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Land Application Uses of Pressurized Fluidized-Bed Combustion (PFBC) Ash

Authors:

J.H. Beeghly
W.A. Dick
W. Wolfe

Contractor:

Dravo Lime Company
3600 One Oliver Plaza
Pittsburgh, PA 15222

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CONTRACT INFORMATION

Cooperative Agreement #	DE-FC21-91MC28060
Contractor	Dravo Lime Company 3600 One Oliver Plaza Pittsburgh, PA 15222 412-566-5500
Contractor Project Manager	Joel H. Beeghly
Principal Investigators	Dr. Warren A. Dick, Ohio State University, Dept. of Agronomy Dr. William Wolfe, Ohio State University, Dept. of Engineering
METC Project Manager	Jerry Harness
Period of Performance	December, 1990 to December 1994

OBJECTIVES

Dry alkaline flue gas desulfurization by-products (dry lime and limestone FGD scrubber ashes) including the American Electric Power (AEP) Tidd PFBC bed and cyclone ash, are being evaluated for beneficial uses via land application for agriculture, mine reclamation, and soil stabilization in a 5 year study that began December, 1990. A 1989 Battelle Memorial Institute report had recommended that the highest priority in stimulating reuse of FGD by-products was the sponsoring of in-field research of coal combustion products generated from high sulfur midwestern coals to (a) better understand and quantify the leach rate, fate and transport of sulfates and trace metals and (b) demonstrate the level of protection necessary to build public acceptance of land-based reuses (1) .

The specific objectives of the demonstration project are as follows:

1. To characterize the material generated from dry FGD processes,
2. To demonstrate the utilization of dry FGD by-products as an soil amendment material on agricultural lands and on abandoned and active surface coal mines in Ohio,
3. To demonstrate the use of dry FGD by-product as an engineering material for soil stabilization,
4. To determine the quantities of dry FGD material than can be utilized in each of these applications,
5. To determine the environmental and economic impact of utilizing the material, and

6. To calibrate environmental, engineering, and economic models that can be used to determine the applicability and costs of utilizing these processes at other sites.

BACKGROUND INFORMATION

For this \$4.5 million research project, there are seven financial sponsors, mainly the Ohio Coal Development Office (50%) and the U.S. Dept. of Energy (25%). The others are Dravo Lime Company, the Electric Research Institute, Ohio Edison, American Electric Power and the Ohio State University.

The Dravo Lime Company is the prime contractor, and the technical work is being performed by the Ohio State University in cooperation with the United States Geological Survey. From its beginning in early 1990, the project has been guided by a steering committee with members from the funding organizations, industry, state regulatory agencies, and a citizens group. The project team has worked closely with the Ohio EPA and Ohio DNR Division of Reclamation. Four dry FGD processes were investigated: Lime Injected Multistage Burner (LIMB), duct injection, lime spray dryer, and fluid bed combustion. A total of 55 samples from 15 sources including the PFBC by-product materials were sampled for characterization, bench and field-scale studies, for utilization applications considered in this project. At Tidd the four by-product materials available were: 1) dry cyclone ash from silo, 2) dry bed ash from the silo, 3) conditioned ash - freshly prepared, and 4) conditioned ash, both cyclone and bed separated or blended at the landfill/stockpile yard.

Two recently presented papers give a broad overview of the overall project (2, 3).

PROJECT DESCRIPTION

The pressurized fluidized bed combustion, process at the American Electric Power Tidd Plant, at Brilliant, OH is a large prototype facility. It is the first full-scale demonstration of the pressurized fluidized bed combustion (PFBC) process in the U.S. The Babcock & Wilcox designed unit has a gross electrical output of 74MW. Pittsburgh #8 coal (3.4% sulfur) is burned with dolomite as the sorbent at a calcium to sulfur molar ratio of 1.6:1. Sulfur removal efficiencies of 90% or better are anticipated along with NOX emissions that meet federal guidelines. Three FGD by-products, totaling approximately 22 tons/h, are produced in the PFBC process: bed ash, cyclone ash, and precipitator ash.

By-Product Characterization - In Phase 1 a large amount of chemical, mineralogical, physical, and engineering data have been collected on 55 samples of dry FGD by-products and are presented in detail in the Phase 1 Final Report (4). The exact composition of dry FGD ash is determined by the injection technology, the coal burned, and the type of sorbent; but, in general, the FGD materials include reaction by-products (calcium sulfate, calcium sulfite, unreacted sorbent (lime, hydrated lime, dolomite, magnesium oxide, calcium carbonate) and fly ash (5).

As part of Phase 2, most of these components have been evaluated individually as soil amendments for use in agriculture and mine land reclamation. Calcium sulfate and calcium sulfite minerals are potential sources of Ca and S for plant nutrition. Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) is widely used to improve the physical properties of alkali and heavy clay soils. Evidence also exists to indicate that gypsum can mitigate the toxicity and acidity of exchangeable aluminum to plant growth (6). Tidd material, because of the higher combustion temperature contains no calcium sulfite, CaSO_3 . This is important because possible but short term detrimental effects have been reported and are being investigated in this study.

Calcium and magnesium carbonates (CaCO_3 , $\text{CaMg}(\text{CO}_3)_2$), and calcium oxide (CaO), and calcium hydroxide ($\text{Ca}(\text{OH})_2$) are, of course, effective neutralizing agents and are commonly applied as alkaline amendments to acid soils and spoils. The FGD by-products have calcium carbonate equivalents (CCE) ranging from 25 to 70% as CaCO_3 (Table 4). Except for the PFBC bed ash material, the dry FGD by-products also have relatively high surface areas (10.2 M^2/g) and mostly (>99%) pass a 100 mesh sieve (i.e. like fly ash). The spreadability of these potential aglime materials with or without sufficient moisture added to control fugitive dust is being evaluated. Fly ash contents range from 10 to 32% in the selected samples (Table 3). Numerous studies have been conducted to determine the value of fly ash as a soil amendment. Coal fly ash added in large quantities can modify (and usually improve) the particle size distribution of spoil materials associated with abandoned mine lands. In the case of very coarse or very fine textured spoils, applications of fly ash may result in the formation of a medium textured "soil". With the exception of nitrogen, fly ash contains many of the elements essential for plant growth. Plant deficiencies of S, B, Mo, Zn, P, Se, Cu, K may be corrected by fly ash amendments.

Leachate Water Quality - Leachate quality was evaluated on samples from most of the 15 sources using water as per standard ASTM extraction procedure and using acid as per USEPA TCLP Method 1311 procedures. The solubilities of all elements of concern with regard to classification as potential hazardous wastes were very low. Major ions in the leachate were calcium and sulfate; pH values in the water leachate generally exceeded 10.0.

Toxic metal concentrations approached primary drinking water quality standards and were

therefore far below the maximum criteria for classification as non-toxic fly ash according to Ohio EPA policy.

To evaluate the long-term solubilities of various chemical species, solutions have been collected after 1, 7, 21, 36, 56, 70, 84, and 112 days of equilibration with water. Analytical results will be processed using various computer specification codes. Strict QA/QC protocols normally required for USEPA leachate testing using ICP, AAS, and IC instrumentation are being followed.

Engineering Properties - The engineering properties most commonly needed to design a engineered fill or soil structure are strength at optimum moisture content, stress-strain relationship, compressibility, permeability and swelling potential. The appropriate ASTM standardized laboratory procedures were followed (2). The effect of time and moist-curing conditions on compressive strength and permeability was determined on the ash itself and soil-ash mixtures. The tendency to expand over time is termed its swelling potential. Swelling tests would determine potential impact of material use due to volume changes in a roadway base course or around culverts.

RESULTS

Phase 1 Characterization Test Results - The Tidd PFBC ash by-products are bed or bottom ash, cyclone ash, and precipitator ash (ESP). Even though the ESP ash is disposed into the cyclone ash silo, one sample was separately collected and analyzed. Reportedly, the ESP ash is only 2-3% of the total ash. It contains the highest concentration of toxic heavy metals. The volume of bed ash produced is about 40% of the total ash.

Table 1

Mineralogical Composition of Dry CCT By-Products (Wt. %) Tidd Plant (AEP)

Sample	CaSO ₄	CaMg(CO ₃) ₂	CaO	CaCO ₃	MgO	Fly Ash	Total
TID-FLB-01 (cyclone)	19	31		9	11	13	103
TID-FLB-02 (bed)	36		4	29	26	10	105
TID-FLB-03 (cyclone)	22	25		12	12	32	103
TID-FLB-04 (bed)	36		4	27	27	10	104
TID-FLB-05 (ESP)	46	17				40	103
TID-FLB-06 (cyclone)	22	17		13	18	40	110

Mineralogical composition of six separate samples of Tidd PFBC bed, cyclone, and electrostatic precipitator dust (ESP), seen in Table 1, show six basic components: anhydrous calcium sulfate (also called anhydrite) (CaSO₄) calcium magnesium carbonate (CaMg(CO₃)₂) (also called dolomite), calcium carbonate (CaCO₃), quicklime (CaO), magnesia (MgO), and fly ash (silica, iron oxide alumina). As compared to other Clean Coal Technology (CCT) dry FGD by-products, all the sulfur capture is formed as calcium sulfate, and there is no calcium sulfite (CaSO₃). On the other hand, it is unique in containing free magnesia (MgO) and dolomite (CaMg(CO₃)₂) but very little free or available quick lime (CaO) and no hydrated lime (Ca(OH)₂). In this pressurized system dolomite is the sorbent used. Due to high pressure, calcium carbonate CaCO₃ does not calcine but magnesium carbonate MgCO₃ does calcine to free magnesia (MgO).

The total elemental composition of PFBC cyclone #3 sample is compared in Table 2 with a LIMB ash and sewage sludge. The leachate water quality for ash sample 3 (cyclone) and 4 (bed) is seen in Table 3. Concentrations of the eight metals (Ag, As, Ba, Cd, Cr, Hg, Pb, and Se) regulated by the Resource Conservation and Recovery Act (RCRA) were below drinking water standards when measured by either the ASTM or TCLP leachate tests. Calcium (Ca+2) magnesium

Mg+2) sulfate (SO₄-2) and hydroxide (OH-) are the predominant leachate concentrations. Using the ASTM leaching procedure, the leachate pH of the cyclone ash was 11.4 and of the bed ash was 11.8. The small amount of free lime CaO in the bed ash causes a higher pH. Other CCT by-products with much more free CaO have pH's from 11.8 to 12.5. The levels of trace elements from coal ash that are sometimes of concern such as As, B, Mo, and Se are seen in Table 3. None are found at significant levels of concentration. Long term solubilities studies were initiated on sample 3 & 4. These results can be found in the Phase 1 report (4). Physical properties such as particle size distribution, specific surface area, particle density, and bulk density are seen in Table 4.

An important attribute of dry FGD by-products is the acid neutralizing potential from its alkalinity measured in terms of calcium carbonate (CaCO₃) equivalency (CCE). As seen in Table 5 the values for bed ash ranged from 60 to 75%, and 56 to 69% for cyclone ash. The low amount of free CaO in the bed ash versus none in the cyclone ash is reflected in the paste pH to be about 12 versus 10 for bed ash. Also, when mixed with a small amount of water, no heat of reaction (hydration) is generated.

Engineering Properties Test Results - The optimum dry density of the Tidd PFBC bed ash and fly ash blends and the unconfined compressive strengths are much higher than the other dry scrubber FGD by-products. They were approximately 1.8 g/cm³ or 112 lbs./cu. ft. These dry density values are at a optimum moisture content of 18-20%. More water than 18-20% is needed to be added because of the hydration chemical reactions. The unconfined compression strength data, some over 1,500 psi, is shown in Table 6.

The very fast cementitious reaction led to its use as a soil cement and a stabilized base material which are higher valued end uses than embankment or fill material. The permeability test results, seen in Table 7, show clay-like values at 7 and 28 day curing time in the range of 10-7 cm/sec. and lower. Swell test results (Table 8) for TIDD 3:4 blend @ 40% cyclone and 60% bed ash showed little expansion growth of only 1.3% in 140 days curing time. Some dry FGD by-products which contain free CaO exhibited much greater expansion. Details of engineering properties can be seen in the Phase 1 final report (4) and other project reports (9, 10).

Greenhouse Study on Abandoned Mineland Spoil - Substitution of alkaline FGD by-products for conventional liming materials in mine reclamation is a potential beneficial use for these by-products. The impact of land application of FGD by-products on water quality and plant growth must be assessed before such practices can be adopted. A field demonstration site has been chosen and construction of test control and watershed application plots will be in the late summer and fall of 1993.

In a greenhouse study at Ohio State University, by-products from the LIMB and Tidd PFBC processes were mixed at rates from 0 to 24% by weight with acid underclay and overburden spoil materials from an abandoned mine land site (AML)

near Dover, Ohio. Sewage sludge at 6% by weight (60 ton/acre) was also mixed with all treatments in order to add necessary organic matter. Additional treatments of spoil amended with 0 and 12% FGD without sewage sludge were also included. Pots were leached with deionized water to obtain 100 to 200 ml of leachate and planted with tall fescue. After 8 months, pots were again leached a second time with deionized water.

Averaged over all treatments, Tidd FGD by-products increased leachate pH, conductivity, Ca, Cl, Cu, F, K, Mg, Mo, Na, Ni, S, Se, and Sr; decreased Al, Ba, Fe, Li, Mn, P, Si, and Zn; and had no detectable effect on As, B, Be, Cd, Cr, Hg, Pb, and V when compared to untreated spoils. However, interactions between FGD by-products and spoil materials were observed with many elements so that leachate composition was a function of type of FGD by-product, type of soil, and application rate. Although leachate concentrations of many metals were increased by sewage sludge amendment, concentrations of potentially toxic metals remained low in all treatments.

The pH of the first leaching and last leaching after 8 months on the mine spoil and the effect on dissolved aluminum is seen in Figure 1 versus PFBC cyclone ash loading. Beginning at the lowest rate of 3% addition rate (30 ton per acre) the pH increased to the neutral pH range from the untreated pH of 3.7. The toxic aluminum dropped from about 45 mg/L Al⁺³ to zero. Table 9 shows these same leachate pH values and the spoil pH (paste pH @ 1:1) during the first and the final leaching.

From the same soil column, the final leachate electrical conductivity and major element composition are shown at the different treatment rates (Table 10). Likewise, the trace element composition is listed in Table 11.

The leaching of sulfate at the 24% rate was much greater than the LIMB ash due to the presence of soluble magnesium sulfate. This causes a potential for excessive salt loading greater than the LIMB product. Dolomite-based dry FGD by-products which do not contain lime (CaO) will not raise pH to excessive levels as the LIMB might at the high rate of application.

The average harvests or yields of six dried cuttings of fescue at each rate in triplicate and measured in grams per pot is listed in Table 12 for the Tidd PFBC cyclone treatments with and without sewage sludge. Good yield results were achieved at the lowest application rate of 30T per acre (3%) after the first cutting. Without sewage sludge and after the third cutting, the 12% rate had good yields. More details on greenhouse test results are referenced (6, 7). These results indicate PFBC by-products have potential for use as alkaline amendments in the reclamation of acid mine land sites and field-scale testing of these by-products is warranted.

Use As Ag-Lime Substitute - Tidd bed ash and cyclone by-products (CaCO₃ equivalents of 55 to 60%) and LIMB ash were separately applied to a Wooster silt loam at 0.25, 0.5, 1, and 2 times the liming requirement in greenhouse pot experiment at OSU. Pots were leached with de ionized water before planting fescue and alfalfa. Crops were harvested 6 times every 30 to 32 days with the first harvest occurring 94 days after planting. Following the final harvest pots were leached a second time.

Leachate composition was dependent on FGD type and rate, but in general showed increased pH, electrical conductivity, calcium, magnesium, and sulfate. Both the Tidd PFBC bed and cyclone products increased soil pH after the final leaching at 8 months from 4.6 to about 7.5 at the highest rate of 28 ton per acre as seen in Figure 2. The toxic soluble aluminum leachate concurrently dropped from 1.7 mg/L Al to near zero at the

lowest application rate of 3.5 ton per acre. Leachate data on other important elements such as manganese and boron are seen the OSU reference 8. Although, leachate concentrations of some trace metals were increased by FGD amendment, potentially toxic metals remained low at all rates.

Yields of both crops, tall fescue and alfalfa were increased by FGD amendment rates. As seen in Figure 3, the alfalfa yields in pots separately amended with PFBC cyclone ash and bed ash were increased at the recommended liming rate of 14 ton per acre in the first cutting from 8 to 11 grams per pot. However, by the time of the sixth cutting, the yields went from less than 2 in the control pot to about 8 grams per pot at the 14 ton per acre (1.4%) rate.

The Tidd PFBC by-products appear to be highly effective as alkaline amendments for acid agricultural soil. Each of the FGD by-products increased soil pH and sustained the increase through 9 months of crop growth. Solubility and plant uptake of Al and Mn, which are often toxic to plants grown in acid soils, were decreased by the FGD by-products. Potential adverse effects on plant growth such as high soluble salts, excessively high pH, and trace metal toxicity's were not observed, even at rates in excess of the liming requirement for the soil. Leachate composition did not indicate potential water quality problems resulting from use of these by-products at agricultural liming rates. Changes in soil pH and leachate pH and composition over time suggest these materials continue to react over a period of several weeks in soil, and indicates the need for application well in advance of planting. Reference 8 gives sufficient detail on the greenhouse results using dry FGD by-product for agricultural lime substitutes. A field study of FGD by-products involving three agricultural soils and production of corn and alfalfa has been initiated.

Stabilized Base Course For Cattle Feed Lot
Laboratory tests showed that Tidd PFBC cyclone

ash (sample #6) alone and the blend of cyclone ash and bed ash (1&2, 3&4) have adequate strength properties to be suitable replacement for select soil in engineered earth structures. To further illustrate these findings, an opportunity arose to show these materials could be useful in constructing a stabilized base and wearing surface for a large cattle feed lot being proposed in southeast Ohio utilizing reclaimed coal surface mine land. The pressure of heavy beef cattle weighing over 1,000 lbs and tractors used to clean the 3,500 sq ft pens along with weather changes would provide a tough test for determining base course durability. The Eastern Ohio Agricultural Research and Development Center (EORDC) operated by the Ohio State University and located near Caldwell, Ohio in Noble County, had three cattle pens that offered to test this beneficial use in the fall of 1992. At that time the pens had soil floors, often in a muddy condition. After scraping off the surface mud the first phase of the construction was to mix dry cyclone ash, i.e. soil cement, into the soft sub-soil at about 15-20% addition rate to stabilize about a 6 -8 inch layer. The work was performed by the EORDC Ohio Bull Test Station crew during the late November rainy season using a chisel plow and disk followed by compaction with a six-ton steel drum roller.

In the second phase of construction, a 12 inch layer of conditioned PFBC cyclone ash was placed as a stabilized base material to further reduce the permeability of the material that makes up the floor of the pens and to provide a strong wearing surface. A beneficial effect of a high strength, low permeability floor, the heavy beef cattle will no longer be wading in the mud, which consumes energy. Also, the rainwater that could seep into underground water supplies, can now be collected and treated. This project, was approved by the American Electric Power Ash Management and Environmental Departments with AEP donating the delivery of 15-20 truckloads of PFBC material. The Ohio EPA Water Pollution Control Office approved a construction permit exemption

based on beneficial use and FGD by-product non-toxicity. These test pens will provide information for a larger commercial size feedlot being proposed for Noble County.

In this second phase the construction was hindered by winter weather conditions and thus the placement and compaction of conditioned cyclone ash, obtained from the Tidd PFBC landfill, could not be done under optimum construction conditions. However, the performance of the #1 pen material under the load of cattle since January with only 6 inches of compacted conditioned ash was satisfactory throughout the winter and wet spring. The forced outage of the Tidd PFBC unit during the late winter and spring has delayed completing two of the three pens. Bed ash was compressed into the top wearing surface in order to make the surface less slippery when wet and provide toughness. The 28 day compressive strength of this blend attained 480 psi at an optimum moisture content of 30.5%. The cyclone ash alone was 360 psi at 28 days. To complete the two remaining pens, a mixture will be blended of bed ash and conditioned cyclone ash into a stockpile at the landfill about 1:2 by volume by front end loader. Storm water runoff samples have been taken during several events and analyzed for pH and metal content. No significant differences are found except for pH than can be attributed to the alkaline ash base course. The pH was slightly elevated to the 8.5 - 8.8 range on two different storm events. The control pH at another cattle pen was pH 6.5.

FUTURE WORK

1. The yield or harvest results of the field applications rates to three soils planted of a ag-lime substitute using a blend of 60% cyclone ash and 40% bed ash to three soils at OSU Research Farms to grow alfalfa and corn will be maintained. The final report of the Phase 2 OSU greenhouse study and laboratory study of soil - FGD mixture physical and leaching properties will be completed,

parts of which are reported herein. Measurements of plant uptake of trace elements from the greenhouse work will be reported.

2. The cattle feed lot base stabilization project will be completed using a blend of conditioned bed ash and cyclone ash mixed by heavy front end loading at the landfill/stockpile site. More experience will be gained on the material handling and placeability of this material both in preparing the blend and construction the stabilized base. The strength-gaining and permeability properties will continue to be monitored by coring the base. A site utilizing this PCFB ash blend as an embankment or fill in highway construction is being pursued.

REFERENCES

1. Battelle, 1989, Technical support for the Ohio Clean Coal Technology Program, Volumes One and Two. Final Report, Ohio Coal Development Office (OCDO) Columbus, OH.
2. J. H. Beeghly, W.A. Dick, J. Bigham "An Ohio Based Study on Land Application Uses of Dry FGD By-Products". Proceedings: Tenth Coal Ash Symposium of American Coal Ash Association, January, 1993.
3. W. E. Wolfe, T. H. Wic, J. H. Beeghly "Laboratory Determination of Engineering Properties of Dry FGD By-Products", Proceedings: Ninth Annual International Pittsburgh Coal Conference, University of Pittsburgh, October, 1993.
4. Land Application Uses for Dry FGD By-products, Phase 1. Columbus, OH. Department of Agronomy, The Ohio State University, April, 1993.
5. R. K. Fowler, J. M. Bigham, U.I. Soto, and S. I. Traina "Mineralogy of Clean Coal Technology By-Products", Proceedings: Ninth Annual International Pittsburgh Coal Conference, University of Pittsburgh, October, 1993.
6. Richard Stehouwer and Paul Sutton "Treatment of Acid Mine Spoil with Dry FGD By-Products". Leachate quality and plant growth. Proceedings: Abandoned Mine Lands Conference, Assoc., Abandoned Minelands, Chicago, IL. August, 1992.
7. Paul Sutton and Richard Stehouwer "Dry FGD By-Product as a Soil Amendment for Acidic Mine Spoils", Ninth Annual Pittsburgh Coal Conference, University of Pittsburgh, October, 1992.
8. Richard Stehouwer and Paul Sutton, "Use of Flue Gas Desulfuration By-Products as Ag-lime Substitutes", Agronomy Abstracts, Agronomy Society America, Madison, WI.
9. Dorothy A. Adams and William E. Wolfe, "The Potential for Swelling in Samples of Compacted Flue Gas Desulfurized By-Product". Proceedings: Tenth Coal Ash Symposium of American Coal Ash Association, Orlando, FL. January 1993.
10. Robert J. Duarte and William E. Wolfe "Permeability Measurements in FGD-Soil Mixtures", Proceedings: Tenth Coal Ash Symposium of the American Coal Ash Association, Orlando, FL. January 1993.

Table 2.

Characterization of LIMB, PFBC, and sewage sludge amendments.

Parameter	LIMB Ash #14	Tidd Cyclone Ash #3 PFBC	Sewage Sludge
Particle size (%)			na [†]
Sand (0.05-2mm)	0	25.5	
Silt (2-50µm)	90	74.1	
Clay (<2µm)	10	0.4	
Mineralogy (%)			na
Anhydrite (CaSO ₄)	25	22	
Calcite (CaCO ₃)	15	11	
Dolomite (CaMg(CO ₃) ₂)	nd ²	23	
Lime (CaO)	21	nd	
Portlandite (Ca(OH) ₂)	5	nd	
Periclase (MgO)	nd	13	
Fly ash	30	32	
CaCO ₃ equivalent (%)	59.4	60.3	0
pH (1:1, water)	12.5	10.5	6.5
Total Chemical Analysis			
Organic C (%)	na	na	31.2
Ca (%)	35.96	17.53	2.76
Mg (%)	0.60	10.64	0.34
S (%)	5.77	5.21	1.41
Al (%)	3.52	3.93	3.40
Si (%)	6.58	7.24	na
Fe (%)	5.56	5.17	1.24
Na (%)	0.33	1.03	0.07
N (%)	na	na	3.8
P (%)	0.02	0.02	1.78
K (%)	0.91	0.50	0.15
Ba (%)	0.03	0.02	0.01
As (mg kg ⁻¹)	55.1	1.9	<0.03
B (mg kg ⁻¹)	233.1	171.2	31.1
Cd (mg kg ⁻¹)	1.0	1.9	6.3
Cr (mg kg ⁻¹)	28.0	36.9	315.2
Cu (mg kg ⁻¹)	21.0	52.5	1174
Pb (mg kg ⁻¹)	16.0	16.0	16.1
Mo (mg kg ⁻¹)	5.9	6.6	11.2
Ni (mg kg ⁻¹)	31.1	52.1	166.4
Se (mg kg ⁻¹)	8.1	5.6	<0.3
Zn (mg kg ⁻¹)	86.0	74.0	1494

[†]not analyzed

Table 3

Leachate tests of Tidd PFBC samples

(03=cylcone ash, 04=bed ash)

ASTM Distilled Water Extraction (18 h, 20:1 water:FGD)

TCLP Acetic Acid Extraction (18 h, 20:1 acid:FGD)

SAMPLE	TID-FLB-03		TID-FLB-04		RCRA	Primary Drinking
	ASTM	TCLP	ASTM	TCLP	Limits	Water Standards
PARAMETER						
pH**	11.42	9.58	11.77	9.61		
TDS (mg/L)***	3136	12870	5154	11980		
Ag (mg/L)	<0.005	<0.011	<0.005	<0.011	5	0.05
Al (mg/L)	<0.049	0.12	<0.049	0.14		
As (mg/L)	<0.005*	<0.005	<0.005*	<0.005	5	0.05
B (mg/L)	0.832	0.767	0.209	0.543		
Ba (mg/L)	0.166	0.141	0.202	0.141	100	1
Be (mg/L)	<0.002	<0.002	<0.002	<0.002		
Ca (mg/L)	844.45	1382.77	1139.57	1741.10		
Cd (mg/L)	<0.001*	<0.003	<0.001*	<0.003	1	0.01
Co (mg/L)	0.02	0.026	<0.01	0.017		
Cr (mg/L)	<0.005	0.011	<0.005	<0.005	5	0.05
Cu (mg/L)	<0.007	<0.007	<0.007	<0.007		
Fe (mg/L)	<0.01	<0.01	<0.01	<0.01		
Hg (mg/L)	<0.0002*	<0.0002*	<0.0002*	<0.0002*	0.2	0.002
K (mg/L)	21.68	21.13	3.43	3.01		
Li (mg/L)	0.133	0.178	<0.030	0.073		
Mg (mg/L)	0.19	1351.80	0.09	881.52		
Mn (mg/L)	<0.001	<0.001	<0.001	<0.001		
Mo (mg/L)	0.033	0.025	0.035	0.031		
Na (mg/L)	8.26	9.82	1.26	1.67		
Ni (mg/L)	<0.010	<0.010	<0.010	<0.010		
P (mg/L)	<0.092	<0.12	<0.092	<0.12		
Pb (mg/L)	<0.001	<0.001	<0.001	<0.001	5	0.05
S (mg/L)	654.3	978.99	641.7	736.65		
Sb (mg/L)	<0.060	<0.060	<0.060	<0.060		
Se (mg/L)	<0.005*	<0.005	<0.005*	<0.005	1	0.01
Si (mg/L)	1.261	0.33	0.337	0.31		
Sr (mg/L)	0.657	1.205	0.615	0.833		
V (mg/L)	<0.006	0.022	<0.006	0.024		
Zn (mg/L)	<0.005	<0.005	<0.005	<0.005		
Cl (mg/L)	7.9	19.6	3.2	28.5		
F (mg/L)	2.8		2.3			
SO4 (mg/L)	1699	2795.2	1569	2264.8		

* Analyses by Burgess and Niple

** pH of final extract solution

*** Total dissolved solids

Table 4**Physical Properties Data - Tidd FBC Ash**

	Percent Fine: than 0.25mm	Particle Density g cm-3	Specific Surface Area m²g-1	Bulk Density g cm-3
Fluidized Bed Ash	1.36	2.92	1.28	1.29
Fluidized Cyclone Ash	56.30	2.70	6.50	1.29

Table 5

Bed Ash	pH	CCE %
TID-FLB-02	11.18	75.20
TID-FLB-04	12.20	60.00
TID-FLB-07	12.25	62.80
Cyclone Ash		
TID-FLB-01	9.90	69.40
TID-FLB-03	10.46	60.30
TID-FLB-06	10.09	56.00

Table 6

Average unconfined compressive strengths: Tidd by-product.

Table 7

Permeability coefficients: Tidd and PEDCO by-products.

Table 8

Swelling test result of TID3:TID4 (40:60)(Update June4,1993)

Table 11

Trace element composition of final leachates from columns of AML amended with sewage sludge and Tidd cyclone by-products.

Treatment	Rate	As	B	Cd	Cr	Cu	Mo	Ni	Se	Zn
	weight %					mg/L				
Spoil with 6% sewage sludge										
Spoil + PFBC	0	<0.05	0.41	<0.003	0.009	0.04	<0.018	0.24	<0.27	3.34
	3	<0.05	0.55	<0.003	0.014	0.16	<0.018	0.03	<0.27	0.20
	6	<0.05	0.57	<0.003	0.011	0.08	<0.018	0.02	<0.27	0.16
	12	<0.05	0.93	<0.003	0.021	0.06	0.089	0.01	<0.27	0.06
	24	0.07	0.97	0.004	0.043	0.21	0.394	0.11	0.54	0.12
Spoil without sewage sludge										
	0	<0.05	0.25	<0.003	0.008	0.07	0.01	0.11	<0.27	0.74
	12	<0.05	0.69	<0.003	0.013	<0.01	0.07	<0.01	<0.07	0.15

Table 12

Means of 6 Harvests of Fescue in AML Spoil amended with Tidd cyclone ash with and without sewage sludge.

	Rate weight %	Above ground dry matter (g/pot)						
		H1	H2	H3	H4	H5	H6	Ave
With 6% Sludge:	0	4.73	4.90	5.43	5.05	2.57	2.10	4.13
	3	7.58	8.00	8.68	8.70	6.39	5.65	7.50
	6	6.65	8.13	8.75	8.18	6.13	5.80	7.27
	12	4.68	6.30	8.18	8.20	6.94	6.35	6.77
	24	7.80	7.70	8.63	9.38	6.27	5.70	7.58
No Sludge:	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12	4.15	5.10	7.95	8.67	8.34	8.38	7.10

Table 9

Leachate and soil pH from columns of AML spoil amended with sewage sludge and FGD by-products.

Treatment	Rate	Leachate		Spoil		
		First	Final	First Surface	Final 0-5cm	Final 15-20cm
		weight-----			pH-----	
		%				
Spoil treatments with 6% sewage sludge						
	0	3.76	3.72	3.95	3.95	4.05
	3	7.34	6.87	6.63	6.60	6.48
Spoil	6	7.28	7.47	7.08	7.43	7.45
+	12	6.99	7.63	8.00	7.80	7.83
PFBC	24	7.85	7.73	8.63	7.98	8.10
Spoil without sewage sludge						
	0	3.07	2.81	-----	3.03	2.98

Table 10

Electrical conductivity and major element composition of final leachates from columns of AML spoil amended with sewage sludge and Tidd Cyclone by-products.

Treatment	FGD Rate	EC*	DOC**	Ca	M	S	Al	Fe	Mn
	weight %	mmho/cm-----				mg/L -----			
Spoil with 6% sewage sludge									
	0	0.96	14	82	35	170	3.04	2.27	2.528
	3	3.83	74	461	560	1063	<0.05	0.08	0.063
Spoil	6	4.21	96	477	674	1170	<0.05	<0.01	0.038
+	12	6.34	130	452	1299	1762	<0.05	<0.01	0.053
PFBC	24	21.97	632	425	7088	7486	0.09	0.07	0.098
Spoil without sewage sludge									
	0	2.24	5	50	48	48	50.17	115	0.868
	12	6.36	52	391	1904	1904	<0.05	<0.01	<0.001

* EC = electrical conductivity, millimhos per cm

**DOC = dissolved organic carbon

pH and aluminum in first and last leaching after 8 months in tall fescue greenhouse pots of abandoned mine spoil versus Tidd PFBC Cyclone Ash Application Rate.

Figure 1

pH and Aluminum of First and Last Leaching in Alfalfa Pots of Wooster Silt Loam versus Tidd PFBC Cyclone Application Rate.

Figure 2

Alfalfa Yields of Cutting #1, #3, and #6 for both Tidd PFBC Bed Ash and Cyclone Ash At Varying Rates of Application.

Figure 3

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