

Concrete Blocks Produced from the Mineral Fraction of Waste to Energy Bottom Ash

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December 24, 2018

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**Abstract:**

Waste management is an important factor in the future of sustainability. Waste-to-Energy (WTE) plants provide an alternative to landfill use that provides energy from the combustion of urban residues. However, the residues from Waste-to-Energy plants are not fully utilized. The ash residues from WTE plants can be used for civil engineering applications, typically as a substitute of sand and aggregates in concrete manufacturing. This study explored the viability of this use in terms of leaching assessments. This study completed the first phase of the Leachability Environmental Assessment Framework (LEAF) Method. The resulting Acid Neutralization Capacity (ANC) graph is a function of leachate pH and the acid added (mmol/kg of acid) to achieve the targeted pH value. The trend that was found was that as more acid or base is added, the final pH is lowered, which can be explained from the decomposition of  $\text{CaCO}_3$  to  $\text{CO}_2$  and  $\text{CaO}$ . Additionally, there were little changes between final pH's from the 24-hour rotation and 48-hour rotation, indicating that the equilibrium of the solution is achieved sooner than the time suggested by the standard.

### Waste-to-Energy:

Waste-management is an integral part of our sustainable future- there cannot be a full achievement of sustainability without proper waste management. However, in the United States, standard-of-living coupled with wasteful product design lends itself to mass amounts of waste with limited space for landfills. Thus, solutions to this imminent issue must be researched, designed and perfected. One solution, broadly implemented in certain parts of Europe, is Waste-to-Energy (WTE) plants. Waste-to-Energy plants are a golden technology in the sustainability world- they convert municipal solid waste (MSW) into usable energy. Not only do they reduce MSW volumes, but they also have a usable end product, as well as a reduction in greenhouse gases. Although there are different types of WTE technologies, “direct combustion over a moving grate with the generation of superheated steam feeding a steam turbine in a *Hirn* cycle is the dominant technology used to recover energy from MSW”<sup>1</sup>. WTE plants efficiencies are constrained by certain thermodynamic characteristics, thus they typically have an efficiency that ranges from 25-30%<sup>2</sup>.

In fact, currently, in Essex County, NJ, the waste management company Covanta currently operates a WTE plant. This plant “combusts 2,800 tons per day of municipal solid waste and generates approximately 65 megawatts of electricity. The plant also recovers ferrous (steel) and non-ferrous (aluminum, brass, copper, etc.) materials for recycling”<sup>3</sup>.

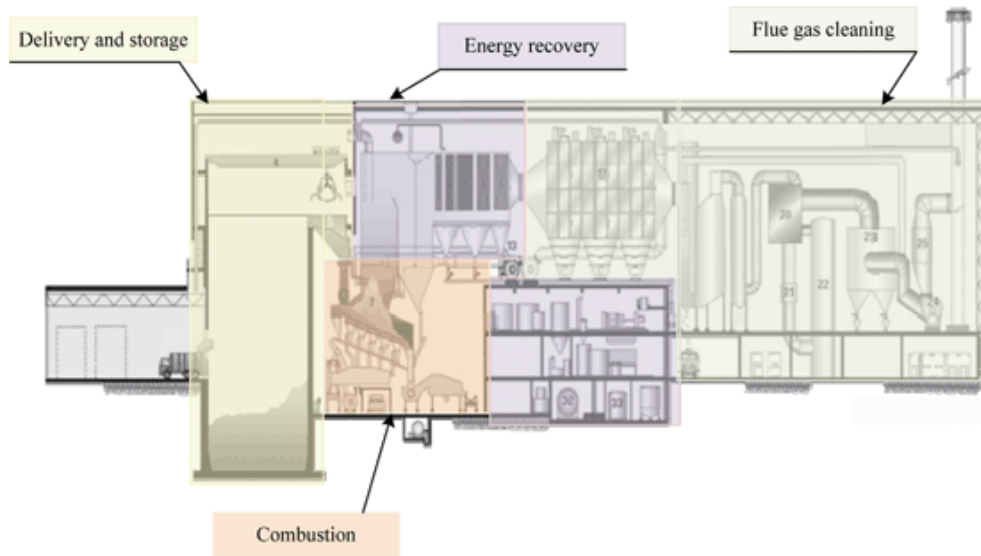
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<sup>1</sup> Branchini, Lisa. “Introduction.” In *Waste-to-Energy: Advanced Cycles and New Design Concepts for Efficient Power Plants*, 3–5. Cham: Springer International Publishing, 2015. [https://doi.org/10.1007/978-3-319-13608-0\\_1](https://doi.org/10.1007/978-3-319-13608-0_1).

<sup>2</sup> Branchini, Lisa. “Introduction.” In *Waste-to-Energy: Advanced Cycles and New Design Concepts for Efficient Power Plants*, 3–5. Cham: Springer International Publishing, 2015. [https://doi.org/10.1007/978-3-319-13608-0\\_1](https://doi.org/10.1007/978-3-319-13608-0_1).

<sup>3</sup> “Covanta.” *Covanta Essex* (blog). Accessed December 13, 2018. <https://www.covanta.com/Our-Facilities/Covanta-Essex>.

A schematic of a simplified WTE plant can be seen here<sup>4</sup>:



As mentioned previously, there are many benefits to implementing WTE plants. Not only is there waste reduction and energy production, but there are recoverable residues as well.

#### Waste-to-Energy Residues:

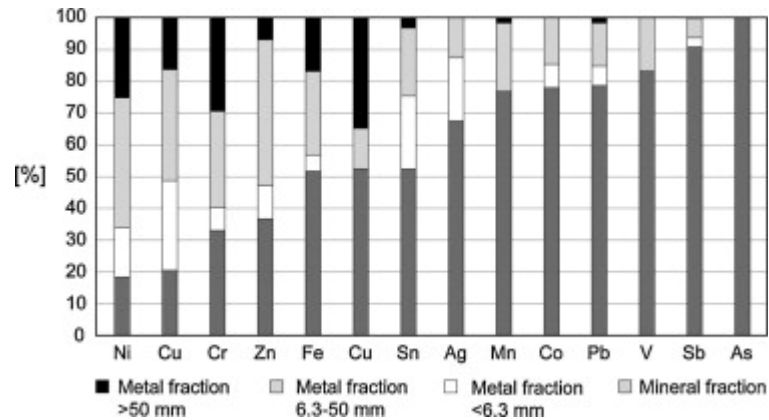
The residues from WTE plants are of particular interest. These residues are the materials left after the WTE process has been completed, thus they are a waste product of the plant. These residues are important, firstly, because they may be hazardous and secondly because they may be recovered as a usable product- adding even more value to the WTE process. “During incineration, atmophilic metals are highly enriched in APC residues, and lithophilic substances accumulate in bottom ash. Incinerators can act as concentrators for many substances, which is a prerequisite for successful material recovery. Hence, attempts for upgrading bottom ash are manifold”<sup>5</sup>.

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<sup>4</sup> Branchini, Lisa. “Waste-to-Energy.” In *Waste-to-Energy: Advanced Cycles and New Design Concepts for Efficient Power Plants*, 19–36. Cham: Springer International Publishing, 2015. [https://doi.org/10.1007/978-3-319-13608-0\\_3](https://doi.org/10.1007/978-3-319-13608-0_3).

<sup>5</sup> Paul Brunner, and Helmut Rechberger. “Waste to Energy – Key Element for Sustainable Waste Management” 37 (March 14, 2014): 3–12.

The first and most evident residues subject to recovery are valuable metals such as iron, stainless steel, aluminum, copper, and brass, which are all concentrated in the bottom ash from WTE plants<sup>6</sup>. Below is figure depicting different selected metals in MSW bottom ash, after magnetic separation of iron<sup>7</sup>.



However, the focus of this research paper is regarding a different part of WTE residues. There is a current aspect of use for bottom ash in which further conservation could be achieved. Research conducted by Yixi Tian, Earth and Environmental Ph.D. student at Columbia University, has explored the structural viability of using WTE ash- residues as an aggregate substitute for concrete production. This is a great opportunity for both economic and environmental purposes. A waste derivative being used for the production of a different material is the epitome of upcycling. This research report investigates the viability of this substituted aggregate, via the leachability of the material.

## (Literature Review)

### Leachability:

<sup>6</sup> Paul Brunner, and Helmut Rechberger. “Waste to Energy – Key Element for Sustainable Waste Management” 37 (March 14, 2014): 3–12.

<sup>7</sup> Paul Brunner, and Helmut Rechberger. “Waste to Energy – Key Element for Sustainable Waste Management” 37 (March 14, 2014): 3–12.

This research was conducted in order to determine the leachability of concrete ash-shapes. Leachability an extremely important aspect of determining the viability of a technology. There can be significant environmental impacts if leachability is of a certain level. Bottom ash contains heavy metals and other hazardous components which could contaminate soil and water in the surrounding environment. Within the environment, the definition of leaching is “the transfer of chemical species or compounds from a solid material into contacting water”<sup>8</sup>. Rainwater, groundwater and surface water all play roles in environmental leaching; additionally, “the constituents that leach into the water have the potential to contaminate adjacent soils or disperse into groundwater or surface water bodies”<sup>9</sup>. The rate at which leaching occurs depends upon the material itself and its physical and chemical properties.

#### Antimony Leaching from Uncarbonated and Carbonated MSWI Bottom Ash:<sup>10</sup>

In *Antimony Leaching from Uncarbonated and Carbonated MSWI Bottom Ash*, Cornelis, Van Gervin and Vandecasteele explore the viability of recycling MSWI through exploring the leachability of antimony (Sb) from the waste products. Thus, testing was completed for Sb leaching in a wide range of both pH and extent of carbonation, in order to determine the full leachability.

Sb was found to almost reach equilibrium with calcium antimonate ( $\text{Ca}[\text{Sb}(\text{OH})_6]_2$ ) at acid and neutral pH, therefore the experiments were designed to test adsorption with synthetic calcite ( $\text{CaCO}_3$ ), ettringite ( $\text{Ca}_6\text{Al}_2(\text{SO}_4)_3(\text{OH})_{12}\cdot 26\text{H}_2\text{O}$ ), gypsum ( $\text{CaSO}_4\cdot 2\text{H}_2\text{O}$ ), and

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<sup>8</sup> Kosson, David et al. “Leaching Environmental Assessment Framework (LEAF) How-To Guide.” EPA, October 2017.

<sup>9</sup> Kosson, David et al. “Leaching Environmental Assessment Framework (LEAF) How-To Guide.” EPA, October 2017.

<sup>10</sup> Cornelis, Geert, Tom Van Gerven, and Carlo Vandecasteele “Antimony Leaching from Uncarbonated and Carbonated MSWI Bottom Ash.” *Journal of Hazardous Materials*, May 30, 2006.

portlandite ( $\text{Ca}(\text{OH})_2$ ). Additionally, adsorption modeling with hydrous ferric oxides (HFO) and amorphous aluminum minerals (AAM) was conducted to investigate which minerals decrease Sb leaching below equilibrium with calcium antimonate.

The results from the experiments are as follows: at high pH values ( $> 12$ ), calcium antimonate comes into solution due to portlandite formation, however, this increase in Sb leaching is counteracted by the strong interaction of Sb with portlandite and ettringite. In fact, it was found that Ettringite is an important host mineral for Sb at the natural pH of mildly weathered bottom ash (11.8) because a minimum in leaching is observed.

“When pH is decreased ( $< 10.5$ ), Ettringite dissolves and Sb comes into solution, approaching equilibrium with calcium antimonate near pH 9. When pH is decreased below 10.5, ettringite dissolves and Sb comes into solution, approaching equilibrium with calcium antimonate near pH 9. Gypsum showed no affinity for Sb. The interaction of calcite with Sb was not clear. Adsorption modeling suggested that HFO, rather than AAM, control Sb leaching when  $\text{pH} < 9$ . During carbonation, Sb leaching first increased, most likely due to the dissolution of ettringite. Then, Sb leaching decreased, since the pH became low enough to allow sorption by HFO.”<sup>11</sup>

The leaching tests conducted for the metals was done using EN- 12457-2 test where “10 g of dry material was agitated in 100 ml distilled water for 24 h. After filtration over a 0.45m filter, the metals in the filtrate were measured with ICP-MS”, different pH standards were created using KOH and HNO<sub>3</sub> in order to test the pH dependency of metal leaching.

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<sup>11</sup> Cornelis, Geert, Tom Van Gerven, and Carlo Vandecasteele “Antimony Leaching from Uncarbonated and Carbonated MSWI Bottom Ash.” *Journal of Hazardous Materials*, May 30, 2006.

Heavy Metals Leaching in Bottom Ash and Fly Ash Fractions from Industrial-Scale BFB-Boiler for Environmental Risks Assessment:

*In Heavy Metals Leaching in Bottom Ash and Fly Ash Fractions from Industrial-Scale BFB-Boiler for Environmental Risks Assessment*, Pokio, Watkins, Nurmesniemi, and Dahl explore the leaching of heavy metals from fly-ash and bottom-ash residues from the co-combustion of wood residues and peat.

The mineral composition of the ash was determined by X-ray diffractograms using Cu K $\alpha$  radiation. Next, “the pH of the ashes was determined using a pH/EC analyzer equipped with a Thermo Orion Sure Flow pH electrode” and finally, the moisture content was “determined according to European standard SFS-EN 12048”<sup>12</sup>.

Next, the total metal concentrations were determined. “the dried sample was digested with a mixture of HCl (3 mL) and HNO<sub>3</sub> (9 mL) in a CEM Mars 5 microprocessor-controlled microwave oven” and then cooled and “transferred to 100 mL volumetric flasks and the solutions diluted to volume with ultrapure water”<sup>13</sup>. These solutions were then put in ICP-OES machine in order to determine the concentrations of P, Ca, Na, K, Mg, and Zn. The concentration of Hg “with a Perkin Elmer Analyst 700 cold-vapour AAS equipped with a Perkin Elmer FIAS 400 and AS 90 plus auto-sampler”<sup>14</sup>. Then, “the solid-phase speciations of heavy metals in the

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<sup>12</sup> Poykio, Risto, Mikko Makela, Gary Watkins, Hannu Nurmesniemi, and Olli Dahl. “Heavy Metals Leaching in Bottom Ash and Fly Ash Fractions from Industrial-Scale BFB-Boiler for Environmental Risks Assessment,” October 12, 2015.

<sup>13</sup> Poykio, Risto, Mikko Makela, Gary Watkins, Hannu Nurmesniemi, and Olli Dahl. “Heavy Metals Leaching in Bottom Ash and Fly Ash Fractions from Industrial-Scale BFB-Boiler for Environmental Risks Assessment,” October 12, 2015.

<sup>14</sup> Poykio, Risto, Mikko Makela, Gary Watkins, Hannu Nurmesniemi, and Olli Dahl. “Heavy Metals Leaching in Bottom Ash and Fly Ash Fractions from Industrial-Scale BFB-Boiler for Environmental Risks Assessment,” October 12, 2015.



bottom ash and fly ash fractions were carried out according to [the] three-step sequential extraction BCR scheme”<sup>15</sup>.

The final results of “the leaching studies indicate that the heavy metals in the bottom ash and fly ash are bound to different fractions with different strengths”. Additionally, “heavy metals in ashes posed different levels of environmental contamination risk”<sup>16</sup>; in bottom ash, As in the bottom ash posed a very high risk and Cd posed a high risk. Also, in the fly As, Cd and Se posed high risks.

**LEAF Method:**

As described earlier, chemicals of potential concern (CPOCs) can leach from solid materials into their surrounding environment. This can lead to potential environmental concerns; thus, a framework was developed in order to determine the extent and rate at which a CPOC leaches into its surrounding environment. It is imperative to conduct laboratory leaching tests because they provide “provide the basis for estimating which constituents will leach, the rate at which they will leach, and the factors that control leaching” along with the ability “to develop quantitative description of the leaching behavior of a material” from the data obtained.

Leaching is a process that is driven by the principles of mass transport, in which the movement of the constituents from a solid phase to contacting water across gradients. Within environmental conditions, it can be estimated as concentration gradients, due to low ionic strength; thus, leaching in the environment is defined as the result of concentration gradients between the constituent and the water. Hence, as time progresses, the gradient slows down, and

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<sup>15</sup> Poykio, Risto, Mikko Makela, Gary Watkins, Hannu Nurmesniemi, and Olli Dahl. “Heavy Metals Leaching in Bottom Ash and Fly Ash Fractions from Industrial-Scale BFB-Boiler for Environmental Risks Assessment,” October 12, 2015.

<sup>16</sup> Poykio, Risto, Mikko Makela, Gary Watkins, Hannu Nurmesniemi, and Olli Dahl. “Heavy Metals Leaching in Bottom Ash and Fly Ash Fractions from Industrial-Scale BFB-Boiler for Environmental Risks Assessment,” October 12, 2015.

eventually reaches chemical equilibrium. However, “due to the slow dissolution of some minerals. and other time-dependent processes, chemical equilibrium may be achieved for some constituents, but not for all constituents, within a defined duration (such as a short assessment interval or the duration of some laboratory tests)”<sup>17</sup>. When and if chemical equilibrium is achieved, leaching then becomes limited by either the available content limit or the solubility limit.

Available content limit refers to the instance when the solid phase of the leachable constituent becomes depleted such that the transfer from solid to liquid stops. Solubility limit refers to the constraint of the chemical parameters of the liquid phase in that they cannot hold any more dissolved solids- the liquid is fully saturated.

#### **Methods:**

In order to determine the leachability of the samples, EPA Method 1313 “Liquid-Solid Partitioning as a Function of Extract pH Using a Parallel Batch Extraction Procedure” was followed. There are other methods in which leachability can be determined, including EPA Methods 1314, 1315 and 1316, as part of the LEAF method.

EPA Method 1313 is a method that was

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<sup>17</sup> Kosson, David et al. “Leaching Environmental Assessment Framework (LEAF) How-To Guide.” EPA, October 2017.

“designed to provide aqueous extracts representing the liquid-solid partitioning (LSP) curve as a function of pH for inorganic constituents (e.g., metals and radionuclides), semi-volatile organic constituents (e.g., polycyclic aromatic hydrocarbons (PAHs)) and non-volatile organic constituents (e.g., dissolved organic carbon) in solid materials. The LSP curve is evaluated as a function of final extract pH at a liquid-to-solid ratio (L/S) of 10 mL extractant/g dry sample (g-dry) and conditions that approach liquid-solid chemical equilibrium. This method also yields the acid/base titration and buffering capacity of the tested material at an L/S of 10 mL extractant/g-dry sample. The analysis of extracts for dissolved organic carbon and the solid phase for total organic carbon allows for the evaluation of the impact of organic carbon release and the influence of dissolved organic carbon on the LSP of inorganic constituents. This method is intended to

Table 3-1. Comparison of Test Parameters for LEAF Leaching Methods

Test Variable	Method 1313	Method 1314	Method 1315	Method 1316
Test Type	Equilibrium; pH-dependent	Equilibrium; percolation	Mass transfer	Equilibrium; L/S-dependent
Test Description	Parallel batch extractions	Column test in up-flow mode	Tank test with periodic eluant renewal	Parallel batch extractions
Sample Type and Dimension	Granular particle size of 85% by mass less than 0.3, 2.0 or 5.0 mm	Granular particle size of 85% by mass less than 2 mm with 100% less than 5 mm	<i>Monolith</i> : cylinder or cube; 40-mm minimum dimension <i>Compacted granular</i> : cylinder with 40 mm minimum height	Granular particle size of 85% by mass less than 0.3, 2.0 or 5.0 mm
Test, Extraction or Interval Duration	Extractions for 24, 48 or 72 hours based on maximum particle size	Continuous elution to L/S 10 mL/g-dry Estimated test time of 13 days based on constant flowrate of 0.75 L/S per day	Intervals of 2, 23, 23 hours, 5, 7, 14, 14, 7 and 14 days Cumulative leaching time of 63 days	Extractions for 24, 48 or 72 hours based on maximum particle size
Eluant Composition	Reagent water with additions of HNO <sub>3</sub> or NaOH	Reagent water or 1 mM CaCl <sub>2</sub>	Reagent water	Reagent water
pH Range	2 to 13 at specified targets	As controlled by material being tested	As controlled by material being tested	As controlled by material being tested
Amount of Solid	Minimum 20 g-dry per extract; Approx. 400 g-dry each for pre-test and test replicate (collect 1 kg for first test; 500 g for each replicate)	Minimum 300 g; 600–700 g per column (collect 1 kg per test run)	<i>Monolith</i> : as specified <i>Compacted granular</i> : 500–750 g per test run + 5 pre-test samples (collect 4 kg for first test, 1 kg for each replicate)	Minimum 20 g-dry per extract; 20 to 400 g-dry each extract (collect 1 kg per test run)
Eluant Volume	L/S of 10 mL/g-dry	Eluates collected through cumulative L/S 10 mL/g-dry	Liquid-surface area ratio of 9 mL/cm <sup>2</sup>	L/S of 10, 5.0, 2.0, 1.0, and 0.5 mL/g-dry
Number of Analytical Solutions per Test	9 extractions (10 if natural pH is outside target range)	9 eluate fractions	9 interval solutions	5 extractions

be used as part of an environmental leaching assessment for the evaluation of disposal, beneficial use, treatment effectiveness, and site remediation options”.

The figure above describes the different variables in each the methods used in LEAF.

Specifically, Method 1313 consists of 10 parallel batch extractions of a solid material at various endpoint target pH values and at an L/S of 10 mL/g-dry. In this experiment, 20 mL and 2 g were used to suffice the L/S at 10 mL/g-dry. In order to achieve equilibrium conditions faster and reduce testing time, the particle size was reduced to <300 um. The acid/base neutralization capacity (ANC/BAC) can be plotted as a function of leachate pH. Additionally, the measured constituent concentrations can be plotted as a function of leachate pH. However, this information will be a next step in the future; the constituent concentrations can be determined through methods such as ICP.

The sample that was used in this research was Fine Bottom Ash from Hempstead, NY (HEM) Covanta Energy Facility, a waste management company.

1. Particle Size Reduction:

- a. First, the sample underwent particle size reduction. The original particle size was <2 mm. This was reduced to <300 um through grinding by hand with mortar and pestle. The reduced particles were then sieved through a 300 um sieve in order to ensure proper size. Method 1313 states “the fraction retained by the sieve should be recycled for further particle size reduction until at least 85% of the initial mass has been reduced below the designated maximum particle size”. Thus at least 85% of the initial mass was reduced.

2. Acid and Base Solution:

- a. Acid (2N HNO<sub>3</sub>) and base (2N KOH) solutions were created.
- b. In order to produce 2N HNO<sub>3</sub> solution, pure 75 mL HNO<sub>3</sub> was mixed with 25 mL H<sub>2</sub>O to produce 100 mL 2N HNO<sub>3</sub> solution.
- c. In order to produce 2N KOH solution, 3.56 grams of pure solid KOH was weighed and added to 100 mL H<sub>2</sub>O and mixed until dissolved thoroughly in order to produce 100 mL 2N KOH solution.

3. pH Solutions:

- a. 12 specific pH solutions were created. Three in each pH category.
- b. 3 solutions with pH 1 were made (A, B, C).
  - i. First, the pH meter was calibrated
  - ii. Next, in a 600 mL beaker, the pH of 200 mL of deionized water was taken using the bench-top pH meter.
  - iii. The initial pH was 6.39. This was adjusted to achieve a pH of 1 by adding 5.075 mL of 2N HNO<sub>3</sub> solution.
- c. 3 solutions with pH 4 were made (A, B, C).
  - i. First, the pH meter was calibrated
  - ii. Next, in a 600 mL beaker, the pH of 500 mL of deionized water was taken using the bench-top pH meter.
  - iii. The initial pH was 6.46. This was adjusted to achieve a pH of 4 by adding .035 mL of 2N HNO<sub>3</sub> solution.
- d. 3 solutions with pH 7 were made (A, B, C) following the three steps above.
  - i. The initial pH was 6.46. This was adjusted to achieve a pH of 7 by adding .015 mL of 2N KOH solution.

- e. 3 solutions with pH 10 were made (A, B, C) following the three steps above.
  - i. The initial pH was 5.83. This was adjusted to achieve a pH of 10 by adding .005 mL of 2N KOH solution.
- f. Finally, 2 grams of HEM Fine Bottom Ash were added, at approximately the same time, to the 12 solutions.
  - i.

	HEM Added (g)
1A	1.999
1B	1.999
1C	2.001
4A	2.000
4B	2.000
4C	1.999
7A	2.001
7B	2.000
7C	2.001
10A	2.001
10B	2.001
10C	2.001

4. Rotator:

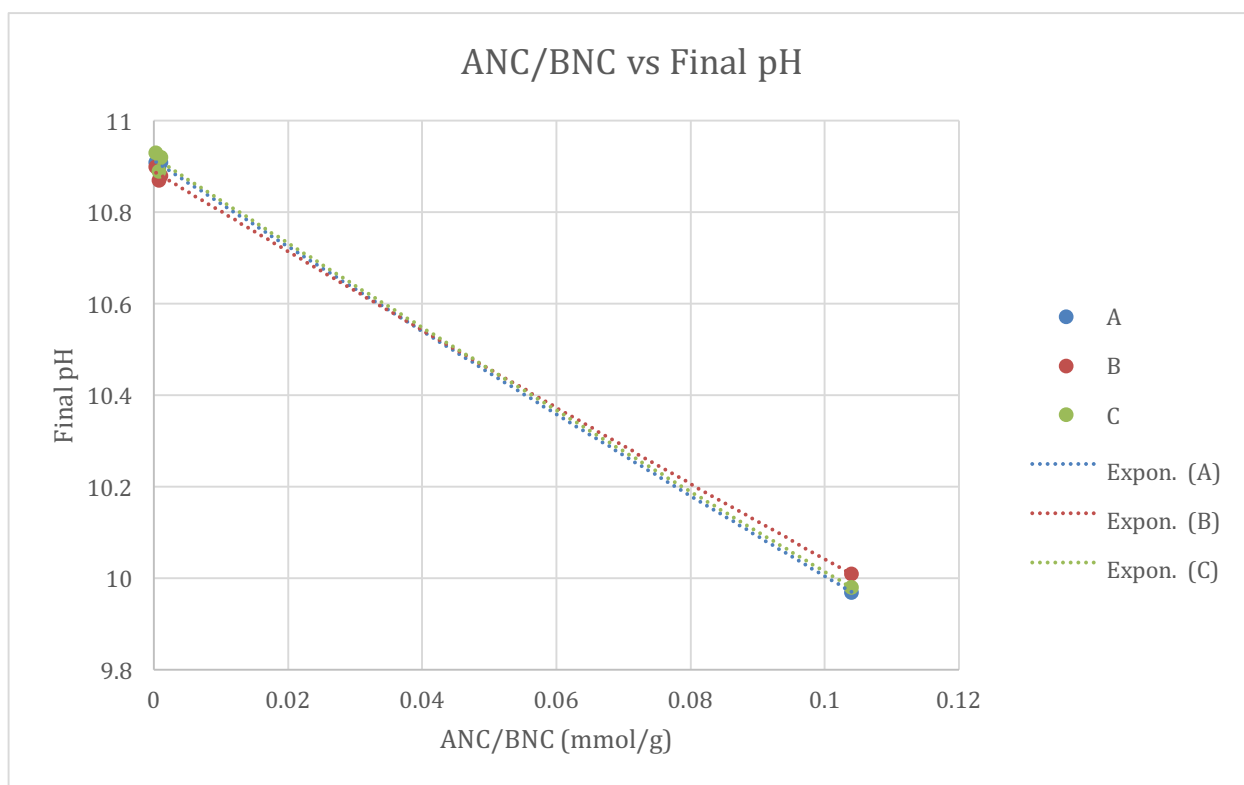
- a. The 12 solutions with HEM Fine Bottom Ash were placed in a rotator for 24 and 48 hours at 28 rpm.
- b. After 24 and 48 hours, the solutions were removed and the final pH value of each solution was recorded.

**Data:**

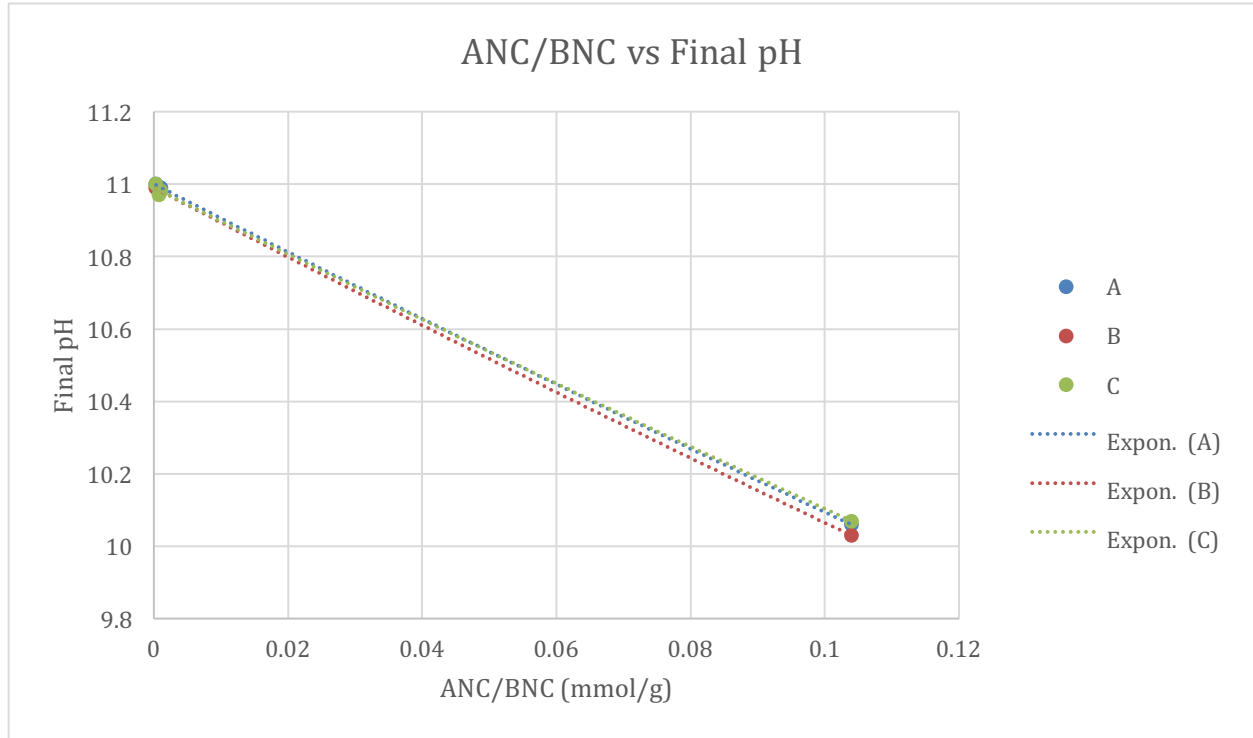
	Initial Volume (mL)	Initial pH	HNO3 Added (mL)	KOH Added (mL)	Solution pH	HEM Added (g)	Final pH (24 hrs)	Final pH (48 hrs)
A	200	6.39	5.075		1.02	1.999	9.97	10.06
B	200	6.39	5.075		1.02	1.999	10.01	10.03
C	200	6.39	5.075		1.02	2.001	9.98	10.07
A	500	6.46	0.035		4.03	2.000	10.90	10.99
B	500	6.46	0.035		4.03	2.000	10.87	10.98
C	500	6.46	0.035		4.03	1.999	10.89	10.97
A	500	5.83		0.015	7.02	2.001	10.91	11.00
B	500	5.83		0.015	7.02	2.000	10.90	10.99
C	500	5.83		0.015	7.02	2.001	10.93	11.00
A	500	5.83		0.05	9.98	2.001	10.91	10.99
B	500	5.83		0.05	9.98	2.001	10.88	10.98
C	500	5.83		0.05	9.98	2.001	10.92	10.98

	HNO3/KOH Added (mL)	HNO3/KOH Added (mmol/g)	Final pH (24 hrs)
1A	5.075	0.103995902	9.97
4A	0.035	0.000717213	10.90
7A	0.015	0.000307377	10.91
10A	0.05	0.00102459	10.91
1B	5.075	0.103995902	10.01
4B	0.035	0.000717213	10.87
7B	0.015	0.000307377	10.90
10B	0.05	0.00102459	10.88
1C	5.075	0.103995902	9.98
4C	0.035	0.000717213	10.89
7C	0.015	0.000307377	10.93
10C	0.05	0.00102459	10.92

	HNO3/KOH Added (mL)	HNO3/KOH Added (mmol/g)	Final pH (48 hrs)
1A	5.075	0.103995902	10.06
4A	0.035	0.000717213	10.99
7A	0.015	0.000307377	11.00
10A	0.05	0.00102459	10.99
1B	5.075	0.103995902	10.03
4B	0.035	0.000717213	10.98
7B	0.015	0.000307377	10.99
10B	0.05	0.00102459	10.98
1C	5.075	0.103995902	10.07
4C	0.035	0.000717213	10.97
7C	0.015	0.000307377	11.00
10C	0.05	0.00102459	10.98







Using the conversion factor of 1 mole per 22.4 liters, the ml of acid and base added was converted into mmol. This was then divided by the amount of solid used, 2 grams.

The data shows that as more acid or base is added, the final pH is lowered. When 0.1039 mmol/g was added, the final resulting pH, after 48 hours was 9.97, in comparison to when 0.00071 mol/g was added, the final pH was 10.9. This can be explained by the decomposition of  $\text{CaCO}_3$  to  $\text{CO}_2$  and  $\text{CaO}$ , which works to increase the pH. Additionally, changes between the final pH's from 24 hours to 48 hours, were small; hence equilibrium was reached before the 48 hour mark.

### **Key findings/ main conclusions**

The resulting Acid Neutralization Capacity (ANC) graph is a function of leachate pH and the acid added (mmol/kg of acid) to achieve the targeted pH value. The trend that was found was that as more acid or base is added, the final pH is lowered, which can be explained from the

decomposition of  $\text{CaCO}_3$  to  $\text{CO}_2$  and  $\text{CaO}$ . Additionally, there were little changes between final pH's from the 24-hour rotation and 48-hour rotation, indicating that the equilibrium of the solution is achieved sooner than the time suggested by the standard.

### Next Steps (ICP-OES):

By definition, Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) is essentially the measurement of light that is emitted by the elements in a sample introduced into an ICP source. The resulting emission intensities are compared to the intensities of standards of known concentration to obtain the elemental concentrations in the unknown sample.<sup>18</sup> There are two different ways one can view the light emitted from: radially and axially. Viewing it radially

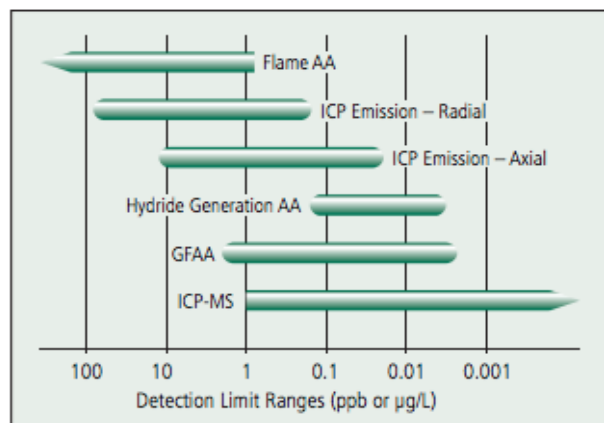


Figure 6. Typical detection limit ranges for the major atomic spectroscopy techniques.

provides the highest upper linear ranges whereas viewing axially, “continuum background from the ICP itself is reduced and the sample path is maximized”. Thus, viewing axially is more effective in providing detection limits.

<sup>18cc</sup>Atomic Spectroscopy - A Guide to Selecting the Appropriate Technique and System.” PerkinElmer, n.d. Accessed November 20, 2018.

Detection limits for ICP-OES for the prevalent elements are the following: Ag (.6 ug/L), Al (1 ug/L), Ba (.03 ug/L), Ca (.05 ug/L), Cd (.1 ug/L), Cr (.2 ug/L), Cu (.4 ug/L), Fe (.1 ug/L), Mg (.04 ug/L), Mn (.1 ug/L), Na (.5 ug/L), Ni (.5 ug/L), Pb (1 ug/L), Sr (.05 ug/L), Zn (.2 ug/L).

In order to choose the proper wavelengths for elements, it depends upon the purpose and solution in which one is testing; some require more sensitive wavelengths, while others require wider ranges. Additionally, interferences must be considered as there are several different types of interferences in ICP-OES. The “severity is dependent on the analyte wavelength, other elements present in the sample, and the sample matrix itself”<sup>19</sup>.

The process of choosing the proper wavelengths begins firstly by choosing two or three wavelengths for each element of interest (both the analyte and any applicable elements within the standard). The “most sensitive wavelength for each element would be chosen, along with two wavelengths of slightly lower sensitivity”.

Typically, it is suggested, to test “a blank (calibration and method blanks, where applicable), a low-concentration calibration standard, a high-concentration calibration standard, a sample that represents each type of sample matrix to be analyzed” in order to determine which specific wavelength to use. From these tests, the data from the blank “provides an emission profile of the matrix in the absence of analytes” and the data from the “calibration standards provides profiles for the elements of interest at low and high concentrations”<sup>20</sup>.

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<sup>19</sup> Rury, Maura. “The Importance of Method Development for Trace-Element Analysis by Inductively Coupled Plasma–Optical Emission Spectroscopy” 31, no. 5 (May 1, 2016): 16–32.

<sup>20</sup> Rury, Maura. “The Importance of Method Development for Trace-Element Analysis by Inductively Coupled Plasma–Optical Emission Spectroscopy” 31, no. 5 (May 1, 2016): 16–32.

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## Appendix

### Log of Research:

Date	Description
9/6/18	Began gathering access's for laboratories. Completed laboratory safety tests etc.
9/12/18	Went to Lamont Laboratory (Palisades, NY) in order to use XRF machine to determine the chemical composition of samples. Ground samples at Lamont then used XRF.
9/20/18	Ground samples in Carleton lab in order to reduce particle size.
9/21/18	Used XRD machine at Columbia in order to determine the chemical composition of samples.
9/27/18	Ground samples in Carleton lab in order to reduce particle size. Used crusher machine.
10/2/18	Used grinder machine in order to reduce particle size. Grinder broke while in use.
10/3/18	Attempted to fix grinder machine.
10/4/18	Attempted to re-run and fix grinder machine.
10/10/18	Bought NOH, HNO <sub>3</sub> and other supplies needed to begin making solutions for leaching. Set up the pH meter in Carleton Laboratory.

10/11/18	Began making acid and base solutions for leaching testing.
10/12/18	Continued making solutions for leaching testing.
10/25/18	Continued making solutions for leaching testing.
10/26/18	Finished making solutions for leaching testing.
10/30/18	Moved equipment from Carleton laboratory to 9th-floor laboratory.
11/13/18	Worked in Carleton Laboratory in order to reduce the particle size of HEM Fine Bottom-Ash to <300 um for leaching testing.
11/14/18	Worked in 9th-floor Laboratory. Began creating solutions for leaching of pH 1, 4, 7, 10 using a pH meter
11/15/18	Worked in 9th-floor Laboratory. Continued creating solutions for leaching of pH 1, 4, 7, 10 using pH meter.
11/16/18	Completed creating solutions (40ml) of pH 1, 4, 7, 10 using pH meter.
12/7/18	Began remaking solutions. Used pipet instead of dropper to be able to keep track of volume of acid and base added.
12/10/18	Continued making solutions.
12/11/18	Finished making pH solutions (1, 4, 7, 10). Transferred 20 mL to rotator tubes. Added 2g HEM Bottom Ash (<300um). Began rotator (24 hours).
12/12/2018	Completed 24-hour rotation. Tested final pH of centrifuge tubes.
12/13/2018	Completed 48-hour rotation. Tested final pH of centrifuge tubes.

12/13-20/2018	Receive data, complete data analysis, finished term paper.
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