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Waste Materials in Construction: Putting Theory into Practice

INTEGRATION OF TESTING PROTOCOLS FOR EVALUATION OF CONTAMINANT RELEASE FROM MONOLITHIC AND GRANULAR WASTES

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ABSTRACT

Testing for evaluation of contaminant release from soils and wastes is necessary to compare management options and project potential environmental impacts. Frequently, the available management options include disposal as either an untreated or treated granular or monolithic waste form with varying extents of water contact. In addition, some wastes may be suitable for utilization as fill material or aggregate replacements in construction applications. Selection amongst these choices requires substantially more intensive leaching testing and evaluation then is provided in most regulatory frameworks. Ideal testing and evaluation protocols would permit the necessary comparisons, provide realistic estimates of contaminant release under the scenarios evaluated, and be accomplished through use of a minimum number of analyses carried out over a very short time interval. A series of testing protocols has been under development for granular and monolithic wastes. The goal has been a series of tests that can be carried out in less than approximately one week with approximately six samples for chemical analysis that provide measurement of fundamental leaching parameters. These fundamental parameters then are used to estimate contaminant release under different management scenarios. Substantial reductions in testing requirements can be achieved through integration of the individual test methods. This paper will present the testing evaluation framework, using data obtained from several wastes to illustrate the benefits of the framework.

INTRODUCTION

Emphasis on sustainable development has focused increased attention on management of process residuals to attain the maximum practical use from materials previously considered only suitable for disposal. Thus, the societal definition of a "waste" must be redefined to reflect new alternative management options, including both utilization and disposal. The following definitions of "waste" have been offered to reflect this change:

> "waste" shall mean any substance or object which the holder discards or intends or is required to discard (EEC, 1991).
>
> "waste" is not an indication of a specific property. It merely describes a situation , a transition in the life of a given product/material namely from being useful to a given purpose to being no longer needed by the owner (EEC, 1996).
>
> "waste" might still be quite useful for somebody else or for other purposes (EEC, 1996).
>
> Whether a product/material is harmful or not is determined by its inherent hazardous properties (e.g., toxic, explosive, radioactive, etc.) and the way the product/material is handled in the environment both during its useful life and waste life (EEC, 1996).
>
> "wastes" per se are not inherently harmful or benign (EEC, 1996).

These definitions necessitate defining the characteristics of a waste in the context of both its constituents which potentially may be harmful and the manner in which it is managed. Thus, tools are needed to infer the behavior of waste constituents during a variety of management options. These management options may include utilization as a replacement material in a variety of applications (e.g., as aggregate in road construction or brick manufacturing), or disposal under varying conditions (e.g., monofill, landfilling with other wastes under defined conditions).

Leaching tests are used as a tool to estimate the release of constituents from solid wastes during utilization and after disposal, assess efficacy of waste treatment processes, and develop endpoints for remediation of contaminated soils. Usually the goal of the testing is to answer the question "Is the selected management option for the waste environmentally acceptable?" However, the answer to this simple question requires consideration of several inter-related aspects, including (i) the release rate and extent of potentially hazardous constituents from the waste, (ii) attenuation processes associated with the constituents of concern as they migrate from the waste to the receptor being considered, and (iii) the inherent toxicity of each specific constituent. Considerable effort has resulted in accurate assessment techniques and data for evaluating contaminant attenuation and toxicity for several cases. In contrast, estimation of constituent release by leaching most often assumes either (i) the total content present is available for release, (ii) the contaminant concentration in the leachate will be equal to that measured during a single batch extraction and is constant with time, or (iii) the fraction of the contaminant extracted during a batch extraction is equal to the fraction that will leach (USEPA, 1990; Goumans et al., 1991; Goumans et al., 1994). These approaches frequently result in grossly inaccurate (both over- and under-estimation) of actual release, which in turn, forces disposal of materials which are suitable for beneficial use, forces remediation of soils to levels beyond that necessary for environmental protection, and unnecessarily depletes disposal capacity. Erroneous estimation of leaching behavior also results in treatment processes that "pass the test" rather than improving waste characteristics. For example, a treatment process for a particular waste stream has been shown to reduce the extracted concentration for a regulatory test (TCLP) but result in increased release compared to management scenarios without the treatment (Garrabrants, et al., 1996). Thus, methodologies which result in a more accurate estimate of contaminant leaching may both improve environmental protection through more efficient use of resources and be economically beneficial.

Motivating concerns against adoption of testing methodologies that provide more realistic estimates of leaching include (i) increased waste management costs would result from more detailed waste characterization, (ii) detailed characterization would result in processing delays, and (iii) more stringent waste treatment methods would be required.

The objective of this paper is to present an integrated framework for solid waste testing that provides more realistic estimates of contaminant release, greater flexibility for waste management, and is economically reasonable. This framework was developed based on current understanding of release of inorganic waste constituents; however, an analogous approach would most likely be applicable to organic species as well. Emphasis is placed on testing that is in support of waste utilization.

WHAT RELEASE INFORMATION IS NEEDED?

Development of a set of protocols to evaluate environmental acceptability of waste management options must begin by defining the specific questions to be answered and overarching characteristics of the particular waste. Typically an answer to one of the following three questions is being sought:

1. Is this waste suitable for a particular utilization, treatment, or disposal option?
2. Which specific utilization, treatment, or disposal options are appropriate for this waste?
3. Which wastes are most appropriate for a specific utilization, treatment, or disposal option?

The first question is the most frequently asked by the generator of limited quantities of waste and by a regulatory agency trying to enforce environmental protection. The comparison is limited to a single waste (type or fixed quantity) and a single selected management option. The second question is appropriate for a generator of a specific waste type on a continuing basis. Here, evaluation of a variety of management options for the waste may be motivated by economic, regulatory or long-term sustainability considerations. Example wastes include coal combustion ash and municipal waste incinerator ash that may be either landfilled or beneficially utilized. The third question is asked by the waste recipient. This is in response to multiple wastes competing for a specific utilization option (e.g., use as aggregate in road base) or disposal facility. Overarching characteristics of a waste that must be considered include quantity and production constancy (both quantity and quality as a function of time)[1], physical characteristics (e.g., particle size, water content), inherent extreme characteristics[2] and public acceptability[3].

The goal of waste testing should be to provide information about contaminant release from a waste in the context of the anticipated disposal or utilization conditions. Thus, testing should reflect the conditions (e.g., pH, water contact, etc.) that will be present in the waste and at its interface with its surroundings during the long-term, which may be significantly different than the properties of the material immediately following production[4]. Three levels of testing can be defined to efficiently address the above waste management questions. In all cases, the material to be tested should be the material as it is going to be used or in its final form, not an untreated form if treatment is going to occur prior to utilization or disposal. Detailed characterization (Level I) is required for initial characterization of a high volume waste stream which may be either disposed on a continuing basis or utilized. Level I testing is used to define the primary waste characteristics (e.g., composition, physical properties, and leaching parameters) and variability associated with critical parameters. After Level I testing is completed, quality control testing (Level III), which requires the least amount of testing of the three levels, can be used to insure constancy of critical waste characteristics within previously established limits of variability. The specific measurements and frequency of testing needed for Level III testing are selected based on both the specific properties of the waste and the critical requirements of management option. Quality control data should be evaluated in the context of the detailed characterization data and be used as an indicator that a major change in critical waste properties has not occurred. Thus, it is anticipated that only specific elements of concern previously identified would be measured using very simple test procedures. Random testing of a more complete set of species with concise testing (Level II) can be used as a verification and a regulatory enforcement tool without the added expense of constant testing. On-site verification testing may not be relevant to utilization because more stringent quality assurance would be required. Level II testing also is used for determining if low volume waste is suitable for a specific disposal option or more detailed assessment of a waste that fails quality control testing.

A decision flow diagram for application of the three testing levels is presented in **Figure 1**.

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[1] The limited quantity or high degree of variability associated with a waste may make utilization technically or economically impractical, or not expeditious.

[2] The origin or composition of a waste may result in characteristics which prima facie preclude certain management options (e.g., high inherent toxicity, extreme acidity or corrosivity).

[3] Public acceptance of certain waste management options may be limited by specific waste characteristics (e.g., noxious odor) or political considerations.

[4] Examples where the material as produced has different constituent release behavior then during utilization are: (i) concrete pillars immersed in surface water where release reflects the neutral pH of surface water rather than the alkali pH of Portland cement concrete, and (ii) use of steel slag in coastal protection applications where V and Cr leaching is reduced by the natural formation of ferric oxide coatings in the utilization environment (Hockley and van der Sloot, 1991).

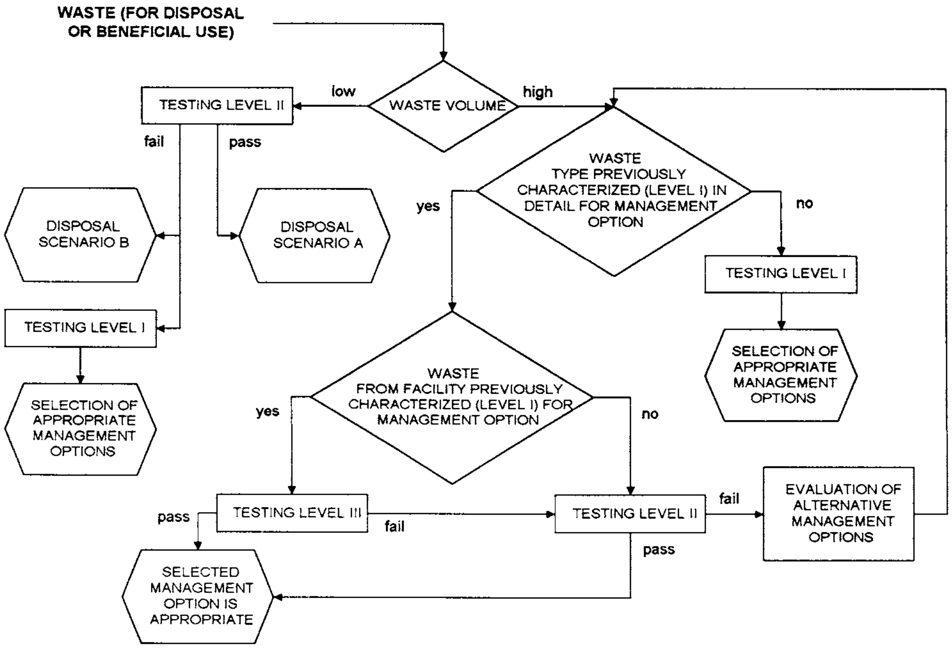

Figure 1. A decision flow diagram for use of different levels of leaching tests to evaluate a waste. Levels I, II, and III are detailed characterization, concise testing, and quality control testing, respectively.

For low volume wastes, Level II testing provides a decision between two types of disposal (nominally, "non-hazardous" or "hazardous") or provides the option of more detailed characterization to facilitate selection of treatment or alternative management options. For high volume wastes, the first decision point is whether or not the generic waste type under consideration has been evaluated in detail for the management option being considered. If this has not occurred, Level I testing is required. If testing of the generic waste type for the specific application has occurred previously, the second decision point is whether or not the waste from the specific generating facility has been characterized in detail. If Level I testing on the specific waste had been carried out, then quality control testing (Level III) can be implemented. If not, then Level II testing is used to verify that critical properties of waste produced from the specific facility are consistent with the previously characterized generic waste type. In summary, the questions to be answered by each level of testing are as follows:

Level I
What actions are required to make the material acceptable for disposal or utilization?
What options are available to make desired changes in material properties?
Is the material acceptable for utilization?

Level II
Is the material (low volume) acceptable for disposal (controlled environment)?

Level III
Is this material the same as the material previously characterized?

For bulk wastes which are managed largely through a small set of options, field testing should be carried out at selected locations and time intervals after utilization or disposal to allow verification laboratory based release estimates. In this manner, laboratory and field measurements can be used in a iterative manner to improve predictive capabilities. One clear advantage of this decision scheme is that it permits waste management decisions to be based on detailed knowledge of the waste characteristics and it's expected behavior under the selected management option rather than based on a single screening test that may have little relevancy to the actual waste behavior.

Detailed leaching characterization of a waste requires measurement of intrinsic parameters which control constituent release. Two modes of constituent release, local equilibrium and diffusion controlled release, can be defined to establish which parameters are important for a particular combination of waste type and management option. Local equilibrium at the boundary between the waste and infiltrating water can be assumed when the Peclet number (Pe) is less than 1 (Massry, 1997) where

$Pe = (R^2/D_{obs})/(L/v)$,
R = median particle radius,
D_{obs} = observed diffusivity of the element through the porous solid matrix,
L = length or depth of fill through which infiltration percolates, and
v = seepage velocity.

This case occurs with granular wastes and seepage velocities are relatively slow. Conversely, diffusion controlled release can be assumed when Pe is greater than 10. This case occurs with monolithic wastes, granular wastes compacted to low permeability, or granular wastes overlain by low permeability covers or surrounded by materials with much greater permeability[5]. For all diffusion controlled release scenarios, water flow is predominately around, rather than through, the majority of the waste. Fortunately, most utilization and disposal scenarios result in one of the above limit cases. Natural infiltration usually results in slow percolation rates and when infiltration is controlled by capping, flow rates are reduced even further. Thus, local equilibrium is a good assumption in these cases. Caution must be used when assuming either of these limit cases if large pH or redox gradients exist at the interface between the waste and it's surrounding environment. Large pH or redox gradients can result in precipitation or rapid dissolution phenomena for some elements as gradient boundaries redistribute over long time intervals (Sanchez, 1996; van der Sloot et al., 1994). For most alkaline wastes, the most prevalent interface reaction is absorption of carbon dioxide, resulting in the formation of carbonate species and pH decreases towards 8. An appropriate assessment of these conditions requires evaluation of the change in leaching in response to external factors. Thus, testing under conditions imposed by the external factors rather than by the waste may be necessary.

Table 1 presents the parameters suggested for each level of testing. There are multiple test methods available for measurement of several of the parameters. Integrated concise testing protocols are presented in more detail in sections of this paper which follow. For the purposes described here, availability is defined as the quantity of a particular element or species which is not tightly bound (e.g., in an amorphous silica matrix) in the waste matrix and potentially may leach. Thus, it serves as the thermodynamic driving force for release. Most often solubility controls aqueous concentrations at local equilibrium because substantially more of a constituent of concern is present in the solid phase than required to saturate the solution. The solubility of many potentially hazardous elements is strongly a function of pH, thus the titration of pH and solubility is required. Integration of measured parameters to estimate long-term release for the cases of local equilibrium and diffusion controlled release has been presented previously in detail (Kosson, Sloot and Eighmy, 1996; Schreurs et al, this conference). Both cases require site-specific information about the management scenario (Table 2) to provide release estimates.

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[5] For the case where $1<Pe<10$, local equilibrium controlled release can be considered a conservative estimate because it will predict greater release then most likely will occur.

Table 1. Suggested parameters to evaluate leaching for different levels of waste testing.

	Release Mode[1]		
Parameter	**L.E.**	**D.C.**	**Test Methods**
Level II - Detailed Characterization[2]			
Availability	+	+	NEN 7341 (1995); EDTA extraction (Garrabrants, et al., 1997)
Solubility vs. pH (4<pH<11)	+	+	Static pH (IAWG, 1997; Comans et al, 1993.); Acid neutralization capacity (Kosson et al., 1993)
Acid neutralization capacity (4<pH<11)	+	+	Same as for solubility above
Diffusivity		+	NEN 7345 (1996) or draft NVN 7347 (compacted granular; van der Sloot et al , 1997; Kosson et al, 1993)
Matrix interactions	+		NEN 7343 (1996) column leaching
Redox capacity	?[7]		Draft NVN 7348 (1994)
Particle size distribution		+	
Porosity		+	
Hydraulic conductivity		+	
Level II - Screening Evaluation[3]			Concise protocols as described in text.
Availability	+	+	
Acidity or alkalinity	+	+	
Release at LS 2 & 10 at pH controlled by waste	+		PrEN 12457 (CEN TC 292, 1996)
Release at pH 8, LS 10	+		
Diffusivity		+	
Level III - Quality Control[4]			
Availability	?[8]	?[8]	
Release at LS 10 (controlled pH)[5]	+		
Release from monolith or compacted granular sample[6]		+	
Random use of Level II testing for regulatory verification (ca. 4/yr)	+	+	Concise protocols as described in text.

[1] Local equilibrium (L.E.) or diffusion controlled (D.C.).

[2] Elements and species analyzed in extracts to include potentially hazardous elements (e.g., Pb, Hg, Cr, etc.), principal cations (e.g., Na, Ca), principal anions (Cl, SO_4, CO_3) and dissolved organic carbon.

[3] Elements and species analyzed in extracts to include potentially hazardous elements (e.g., Pb, Hg, Cr, etc.), total dissolved solids, and dissolved organic carbon.

[4] Elements and species analyzed in extracts limited to minimum necessary to verify constancy of waste.

[5] Single extraction at pH controlled to constant pH consistent with natural pH of waste or pH =8.0.

[6] Leachant refreshed at 1, 8 and 24 hrs with extracts combined for single cumulative release estimate.

[7] Only if waste origin or initial testing suggests strongly reducing matrix.

[8] Used if Level I testing indicates wide variability in availability of potentially hazardous elements.

Table 2. Intrinsic waste properties management option characteristics needed to estimate constituent release for a specific management option.

Intrinsic Waste Properties (local equilibrium or diffusion controlled release)	Management Option Characteristics (disposal or utilization alternatives)
Availability	Application Geometry (length, width, depth)
Multi-phase Partitioning	Application Boundary Conditions
Solubility as a function of pH	Low permeability caps or liners
Desorption partitioning[1]	Drainage layers
Diffusivity	Water Balance
Observed diffusivity	Precipitation frequency
Tortuosity	Net infiltration and seepage velocity
Waste Controlled Chemical Influences	External Chemical Influences
Alkalinity or acidity	Reducing or oxidizing conditions
Reducing or oxidizing potential and capacity[2]	pH range
Constituent matrix interactions[3]	Dissolved organic carbon or complexing agents
Physical Characteristics	Temperature Variations
Particle size distribution[4]	Annual mean temperature[8]
Monolith dimensions[5]	Exposure to Frost or freezing[9]
Hydraulic conductivity[6]	
Porosity[7]	

[1] Required only when constituent is present as a sorbed species rather than a solid phase. This distinction can be obtained from the slope of the extraction data as a function of LS in the concise protocol.

[2] Required only for wastes that exhibit extreme reducing potential or oxidizing potential during initial testing (e.g., blast furnace slag).

[3] Preliminary indication of this condition is obtained from the slope of the extraction data as a function of LS in the concise protocol. Includes dissolved organic carbon as potential chelating agent and and depletion of solubility limiting species such as sulphate.

[4] Required for granular materials only.

[5] Required for monolithic materials only.

[6] Used to estimate seepage velocity and infiltration rates.

[7] Can be used to estimate diffusion resistance or tortuosity (see Schaefer, et al., 1995).

[8] Used to calculate constituent diffusivity in water.

[9] Needed to evaluate requirements for physical durability of waste form.

CONCISE TESTING APPROACH

Understanding of the specific testing objectives and the controlling variables allows for integration of testing. Use of integrated, or concise, testing protocols permits coverage of a broad range of leachability controlling aspects with a minimum of experimental work. The goal is to include as many controlling factors as possible with a minimum number of extracts and analyses. Application of concise testing protocols is targeted towards Level II testing and can be used for screening as an initial step for Level I testing. An example of a concise testing protocol for granular wastes, along with test results for a lead and zinc smelting slag, is presented in Figure 2. The test method can be summarized as follows (van der Sloot et al., 1994):

Part A. 2-Step Serial Batch Test

Deionized water as extractant, no pH control (waste controls extract pH)
Particle size reduction with 95% to less than 4 mm
Extraction 1 - LS[6]=2 ml/g, contact period of 6 hr, well mixed, closed vessel
Extraction 2 - LS=8 ml/g (cumulative LS=10 ml/g), contact period of 18 hr, well mixed, closed vessel
Measurements (each filtered extract): pH, Eh, TDS[7], DOC[8], conductivity, relevant major[9], minor or trace elements

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[6] liquid-to-solid ratio (LS)

[7] total dissolved solids (TDS)

Part B. pH Controlled Serial Batch Test
Deionized water as extractant with specified pH control
Particle size reduction 95% to less than 300 μm
Extraction 1 - LS=10 ml/g, pH=8 or 12, contact period of 24 hr, well mixed[10]
Extraction 2 - LS=50 ml/g (cumulative LS=60 ml/g), pH=4, contact period of 24 hr, well mixed
Measurements for each extraction: acid or base consumption, DOC, Eh, relevant major, minor or trace elements (filtered extracts)

From the above combination of 4 extractions several leaching considerations can be evaluated. Part A of this procedure facilitates distinction between solubility, availability, desorption and matrix interaction controlled release[11]. Comparing release at pH 8 (LS=10) to that at the material's own pH (cumulative release after second extraction) permits evaluation of the extent of constituent retention in the matrix relative to very mobile species (e.g. Na, Cl). E_H measurement (relative to pH) provides indicates if the matrix has reducing properties. DOC measurement proivdes an indication of the potential for chelation effects for mobilization of metals. TDS provides for evaluation of the potential impact from total soluble salts. Part B of this procedure permits evaluation of leachability changes in crucial pH domains (pH 4 , 8, own pH) and estimation of availability. In addition, acid/base neutralization capacity is determined from acid or base consumption used to control pH at the designated levels. This information is relevant for determining how long a material can impose its own pH conditions on a leachate. DOC measurement during these extractions is used to evaluate the potential for future mobilization of DOC. Finally, the combination of leachability and pH data from the four extractions shows the potential sensitivity of leaching to changes in pH domain relevant to conditions observed in practice. It also provides an indication of the likely changes in leachability when leaching conditions change in the long term (e.g., pH changes resulting from uptake of biologically generated carbon dioxide, remineralization, or acidification). Results for a primary slag from a lead and zinc smelting process are illustrated in Figure 2, where concise results are compared to more detailed characterization testing. Solubility controlled release and oxidized conditions is indicated for lead (Mandin et al., this conference). Concise results are consistent with the more extensive test methods.

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[8] dissolved organic carbon (DOC)

[9] Relevancy is based on either regulatory significance or known presence of significant content in the waste being evaluated.

[10] The objective of this protocol is to obtain leaching data for three pH values: (i) the pH of the pore solution of the material, (ii) pH 4, and (iii) pH 8. If the pH of the material is approximately 8, the pH 8 extraction (Part B, Extraction 1) is replaced by using the same conditions but controlling the extraction at pH 12.

[11] Cumulative release plotted as a function of LS can be interpreted as follows: slope=1, solubility control; slope<1 and cumulative release approximately equal to availability, availability control; slope<1 and cumulative release less than availability, desorption control; slope>1, matrix interaction control (e.g., depletion of sulfate during initial extraction resulting in greater solubility during second extraction).

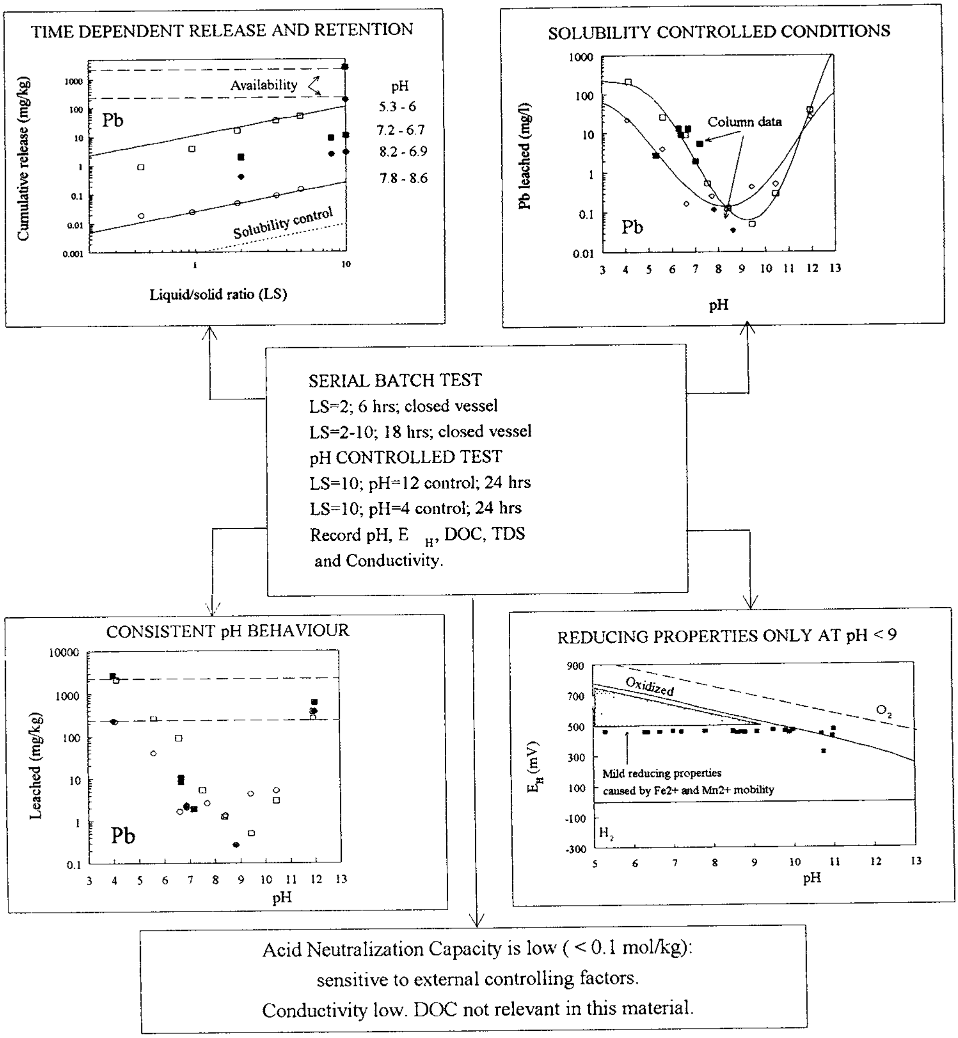
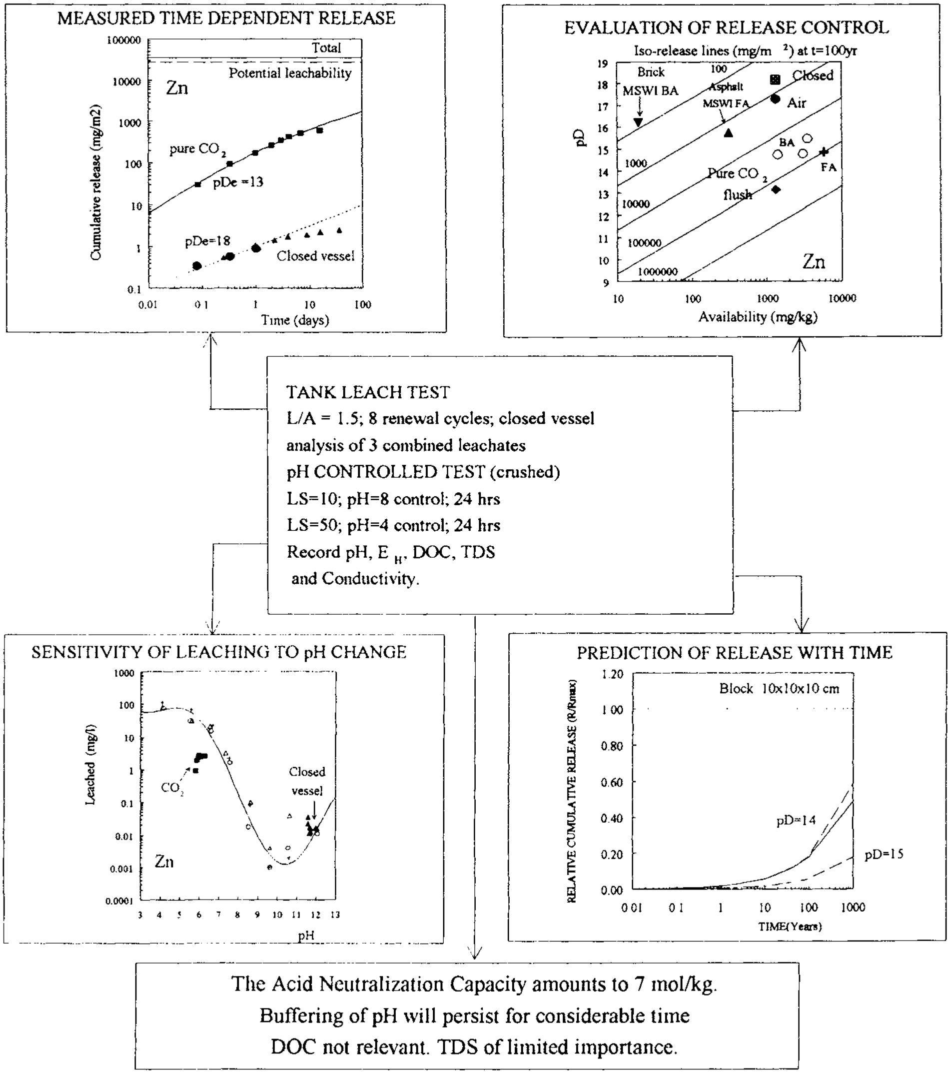


Figure 2. A concise testing protocol for granular materials and concise testing results for a lead and zinc smelting slag in comparison with results from detailed characterization.

The leaching of pulverized coal ash is presented as a second example of application of the concise protocols to a granular material in Figure 3 (van der Sloot et al., 1989). Two sets of graphs are presented for calcium (a major constituent), molybdenum (an oxyanion) and zinc (a trace metal) in the figure: (i) leaching as a function of pH, and (ii) leaching as a function of LS. Both Level I characterization data and Level II concise data are included to illustrate consistency between the data sets. The concise leaching results at cumulative LS 2 and 10 follow the same pattern as observed in the more elaborate column leaching test. These data comparisons for granular materials reflect a wide range of practical conditions encountered in field scenarios. In addition to the leaching behavior as a function of pH or LS, the availability and total composition data are provided. The availability corresponds to the greatest release observed in the pH controlled test. All leaching and composition data are expressed in the same units (mg/kg), to allow direct comparison of data between the two graphs. The impact of a treatment process or changes in pH on constituent release can be quantified from the combined graphs. Release as a function of time is related to LS using the infiltration rate. These results show that while characterisation cannot be replaced by concise testing, concise testing can be used for rapid evaluation of material behavior in the context of prior characterization for management decisions.



TANK LEACH TEST
L/A = 1.5; 8 renewal cycles; closed vessel
analysis of 3 combined leachates
pH CONTROLLED TEST (crushed)
LS=10; pH=8 control; 24 hrs
LS=50; pH=4 control; 24 hrs
Record pH, E_H, DOC, TDS
and Conductivity.

The Acid Neutralization Capacity amounts to 7 mol/kg.
Buffering of pH will persist for considerable time
DOC not relevant. TDS of limited importance.

Figure 4. A concise testing protocol for monolithic materials (including compacted granular materials) and concise testing results for zinc in a cement stabilized municipal solid waste fly ash in comparison with results from detailed characterization.

An example of a concise testing protocol for a monolithic waste, cement stabilized MSWI fly ash (van der Sloot et al, 1995), is illustrated in Figure 4. The same approach may be applied for compacted granular materials which exhibit diffusion controlled release in the field. The test method can be summarized as follows:

Part A. Tank Leaching Test
Monolith size: 4x4x4 cm cube (compacted granular ca. 10 cm dia. x 4 cm min. height)
Liquid to surface area 1.33 ml/cm^2 (monolith -128 ml; compacted granular - 105 ml)
Deionized water as leachant, leachant renewal at 1, 8 and 24 hr.
Closed vessel
Measurements (each filtered extract): pH, Eh, DOC, TDS and conductivity, relevant major, minor and trace elements

Part B. pH Controlled Serial Batch Test
Deionized water as extractant with specified pH control
Particle size reduction with 95% to less than 300 μm
Extraction 1 - LS=10 ml/g, pH=8, contact period of 24 hr, well mixed
Extraction 2 - LS=50 ml/g (cumulative LS=60 ml/g), pH=4, contact period of 24 hr, well mixed
Measurements for each extraction: acid or base consumption, DOC, Eh, relevant major, minor or trace elements (filtered extracts)

The pH controlled serial batch test provides constituent release at a pH typical of carbonate buffering at an LS=10, which is typical of longer term liquid-to-solid ratios attained in the field from infiltration. This condition also provides an indication of availability for oxyanions, acid neutralization capacity and potential for reducing conditions. The second step extraction at pH 4 provides an estimate of availability for heavy metals and acid neutralization capacity. The tank leaching test provides an estimate of observed diffusivity for elements of interest and effective diffusivity or tortuosity based on release of a non-interactive species (e.g., Cl). Combined interpretation of availability and observed diffusivity permits evaluation of long-term release by comparison with an iso-release lines on a pD vs. availability nomograph (IAWG, 1997; Kosson et al, 1996). Measurement of TDS on all extracts allows evaluation of the potential for rapid release of very soluble salts. Results of the concise testing presented in Figure 4 indicate that good agreement was attained with the results of more extensive testing carried out on the same material.

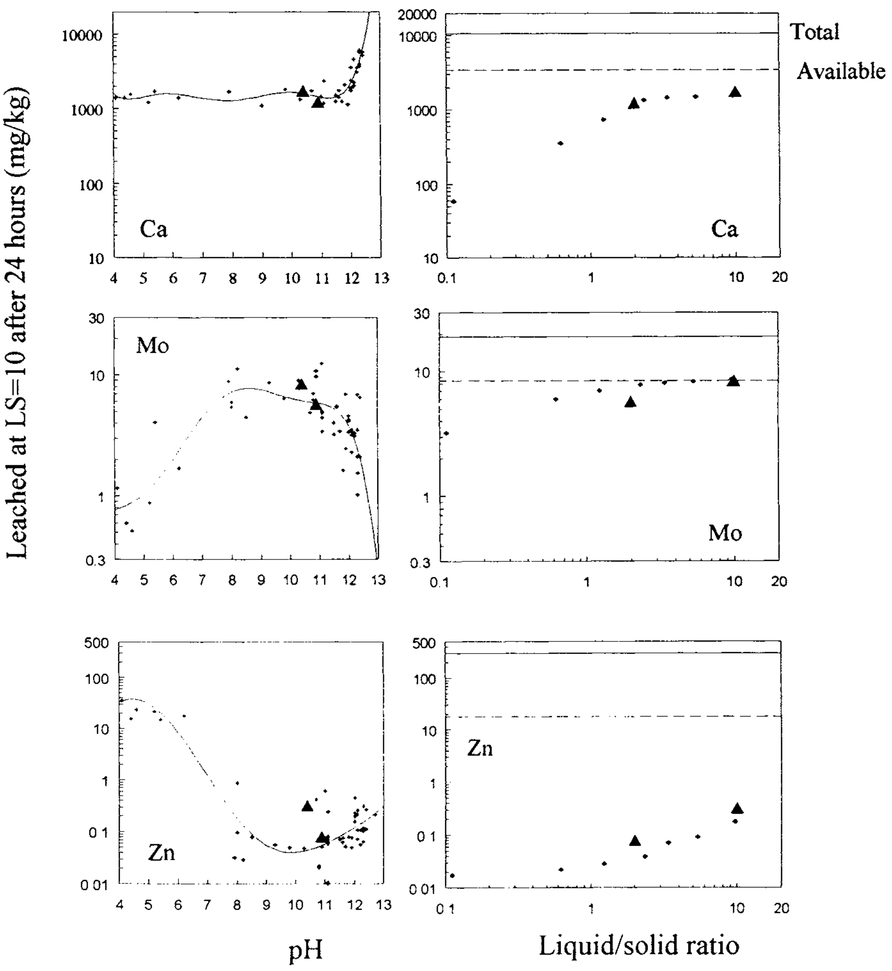


Figure 3. Concise testing results for pulverized coal ash in comparison with results from detailed characterization.

Two additional sets of graphs (Figure 5) are presented on leaching of calcium, molybdenum, and zinc from the same cement stabilized MSWI fly ash (van der Sloot et al, 1995): (i) leaching as a function of pH, and (ii) leaching as a function of time. In addition to the pH or time dependent release, the availability and total composition data are provided. Both Level I characterization data and Level II concise data are included to illustrate consistency between the data sets. The data are consistent for the elements representing the behaviour of a major element (Ca), an oxyanion (Mo) and a metal (Zn). The release during the short time interval of concise testing (< 24 hours) follows the same pattern as observed in the longer duration tank leaching test. These data presentations for monolithic materials reflect a wide range of practical conditions to be encountered in field scenarios. In these graphs not all leaching and composition data can be expressed in the same units, which limits the direct comparison of data between the two graphs. However, the consequences of changes in pH with time or after treatment on the release as a function of time can be evaluated qualitatively from the combined graphs. These results also show that while characterisation cannot be replaced by concise testing, concise testing can be used for rapid evaluation of material behaviour in the context of prior characterization for management decisions.

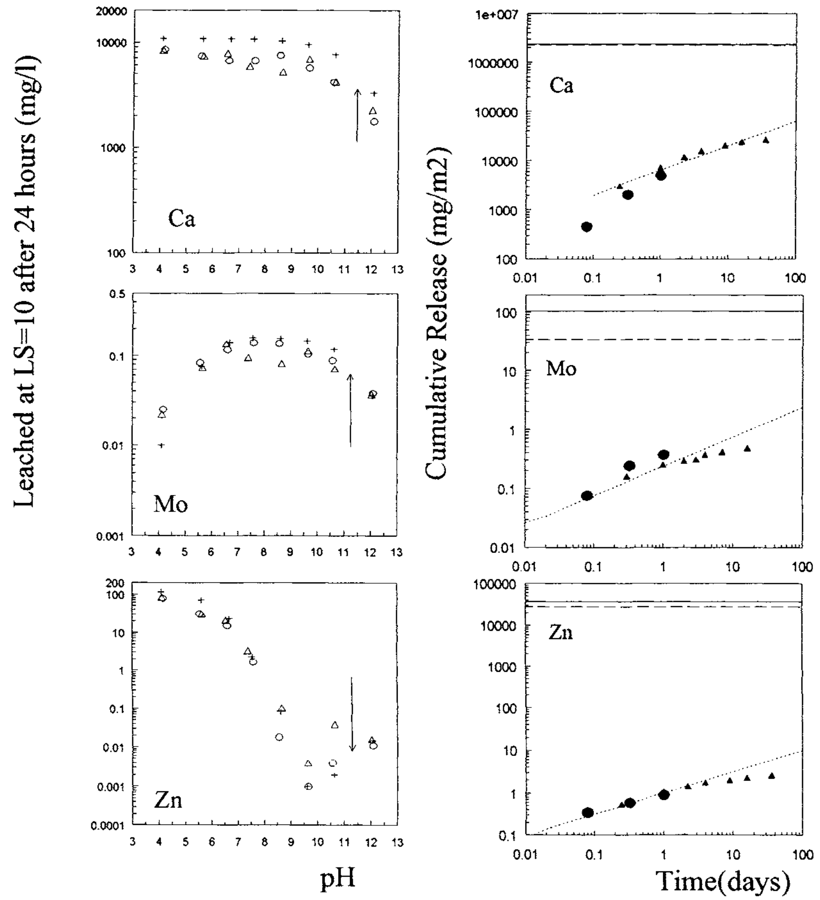


Figure 5. Concise testing results for calcium, molybdenum and zinc in a cement stabilized municipal solid waste fly ash in comparison with results from detailed characterization. The arrows in the graphs of concentration as a function of pH (left side) indicate the pH of the extracts from the tank leaching test for the monolithic materials.

ECONOMIC CONSIDERATIONS

Testing costs must be considered for an evaluation protocol based on initially detailed characterization (Level I) followed by quality control testing (Level III) and random application of Level II testing for validation. A basis for economic comparison was developed assuming that typical current evaluation protocols for bulk wastes incorporate a single step batch extraction on a bi-weekly basis with a full elemental analysis (ca. 20 elements). The alternative approach considered here would require initially

Level I characterization followed by Level III on a monthly basis using a composite sample with a reduced analytical set (ca. 5 elements). The alternative approach also would include Level II testing on a random basis four times per year. While initial costs are greater for the alternative approach, long-term costs are reduced. Based on these assumptions, the payback period for the alternative approach would be approximately two years.

CONCLUSIONS

An alternative approach for evaluation of the environmental impact of waste utilization and disposal has been presented. The alternative approach requires initially detailed waste characterization followed by greatly reduced testing requirements to achieve quality control and integrated concise testing to screen new wastes that are similar in origin to previously characterized wastes and low volume wastes being evaluated for disposal. The advantages of this approach include: (i) flexibility of waste evaluation and management based on improved understanding of waste characteristics, (ii) estimation of contaminant release in the context of the waste management scenario and anticipated environmental conditions, (iii) quality control in the context of a detailed understanding of waste characteristics, and (iv) long-term reduction in costs associated with waste testing.

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