Session VII:

CASE STUDIES

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COAL COMBUSTION FLY ASH AS CONSTRUCTION MATERIAL IN A SANITARY LANDFILL PROJECT

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Abstract

This paper describes a project in which nearly one million tons of Class F fly ash were used as a substitute subgrade fill material in place of natural soil during the construction of a new cell of a sanitary landfill in southern Delaware. The paper discusses the basic design of the landfill cell, the engineering properties of the fly ash, the transportation and placement of the fly ash, and the relative economics of substituting fly ash for natural soil in this project.

Background Information

Description of Landfill Facility

The Delaware Solid Waste Authority (DSWA) owns and operates three sanitary landfill facilities in the state. The Southern Solid Waste Management Center, sometimes referred to as the Jones Crossroads Landfill, is located on State Route 20 in central Sussex County. The facility is situated near the town of Hardscrabble and is approximately 14 miles away from Millsboro to the east and 10 miles away from Seaford to the west.

The Hardscrabble landfill was originally opened in September, 1974. The entire landfill property occupies 572 acres of land, much of which is still wooded. For the first 14 years of operation, municipal solid waste was placed into a single cell. In 1988, a second cell was constructed at the landfill. At that time, DSWA officials agreed to the use of fly ash on an experimental basis as a portion of the subgrade fill material that was used for cell number 2 construction.

In 1995, construction began on cell number 3 of the landfill. This involved the clearing of approximately 15 acres of woodlands and the removal and re-use of topsoil within the cleared area. Groundwater in the vicinity of the new landfill cell was generally found within 2 feet below the ground surface, causing soft soil support conditions.. The depth of subgrade fill material beneath the new liner system for cell number 3 was designed to vary from 6 to 22 feet.

Approximately 690,000 cubic yards of subgrade fill material were required to be placed and compacted beneath the liner system for cell number 3. An additional 60,000 cubic yards of fill material were required for berm construction. Because of the availability of granular borrow material in Sussex County, original cost projections by DSWA for earthwork construction were based on the use of select borrow from sand and gravel suppliers in the general area.

Figure 1 is a site plan of the Sussex County landfill facility, showing the layout of the two existing landfill cells and the location of new cell number 3. Figure 2 is a cross-section of the new cell, indicating the configuration of the subgrade fill material and the design of the liner system and associated leachate collection systems.

Initial Ash Marketing Efforts at the Landfill

After the construction of cell number 2, Baker Engineers of Beaver, Pennsylvania analyzed the shear strength of the fly ash and reported that the fly ash performed acceptably in cell number 2. In anticipation of the construction of cell number 3, Delmarva Power, together with VFL Technology Corporation, its ash marketing contractor, developed a long-range strategy for obtaining DSWA approval for the use of fly ash on this project.

Because of the successful use of fly ash in cell number 2, key personnel at DSWA were already familiar with the characteristics and benefits of Indian River fly ash. Also, in 1986, VFL Technology had constructed a new 2 mile long haul road into the Hardscrabble facility and the road was built with a cement-fly ash-bottom ash stabilized base, resulting in a cost savings of more than $250,000 compared to the original design using crushed stone base. Over its 10 year life, this haul road has performed very well and has still not needed to be resurfaced.

The first step in the formal approval process for using fly ash in cell number 3 involved a meeting between representatives of Delmarva Power and personnel from DSWA and Geosyntec Consultants of Baltimore, Maryland, the designers of the new landfill cell. This meeting was useful in identifying what additional information was needed in order to permit fly ash to be incorporated into the design of the new cell.

As a follow-up to this meeting, Delmarva Power engaged the services of John Hynes Associates of Salisbury, Maryland to obtain representative samples of Indian River ash and to analyze the geotechnical properties of the fly ash. The analysis concentrated on the grain size, unit weight, moisture-density, shear strength, and permeability characteristics of the ash, especially on the relationship of the shear strength to the degree of compaction of different ash samples with a variable amount of carbon. Additional factors favorably influencing the selection of fly ash were its low unit weight and low permeability.

Ash Approval as Alternate Material

In the spring of 1994, after an extensive review of the geotechnical information submitted by Delmarva Power, Geosyntec modified the project specifications for subgrade fill material to permit fly ash to be used as an alternate to granular borrow material. Fly ash was also permitted to be used for constructing the interior portion of the perimeter berm and sedimentation basin embankments, although fly ash placement was limited in the specifications to within 3 feet of the exterior portions of the berms and embankments.

Additional data was also provided to DSWA and Geosyntec on the leachate characteristics of Indian River fly ash using the Synthetic Precipitation Leaching Procedure (SPLP). After a careful review of the engineering and environmental properties of the fly ash, DSWA granted its final approval for the use of fly ash in cell number 3 in November, 1994.

Description of Ash Sources

Fly ash approved for use in the Hardscrabble landfill project was produced from two sources in southern Delaware. The primary source of fly ash was from Delmarva Power's Indian River power plant. located approximately two miles east of Millsboro. An alternate source of fly ash was from DuPont's Seaford nylon plant. located in Seaford. Each of these plants and ash sources is described in this section.

Indian River Power Station

The Indian River power station consists of four coal-burning units having a total rated capacity of 782 megawatts (Mw). Bituminous coal is supplied to the plant by rail from sources in Pennsylvania,

Virginia, West Virginia, and Kentucky. The plant is equipped with electrostatic precipitators and cooling towers. Approximately 240,000 tons per year of fly ash are produced at the Indian River power station. The fly ash is collected and stored in silos. The majority of the fly ash in the silos is water conditioned and placed into an on-site storage area. Ash is excavated and removed from the storage area as utilization opportunities occur. Some dry fly ash is also made available to local ready-mix suppliers for producing flowable fill.

Delmarva Power Ash Marketing Program

In the late 1980's, Delmarva Power recognized that, in order to develop a credible-and successful ash marketing program, it was necessary to spend money up front to establish the necessary infrastructure at the power plant to facilitate supplying large volumes of ash to end use locations. In the fall of 1991, a new haul road was built on site to handle ash deliveries. Shortly thereafter, construction began on a new weigh scale and adjacent ash marketing building, both of which were placed into service in early 1992.

Delmarva Power then contracted with VFL Technology Corporation for management of all the ash from the Indian River power plant, including an estimated 2 to 3 million cubic yards of ash that is contained in the on-site storage area. Delmarva Power and VFL are constantly seeking opportunities for utilization of Indian River fly ash and bottom ash, particularly in high-volume applications. In addition to DSWA, users of Indian River ash include Delaware and Maryland state highway agencies, contractors, and ready-mix suppliers.

Indian River fly ash was used for embankment construction on a section of State Route 1 near Dover, Delaware and at the new Route 301-213 interchange near Galena, Maryland. This material has also been used as a structural fill for the construction of lagoon containment berms at wastewater treatment plant facilities in Georgetown, Delaware and Berlin, Maryland, as well as for flowable fill. Both the fly ash and bottom ash from Indian River have been used to produce cement-stabilized roller compacted base materials for parking lots, local streets, and haul roads, including ones for the Hardscrabble landfill and the power plant itself.

Experimental Ash Haul Road

During October, 1991, in anticipation of the additional truck traffic associated with supplying large volume ash projects, Delmarva Power constructed and designed a 3,500 foot long ash haul road on the Indian River power station property. The purpose of the haul road was to facilitate access to and from the Indian River ash storage area for ash hauling vehicles while demonstrating the performance of cement-stabilized roller compacted ash base materials to the Delaware Department of Transportation (DEL DOT). Delmarva Power also envisioned the use of this haul road as the quickest and least congested route for dump trucks hauling ash to high volume utilization sites.

The haul road consisted of five 700 foot long sections, involving a control section at each end with three cement-stabilized ash sections in the middle. The composition of the five test sections is as follows:

- Control A - Crushed concrete aggregate base
- Mix No. 1 - Indian River fly ash -bottom ash - cement
- Mix No. 2 - Indian River fly ash -borrow soil - cement
- Mix No. 3 - DuPont Seaford fly ash - borrow soil - cement
- Control B - Borrow soil - cement base

The crushed concrete aggregate was placed to a total thickness of 12 inches. The three ash test sections, as well as the soil-cement control section, were placed to a compacted thickness of 8 inches. A total of 3 inches of asphalt was placed over all the base course test sections. The borrow soil in three of the test sections was a well graded coarse to fine sand that was obtained from an existing on-site borrow

pit that was only a few hundred yards away from the haul road.

Aside from the late season temperatures, which resulted in fairly low initial curing, there were few problems encountered in the construction of the haul road. This road has been in service for five years and has accommodated a substantial amount of heavy wheel loadings during that time; In fact, it is estimated that at least 1.5 million tons of ash have been hauled over this road during the past five years.

With the exception of a few small isolated areas of cracking, the surface of the haul road is virtually free of distress. This haul road has been extremely beneficial in allowing Delmarva Power to load and supply large quantities of ash to construction projects in lower Delaware and the Eastern shore of Maryland without disrupting traffic within the power station or in the immediate surrounding area.

DuPont Seaford Nylon Plant

The other approved source of fly ash for the Hardscrabble landfill project was the ponded ash from the DuPont nylon manufacturing facility, located at Seaford, Delaware. This facility was the first nylon manufacturing plant in the United States and was constructed in 1939. The power plant at this facility bums coal from Virginia and West Virginia and produces approximately 25,000 tons per year of fly ash and bottom ash, which is sluiced into two on-site ash holding ponds. Ash is periodically reclaimed from the ponds and stockpiled on nearby ground to assist in dewatering the ash. The stockpiled ash from these ponds was also occasionally supplied to the Hardscrabble landtill project.

Project Description

Design of Landfill Cell Number 3

New landfill cell number 3 measures approximately 1,000 feet long by 1,000 feet wide. During the next 8 to 10 years of operation, it is projected to extend to a maximum overall height of approximately 50 feet. The cross-section of the landfill berm, as shown in Figure 2, is designed with slopes of 3 horizontal to 1 vertical. It is anticipated that cell number 3 will be able to receive an estimated 655,000 tons of solid waste during its operating lifetime.

The new cell is designed to have a leachate collection system underlain by a double liner. The leachate collection system consists of a network of perforated PVC collection pipes surrounded by bedding gravel sandwiched between a layer of washed sand above and below the gravel. The leachate collection system includes leachate-collection manholes located on either side of the landfill cell, solid PVC leachate collection piping, and a pumping station which directs the leachate into one of four 30,000 gallon above ground leachatk storage tanks, two of which are located on either side of the landfill cell. The leachate is ultimately recirculated back through the solid waste within the landfill cell.

The double liner system beneath the leachate collection system consists of two 30 mil polyvinyl chloride (PVC) synthetic liners. Between the primary and secondary liners is a 12 inch thick layer of washed sand that comprises the leak detection system. This leak detection system operates independently from the leachate collection system and is installed to detect leachate which may have permeated the primary liner. The leachate detection system drains the leachate through solid PVC piping into leachate detection manholes located on either side of the landfill cell.

The secondary liner is supported by 6 to 22 feet of subgrade fill material, with an average depth of 15 feet. The secondary liner was designed to be at least 5 feet above the seasonal high water table at the site. Test borings taken in the area prior to the design of the cell indicated that groundwater in the vicinity of the new cell generally fluctuated within 2 feet of the ground surface. As shown in Figure 2, the subgrade till material is also placed within the perimeter berm that surrounds the base of the cell. The double liner system is also extended up to the top of the perimeter berm and is supported by the subgrade fill material.

The Hardscrabble landfill accepts only municipal solid waste. The solid waste is placed and compacted in the landfill cell in 10 foot thick layers. At the end of each day, the active portion of the landfill area is covered with 6 inches of soil to minimize odor, vermin infestation, and wind-blown waste. The side slopes of the landfill cell will be maintained at a 3: 1 slope as the height of the landfill increases.

Bidding and Contract Award

Bids for the construction of cell number 3 at the Hardscrabble landfill were received on July 13, 1995. A total of 8 contractors submitted bids for this work. All but one of these contractors based their bids on using fly ash as subgrade fill material instead of granular borrow material. The low bidder for the project was a joint venture of George and Lynch of New Castle, Delaware, and David A. Bramble of Chester-town, Maryland, who had bid the project using fly ash.

The contract was awarded to George and Lynch/Bramble on August 8, 1995 and work commenced on September 13, 1995. VFL Technology Corporation engaged the services of David Horsey of Georgetown, Delaware to do all of the hauling of fly ash from the Indian River power station to the job site. VFL, with assistance from David A. Bramble, loaded all of David Horsey's trucks. Fly ash from the DuPont Seaford plant was loaded and hauled to the job site by George and Lynch.

Delivers and Placement of Fly Ash

Fly ash from the Indian River power station began being delivered to the job site on September 13, 1995. Two front end loaders and one power excavator were used to excavate and load the fly ash. For the first month, fly ash was delivered using 30 end dump vehicles and an average of 4,800 tons per day of fly ash was delivered to the job site.

After the first of the month, the number of end-dump trucks was increased from 30 to 80 and the average amount of fly ash from Indian River that was delivered to the job site was increased to approximately 8,000 tons per day. The maximum tonnage of fly ash that was delivered on any one day was 15,606 tons on December 12, 1995. The last day Indian River fly ash was delivered was on June 13, 1996. In all, a total of 872,105 tons of Indian River fly ash were delivered to the job site on 109 different days, involving a total of 43,605 truckloads.

Fly ash from the DuPont Seaford facility began being delivered to the job site on October 10, 1995. The last day fly ash from DuPont Seaford was delivered was November 5, 1995. In all, a total of approximately 51,000 tons of DuPont Seaford fly ash were delivered to the job site on 17 different days, which is an average of 3,000 tons per day. The total amount of fly ash from both power plants used as subgrade fill and/or berm construction material on this project amounted to 923,105 tons, making this one of the largest single ash utilization projects in the eastern United States.

According to the project specifications, subgrade fill and/or berm construction material was to be placed in loose lifts not exceeding 8 inches in depth, resulting in a compacted thickness not exceeding 6 inches. Each lift was to be compacted to at least 95 percent of maximum dry density, as determined by the standard Proctor method (ASTM D698). The moisture content of the subgrade fill and/or berm construction material when placed was required to be within 2 percentage points below to 1 percentage point above of the optimum moisture content, also as determined by ASTM D698.

Technical Aspects of Ash Placement

Moisture control of the Indian River fly ash was a cooperative effort between VFL's ash management personnel at the power plant and the project's geotechnical engineering consultant (Harding and Knight of Bishopville, Maryland). Ash to be delivered to Hardscrabble was excavated from the Indian River landfill the day before, stockpiled. and a series of one-point Proctor tests, were performed by VFL. The results of the one-point Proctor tests were shared with Harding and Knight, who determined

from a family of moisture-density curves what, if any, adjustments were needed in moisture content of the ash prior to delivery. Normally, the fly ash from the landfill required some additional water to be brought up to the target optimum moisture content of 37 percent. During rainy periods, ash from the landfill could be added to wet ash to lower the moisture content, as needed.

Field quality assurance of fly ash compaction was performed by using nuclear densimeter test methods, together with visual monitoring of lift thickness, number of passes, and response of each lift to the passage of construction equipment. One in-place nuclear density test was specified to be performed for every 10,000 square feet (100 feet by 100 feet) of surface area, with a minimum of six tests for every lift placed.

Fly ash was placed and compacted at the Hardscrabble landfill project on a total of 109 working days during the course of the project. During that time, an average of at least 50 in-place nuclear density tests were performed daily. On a typical day, the working area involved approximately 4 acres and at least three lifts of subgrade till material were placed. A total of 5,870 in-place density tests were performed during the course of ash placement.

Throughout the entire 10 months of construction of the base of cell number 3, only 2 percent of all the in-place density tests indicated that the specified 95 percent compaction value had not been achieved. During that time, only 1.8 percent of the moisture content values were found to not be within the specified percent of the designated 37 percent optimum moisture content. Nearly all of these instances occurred during rainy weather conditions. In locations where there was less than 95 percent compaction, additional compactive effort was applied. Normally, four passes of a vibratory roller were sufficient to achieve the desired compaction.

In locations where the moisture content was more than 2 percent below optimum, additional water was applied and the area recompacted. In locations where the moisture content was more than 1 percent above optimum, the area was scarified the full depth of the lift, allowed to air dry for a sufficient time, and then recompacted. Normally, these measures were able to bring the affected areas back into compliance within the specification requirements.

Early in the project, the contractor, in an effort to expedite the project, investigated the possibility of increasing the lift thickness from 8 to 12 inches. Because the fly ash is a relatively light material, compared to granular soil, it tended to form a small wave ahead of the roller when placed at the greater depth, making compaction more difficult. The additional roller passes needed to achieve the required degree of compaction more than offset any potential time savings from increasing the lift thickness. Therefore, it was decided not to modify the specified 8 inch loose lift thickness.

Logistical and Climatic Considerations

Logistical Considerations

The principal logistical considerations associated with supplying fly ash from the Indian River power station involved providing the necessary trucks and equipment and the routing of the trucks. In order to keep the project on schedule, it was necessary to supply George and Lynch with about 5,000 tons of fly ash for each working day. There were many days when VFL was able to supply 8,000 tons or more of fly ash to the project.

To supply at least 5,000 tons of fly ash per day required 30 dump trucks and two front-end loaders and one large power shovel with an 8 cubic yard bucket working a full 8 hours a day. Each truck hauled approximately 20 tons of fly ash per trip and was able to complete a round trip in roughly one hour. When supplying up to 8,000 tons per day of fly ash, as many as 80 dump trucks were used on a given day and a second power shovel was needed. When it was not possible to obtain enough dump

trucks, the hours per day were extended to 10 or even 12 hours, on those days were there was sufficient daylight.

During the first month in which fly ash from the Indian River power station was delivered to Hardscrabble, all of the dump trucks hauling fly ash used the same route through the nearby town of Millsboro. This prompted concerns on the part of some residents along this route with regard to noise, dusting, safety, and long-term damage to the roadway.

Following a meeting between all involved parties, it was agreed that dump trucks, upon leaving the Indian River power station property, would take one of three possible routes through Millsboro. Once out of the town of Millsboro, all trucks took Delaware Route 20 to the Hardscrabble site. This minimized road damage and satisfactorily resolved the concerns of the local residents in Millsboro.

Throughout the duration of the project, care was taken to tightly tarp all loaded dump trucks in order to minimize or eliminate dusting during transport of the fly ash. There were no incidents of spillage or complaints about dust generation at any time during the lb months that fly ash was being hauled.

Climatic Considerations

By using fly ash as the subgrade fill material on this project, the number of days in which construction could not proceed due to weather conditions were minimized. The winter of 1995-96 involved a record snowfall accumulation. The spring and summer of 1996 were unusually wet. Very few working days were lost during the winter, except for days with heavy snowfall or accumulation. Virtually no time was lost due to sub-freezing temperatures because the fly ash was able to be spread and compacted below freezing and was still able to satisfy density requirements.

During the spring, the use of fly ash as a subgrade fill material resulted in no lost construction time due to wet conditions, even though all other earthwork construction in the region was forced to shut down for extended periods because of the rainy weather. Even when there were wet conditions at the Hardscrabble site, fly ash from the Indian River landfill, which was at a moisture content below optimum, was hauled to the site and blended with the wetter ash so that construction work could still proceed.

Overall Assessment of Project

Ability of Flv Ash to Meet Specifications

Throughout the 10 month duration of this project, nearly 1 million tons of fly ash were delivered and placed in the new landfill cell. During this time, the fly ash was supplied from two approved sources - Delmarva Power's Indian River power station and DuPont's Seaford nylon manufacturing facility. Over 95 percent of the ash was supplied from the Indian River power plant. The fly ash consistently met the project specifications for particle size (less than 1 inch) and moisture-density-requirements (95% of standard Proctor density with a total 3% deviation from optimum moisture).

Flv Ash Handling and Performance

The fly ash used for subgrade fill and berm construction at this project performed excellently, insofar as there was no dusting and the moisture content was very carefully controlled prior to delivery. The material spread easily, compacted readily, met density requirements consistently without the need for additional compaction. and was even able to be placed under adverse weather conditions that are normally a problem for granular borrow materials.

Economic Considerations

The overall cost of constructing cell number 3 at the Jones Crossroads landfill was approximately 15 million dollars. The low bid price submitted by George and Lynch/Bramble was at least $50,000 less than the second bidder, who had bid the project using granular borrow soil.

Future Develoument

Beginning in 1997, a fourth cell will be developed at the Jones Crossroads landfill. Based on the successful use of fly ash to construct cell number 3, DSWA has agreed to allow the use of fly ash the subgrade fill and berm material for cell number 4. Since this new cell will be comparable in size to cell number 3, there is the potential to utilize nearly one million more tons of fly ash at this landfill. Construction of cell number 4 is expected to be spread out over a 3 to 4 year time period.

Acknowledgments

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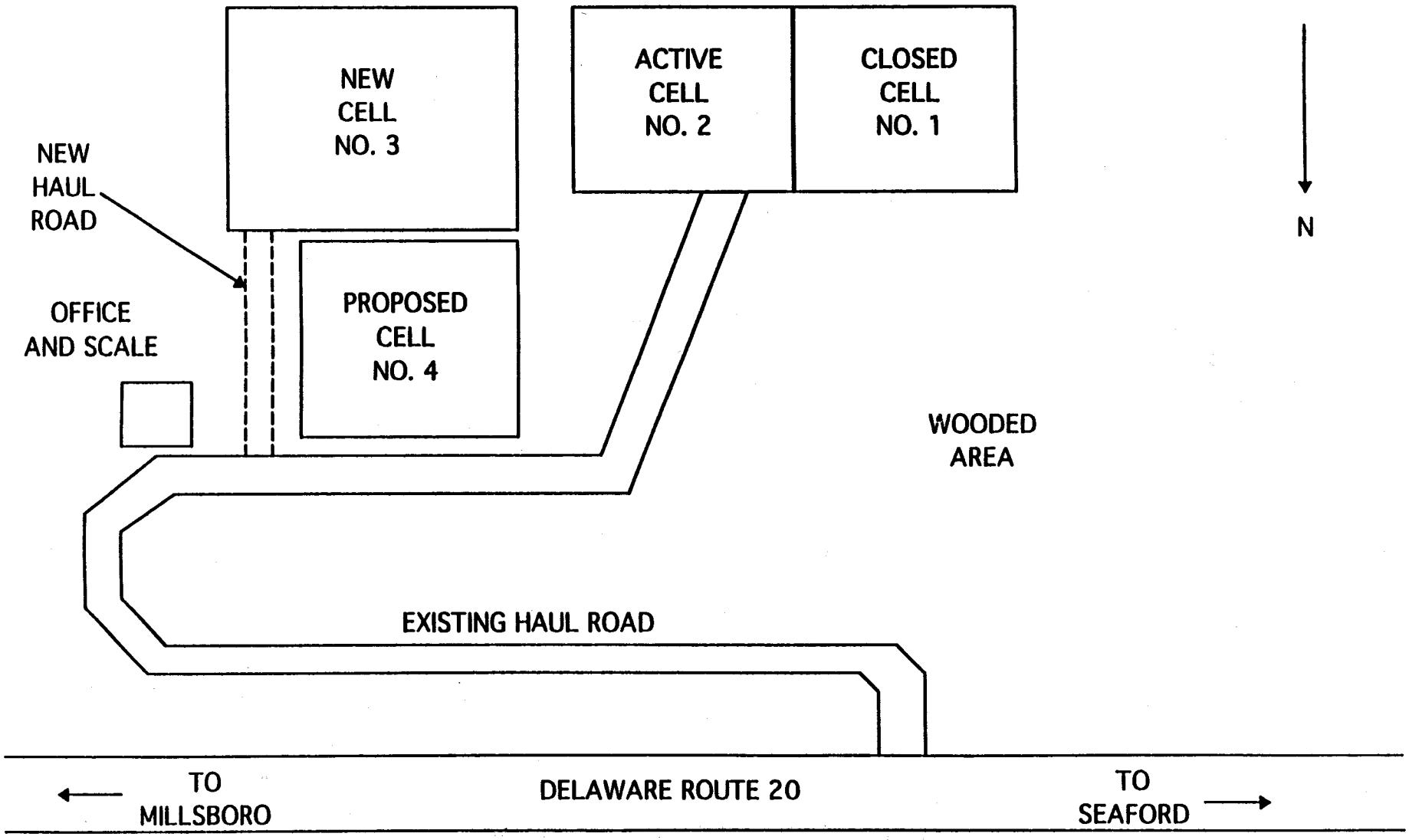
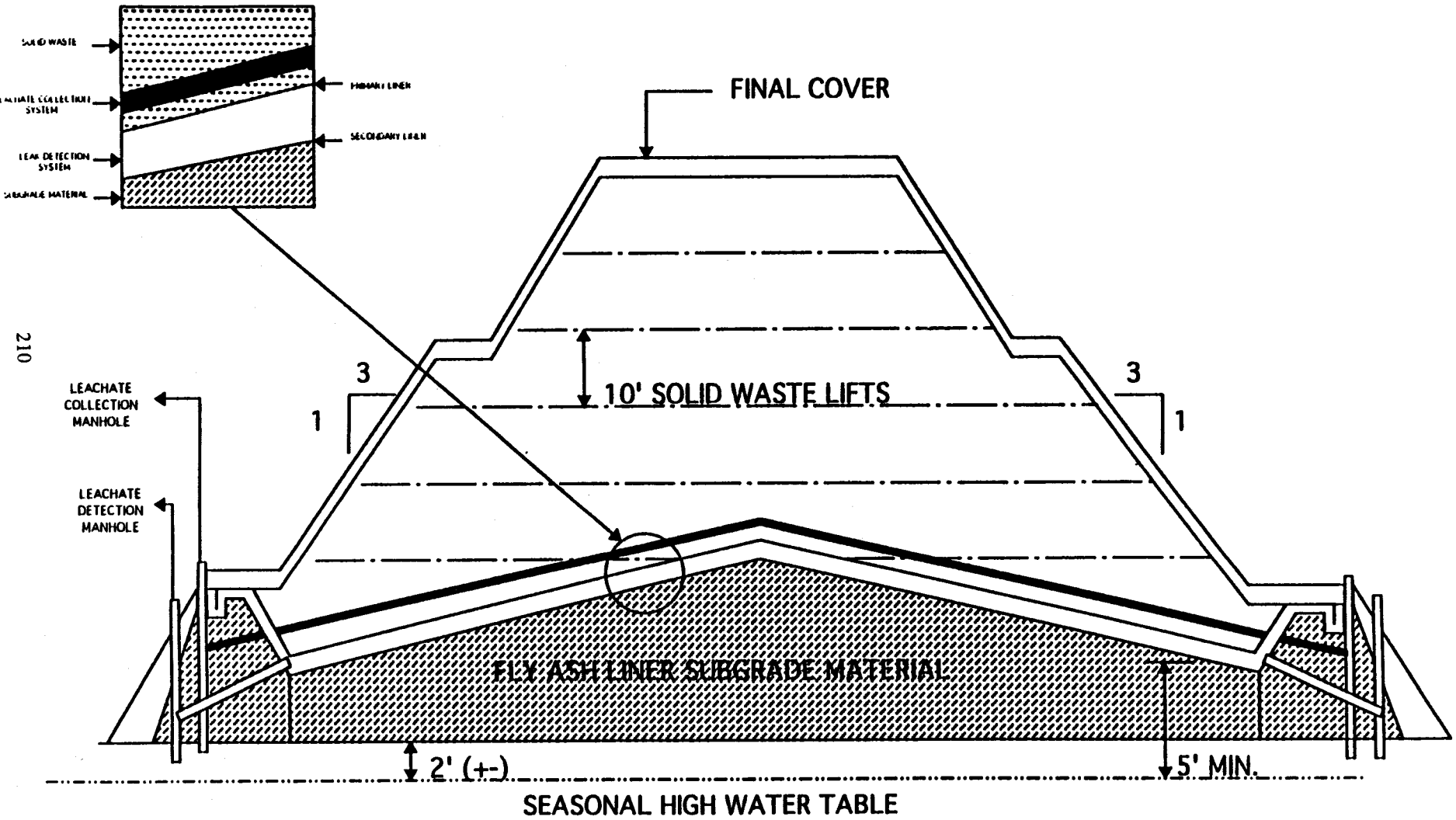
FIGURE 1
SITE PLAN OF THE
SUSSEX COUNTY LANDFILL FACILITY



MAC: SUSSEX1

FIGURE 2
CROSS-SECTION OF NEW CELL #3



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FLUID PLACEMENT OF FIXATED SCRUBBER SLUDGE IN ABANDONED UNDERGROUND COAL MINES TO REDUCE SURFACE SUBSIDENCE AND TO ABATE ACID MINE DRAINAGE

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Abstract

The goal of this project was to demonstrate the technical feasibility of placing fixated scrubber sludge (FSS) into abandoned underground coal mines to control subsidence and to reduce acid mine drainage. The effectiveness of the technology was determined by the total reduction of the mine void and the strength of the injected FSS. The overall effect on the hydrogeologic environment by using this technology was determined through a ground water monitoring program. Laboratory and bench scale testing determined the composition for optimum flow, minimization of free water, and the optimum settling / physical characteristics. 'The full scale demonstration involved the injection of approximately 16,400 cubic yards of FSS. Borehole photography and core sampling of the placed FSS provided the data necessary to determine the effectiveness of subsidence reduction. The investigative techniques documented good overall roof contact of the injected FSS, unconfined compressive strengths greater than 100, and low permeability coefficients. The groundwater monitoring detected changes in the concentration of chemical parameters in the mine pool water, but no significant changes in ground water chemistry surrounding the mine.

Introduction

Indianapolis Power and Light Company (IPL) began this research to develop a technology to reduce surface subsidence using fluid placement techniques of the FSS because abandoned underground coal mines surrounded property adjacent to existing coal combustion by-product (CCBP) landfill area. Landfill expansion into the area is in question because of the high potential for sinkhole subsidence. Sinkholes manifested at the surface put the integrity of a liner or runoff pond containment structure for CCBP disposal facility at risk. The Indiana Solid Waste Regulations prohibit the construction of a land disposal facility over abandoned underground mines without some demonstrated method of subsidence control. The fluid placement techniques of FSS as a subsidence abatement technology was demonstrated during an eight week period in September, October, and November, 1994 at the Petersburg Generating Station located in Pike County, Indiana. The EPA (Region V) required IPL to register the injection boreholes used during the demonstration in the Underground Injection Control Program.

Site Selection

The abandoned underground coal mines evaluated for this project are found in the Illinois Basin No. V coal seam. The abandoned mines at.or around the Petersburg Station were ranked on the basis of the following criteria:

- probable open voids
- ability to isolate the area to receive the injected material
- ability to locate the mine by the use of mine maps and land surveying
- probable surface conditions.

The Arnold Willis "City" Mine was selected primarily because of its small size, available mine maps, easy surface access, and proximity to the power plant. The initial borings documented the accuracy of the City mine map and determined the condition of the mine workings. Depth to the mine voids varied from 32 to 64 feet. Mine void varied from 2.0 to 7.0 feet in height. The borings encountered both dry mine and flooded conditions. Due to the mine floor slope, sections of the mine workings were completely flooded. The mine pool elevation was at 436 and remained constant throughout the

monitoring period. A map of the Arnold Willis "City" Mine *Figure 1. Mine Map* depicts the existing surface topography, and coal seam elevations. The coal was removed from this mine in the late 1940's and early 1950's at different extraction rates varying from 50% to 70%.

Environmental Monitoring

The objectives of the water quality monitoring plan were to define baseline conditions existing prior to the FSS injection and to monitor changes during and after the demonstration. The monitoring program assisted in identifying environmental changes related to the mine stabilization and defined the migration patterns of FSS constituents and the fluids that were displaced from the mine by the injected grout. The monitoring wells were placed in close proximity to the mine workings so that any water quality impacts would be readily detected and evaluated. There were two monitoring wells located upgradient to determine background water quality (SC-1 and FW-1). The monitoring points located in voids and pillars were used to monitor the water quality of the mine pool (B-4, B-7, B-12, B-14, B-16, B-22, B-23). Other monitoring points were located in the coal seam downgradient of the mined area (B-17, B-18, B-19, SC-3, and SC-4). The location of these monitoring points with respect to the mine can be found in *Figure 2. Borehole Location.*

A total of nine sampling events were completed. The monitoring points were sampled during each event and tested for twenty two different water quality parameters. In examining the post injection ground water monitoring data as compared to the leachate data for the FSS, the constituents that emerged as the most useful or as primary indicators of water quality changes related to the FSS injection were, in order of decreasing significance, sodium, potassium, calcium, boron, chloride, and magnesium. Sulfate, TDS, and specific conductance were secondary indicators of FSS injection effects, i.e., changes in these parameters were observable at some monitoring sites but were generally of lesser magnitude and frequency. Arsenic, cadmium, chromium, 'lead, selenium, aluminum, barium, nitrate, and sulfide were relatively unaffected by the injection of FSS into the mine. The pH (6.0 to 7.5) and acidity of the mine pool were not significantly affected by the injection of FSS into the mine, suggesting that the mine water's buffering capacity effectively resisted changes in these parameters.

Ground water in rock and tmmined coal exhibited no increases or only subtle, attenuated increases in constituent concentrations and in the number of affected chemical constituents compared to water in mine voids. Comparisons of leaching test and field monitoring data suggest the laboratory data can be employed as broad indicators of probable chemical changes within the mine pool.

'Fixated Scrubber Sludge - FSS

FSS is a flue gas desulfurization by-product blended with dry flyash and quicklime. The Petersburg Generating Station burns bituminous coal mined in Indiana. The resultant fly ash (Type F) is a good quality pozzolan meeting ASTM C-593. The flue gas desulfurization systems are wet limestone scrubbers. The scrubbers are inhibited oxidation systems which produce a by-product that is primarily a calcium sulfite hemihydrate, containing minor quantities of calcium sulfate dihydrate (gypsum) and silicon dioxide (as quartz). The pozzolanic activation additive is calcitic quicklime (calcium oxide) with minor quantities of magnesium oxide and silicon dioxide (as quartz). All of the CCBP components of FSS and the quicklime were characterized to develop a baseline of the constituents of the FSS grout. A surface water source (an abandoned strip pit) and the actual mine pool water were also characterized. The abandoned strip pit was used as dilution water source for the FSS blend during the demonstration.

Microstructure/Cementation/Stability Evaluation

EPRI has found in related studies of cementation in coal combustion residues, developing this type of chemical information is critical to optimizing performance and stability. FSS materials are chemically active in the sense that the main constituents (i.e., fly ash, scrubber sludge, lime and water) react over time with each other to form other distinct chemical and mineralogical phases. These phases

are responsible for the "self-cementing" action which produces the physical strengths in the FSS by-products after they have "cured". Understanding the chemical processes responsible for cementation of the FSS grout would determine the chemical stability of FSS by-product when exposed to the mine water environment.

The principal hydration product in FSS is calcium sulfoaluminate or ettringite $Ca_6Al_2(SO_4)_3(OH)_{12}\bullet 26(H_2O)$. The cementation in the FSS grouts occurs largely through the formation of the ettringite by sulfo-pozzolanic reactions involving the gypsum and aluminate derived from flyash in an alkaline media. The mineralogy data confirmed the reactive phase in the scrubber sludge is the gypsum ($CaSO_4$), representing 5-10% by mass of total solids. The reactive component in a Class F flyash is principally the aluminosilicate glass representing 45-50% by mass. Other reactive components in flyash include soluble alkali sulfates (typically deposited on the surface of ash particles) and free lime.

The growth of ettringite strongly parallels the strength development in FSS. Also a notable feature is the steady increase in bound water with time which correlates with the compressive strength gains. The microstructure shows good densification by six months with cementing by the ettrignite and C-S-H. Some expansion (≈ 5 vol%) during curing appears to be a characteristic feature of the FSS grout system which proved to be a beneficial effect underground improving contact with the walls and roof of the mine.

Bench Scale Test Program

Although a considerable amount of information has been generated by the utility industry and others on the chemical and physical properties of FSS by-product materials (e.g., strength, permeability, leachability), very little is known about the fluid and/or FSS grout materials used for injection. In meeting the goals of the project, the placement of FSS eliminated the mine void space with a minimal number of injections points. To accomplish this, the FSS mix design had to be optimized for flowability and strength development in a bench scale test program. The objective of the bench scale study was to provide information focused toward determining the best compositions for mine injection. Dispersion in underground voids is necessary if the voids are to be filled. In addition, quantities of supernatant fluid after settling, and resistance to acidic mine water were critical criteria.

The bench scale test program studied a wide range of compositions consisting of 36 test different compositions. Four levels of solids content (45%, 50%, 55%, 60%, wet weight basis), three levels of fly ash to FGD by-product ratios (0.7:1, 0.9:1, and 1.1:1 dry weight basis) and three levels of quicklime content (2%, 3%, and 4%, dry weight basis) were explored. The various compositions were evaluated for viscosity, density as blended, density after settling, flowability in a one-dimensional "tunnel flow" protocol, and angle of repose. The various compositions were then cured under accelerated conditions to project strength development. The underground void temperatures have been found to be in the range of 50" F to 55" F. Ambient conditions as defined by ASTM, focus on 73" F. Time temperature relationships for pozzolanic or sulfopozzolanic reactions are approximately as follows: 50" F for eight weeks is approximately equal to 73" F for four weeks. The accelerated cure test promoted the desired hardening chemistry in half the time.

Optimization of Strength of the FSS Mix Design

Laboratory testing determined the range of strengths available from different FSS mix designs conforming to the flow characteristics developed during the bench scale testing. The solids content of the FSS grout mixtures is the dominant factor in determining strength property. Quicklime content is also a critical component of the FSS grout. It was determined that a minimum of 4% lime content is required to meet a design specification of 100 psi or greater. It is possible to tailor the strength potential of the FSS to different areas of the mine by increasing flyash to sludge ratios or increasing quicklime content without changing the moisture content. The higher strength mix could be designed into the "batch mix"

when additional ground or lateral support is required; and a lower strength used when bulk filling a large underground void.

Optimization of Flow/Rheolonical Prouerties of FSS Mixes

The relationships between the rheological properties and mix proportions of the range of FSS mix designs over a wide range of solids contents were determined. Fluid characteristics were determined to be cohesive and stable under shearing conditions. The flyash to sludge ratio of the grouts was a less important design variable. However a higher flyash content has been shown to improve fluidity of the grout. Higher flyash contents are also expected to improve stability of the grout underground.

An examination of the effect of selected chemical flow additives (such as water reducers or plasticizers) on the rheological properties of the FSS mixtures was conducted. Chemical agents of this type are widely used in the concrete construction industry as a means of reducing the amount of water needed in a cementitious mixtures for a given flow/workability. The feasibility of using these flow enhancing additives determined the solids content of the FSS mixtures can be increased while at the same time maintaining adequate flow. Selection of the proper plasticizers is critical because some effect the pozzalonic chemistry that can result in a decrease in strength

Equipment Testing: One critical equipment component extensively tested was the fluid placement pump. Both centrifugal and positive displacement pumps were considered. The centrifugal pumps have characteristics of high capacity but low to medium discharge head delivery and extreme sensitivity to viscosity. The general experience shows that the centrifugal pumps can be used to pump slurried grout 45% to 50% solid. The positive displacement pumps have been widely used in the concrete and the mining industry for a variety of applications. In the mining industry, these pumps are used to pump mine tailing and backfill material, which can be as much as 80% in solids content. These pumps are known to exhibit high discharge head delivery. Generally, positive displacement pumps are more expensive to purchase and maintain than centrifugal pumps. A series of pipeline tests were performed to determine the flow characteristics of the slurries on the centrifugal pump performance. The experimental work was conducted in a 3 inch diameter pipeline loop powered by a centrifugal pump. The FSS tested in **this** pipe loop test would be classified as pseudo-plastic material. FSS, with high solids content, clearly indicates its non-Newtonian behavior.

Project Demonstration

The field work was designed to demonstrate the concept of the fluid placement of FSS at full scale. The demonstration was a continuous operation requiring large inventories of the FSS. During the demonstration approximately 250 to 600 cubic yards of FSS was placed each eight hour working day for a total of 16,35 1 cubic yards over the eight week period. The demonstration plant was operated one shift a day, five days per week.

Process Equipment

Freshly produced FSS was trucked to the demonstration site and stored on a small temporary storage pad adjacent to the dilution plant. The dilution plant used for this full scale demonstration was a tractor trailer mounted unit manufactured by Excel Machinery Co., see *Figure 3. Dilution Plant. The* portability of this unit allows it to be moved to multiple locations for injection on projects covering large areas. For this demonstration the unit was centrally located over the City mine and was not moved during the eight week demonstration period. The discharge piping was flexible and easily moved to the various injection points, some were located as far as 300 feet from the unit. The mixing of FSS materials for small projects can also be accomplished utilizing cement mixing trucks or other portable batch plants.

A front end loader was used to transfer the material from the temporary storage pad to the feed hopper of the dilution plant. The FSS was weighed on a belt scale as it discharged from the feed hopper

which discharged into a 4' x 8' heavy duty twin shaft pugmill mixer. A programmable controller operated the lime and water feed equipment to achieve the desired ratios of the grout mix. This dilution plant was able to consistently mix the FSS grout to the optimum percent solids content required for fluid placement. The FSS grout discharged from the pugmill onto an inclined belt conveying it to the .surge hopper located over top of the injection pump. The FSS was then pumped into the mine voids using a Schwing trailer mounted concrete pump (max. capacity - 127 $yrds^3$ / hr). The positive displacement injection pump delivered the FSS through an overland slurry line to the various injection points. A 90' elbow directed the FSS down the injection hole.

At the beginning of the demonstration, the FSS was allowed to fall unrestricted down the hole and into the mine workings. After a few premature refusals, the free-fall method was changed to a "tremie" method. A tremie system is simply a pipe that is long enough so that the lower end of the pipe is always kept below the mine roof, see *Figure 4. Injection Borehole with Tremie Pipe. The* length of the tremie pipe varied from borehole to borehole depending on the depth of individual mine void from the surface, generally, from 30 to 60 ft.

As with any equipment startup, adjustments to the equipment were required initially. After making the startup revisions, injection proceeded at a satisfying pace. The first injection hole was B-10, borehole television examination showed good void height and interconnected mine workings. Injection into the mine workings was monitored at the injection site utilizing a pressure gauge mounted on the 90" elbow at the top of the hole. Pressure would build as injection proceeded and then suddenly fall off to zero as the grout's path opened into another room or void. The pressure would begin to increase again and the process would repeat itself. Injection into a particular borehole continued until the hole refused by blowing FSS out the top of the hole between the casing and the injection pipe or when the sustained injection pressure became high enough to cause concern. At the completion of injection each day, water was pumped through the pugmill, concrete pump and injection piping to both clean all the equipment and to open the flow path through the FSS in the mine workings for startup the next day.

Injected FSS Monitoring: During the field demonstration, monitoring of the FSS placement consisted of two different methods. The first method consisted of observations of depth to bottom of the mine in the boreholes located in the mine workings. The changes to the water level in the mine pool and to the water quality, specifically the pH and specific conductance, also indicated the path that the FSS traveled. The other method was conducted only briefly but was the most informative, that being the borehole photography. Daily monitoring during the FSS injection was concentrated in the boreholes directly around the injection point, although all open boreholes into the mine workings were monitored every few days. The results of the monitoring gave good indications of FSS movement. Once the FSS arrived at a monitoring hole, the grout level in the hole rose to the mine roof within one or two days of injection. Water levels in the mine varied little during injection but on occasion, a rise in the mine pool of about one tenth of a foot was noted at the end of a day. The mine pool would be at its normal level the next morning. No evident changes were noted in the pH or specific conductance of the mine pool until FSS was actually measured in a particular hole.

Injection Rates: The injection rates varied from about 280 to 650 cubic yards of FSS per day, with the lower rates occurring primarily during the first two weeks of injection and the rates generally increasing thereafter as the system operation was refined. Overall, 16,351 cubic yards of FSS was injected during the eight week field demonstration with 6,782 cubic yards in B-10 (covering approximately 1.3 acres), 4.318 cubic yards in B-20 (covering approximately 1.2 acres), 4,874 cubic yards in B-35 (covering approximately 1.1 acres). All of the injection holes were filled to refusal. In general, the FSS fluid placement material contained about 55% to 60% solids, fly ash to filter cake ratio per plant production (to be 0.7 to 1 or higher as circumstance allowed), and more than 4% total lime content. *Figure 5. FSS Injection Calculated Volumes* detail the quantities injected and test results of core samples retrieved after the demonstration can be found below.

Borehole Television: Three rounds of borehole photography was conducted by a crew from the Eastern Technical Center of the Office of Surface Mining, Reclamation, and Enforcement (OSMRE), U.S. Department of the Interior, Pittsburgh, Pennsylvania. The camera work was requested from OSMRE through the Abandoned Mine Lands Program of the Indiana Department of Natural Resources. The initial camera work was used to determine which borings had encountered open voids and which were into obstructed (broken rock) mine workings. The camera work completed during demonstration concentrated on observing FSS as it was placed in the mine void. While injecting into B-20, and photographing in B-21, movement of FSS was recorded almost from the time it entered the mine room where B-21 was located, until the room was completely filled. The camera showed that the FSS did move as a mass in a lava type flow. The third and final round of camera work was used to verify roof contact into the random boreholes drilled to retrieve core samples and also in the existing boreholes.

Conclusions

- The demonstration clearly showed that the FSS flow from the injection borehole exceeded 100 feet, and based upon volume estimates, approached 135 feet. A mine void area in excess of one acre can be filled with one injection point.
- The lava-like flow of FSS does not appear to mix with mine water but rather displace it, only the outer surface of the FSS grout is exposed to the mine water. Air and water in the voids can be completely displaced by FSS grout injection, the potential for acid generation from pyrites and organic sulfides is then greatly diminished.
- The FSS grout does not shrink or settle away from the mine roof and generally achieves unconfined strength of 100 psi or higher.
- FSS grout injection can be accomplished with "off the shelf' equipment with only minor modifications required.
- Short term results indicate no discernible chemical effects from FSS on mine water and no chemical effects on the surrounding ground water.

Acknowledgments

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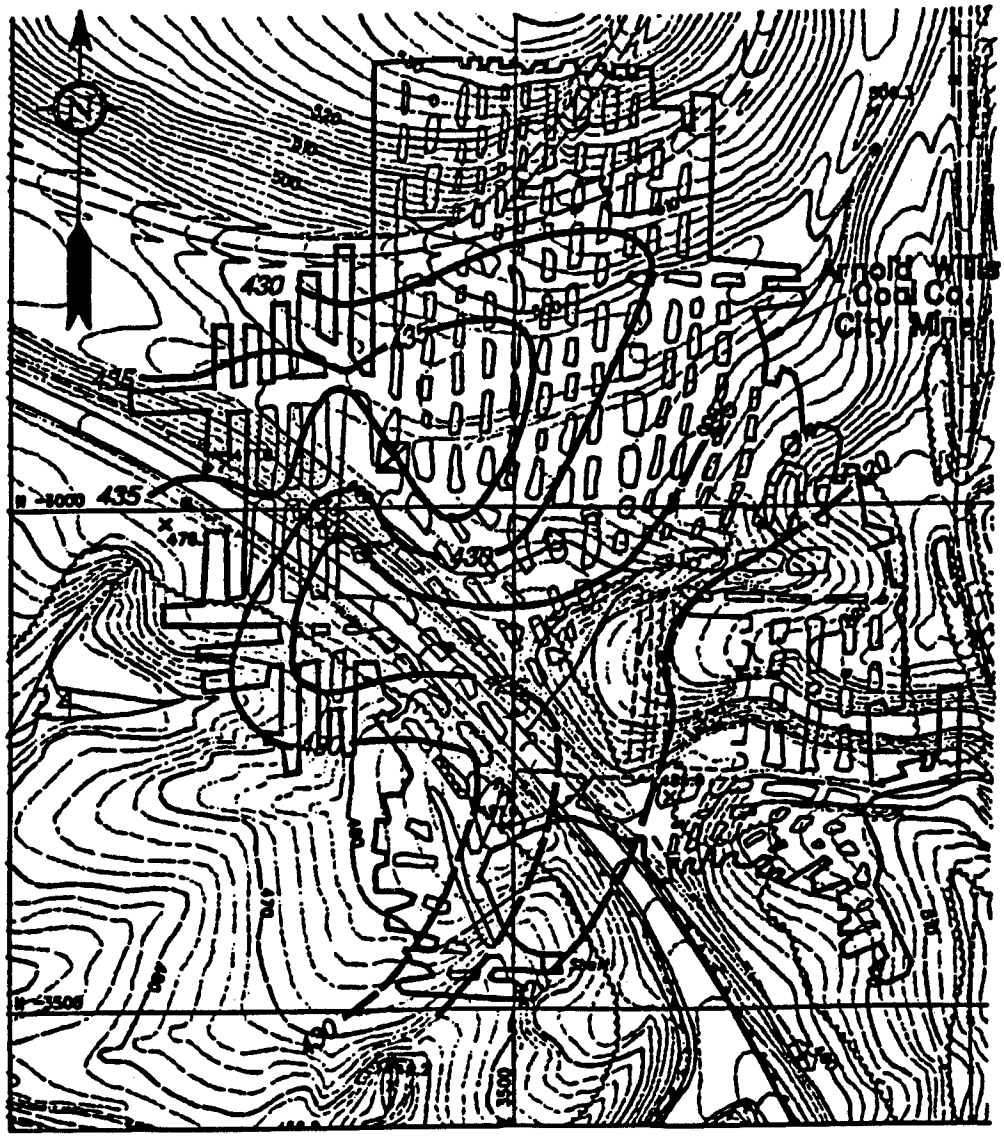
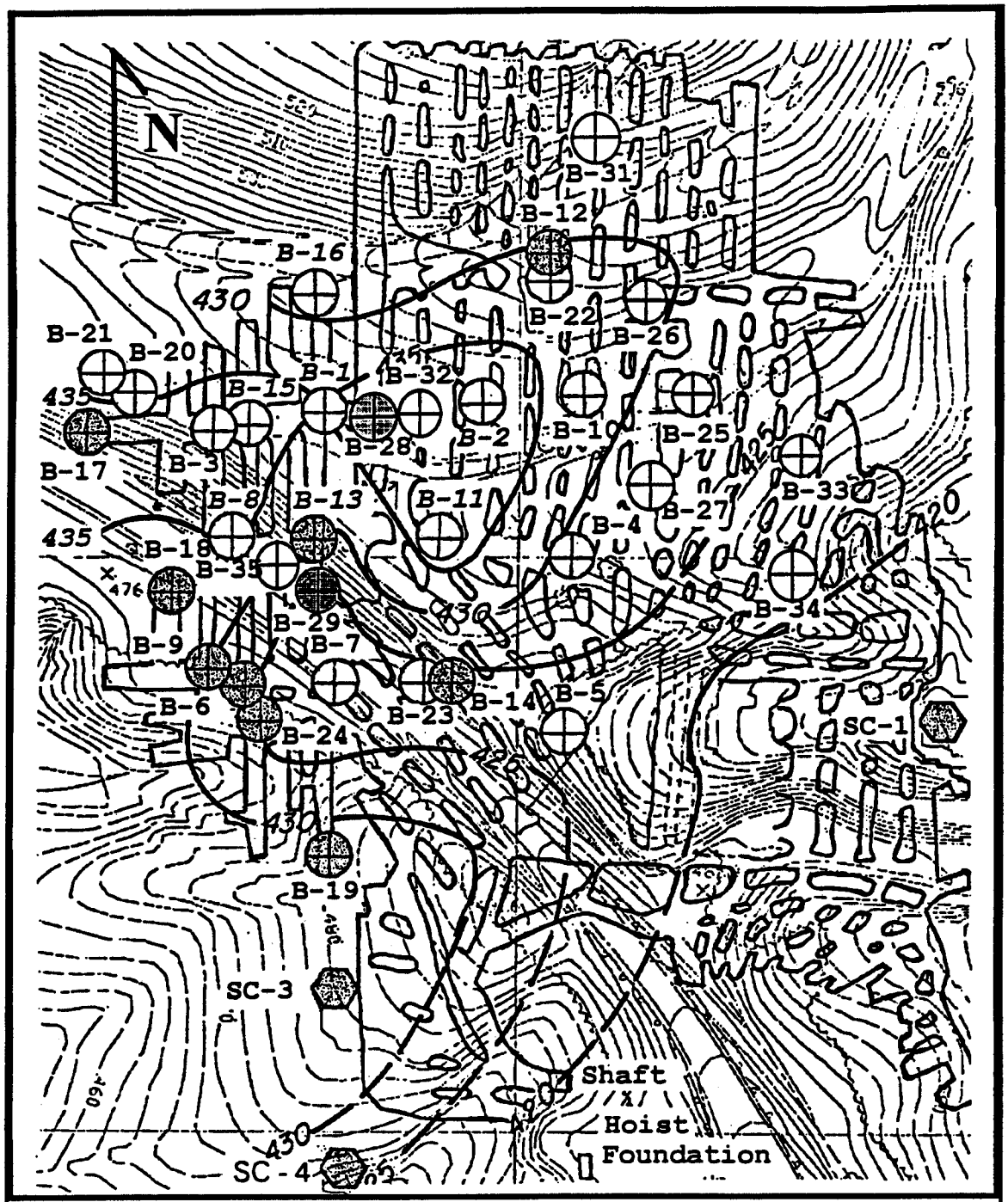


FIGURE 1.

MINE MAP



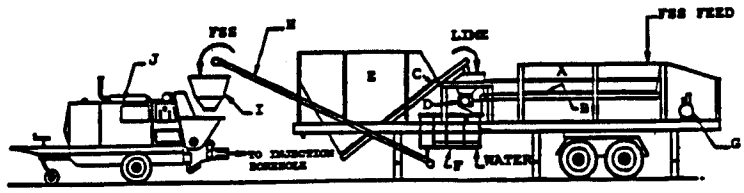
BOREHOLE - VOID

BOREHOLE - COAL

MONITORING WELL

FIGURE 2.

BOREHOLE LOCATION



A - Feed Hopper
B - FSS Belt Feed
C - Lime Screw Feed
D - Lime Weigh Scale
E - Lime Silo
F - Pug Mill Mixer
G - Air Compressor
H - Mixer Discharge Belt
I - Pump Feed Hopper
J - Injection Pump

FIGURE 3.
DILUTION PLANT

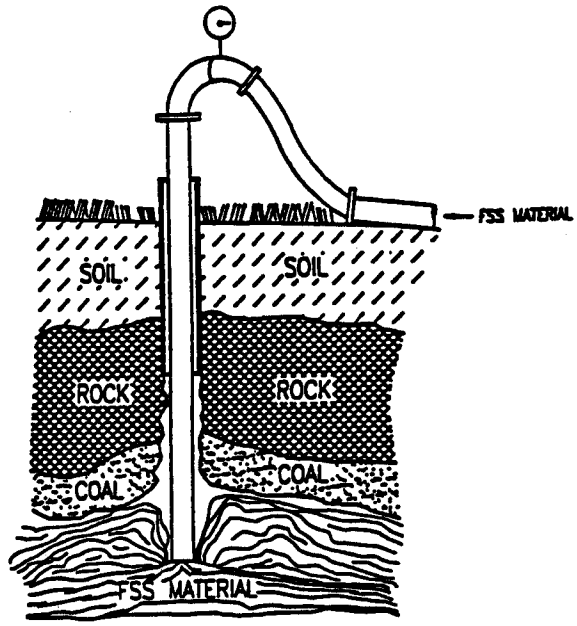


FIGURE 4.
INJECTION BOREHOLE
WITH TREMIE PIPE

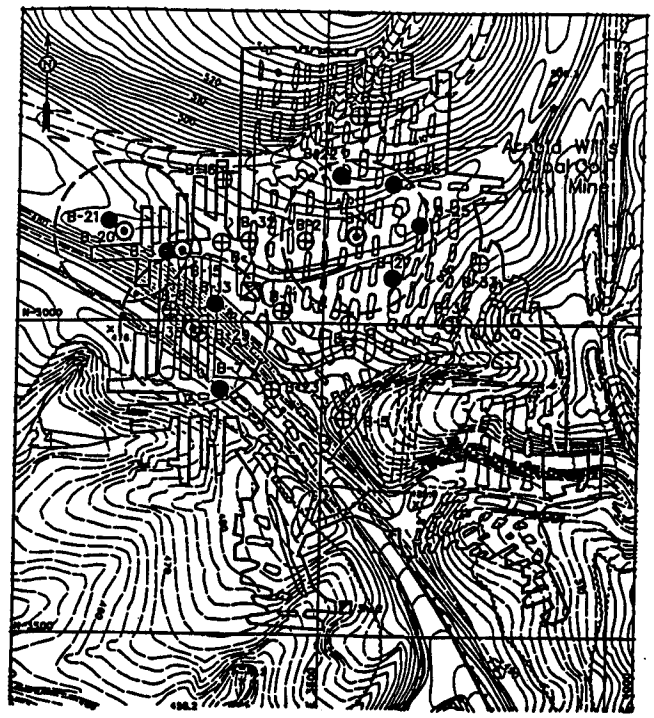


FIGURE 5.
FSS INJECTION
CALCULATED VOLUMES

Borehole B-10 Flooded Mine Void

FSS 6,315 tons Ave. 371.5 tons/day
Dilution Water 522,040 gals. Ave . 30,708 gals./day
Quicklime 229 tons Ave. 13.4 tons/day
FSS Grout Injected 9,374 tons or 6,782 cubic yards
QA/QC tests → 17 Samples = 1 test / 398 yrds^3 injected
Ave.: Solids - 56.10 % Lime - 4.36% FA/FC Ratio - 0.80:1.00

Cores - Test Results

9 cores collected, 9 months after injection
Ave. Strength (U.C.S.) 190.1 psi Range → 99 - 479 psi
Ave. Density (Wet) 96.9 lbs/ft^3 Range → 93 - 102 lbs/ft^3
Ave. Permeability (2 cores) 3.58 x 10^{-5} cm/sec

Borehole B-20 Dry Mine Void

FSS 3,938 tons Ave 393.8 tons/day
Dilution Water 351,100 gals. Ave. 35,110 gals./day
Quicklime 144 tons Ave. 14.4 tons/day
FSS Grout Injected 5,538.1 tons or 4,318 cubic yards
QA/QC tests → 10 Samples = 1 test / 432 yrds^3 injected
Ave.: Solids - 58.70% Lime - 4.43% FA/FC Ratio - 0.73:1.0

Cores - Test Results

2 cores collected , 12 months after injection
Ave. Strength (U.C.S.) 316.5 psi Range → 276 - 357 psi
Ave. Density (Wet) 95.8 lbs/ft^3 Range → 90 - 101.2 lbs/ft^3
Ave. Permeability (3 cores) 3.14 x 10^{-6} cm/sec

Borehole B-35 Partially Flooded Mine Void

FSS 3,814 tons Ave. 381.4 tons/day
Dilution Water 46,200 gals. Ave. 34,620 gals./day
Quicklime 149 tons Ave. 13.5 tons/day
FSS Grout Injected 5,993.7 tons or 4,874 cubic yards
QA/QC tests → 11 samples = 1 test / 443 yrds^3 injected
Ave.: Solids - 56.50 Lime - 4.39% FA/FC Ratio - 1.03:1.00

Core - Test results 1 Core collected 12 months after injection
Strength (U.C.S.) 348 psi
Density (Wet) 97.37 lbs/ft^3
Ave. Permeability (2 cores) 1.60 x 10^{-7} cm/sec

ENGINEERING DESIGN FOR THE INJECTION OF ALKALINE CCBS INTO A MARYLAND COAL MINE TO ABATE ACID MINE DRAINAGE

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Abstract

The Maryland Department of Natural Resources Power Plant Research Program and Maryland Department of the Environment Bureau of Mines have undertaken the Western Maryland Coal Combustion By-Products (CCB)/Acid Mine Drainage (AMD) Initiative, a joint effort with private industry to permanently abate AMD in Western Maryland. The Initiative's current undertaking, the Winding Ridge Project, is a small-scale demonstration of the wet injection of alkaline CCBs into an underground coal mine in Garrett County, Maryland, with injection scheduled forFall 1996.

The engineering design includes logistical, transportation and on-site storage considerations, construction/injection components, quality control procedures, and injection procedures. Design criteria were based on mine geometry and expected in-situ grout behavior. The optimal grout formulation was determined by subjecting candidate alkaline CCBs, with varying admixtures of water, fly ash, and quick lime, to laboratory tests. Testing included grout flowability under submerged AMD conditions, unconfined compressive strength, and grout cohesion.

Introduction.

The Maryland Department of Natural Resources (DNR) Power Plant Research Program (PPRP) and the Maryland Department of the Environment Bureau of Mines (MDE) have undertaken the Western Maryland Coal Combustion By-Products (CCB)/Acid Mine Drainage (AMD) Initiative, a joint effort with private industry to develop permanent solutions to abate AMD. The Initiative is based on the concept that alkaline CCBs generated by clean coal technologies, such as fluidized bed combustion (FBC) and flue gas desulfurization (FGD), can be injected into underground mines to prevent the formation of AMD by sealing mines from exposure to oxygen and water. The Initiative's goal is to demonstrate the beneficial application of alkaline CCBs to abate AMD from underground coal mines, through the implementation of several scale-up projects. Ultimately, the Initiative is targeting abatement of AMD from serious AMD sources in the state, such as theKempton Mine Complex.

The Winding Ridge Project (the Project) is the Initiative's first demonstration project. The Project began with a site screening and selection process conducted by MDE in which mine size, geometry. acidic discharge flow, access, topography, and land ownership characteristics were evaluated to identify the most suitable mine site for injection. The Frazee Mine, located at the top of Winding Ridge about one mile east of Friendsville, Maryland, was determined to be the most favorable location for the first demonstration project. The Frazee Mine produced coal from the Upper Freeport seam.

The Prqject Scope of Work consists of multiple tasks grouped into six phases, extending from the initial mine characterization to eventual mineback at the site. Project phases and objectives include

the following:

1. Phase I - Frazee Mine Characterization: Develop a mine map, determine the hydrology of the mine, establish baseline water quality conditions, and identify the regulatory permitting requirements for implementation of the Project.
2. Phase II - Characterization and Procurement of Alkaline CCBs for Mine Injection: Determine the optimal formulation for the alkaline CCB grout and procure material sources.
3. Phase III - Design of Underground Injection Program: Prepare an engineering design for the injection of alkaline CCBs and procure all necessary permits.
4. Phase IV - Injection of Alkaline CCBs: Inject the CCB grout into the Frazee Mine in accordance with the engineering design.
5. Phase V - Post-Injection Monitoring: Monitor the effectiveness of the injected alkaline CCBs to abate AMD and observe the physical characteristics of the injected materials.
6. Phase VI - Mineback for In-Situ Grout Inspection: Expose the injected materials for detailed examination of their emplacement and in-situ weathering. Phase VI could also include recovery of the remaining coal at the site.

The remainder of this paper focuses on Phases II and III of the Project. The characteristics of the alkaline CCB grout formulations are presented first, as they influence the engineering design for grout injection. The engineering design is then discussed in terms of materials handling, water management, mixing and injection, and site restoration.

Phase II - Summary of Alkaline CCB Grout Formulation Laboratory Study

The Project team set as its primary goal the complete filling of mine voids at the Project site using a hydraulic (wet) injection of alkaline CCBs. This will minimize the contact between exposed coal surfaces, air and water, thus preventing the future formation of any significant amount of AMD.

The optimum grout, therefore, must have good flowability with minimum bleed and settlement. These properties of grout workability are balanced against the need for acceptable long-term strength characteristics to prevent mine subsidence. A laboratory study was conducted by Southern Illinois University at Carbondale (SIUC) to evaluate different ratios of the following grout components, in order to determine the grout formulation that would best meet the Project requirements:

1. FGD by-product from Virginia Power Company's Mt. Storm power plant, Mt. Storm, West Virginia;
2. PCC Class F fly ash from Virginia Power Company's Mt. Storm power plant, Mt. Storm, West Virginia;
3. FBC by-product from Morgantown Energy Associates' power plant in Morgantown, West Virginia.
4. Quick lime - used only with the FGD by-product and Class F fly ash materials.
5. Water - mine water and potable spring water were investigated.

Essentially, two grout mixes were tested. One consisted of FGD by-product, FBC by-product, and Class F fly ash, while the other consisted of FGD by-product, quick lime, and Class F fly ash. Each grout mix was tested with varying percentages of the component materials, and each was prepared using mine and spring water.

In addition to requiring a grout mix with suitable workability and strength properties, the Project seeks to minimize costs by utilizing readily available CCBs generated or handled near the Project site, and nearby water sources, particularly mine water. The emphasis on cost minimization throughout the Project will encourage the development of mine injection techniques that will be economically feasible for larger scale projects. The Project therefore did not consider using additives, such as plasticizers or bentonite, that could improve grout characteristics.

Selected results of the final mix testing are summarized in Table 1. The FGD-FBC mixes in Table 1 demonstrated a bleed of less than 2%, slumps in the range of 8 to 8.5 inches, and 28-day compressive strengths ranging from about 600 to 700 psi. Trial mix testing had shown that increasing the water content will increase flowability of these mixes, but will also cause a high bleed (i.e., above 3%). When the FBC content was reduced to 20% during trial testing, greater bleed and settlement and lower compressive strength were observed.

FGD-lime mixes were also investigated. These mixes generally had better flowability, less bleeding, and higher 28day strength compared to FGD-FBC mixes (Table 1). Mixes with 10% lime, by dry weight, had much better strength characteristics than those made with only 5% lime. However, using large quantities of lime poses operational difficulties, and entails much greater cost. Mixes with 10% lime and 40% water content, and approximately equal parts fly ash and FGD by-product, had a slump in the range of 8 to 8.5 inches. The compressive strength after 28 days was about 1,100 to 1,200 psi.

SIUC concluded that it is possible to formulate either type of mix (FGD-FBC or FGD-lime) to safely achieve suitable workability and strength properties for mine injection. The FGD-FBC mix was selected for the demonstration project over the FGD-lime mix largely because of the lower costs of FBC by-products compared to lime. Use of the FGD-FBC mix also has an environmental benefit in that the injection materials consist of 100% by-products that otherwise would require disposal, typically by landfilling. The Project team selected the grout mix consisting of 38% fly ash, 32% FGD by-product, and 30% FBC material, with 38% water, as the optimal formulation.

Phase III - Engineering Design for Mine Injection

Permitting

Permitting issues were addressed while preparing the engineering design. The Project team determined that both an approved Erosion and Sediment Control Plan and an Air Permit to Construct must be prepared and implemented for injection. However, other permits, including Wetlands/Waterways Construction, Underground Injection Control, and NPDES were deemed unnecessary by the appropriate state agencies, based on the unique nature and scope of the Project.

Site Preparation and Materials Handling

In order to allow heavy equipment and by-product delivery trucks to reach the Project site, the access road must be improved. This is being done through the placement of a gravel road that primarily follows the existing dirt/gravel access road to the site. On-site temporary roads will also be required for trucks to access the material stockpiles. Erosion and sediment control measures will be required for the improved access road and for soil disturbances on the site itself, such as the construction of the on-site temporary roads and the material stockpile areas.

Grout injection will take place during a two-week field effort in Fall 1996. As a conservatively large estimate, about 3,900 cubic yards (cy) of material is needed to fill the Frazee Mine, which will entail about 20 to 25 truckloads of CCBs delivered daily during the injection. Using the mix ratios determined in the laboratory study, the following volumes of CCBs and water will be needed for the Project:

1. Fly ash - 2,050 cy, assuming a non-compacted density of 66 pounds per cubic foot (pcf) and a moisture content of 16 percent.
2. FGD by-product - 1,970 cy, assuming a non-compacted density of 62 pcf and a moisture content of 24 percent.
3. FBC by-product - 1,300 cy, assuming a non-compacted density of 80 pcf and a moisture content of 12 percent.
4. Water - 206,000 gallons for mixing and 20,000 gallons for daily flushing of equipment and

lines, for a total Project water requirement of 226,000 gallons.

5.

Up to 250 trucks will be required to deliver this volume of material to the site. All CCBs will be transported in a pre-conditioned state in covered, bottom dump trailers to minimize fugitive dust emissions. All transportation activities will be conducted under air permits currently held by the coal companies and/or power plants donating the CCBs.

It is anticipated that material stockpile areas will be sized to accommodate a minimum of 250 cy of fly ash, 160 cy of FBC by-product, and 240 cy of FGD by-product. This represents a 1.5-day supply of material, at an expected injection rate of nearly 40 cyihour. When material is not being delivered or being removed to the mixing plant, the piles will be covered in plastic. Additional dust suppression controls, such as hydration of the surface of exposed material, will be implemented as necessary. Prior to placing CCBs on the ground, the top 8 to 12 inches of topsoil will be removed and stockpiled, to be replaced later during the site restoration. The topsoil stockpile will also be covered in plastic.

Water Management

As mentioned in the previous section, approximately 226,000 gallons of water will be needed over the course of the Project. The mine pool is estimated to consist of about 350,000 gallons of acidic water (pH about 3 to 4). Assuming 50% of the mine water is recoverable, about 175,000 gallons may be available for the grout mix. Additional water, if needed, will be obtained from the Town of Friendsville's abandoned water line adjacent to the Project site, a maximum of about 500 feet from any injection hole (Figure 1).

The injection will require 13,000 to 20,000 gallons of water daily. Aboveground storage tanks will be provided at the site, with a capacity of about 40,000 gallons, equivalent to two or three days of storage. The water supply to the tanks will consist of connections from both the mine dewatering and the municipal water line. The tanks will be filled with mine water during contractor mobilization and site preparation, prior to the commencement of grout mixing. The storage facility will be the sole supply of water to the mixing and injection equipment.

Besides ensuring an adequate supply of mixing water, another significant water management issue involves the handling of mine water as injection proceeds and displaces the mine pool. Based on our current understanding of mine conditions, the proposed injection sequence will direct water towards open boreholes where it can be extracted with a submersible pump. The current flow of AMD from the mine opening may continue throughout the injection activities and may increase somewhat during injection at the most downdip boreholes. A small discharge may also occur at a currently dry mine opening, due to changes in flow paths as grouting proceeds. Depth-to-water measurements will be taken in open boreholes prior to the start of injection each day to monitor the movement of mine water during the Project.

Mixing and Injection

Injection holes and their associated mine voids will typically be filled in one continuous grout injection stage (a stage being an uninterrupted period of injection at a particular hole). If mine backfilling at an injection borehole requires two or more injection stages (due to mechanical problems, end-of-day time constraints, or other reasons), the borehole will be completely flushed with water to provide a clear flow path for the next stage of the injection.

The injection system will be capable of pumping a minimum of 40 cy/hour while producing 150 psi of pressure at the injection point, assuming a slump of 8 inches for the grout mixture. The anticipated injection sequence has been developed based on three key factors:

1. Injection will be completed in an updip manner (i.e., from areas of lower tunnel elevation to higher tunnel elevation) where possible. This will help reduce the chance of accidentally

sealing adjacent boreholes prior to using them for injection.

2. Grout injection will be used to assist in the control and recovery of mine water. Sealing certain areas of the mine first will reduce the possibility of uncontrolled discharge through the mine openings. The grout backfill will also be used to displace the mine water toward open boreholes to aid in dewatering.
3. Grout injection will occur in both dry and submerged conditions. The injection sequence is set to allow injection under both types of mine conditions. The Project will start with injection into dry portions of the mine and then move towards injection under submerged conditions.

As noted earlier, the selected optimal grout mix consists of 32% FGD by-product, 38% fly ash, and 30% FBC by-product. Moisture content was quite variable in the laboratory samples, which in turn has a significant impact on the amount of water required for the mix. Therefore, moisture contents will be determined in the field periodically by sampling material stockpiles. Slump tests will be conducted on the mixed grout for quality control, in addition to visual inspection of the materials prior to and after mixing.

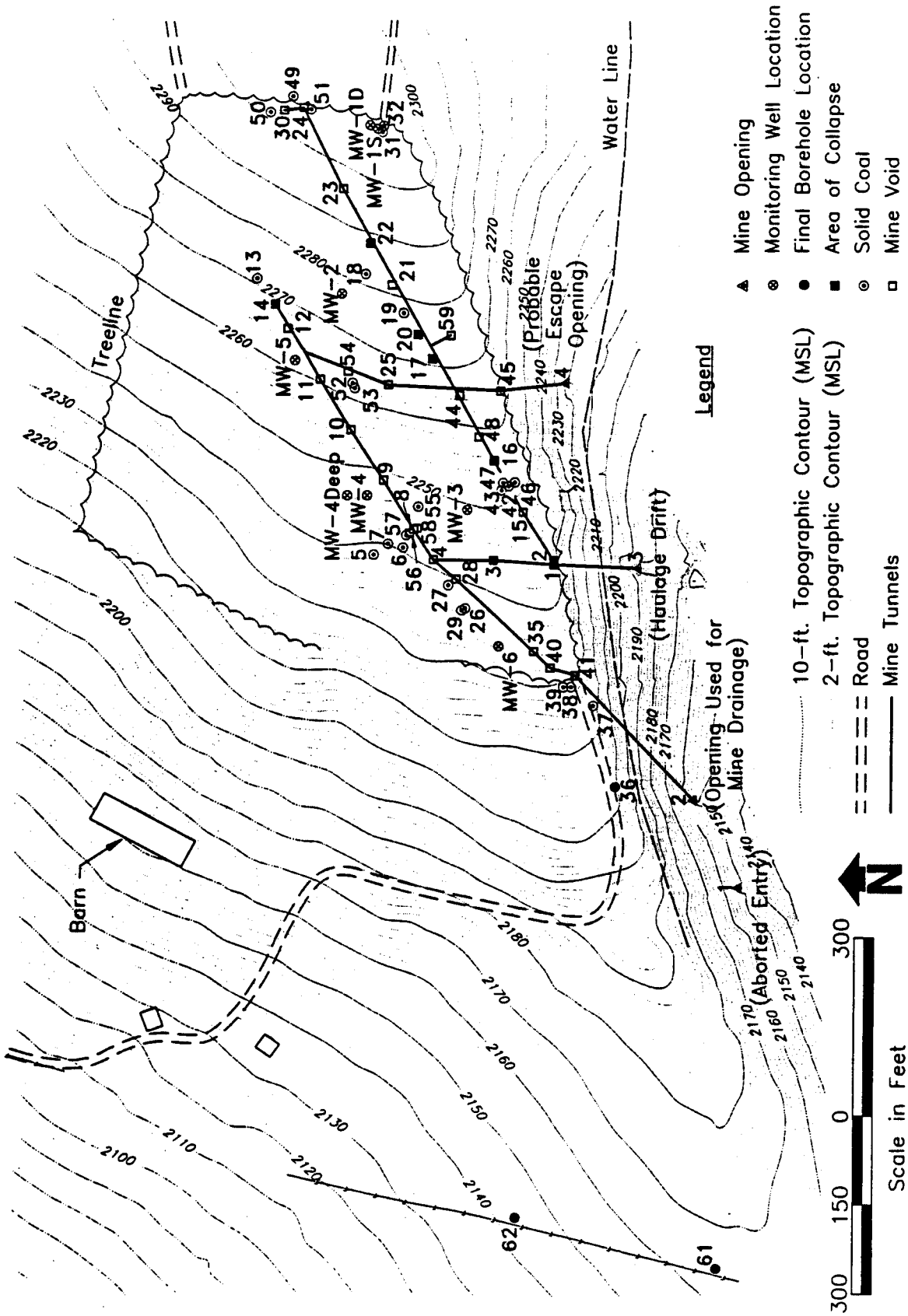
Site Restoration

When mine injection activities are complete, each borehole will be backfilled with grout to within two feet of the ground surface. After the grout within the injection hole has set, the soil around the top two feet of the casing will be excavated, the casing will be cut, and the top two feet of casing removed. The excavated area will then be backfilled with topsoil and the entire site regraded to match pre-project contours. Some boreholes will be preserved for future observations and core sampling during post-injection monitoring.

Table 1. Selected Results of Grout Mix Testing

Grout Mix	Slump (in.)	Bleed (%)	28Day Strength (psi)
30% fly ash, 40% FGD, 30% FBC plus 38% water	8.25	1.7	627
38% fly ash, 32% FGD, 30% FBC plus 38% water	8.50	1.8	711
50% fly ash, 40% FGD, 10% lime plus 40% water	8.10	1.0	1,095
40% fly ash, 55% FGD, 5% lime plus 38% water	9.40	1.8	548

Figure 1. Detailed Site Location Map for the Winding Ridge Project.



USE OF WET FGD MATERIAL FOR RECLAMATION AND AMD ABATEMENT IN ABANDONED ACIDIC COAL REFUSE PILES

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Abstract

American Electric Power (AEP) and the Ohio State University conducted a field and laboratory greenhouse research program at the Rehoboth Mine Reclamation site to determine if direct revegetation of acidic coal refuse was possible by amendment with wet FGD material and to determine what the potential effects of such amendment would be on coal refuse, plant and water quality. Also, AEP and the Ohio Department of Natural Resources conducted a pilot program at the Rehoboth site to study the slope stability, strength, and other construction constraints associated with application of FGD material as a neuralization agent as well as an impermeable cap.

Introduction

In the Eastern U.S.A., coal mining and coal preparation practices in the years prior to enactment of stringent environmental protection and reclamation laws frequently resulted in dumping of coal cleaning refuse into large piles. Oxidation of pyritic material in the coal refuse can cause these piles to become hyper-acidic with extremely high levels of soluble Fe^{3+}, Al^{3+}, and SO_4^{2-}[1]. The refuse piles, which can be several hectares in area and several meters in depth, can cause severe offsite degradation of water quality due to acidic drainage and leaching of Fe and S, as well as deposition of acidic sediments in waterways[2]. Revegetation of such sites is challenging and traditionally has involved application of limestone to the pile surface and covering the pile with a 20-cm layer of topsoil to provide a suitable medium for plant growth[3].

Frequently, however, suitable borrow soil does not exist adjacent to the refuse pile. Cost of reclamation increases dramatically as the distance to the borrow area increases and necessitates disturbing another landscape. Direct revegetation of the refuse using suitable amendment materials would represent substantial economic and environmental benefits.

Flue gas desulfurization (FGD) material is a by-product of scrubbing SO_2 from the emissions of coal-tired boilers. This material, which is primarily $CaSO_3$, is normally blended with coal fly ash at a 1: 1 ratio and stabilized with 2-3% CaO prior to landfilling. When FGD is placed in an aerobic soil environment the $CaSO_3$ component of FGD will readily oxidize to form gypsum ($CaSO_4 \cdot 2H_2O$). Gypsum has been shown to have beneficial effects in acidic subsoils primarily by supplying Ca and reducing toxicity of Al[4]. Thus the combination of gypsum and alkalinity in FGD may make it an ideal AL substitute for reclamation of acidic coal refuse.

Greenhouse and field experiments were conducted to investigate the revegetation efficacy and potential environmental impacts of FGD and compost as amendments for revegetation of acidic coal refuse. In each experiment FGD was applied with and without compost and the effects on plant growth and refuse quality were determined in relation to those of agricultural lime (AL).

The pilot program was conducted to study the slope stability, strength, and other construction constraints associated with the application of FGD material from AEP's Conesville Plant to an abandoned coal refuse pile. The FGD material, due to its neutralization potential (TNP of 15%) will act as a buffering agent when mixed with the acidic coal refuse pile. Also, due to the low permeability of FGD material, it will also be applied to the mine gob as an impermeable cap to reduce infiltration and the resulting production of acid mine drainage. Results of this experimental project will be used to determine design and construction parameters for the future full scale reclamation project at the site.

Materials and Methods

The field experiment and the pilot program were conducted at an abandoned coal refuse pile located near New Lexington, OH. Coal refuse for the greenhouse study was collected from the O-6 in depth of this refuse pile. The refuse was extremely acidic with a pH of 2.3 and a potential acidity of 160 cmol kg-‘. The FGD used in these experiments had a neutralizing potential of 15% calcium carbonate equivalency and was obtained from the Conesville, Oh power plant of the American Electric Power Corporation. Compost **used** in these experiments was produced at the Kurtz Brothers Inc. composting operation located near Columbus, OH. The compost was produced from a feedstock of leaves, brush and grass clippings and had a C to N ration of 20: 1.

Greenhouse Experiment

All materials were air-dried and passed through a 10 mm screen before being used. A 15 in layer of coal refuse was placed in the bottom of a,24 in tall x 6 in diameter PVC pot. Above this layer was placed a 7.5 in layer of coal refuse mixed with either FGD (500 g kg-‘) or AL (80 g kg-‘) both alone and with compost (50 g kg-‘). Preliminary incubation studies with coal refuse and FGD and AL showed that these amounts would increase refuse pH to 7. Each amendment combination was replicated 3 times. The pots were planted with a mixture of orchardgrass, fescue, timothy, and birdsfoot trefoil. Pots were watered to maintain sufficient moisture for plant growth, and once each month were leached to simulate leaching due to natural rainfall. After a 3 month establishment and growth period plant growth was harvested once each month for 4 harvests. Harvested plant material was dried and weighed, and material from the final harvest was ground, digested and analyzed by ICP for total concentration of Al, As, B, Ba, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, S, Se, and Zn. Leachates collected at time 0, 2, and 5 months were analyzed for pH and electrical conductivity (EC) and by ICP for the elements listed above. At the conclusion of the experiment columns were sampled in 3 depth increments: O-7.5, 7.5-15, and 15-22.5 in. Sampled material was dried, ground to pass a 2-mm screen, analyzed for pH and EC, and extracted with a 1: 10 ratio (w/w) of water. The water extracts were analyzed by ICP for the elements listed above.

Field Exueriment

In the fall of 1994 four rates of FGD (300,500, and 700 tons acre“) and one rate of AL (80 tons acre-‘), each with and without compost (50 tons acre-‘) were applied to 20x22 ft plots and incorporated to a depth of approximately 8 in with two passes of a moldboard plow and multiple passes with a rototiller. These treatments were arranged in four randomized complete blocks. Immediately after treatment the plots were planted with orchardgrass, perennial ryegrass, timothy, birdsfoot trefoil, ladino clover, and winter wheat and mulched with wheat straw. One week after treatment , and again in spring and fall of 1995 core samples (24 in depth) were collected from the plots in 4 in increments. Sampled material was dried, ground and analyzed as described for the greenhouse pot samples. Vegetative growth was cut on July, 1995 and harvested plant material was analyzed as described in the greenhouse study. Data presented and discussed in this paper will focus on the AL and 500 ton acre-’ FGD treatments.

Pilot Program

Staging Area

A staging area for unloading and stockpiling FGD and lime kiln dust for mixing these materials was prepared at the base of the coal refuse pile. A large area was bulldozed level to provide ample space for tactor-trailer rigs to turn around and unload. Also, enough space had to be provided to stockpile 7,000 to 10,000 tons of FGD and up to 160 tons of lime kiln dust.

Coal Refuse Pile

Site grading for the reclamation pilot project was targeted at 4-5 acres on the north-northwest slope of the coal refuse pile. The objective of the site grading was to develop firm, smooth, uniform slopes of at least 4h:lv as a base for an FGD cap. Upon completion of grading with the dozers, the reconfigured slope was proof rolled with a smooth drum vibratory roller in an effort to locate and eliminate any soft spots and to tighten the surface so as to minimize erosion prior to capping.

Sediment Basin

A sediment basin was constructed, lined with FGD, to test the material's suitability as pond liner and to capture the runoff from the pilot site. The location chosen was an old basin which was filled with coal fines. The fines were saturated and soft, and could not support equipment loads. A sump was excavated using a hydraulic excavator at the northeast comer of the basin and water was pumped out. As the site was dewatered the coal tines were excavated and spoiled.

Once all the coal tines and mud were removed, the dike slopes were repaired and graded to approximately 3h:1v using locally borrowed clay and shale.

A ditch to convey runoff water from the test site to the basin was concurrently constructed using in-situ materials. The ditch and basin were constructed so that only runoff from the test areas is captured. A primary spillway consisting of two 24 inch diameter pipes was provided, and an emergency spillway was also provided.

Results and Discussion

Greenhouse Experiment

Leachate pH remained low throughout the study, however EC and concentrations of S, Ca, Al, and Fe in the leachate decreased with time for all surface treatments. This indicates that once the pile surface has been stabilized and revegetated the quality of water seeping from the refuse pile will gradually improve.

Concentrations of Ca were larger with FGD than with AL which would be expected given the large solubility of gypsum compared to calcium carbonate. Boron, however, was in the range 6 to 17 mg L^{-1} for FGD leachates and 0.8 to 1.5 mg L^{-1} for AL leachates. This reflects the presence of relatively soluble B in FGD and indicates the B was being moved out of the surface layer.

Amendment with FGD increased coal refuse pH to 7 or greater in the depth of incorporation, but had no effect on the pH on underlying coal refuse.

Plant uptake of all measured elements was similar for FGD and AL with the notable exception of B. Plant tissue B concentrations were in the range 380 to 450 mg kg^{-1} with FGD and in the range 13 to 16 mg kg^{-1} with AL. While there was some evidence of B toxicity with FGD in the first harvest, it was no longer visible in subsequent harvests.

Field Experiment

As was seen with pH and in the greenhouse study, downward movement of Ca was greater with FGD than with AL. One year after amendment application the FGD combined with compost was the most effective treatment in reducing soluble Fe throughout the profile. The amendment treatments had similar effects on soluble Al. As was seen in the greenhouse, FGD produced large increases in water soluble B which again decreased with time.

Although some plant growth was produced with all amendment treatments, FGD produced larger yield than AL. Addition of compost to the FGD further increased yield whereas with AL there was no effect from compost. Plant tissue concentrations of major elements were similar for FGD and AL treatments. Compost, however, increased tissue P and K concentrations with both FGD and AL. Plant tissue trace element concentrations were not affected by the amendments, again with the exception of B. With AL tissue B was 1.2 mg kg^{-1} while with FGD it was 40.5 mg kg^{-1}, and with FGD and compost tissue B increased to 83.8 mg kg-'.

Pilot Program

Sediment Basin and Ditch Liner

The criteria for basin and ditch liner material are that it be relatively impervious (k, = 10^{-6} cm/set) and durable (resist erosion). To increase durability and strength in an exposed situation, where the FGD will be subjected to erosion and freeze-thaw forces, the FGD should be enriched with a reagent (lime kiln dust, cement kiln dust, lime, or cement). FGD, as produced at the plant, typically has a compressive strength at 56 days of 60-100 psi. The minimum compressive strength necessary for the FGD to resist the actions of freeze-thaw has not been specifically defined, but, based upon experiences at other test projects, it is believed that a minimum compressive strength of 400 psi must be achieved before it is exposed to freeze-thaw cycles. The reagent added at this project was lime kiln dust (LKD) donated by the Dravo Lime Company. The lime kiln dust has a free lime content of 15% to 18% and we attempted to produce an FGD/LKD blend that had 25% to 30% LKD.

Absent the availability of a pug mill, which was not economical for this scale of project, we were forced to develop a field mixing procedure which would produce a thoroughly mixed homogenous product of approximately the desired proportions using front end loader, agricultural disc and rototiller.

The best method of mixing was determined to be when a front end loader was used to initially blend the materials. The front end loader turned over the combined pile of FGD and lime kiln dust several times. This helped to break down large clumps in the FGD and achieved a moderately uniform mixture of the two materials. This mix was then loaded into a truck and taken to the basin where it was dumped and spread in an 6-8 inch thick lift. This action provided additional mixing and breaking down of clods. Finally, the material was rototilled with 3 to 4 complete coverages by the rototiller. This produced a very uniform blend with clumps no larger than 3/4" to 1" in diameter. The mix was then compacted with a Bomag smooth drum vibratory roller (Bomag model BW6) towed by a D6H dozer.

Coal Refuse Cap

This portion of the pilot project investigated various construction techniques for placing FGD on the regraded surface of the mine refuse to act as an impervious cap to minimize the infiltration of surface water, and thereby prevent the creation of acid leachate. The project also investigated various construction methods for blending FGD and mine refuse to create deep root penetration zones for the cap, and to create artificial topsoil.

The 5 acre test site was initially divided into 10 plots with each plot being capped with a different technique or method. However, during the course of the project it was decided to reduce the number of tests, and plots 8, 9, and 10 received the same treatment. Plots 1, 2, and 3 were each capped with FGD in lift thicknesses of 2', 4', and 1' respectively. The remaining plots were capped with a 1:l mix of FGD and coal refuse blended with different construction equipment and methods.

Once the cap zone was completed the site was divided into three equal segments and topsoiled. Each segment received a different artificial topsoil cover. Segment 1 had a topsoil which consisted of 12 inches of coal refuse blended with 1000 tons per acre of FGD; Segment 2 had a topsoil which consisted of 12 inches of coal refuse blended with 1000 tons per acre of FGD and with 100 tons per acre of yard

waste compost blended into the top 3 inches; Segment 3 had a topsoil which consisted of 12 inches of coal reuse blended with 1000 tons per acre of FGD and with 33 tons per acre of sewage sludge blended into the top 3 inches. The yard waste compost was obtained from the Kurtz Brothers composting facility in Grove City, Ohio, and the sewage sludge was obtained from the city of Baltimore, Ohio.

Conclusions

Greenhouse/Field Experiments

Wet FGD scrubber material was found to be an effective amendment for revegetation of hyper-acidic coal refuse. When applied at rates with equivalent alkalinity to AL it was equally effective as AL in neutralizing refuse acidity. With FGD Ca was more soluble and moved more rapidly down the profile than with AL. Application of compost with FGD provided additional pH buffering and appeared to enhance downward movement of Ca. Compost also appeared to increase the solubility and downward transport of Al and Fe, two elements which can be phytotoxic in acid conditions. In the greenhouse FGD was equally effective as AL in ameliorating phytotoxic conditions in the refuse and allowing plant growth, in the field, plant growth with FGD was superior to AL. Compost improved plant growth with both AL and FGD, although in the field the increase was greater with FGD. Salt-loading of drainage waters was not increased by FGD, nor was there a detectable increase in concentrations of trace metals in leachates from FGD amended refuse. Potential problems with use of FGD include high soluble salts and soluble B in the rooting zone immediately after FGD application. Phytotoxicity was not observed in the field and concentrations of soluble salts and B decreased with natural leaching. Therefore, the potential for detrimental effects of FGD on early growth and establishment could be diminished by delaying planting for several weeks after FGD incorporation.

Pilot Program

Unless there are overriding load bearing requirements, it is recommended that liners be constructed with raw FGD without any additional pozzolanic agent added. The liner thickness should be at least 44 inches and it should be placed and compacted in multiple lifts. This will ensure that 12 inches of liner are below the maximum frost penetration (32” +/-) for this area. The liner should be covered with topsoil and seeded, or with geotextile and cover stone, in all exposed areas above the water and to a point at least 18 inches below the water line to provide surface protection. To attain the necessary strength to resist freeze-thaw it now appears that approximately 50% (by dry weight) of LKD would have to be blended in with the FGD. At that ratio a cost analysis must be made to compare the economics of adding LKD, versus quick lime, or cement at lower percentages but higher unit cost.

When the FGD material being used for impervious cap has been stockpiled for several weeks the curing process will be quite advanced, and in those cases it is recommended that the impervious cap be constructed in thinner, multiple lifts to ensure the construction of a homogenous cap system. Subgrade slopes should be at 5h:lv or flatter in an effort to allow trucks hauling FGD or coal refuse to traverse across preceding lifts. This will greatly expedite the placing operation.

As shown in table 1, the undisturbed water from the site was highly acidic and toxic with high concentrations of heavy metals. On the other hand the water quality of the FGD lined sediment basin meets the Ohio EPA’s drinking water standards which highlights the profound environmental benefits of FGD material in an abandoned coal refuse pile.

Unfortunately, bad weather set in before the entire site could be seeded and mulched, and that work will have to be done in the spring of 1996, so a large scale evaluation of sewer sludge versus yard waste compost versus a mixture of only refuse and FGD is not yet available.

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Table 1. Water Quality Analysis Data

Parameter	Site Undisturbed Water (mg/l)	FGD Pond Water (mg/l)	OEPA Drink'g Water Standards (mg/l)
Aluminum, Al	414	0.12	
Arsenic, As	0.566	0.01	0.05
Barium, Ba	0.03	0.041	2
Beryllium, Be	0.0224	< 0.0002	
Cadmium, Cd	0.0023	< 0.0005	0.005
Chromium, Cr	0.189	0.003	0.1
Copper, Cu	0.167	0.003	
Iron, Fe	2640	0.12	
Lead, Pb	0.117	< 0.002	0.05
Manganese, Mn	14.52	0.01	
Mercury, Hg	< 0.0002	< 0.0002	0.002
Nickel, Ni	0.381	0.003	
Selenium, Se	< 0.02	0.012	0.05
Silver, Ag	< 0.0002	0.0006	
Sodium, Na	9.4	34.9	
Thallium, Tl	0.033	0.002	
Vanadium, V	0.264	< 0.003	
Zinc, Zn	1.46	< 0.004	
Acidity	10400	< 1	
Alkalinity	< 1	39	
Chloride, Cl	5	211	
Conductivity	8380	2930	
Fluoride, F	< 0.1	< 0.1	
Residue-Filterable, TDS	13100	2740	
Sulfate, SO4	9040	1490	
pH	2.06	8.56	

Figure 1. Effect of AL, FGD, and compost on the distribution of pH, and water soluble concentrations of Fe in 22.5 inch pots of coal refuse.

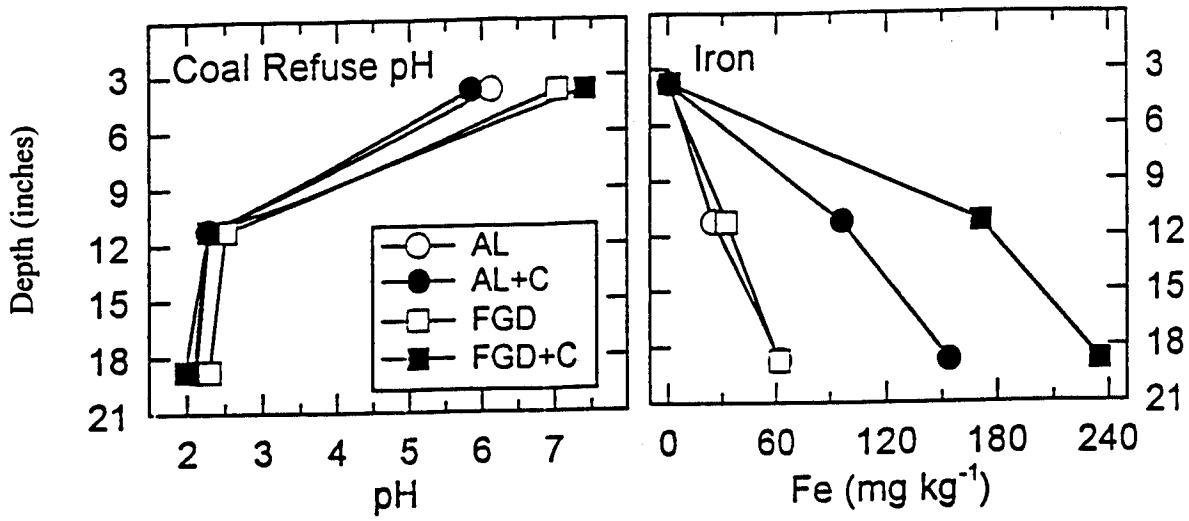
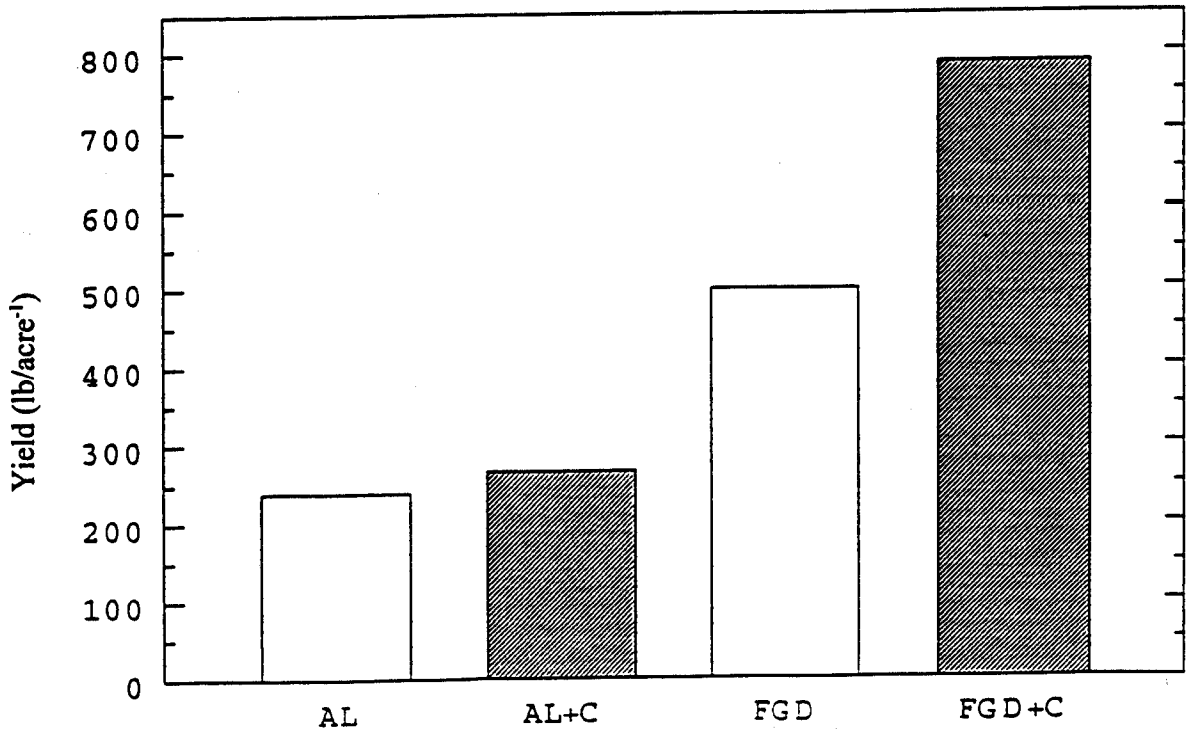


Figure 2. Total 1995 plant yield from coal refuse amended with AL, FGD, and compost.



BAKER SOIL TEST® DEVELOPMENT AND FIELD CASE STUDIES PROVIDE THEORY AND DATA SHOWING THAT PLANTS DON'T GROW IN SOILS.

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Abstract

Initial experiments conducted in 1977 by the senior author involved the use of chemical ion activities of the solution phase of coal combustion by-products (CCB's) and cement kiln dusts (CKD's) used for land reclamation. Using combinations of soil and CCB's or CKD's in layers with depths ranging from no soil and no ash to combinations up to 4 feet, we found that from the point of view of plant nutrition, CCB's and CKD's are equivalent to soil. However, both materials are more susceptible to erosion thau soils. Using standard erosion station methods, we found that with proper water management for erosion control, CCB's and CKD's can be used as cover soil for land reclamation, and as a substitute for soil in several applications. The cellulose to organic matter connection is important with respect to substrate air-water relations. The Baker Soil Test (BST) is used routinely to evaluate mixtures of wastes used under field conditions as synthetic soils. Data and experience from these sites and our projections for the future are the subjects reviewed here.

Introduction

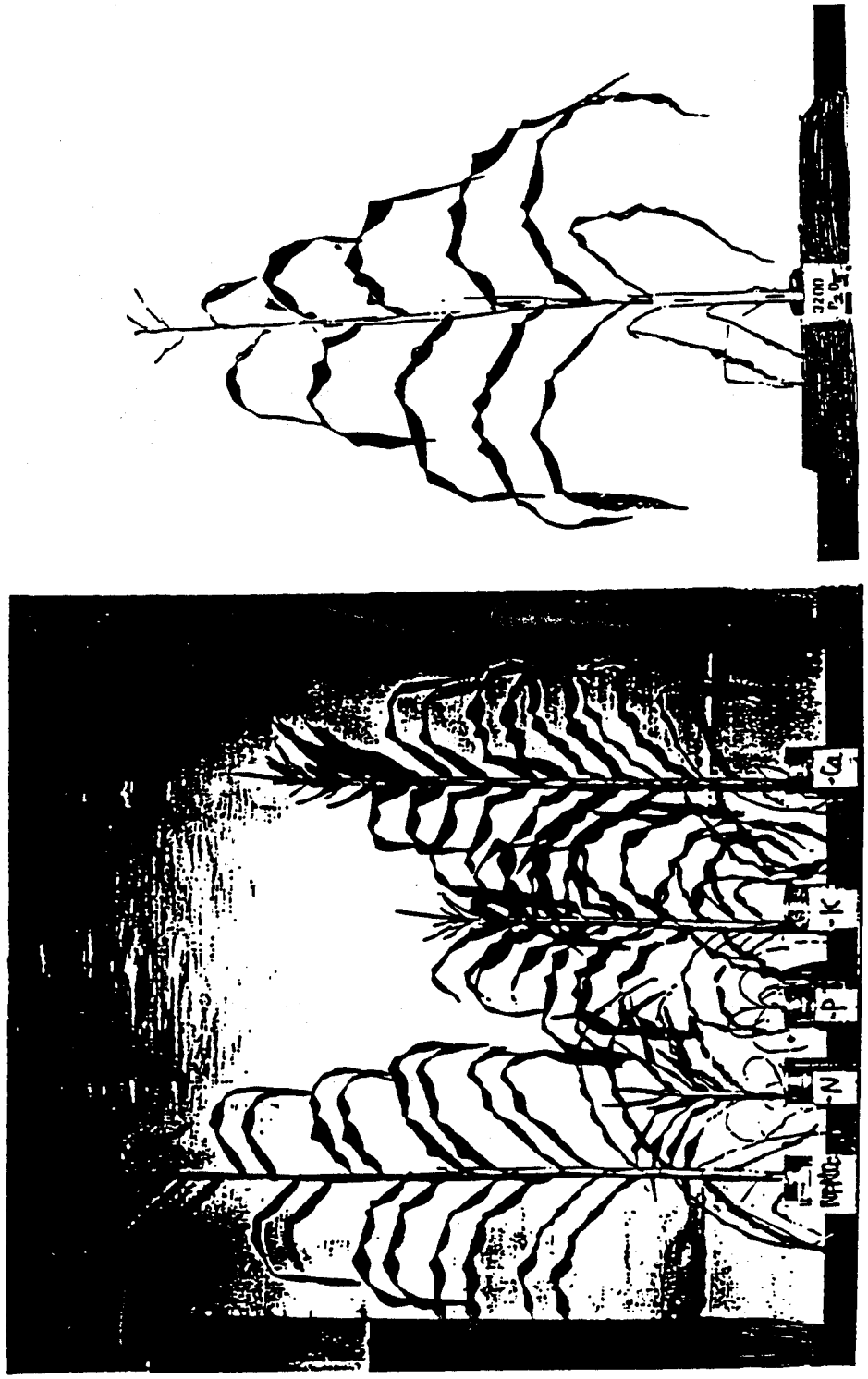
With a Ph. D. in Soils from the University of Missouri and a Year at the University of Minnesota, Northeast Experiment Station, the senior author's career at Penn State University started in 1961. With help from many Penn State graduate assistants and Leon Marshall, his research aide for 30 years, numerous investigations were conducted to evaluate and explain data enabling integrated laud and waste management systems for crop production and environmental quality. The Baker Soil Test@ (BST), (Official ASTM Method D5435-93 "Standard Diagnostic Soil Test for Plant Growth and Food Chain Protection") enables the use of mixtures of non-soil, silicate wastes and selected organic wastes as soil substitutes A high surface area per unit volume of soil per plant is important for crop production. Based on theory and experience as a University of Missouri student, Dale produced a mature corn plant in soil contained within a one quart oil can (Plate 1). The "rootless wonders" and related results were important factors leading eventually to the Baker Soil Test from theory aud case studies. As evaluated by the BST, fly ash (CCB's) and CKD's, sewage sludges, manures, and industrial wastes have been used as synthetic soils.

Magic Green Corporation@ Utilizes CKD's for Increased Crop Yields

Gregory, "Greg", Wommack has excellent field evidence that combinations of existing N, P, & K commercial fertilizers combined with CKD's result in synergistic crop growth responses. His technology is now being offered local growers and marketing agencies for distribution as the products "Ura-Cal®","Potassa-Cal®" and "Combined Nutrient Positioning@" technology. Magic Green Corporation@ materials are being offered to marketing partners for distribution in the USA and abroad.

The Wommack technology is an example of needed land management technology. Land managers must seek an understanding of the components of their systems. Interacting effect involving differential responses of crops to new technology will be important as the Magic Green Corporations technology evolves. Cement Kiln Dust CKD' s) as a source of potassium was mentioned by Tisdale and Nelson. Land Managers must seek an understanding of the components of existing systems. Interacting

Plate 1. Corn plants grown in greenhouse studies by Dr. Baker while a student at the University of Missouri, showed that phosphorus was the most limiting element when corn plants were grown in no. 10 tin cans. This led to his trial in which a mature corn plant was grown in a 1 quart can of soil receiving 3200 lbs. of phosphorus as P_2O_5 per acre (2,000,000 lbs.) equivalent.



Technology evolves. Land management decision making requires that one seek an understanding of the components of the system and their interactions. Crop Production requires a knowledge of cultural practices and soil management, as affected by climatic conditions, and other components of each system. Scientific bases for management practices often are discovered after they have become standards.

Education and Experience are Essential for Land Managers

Dr. Baker, as an undergraduate at the University of Missouri, was employed during the summer months for 3 years as a student trainee for a career appointment as a USDA-SCS Farm Planner in Higginsvillle, MO. He holds this work as his enlightening experience. With the freedom to seek help when he was not sure that he could provide the best advice to farmers, he gained confidence as he assisted farm operators in making Land Management Decisions. The authors are well aware that in order to serve the farm production sector with new products and reliable decision support, they must seek an understanding of the components of each system and their interactions. Crop production requires a knowledge of cultural practices and soil management, as affected by climatic conditions and all other art and science components of each system.

While attending the Southwest Fertilizer Industry Conference in San Antonio, Texas; Dr. Baker was impressed with the knowledge and dedication of Gregory Wommack and his crop production experiences with CKD's. Greg was invited to coauthor this manuscript in order to provide readers with another approach for providing "decision support". Decision support requires that we seek an understanding of the needs and goals of clients without just being critical of existing systems. For some systems, especially daii operations, that Dr. Baker works with, are so complicated that one has to "leave it to the operator" when it comes to many of the business management decisions that must be made. Here, we only consider field operations involving waste utilization and problem solving for environmental quality and compatible land use systems involving CKD's and CCB's. User initiated decision support for the management of land and industrial wastes for erosion control, crop production, and interactions provide exciting, new vocations, within the LMD areas of emphasis.

Theory and practices applied to case studies over time involve concerted efforts to integrate land and waste management systems. For this manuscript, attention is focused on the concepts leading to the Baker Soil Test (BST) and its application for land management, which includes the theory supporting the conclusion included in the title that "plants don't grow in soil". It is important that soil management include the concepts relating to the importance of the soil solution as the continuous phase from which plants obtain water and the required nutrients. In addition, the approach of authors regarding CKD's as components of crop management systems and related university research are worthy of emulation.

Land Reclamation Studies Indicated a Need for A New Approach to Soil Testing

Mine land reclamation has been under investigation by Baker and others for many years. Often land reclamation programs fail because the site has very low pH associated with phytotoxic levels of Al and Mn, limiting water holding capacities and/or steep, long slopes causing excessive soil erosion. With proper site preparation, including the return of overburden soil with topography and vegetative cover to prevent excessive erosion, the next major step requires the BST and surface application of waste mixtures to serve as mulch, a source of plant nutrients, and erosion control. Many wastes now going to land-fills are suitable for the production of synthetic soils and mulch materials for reclamation of many disturbed sites. For agricultural lands, we must take precautions to protect the food chain and environmental quality. The elements cadmium and copper require special attention to protect animal and human health, and soil productivity for the respective elements.

Using standard erosion station methods, we found that with runoff management for erosion control, CCB's and CKD's can be used as cover soil for land reclamation, and/or as substitutes for soils. Using a slope of 9%, with a slope length of 22.3 m, a K factor from 0.71 to 0.82 were obtained by Lehrsch, et.al.. 1981. With erosion control, CCB's and CKD's can be used as cover soil for land

reclamation, and/or as substitutes for soil in many applications. For field plots with slopes of 9 %, fly-ash erosion was somewhat greater than for soil, but acceptable, for slope lengths of 100 feet. In 1975, Baker, et al. demonstrated that CKD's were more effective than lime for vacuum filter processing of sewage sludge. However, the plant operators speculated that the silicate waste was more abrasive to equipment than hydrated lime. Therefore, the sludge conditioning technology was never adopted. Risser, Doty and Baker in 1980 demonstrated that CKD's are useful as a lime-potash fertilizer. With our past experience, we are delighted with the technology under development by Magic Green Corporation.

Magic Green Corporation@ CKD's and Pulverized Limestone Compared for Liming

For each material (dry kiln dust and pulverized limestone) 300 grams were placed in 500 ml beakers and distilled water was added to produce saturated pastes (no air or free water were present within or on top of the suspensions at equilibrium). Under vacuum to remove capillary water, the 300 g of limestone with a guaranteed calcium carbonate equivalence of 103% held 75.2 g water, while the 300 g of CKD material held 159.3 g of water. As expected, the silicate material has a substantially higher water holding capacity than pulverized limestone. The pH of the CKD suspension was 12.57 and the liquid filtrate had a pH of 13. For the limestone suspension, the pH was 9.08 and the filtrate had a pH of 8.95, which is higher than the theoretical pH of 8.1 for pure calcium carbonate ($CaCO_3$) in equilibrium with the CO_2 pressure of the atmosphere. From these results it is obvious that by blending fertilizers containing Wommack's CKD's which are banded 4 inches to the side of the rows and 2 inches deep, the plant environment is enriched with water, Ca++, and other many components included in Table 1.

The analyses presented in Table 1 were performed to ascertain if any potentially toxic elements could be encountered by animals consuming crops grown where CKD's are used as a nutrient source. The composition of the CKD is compatible with soil and soil parent materials for all parameters. Since the CKD's are produced from bedrock that is also parent material for soils, no adverse effects were expected. From an environmental quality perspective, however, one should verify that no adverse effects are possible.

Soil Biology Related to the Physical Chemistry of Soil Solutions

The soil solution, as the continuous phase in soil-plant systems, even in relatively dry soil, insures that growing plants stand in water, which exists as a continuous film, stretched over soil particles and plant root surfaces. As the soil dries, the thickness of water films decrease and water properties change to conform with the structure of both the soil solid phase and the plant vascular system even as the living plants wilt. When plants wilt, the water films approach water of hydration which is immobile (the structure of adsorbed water is more ice like than free water).

Productive soils include those with deep, well drained profiles that allow plant rooting depths of 4 feet or more. While nutrient availability with depth is important with respect to water availability to plants, nutrient management within the soil surface plow layer can provide crops with all essential chemical elements taken up as chemical ions by plants. The deep, well drained silt loam soils developed under prairie vegetation represent the more productive agricultural soils of the USA because of their greater plant available water holding capacities. The silt loam soil texture, which prevails in loess soils where the native vegetation was prairie grasses; have nearly ideal air-water relations for farm crops. While water availability over the growing season is very important, nutrient availability is often the limiting factor for crop production. Justus von Leibig (1803-1873), a German chemist, made historically valuable statements regarding the factors which determine plant growth:

1. Most of the carbon in plants comes from CO_2 (carbon dioxide within the atmosphere).
2. Hydrogen and oxygen come from water.
3. The alkaline metals are needed for acid neutralization of from plant metabolite activity.
4. Phosphates are necessary for seed formation.

Table 1. Total Chemical Composition of Water Filtrate Removed Under Vacuum To Determine the Water Holding Capacity of The Material.

ICP Metal	Filtrate (ppm)	Total (ppm)	ICP Metal	Filtrate (ppm)	Total (ppm)
Ag	<0.003	<1.13	Mo	0.360	1.51
Al	<0.01	7638.002	Na	285.55	3773.58
As	0.004	8.516	Nb	<0.005	<1.89
Au	0.029	<1.89	Nd	<0.005	10.059
B	0.022	12.254	Ni	<0.006	19.244
Ba	0.720	48.420	Oe	<0.005	<1.89
Be	<0.004	<1.51	P	<0.50	234.879
Bi	<0.005	<1.89	Pb	0.038	42.029
Br	1.921	<188.68	Pd	<0.005	<1.89
Ca	391.587	341,195.174	Pr	<0.005	5.200
Cd	<0.003	1.225	Pt	<0.005	<1.89
Ce	<0.005	12.136	Rb	14.235	11.674
Cl	2660.725	18,833	Re	0.008	<1.89
CO	<0.004	2.285	Rh	<0.005	<1.89
Cr	0.204	8.596	Ru	<0.005	<1.89
Cs	4.245	6.359	Sb	0.008	<1.51
Cu	0.016	2.271	Sc	<0.005	2.522
Dy	<0.005	<1.89	Se	0.391	<1.13
Er	<0.005	<1.89	Si	<0.50	<188.68
Eu	<0.005	<1.89	Sm	<0.005	<1.89
Fe	0.154	6018.106	Sn	<0.003	<1.13
Ga	<0.005	2.090	Sr	5.273	148.454
Gd	<0.005	<1.89	Ta	<0.005	<1.89
Ge	<0.005	<1.89	Tb	<0.005	<1.89
Hf	<0.005	<1.89	Te	<0.005	<1.89
Hg	<0.0005	<0.19	Th	<0.005	<1.89
HO	<0.005	<1.89	Ti	2.254	827.278
I	4.19	<188.68	Tl	0.019	<0.75
In	<0.005	<1.89	Tm	<0.005	<1.89
Ir	<0.005	<1.89	U	<0.005	<1.89
K	88.492	38,382.75	V	0.010	77.629
La	<0.005	15.51	W	<0.005	<1.89
Li	1.681	9.005	Y	<0.004	<1.509
Lu	<0.005	<1.89	Yb	<0.005	<1.89
Mg	<10.00	7,184.04	Zn	<0.004	39.575
Mn	0.034	372.83	Zr	<0.005	5.346

Please note that 2 g of the solid sample was digested in both nitric and hydrochloric acid, and then diluted to a final volume of 100 ml. This solution was then analyzed by ICP-Mass Spectrometer. The filtrate was directly iniected into the ICP-Mass Spectrometer.

5. nonessential materials.

While all of Leibig's ideas were not correct, he eventually developed his "Law of the Minimum", which, in effect, says that the growth of plants is limited by the plant nutrient element or growth factor present in the smallest relative quantity, with all others being present in adequate amounts. Plants require C as CO_2 from the atmosphere above and below the soil surface, H as H_20 from water within the rooting area and from deposition on leaves, 0 as O_2 from the atmosphere; P as $H_2PO_4^-$ or HPO_4^{-2}, K as K^+, N as NO_3^- and/or NH_4^+, S as SO_4^{-2}, Ca^{+2}, Fe^{+2} or $^{+3}$, Mg^{+2}, (C HOPKNS CA Fe, Mg) and other trace elements including Mn, Zn, Cu, Mo, B, and Cl. It is interesting that aluminum (AL) and Silicon (Si), the most abundant elements in soils are not essential for higher plants or and animals..

The Baker Soil Test® (BST) Applied to Land Reclamation Studies

Mine land reclamation has been under investigation by Baker, graduate students, and colleagues for many years. Often reclamation programs fail because the sites have a very low pH associated with phytotoxic levels of Al and Mn, limiting water holding capacities, and/or steep, long slopes causing excessive soil erosion. With appropriate site preparation including the return of overburden surface soil combined with topography and vegetative cover to prevent excessive erosion, and use of the BST, the next major step should include the surface application of waste mixtures to serve as mulch, a source of plant nutrients, and soil erosion control. Many wastes now going to landfills are suitable for the production of synthetic soils and mulch materials for reclamation of many disturbed sites. Magic Green Corporation has demonstrated some of the technology for which Land Management Decisions, Inc was founded.

Using standard erosion station methods, we found that with runoff management for erosion control, CCB's and CKD's can be used as cover soil for land reclamation, and/or as substitutes for soils id many applications. Using a slope of 9%, with a length of 22.3 m, a K factor ranging from 0.71 to 0.82 were obtained. For field plots with a slope of 9%, fly-ash erosion was somewhat greater than for soil, but acceptable, for a slope of 9 %, with a length of 100 feet. In 1975, Baker, Welch, Stout and Doty demonstrated that CKD's were more effective than lime for vacuum filter processing of sewage sludge. However, the plant operators speculated that the silicate waste would be more abrasive to their equipment than hydrated lime. Therefore, the technology has never been accepted. Kisser, Doty and Baker demonstrated that CKD's are useful as lime-potash fertilizer. From our past experience, we are looking forward to the time when the Magic Green Corporation becomes established.

Clients currently use the Baker Soil Test to provide the data and interpretations required for the use of CCB's and CKD's combined with other wastes to produce synthetic sails and/or soil conditioners. The cellulose (organic matter) connection is important with respect to air-water relations. The methods have been successfully applied to fly-ash piles, ash amelioration of abandoned mine lands and severely eroded sites.

It has been known for centuries that the soil solution is the continuous phase in soils-plant systems. Even in relatively dry soil, growing plants stand in water which exists as continuous firma, stretched over soil particle and plant root surfaces. As the soil dries the thickness of water films decrease, and water properties change to conform with the structure of both the soil solid phase and the plant vascular system, even as living plants wilt.

Evolution of the The Baker Soil Test (BST) as Related to Soil-Plant Interactions

After six years at Penn State, Dr. Baker spent six months at Purdue University working with Dr. Philip Low. Low and his students had shown that silicate, clay gels when disturbed by tapping the container on the lab bench changed to a sol (liquid suspension). Using radioactive sodium (Na) as a tracer. Baker postulated and verified that the "physical change" was accompanied by a "chemical

change" with respect to availability of Na ions to plants. Using radioactive Na, he found Na in a sodium saturated bentonite clay became higher in ionic activity and plant availability when the gel was disturbed by tapping on the laboratory bench (Low, Davey, Lee,& Baker, 1968; and Baker and Low, 1970).

Upon his return from Purdue University, Dr. Baker began to ponder the soil physical chemistry involved. He set up chemical equations that were known to be important to soil-water-plant relations and solved them simultaneously. To his surprise, all of the soil parameters fell out leaving only the solution chemistry (Baker, 1971). Baker asked the late Dr. Louis Kardos to check his results to see if he had made a mistake. He returned in a few hours feeling grim. He said to Dr. Baker, "No, you didn't make a mistake, but do you know what you have done?" Baker replied, "Yes, plants don't grow in soils".

An example of the Baker Soil Test (BST) report is presented as Figure 1. For routine soil test operations, the BST includes 2 pages of output, which includes concentrations of toxic metals. The results include a "small exchange", quantity and intensity parameters for each element expressed as the negative logarithm of the solution activity (pH, pK, pCa, pMg, pFe, pMn, pCu, pZn, pCd, etc.). As indicated above, The Baker Soil Test is not like other soil test methods, it measures the parameters of the soil solution in equilibrium with the solid phase of soils. The results include "small exchange", quantity and intensity parameters. (pH, pK, pCa, pMg, pFe, pMn, pCu, pZn, pCd, etc.).

We are at a dawning of new knowledge of waste-soil-plant relations. We may continue to rely on knowledge of soil properties and their management for crop production, but several factors indicate a need to begin to use suitable wastes to improve the air, water, and nutrient relationships of soils. Beneficial utilization of wastes that are now going to landfills, at a substantial cost, could lead to even more economical waste utilization and increased crop production. Colored slides are available to illustrate the concepts and data presented. One can rest assured that a soil management revolution is in the making. While the products developed by Wommack are not expected to be "cure alls", they are examples of products that combine common sense with technology and experience that show great promise for CKD's and synergistic effects yet to be quantified. Aspiring college students are urged to seek to integrate the knowledge they obtain from the pure sciences to better define and interpret soil properties using laws of physics and chemistry.

Summary

1. CKD's improve the three-phase systems called soils. An Ideal Soil System contains on a volume basis half solids and half pore space with half of the pore space full of water after the soil .is saturated and allowed to drain for 24 hours. The most important role of CCB's and CKD's as soil amendments involve their role as sources of nutrients and as "more soil" defined as "Those surface layers or deposits in which plants grow", Hunt, 1972.

2. The Baker Soil Test provides investigators with a means of evaluating CKD's, CCB's, etc. for use as soil amendments.

3. Chemical elements in the solid and solution phases provide the plant nutrient requirements of plants. In Figure 2, we present an over-simplified, but operational definition of soil systems. The oxides of the biologically nonessential elements, Al and Si, combined with the essential elements, Fe and Mg, may be considered as the major components of the matrix of all soils. However, it is water that is the continuous phase in soils and the compound that is central to all living organisms. Plant growth, then. relates to the properties of the aqueous solution phase which surrounds every soil particle which makes up the solid phase of soil or any media in which plants grow.

Figure 1. Copy of a Baker Soil Test output form for soil assumed to be at normal background levels for most parameters

LMD OUTPUT
FOR ASTM
BACKGROUND FOR
BAKER SOIL TEST.

LAND MANAGEMENT DECISIONS, INC.
3048 RESEARCH DRIVE
STATE COLLEGE, PA 16801
SOIL CHEMISTRY, LAND & WASTE MANAGEMENT DECISIONS

LMD INTERPRETATION OF BAKER SOIL TEST™ (BST) DATA. THE BST IS ASTM OFFICIAL METHOD # D5435-95.

IDENTIFICATION	DATE	LAB NO	COUNTY	SOIL	LIME REQ.(T/AC)	SOIL PH	BST PH	CEC (MEQ/100 G)	ELEC.COND.
ASTM1	09-04-1996	12	34	56	0.50	6.50	7.00	10.00	2.20

	TEST LEVEL	LOW	NORMAL	HIGH
NITROGEN:				
NITRATE N (PPM))	20.00			
PHOSPHORUS:				
CALCULATED EPC(PPB)	27.01			
Mehlich 3 P (PPM)	30.00			
BAKER SOIL TEST POTASSIUM:				
BST pK	3.66			
BST K (PPM)	9.80			
Exchangeable (ppm)	78.00			
Percent Of CEC	2.00			
BAKER SOIL TEST MAGNESIUM:				
BST pMg	3.25			
BST Mg (PPM)	24.00			
Exchangeable (PPM)	98.40			
Percent of CEC	8.20			
BAKER SOIL TEST CALCIUM:				
BST pCa	2.57			
BST Ca (PPM)	200.00			
Exchangeable (PPM)	1400.00			
Percent of CEC	70.00			
BAKER SOIL TEST CATION RATIOS:				
(Ca plus Mg)/K	5.76			
Mg/K	2.04			
Ca/Mg	0.67			
BAKER SOIL TEST MANGANESE:				
BST Mn (PPM)	20.00			
BST pMn	8.27			
BAKER SOIL TEST IRON:				
BST Fe (PPM)	10.00			
BST pFe	20.89			
BAKER SOIL TEST COPPER:				
BST Cu (PPM)	2.00			
BST pCu	14.93			
BAKER SOIL TEST ZINC:				
BST Zn (PPM)	4.00			
BST pZn	11.58			
PLANT NON-ESSENTIAL ELEMENTS:				
BAKER SOIL TEST SODIUM:				
BST Na (PPM)	50.00			
BAKER SOIL TEST ALUMINUM:				
BST pAL	12.35			
BST Al (PPM)	5.00			
BAKER SOIL TEST LEAD:				
BST pPb	12.72			
BST Pb (PPM)	2.00			
BAKER SOIL TEST NICKEL:				
BST pNi	14.33			
BST Ni (PPM)	0.50			
BAKER SOIL TEST CADMIUM:				
BST pCd	14.10			
BST Cd (PPM)	0.10			
		LOW	NORMAL	HIGH

PK, PMG, PCA, PAL, ETC. INDICATE THE AVAILABILITY OF RESPECTIVE ELEMENTS AND ARE CALCULATED NEGATIVE LOGARITHMS OF IONIC ACTIVITIES WHICH ARE ANALOGOUS TO PH, ACTIVITY OF THE HYDROGEN ION.
pLIGAND=14.76 DILUTION FACTOR= 1.00

Figure 2: Master Variables with Al and Si

Mater Variable With Al and Si In Soil-Water-Plant Systems
pH_2O, pO_2, pH, pCO_2, pNO_3, pNH_4, pCa, pMg, pK, pH_2PO_4, $pHPO_4$, pSO_4

Essential Trace Elements:
pFe, pMn, pB, pZn, pCu, pMo, pCl (+ For Animals pNa, pCo, pO_2, pI, pNi, pSe, pV)

Non-Essential, Potentially Toxic Elemetnts:
pA1, pPb, pCr, pAs, pCd, pHg+ ? (pAg, pSb, pBr, pGe, pRb, pSr, pSn)

4. Ionic activities in soil-water systems and the Quantity/Intensity (Q/I) concept. The quantity (Q) value for an essential plant nutrient other than water, refers to the amount of that nutrient element of ionic form (I) that is in dynamic equilibria with the true activity Ai within the soil solutions. The (Q) value then may be thought of as the "labile pool", "adsorbed fraction", or other terms for the concentration © in the equation:

$$A_i = f_i C_i \qquad \text{(I)}$$

Where A_i is the chemical activity of ion, I, in true solution and f is the activity coefficient. The activity coefficient relates inversely to the bonding energy with which an ion (I) is retained as an adsorbed, exchangeable ion within the soil.

5. Decision support for users of the BST is based on LMD Technology gained from soil chemistry theory and experience.

6. By-product usage developed by Magic Green Corporation is an example of the "integrated Land and Waste Management Systems for soil improvement, increased crop production, and a truly sustainable agriculture for the 2 1 st century.

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Leachate Quality from Coarse Coal Refuse Mixed with Coal Fly Ash: Effects of Ash Blending Rates

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Abstract

The exclusion of coal fly ash from regulation as a hazardous waste has led to increased interest in returning ash to the coalfields for disposal. Bulk-blending alkaline fly ash with acid forming coal refuse may present a disposal option that aids in the control of acid mine drainage. A preliminary column leaching study examined the leachate quality from acid-forming. coal refuse:fly ash blends. Coal refuse (2.2 % total-S), and two refuse:fly ash blends (20% and 33% ash w/w) were packed into leaching columns and leached under unsaturated conditions for over four years. The coal refuse columns acidified quickly, producing peak leachate levels of acidity (pH 1.7), Fe (10,000 mg l^{-1}), SO_4^{-2} (30,000 mg l^{-1}), and Mn (300 mg l^{-1}). Both ash blended treatments provided alkaline leachate with low metal levels. A second column study used a refuse with higher potential acidity (4% total-S), and two alkaline ash sources; one blended at two rates (20% and 33%) and one at four rates (5%, l0%, 20%, and 33%). Bulk-blended ground agricultural limestone, rock phosphate ore, and topsoil treatments were also studied. The unamended refuse treatment acidified rapidly and produced acidic (pH 1.7) leachates with high peak dissolved metal levels (>15,000 mg l^{-1} Fe; 200 mg l^{-1} Mn) Treatments blended with 33% ash produced alkaline (pH >8.4) leachates with low metal levels (Al <l.0 mg l^{-1}; Cu-0.10 mg l^{-1}; Fe < 2.0 mg l^{-1}; Mn < 3.0 mg l^{-1}). Treatments containing less ash eventually acidified and ash bound metals (Mn and Cu) were stripped from the ash and eluted in quantities proportionate to the amount of ash in the blend. Treatments in which a low alkalinity ash was augmented with ground limestone produced alkaline leachates with low metal levels. Examination of the soil phases from the column studies confnmed that pyrite oxidation had taken place in the columns producing acidic leachates. Overall, the inhibition of pyrite oxidation by high ash blends was attributed to alkalinity effects, chemisotption, decreased hydraulic conductivity, and decreased oxygen diffusion to pyritic surfaces. Ash alkalinity and refuse potential acidity must be balanced for environmental safety in this co-disposal environment.

Introduction

This project is a comprehensive investigation of the potential use of fly ash as a liming agent and/or soil conditioner on coal refuse and mine soils. Using fly ash in this manner would represent a beneficial reuse of a material that is currently land tilled. The fly ash would benefit nonacidic, coarse textured, mine soils by adding fine particles that would increase the water holding capacity which is a limiting factor in many mine soils. Alkaline fly ash could also be applied to most refuse materials and to acidic mine soils. The alkalinity in the ash would serve to neutralize the acidity generated by the oxidation of iron pyrite (FeS_2). The fine texture of the fly ash would also enhance the water holding capacity of the refuse, which generally has a very low level of available water.

Current mining regulations allow for the release of acidic mine drainage (AMD) from refuse piles to holding ponds, where the drainage is impounded and treated with caustics to neutralize the acidity before the water is released to local waters. The AMD and the associated impoundments present a threat to the quality of both ground and surface waters near the refuse pile. One may also question the effects of releasing high pH water into surface waters. An alternate solution would be to bulk blend a liming agent, such as limestone, with the refuse at a rate that would neutralize all the acidity potentially produced by pyrite oxidation within the refuse pile. A problem with this treatment would be cost.

Alkaline fly ash could offer a cheaper alternative to limestone. Fly ash is produced at coal fired power plants, which burn coal that was cleaned at a prep plant with an associated with a refuse pile. The fly ash is currently land filled at a suitable site near the power plant. Back hauling fly ash could offer a cost effective liming agent for use on refuse piles and surface mined lands. Returning the ash to where the coal was mined and cleaned also makes some sense from a material balance point of view.

It has yet to be determined if this is a worthwhile practice from an environmental standpoint. Fly ash is enriched in many trace elements, particularly metals. These metals are part of the pyrite structure in the coal and become concentrated in the fly ash during the combustion process. These elements may be surface adsorbed on the glassy spherical fly ash particles or they may exist internally in the sphere. Elements that are surface adsorbed can be quite mobile. Many of these trace elements could be quite leachable under low pH conditions. We must examine the interactions between the fly ash and the coal refuse. Can pyrite oxidation occur rapidly enough to allow the material to become acidic? Is there enough alkalinity in the fly ash to keep the pH high and retard or stop pyrite oxidation or neutralize the acidity generated by any pyrite oxidation that does occur? Will pyrite oxidation simply be delayed until the alkalinity of the material is exhausted and then recommence? These are fundamental questions that must be answered before the co-disposal of fly ash and coal refuse can become a widespread practice.

To answer these questions we have undertaken several studies. This paper will concentrate on the results of two column studies which we have been conducting over the last 4 years.

Objective

The objective of the column studies was to determine the influence of the various treatments on acid sulfate weathering and reaction products and to these findings to the quality of the coal refuse drainage.

Materials and Methods

Preliminary Column Study

The initial column study (experiment 1) was started in Feb. 1991. This study was initiated to examine the general quality of leachate from refuse/fly ash bulk blends. The refuse used in this study had a potential acidity of 73 tons $CaCO_3$/1000 tons of refuse. This study used columns described in a dissertation by Stewart (1996). They were 18 cm (diam) by 60 cm (L). Two columns were packed with tmamended refuse. Three columns were packed with a 4: 1 refuse:ash mix (20% ash), and three columns were packed with a 2:l refuse:ash mix (33% ash). The ash (WV) used in this study was generated at Westvaco's paper mill in Covington, VA. The calcium carbonate equivalent (CCE) of the ash was 5.0 % by the method of Sobek et. al, 1978. These columns were not totally balanced as far as alkalinity added:potential acidity, but it seems that the 33% ash mix is about the highest rate of ash that could be practically handled.

Second Generation Column Study

The second set of columns (experiment 2) used larger columns (24 cm diameter) of varying lengths. Each column was packed with the same amount of refuse (36 kg) and the prescribed amount of amendment(s) for each treatment. There are 15 treatments in this study and each treatment is replicated three times. The treatments were:

1. unamended refuse (control)
2. unamended refuse + topsoil
3. refuse + 5% Westvaco fly ash (5% WV)
4. refuse + 10% Westvaco fly ash (10% WV)

5. refuse + 20% Westvaco fly ash (20% WV)
6. refuse + 33% Westvaco fly ash (33% WV)
7. refuse + 33% Westvaco fly ash + topsoil
8. refuse + 33% Westvaco fly ash + 5% rock phosphate
9. refuse + 20% Clinch River fly ash (20% CR)
10. refuse + 33% Clinch River fly ash (33% CR)
11. refuse + 13% limestone (13% Lime)
12. refuse + 13% limestone + topsoil
13. refuse + 5% rock phosphate (5% RP)
14. refuse + 5% rock phosphate + topsoil (5% RPTS)
15. refuse + 300 tons/1000 tons Westvaco fly ash surface applied.

These columns were run under unsaturated conditions and leached with 2.5 cm of a simulated rain each week. Refuse used in this experiment was about 4% total sulfur. The Clinch River Fly Ash (CR) is an alkaline ash with a pH of 11 and a CCE of about 10%. The Westvaco fly ash (WV) was collected at the same site that the WV fly ash in experiment 1. Leachates were collected and analyzed for pH, EC, Fe, Mn, SO.,, and B regularly. Other elements (Ca, Mg, K, Na, Cu, Zn, Al, Ni, As, and Se) were monitored on a less frequent basis. One objective of this phase of the experiment was to provide data on the leachate quality generated by these treatments under tightly controlled laboratory conditions. Leaching of this phase began in March of 1992.

Nonalkaline Ash Study

In addition to the 45 columns in this study, four columns were packed with an acidic fly ash from the Celauese plant in Pearisburg, VA. These columns were packed with the same refuse used in the second column experiment. The mixing ratio was 20% by weight fly ash. This ash was quite light in weight aud getting the refuse/ash blend to mix well and remain mixed was difficult. Two of the columns (20% ash + lime) were limed to their ABA (acid base accounting) acidity of 132 tons $CaCO_3$ per 1000 tons refuse or 13.2% limestone by weight. Leaching of these columns began in September of 1992.

Results and Discussion

Preliminarv Column Study

After over four years of weekly leaching the leachate from the ash amended columns remained at pH 8 with very low levels of Fe aud Mn (Fig. 1, 2, 3). The leachates from the unamended refuse are pH 1.9 with very high levels of Fe, Mn, Al, Cu, Zn, and other toxic elements (Fig 1, 2, 3, Table 1). Close inspection of the data from the composite samples in Table 1 reveals that the refuse was intensely weathered by the acidity generated by pyrite oxidation. The levels of Ca and K dropped below our detection limits in the third composite which was taken after nearly three years of leaching . The levels of all elements tested declined during the four years of leaching. The quality of the leachates improved with time. There was a slight, but noticeable decrease in leachate pH in the 20% ash treatment due to the acidification of one of the three replicates, after -1000 days of leaching. The acidification process was quite rapid in this column. Leachate pH decreased from 8.1 to 4.1 in about 100 days (14 seven-day leaching cycles). The pH of the other two columns in this treatment remained at pH 8.1 for the duration of the experiment. The leachate pH from the 33% columns remained at 8.1 for the duration of the experiment.

Fly ash was very effective in controlling the effects of pyrite oxidation and acid generation. Both the 20% and 33% treatments were very effective, however the decline in pH of one of the 20% columns may indicate that the pyrite in that column had not been permanently atrested. Leachates from the ash treated columns contained higher levels of Na and K than the leachates from the unamended columns. The ash blends also had much lower EC values than those of the control columns at the peak of acid generation. In the last year the EC of the control columns declined to < 4 mmhos cm^{-1}. There

are some fluctuations in the EC data due to stoppages in column leaching to simulate dry conditions (Figure 4). During these periods salts are precipitated and then these salts dissolve when leaching resumed, producing higher levels of soluble salts. Information on the solid phases found when these columns were dissected upon the completion of this experiment can be found in Stewart (1996).

Second Generation Column Study

Leaching of this phase began in March of 1992 and ended in July of 1995. The 5% (5% WV) Westvaco ash mix maintained a basic pH through a few weeks but subsequently failed, and began generating an acidic leachate (Figure 5). The 10% (10% WV) Westvaco ash blend has maintained a pH near 8 for almost 40 weeks, but it also failed and began to produce acidic leachate. The 20% (20% WV) Westvaco ash blend maintained a pH near 8 for two years and then slowly acidified. The 33% (33% WV) Westvaco ash blend maintained a pH above 8 for over three years and had a correspondingly low level of leachate metals (Figure 5). When an ash blended column acidified, the elements in the ash were available to be leached in a low pH environment. This led to acid stripping of some elements from the fly ash and produced leachates which were enriched in some metals. When the 5% WV columns acidified they produced a leachate with twice as much Mn as the control columns. We assume that the added Mn came from the ash. The refuse used in this experiment was about 4% total sulfur and the unamended column leachate has a pH of 1.6 with about 15,000 mg kg^{-1} Fe. The high concentration of elements in solution was reflected in the high EC values from these cohmms. The EC values do decrease with time but a large increase in EC was observed whenever a column acidified (Figure 6). The EC values plotted in order of fly ash addition once they acidify. The control having the highest EC, the 5% WV the next highest and so on. A more comprehensive analysis of the data from the early stages of this experiment is available in a thesis by Jackson (1993) and a paper by Jackson et al. (1993) and are also discussed in a dissertation by Stewart (1996).

The Clinch River Ash (CR) contained more alkalinity than the WV ash. The 20% CR columns maintained a pH of 9 for over three years. This was about half a pH unit above the leachates from the 33% CR columns. The lime treatment has maintained a pH of about 8 for the past three years, as expected. The 5% RP and 5% RPTS represent treatments that were bulk blended with rock phosphate. Rock phosphate was used by others (Spotts and Dollhopf, 1992) to control AMD by limiting Fe mobility due to Fe phosphate formation. In this case the rock phosphate seemed to control Fe somewhat but not completely. The pH values from the rock phosphate treated columns are < 4. The pH values from the topsoil treated rock phosphate columns (5% RPTS) were nearly identical to those of the 5% RP columns. In some of the other treatments the topsoil apparently lowered the hydraulic conductivity of the column material and the leaching waters had more time to dissolve weathering products in the column.

Nonalkaline ash columns

We had expected these columns to acidify quickly and have high levels of metals leached from the ash under the acidic conditions present in the unlimed columns. Surprisingly, this did not happen. The unlimed columns acidified much more slowly than the control columns (Figure 7). The 5% WV ash (a much more alkaline ash than Celanese) columns in the second column experiment also acidified more quickly than these columns (Jackson et al. 1993). We believe that the ash in these columns slowed down the rate of water movement in these columns to the point where amorphous Fe compound formation is favored over Fe^{+3} oxidizing the iron pyrite. This would keep the rate of pyrite oxidation low and the generation of acidity would also be slowed as observed. The unlimed Celanese ash cohmms had a pH profile similar to that of the rock phosphate treatments. Iron, Mn, and Al show trends that were much like those for the limed ash cohmms. Boron levels in these materials were a bit high. Other than low pH values and high B levels , there seem to be no apparent water quality problems with mixing this acidic fly ash with this very acidic refuse. The Celanese column results are important because acidic fly ashes will likely be used on or in refuse piles because of backhaul obligations. In this particular case the effects of the ash appear to be positive, however, other ashes and other refuse combinations may not share this finding.

Conclusions

1. Alkaline fly ash can control the oxidation of pyrite in coal refuse if enough alkalinity is present. If enough alkalinity is not present the ash will act to delay the onset of acidification, but not prevent it from happening.
2. If pyrite oxidation occurs in ash amended mixtures the metals in the ash will be exposed to acid stripping and could result in higher levels of dissolved metals than would have been present in the unamended coal refuse.
3. A blend of nonalkaline fly ash and ground limestone may be effective in controlling acid mine drainage from coal refuse.

Acknowledgments

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Table 1. Elemental content in composite leachate samples.

Sample	Control				20 % Ash				33 % Ash			
	257†	360‡	970§	1363¶	160#	360‡	970§	1363¶	160#	360‡	970§	1363¶
Element	----------mg kg^{-1}----------											
Al	870	350	72.6	33.2	0.12	0.18	0.74	42	0.13	0.61	0.14	0.23
B	3.1	1.6	0.08	0.31	3.6	2.5	1.1	0.91	5.0	4.1	0.88	0.42
Ca	810	590	<0.1	3.34	300	433	542	651	370	450	489	188
Cr	0.87	0.33	nd	nd	0.01	0.01	nd	nd	0.01	0.53	nd	nd
Cu	16.6	5.1	0.96	0.49	0.01	0.06	0.02	0.25	0.01	0.01	0.02	0.034
Fe	7600	3900	348	104	3	0.13	0.14	0.52	0.03	1.4	0.31	0.10
K	0.84	0.44	<0.3	<0.3	36	41	51	63	44	50	44	25
Mg	371	149	54	27	54	103	93	61	62	111	51	11
Na	17.8	0.7	0.45	0.98	82	19	14	10	61	26	8.7	5.9
Ni	10.3	2	nd	nd	0.01	0.01	nd	nd	0.01	0.12	nd	nd
P	30	11	0.06	0.06	0.42	0.35	0.06	0.06	0.34	0.38	0.06	0.06
Pb	0.91	0.44	nd	nd	0.01	0.01	nd	nd	0.01	0.01	nd	nd
S	9246	4440	660	334	323	458	523	673	405	481	415	134
Si	123	79	nd	nd	16	15	nd	nd	13	15	nd	nd
Zn	25	3.8	0.84	0.50	0.04	0.09	0.03	4.0	0.04	0.08	0.03	0.004

† Data for sample 257 is from a composite sample from the Control treatment. Samples from day 66 to 191 were combined.
‡ Data for sample 360 is from a composite sample from each. Samples from day 304 to 413 were combined.
§ Data for sample 970 is from treatment composite samples, samples were combined by treatment from day 956 to 984.
¶ Data for sample 1363 mean values from samples taken on day 1363 of the experiment.
# Data for sample 160 is from a composite sample from within each ash treatment. Samples from day 126 to 195 were combined.

Figure 1. Mean leachate pH values. Error bars extend one standard deviation of the mean.

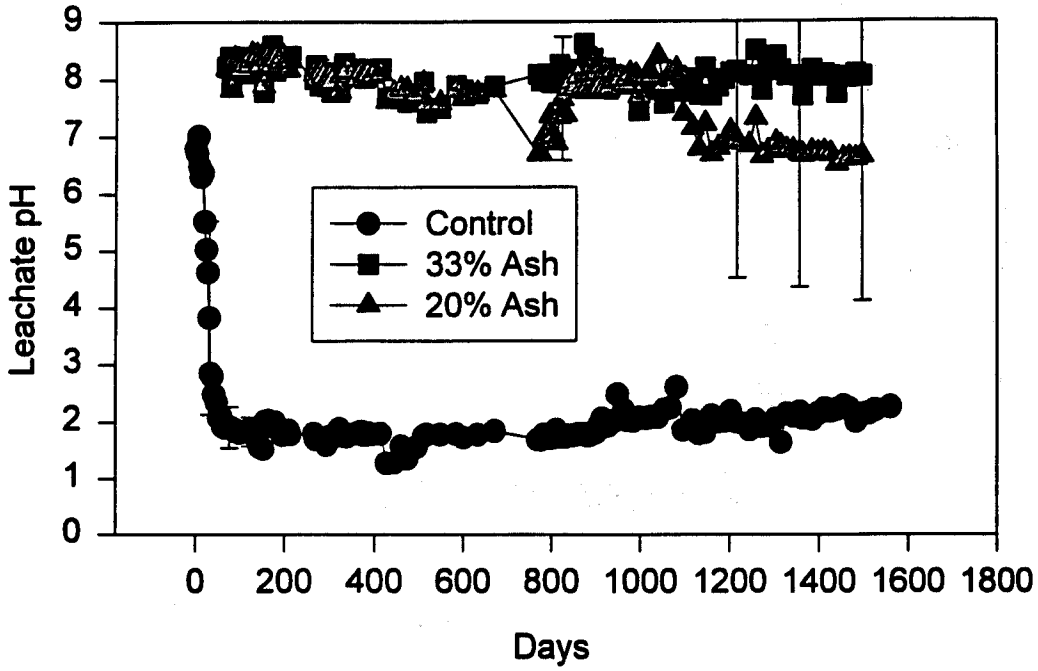

Figure 2. Mean column leachate Fe content. Error bars extend one standard deviation above and below the mean.

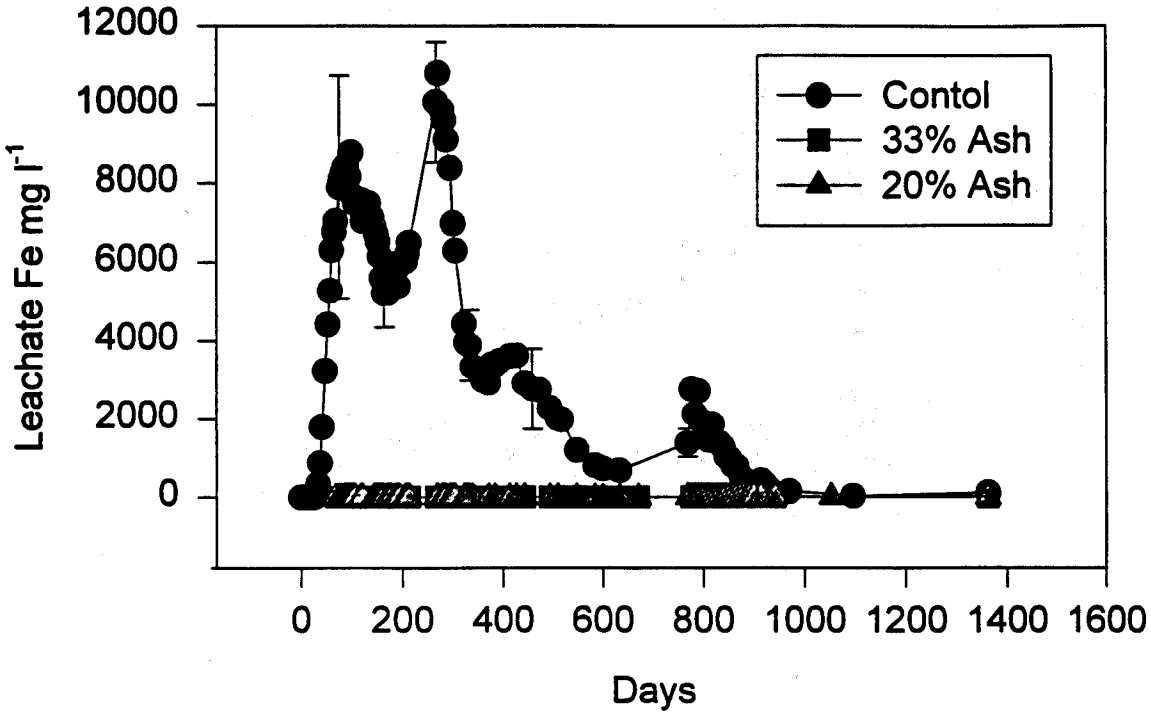

Figure 3. Mean leachate Mn content.

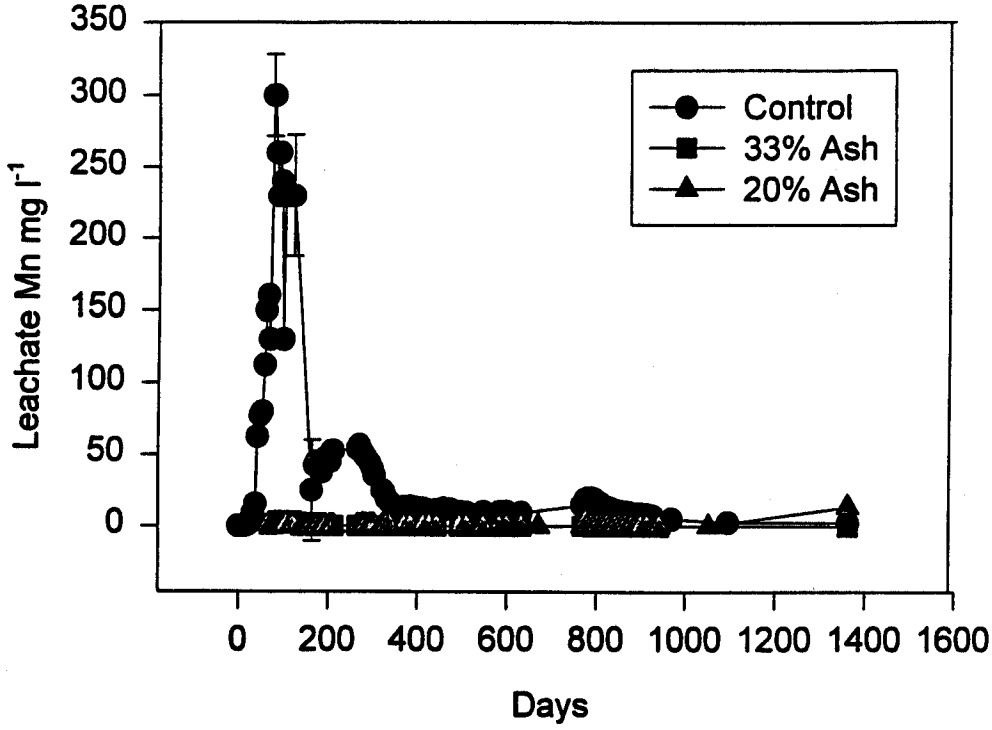

Figure 4. Mean column leahcate EC values. Error bars extend one standard deviation above and below the mean.

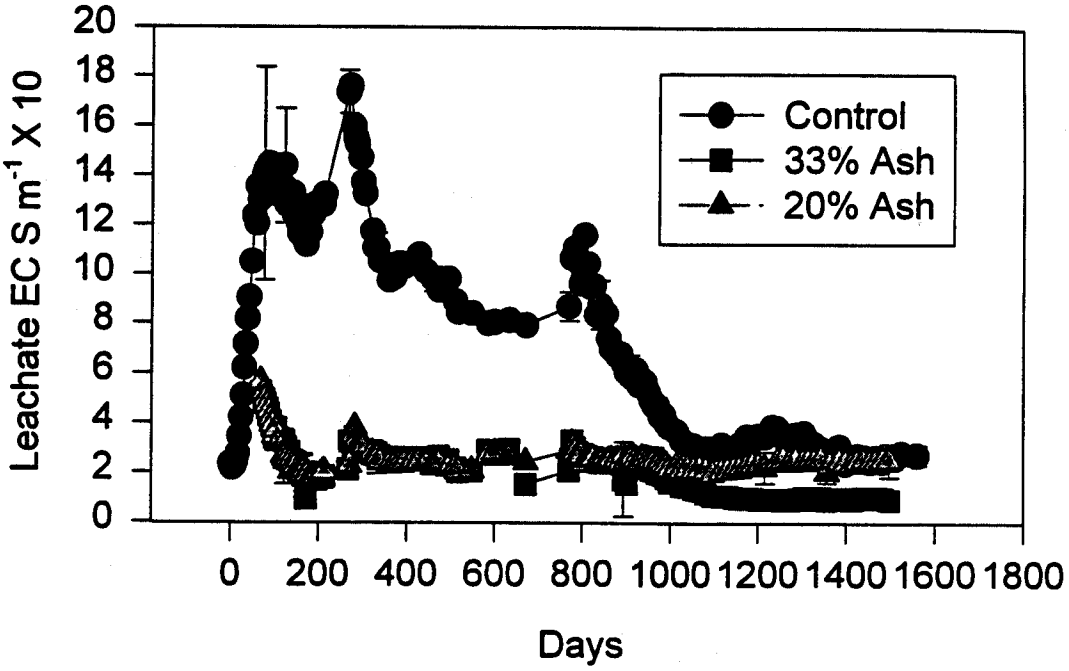

Figure 5. Mean pH leachate pH values from the WV ash treatments in the second generation column studies.

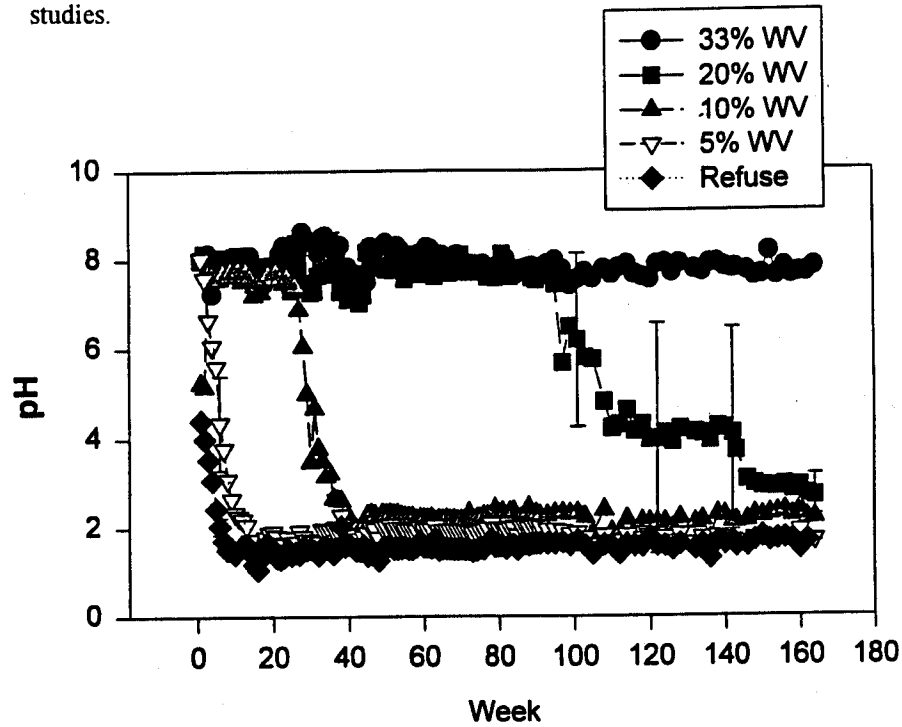

Figure 6. Mean leachate EC values from the WV ash treatments from the second generation.

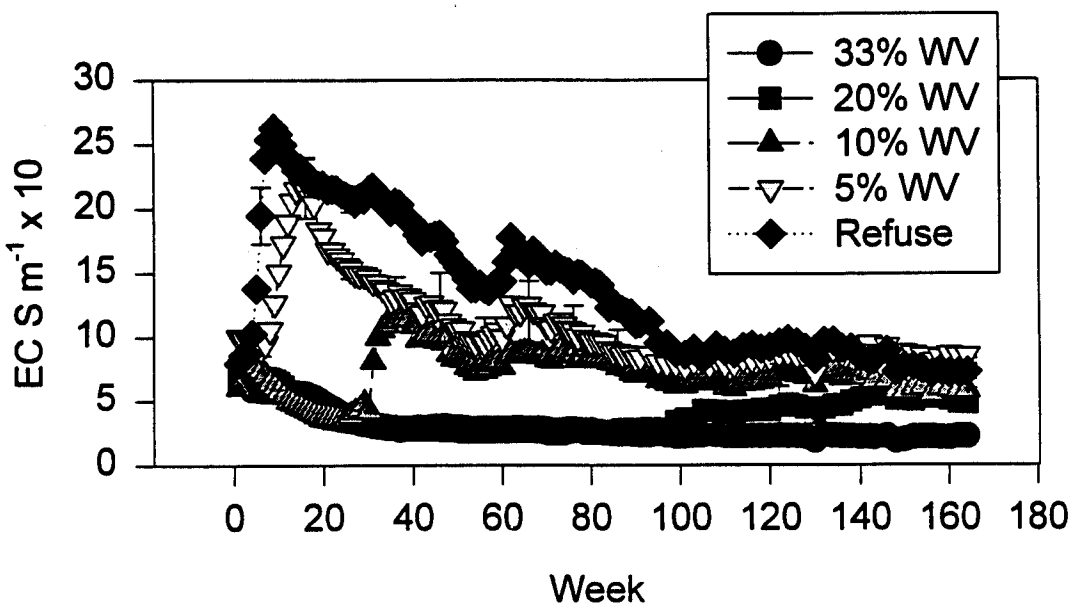
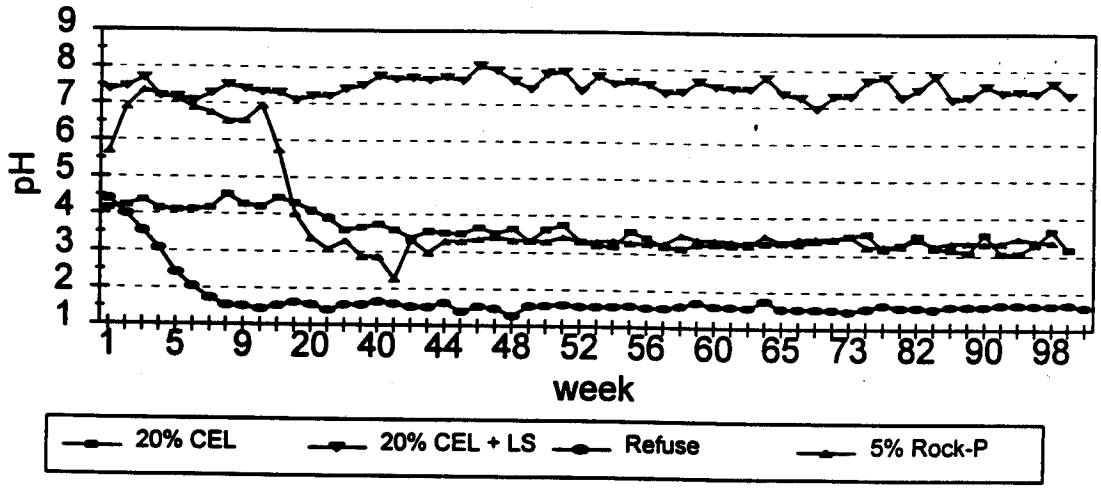
Figure 7. Changes in leachate for the non-alkaline ash columns. Data for Refuse and 5% Rock-P included for comparison.