The use of Microbial Induced Calcite Precipitation to Reduce Trace Elements Leaching from Fly Ash

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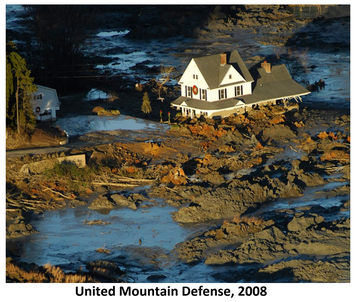
Introduction

- Fly ash is a byproduct of coal combustion
- It is kept in slurry ponds (ash + water), or stores of dry coal ash
- 19+ billion gallons of coal ash in North Carolina
- 2008 spill in Kingston, TN, jeopardized wildlife and drinking water
- 2014 spill in Eden, NC polluted the Dan River, biggest of its kind in US history
- Cause of major and costly litigation and settlement cases
- Efforts to capitalize on the abundance of this material through construction
- Use in construction recently approved by Environmental Protection Agency (EPA)
- Interest in a lower density highway embankment
- Rain events could transport leachate from ash containing heavy metals such as arsenic, mercury and selenium to surface water and groundwater sources



United Mountain Defense, 2008

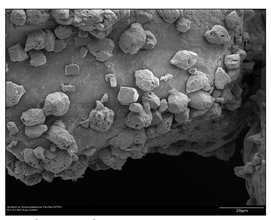
CNN, 2014

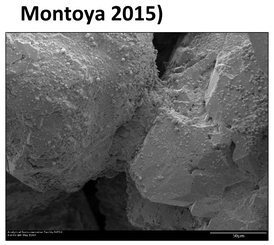
Project Objectives

- Characterize the geotechnical properties of this particular fly ash (from Western North Carolina)
- Determine the efficacy of bioremediation methods on reducing concentrations of heavy metals in fly ash leachate
- Determine the optimal treatment specifications that are field-applicable and realistic
- Determine if the levels of nitrogen produced by the system are a threat to surface water

Bio-Cementation

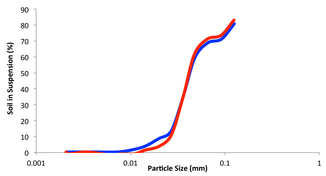
- Microbial induced calcite precipitation (MICP); a biogeochemical process that stimulates calcium carbonate precipitation within the soil matrix
- Bacterium *Sporosarcina pasteurii* converts urea into ammonia (NH_3) and carbon dioxide (CO_2)
- Net increase in pH due to hydroxyl ions (OH^-) generated from the production of NH_4^+, which exceeds the available Ca^{2+} for calcite precipitation
- This provides the alkaline environment and carbonate required for the precipitation of calcite ($CaCO_3$)



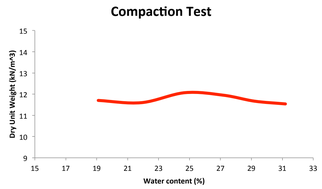


Above: bacteria impressions, Below: a calcite bridge (Feng & Montoya 2015)

Geotechnical Characteristics



Particle Size Analysis completed with a hydrometer. Uniform distribution. D_{50} = 0.04mm

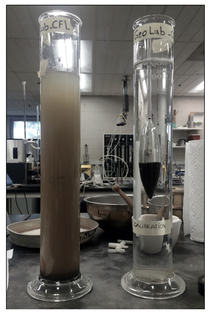


Water content ranges from 19 – 31% in 2% increments. Optimum dry unit weight = 12.1 kN/m^3 at 25% water.

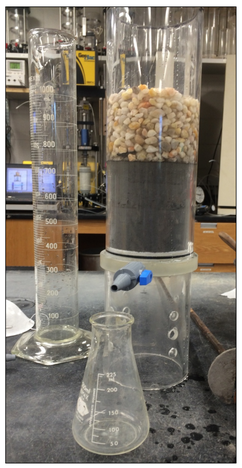
Materials and Methods

Geotechnical Characteristics:

- Particle size analysis was implemented using a 152 hydrometer and ASTM (American Society of Testing and Materials) standards
- Compaction done with a 4" diameter mold and by ASTM standards. Sample was compacted at different moisture contents. Each of three lifts was compacted using a 5.5lb standard compaction hammer.



Hydrometer Analysis



Prepared Sample

Effluent Testing:

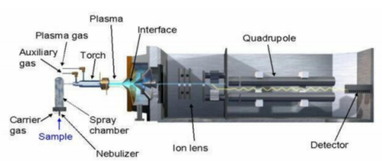
- To establish a baseline, fly ash at 25% water was compacted manually with a tamper in an acrylic mold. 10 pore volumes of water were added incrementally and flushed through over ~8 days. Samples were collected incrementally directly from the spout for testing.
- Next, *Sporosarcina pasteurii* and urea were added to dry fly ash following the recipe below. The sample was compacted, and the same amount of water was flushed through. More bacteria was added after 6 pore volumes of water. Samples were collected the same way as above.

Bio-Cement Recipe

- 75 mL *Sporosarcina pasteurii* bacteria solution
- 212.5 mL of 333 mM Urea solution
- 212.5 mL of 200 mM $CaCl_2$ solution
- 2000 g dry fly ash

ICP-MS

- Inductively Coupled Plasma – Mass Spectrometry
- Capable of detecting metals and some non-metals at concentrations as low as one part per quadrillion
- Sample is ionized with ICP and then a mass spec is used to separate and quantify ions



ICP-MS Mechanism

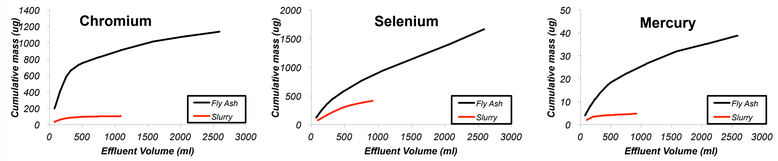
Results

*Concentrations in mg/L

SAMPLE NAME	Volume Elapsed (mL)	Conc of Ca	Conc of As	Conc of Cd	Conc of Cr	Conc of Hg	Conc of Se
BASELINE	75	703	195	52.6	2611	53.2	1633
	2580	257	114	<0.1	130	9.06	504
SLURRY	100	782	298	5.64	319	19.9	746
	905	26.7	832	<0.1	31.3	1.24	187
TREATED	0	2025	248	81.6	2844	112	856
	500	664	216	2.37	247	17.5	310

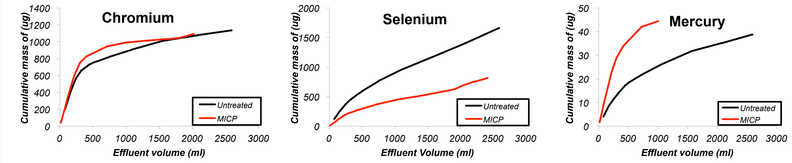
pH testing to determine microbial activity

Baseline: Slurry versus dry fly ash



- Slurry had a lower concentration of all heavy metals tested except arsenic
- Concentrations of heavy metals decreased as more water was passed through the sample

Treated sample versus baseline



- For most metals, there was an initial spike in concentration, then a decline; cumulative graphs show how much has been leached out
- Selenium levels in the treated sample were lower than those of the baseline at all points

Discussion

• Data indicates that dry fly ash contains higher concentrations of heavy metals than slurry, indicating need for mitigation for construction

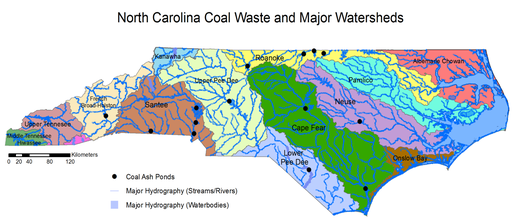
• Treated samples showed an initial spike and a potential delayed decline in metal concentration

•Treatment shows potential, but likely needs to be optimized

•After 7 pore volumes had been added to the sample, a second treatment of bacteria was passed through the sample, using a field-applicable technique.

Future Work

- Total Nitrogen testing to assess the threat to surface waters via eutrophication
- Optimize for urea, pH
- Investigate fly ash materials from other sources, specific watersheds



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