Fundamentals of Testing Stabilized Coal Combustion Residuals for Encapsulation and Beneficial Use

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ABSTRACT

In the Final Rule for the Disposal of Coal Combustion Residuals (Final CCR Rule), the U.S. Environmental Protection Agency (EPA) provides a summary of research conducted and recommended guidelines for evaluating encapsulated beneficial use. In addition, the sections in the Final CCR Rule that speak to beneficial reuse provide specific reference to background information about the Leachability Environmental Assessment Framework (LEAF), and recommendations for evaluating encapsulation and beneficial use of coal combustion residual (CCR) materials. This paper and presentation will provide information on the fundamentals of sample preparation, and selection of test methods depending on the proposed use of the stabilized and encapsulated CCR materials. In addition, this paper and presentation provide practical examples of how the different types of leachability testing can be used to meet the requirements in the Final CCR Rule, and assist with obtaining the necessary approvals from State regulatory agencies. Items that will be presented for discussion and consideration include the following:

- An explanation of the different LEAF methods and examples of how the different methods are used for assessing leaching potential, and/or the effectiveness of additives used for stabilization and encapsulation;
- A list of recommended EPA guidance documents for the use and interpretation of leachability test methods as it pertains to stabilization and encapsulation of CCRs;
- Practical examples of recently completed stabilization mix design and leachability verification testing for construction projects, including a summary of how this can be used as part of a field quality control test program;
- Several case studies of stabilized and encapsulated CCRs materials and the application to typical State regulatory requirements;
- Guidelines for checking the field-relevant pH, soil type, hydraulic conductivity and other site-specific parameters that could influence the use and interpretation of leachability test methods for construction projects.

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INTRODUCTION

The authors of this technical paper have been closely involved with contractors and field engineers who are actively engaged in the construction, safety evaluation and technical designs associated with recent CCR impoundment closure and beneficial use projects. To address the safety concerns of the ash basin owners – electric power utilities, and to respond to an increasing emphasis on beneficial use and encapsulation of CCR materials additional understanding of the regulatory and technical requirements is needed. The practical experience and regulatory guidelines referenced in this technical paper are provided to decrease misinformation about proper understanding of encapsulation and beneficial use as identified in the Federal CCR Rule, and to promote innovative and cost effective methods for using CCR materials.

This technical paper and presentation provides a summary of practical information from the Federal CCR Rule, and several guidance documents developed by the US EPA. This information and guidance offer clear direction about how to evaluate encapsulated beneficial uses, and how to use the Leaching Environmental Assessment Framework (LEAF) to determine how best to stabilize and fixate heavy metals in a solid matrix. In addition, the Federal CCR Rule provides information on how and why coal combustion residuals (CCRs) are considered non-hazardous and regulated under the US EPA Subtitle D as a “non-toxic” solid waste material.

BACKGROUND INFORMATION

To provide some context about the practical aspects of encapsulation and beneficial use of CCRs in the US EPA Federal CCR Rule the following information is provided:

- Criteria 1: CCR must provide a functional benefit.
- Criteria 2: CCR must substitute for the use of a virgin material, conserving natural resources that would otherwise need to be obtained through practice such as extraction.
- Criteria 3: The use of CCR must meet relevant product specifications, regulatory standards, or design standards, when available and where such specifications or standards have not been established, CCR may not be used in excess quantities.
- Criteria 4: Encapsulated CCRs are considered non-hazardous and will not impact the environment when the encapsulated CCR mateirals are tested according with EPA Methods that are part of the Leachabilty Environmental Assessment Framework (LEAF).   (Ref.   Federal CCR Rule Page 21347)

The regulatory approach for the management and containment of CCRs has evolved over the past 20 years in response to public concern, legislation and legal action across the United States.   **At the same time the technical approach to encapsulation and containment of potentially harmful heavy metals has remained the same.** Simply put, if coal ash and other types of CCRs can be encapsulated with additives in a manner such that the harmful heavy metals are contained and prevented from being released to the natural environment then these the coal ash can be used a valuable construction material.

Recognizing that coal ash or coal combustion residuals (CCRs) are the second largest waste stream in the United States and the world, being able to manage coal ash safely and cost effectively as a construction material provides substantial benefits to the general public and the electric power industry. When coal ash and other types of CCRs are safely stabilized and the heavy metals are fixated in a solid matrix with additives and construction methods, then the associated risk and liability is greatly reduced.

The following technical resources provide a summary of the information that is used by State and Federal regulatory agencies for assessing the safe and effective containment and encapsulation of CCR materials.

- Determination of Non-hazardous Use of CCRs for Construction and Beneficial Use: See Federal CCR Rule Pages 10, 12, 19, 48, 165 and 210. Simply put: Encapsulated CCR are Non-hazardous.
  https://www.epa.gov/coalash/coal-ash-rule#summary
  https://www.epa.gov/sites/default/files/2014-12/documents/ccr_bu_method.pdf
  https://www.epa.gov/coalash/methodology-evaluating-encapsulated-beneficial-uses-coal-combustion-residuals

- Encapsulation of CCRs and coal ash is verified by following the EPA Protocols and guidelines. The Leachability Environmental Assessment Framework (LEAF) and the US EPA SW-846 provide practical guidance for evaluation, design and assessment of Encapsulation and Leaching Potential of heavy metals from CCRs and coal ash.
  https://www.epa.gov/hw-sw846/leaching-environmental-assessment-framework-leaf-methods-and-guidance
  https://www.epa.gov/sites/default/files/2017-11/documents/leaf_how_to_guide.pdf

This paper is based on practical experience with a wide variety of CCR and coal ash materials and applying additives for stabilization and encapsulation. A few key points are made to establish a baseline for evaluation and testing of coal ash and CCR materials for beneficial use and encapsulation.

- **The various LEAF methods (EPA Method 1313, 1314, 1315, and 1316) are design and/or evaluation methods to develop mix designs and are NOT compliance and/or regulatory thresholds** for acceptance or rejection of mix designs or additives.
- Experience with the application of the LEAF Methods and other test methods within EPA SW-846 is necessary to avoid an overly stringent approach to testing and/or missing key compliance tests that are essential for beneficial use of CCRs and coal ash.
- Reasonable and time-tested methods for evaluation of encapsulation are outlined the US EPA Leachability Environmental Assessment Framework How to Guide for Beneficial Use. Reference: The LEAF Method How to Guide, May 2019
  https://www.epa.gov/sites/default/files/2017-11/documents/leaf_how_to_guide.pdf

ALTERNATIVE USES FOR ENCAPSULATED COAL ASH

During 2021 and the first half of 2022, the CCR impoundment closure industry has experienced significant changes to keep contaminants from porewater beneath coal ash impoundments from impacting groundwater resources. Alternatives to "Close in Place" and the "Excavation and Landfill" option are becoming necessary to reduce the cost of construction and increase compliance with State and Federal environmental regulations.

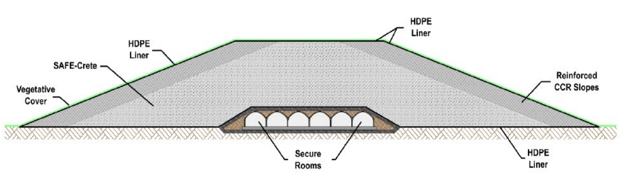
When encapsulated CCRs are used to create valuable energy storage by means of containment these structures can be monetized in the electric power rate base. There have been rapid advancement in energy storage technology the last three years that includes an increased focused on using coal ash for beneficial use by building renewable energy storage structures. The electric power industry has tremendous needs for energy storage structures and compressed air energy storage - all supportive of the renewable energy field. These energy storage and containment structures can now be built safely out of encapsulated coal ash. This type of technology is mentioned prominently in the Federal CCR Rule and it is a time-tested encapsulation method. The encapsulation and stabilization of coal ash using lime and/or cement has been used in dams and roadways for over 40 years. It's been used in hazardous waste remediation for over 30 years where coal ash is the stabilization agent with lime. See Handbook for Stabilization/Solidification of Hazardous Wastes, EPA/540/2-86/001

A few examples of energy storage and electro-magnetic pulse structure that can be created from coal fly ash encapsulated with quicklime or cement are provide below:

Total Protective Structure

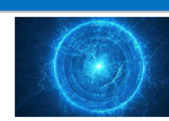
Design Flexibility

- Structure sizes can range from 1 acre to over 100 acres in size
- Height and shapes can be in many different designs
- Undulating features – low variegated plantings
- Large scale labyrinths and/or equipment entrances and exits



Krubera
Management Group, LLC

Hazard Protection



- EMP / Solar Flares
  - CCR cover, "faraday" surrounds
- Blast Protection
  - Protected by 125' of CCR material
- Limited / Controlled Access / Remote Eavesdropping
  - Limited ingress / egress access ways
- Thermal
  - Constant temperature similar to being underground
- Hurricanes / Tornadoes
  - Eliminates risk of wind damage
- Proximity to Power
  - Direct line to power

BASIC EXPLANATION OF THE EPA LEAF METHOD FOR ENCAPSULATION DESIGN

Leaching from Constituents of Potential Concern (COPCs) from a solid matrix like stabilized coal fly ash to surrounding soils, groundwater and surface water can be a difficult condition and/or problem to assess. The Leachability Environmental Assessment Framework (LEAF) was developed from 2010 to 2015 by the US EPA, internationally recognized experts and research universities to address these problems and provide practical "real world" guidance. It is important to emphasize that LEAF is not a compliance method per se, but was developed to provide guidelines for leachability assessments and to estimate the extent of the COPCs that could be release to the environment and waterborne pathways.

Even though LEAF is not a direct regulatory compliance test method, it was developed to evaluate the leaching potentiof COPCs from solid materials to surrounding soils, groundwater, or surface water that can occur in the environment whenever a material is placed on or in the ground. The LEAF test methods are associated US EPA SW-846 that are applicable to the leaching of COPCs to soils, groundwater and/or surface water. These methods also include the Toxicity Characteristic Leaching Procedure (Method 1311), and several other methods practitioners to develop a thorough understanding of site and leaching conditions at any given site. The following quote from the US EPA LEAF How To Guide provides a summary of how the four LEAF test methods can be used:

> "LEAF provides a consistent approach to estimate leaching of COPCs from a wide range of solid materials including as-generated wastes, treated wastes (e.g., solidified/stabilized soils and sediments), secondary materials (e.g., blast furnace slags), energy residuals (e.g., coal fly ash, air pollution control residues), industrial processing residuals (e.g., mining, and mineral processing wastes) and contaminated soil or sediments. The LEAF test methods consider the effect on leaching of important leaching factors, such as pH, liquid-to-solid ratio (L/S) and physical form of the material, that represent a range of plausible field conditions (U.S. EPA, 2010). Thus, a single set of leaching data can be used to evaluate multiple management options or scenarios."

LEAF is a focused collection of four different laboratory test methods that are designed to simulate a parameter that can influence leaching from solid materials and stabilized industrial waste materials like coal fly ash. The LEAF guidance document explains that 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. The LEAF methods that have been adopted by the US EPA include:

Method 1313 - Liquid-Solid Partitioning as a Function of Extract pH Using a Parallel Batch Extraction Procedure

Method 1313 is designed to evaluate the partitioning of constituents between liquid and solid phases at or near equilibrium conditions over a wide range of pH values. The method consists of 9-10 parallel batch extractions of solid material at various target pH values.

Method 1314 - Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio for Constituents in Solid Materials Using an Up-Flow Percolation Column Procedure
Method 1314 is a percolation column test designed to evaluate constituent releases from solid materials as a function of cumulative liquid-to-solid ratio. The method consists of a column packed with granular material with moderate compaction. Eluent is pumped up through the column to minimize air entrainment and preferential flow.

Method 1315 - Mass Transfer Rates of Constituents in Monolithic or Compacted Granular Materials Using a Semi-Dynamic Tank Leaching Procedure
Method 1315 is a semi-dynamic tank leaching procedure used to determine the rate of mass transport from either monolithic materials (e.g., concrete materials, bricks, tiles) or compacted granular materials (e.g., soils, sediments, fly ash) as a function of time using deionized water as the leaching solution. The method consists of leaching a sample in a bath with periodic renewal of the leaching solution at specified cumulative leaching times.

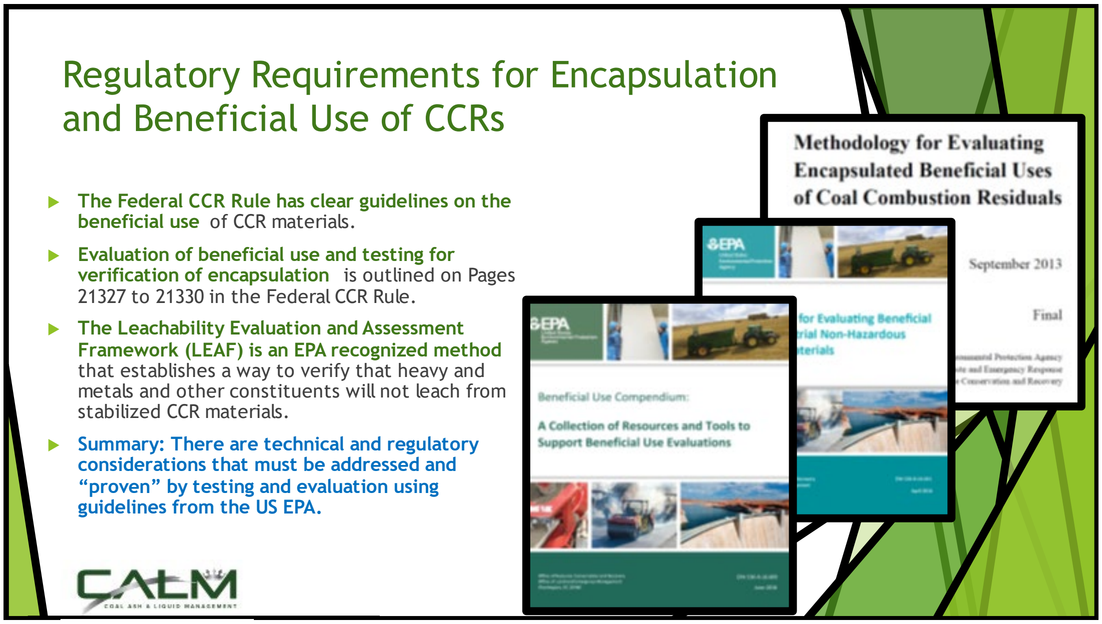
Method 1316 - Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio Using a Parallel Batch Extraction Procedure
Method 1316 is an equilibrium-based leaching test intended to provide eluate solutions over a range of liquid-to-solid ratios. This method consists of five parallel batch extractions of a particle-size-reduced solid material in reagent water over a range of liquid-to-solid ratios. At the end of the contact interval, the liquid and solid phases are separated for constituent analysis. See the following US EPA Guidance documents on the use and application of LEAF as it applies to the beneficial use of coal ash and industrial materials.

https://www.epa.gov/hw-sw846/leaching-environmental-assessment-framework-leaf-methods-and-guidance#LEAF%20Methods

https://www.epa.gov/hw-sw846/how-guide-leaching-environmental-assessment-framework

https://www.epa.gov/smm/methodology-evaluating-beneficial-uses-industrial-non-hazardous-secondary-materials-and

https://www.epa.gov/sites/default/files/2016-06/documents/ben_use_compendium_062216.pdf



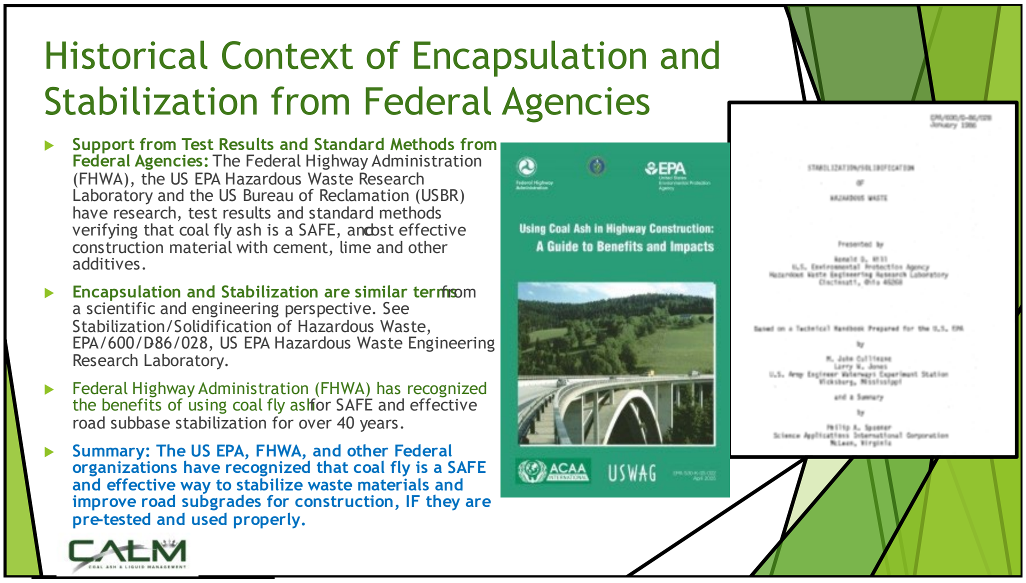
CASE STUDY AND APPLICATION OF LEAF FOR COAL ASH BENEFICIAL USE

This project involved the placement of a deep soil mixing (DSM) stabilization wall that was used to contain partially saturated coal ash to minimize and/or prevent impacts to groundwater. After the stabilized coal ash wall was installed core samples were obtained and the samples were tested using LEAF Method 1313 pH Extraction, and Method 1315 Semi-Dynamic Test of a Solid Monolithic Material.

The purpose of the testing was to: a) Use Method 1313 to measure and evaluate what metals could leach from the solid matrix material is a variable pH, or "worst case" situation. The metals that were measured using Method 1313 were the same metals tested using the Method 1315 Semi-Dynamic Test of a Solid Monolithic Material. b) The Method 1315 was used to test the potential for leaching of metals from solid matrix at a pH that would be typical of actual field conditions.

A Few Key Points on Use of the LEAF Methods:

- The Method 1313 pH testing provides a "worst case" of what could happen, but should not be used as a compliance test method like Method 1311, TCLP and other EPA leachability test methods.
- Solid matrix materials from coal ash stabilized with lime and/or cement SHOULD NOT be "ground down" to less than 3 mm prior to testing Method 1315 because that does not represent actual site conditions.



SUMMARY AND CONCLUSIONS

The Leaching Environment Assessment Framework (LEAF) was developed as a collection of 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 were developed to support and encourage the beneficial use of secondary industrial materials including coal fly ash. Improper use and/or confusion over the use and application of the LEAF methods has resulted at times with inaccurate test results that are not representative of actual site conditions and leaching potential.

Properly used by experienced professionals, the LEAF methods can be used to evaluate the leaching potential of CCRs, and promote SAFE and cost effective beneficial use of encapsulated coal ash for a wide range of energy storage and EMP protective structures. When used as part of a regulatory compliant and “common sense” approach for assessing coal ash basin closures, the LEAF Methods can be used to verify and “prove” that the degree of encapsulation of the CCRs will protect both groundwater and surface water resources.