentration in the different test leachates of a single parameter leached from a waste. This has been done in Table 5 for selected parameters from selected wastes. Such a single parameter comparison does little good in understanding the relative aggressiveness of the tests unless the factors affecting the parameter concentration in the leachates are known. However, the relative aggressiveness of the tests can be analyzed by comparing the number of times each test gave the highest concentration (or release) of a parameter for all the parameters analyzed throughout the test comparison. This has been done for parameter concentration in Table 6. As can be seen for the parameters measured, the SLT gave the highest concentration much more frequently than the other tests. Table 7 shows a similar comparison for acid and water leachates, comparing only parameters that were measured in both. It is obvious from the table that acid leachates are much more aggressive than distilled water leachates.

A more complete comparison of the tests entails an analysis of the effects of the differences between the tests on the test results, and the importance of these differences for interpreting the test results. The tests were compared as whole units with several factors differing between them. Therefore, it is not possible with any degree of certainty to isolate one factor and explain differences between the tests as based on that single factor. Rather, one can only say that a given factor varied between tests and that it seems reasonable to ascribe a given difference in the test results to this factor, as in the following sections.

LEACHATE COMPOSITION

The profound effect of leaching solution composition on the materials and concentrations leached from a waste is shown with several wastes used in the test comparison, most notably the $CuO-Na_2SO_4$ sludge. Using the $CuO-Na_2SO_4$ sludge as an example, acidic leachates—the synthetic leachate and the acetate buffer—leached potentially hazardous trace metals in significant concentrations as shown in Figure 1. These metals were either below detection limits or leached in very low concentrations in the water leachates. The copper concentrations in the acidic leachates were four orders of magnitude (10,000 times) higher than the copper concentrations in the water leachates. Since landfills produce acidic leachates comparable with respect to both pH and buffering capacities to the synthetic leachate used in the tests during part

TABLE 5. A SUMMARY OF TEST COMPARISON RESULTS FOR SELECTED PARAMETERS FROM SELECTED WASTES

Waste / Parameter	Concentration, mg/L SLT S.L.* Proc C	SLT S.L.* Proc R	SLT $H_2O^\dagger$ Proc C	SLT $H_2O^\dagger$ Proc R	IUCS $H_2O^\dagger$	Minn. Acet‡	Minn. $H_2O^\dagger$	Release, mg/kg SLT S.L.* Proc R	SLT $H_2O^\dagger$ Proc R	IUCS $H_2O^\dagger$	Minn. Acet‡	Minn. $H_2O^\dagger$
Ink & Paint Waste:												
Na				190	455		35		2410	2862		1400
K		24.5		10	30.5	9	2.5	505	169	274	360	100
Mg		23		5.5	18	1.9	1.3	292	83	137	72	52
Zn		36		0.27	1.17	38	0	681	2.7	5.8	1520	0
Pb		4.2		0	0.24	10.2	0	85.5	0	0	406	0
Cu		0.20		0.34	1.15	0.14	0.09	3.8	3.9	5.3	5.6	0
Cd		0.28		0	0	0.11	0	4.2	0	0	4.4	0
Cyclohexanone		176		260	435	54	115	2580	3750	4120	2170	4700
Napthalene		0.31		0.65	0.65	1.3	1.64	6.9	6.6	4.0	52	65
COD				41,500					480,000			
Coal Tar Waste:												
Napthalene	12.7	21.9	20.1	20.9	5.7	2.8	2.4	624	578	81.2	112	96
Phenol	493	96	193	112	679	2.6	2.7	1644	1949	472	104	108
Cresol	138	58.5	80.2	58.1	36.5	1.4	1.3	1290	1338	288	56	52
Quinoline	307	93.5	64.0	620	26	0	0	2176	1726	333	0	0
COD			2250	730					15,390	4492		4560
Health & Beauty Care Waste:												
Zn	25.0	12.8	11.0	5.9	11.5	2.9	1.4	174	73	67	116	56
Cd	0.92	0.39		0.14				6.0	1.4			
Fe			122	37.0	81.0	52	11		543	440	2080	440
Cu	5.60	1.55	14.0	5.9	10.0	9.6	1.5	38	112	79.2	384	60
Pb	0.86	0.69	0	0	0	0.40	0.21	18.8	0	0	16	8.4
COD			93,600	12,670	33,600				149,000	186,000		
Food Industry,												
Zn	1.8	2.0	0	0	0	1.5	0	51	0	0	60	0
Pb	0.95	3.8	0	0	0	6.5	0	56	0	0	260	0
COD			340	190	128		4		3340	1800		160
Marble Wash:												
Pb	0.60	0.63	0	0	0	3.5	0	16.6	0	0	140	0
COD			142	128	116		72		2230	1576		2880

Waste / Parameter	Concentration, mg/l SLT S.L.* Proc C	SLT S.L.* Proc R	SLT $H_2O^\dagger$ Proc C	SLT $H_2O^\dagger$ Proc R	IUCS $H_2O^\dagger$	Minn. Acet‡	Minn. $H_2O^\dagger$	Release SLT S.L.* Proc R	SLT $H_2O^\dagger$ Proc R	IUCS $H_2O^\dagger$	Minn. Acet‡	Minn. $H_2O^\dagger$
$CuO-Na_2SO_4$ Sludge												
Na			42,000	9,740	23,000		4970		220,000	170,000		207,000
K	32.4	5.2	39	4.30	24	4.4	3.5	171	90	140	185	150
Mg	3281	1970	153	132	6.4	380	12	43,200	6734	104	15,300	616
Cu	2916	3120	0.57	0.38	0.27	1450	0.18	104,000	6.9	2.0	74,200	13.6
Zn	7.65	6.84	0.20	0	0.12	3.7	0	155	0.6	0.7	155	2
Fe			1.55	0.1	0.31	120	0.18		3.8	2.2	5,100	18
Electroplating Sludge												
Zn	45	160	0	0	0	210	0	6,570	0	0	9,540	0
Cd	7.50	19.9	0	0	0	7.4	0	943	0	0	344	0
Wastewater Treatment Sludge												
Zn	2.0	18.0	1.0	1.0		11	0	460	23		800	0
Cu	200	290	0	0		85	28	5,800	0		6,050	350
COD			5,500	1,800		0			23,000			

*S.L. - synthetic municipal landfill leachate.

†H_2O - distilled, deionized water.

‡Acet - acetate buffer, pH 4.5.

TABLE 6. THE NUMBER OF TIMES EACH TEST LEACHING SOLUTION GAVE THE HIGHEST CONCENTRATION OF AN INORGANIC PARAMETER FROM A WASTE FOR THE DIFFERENT TEST LEACHATES

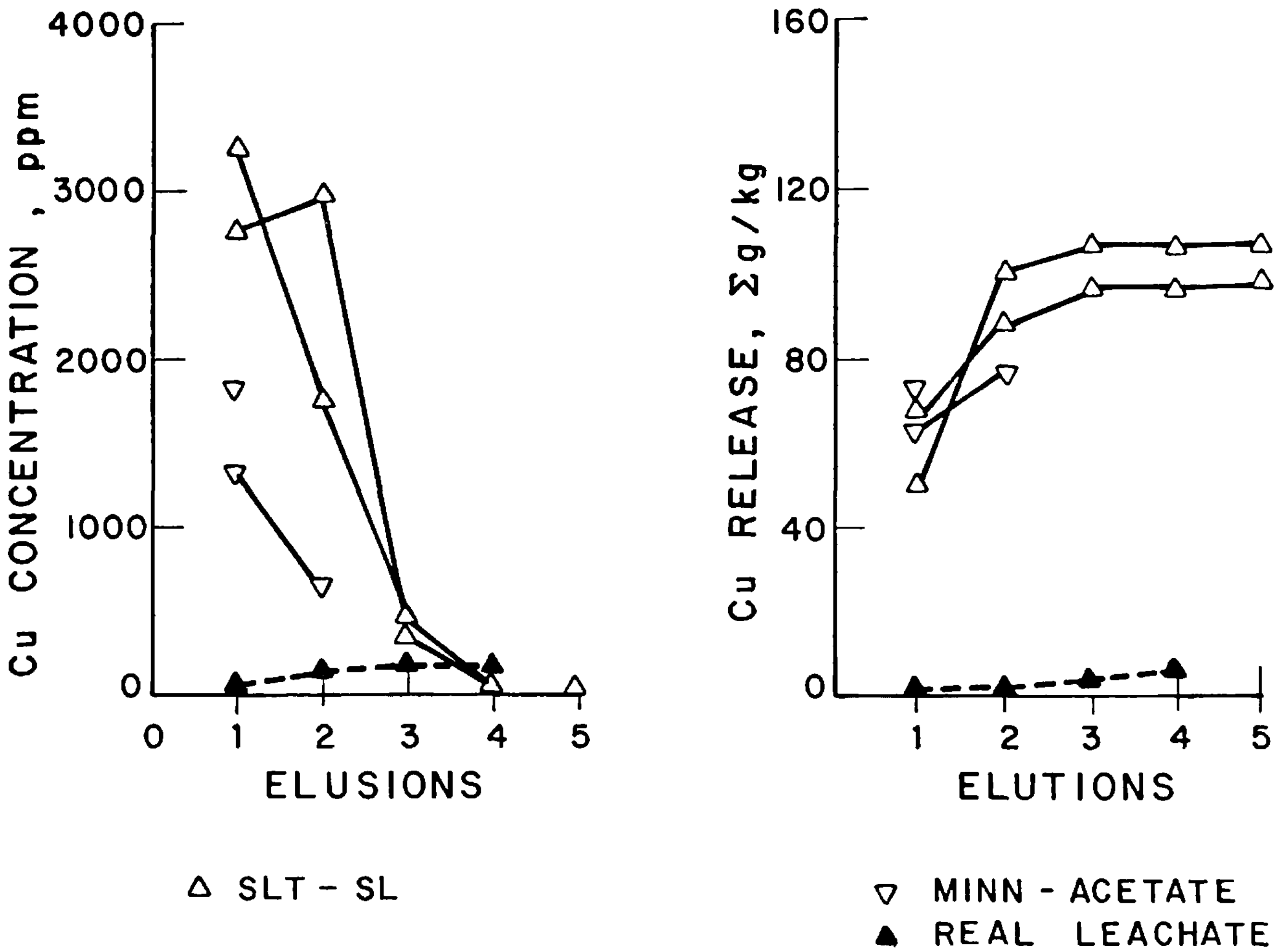
	SLT						
	Proc C		Proc R		Minn		IUCS
	H_2O	SL	H_2O	SL	Acet	H_2O	H_2O
Na	8	--*		--	--		4
K	1	10					1
Mg	1	7		1	1		
Fe	1	--	1	--	1		
Zn		6		5	2		
Pb		1		1	4		
Cu	1			2			1
Cd				2			
COD	4	--		--	--		
Total Number	16	24	1	11	8	0	6
Total %	60.6		18.2		12.0	0	9
Total % for Each Test	SLT 79%				Minn 12%		IUCS 9%

*Not measured.

TABLE 7. NUMBER OF TIMES ACID OR H_2O LEACHING SOLUTIONS GAVE HIGHEST CONCENTRATIONS OR RELEASE OF AN INORGANIC PARAMETER FROM A WASTE FOR PARAMETERS MEASURED IN BOTH ACID AND H_2O LEACHATES

	SLT		Minn		IUCS	Total		TOTAL TESTS
	Acid	H_2O	Acid	H_2O	H_2O	Acid	H_2O	
				Number of Times Giving Maximum Concentration				
K	10	1			1	10	2	12
Mg	8	1	1			9	1	10
Zn	11		2			13	0	13
Pb	2		4			6	0	6
Cu	2	1			1	2	2	4
Cd	1					1	0	1
						41	5	46*
				Number of Times Giving Maximum Release				
K	8		4			12	0	12
Mg	8	1	2			10	1	11
Zn	8		4			12	0	12
Pb	1		5			6	0	6
CU	1		2		1	3	1	4
Cd	2		1			3	0	3
						46	2	48*

*Totals are not equal because two tests may both give the maximum concentration but have different maximum releases. In cases where the maximum concentration or release were the same, the results were not tabulated.



NOTE: Cu concentrations in all distilled water leachates were less than 0.6ppm.

Figure 1. Cu concentration and release from a $CuO\text{-}Na_2SO_4$ sludge in test leachates.

of their life span, and would leach Cu from the $CuO-Na_2SO_4$ sludge, the need for such a leachate in the leaching test is apparent. The comparison of the synthetic leachate and actual leachate is indicated by the results of the SLT leaching test using municipal landfill leachate. Although not as acidic as either of the acid leachates, the municipal landfill leachate still leached much higher concentrations of copper than were obtained using distilled water as the leachate.

The synthetic leachate gives a more accurate view than does the acetate buffer of the leaching that would occur in a young municipal landfill. This is because it models more aspects of municipal leachate than does the acetate buffer, which models only pH. The synthetic leachate models an anaerobic municipal leachate. Being anaerobic, it is air sensitive and requires careful handling to avoid changes brought about by air contact. The most readily observed change is the formation of an iron precipitate which forms an oxidation. Precipitation introduces the possibility of loss from solution of materials by either occlusion in or adsorption on the precipitate. Thus, simple air contact of the synthetic leachate may cause inaccurate results. An alternative, an aerobic synthetic leachate, has been developed. This leachate avoids the oxidation-precipitation problem, but does so at the cost of not modeling the redox potential of real leachate as completely as does the anaerobic synthetic leachate.

The anaerobic synthetic leachate is designed to model the leaching environment found in actively decomposing municipal landfills. Since many wastes will be landfilled by themselves or with other industrial wastes, other leaching solutions are needed to model the leaching environment found in those landfills. For such situations, the SLT procedure recommends use of other leaching media such as distilled water or that obtained by prior contact of distilled water with the other wastes in question, or the media may be specially formulated to relate to the leachate expected from the other wastes. All three tests use a distilled water leachate which would be more realistic than synthetic municipal landfill leachate in many landfill situations.

SOLID-LIQUID RATIO

A direct dependence of concentration on solid/liquid ratio was frequently seen with very soluble parameters, such as Na and K. Good examples of this behavior are found in the Na and K data derived from leaching ink and paint waste. A graph of the Na and K concentrations in the first H_2O leaching from ink and paint waste versus the amount of solid present per 100 ml leachate (Figure 2) shows that the Na or K concentrations fall nearly on a straight line. This indicates that the concentration in solution is directly dependent on the amount of solid present for these parameters.

At the other extreme is a parameter whose concentrations are controlled strictly by solubility equilibrium. In this case, the concentration in solution would appear to be independent of the amount of solid present and would be the same in all tests. Such a situation has been ecnountered with the wastes studied. For most parameters, concentration will probably be controlled

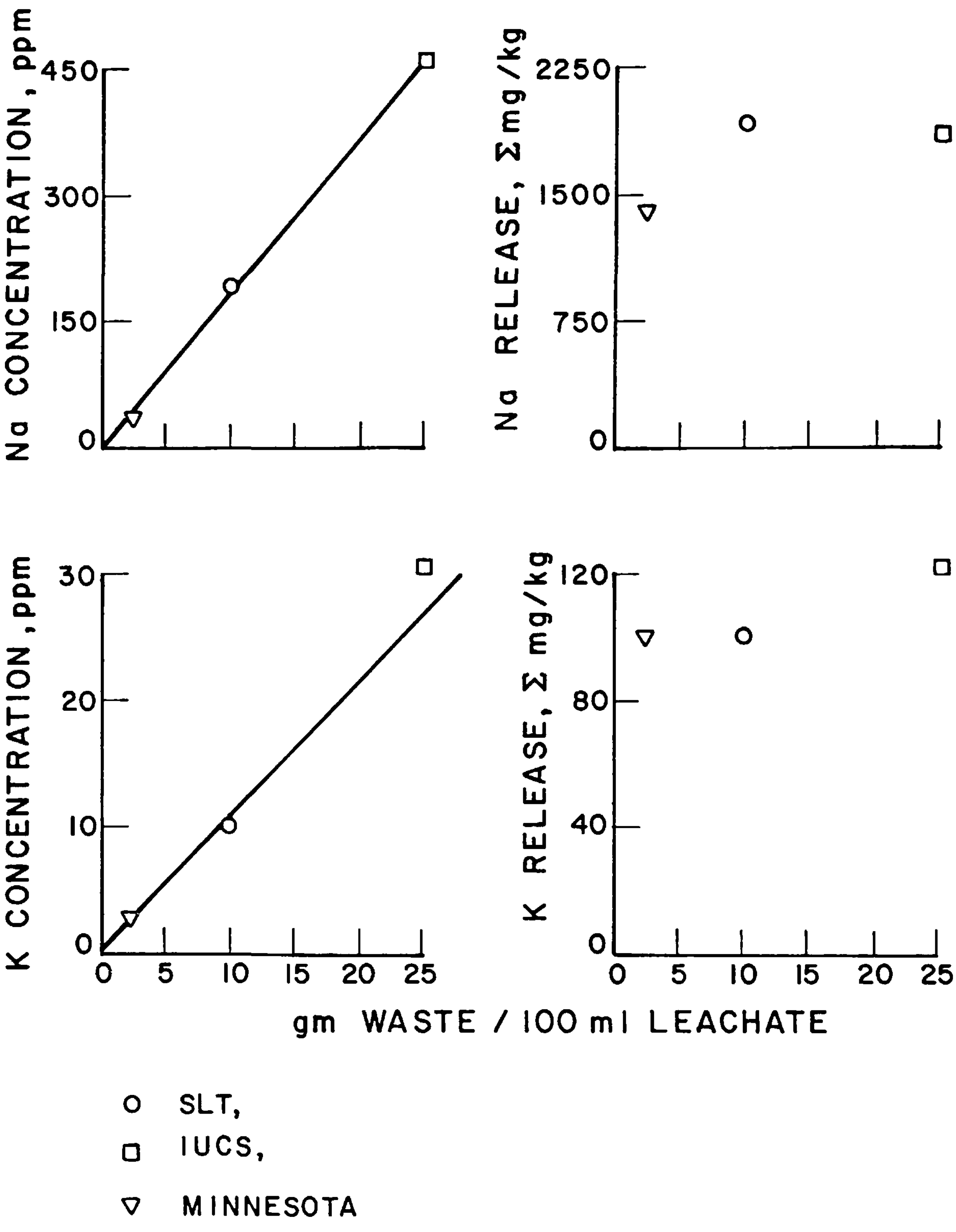


Figure 2. Variation in Na and K concentration and release from an ink and paint waste with solid-liquid ratio (in grams waste per 100 ml leaching media), using a distilled water leachate.

by a number of competing factors—amount present, solubility, sorption or desorption, etc.—and the effect of solid/liquid ratio on the concentration will be more complicated than simple solubility relationships would suggest. However, several practical considerations enter into the choice of a solid/liquid ratio for a reliable standard test. A very low ratio, such as that used in the Minn. test, requires small amounts of solid and generally produces low concentrations of eluted parameters. This emphasizes analytical and sampling errors. Also, a very low solid/liquid ratio models a much longer leaching time in a landfill than does a higher ratio. While this might at first appear to be an advantage, the accuracy with which a short test models long-term leaching in a landfill probably decreases as the landfill time span modeled gets longer. Thus, a test with a very low solid/liquid ratio is less accurate for both modeling reasons as well as analytical ones in comparison with tests using higher ratios. On the other hand, a test with a very high solid/liquid ratio, while decreasing subsampling and analytical errors, requires more elutions to deplete a partially soluble parameter in a waste in order to determine maximum release than does a test with a lower ratio. A solid/liquid ratio should, therefore, be selected between these two extremes. Experiments conducted during development of the SLT (1) suggest that the 1 to 40 ratio used in the Minn. test is rather low and that both the 1:10 and 1:4 ratios used in the SLT and IUCS tests, respectively, are reasonable. Either ratio could be used in a reliable standard test.

It is important to note how the weight of waste material is measured when calculating the solid/liquid ratio. Dry weight, which is commonly used, can present analytical difficulties for wastes containing volatile or semi-volatile components other than water. Experiments with a variety of wastes during development of the SLT suggested the use of drying at 105°C in a forced air convection oven for 24 hours as a reasonable procedure to define dry weight (1).

The choice of a solid/liquid ratio generally is not directly based on landfill conditions (unless calculated from waste and rainfall conditions) and, within a range between the extremes discussed above, is, therefore, arbitrary.

NUMBER OF ELUTIONS

Both the SLT and IUCS tests use multiple elutions. Far more information can be obtained from multiple elutions than from a single elution as used in the Minn. test. The IUCS test uses five elutions, while the SLT uses three (unless the pH in the synthetic leachate samples has not returned to below 5.0, in which case additional elutions are suggested until the pH does return to 5.0 (1)). The extra elutions in the IUCS test provide more information than the three elutions in the SLT; however, they also require more work. A compromise needs to be made between the value of added information obtained. from the extra elutions and the added work involved in obtaining it.

Multiple elutions provide information about the kinetics of release; for example, whether the release of a particular parameter is controlled by solubility or by the release of another parameter (i.e., matrix or surface decomposition triggering subsequent release of parameters held in the matrix within the waste particles). With one elution, some species may not be observed leaching from a waste when, in reality, they release in significant amounts in later elutions. On the other hand, the last elution generally yields successively less information as more elutions are specified. Thus, the twentieth elution in a twenty-elution test is likely to yield substantially less information than the third elution in a three-elution test. For some wastes, one elution will give all the information obtainable; some wastes will require three elutions, some five, a few wastes, perhaps, fifty. There is no way of knowing the required number of elutions for a given waste without running extensive tests to determine when some relative equilibration is reached. This, obviously, is contrary to the concept of a standard test. Experiments performed with a variety of wastes in developing the SLT indicated that more elutions than three generally provided little or no additional information (1). This was also found to be true in the present study.

Another factor in the selection of the number of elutions for a standard leaching test is simply convenience. When it is technically feasible, the number of elutions chosen should be convenient for laboratory personnel. The IUCS test is more inconvenient and/or expensive than the other tests in that it requires working on weekends to perform five 48-hour elutions.

It is concluded that selection of the number of elutions should be based on the number of elutions found useful for a variety of extensively tested wastes and on convenience. The author's experience is that three is generally sufficient, but if some key parameter with a particular waste suggests additional elutions (e.g., pH remaining above 5 using the synthetic leachate), additional elutions should be run.

AGITATION TECHNIQUE AND SURFACE AREA OF CONTACT

The SLT and the IUCS tests had generally effective agitation techniques in that little particle abrasion was observed and particle and leaching media movement was sufficient to avoid visually obvious concentration profiles in the media. The Minn. test developed pronounced concentration differences which were observable between the liquid located near the waste particles and that located away from the particles when colored components were being leached. These concentration differences are not surprising, since the waste is not agitated for 24 hours following the initial shaking.

For two wastes, namely, the coal tar waste and the $CuO-Na_2SO_4$ waste, the SLT agitation method in itself appeared to be one reason for the higher release with the SLT test than with the IUCS test. In the SLT agitation procedure, the waste is always gently tumbling through the leachate. This exposes more surface area of the waste to leachate contact. The IUCS test agitation procedure did not provide such particle agitation of the waste, resulting in approximately the same waste surface being in contact with the leachate. With coal tar waste, the concentration of napthalene was higher in the SLT H_2O leachates than in the IUCS H_2O leachates (Figure 3). Given the physical nature of coal tar, it is reasonable to ascribe the higher con-

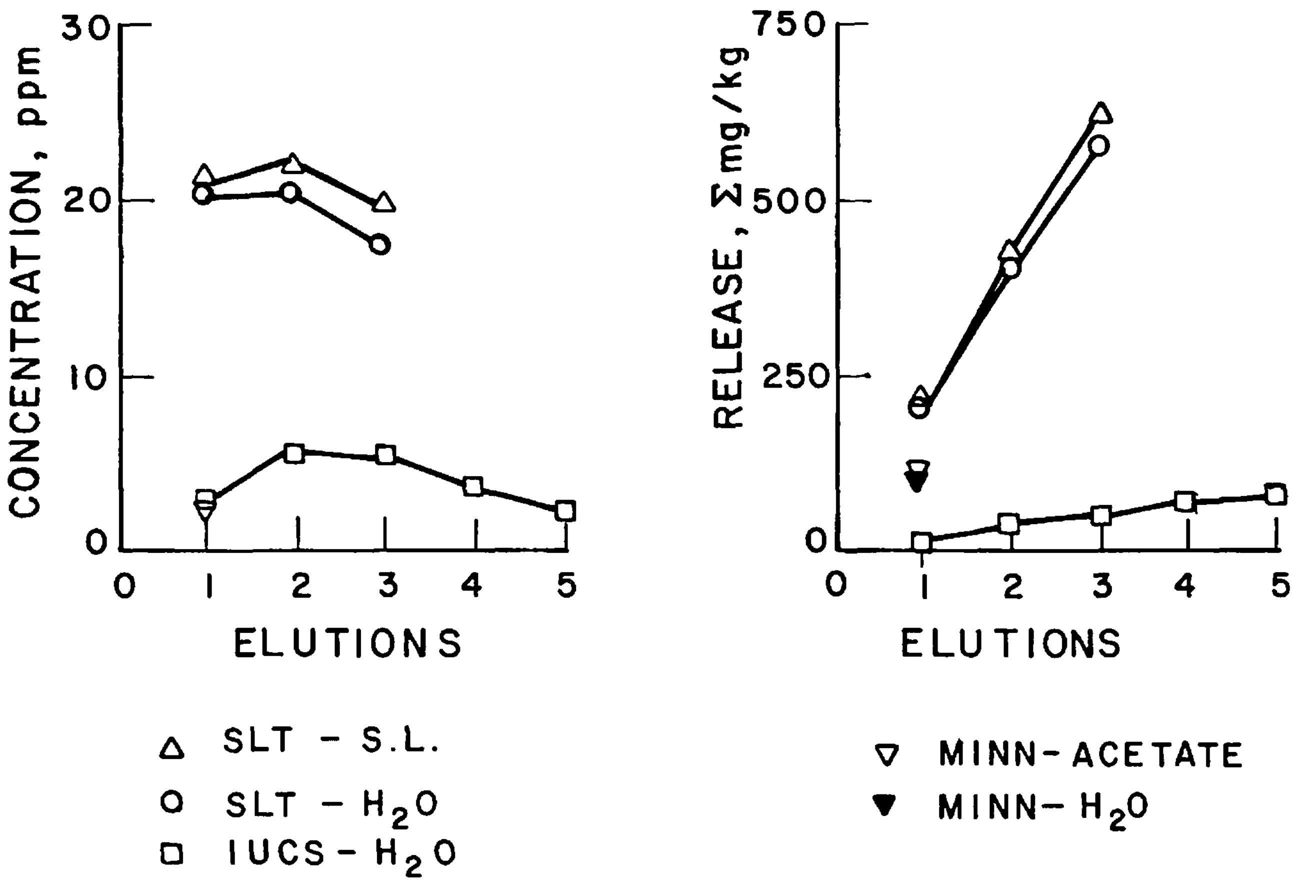


Figure 3. Napthalene concentration and release from a coal tar waste in test leachates.

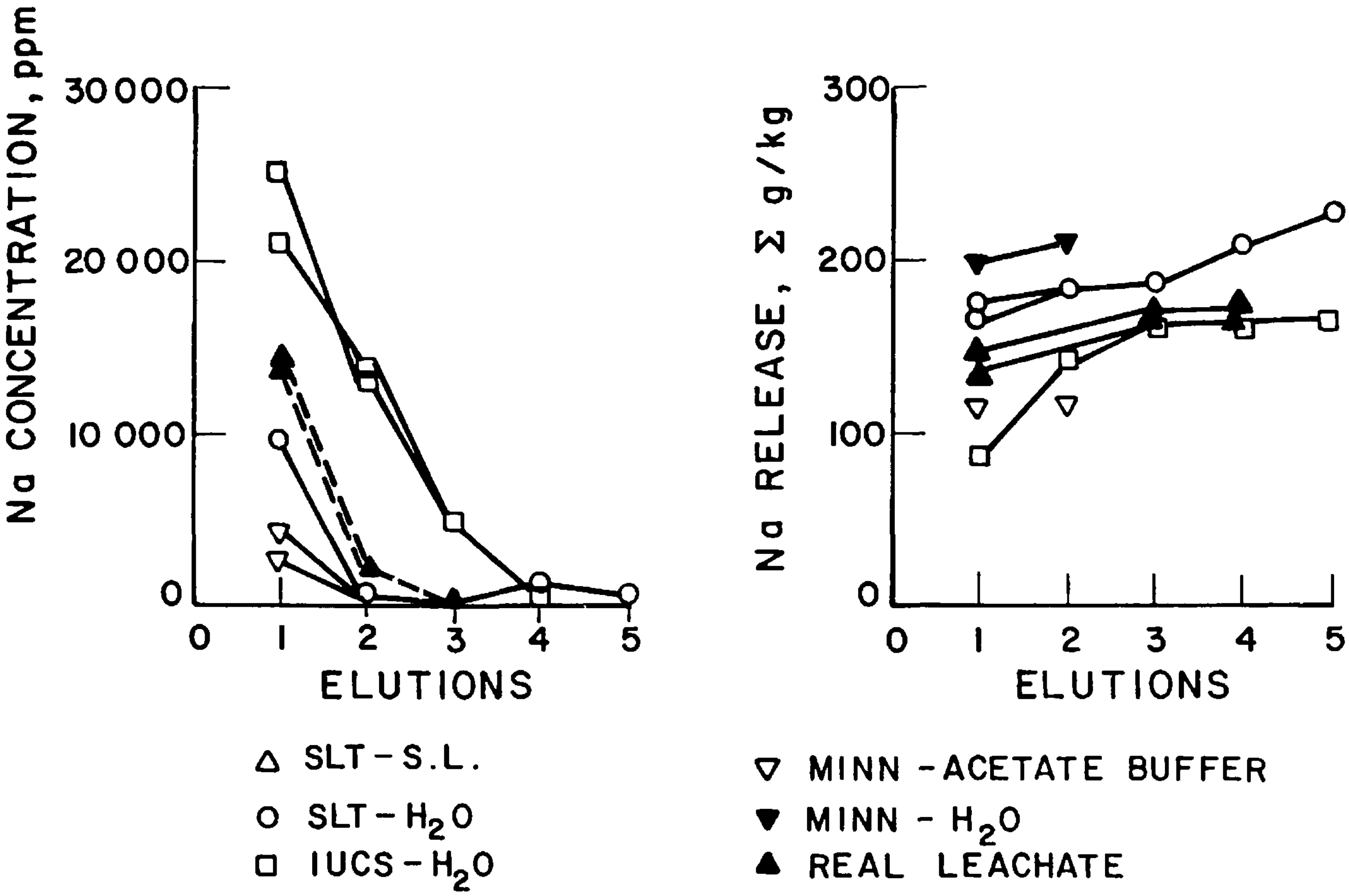


Figure 4. Na concentration and release from a $CuO\text{-}Na_2SO_4$ sludge in test leachates.

centrations to the greater surface area in contact with the leachate. Coal tar is impervious to water and viscous enough to inhibit internal diffusion. Thus, for unsaturated parameters, the concentration in leachate will depend on the surface area of contact with the waste. Another probable example of the effects of agitation on release can be seen in the Na release from the $CuO-Na_2SO_4$ sludge (Figure 4). A comparison of the Na release in the SLT and IUCS tests using H_2O as the leaching media shows a more rapid drop off in release in the IUCS test such that the fifth elution, for example, provided little additional release beyond that of the fourth elution. The SLT data indicate that the Na is continuing to be released in the later elutions. It appears that the waste in the IUCS test formed a thick layer in the test vessel and was subsequently released slowly by diffusion. In the SLT, the tumbling agitation constantly mixed the waste and leachate in order to minimize the amount of stagnant interstitial water. Thus, the more complete mixing in the SLT promoted continued dissolution of very soluble components.

ADDITIONAL TEST COMPARISONS

The SLT uses either or both of two elution procedures: one in which fresh waste is contacted with leachate fromthe previous elution (procedure C), and one in which fresh leachate is contacted with a previously eluted waste (procedure R). The IUCS test uses only a procedure similar to procedure R; whereas, the Minn. test uses only one elution. Procedure C gives an indication of what will happen to a given parameter as the leachate passes through a large volume of waste; i.e., the procedure will give results which approximate or approach saturated conditions. As landfills will generally have very high solid/liquid ratios, at least temporarily, and the leachates will often be saturated, this information can be very useful. On the other hand, an estimation of the total amount of a parameter which may potentially be released to the environment requires information about the maximum release under landfill conditions per unit mass of waste. The two procedures in the SLT allow an estimation of both maximum concentration and maximum release. Neither of the other tests, nor any others known to the authors, allow both estimations. The IUCS test gives an estimate of maximum release, since it also involves multiple leachings of the same waste sample.

The Minn. test results cannot be used by themselves to provide with any degree of certainty either maximum concentration or release information. The results may have practical value bv being comparable to results from some full scale landfills, but there is no way of knowning this in advance without having an extensive data base from monitoring actual landfills.

The effects of two test conditions, namely, time per elution and temperature, could not be analyzed from the test results. All the tests were run at the same temperature (ambient or 20°C). The IUCS test uses a 48-hour elution time, while both the Minn. and SLT tests use a 24-hour elution time. The effect of elution time cannot be separated from other variables in comparing the three tests.

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16. ABSTRACT

A comparison of three leaching tests was performed with thirteen industrial wastes to evaluate the potential of each test for use as a standard leaching test procedure. Such a procedure would be used to assess the leaching characteristics of industrial wastes for land disposal. The study was done in conjunction with a background study on the development of a standard leaching test.

The advantages and disadvantages of each test based on the leaching characteristics of the thirteen wastes and the usefulness of each procedure as a standard test are analyzed and compared. Finally, comments are provided on the need for careful interpretation of test results.

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