Recommended Guidelines for the Use and Application of the Leaching Environmental Assessment Framework (LEAF) for Coal Combustion Residuals

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ABSTRACT

In its proposed ruling, the U.S. Environmental Protection Agency (US EPA) provides a summary of research and comments from an array of researchers and organizations on the leachability of coal combustion residuals (CCRs).

In an effort to address concerns associated with single-point pH tests (e.g., TCLP, SPLP) the US EPA funded research that lead to a more comprehensive approach to leaching testing. The suite of test methods that have collectively become known as the Leaching Environmental Assessment Framework (LEAF) are the result of that research. The complete LEAF protocol involves four different test methods, two of which remain under review as part of US EPA's "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods", also known as SW-846. The LEAF methods bracket a range of pH and solid to liquid ratios, resulting in data that theoretically capture the spectrum of leaching behavior parameters.

While these methods provide more data and insight into CCR leaching processes, additional research and guidance is needed before they can be used to form site-specific decisions regarding the beneficial use of CCRs. For example, a given beneficial use scenario will generally involve a much narrower field-relevant pH range than the entire 2-13 range that is tested as part of LEAF Method 1313 and a narrower liquid to solid exposure range during a given period than Method 1314, 1315 or 1316 . Moreover, differences in the flow regime (e.g., hydraulic gradient, intermittency and duration) may also lead to differences between field observations and laboratory data. Such differences influence data interpretation, efforts to perform fate and transport modeling and overall risk assessment.

INTRODUCTION

Since the development of the Proposed Rule on coal combustion residuals (CCRs) in March 2010 the US EPA completed its research on the tests for constituents leaching from coal combustion residuals (CCRs). This research was conducted under the guidance of the US EPA's Office of Research and Development (ORD) to identify appropriate leaching test methods (including LEAF) that can be used to assess leaching under known or proposed CCR management conditions (US EPA 2010). Evaluation of LEAF by the Electric Power Research Institute (EPRI) and other research institutions indicates that LEAF provides more information as compared to single-point batch tests such as the Toxicity Characteristic Leaching Procedure (TCLP SW-846, Method 1311) and the Synthetic Precipitation Leaching Procedure (SPLP SW-846 Method 1312) (EPRI 2010).

The TCLP was designed as a screening test to determine if a material should be classified as hazardous under the RCRA Act. The regulatory levels set for the toxicity characterization were based on calculating an acceptable chronic exposure risk to the constituent of concern at a theoretical well location and calculating back through the saturated and unsaturated soil to the source at the bottom of a theoretical landfill (Kimmell 1999). The TCLP test is used for a variety of liquids and solids, organic and inorganic substances. The TCLP test is a single point test which subjects the solid material being tested to a weak acid, glacial acetic acid, essentially strong vinegar. Depending on the initial pH of the material being tested, the extraction fluid for the leaching test is pH 4.93 or pH 2.88 (US EPA 1992). The Resource Conservation and Recovery Act (RCRA), which gave the US EPA the authority to determine and regulate hazardous wastes, specifically exempted CCR wastes under an amendment to RCRA. CCRs were not required to be tested using the TCLP to determine whether constituents of concern exceeded the federal maximum contaminant levels (MCLs) to designate a substance as hazardous (US EPA 2012). Under TCLP testing CCRs do not generally exceed MCLs. The constituents present in CCRs are extremely variable as found by many research studies. Variations result from the CCR type such as fly ash or bottom ash, source coal, combustion process, and the air pollution control measures used among other factors (Daniels and Das 2006; Kosson et al. 2009).

The TCLP test was never intended to capture all plausible field situations and the results are typically not suitable to define source terms in groundwater modeling applications. In short, results from the TCLP test may overstate (e.g., divalent cations such as cadmium) or understate (e.g., oxyanionic constituents such as chromium) the actual leachability of a given constituent. In an effort to address concerns associated with single-point pH tests (e.g., TCLP, SPLP) the US EPA funded research that lead to a comprehensive approach for leaching testing titled the Leaching Environmental Assessment Framework (LEAF). LEAF was developed to assess leaching for a wide variety of solid materials, including process wastes, construction materials and mining wastes. The concepts for LEAF have circulated in the academic literature long before the U.S. EPA became involved and recognized LEAF as a framework (Kosson et al. 2002).

During the leaching process liquid-solid partitioning occurs. Liquid-solid partitioning is the movement of a constituent such as a metal from the solid matrix into the liquid to which it is exposed until equilibrium is reached. The liquid-solid partitioning is affected by such release controlling parameters as pH, liquid to solid ratio, leaching period and the specific chemistry of the solid. The four LEAF test methods are:

Method 1313: Liquid-solid partitioning as a function of eluate pH using a parallel batch extraction test.

Method 1314: Liquid-solid partitioning as a function of liquid-solid ratio using an up-flow column test.

Method 1315: Mass transfer in monolithic or compacted granular materials using a semi-dynamic tank leach test.

Method 1316: Liquid-solid partitioning as function of liquid-to-solid ratio using a parallel batch test.

The US EPA has included Method 1313 and 1316 in the New Methods section of "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods" (SW-846) as of October 2012. Inter-laboratory validation testing of Methods 1314 and 1315 have been completed and the results are being evaluated in anticipated of inclusion in SW-846 (US EPA 2013).

As with any new test method there is a need to develop a sufficient body of data to determine how the method should be used or interpreted, and if there are any precision and bias issues that need to be addressed. Since the LEAF test methods are relatively new, the body of data that is available for a scientific evaluation is relatively small. By comparison, the body of data available for TCLP and SPLP was compiled over 20 years. The purpose of this paper and presentation is not to debate the accuracy or merits of the LEAF test methods, but to simply provide some basic guidelines and suggestions for the use and application of these methods for CCRs. Moreover, since LEAF use and application is relatively new, a secondary purpose of this paper is to initiate discussion about where and when LEAF should be used by both regulatory agencies and private industry.

WHAT IS THE LEAF PROTOCOL?

LEAF is an organized collection of four different laboratory test methods each designed to simulate a parameter that affects leaching. The leaching characteristics of a wide range of solid materials, including CCRs can be evaluated under the parameters of pH and liquid to solid ratio and leaching time. LEAF requires the collection of considerably more data than standard single-point batch leaching tests such as the TCLP and the SPLP. The additional testing and data are intended to provide a more robust dataset that can be used to evaluate CCRs over a wider range of pH and site-specific conditions. The LEAF methods that have been adopted by the EPA as acceptable methods for leaching analysis, Method 1313 and Method 1316, state that they are "not required by federal regulations to determine whether waste passes or fails the toxicity characteristic as defined at 40 CFR 261.24" (US EPA 2013)

TCLP, SPLP and the LEAF methods are leaching extraction procedures only. Following the extraction procedure, the liquid is filtered and preserved for analytical analysis by inductively coupled plasma (ICP) spectrometer or similar instrument according to other US EPA approved procedures such as "Analysis of Metals in Waters and Wastewaters by

ICP Method 200.7.” The ICP instrument is used to determine the concentration of a metal or other element in the leachate sample. One lab may be used for the extraction procedure and another lab may be engaged for the analytical analysis to determine the concentrations for each element in the leachate samples collected. This analysis is also required for the TCLP and SPLP tests. The TCLP method specifies that the ICP samples be “digested.” LEAF requires more samples be analyzed than for a TCLP or SPLP but it also provides a more complete characterization. The complete testing protocol is effective in comparing different treatments and different applications of the material. The following sections provide a description of the four LEAF test methods and their probable uses:

Method Descriptions

Method 1313 pH Batch Extraction Leaching Test
(Abridgment of LEAF Method 1313, complete method available at http://www.vanderbilt.edu/leaching/wordpress/wp-content/uploads/US EPA_M1313.pdf or http://www.epa.gov/osw/hazard/testmethods/sw846/pdfs/1313.pdf)

Method 1313 is a procedure that determines liquid-solid partitioning as a function of pH for constituents in solid materials using a parallel batch extraction procedure. The acidity or alkalinity, as indicated by the pH of a liquid, affects the concentration of a metal or other element that will leach from the solid into the liquid to which it is exposed. Figure 1 illustrates the settling behavior of the solid which is also affected by the pH.

The pH batch extraction leaching test procedure calls for reaching nine specific pH targets after mixing the reagent water, nitric acid or sodium hydroxide (or potassium hydroxide) and the material to be tested. If the natural pH of the material, without acid or base addition, is not one of the nine targeted pH positions the natural pH is a tenth position in the procedure. The nine target pH solutions are 2, 4, 5.5, 7, 8, 9, 10.5, 12 and 13.

The amount of material needed and the mixing time for each sample depends on the particle size of the material. Particle size reduction is allowed. For fly ash, 20 grams of dry material to 200 grams of solution provides the desired liquid-to-solid ratio (L/S) of 10 mL solution/g dry sample (g-dry) as specified in Method 1313. A rotary tumbler which can rotate the extraction vessels end-over-end at a constant speed of 28 ± 2 rpm tumbles the samples in bottles for 24 hours.

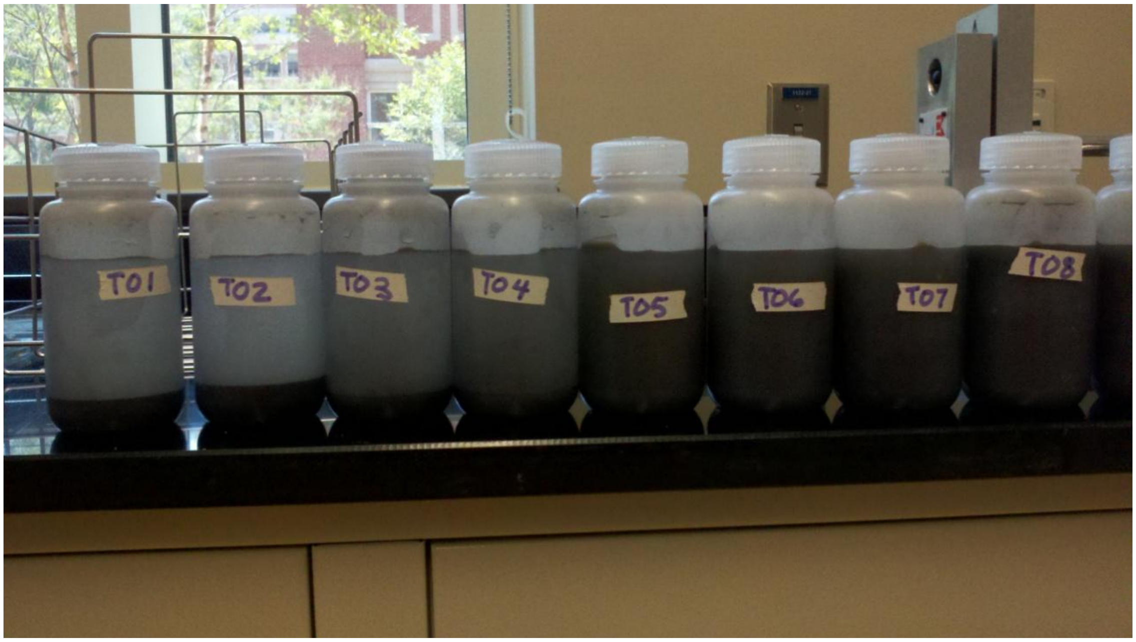

Figure 1 Method 1313 pH target test positions illustrate different settlement behavior of a material at different pH.

Method 1314 Up-Flow Percolation Column Procedure
(Abridgment of LEAF Method 1314, complete method available at http://www.vanderbilt.edu/leaching/wordpress/wp-content/uploads/M1314_V.pdf)

Method 1314 is a procedure designed to determine liquid-solid partitioning as a function of the liquid-to-solid ratio for constituents in granular solid materials using a percolation column. Reagent water is pumped into the bottom and through a 30 cm long by 5 cm diameter column of moderately packed material. The resulting fluid is sampled at nine discrete liquid-to-solid ratios. The ratios are 0.2, 0.5, 1, 1.5, 2, 4.5, 5.0, 9.5 and 10 ml/g-dry material. The low rate of flow requires 14 to 21 days to complete this test.

Figure 2 up flow columns ready for liquid to solid ratio material testing

<u>Method 1315 Semi-dynamic Tank Leaching Test</u>
(Abridgment of LEAF Method 1315 complete method available at
http://www.vanderbilt.edu/leaching/wordpress/wp-content/uploads/M1315_V.pdf)
Method 1315 is a semi dynamic tank test that can be used to determine the rate of mass transfer as a function of time for a constituent of concern. This test quantifies the concentration of a metal or other element that will dissolve from the solid material and dissolve into solution over time. The liquid in the tank, is sampled, drained and replaced with fresh reagent water at nine specific intervals. The first time interval is 2 hours and subsequent intervals are 1, 2, 7, 14, 28, 42, 49 and 63 days.

For this test, solid or monolithic samples may be any shape but geometric shapes simplify the calculations. Granular samples may also be tested with this method if they can be consolidated. If granular samples do not retain their shape even after consolidation the test can also be conducted with a single surface exposed to the fluid as a one dimensional test.

<u>Method 1316 Liquid-Solid Ratio Batch Extraction Leaching Test</u>
(Abridgment of LEAF Method 1316 complete method available at http://www.vanderbilt.edu/leaching/wordpress/wp-content/uploads/US EPA_M1316.pdf or at http://www.epa.gov/osw/hazard/testmethods/sw846/pdfs/1316.pdf)

Method 1316 is a procedure that determines liquid-solid partitioning as a function of the liquid to solid ratio for constituents in solid materials using a parallel batch extraction procedure. The ratio of liquid to solid affects the concentration of a metal or other element that will leach from the solid into the liquid to which it is exposed. The liquid-solid ratio batch extraction leaching test procedure calls for testing at five specific liquid to solid ratios. The five target ratios are 10, 5, 2, 1 and 0.5 mL reagent water/g dry material.

A rotary tumbler which can rotate the extraction vessels end-over-end at a constant speed of 28 ± 2 rpm tumbles the samples in bottles for 24 hours for the smaller particle size such as fly ash. After the extraction procedure the liquid is filtered and preserved for analytical analysis by an ICP or similar instrument. The concentrations for each element at each liquid to solid ratio are determined.

Figure 3 Rotary agitators tumbling samples for Method 1313 and Method 1316

TYPICAL TEST RESULTS FROM LEAF TESTING OF CCRs

Method 1313 pH Batch Extraction Leaching Test

Unlike the TCLP test that mixes a single solution at a set pH and then adds the material to be tested, Method 1313 requires determining the amount of acid or base needed to reach a specific pH with the water and material. The difference is important in determining how a material would behave if subjected to conditions that are more alkaline or acidic. With the weak acid used in the leaching solution for the TCLP an alkaline material could quickly neutralize the effect under test conditions yet be overwhelmed under field conditions depending on the extent to which low pH conditions persist.

Determining the acid/base titration and buffering capacity of the tested material is an initial step in this procedure. Buffering capacity determination is useful in determining if a field use of the ash will influence the material surrounding it or vice versa. If a CCR is sufficiently alkaline it may be very useful in reducing the acidity and reactivity of acid rock drainage fluid. However if the buffering capacity is low, the alkalinity may dissipate too quickly to be effective. In that case the high acidity from the acid rock drainage may increase leaching of some constituents and exacerbate the environmental damage.

The concentrations of the elements and pH relationship generated by this method can be used in conjunction with geochemical speciation modeling to infer the mineral phases of the constituents. The speciation of the elements can be a factor in determining the risk of greater or lesser toxicity or suggest an effective treatment regime.

If the concentrations are plotted against the pH for the individual elements it is evident that the different elements have different characteristic behaviors based on whether they are highly soluble, cationic, amphoteric or oxyanionic. After initial testing using the complete Method 1313 test for a material such as fly ash from a particular power plant, it would be reasonable to use only the natural pH test position as a screening test. If the pH and constituents concentrations for the natural pH are reasonably consistent with previous tests of that same material the concentrations at the other pH's can be inferred from the characteristic curve. Figure 4 illustrates a characteristic pattern for CFA release of arsenic with the natural pH of 5.5 releasing the lowest concentration of arsenic. If a fill area of this fly ash were covered with a soil of a much higher or lower pH, the release of arsenic would be expected to be higher.

Most of the 17 elements tested for in the UNC Charlotte study had their highest release rate at pH 2. Method 1313 protocol identifies pH 2 as providing an estimate of the total or available content of a constituent of concern. Highly complex physical and chemical interactions act to retain elements in the solid matrix. The very low pH acts to release many of the chemical bonds. Unless the material being tested will be subjected to highly acidic conditions such as acid rock drainage or mine reclamation in acidic conditions pH 2 concentrations should only be used as a total content analysis.

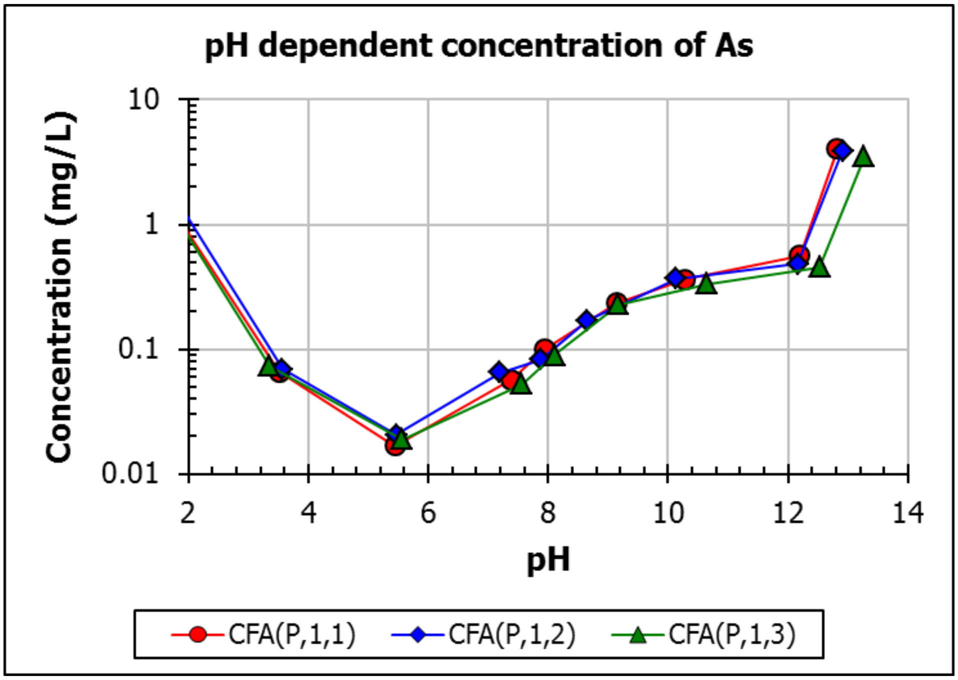

Figure 4 Method 1313 test of CFA in triplicate. Natural pH for this CFA was 5.5.

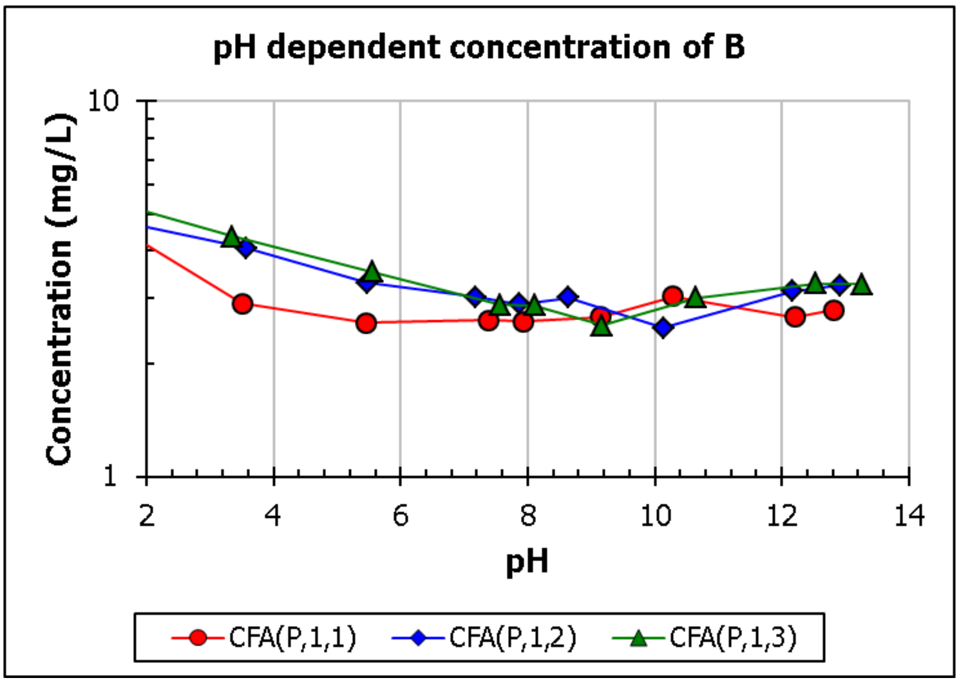

Figure 5 Method 1313 Boron concentrations show high solubility and low pH variability.

The other extreme, highly alkaline or basic causes concentrations of some elements to increase and has almost no effect on others such as Boron as shown in Figure 5. The complete Method 1313 is important for comparison testing different treatments that may be used for sequestering undesirable constituents. A change in pH may render a treatment that looked good under a specific pH totally ineffective under a different pH. Figure 6 shows similar concentration results for Arsenic concentrations for the five materials at pH 4 but the effectiveness of each treatment with respect to the others changes with the pH. In figure 6 CFA is untreated fly ash and WK02, WK, ZY and TG are treated fly ash. TCLP is the federal maximum contaminates level for arsenic using the TCLP test. DW is the federal drinking water limit for Arsenic.

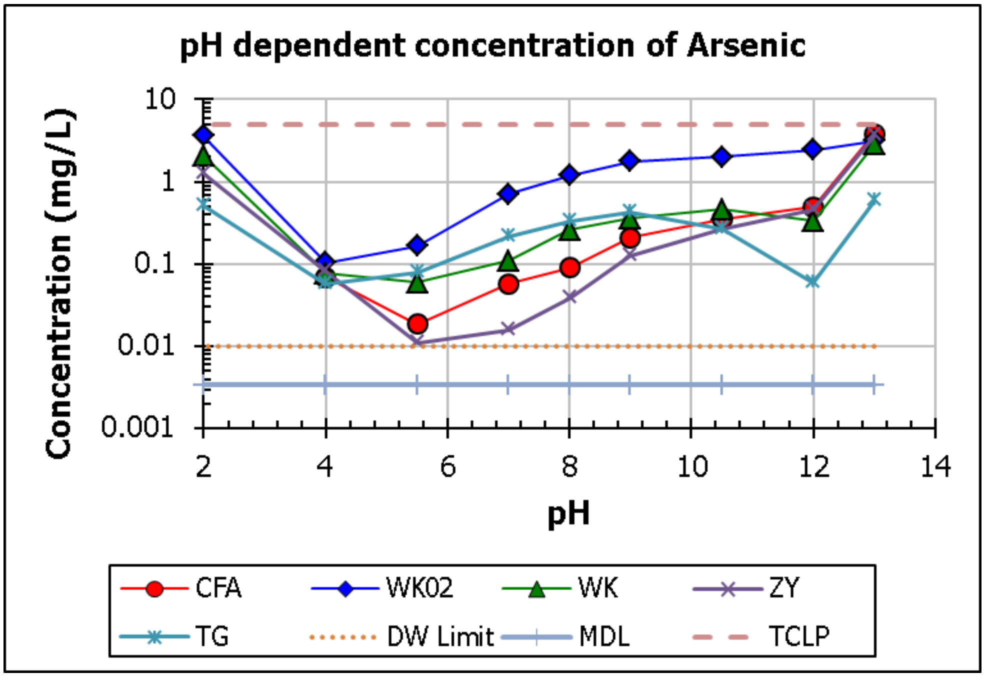

Figure 6 Method 1313 Arsenic concentrations for untreated and three treated CFA.

Method 1314 Up-Flow Percolation Column Procedure

The initial sample results from this test provide an estimate of pore water concentrations. Highly soluble elements generally have high initial concentrations which decrease rapidly with the increase in cumulative liquid to solid ratios. Figure 7 shows the soluble behavior of Boron. Successive samples have greater liquid to solid ratios and the release concentrations for some elements may increase as the LS ratio increases. Arsenic and selenium exhibit this behavior as shown in Figure 8. The cumulative total extract concentration as an "estimate of the maximum mass of that constituent to be leached under field leaching over intermediate time frames (e.g., up to 100 years) and the domain of laboratory test pH (US EPA 2012)." The leaching behavior of the material over time can be estimated for a specific application if field condition data is available on mean infiltration rate, density and depth of material application.

The density of the material in the column test compared to the density of the same material in a field application is a significant factor in the leaching rate of constituents that should be considered when translating Method 1314 results for field use. For the column test the material is moderately compacted with a rod by hand. The lower compaction in the column results in both more and larger pore spaces than a field application of the same material compacted by heavy machine. In a heavily compacted material in a field application, the movement of water through the soil is reduced. The reduction in permeability decreases the water-material contact and reduces the leaching of even the most soluble constituents. If the compaction is accomplished with the optimal moisture content, the movement of capillary water is minimized (Army 1997).

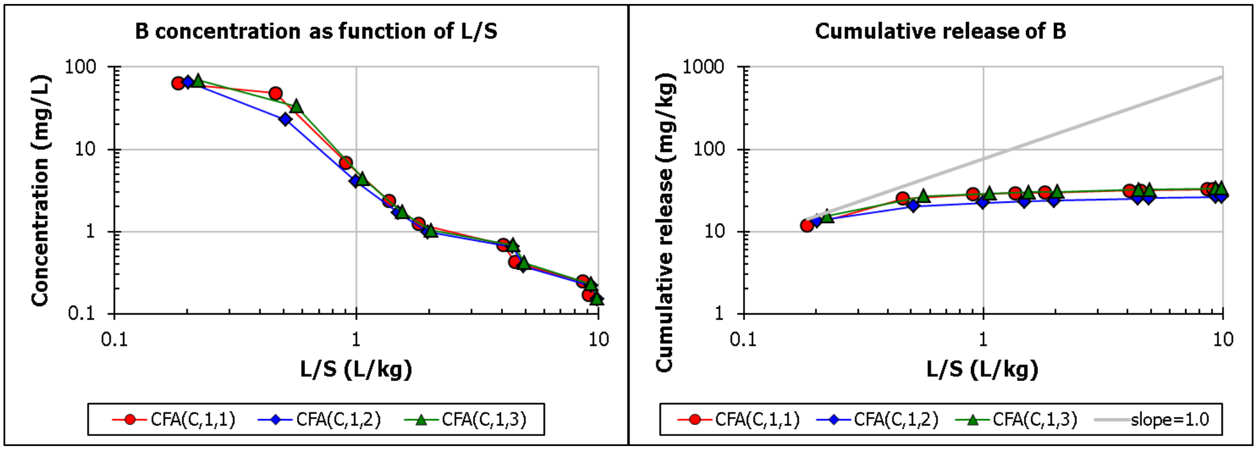

Figure 7 Method 1314 Boron concentrations as L/S ratio and cumulative release showing soluble behavior.

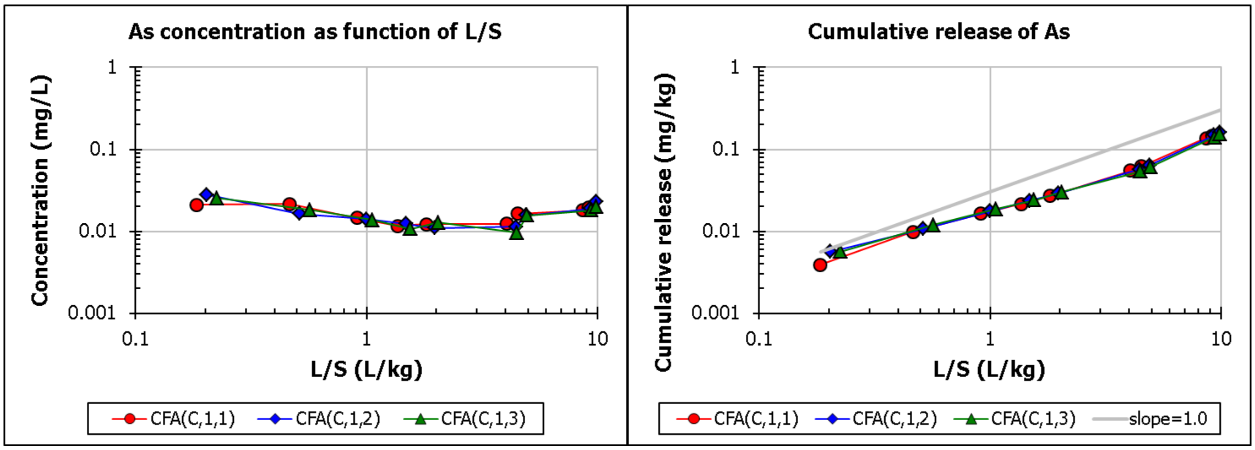

Figure 8 Method 1314 Arsenic concentrations as a function of L/S ratio and cumulative concentration

<u>Method 1315 Semi-dynamic Tank Leaching Test</u>

Method 1315 testing was not conducted as part of this particular study at UNCC. This test method is good for determining the mass transfer and diffusion coefficients useful in transport modeling.

<u>Method 1316 Liquid-Solid Ratio Batch Extraction Leaching Test</u>

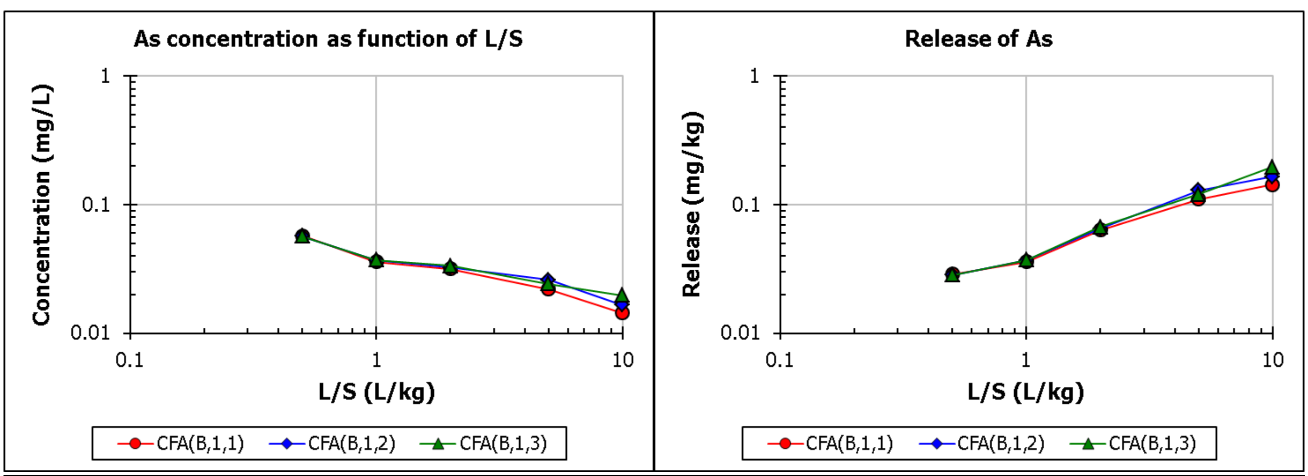

Figure 9 Method 1316 Arsenic concentration as a result of L/S ratio and release rate per kg.

For highly soluble constituents the mass released (mg/kg) is more reflective of field condition behavior than the concentration. For the short period of this test (24 hours) the results are similar to the method 1314 test which takes 14 to 21 days.

General comments about LEAF:
While the concentrations extracted from material using these methods should not be taken as the concentrations that would enter a surface or groundwater supply, the trends and behaviors that are illustrated by these tests make it clear that small variations in the pH or L/S ratio can have significant impacts on the constituent release rates. Another important lesson from these tests was that when comparing treatments, the natural pH of a treated material does not indicate similar release rates as another treatment with the same natural pH. There are many physical and chemical interactions at work in the leaching process.

ADVANTAGES AND DISADVANTAGES OF LEAF FOR CCRs

One of the main reasons that the LEAF protocol was developed was to provide a more robust dataset for evaluating the potential impacts of CCRs over a wide range of conditions. A few of the advantages of using LEAF for the evaluation of CCR leachability are:

- Provides a larger dataset that can be used to evaluate the reason for impacts to groundwater and surface water by CCRs.
- Testing can be tailored to address site-specific conditions, such as a limited pH range for cementitious materials.
- A site test protocol can be developed using selected LEAF methods with existing SW-846 methods like TCLP or SPLP.

One of the main drawbacks or disadvantages of using LEAF is the large volume of data provided by the LEAF test methods, and the potential of the results being improperly used by regulators and others who are not familiar with the geochemistry of coal combustion byproducts. Many of the LEAF methods will generate test results that are above the Federal or State maximum contaminant levels (MCLs), by using test conditions that are impossible outside of an analytical test laboratory environment. The wide range of results allows experienced geochemists, engineers and scientist to make interpretations about site conditions that can influence the leachability of CCRs. In the hands of less experienced scientists or the general public these results can be cause for unnecessary concern and/or misrepresentation of the potential risk. Some of the drawbacks and disadvantages of LEAF that have been identified are:

- Concern over possible inappropriate use of the large volume of data provided by the LEAF protocol.
- Need for comparison between LEAF test results and field data to guide the site-specific application for structural fills, mine reclamation and other beneficial uses.
- A wider range of pH (Method 1313) that may not be representative of actual site conditions and potential for some regulators to use “worst-case” results. The authors suggest defining a field-relevant zone of interest.

- Limited number of laboratories able to perform the LEAF testing and concern over repeatability between labs and cost.
- Need for continued independent evaluation of the LEAF protocol by those with site specific experience in the fate and transport of constituents found in coal combustion byproducts.
- A potential of causing conflicts or discrepancies with the existing SW-846 test methods like the TCLP and the SPLP that have a much larger dataset and have been used a regulatory tool for many years.
- A concern over the consistency of test results and the precision and bias between laboratories, test devices, and lab technicians.
- Proper interpretation requires special knowledge of geochemistry and an understanding of interrelated issues that may impact environmental systems.

CONCERNS WITH THE USE AND APPLICATION OF LEAF

One of the concerns over the use of the LEAF protocol for the testing of CCRs is how the large volume of data generated by the test methods will be used to assess existing beneficial use structural fills or mine reclamation sites. LEAF has been proposed for use in situations where the TCLP method is not required or the best suited test method. Since there is still a significant of debate over what is considered a beneficial use of CCRs, it reasonable to assume that the indiscriminant use of the LEAF protocol will be subject to a similar amount of scrutiny and debate. The LEAF test methods are continuing to evolve in terms of repeatability testing and acceptance. By comparison TCLP and SPLP have been used for many years as a screening tool, and so there is a large body of data and widespread familiarity for these methods. Over time it is anticipated that LEAF methods, as a more robust leaching assessment tool, will gain acceptance with the regulatory and industrial community.

GUIDELINES FOR INTERPRETING AND COMPILING LEAF TEST RESULTS

The LEAF methods were developed to address the concerns of the US EPA Science Advisory Board with a primary focus on the parameters that affect leaching (A.C. Garrabrants 2010). The LEAF methods are not a single point test like TCLP or SPLP, and were designed to provide an in-depth look at the parameters affecting leaching of constituents from CCRs and a wide range of industrial waste materials.

One of the purposes of the LEAF methods is to bracket the outer limits of spectrum of results where leaching could occur. By comparison the TCLP and SPLP test methods are single point tests that have been used primarily as a screening tool to assess whether waste materials can be disposed of in a municipal solid waste or hazardous waste landfill. As explained in the proceedings entitled, "Development and Implementation of the Leaching Environmental Assessment Framework (LEAF) in the United States" 2010, the LEAF methods were developed:

"*under the direction of US EPA as a basis for more robust leaching assessment for a range of possible applications, including evaluation of beneficial uses of secondary materials, waste treatment processes, soil remediation, and life-cycle assessments (Kosson et al. 2010)*

As such the test results from the LEAF test methods develop a large amount of data that may or may not indicate a potential problem with actual in-situ or field conditions at a CCR beneficial use site. To avoid developing a large amount of data that could be improperly used or misinterpreted the following guidelines are suggested:

- Define the objective for performing leach testing as well as the relevant stakeholders. Attempt to obtain agreement between regulatory professionals, experienced industry professionals, and geochemists on how the data generated from the LEAF test methods will be used before embarking on an extensive testing program. To obtain a meaningful outcome that yields results and produces the desired change in approach, it is often best to agree on common test methods and methods of interpretation at the beginning of the project.
- If a single point, leaching contamination level is required for a “Yes” or “No” determination of leachability of CCRs, then it is often best to use a risk-based approach where the site specific maximum contaminant level is developed according to accepted scientific protocol. The boundaries and approach on how the LEAF methods will be used in a risk-based scenario are still in the process of being developed.
- If a wider range of leaching data is required, obtain an indication of the field parameters such as pH, hydraulic conductivity, soil type and hydraulic gradient, first. This information can be used to interpret and/or “calibrate” the results of the LEAF methods to field relevant conditions after they are complete.

CONSIDERATIONS FOR AN INTEGRATED LEACHABILITY TEST PROGRAM

An important part of any leachability testing program is to determine the end point or desired result of the program before the sampling and testing has started. LEAF is designed to provide a more robust set of data, so that experienced professionals and/or geochemists can make an assessment on beneficial use of CCRs, waste treatment, soil remediation, and life-cycle assessments.

Some of the most important parts of any environmental sampling and testing program are to: 1) protect groundwater from known contaminants and 2) to limit the exposure pathways for surface or groundwater contamination. How and where the LEAF test method will be used as a tool to achieve these important parts of any environmental testing program is still in the early process of being developed. The following are a few items that should be considered when attempting to develop an integrated leachability test program for CCRs:

- Continue to use the TCLP or SPLP tests as the screening methods, and use the appropriate LEAF method on a tiered-basis as information is needed about the leaching characteristics. An example this may include additional testing for a site with a variable or changing pH, a changing hydraulic gradient, and decreasing or increasing hydraulic conductivity.
- Work with engineers and scientists who are experienced with the use and interpretation of TCLP, SPLP and LEAF for a wide variety of industry materials.

- Develop a larger body of data, over a period of years using a combination of the TCLP and SPLP results, and applicable LEAF methods. The purpose of this approach is to identify trends and potential sources of error in the sampling or testing methods that may not represent the actual site conditions.
- Make an effort to know the value and limitations of the TCLP, SPLP and LEAF test methods for a given material and application. Attempt to use the various test methods to fill gaps in the data about leachability about a specific CCR material.

FIELD RELEVANT PARAMETERS FOR REPRESENTATIVE LEAF TESTING

For the proper use and application of the TCLP, SPLP, or LEAF test methods to a site-specific CCR beneficial use application it is essential to obtain field relevant parameters from the site. In addition, the proper application of any leaching test method requires an understanding of the site where the CCRs have been used. The field parameters and an understanding of the site allow the development of a site conceptual model (CSM) that attempts to explain the following:

- The nature of potential contaminants in the CCRs – will the contaminants leach from the CCRs, and if so what are the conditions that will allow leaching to occur;
- The extent to which contaminants present in the solid phase are available for leaching into the aqueous phase.
- How thick and what is the area over which the CCRs have been placed;
- Where is the groundwater table in relation to the CCR, and does this produce the potential for leaching of contaminants from the CCRs.

When determining which field parameters should be sampled a basic understanding of the concepts of leachability for CCRs is necessary:

- Leachability of coal ash or CCRs is influenced by combination of the contaminant concentration, pH, particle size, and the degree of saturation.
- Risk caused by a material's toxicity is dependent on whether an exposure pathway exists – no exposure pathway, no risk.

ADDITIONAL RESEARCH AND GUIDANCE FOR LEAF PROTOCOL

As mentioned previously, the test methods of the LEAF protocol are in the early stages of adoption in industry. A few of the important research issues that still need to be addressed include:

- A comparison of the laboratory generated values, and the field verified values of actual leaching results.
- Development and testing of the LEAF method for common uses such as:
    - Leaching of constituents from concrete
    - Leaching from native soils – clays, silt and sand
    - From CCR structural fills
    - Leaching from beneficial reuse and recycled CCRs

- A comparison of the LEAF methods to the TCLP and SPLP.
- Explanation and guidance documents for the use and application of LEAF in a wide range of field and laboratory conditions.
- A more robust assessment of the precision and the bias of the LEAF test method based on a larger dataset of test results from a wider range of materials.

SUMMARY AND CONCLUSIONS

The Leaching Environment Assessment Framework (LEAF) has been included as another leaching test method by the US EPA under SW-847 for the evaluation of the physical and chemical properties of industrial wastes and secondary materials. The LEAF test methods are expected to be useful for providing more data and more insight into the processes that influence the rate and extent of leaching from CCRs. While the LEAF methods are expected to provide useful information, additional guidance and research is needed before they can be used to make and/or influence site specific decisions about leaching from a CCR beneficial reuse site. To address the issues associated with the use and application of the LEAF protocol on CCR beneficial use sites, it is essential that the coal combustion utilities, state regulatory agencies and the CCR recycling industry have an opportunity to discuss the use of the LEAF methods. In the interim, this paper has provided some general guidelines and other topics that should be considered.

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