A Guide to the Use of Leaching Tests in Solid Waste Management Decision Making

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The information presented in this report is intended to provide an overview of the use of leaching tests in solid and hazardous waste management. While regulatory aspects of leaching tests are presented within, the appropriate regulatory agencies should always be contacted for final answers to regulatory questions. Questions or comments regarding this report should be addressed to Dr. Townsend at ttown@ufl.edu.

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Section 1. Overview and Purpose

1.1 Overview

Professionals involved in the management or regulation of solid wastes are often required to perform or interpret leaching test data as a means of assessing the risk of the solid waste to human health or the environment. In short, leaching tests are used to help assess the ability of a pollutant to partition from a waste into a surrounding liquid medium.

1.2 Document Purpose and Scope

The purpose of this document is to serve as a reference guide on leaching tests for solid waste professionals. This document discusses the basics of leaching tests for waste materials, current regulatory leaching tests, interpretation of leaching test results, factors influencing contaminant leaching, and uses of leaching tests for evaluating risk associated with solid waste management for decision making. This document mainly describes leaching of inorganic species.

Section 2. Leaching Test Basics

2.1 Leaching Test Objectives

Many batch leaching test protocols have been developed to simulate the leaching processes of waste materials in landfill or other disposal scenarios to evaluate potential risks to human and/or groundwater. The results of batch leaching tests should be carefully evaluated before being used for regulatory or design purposes. The basic objectives of leaching tests are as follow:

- Classify a waste as hazardous or non-hazardous for regulatory application
- Evaluate leaching potential of pollutants resulting from a waste under specified environmental conditions
- Simulate waste or site-specific leaching conditions to evaluate leaching potential
- Provide an extract that is representative of the actual leachate produced from a waste in the field
- Measure treatment effectiveness of a waste
- Identify the appropriate waste management scenario or waste disposal environment
- Determine partition and kinetic parameters for the purpose of contaminant transport modeling

2.2 Types of Leaching Tests

Common batch leaching tests include Extraction Procedure Toxicity (EP-Tox; US EPA Method 1310, 2001), Toxicity Characteristic Leaching Procedure (TCLP; US EPA Method 1311, 2001), Synthetic Precipitation Leaching Procedure (SPLP; US EPA Method 1312, 2001), Waste Extraction Test (WET; California Code of Regulations, 1985), American Society for Testing and Materials extraction test (ASTM D 3987-85, 2001), and Multiple Extraction Procedure (MEP; US EPA Method 1320). The batch tests typically involve mixing size-reduced waste with extraction solution and then agitating the mixture. These tests generally are performed for a short period of time (typically for hours or days) and therefore are often called short-term tests. The main differences among these tests are leaching solution, liquid to solid (L/S) ratio, and number and duration of extraction.

A column or lysimeter test has also been used for simulation of leaching from waste. This test involves the placement of waste material in a column or lysimeter and then the addition of leaching solution to the material to produce leachate. Unlike the batch leaching tests, the leaching solution is under continuous flux. Therefore, this test is often called a dynamic test and may be more representative of field conditions. However, controlling experimental conditions for this test is not easy. Some operational problems, such as channeling and clogging of the column, may result in a non-reproducible problem. No standardized column test is currently available in the United States. Table 1 summarizes the main differences between batch leaching and column leaching tests.

Table 1 Comparisons of Batch Test with Column Test

Parameters	Batch Test	Column Test
Testing period	Short-term (hours to days)	Long-term (days to months)
Operation	Easy to operate	Difficult to operate (channeling due to non-uniform packing of waste or clogging of column)
Cost	Relatively low	Relatively high
Application of results	Depending on type of batch test	More specific scenario
L/S ratio	Relatively high (To estimate maximum amounts of pollutants to be leached)	Relatively low (close to field conditions)
pH control	Easy to control pH with appropriate chemical	Material dictates its own chemical environment

2.3 Application of Leaching Test Results

Since many batch leaching tests simulate many different leaching processes under certain conditions, results should be carefully evaluated before used for regulatory or design purposes. For example, one method uses TCLP results for regulatory purposes by comparing the results to the listed Toxicity Characteristic (TC) levels to determine whether a waste is hazardous. More discussion on the applicability of batch test results can be found in subsequent sections.

Section 3. Regulatory Leaching Tests

This section discusses the introduction and protocols of regulatory leaching tests that have been widely used in the United States and other countries, especially Europe.

3.1 The U.S. Environmental Protection Agency (US EPA) Toxicity Characteristic Leaching Procedure (TCLP)

The TCLP method is one of the most commonly used laboratory leaching tests and was developed to simulate contaminant leaching resulting from waste in a municipal solid waste (MSW) landfill environment.

3.1.1 The Predecessor to TCLP: EP-Tox

The Extraction Procedure Toxicity (EP-Tox) test was used to classify wastes as hazardous or non-hazardous prior to development of the TCLP by simulating the leaching process of a waste disposed of in a sanitary landfill. The basic experimental procedure is similar to the TCLP procedure, as described in the following. A 100-g sample of waste (less than 9.5 mm) extracted with deionized water for 24 hours is maintained at a liquid to solid (L/S) ratio of 16:1 (20:1 final dilution), as well as a pH of 5 ± 0.2 using 0.5 N acetic acid. The 20:1 L/S ratio was used based on the assumption that 5 percent of the potentially hazardous waste was co-disposed in an MSW landfill. The acetic acid simulates the organic acids produced from the MSW landfill.

3.1.2 The Switch to the TCLP

In 1990, the US EPA adopted the TCLP to improve the leaching test procedure and replace the EP-Tox Test. One of the major criticisms of the EP-Tox test was its inaccuracy when organic compounds, especially volatile organic compounds, were involved. A Zero Head Extraction (ZHE) procedure for volatile organic compounds has been included in the TCLP test.

3.1.3 TCLP Methodology

Developed as a modification of the US EPA's extraction procedure test, the TCLP was intended to simulate the conditions that might occur in a landfill where decomposing garbage is present. The TCLP test involves extracting contaminants from a 100-g size-reduced sample of waste material with an appropriate extraction fluid. A specific L/S ratio (20:1) is employed, and the mixture is rotated for 18 ± 2 hr at 30 rpm. The extraction fluid of TCLP depends on the alkalinity of the waste material. Very alkaline waste materials are leached with a fixed amount of glacial acetic acid without buffering the system (pH 2.88 ± 0.05), while other waste materials are leached with glacial acetic acid buffered at pH 4.93 ± 0.05 with 1-N sodium hydroxide. After rotation, the final pH is measured, and the mixture is filtered using a glass fiber filter. The filtrate is collected in an appropriate container, and preservative may be added if needed. The filtrate is analyzed for a number of constituents. If these constituents exceed the concentrations describing in 40 CFR 261, the waste is hazardous for the TC (unless otherwise excluded). Figure 1 shows a diagram of the TCLP test procedures.

3.2 The US EPA Synthetic Precipitation Leaching Procedure (SPLP)

The SPLP test is performed in the same manner as the TCLP. The extraction fluid is made of two inorganic acids (nitric and sulfuric acid) to simulate acidic rainwater. East of the Mississippi River, the fluid is slightly acidic at a pH 4.22 ± 0.05, which reflects the impact of air pollution due to heavy industrialization and coal utilization. An extraction solution with a pH of 5.0 is used west of the Mississippi River, reflecting less industrialization and smaller population densities. In a similar fashion as the TCLP, a 100-g sample of waste material is placed in a 2-liter extraction vessel and mixed with the extraction fluid. The mixture is rotated for 18 ± 2 hr at 30 rpm. The leachate is then filtered and analyzed for chemical analysis (US EPA, 1996a).

3.3 California Waste Extraction Test (WET)

The WET test is similar to the TCLP in that it uses a buffered organic acid solution as the extraction fluid. This test uses a pH-buffered citrate acid solution with sodium hydroxide, a 10:1 L/S ratio, and a 48-hour testing period. The WET extraction solution is prepared with a combination of 0.2 M citric acid solution and 4.0 N NaOH to pH 5.0 ± 0.1. One liter of this solution is added to a 100-g sample and rotated for 48 hours. After rotation, the final pH is measured, and the sample is filtered and analyzed.

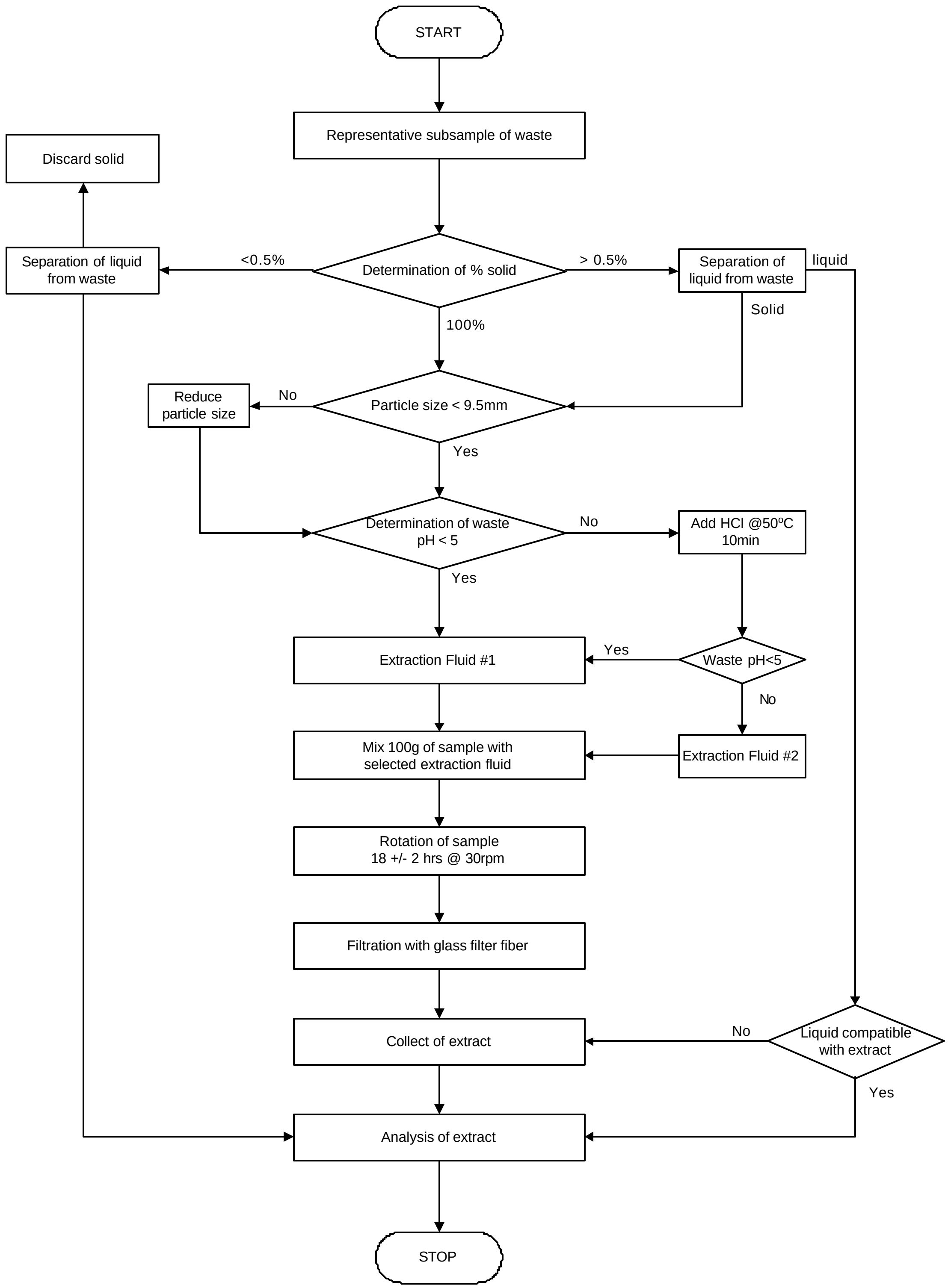

Figure 1. Flow Chart of TCLP Test Procedure

3.4 The US EPA Multiple Extraction Procedure (MEP)

The MEP test involves an initial extraction with acetic acid, which is used to simulate MSW leachate, and at least eight subsequent extractions with an inorganic acid mixture (nitric and sulfuric acids) to simulate acid rain. The MEP test starts with the EP-Tox test run for 24 hours. After the 24-hour rotation period and filtration of the leachate, seven additional extractions are performed on the solid phase of the sample captured on the filter. The extraction fluid is the inorganic mixture with pH 3.0 ± 0.2, which is prepared in the similar manner as the SPLP leaching fluid. During each subsequent extraction, the synthetic rain extraction fluid is added to the waste at an L/S ratio of 20:1, and the mixture is rotated for 24 hours per extraction. After each extraction, the final pH is measured, and the leachate is collected and analyzed. This synthetic rain extraction process is repeated at least eight times. If the concentration of any of the chemical constituents of concern increases over that observed in the seventh and eighth extractions, the extraction should be repeated until the concentration in the extract ceases to increase. This test is currently used for the US EPA's de-listing program.

3.5 American Society for Testing and Materials (ASTM) test

The ASTM test (ASTM D 3987-85) is a deionized (specifically, Type IV reagent water described by ASTM D 1193) extraction test to simulate a condition in which waste material is a dominant factor in determining the pH of the extract. The test uses a 70-g sample of size-reduced waste material (less than 10 mm) with reagent water using L/S ratio of 20:1 for 18 ± 0.25 hours at 30 rpm. This test has been recommended to determine leachability of inorganic constituents only and is not applicable to organic substances.

3.6 Regulatory Batch Tests in European Countries

Many waste leaching tests have been commonly used in various countries for regulatory purposes. More thorough descriptions and procedures of these many leaching tests can be found in the literature (van de Sloot et al., 1997). However, in this guide only a few of these leaching tests are introduced for the purpose of comparison with the leaching tests that have been frequently used in the United States.

The DIN 38414 S4 batch test, which is a standardized German leaching procedure for water, wastewater, sediment, and sludge testing, has been widely used for regulatory purposes. This test uses a 100-g size-reduced sample with unbuffered demineralized water using an L/S ratio of 10:1; the test is run for 24 hours while agitating.

In France, the AFNOR X 31-210 batch test for granular solid mineral waste has been employed for regulatory purposes (AFNOR, 1988). The test is similar to the German batch test but uses a smaller particle size (less than 4 mm).

In the Netherlands, the availability test (NEN 7341) is the Dutch standard leaching test for assessing maximum leachability of waste for regulatory purposes. The procedure consists of reducing the particle size of waste (less than <125 µm), extracting with leaching solution of pH 7 followed by pH 4 using nitric acid or sodium hydroxide, and agitating for three hours. The pH conditions are consistently maintained throughout the test. The extract in each step is combined for chemical analysis.

The NEN 7349 test is another Dutch regulatory batch leaching test for granular waste. This test is a serial batch test consisting of five successive extractions of waste material with demineralized water. The test is first run at pH 4 using nitric acid at an L/S ratio of 20:1 for 23 hours, followed by four successive extractions with fresh leaching solution.

Section 4. Alternative Leaching Methods

4.1 Tank Tests

A tank leaching test (Dutch NVN 5432) has been used to simulate leaching behavior of construction waste materials under a diffusion-controlled environment (Groot and van der Sloot, 1992). The test consists of submerging the material in a beaker containing deionized water adjusted at pH 4 using nitric acid, covering the surface of the material to be exposed to the water, placing the beaker in a tank filled with deionized water, and replacing the water five times at regular intervals. The extracts are analyzed for chemical analysis.

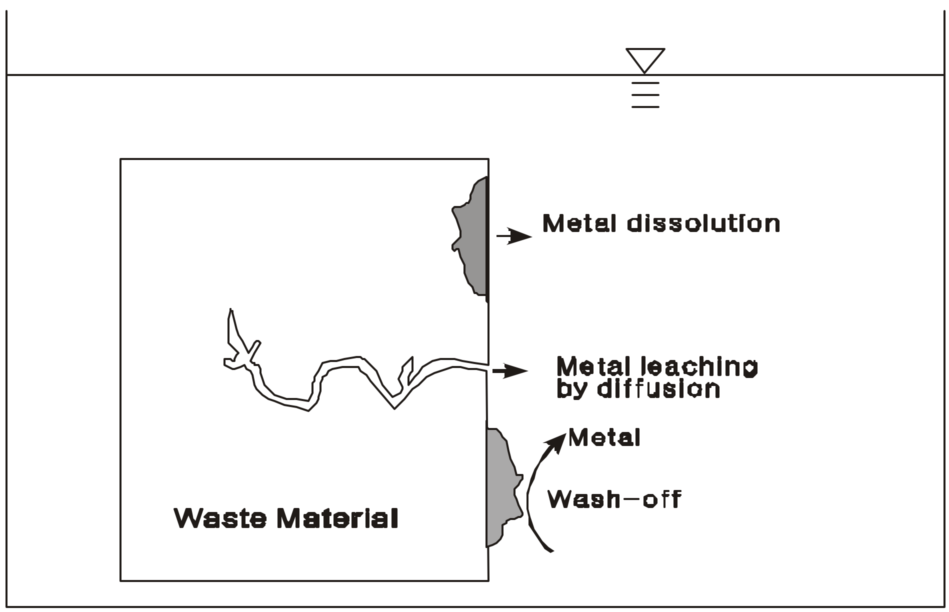

Figure 2. A Schematic Diagram of a Tank Test
(Adopted from Groot and van der Sloot, 1992)

4.2 Column Test

A column test is another type of leaching test used to study the leaching process from waste material. The test involves a continuous flow of leaching solution through waste material placed in a column (Figure 3). Although this test may be more representative of waste leaching processes under field conditions than batch tests, results from the column test may not be reproducible, probably due to flow channeling, clogging, and biological activity.

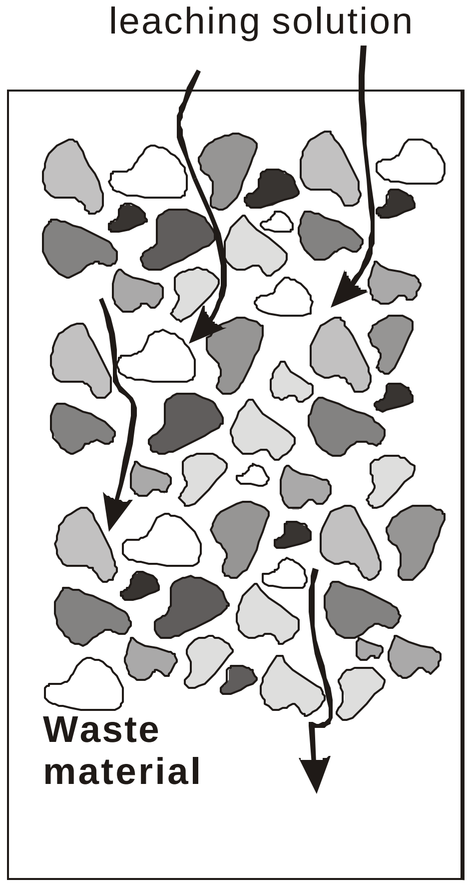

Figure 3. A Simple Schematic Diagram of a Column Test

4.3 Field Test

A field-scale leaching test (e.g., a test cell experiment) may be performed to simulate leaching processes of waste by constructing and operating simulated waste cells under actual field conditions. Although the test may provide considerably valuable information regarding the true leaching behavior of waste, this option may be very time-consuming, extremely expensive, and labor-intensive. Hence, very limited leaching data of field study are available.

Section 5. Factors Controlling Leaching

Factors influencing chemical leaching from waste material may include pH, particle size, complexation with organic or inorganic chemicals, liquid-to-solid ratio (L/S), leaching (or contact) time, kinetics, redox conditions, and chemical speciation of pollutants of interest. The following subsections address some of these factors.

Table 2. Factors Affecting Leaching

Physical Factors	Chemical-Biological Factors
Particle size, contact time, homogeneity, liquid to solid ratio, porosity, sorption, partitioning, temperature, type of flow	pH, redox, complexation, precipitation, organic carbon content, alkalinity, common ion effect

5.1 pH

One of the significant factors influencing the release of contaminants from waste material is pH. The pH in leaching experiments is controlled by a number of reactions (e.g., dissolution of atmospheric CO_2, production of CO_2 as a result of biological activity, dissolution of minerals in waste material). Many metals are widely known to have the tendency to leach more at extreme pH values (Goumans et al., 1991; van der Sloot et al., 1997; Jang et al., 2002). To evaluate pH effect on metal leaching, a pH static test is commonly employed over a broad range of pH. Figure 4 presents the results of the pH-dependent leaching tests for MSW incineration electronic precipitator ash.

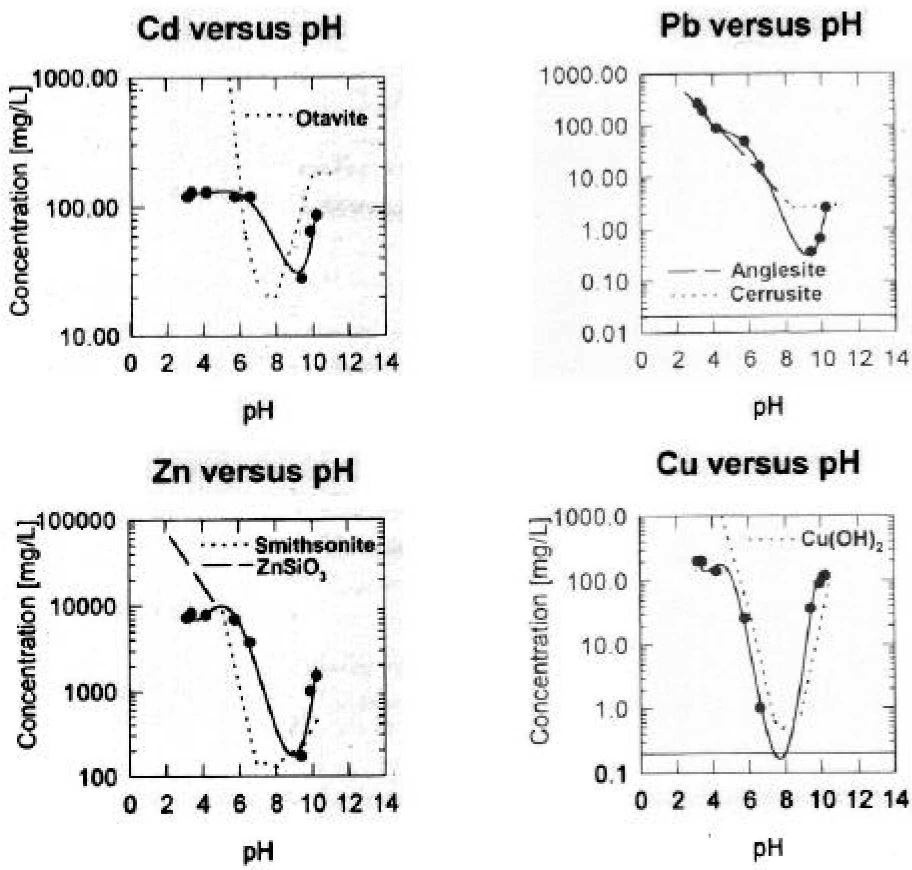

Figure 4. pH effect on Leaching Behavior of Waste Materials

(Source: Eighmy et al., 1995)

5.2 Particle Size

Particle size of waste material determines the surface area exposed to the leaching solution. Because many leaching tests are carried out on size-reduced material, a larger surface area is exposed to leaching solution, resulting in more chance of leach contaminant from the material into the solution.

5.3 Complexation

Complex formation occurs when a number of molecules, called ligands, are attached by covalent bonds to ions, usually metal. A common example of such complexation is metal/organic acid complexes. The TCLP test uses acetic acid (CH_3COOH). When the TCLP leaching test for lead-coated cathode ray tube glasses was performed, lead complexes were formed with the acid, resulting in high concentrations of lead in the extract (Musson et al., 2000).

5.4 Oxidation Reduction Condition

Oxidation and reduction conditions may play a significant role in chemical leaching from waste. To measure oxidation and reduction condition in a given chemical system, oxidation reduction potential (ORP) is measured to determine electron availability; ORP indicates the intensity of oxidation or reduction in the chemical system. For some heavy metals, the ORP directly changes the oxidation state of the metals and consequently determines their mobility in the environment.

For example, arsenic is known to commonly exist as As^{+3} and As^{+5}. The As^{+3} is believed to be more mobile and more toxic than the As^{+5}. As a result, arsenic will leach from waste at a higher rate under reduced conditions. Chromium typically exists as either Cr^{+3} or Cr^{+6}. Trivalent chromium has low solubility in water and therefore is less mobile, while hexavalent chromium is more mobile and toxic to the environment. Under oxidizing conditions, trivalent chromium is converted into hexavalent chromium, resulting in the toxic and very mobile form of the metal.

Biologically active environments (e.g., MSW landfill) can create reducing conditions (typically ORP less than -200 mV), resulting in heavy metals being substantially immobilized within the waste through precipitation with sulfides and complexation with organic acids. Currently, the leaching behavior of waste materials under reducing conditions has not been well addressed by the commonly used batch leaching tests. Figure 5 illustrates the leaching behavior of chromium and barium from steel slag under either reduced or oxidized conditions.

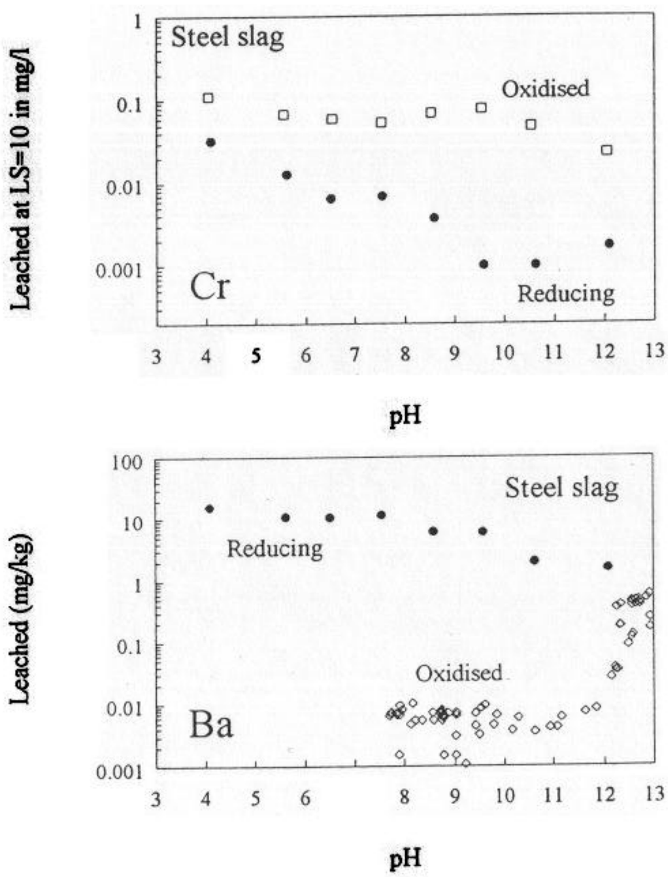

Figure 5. Leachability of Chromium and Barium from Steel Slag under Reduced or Oxidized Conditions

(Source: van der Sloot et al., 1997)

5.5 Liquid-to-Solid (L/S) Ratio

The L/S ratio is defined as the amount of a leaching solution in contact with the amount of waste materials tested (e.g., liter/kg). In batch tests, L/S ratios typically range from 20 to 10, while relatively low L/S ratios are used in a column (or field) test. In general, chemical concentrations are greater at lower L/S and decrease as the L/S increases because of less dilution of waste material with leaching solution.

5.6 Contact Time

The amount of time during which a leaching solution is in contact with waste material may influence the quantity of contaminant leached unless equilibrium conditions are established. The amount of contaminant released may depend upon contact (or leaching) time. In extraction batch tests, the contact time is equal to the duration of the test. For this reason, contact time for extraction tests should run until equilibrium conditions are reached for the contaminants of interest. Batch leaching tests such as TCLP and SPLP are based on the assumption that kinetic equilibrium or local equilibrium is reached. Since the tests may not give sufficient time for equilibrium to be reached, attempts should be made to ensure that kinetic equilibrium is reached during the testing period.

Section 6. Interpretation of Leaching Test Results

This section reviews uses of leaching test results and their interpretation based on a review of available literature and data. The results of leaching tests are normally expressed as a concentration of a chemical constituent leached in the extract (e.g., mg/L).

6.1 TCLP Results

The TCLP test developed by US EPA is currently used to determine whether a waste is hazardous by its TC. The chemical concentrations of the TCLP leachate are compared with specified concentrations of chemical constituents listed in the TC list. In addition to determining the toxicity characteristic, the TCLP pollutant concentrations are used to determine whether a hazardous waste has met the requirements of the land disposal restrictions.

6.1.1 TCLP Results and Toxicity Characteristic

As a regulatory test, the TCLP test is used to determine whether a waste is hazardous. The concentrations of chemical constituents in the leachate obtained from the TCLP test are determined and compared to the specified TCLP regulatory levels of 40 different toxic chemicals listed (Table 3). If the determined concentrations of the chemicals in the TCLP leachate exceed the TCLP levels, the waste is hazardous by the TC. The toxic chemicals in Table 3 consist of 8 metals and 32 organic compounds.

6.1.2 Other Uses of the TCLP

As briefly indicated above, the TCLP test is used to determine whether a hazardous waste meets a specific treatment standard before it can be land-disposed. Under the Resource Conservation and Recovery Act (RCRA) Land Disposal Restriction (LDR) program (40 CFR 268, 1998), the toxicity of the hazardous waste must be reduced to less than the designated concentration levels for hazardous constituents in the waste or specified waste-specific treatment standards before land disposal. The TCLP test is run in the same manner as under the TC determination. The specified concentrations listed in the LDR program are based on the Best Demonstrated Availability Technology (BDAT), and the toxicity regulatory levels are based on the risk-based assumptions.

Table 3. TCLP Toxicity Characteristic Regulatory Levels

Chemical	Regulatory Level (mg/l)
Arsenic	5.0
Barium	100.0
Cadmium	1.0
Chromium	5.0
Lead	5.0
Mercury	0.2
Selenium	1.0
Silver	5.0
Benzene	0.5
Carbon tetrachloride	0.5
Chlordane	0.03
Chlorobenzene	100.0
Chloroform	6.0
o-Cresol	200.0
m-Cresol	200.0
p-Cresol	200.0
Cresol	200.0
2,4-D	10.0
1,4-Dichlorobenzene	7.5
1,2-Dichloroethane	0.5
1,1-Dichloroethylene	0.7
2,4-Dinitrotoluene	0.1
Endrin	0.02
Heptachlor (and its epoxide)	0.008
Hexachlorobenzene	0.1
Hexachlorobutadiene	0.5
Hexachloroethane	3.0
Lindane	0.4
Methoxychlor	10.0
Methyl ethyl ketone	200.0
Nitrobenzene	2.0
Pentachlorophenol	100.0
Pyridine	5.0
Tetrachloroethylene	0.7
Toxaphene	0.5
Trichloroethylene	0.5
2,4,5-Trichlorophenol	400.0
2,4,6-Trichlorophenol	2.0
2,4,5-TP (Silvex)	1.0
Vinyl chloride	0.2

6.1.3 Limitation of TCLP

A number of potential shortcomings of the TCLP test can be cited. The TCLP is a batch test with an arbitrary L/S ratio. This ratio may not be representative of actual field conditions. The role of kinetics is minimized as the test is performed for a standard 18 hours. The pH of leaching fluid does not necessarily represent the pH of the leaching environment. The pH of the leachate during the TCLP is highly dependent on the buffering capacity of the waste materials, which may lead to inaccurate determination of waste behavior in the environment. The continued leaching of chemicals into the environment over time is also not addressed with the TCLP test. The application of a dilution factor to the TCLP test results when conducting a risk-based management evaluation is also not defined.

Therefore, TCLP's broad application and use as the only acceptable test for most risk-based waste management decisions has been questioned (US EPA 1999, Kosson et al., 2002). As mentioned, many complicated factors control the leaching of chemicals from wastes. The TCLP was developed specifically to address the co-disposal of hazardous waste in an organic waste landfill. As a result, the TCLP may not allow for extrapolation of long-term environmental effects, nor does it address different leaching mechanisms. Leaching behavior of metals from wastes is more complex than can be determined by a single batch test. Research is needed to improve, validate in the field, and implement leaching test procedures.

6.2 SPLP Results

For conditions in which leaching to groundwater is a concern (e.g., waste disposal in an unlined landfill or through land application of waste), the SPLP test is commonly used to simulate the effect of acid rain on land-disposed waste. The SPLP leachate concentrations are generally compared to drinking water standards (e.g., groundwater cleanup target levels in Florida) (Table 4). Unlike the TCLP test, the SPLP test is not required as a regulatory test; rather, it was developed to screen wastes that are clearly not low hazard.

Table 4. National Drinking Water Standards of Metals

Chemical	Concentration (μg/l)
Aluminum*	200
Antimony	6.0
Arsenic	50
Barium	2,000
Beryllium	4.0
Cadmium	5.0
Chromium	100
Copper*	1,000
Cyanide	200
Iron*	300
Lead	15
Manganese*	50
Mercury	0.2
Nickel	100
Selenium	50
Silver*	100
Zinc*	5,000

*Secondary standards

6.3 California Waste Extraction Test (WET) Results

The State of California adopted the WET test to classify wastes as either hazardous or non-hazardous for regulatory purposes. The WET test results are compared to the regulatory levels of 17 inorganic constituents listed (Table 5) [California Code of Regulations, 1985], while eight inorganic constituents are listed in the TC table (Table 3).

Table 5. California WET Regulatory Limits

Chemical	Concentration (mg/l)
Antimony	15.0
Arsenic	5.0
Barium	100
Beryllium	0.75
Cadmium	1.0
Chromium (VI)	5.0
Cobalt	80
Copper	25
Lead	5.0
Mercury	0.2
Molybdenum	350
Nickel	20
Selenium	1.0
Silver	5.0
Thallium	7.0
Vanadium	24
Zinc	250

6.4 Comparison of Batch Leaching Test Results

Batch leaching tests have been commonly used to examine leachability of contaminants in waste materials over a wide range of experimental conditions (e.g., leaching solution, pH, contact time). Therefore, the batch results may differ depending on the type of leaching test employed. Figure 6 presents the results of the batch tests for soils contaminated by heavy metals. This figure illustrates how WET and TCLP tests extracted greater concentrations of the metals than those extracted by the SPLP and deionized water leaching procedure (DWLP) test.

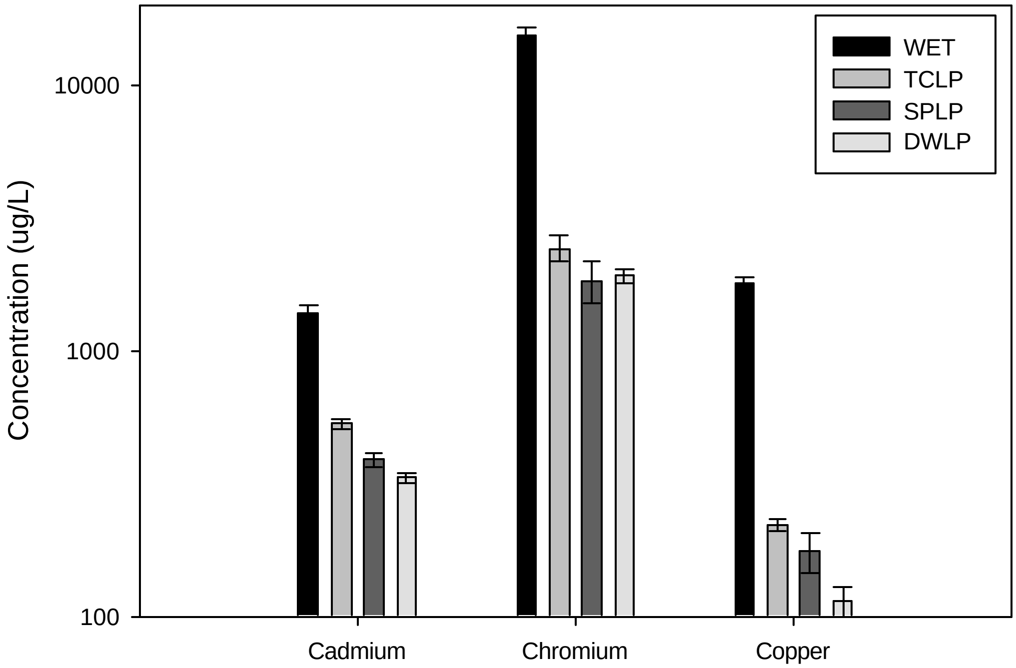

Figure 6. Comparisons of Batch Leaching Test Results

(Source: Lackvoic et al., 1997)

Section 7. Leaching Tests for Risk-Based Decision Making of Solid Waste Management

Decisions made regarding the appropriate waste management options (i.e., disposal, beneficial reuse) of solid wastes frequently rely on an assessment of risk. One of the key pathways when evaluating the risk of a solid waste on human health and the environment is leaching of pollutants to groundwater. In order to evaluate the leaching risk, many leaching tests have been developed and are widely used under a vast range of waste management scenarios. However, determining the risks associated with contaminants in solid wastes, based on leaching test results, is not well understood. This section describes the use of leaching tests for evaluating risk in solid waste management decision making.

7.1 Risks Associated with Solid Waste Management

A waste that is not hazardous as defined by RCRA can be disposed of in a lined sanitary landfill. For some waste generators, this is uneconomical due to growing landfill tipping fees. Land disposal is an expensive option, especially for waste materials with no previous management steps required. This factor, along with the desire to recycle the materials back to the environment, has led generators to find reuse options for their wastes outside landfills. When this is the case, the possible risk to human health and the environment must be considered. In such case, two general routes of risk must be evaluated: direct exposure (e.g., direct ingestion, inhalation of volatiles and fugitive dusts, dermal absorption) and leaching to groundwater.

7.1.1 Evaluating Risk of Direct Exposure

For direct exposure, the total concentration of a pollutant (typically expressed as mg/kg) is compared to a risk-based level. While federal risk-based standards have been established for municipal biosolids (US EPA 1995), no standards exist for many industrial wastes (e.g., coal ash, abrasive blasting media, sewage sludge, street sweepings, residues from air pollution control systems). Many states have adopted approaches that employ generic Soil Screening Levels (SSLs) (US EPA, 1996b).

The SSLs are risk-based pollutant concentrations (mg/kg) derived from standardized equations combining exposure assumptions with toxicological information. A method frequently employed to determine SSLs was developed and is used by the US EPA superfund program. The level may be calculated based on site- or media-specific conditions, but in most cases a generic default concentration is used. The default values are typically used for assessment of the beneficial reuse of waste materials because the material is destined for many possible locations, thus making site-specific assessment difficult. The generic number is usually a concentration conservatively determined for the different direct exposure routes; in some cases, multiple risk pathways are factored into a simple concentration. Some states have different risk-based soil screening levels for different reuse scenarios. For example, in Florida default Soil Cleanup Target Levels (SCTLs) have been established for both residential and industrial reuse and contact scenarios (FDEP, 1999).

7.1.2 Evaluating Risk of Leaching

The evaluation of potential risk to groundwater is somewhat more complicated. The risk evaluation is performed via two different mechanisms. In one, a leaching test is performed and the pollutant concentration in the leachate is compared directly to applicable water quality standards, such as drinking water standards (which are adopted as groundwater guidance concentration in Florida), with appropriate consideration of dilution that may occur in groundwater. The common leaching test used is the SPLP test. The performance of a leaching test is an additional step beyond the measurement made for direct exposure.

The second mechanism for assessing leaching risk involves comparing the total concentration (mg/kg) to a risk-based leaching level. The risk-based leaching level represents the theoretical concentration of a pollutant in a waste (mg/kg) that results in a leachate concentration that exceeds the applicable groundwater standard for that pollutant.

An equation for the determination of the leaching level is described as follows (US EPA, 1996b):

$$C_t = C_w * \left\{ K_{oc} \cdot f_{oc} + \left(\frac{q_w + q_a * H'}{r_b} \right) \right\}$$

where C_t = screening level in soil (mg/kg)

C_w = target leachate concentration (mg/L) ($C_{standard} \times$ dilution factor)

$C_{standard}$ = risk-based groundwater guidance concentration or regulation

Koc = soil organic carbon-water partition coefficient (L/kg)

Foc	=	organic carbon content of soil (kg/kg)
θw	=	water-filled soil porosity (Lwater/Lsoil)
θa	=	air-filled soil porosity (Lair/Lsoil)
H'	=	dimensionless Henry's law constant
ρb	=	dry soil bulk density (kg/L).

While the performance of a leaching test should better reflect actual leaching concentrations of pollutants from waste, the generic risk-based leaching level provides a less expensive evaluation. In most circumstances, the leaching test is only conducted after the generic risk-based leaching concentration (mg/kg) is exceeded.

7.1.3 Dilution Attenuation Factor

Batch tests (e.g., TCLP) estimate the concentration of pollutants in leachate at the interface between the bottom of the landfill and the underlying subsurface layer. The chemical constituents in the leachate are to be diluted, and subsequent pollutant transport in the subsurface may cause attenuation when the leachate enters the groundwater underneath the landfill. Dilution and attenuation are often expressed by a means of a Dilution Attenuation Factor (DAF). The degree of dilution and attenuation is dictated by hydrogeologic conditions, the types of pollutants of concern, and the rate of discharge. A conceptual diagram is presented in Figure 7.

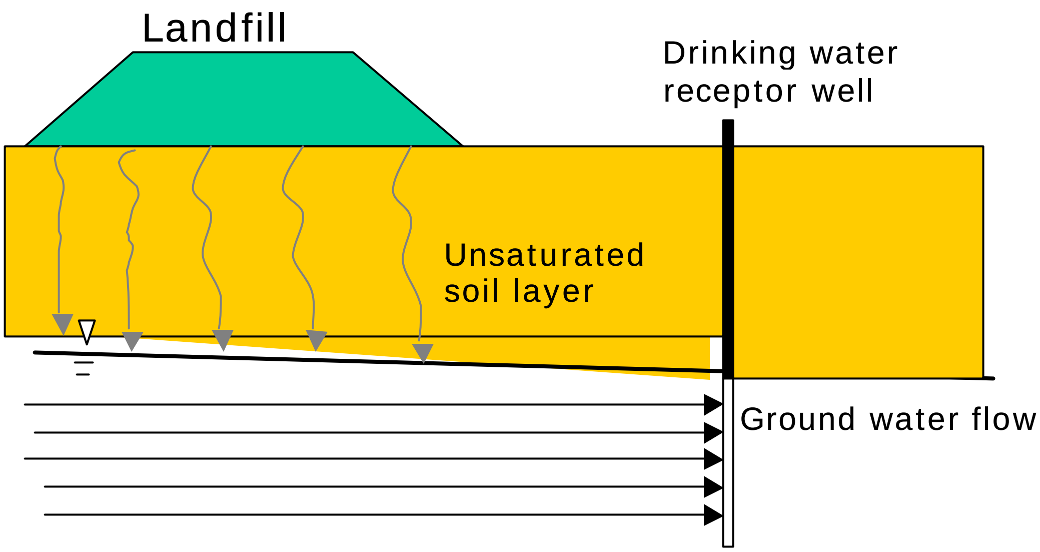

Figure 7. Schematic of DAF from a Landfill to a Receptor Well

A DAF of 100, for example, was used to determine the TCLP TC regulatory level for metals, while the SPLP test inherently has a DAF of 20. A DAF may be less under waste disposal conditions in which a landfill is large and the dilution provided by the subsurface layer is small.

7.2 Use of Leaching Tests for Evaluating Risks in Solid Waste Management

Based on leaching test results, risk-based decision making for the solid waste management may be occur in four major steps. The first step involves the classification of solid waste in regard to TC based on the TCLP leaching test. If the concentration of toxic chemicals in the TCLP leachate exceeds the TC levels, a waste is hazardous and subject to RCRA Subtitle C (hazardous waste regulations). If a waste is not hazardous as defined by RCRA, the potential risk to human health and the environment, such as groundwater contamination, must be evaluated when disposal and reuse options of the waste are considered. In this step, the leaching results of the SPLP test for waste materials may be compared to a risk-based water quality standard or guideline (e.g., groundwater cleanup target levels in Florida).

If the concentrations of pollutants in the SPLP leachate are higher than the set standards, the waste may be disposed of in a lined landfill. If no concern of risk is associated with leaching to groundwater, possible direct exposure should be considered for reuse options, based on total concentrations of the waste. The total concentration can be compared to a risk-based level (e.g., SCTLs in Florida). If the total concentration is less than the direct exposure levels, additional leaching tests may still be needed for a proposed waste management reuse scenario. The leaching tests may be conducted under specific testing conditions such as pH, L/S ratio, and time.

Section 8. Leaching Acronyms and Glossary

8.1 List of Acronyms

ASTM	American Society for Testing and Materials
BDAT	Best Demonstrated Available Technology
DAF	Dilution Attenuation Factor
EP-Tox	Extraction Procedure Toxicity
FDEP	Florida Department of Environmental Protection
L/S Ratio	Liquid to Solid Ratio
LDR	Land Disposal Restriction
MEP	Multiple Extraction Procedure
MSW	Municipal Solid Waste
ORP	Oxidation Reduction Potential
RCRA	Resource Conservation and Recovery Act
SCTL	Soil Cleanup Target Levels
SPLP	Synthetic Precipitation Leaching Procedure
SSLs	Soil Screening Levels
TC	Toxicity Characteristic
TCLP	Toxicity Characteristic Leaching Procedure
US EPA	United States Environmental Protection Agency
WET	Waste Extraction Test

8.2 Glossary

Batch Leaching Test: A laboratory test to determine leaching potential from waste materials following a pre-determined experimental protocol. Typically, it involves the preparation of waste samples (e.g., particle size reduction) and leaching solution, the mixing of the samples with the solution, the filtration of the mixture, and the analysis of the extracts.

Dilution Attenuation Factor (DAF): The DAF describes how much a chemical constituent in leachate is diluted and attenuated in the subsurface during pollutant transport processes before it is detected at the down-gradient compliance point. The DAF may thus be calculated by the concentration of a chemical constituent in leachate divided by the chemical concentration in water sample at a down-gradient compliance point.

Extraction Procedure for Toxicity (EP-Tox): The EP-Tox was the original laboratory leaching test developed by the US EPA to classify hazardous wastes. This test is a predecessor of TCLP.

Liquid to Solid Ratio (L/S Ratio): The amount of a leaching solution in contact with the amount of a waste tested (e.g., liter/kg).

Lysimeter: A column that is prepared for a leaching experiment in the laboratory (or in the field). A leaching solution (or natural rainfall) is added to the lysimeter to simulate leaching of waste materials tested.

Multiple Extraction Procedure (MEP): A laboratory leaching test to simulate the leaching that waste undergoes from repetitive precipitation of acid rain on an improperly designed sanitary landfill. This test simulates leaching processes for 1,000 years of freeze and thaw cycles.

pH Static Test: A laboratory leaching test to examine leaching behavior of contaminants as a function of pH.

Synthetic Precipitation Leaching Procedure (SPLP): A laboratory test developed by the US EPA to simulate the effect of acid rain on land-disposed waste. Simulated rain water as leaching solution is prepared with a combination of diluted sulfuric and nitric acids to make pH 4.2.

Toxicity Characteristic (TC): Toxicity characteristic was designed by US EPA to reduce potential risks to human and the environment (especially groundwater) caused by releases of toxic chemicals from land-disposed wastes. A total of 40 toxic chemicals with regulatory levels are listed (40 CFR 261).

Toxicity Characteristic Leaching Procedure (TCLP): A laboratory leaching test developed by the US EPA to determine whether solid waste is hazardous by the toxicity characteristic (TC). This test simulates contaminant leaching of waste materials that are co-disposed with actively decomposing municipal solid waste in a landfill.

Waste Extraction Test (WET): A laboratory leaching test adopted by the State of California is used to classify hazardous wastes. This test uses a combination of 0.2 M citric acid solution and 4.0 N NaOH to make leaching solution of pH 5.0 ± 0.1.

Section 9. Leaching Bibliography

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