

Appendix F. Ashlines



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COMBUSTION BYPRODUCTS RECYCLING CONSORTIUM

Ashlines

a program of the
National Mine Land
Reclamation Center at
West Virginia University
in cooperation with the
U.S. Department of
Energy - National Energy
Technology Laboratory
www.netl.doe.gov

To promote and support the commercially viable and environmentally sound recycling of coal combustion byproducts for productive uses through scientific research, development, and field testing.

Manufacturing Fired Bricks with Class F Fly Ash from Illinois Basin Coals

Mei-In Melissa Chou, P.I.

Researchers at the Illinois State Geological Survey (ISGS) and the University of Illinois are working with brick manufacturers to develop high-quality, marketable brick products using large volumes of Class F fly ash. The fly ash is generated from power plants burning Illinois coals.

In this fired brick-making process, fly ash is used as a raw material to substitute for part of the clay and shale, which are the two main raw materials of a conventional brick. Test bricks produced so far have met or exceeded ASTM commercial specifications.

Objectives of the project included assessing the technical, economic, and environmental suitability of fly ash for commercial production of fired bricks and conducting a public outreach campaign to promote the use of similar fly ash from other adequate sources by brick producers.



(L to R) Sheng-Fu Joseph Chou, Mei-In Melissa Chou, and a Colonial Brick Company representative examine bricks manufactured with Class F fly ash. The company is testing the manufacture of the bricks on a commercial scale. Photo courtesy of ISGS.

The project was funded by the U.S. Department of Energy-National Energy Technology Laboratory and the Combustion Byproducts Recycling Consortium. Additional partners included the Colonial Brick Company and

Cinergy PSI's Cayuga Power Generation Station (CPSIC).

Project Description

More than six million tons of Class F fly ash are generated from
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Manufacturing Fired Bricks with Class F Fly Ash from Illinois Basin Coals *(continued from page 1)*

burning about 100 million tons of Illinois Basin coal each year. Most of this fly ash is ponded or landfilled, but could be readily available for making fired bricks. Nevertheless, until the brick industry gains more confidence in using fly ash as a raw material for brick production, evaluation and testing will be needed on a case-by-case basis.

In this project, researchers determined if the Class F fly ash produced by Cinergy PSI's Cayuga Power Generation Station, which burns Illinois Basin coals from Illinois and Indiana, is a viable raw material for brick production at Colonial Brick Company, a brick plant in Indiana near the Illinois border. Project tasks included:

- sample acquisition;
- characterization of raw materials,
- production of commercial-size green bricks;
- evaluation of preliminary in-plant firing;
- commercial-scale production;
- economic assessment; and
- an environmental feasibility study.

Results

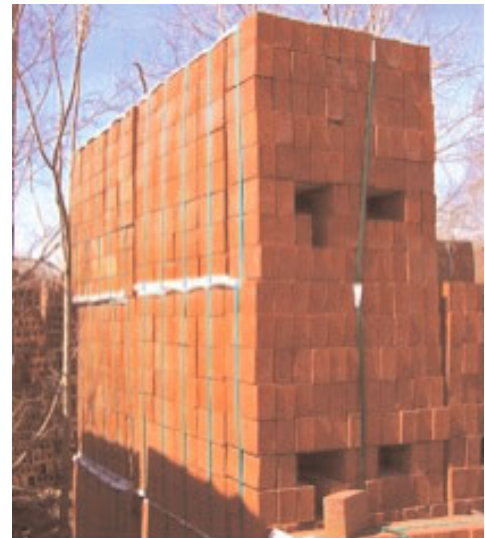
To prepare for the commercial-scale production test runs, precursor tests were conducted at the ISGS bench-scale facility, and more than 80 commercial-size test bricks of various formulations were made. In addition to the paving bricks containing fly ash at 10, 20, 30, 40, and 50 percent of volume balanced with clay and shale material, researchers at the ISGS also made three-hole building bricks containing fly ash up to 60 percent of volume

(about 56 percent of weight).

Researchers fired a set of these mold-pressed green bricks using the ISGS kiln. They also fired another set of these mold-pressed green bricks at the brick plant as part of a commercial firing. Both firings produced high-quality, attractive, and strong paving and building bricks.

The brick plant conducted two commercial-scale production test runs of paving bricks (2,000 bricks per run – including extrusion and firing). Run I produced paving bricks with a raw material formulation containing fly ash at 20 percent of volume (about 14 percent of weight) balanced with shale material at 80 percent of volume. Run II was composed of a mix of fly ash at 20 percent of volume, shale at 60 percent of volume, and clay at 20 percent of volume. These runs produced high-quality paving bricks with a yield of 75 and 100 percent for Runs I and II, respectively.

The engineering properties of these bricks either met or exceeded ASTM standards for commercial



Two thousand paving bricks with fly ash from commercial scale-up production (Run II).

application. For example, their compressive strength was three times greater than the minimum allowable strength.

Mold-pressed paving bricks produced at the ISGS bench-scale facility before firing (A) and after firing (B) are shown below. The brick plant also conducted four



(A)

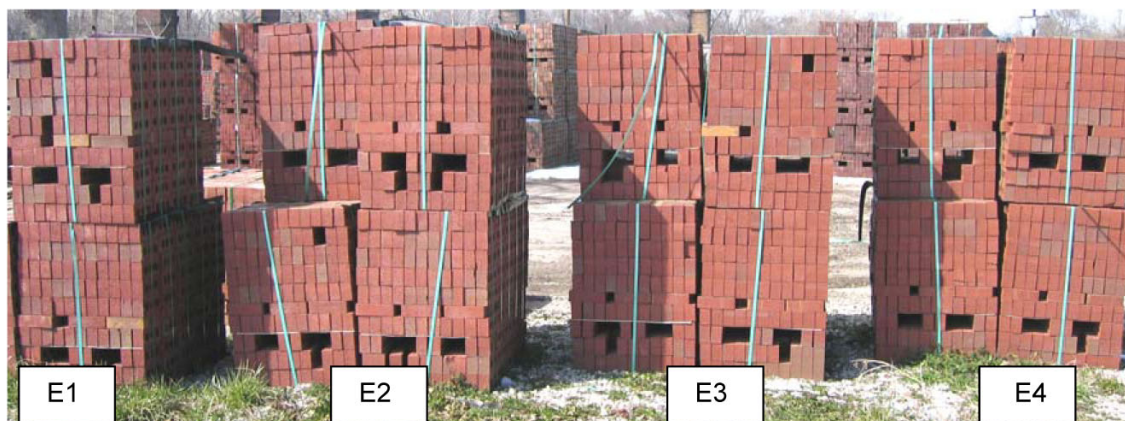
paving bricks before firing



(B)

paving bricks after firing

Manufacturing Fired Bricks with Class F Fly Ash from Illinois Basin Coals *(continued from page 2)*



Four batches of fired building bricks produced from scale-up production test runs with fly ash inputs at 0, 20, 30, and 40 percent by volume.

commercial-scale production test runs of three-hole building bricks (2,000 bricks per run, including extrusion and firing).

The bricks contained fly ash levels of 0, 20, 30, and 40 percent of volume (about 37 percent of weight), labeled as E1, E2, E3, and E4 above. The run with zero percent fly ash (E1) was used as a control run to mimic the standard production formulation for the brick plant. Each run produced strong and attractive bricks with a commercially acceptable yield of greater than 95 percent. The engineering properties of these bricks either met or exceeded ASTM standards for commercial application.

An evaluation indicated that it would be economically feasible for the participating brick plant to use CPSIC's fly ash as a raw material in commercial brick production. An environmental feasibility leaching study showed that, similar to the regular commercial brick, the fly

ash containing bricks are environmentally safe construction products.

The number of bricks produced in the U.S. has steadily increased each year. In 2001, nationwide production was estimated at 8.3 billion SBE (standard brick equivalents). By the year 2003, it had increased to 8.6 billion. In 2004, it reached 9.3 billion, which would weigh 23.25 million tons (at five pounds per brick). The amount of ash that could be consumed, using as a substitute raw material, will depend on the brick plant's production rate and the amount of ash that can be successfully incorporated into the brick body.

At the current brick plant production rate of 16 million bricks per year, utilizing 40 percent by weight of fly ash per brick, an annual consumption of approximately 14,000 tons of fly ash could be achieved.

Successful commercial manufacture of bricks containing fly ash could provide a growing

and profitable market for Illinois Basin coal ashes generated. It could also encourage electric power generation companies to continue to use Illinois Basin coals, and will help provide a reliable and inexpensive new source of raw materials for fired brick manufacturing.

Another brick plant in Indiana has expressed an interest of this technology. Researchers at the ISGS will continue to use their expertise and brick-making facilities to assist companies who are interested in developing commercial-scale bricks that contain substantial amounts of fly ash.

For More Information, contact Mei-In Melissa Chou, Illinois State Geological Survey, at (217) 244-0312, or by e-mail to chou@isgs.uiuc.edu. The complete project report (#02-CBRC-M12) is expected to be available later this fall on the CBRC's Web site at <http://www.wvri.nrcce.wvu.edu/programs/cbrc>.



Arsenic and Selenium Leached from CCBs: Is it Going Anywhere?

Bradley C. Paul, Ph.D., P.I.



Caney Fork River, Tennessee. Photo courtesy of the U.S. Army Corps of Engineers.

Coal combustion byproducts (CCBs) make suitable fills for use in a variety of settings. In many instances, concerns arise that these materials might leach toxic ultra-trace elements, such as arsenic and selenium, into groundwater supplies with deleterious effects.

Many test procedures have been developed to characterize whether various elements may leach from CCBs, but site characteristics have been heavily ignored. Specifically, the question of whether elements once leached

from CCBs would actually remain in solution has not been addressed. Obviously, an element once leached from a CCB would not be a water contaminant if it were not in the water.

The objective of a research project funded by U.S. Department of Energy-National Energy Technology Laboratory and the Combustion Byproducts Recycling Consortium (CBRC) examined whether soils and degraded rocks common to the road-cut and mine environments in which CCBs are

placed would allow arsenic and selenium to remain in the water if leaching occurs. The goal is to provide an environmental risk assessment check seldom used in today's permitting reviews.

Basis for Environmental Concern About Arsenic and Selenium in CCBs

Arsenic and selenium are two trace elements that have often been raised as an environmental and

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Arsenic and Selenium Leached from CCBs: Is it Going Anywhere? *(continued from page 4)*

health concern in relation to CCBs. Coal itself is a product of plant and soil sedimentation in ancient swamp-like environments. Of course, the fossilized plant portion of coal will burn in boilers today, but the swamp soils mixed in with the plant material will not. These ancient swamp soils become the feedstock for fly and bottom ash left as residue from the coal combustion process.

Taken as a whole, these ash products are, not surprisingly, quite similar in arsenic and selenium content to soil materials deposited in swamps today. Combustion temperatures can, however, alter the mineralogy and distribution of arsenic and selenium. Both trace elements have comparatively low volatilization temperatures, meaning that the elements become gaseous and tend to move with the hot flue gases. The volatile trace elements will condense on the fly ash or some of the particles used in scrubber systems as the flue gas cools.

Since only part of the ancient swamp soil is processed into fly ash, but almost all of the contained arsenic and selenium move in this direction, there will be a modest but measurable increase in trace element content in fly ash versus the original swamp soils. Further, the arsenic and selenium will tend to be deposited on the fly ash surfaces in higher concentrations, just as dust particles can be nucleation sites for rain drops.

This change in the position of the arsenic and selenium then becomes the basis of concern. Most

CCBs are assessed for environmental safety on the basis of shake tests that contact fresh ash with water for a limited and single time. To the extent that arsenic and selenium have been moved and concentrated at surface leaching sites, one can see higher levels of arsenic and selenium in the leachate than one might guess from the limited arsenic and selenium content of the ash.

Leaching tests will at times give arsenic or selenium concentrations that would violate primary drinking water standards though usually not by enough to merit hazardous or hazardous like waste characterization. The apparent concern can be even worse if one places a well in a CCB fill and then measures pore water concentrations. This can be particularly true if the CCB fill is relatively tight so that the pore water is largely stagnant and unexchanged.

Concern about Arsenic and Selenium Contaminating Down-Gradient Water Resources

As a practical matter, however, the real concern would be that leachate from CCBs could contaminate down-gradient water resources enough to harm individuals or species using that water. One would not, for example, locate a water well in a tight formation that would not yield significant water. Thus, high trace element concentrations in tight, stagnant pore waters and contaminated water entering a water well are almost mutually exclusive. In the event that con-

taminated leachate does move out of the fill, a variety of computer programs can look at down-gradient concentrations considering the effects of dilution and dispersion.

The problem is that such models assume that trace elements once in the water will be carried and moved by the water almost indefinitely. When one realizes that much of the arsenic and selenium in fly ash was adsorbed from ancient swamp waters, one wonders why similar sediments today would not also adsorb trace elements.

Project Overview

The work funded by the CBRC considered the case of CCBs placed as fills in the bottoms of surface mines or as fill in road cuts. Samples were taken of the coal overburden formations that would be placed over CCB cells as surface mining advanced. In addition, samples were taken of the soils found around typical road cuts of southwestern Indiana.

The question being studied was whether these materials would behave as inert with respect to arsenic or selenium contaminated waters, or whether they would adsorb the arsenic and selenium out of the groundwater. There would be little chance of regional groundwater contamination if all the arsenic and selenium were adsorbed back into the rocks and soils within a few feet of being leached out.

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Arsenic and Selenium Leached from CCBs: *Is it Going Anywhere?* (continued from page 6)

U.S. Environmental Protection Agency procedures were used to construct adsorption isotherms for these materials. The isotherms indicated very strong adsorption tendencies, especially for arsenic. Tests were then performed on the reversibility of the adsorption.

Most of the materials showed no tendency to release measurable concentrations of arsenic or selenium as the concentration in the surrounding water fell. Those that did always released levels well below limits for drinking water, indicating that if arsenic and selenium release did occur, it would be relatively benign.

The adsorption and desorption isotherms were then used with typical two-dimensional contaminant transport computer models to assess whether CCB fills placed in contact with groundwater at mines or in road sub-bases and fills could be expected to develop leachate plumes in the down-gradient groundwater. The control model assumed no adsorption took place and the leachate source continued to release arsenic or selenium at concentrations of 0.5 ppm. Over 80 years of simulation contaminant plumes, though not especially large ones, did develop.

Refinements were then added to the model. First, retardation coefficients were derived from the isotherms. Retardation coefficients assume that the leachate front moves forward only after it has saturated the adsorption capacity of the soils. This assumption caused leachate plumes to be rather small.

The final model assumed that arsenic and selenium in the source was depleted over 80 years (i.e., that the fill cannot keep putting out arsenic and selenium forever without regard to a mass balance). The model kept track of the amount of arsenic or selenium adsorbed by the soil and the amount available to move on with the water. This model indicated either no plume at all or very weak plumes extending about 20 feet in 80 years.

Essentially these models answered the question of whether arsenic or selenium from CCB fills could contaminate the groundwater by suggesting that it is not going anywhere. This is generally what is found at mine sites that have been heavily monitored. Arsenic and selenium may be released, but it seems not to go anywhere or produce plumes of any size.

Of course there are limitations to the results found here. The models considered the aquifers have isotropic hydraulic conductivity at a field scale. Such a model does not cover flow occurring on large-scale open fractures. Fracture flow can allow dye tests to carry for miles in a matter of days. Fractures have less contact surface area to adsorb arsenic and selenium. Of course, contamination is largely restricted to a single fracture if dilution or exposure to a larger adsorbing surface area is to be avoided. Thus, no plume can develop in this type of setting, and water might show arsenic or selenium contamination in one place and no effect at all only a few feet away.

The model also deals with saturated groundwater flow—i.e., the CCBs are buried beneath the surface and are submerged in groundwater. To many, this would be a worse-case scenario and something to be avoided, but the work done in this project suggests that CCBs buried at mine sites pose little risk to groundwater, even if they become saturated below the water table. The model does not consider the case of surface run-off, which, again, may have less contact surface area to adsorb the arsenic and selenium and may allow water to move much faster than the somewhat tight aquifers found underground at mine sites.

For more information about this project, contact Bradley C. Paul at Southern Illinois University Carbondale, Mining and Mineral Resources Engineering, at (618) 453-792, or by e-mail to paul_b@siu.edu. For the complete project report, visit the CBRC's Web site at <http://wwwri.nrcce.wvu.edu/programs/cbrc>. Refer to project 02-CBRC-M21.



Calendar

May 7–10, 2007

2007 World of Coal Ash...Science Applications and Sustainability

Covington's Northern Kentucky Convention Center, Cincinnati, Ohio
Organizers: American Coal Ash Association and University of Kentucky Center for Applied Energy Research

World of Coal Ash is a conference that combines the previous international symposia of the ACAA and CAER. It will focus on the science applications and sustainability of coal ash worldwide. It is planned to encompass all aspects of coal combustion products as well as gasification.

www.worldofcoalash.org.

January 29–31, 2007

American Coal Ash Association Meeting

Crown Plaza Riverfront Jacksonville, Florida
For more information: Annely Noble; 720-870-7897

www.acaa-usa.org/ASP/DirectorCalendar

June 11–13, 2007

Sustainable Construction Materials and Technologies

Coventry, U.K.
Sponsored by Coventry University and University of Wisconsin, Milwaukee

The construction materials industry is a major user of the world's resources. While enormous progress has been made towards sustainability, the scope and opportunities for further improvements are significant. This conference is intended to highlight case studies and research that show new and innovative ways of achieving sustainability of construction materials and technologies.

www.uwm.edu/dept/cbu//coventry.html

CBRC Contacts

Program Manager

William Aljoe, U.S. Department of Energy-National Energy Technology Laboratory, 412/386-6569, aljoe@netl.doe.gov

National Center

Paul Ziemkiewicz, Ph.D., *Director*
Tamara Vandivort, *Consortium Manager*
CBRC National Center located at the National Mine Land Reclamation Center at West Virginia University, 304/293-2867, pziemkie@wvu.edu or tvandivo@wvu.edu

National Steering Committee Chair

Paul Ehret, Kentucky Department of Natural Resources, 317/232-4020, paul.ehret@ky.gov

Eastern Regional Chair

Cheri Miller, Tennessee Valley Authority, 423/751-4419, ecmiller@tva.gov

Midwestern Regional Chair

Kimery Vories, U.S. Office of Surface Mining, 618/463-6463, kvories@osmre.gov

Western Regional Chair

Richard Halverson, Headwaters Resources, 206/575-1981, rhalverson@isgresources.com

Eastern Regional Technical Director

James C. Hower, Ph.D., University of Kentucky, 859/257-0261, hower@caer.uky.edu

Midwestern Regional Technical Director

Y. Paul Chugh, Southern Illinois University at Carbondale, 618/536 6637, chugh@engr.siu.edu

Western Regional Technical Director

Deborah Pflughoeft-Hassett, University of North Dakota, 701/777-5181, dphassett@undeerc.org

National Steering Committee Members

Jackie Bird, *Member-at-Large*
Ohio Coal Development Office, 614/466-3465, jbird@aqda.state.oh.us

John Glassock, Synthetic Materials Synmat, 727/367-0402, jrg@synmat.com

David Goss, American Coal Ash Association, 720/870-7897, DCGoss@ACAA-USA.org

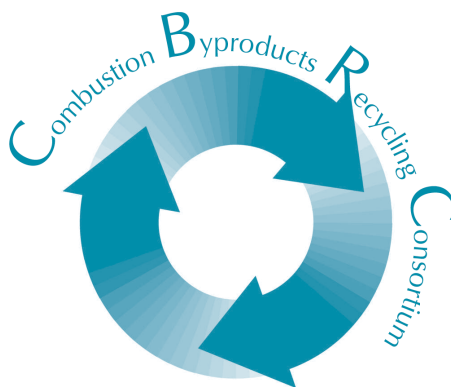
Howard Humphrey, *Ex-Officio*, American Coal Ash Association, 614/846-1726, hhumphrey@columbusrr.com
Jimmy Knowles, South Eastern Fly Ash Group, 803/794-3230, jknowles@SEFAGroup.com

David Meadows, USACE-Huntington District, 304/529-5243, david.f.meadows@usace.army.mil

Bonnie Robinson, EPA-Office of Solid Waste, 423/751-4419, robinson.bonnie@epa.gov

James Roewer, Utility Solid Waste Activities Group, 202/508-5645, jim.roewer@uswag.org

Dan Wheeler, Illinois DCCA Office of Coal Development and Marketing, 217/558-2645, dwheeler@lidceo.net



Ashlines is published by the Combustion Byproducts Recycling Consortium, headquartered at West Virginia University in Morgantown, WV. Would you like to be on the CBRC electronic mailing list? If so, please send an e-mail to cbrc@wvu.edu.



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CCB Use in Mine Filling Applications: A Review of the Literature and Case Studies

Ishwar Murkaka and
Jim Erickson, PIs

Surface and underground mining combine to produce over 800 million tons of coal annually, and the vast majority of this coal is burned in utility boilers to generate electricity. Combustion of coal in utility boilers produces coal combustion residues or byproducts (CCBs) in the form of fly ash, bottom ash, boiler slag, and flue gas desulphurization (FGD) sludge.

In 2003, U.S. electric utilities produced approximately 122 million tons of CCBs. Coal fly ash constituted about 70 million tons, the bottom ash/boiler slag accounted for about another 20 million tons, and the remaining 30.8 million tons were FGD materials.



Mine reclamation has been identified as a long-term, large-volume beneficial use market for CCBs. Nonetheless, use of CCBs in mine reclama-

tion currently is performed on a limited basis relative to the overall quantity of CCBs generated each year. Only 0.68 million tons of fly ash, 1.2

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VISIT THE CBRC WEBSITE AT [HTTP://WVWRI.NRCCE.WVU.EDU/PROGRAMS/CBRC](http://WVWRI.NRCCE.WVU.EDU/PROGRAMS/CBRC)

CCB Use in Mine Filling Applications

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million tons of bottom ash, and about 0.39 million tons of FGD materials were used in mining applications in year 2003 (American Coal Association, 2004).

Although CCBs possess several beneficial physical and chemical properties, there are concerns from regulators and environmental groups regarding the potential for release of toxic chemicals in the leachates from CCBs. Therefore, scientifically sound information is needed so that environmental concerns can be adequately and reliably identified and addressed.

The Combustion Byproducts Research Consortium (CBRC) selected Ish, Inc., and GeoTrans, Inc., to conduct a literature review and review of information from several case studies involving CCB use for mine application. Cofunding for the review was provided by Public Service Company of Colorado, McDonald Farms, American Coal Ash Association, Utility Solid Waste Activities Group, GeoTrans, Inc., and Ish, Inc.

The purpose of the project is to inform regulators, environmental interest groups, and the generators of CCBs about the benefits and impacts of CCB use for mine filling.

The complete project report contains information gleaned from the literature about the chemical and physical characteristics of CCBs produced in the U.S., along with some information on mine spoil material. Background information on coal mines and a brief discussion of the geochemistry in coal mines is included, particularly to describe the formation of acid mine drainage (AMD).

The final project report also presents a summary of available data on water quality characteristics of mined areas and a description of the geochemical interactions between the AMD water and CCBs. A summary list of mine sites where CCBs are being utilized for filling the mined land and/or for abating AMD conditions is also included.

The final report (project 99-EC-W5) will be available later this fall on CBRC's Web site at <http://www.wri.nrcce.wvu.edu>. Following is some information from the report.

Use of CCBs in Mines

Mine reclamation represents a potential beneficial use of CCBs that has received

increased attention in recent years. Coal mining operations have produced both open pits and deep underground cavities that can be filled by CCBs.

CCBs possess physical and chemical characteristics that are both environmentally and economically beneficial. Placement of CCBs into deep mines can provide structural support to abate subsidence, and placement of CCBs in surface mines or other open pits can aid in restoring mined land to beneficial use. Use of CCBs as mine backfill may provide the additional potential benefit of limiting impacts of AMD.

Many CCBs are alkaline materials that can neutralize acidic groundwater and/or inhibit production of acid. Placement of CCBs in mines also may reduce the permeability of mine strata and divert water away from acid-generating materials.

Literature Search Results

Beneficial use of CCBs for coal mine reclamation occurs in varying degrees across the U.S. Injection of CCBs into

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CCB Use in Mine Filling Applications

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deep mines has been performed to provide structural support for subsidence abatement, and placement of CCBs in surface mines has been utilized to reclaim mined land to original grade and to mitigate AMD. Such practices have been employed at both active and abandoned coal mines.

Several surface and deep mines in the U.S. that have utilized CCBs for reclamation are identified in this study. Thirteen were selected for review based on availability of site-specific data required to perform a reasonable evaluation of the benefits and impacts of CCB placement on groundwater quality. Tables and graphs are included in the final report, when available, to illustrate important aspects of each case study.

These case studies represent a large range of CCB uses, from the filling of mine pits to using CCB grout mix to minimize/eliminate acid mine drainage. Following is a brief summary of case studies from the report:

Wyodak Mine, WY

Placement of fly ash, bottom ash, and scrubber ash in mined areas at Wyodak began in 1978. Approximately

5,000,000 cubic yards of ash has been placed in 13 separate pits. Results indicate that the average groundwater quality throughout the Wyodak site compares favorably with the Wyoming Department of Environmental Quality class III (livestock use) standard. Mean concentrations for all of the measured constituents in wells are at or below class III standards.

Keensburg Mine, CO

Reclamation at the Keensburg Mine site is being performed using fly ash and bottom ash derived primarily from combustion of Keensburg coal. Ash was placed at least 5 feet above the pre-mining groundwater table, and reclamation includes placement of a vegetative final cover consisting of at least 5 feet of compacted overburden and 3 feet of topsoil material.

Comparison of the water quality in up-gradient versus down-gradient wells, and sampling events prior to ash placement (1978-1986) relative to sampling events following ash placement (1988-2000), show little evidence that elevated levels of regulated constituents in site groundwater are a direct result of leaching from the ash.

Trapper Mine, CO

Trapper mine is a surface coal mine located approximately 6 miles south of Craig, Colorado. The mine began operation in 1977 and produces up to 2.8 million tons of coal annually. Deposition of CCBs in the mined out areas of Pit A began in 1984.

Trapper Mine has managed approximately 390,000 tons of CCBs per year since 1984, with total disposal quantities approaching 7 million tons to date. Current ash placement practices involve deposition of sufficient overburden material into the pit bottom, such that the ash is placed above the expected post-mining groundwater table. Overburden materials are placed above the ash and revegetated as part of the final reclamation plan.

Comparison of the historic groundwater concentration data with Colorado standards indicate little or no evidence of groundwater impacts associated with most of the analyzed constituents.

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CCB Use in Mine Filling Applications

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Savage Mine, MO

Savage Mine has been in operation since 1958 as a surface lignite mine and currently produces 250,000 tons of lignite annually. The mine began utilizing fly ash and bottom ash as backfill in 1987.

Annual volume of ash received by the Savage Mine is variable and dependent upon the amount of coal burned by Holly Sugar in relation to the quantity of sugar beets processed. The estimated cumulative volume of ash placed between 1987 and 2000 is approximately 130,000 cubic yards.

Mount Storm Mine, WV

The Mount Storm case study concerns placement of coal ash in an active coal strip mine. The down-gradient groundwater monitoring data reveals no evidence of contamination over the 10-year period of operation.

Coal ash (both bottom and fly) is being placed at a rate of about 800,000 tons annually in an active strip mine near an electric power plant in West Virginia. The strip mine provides coal for the power plant and is located on the

plant property. Ash placement began in 1987. No ash has been placed below the water table, because the groundwater table is deeper than the mine floor.

Universal Mine, IN

In 1988, PSI Energy, Inc., (now Cinergy Corporation) acquired a portion of the Universal Mine site containing the final cut pit for the express purpose of coal ash deposition and surface mine reclamation. Indiana DNR issued a permit to PSI Energy to dispose of fly ash/bottom ash from its nearby Wabash River Station to fill and reclaim the mine pit.

Between April 1989 and the end of October 2001, Cinergy placed approximately 1.6 million tons of coal ash from a nearby power plant to completely fill the open-pit. The monitoring data to date indicate that the alkaline coal ash leachate has been effective in improving the AMD water quality that was present at the site. The coal ash leachate neutralized the acidic pH, increased alkalinity, essentially eliminated acidity, and significantly decreased manganese, iron, and sulfate

concentrations. There were no indications of any other trace metals migration via the mine-seep. However, the coal ash leachate did increase significantly boron concentrations in the mine seep water.

Midwestern Abandoned Mine, IN

Midwestern abandoned coal mine is a case study where a state agency elected to place CCBs with a Poz-O-Tec cap (a mixture of FGD sludge, fly ash, and quicklime), which resulted in reduced infiltration and improvement in water quality by neutralization.

The mine consists of approximately 550 acres of previously mined land, which, in some instances, intersects with abandoned deep mining of the same coal seam.

Based on the monitoring results, Branam et al. (1999) concluded that using CCBs to reclaim the Midwestern Abandoned Mine has resulted in the reduction of AMD leaving the site. The authors ascribe this response to the reduction in vertical recharge of oxygenated water by the fixated scrubber sludge cap

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and the neutralization provided by the alkaline CCBs.

Arnold Willis City Mine, IN

The Arnold Willis City underground coal mine in Indiana is an example in which fixated scrubber sludge (FSS) has been successfully injected into an abandoned underground coal mine for stabilization by filling mine voids. Groundwater monitoring data indicated that trace metals and sulfide remained unaffected by the placement of FSS.

An FSS grout consisting of a mixture of FGD scrubber sludge, fly ash, lime, and water was developed for injection in the abandoned deep mine to abate surface subsidence and reduce acid mine drainage. A total of 12,502 cubic meters of FSS was injected over an eight-week period, resulting in filling of about five acres of the mine.

Harwick Mine Complex, PA

The Harwick Mine Complex includes the Monarch, Old Harwick and Cornell Mines covering approximately 7,000 acres. The complex is a deep

mine and was operated from about 1932 through June 1970.

The mine disposal operation consists of a wet ash handling system to pump 10 percent solids slurry for a distance of approximately 8,000 feet to two operating injection boreholes at the Harwick Mine Complex. Approximately 3 to 4 million gallons per day of the slurry are conveyed. Approximately 150,000 tons of coal ash is injected annually in the mine along with millions of gallons of water. The water quality data from samples of the mine water indicates no adverse effect on the water in the Harwick Mine Complex.

Clinton County, PA

The Clinton County, Pennsylvania, mine provides an example of how placement of FBC ash in a closed-surface coal mine can result in beneficial effects on water quality, because of the favorable geochemistry that occurs. The alkaline FBC ash neutralizes the acidic AMD waters resulting in precipitous decreases in arsenic, cadmium, and aluminum concentrations due to lower solubility and

precipitation of solids.

Results indicate that the injection of grout caused a temporary increase in pH from about 2.3 to about 9, as the alkaline FBC ash neutralized the acidic AMD waters. The pH increase resulted in precipitous decreases in arsenic, cadmium, and aluminum concentrations reflecting lower solubility and precipitation to solid phase compounds.

However, within a short time, the pH again became acidic, with sulfate and aluminum returning to the pre-grouting concentrations, although arsenic and cadmium remained at much lower levels.

Big Gorilla Pit, PA

In eastern Pennsylvania, there are several pre-act stripping pits in the middle of an anthracite coal basin where active strip and deep mining for coal was practiced since the 1800s. The strip mined pit known as Big Gorilla was one such location.

The Pennsylvania Department of Environmental Protection's Regional Mining office in conjunction with the

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CCB Use in Mine Filling Applications

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Wilkes-Barre Regional office issued a demonstration permit for the placement of cogeneration-derived dry fly and bottom ash into standing water in the Big Gorilla Pit. Ash deposition has taken place since August 1997. Over three million tons of ash was used to completely fill the pit which contained acid mine water pool.

The Big Gorilla water has maintained a consistently high pH value in response to the placement of ash. Iron, manganese, magnesium, aluminum, and zinc all have decreased significantly. One long-term effect of ash placement in the former Big Gorilla mine pool will be the prevention of acidic water production through the surface mine pool.

Red Oak Mine, OK

The Red Oak coal mine was operated from 1907 to 1925 utilizing the room-and-pillar extraction method. The mine, which covers approximately 46.5 acres, contains water pools or reservoirs of AMD.

The University of Oklahoma and the Oklahoma Conservation Commission injected 418 tons of FBC ash in 15 hours into this acidic (pH 4.3) flooded mine to chemically alter the mine water.

Winding Ridge Project

The Maryland Department of Natural Resources Power Plant Research Program and the Maryland Department of Environment Bureau of Mines launched a joint effort with private industry to demonstrate large-volume beneficial uses of CCBs to create flowable grouts for placement of abandoned, underground coal mines to reduce acid formation. In April 1995, this multi-year project initiative started with the Winding Ridge Demonstration project, which involved injection of a 100 percent CCB grout into the Frazee Mine, located near Friendsville, Garrett County, Maryland.

The Winding Ridge demonstration project at the Frazee Mine has shown that CCB grout mixture can be beneficially used for abandoned, underground coal mine to reduce acid formation as well to fill mine voids with a high-strength, low-permeability material that would control mine subsidence. The placement of the CCP grout appears to have not caused an unacceptable water quality impact either.

Conclusions

This literature review report on the use of CCBs in mine filling activities provides a readily available resource for regulators, general public, environmental interest groups and potential CCB users synthesizing technical information on a range of case studies. Each case study is different in several details and provides the readers insights into the use of CCBs and their benefits and limitations. The technical information can be used to determine and decide on environmentally compatible uses of CCBs in surface and underground coal mines.

More Information

The CBRC Web site at <http://www.wri.nrcce.wvu.edu/programs/cbrc> features program news, factsheets, project reports, contact information, a calendar of events, and publications, including *Ashlines*, which is available in electronic pdf format only. To be placed on the CBRC electronic mailing list, send an e-mail to cbrc@nrcce.wvu.edu. Or contact the CBRC Consortium Manager, Tamara Vandivort, at Tamara.Vandivort@mail.wvu.edu or at 304.293.2867.



Calendar

Sept. 25–28, 2006

23rd Annual International Pittsburgh Coal Conference
Pittsburgh, PA
www.engr.pitt.edu/pcc

The Twenty-Third Annual International Pittsburgh Coal Conference will focus on environmental emissions issues and technologies surrounding the continued use of coal and the development of future coal-based energy plants to achieve near-zero emissions of pollutants, reduced costs, and high thermal efficiency while producing a suite of products to meet future energy market requirements. Technical, business, and policy-related papers will be presented at the conference.

October 24–25, 2006

20th Western Fuels Symposium International Conference on Lignite, Brown, and Subbituminous Coals
Denver, Colorado
<http://www.undeerc.org/wfs/>

The goal of the Twentieth Symposium on Western Fuels is to provide a forum in which industry, government, and research organizations can share up-to-date information on the role of lignite, brown, and subbituminous coals in meeting future energy demands. Low-rank fuels have unique properties that present challenges and opportunities related to meeting future environmental regulations and in the development and application of advanced technologies.

June 11–13, 2007

Sustainable Construction Materials and Technologies
Coventry University, Coventry, UK
www.uwm.edu/dept/cbu/coventry.html

This conference will highlight case studies and applied research that show new and innovative ways of achieving sustainability of construction materials and technologies. Papers have been invited on all the different materials used in construction, including cementitious materials (fly ash, wood ash, silica fume, slag, natural pozzolans, and others); aggregates; admixtures, concrete; timber; masonry; metals; plastics; glass; bitumen; lime; and gypsum, and on paints, adhesives, preservatives, and preservation processes. Sponsored by Coventry University and University of Wisconsin-Madison Center for By-Products Utilization

CBRC Contacts

Program Manager

William Aljoe, U.S. Department of Energy-National Energy Technology Laboratory, 412/386-6569, aljoe@netl.doe.gov

National Center

Paul Ziemkiewicz, Ph.D., *Director*
Tamara Vandivort, *Consortium Manager*
CBRC National Center located at the National Mine Land Reclamation Center at West Virginia University, 304/293-2867, pziemkie@wvu.edu or tvandivo@wvu.edu

National Steering Committee Chair

Paul Ehret, Kentucky Department of Natural Resources, 317/232-4020, paul.ehret@ky.gov

Eastern Regional Chair

Cheri Miller, Tennessee Valley Authority, 423/751-4419, ecmiller@tva.gov

Midwestern Regional Chair

Kimery Vories, U.S. Office of Surface Mining, 618/463-6463, kvories@osmre.gov

Western Regional Chair

Richard Halverson, Headwaters Resources, 206/575-1981, rhalverson@isgresources.com

Eastern Regional Technical Director

James C. Hower, Ph.D., University of Kentucky, 859/257-0261, hower@caer.uky.edu

Midwestern Regional Technical Director

Y. Paul Chugh, Southern Illinois University at Carbondale, 618/536 6637, chugh@engr.siu.edu

Western Regional Technical Director

Deborah Pflughoeft-Hassett, University of North Dakota, 701/777-5181, dphassett@undeerc.org

National Steering Committee Members

Jackie Bird, *Member-at-Large*
Ohio Coal Development Office, 614/466-3465, jbird@aqda.state.oh.us

John Glasscock, Synthetic Materials Synmat, 727/367-0402, jrg@synmat.com

David Goss, American Coal Ash Association, 720/870-7897, DCGoss@ACAA-USA.org

Howard Humphrey, *Ex-Officio*, American Coal Ash Association, 614/846-1726, hhumphrey@columbusrr.com

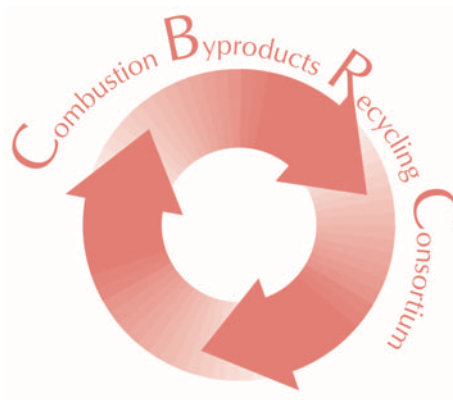
Jimmy Knowles, South Eastern Fly Ash Group, 803/794-3230, jknowles@SEFAGroup.com

David Meadows, USACE-Huntington District, 304/529-5243, david.f.meadows@usace.army.mil

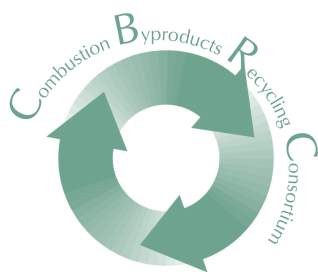
Bonnie Robinson, EPA-Office of Solid Waste, 423/751-4419, robinson.bonnie@epa.gov

James Roewer, Utility Solid Waste Activities Group, 202/508-5645, jim.roewer@uswag.org

Dan Wheeler, Illinois DCCA Office of Coal Development and Marketing, 217/558-2645, dwheeler@lidceo.net



Ashlines is published quarterly by the Combustion Byproducts Recycling Consortium, headquartered at West Virginia University in Morgantown, WV. Would you like to be on the CBRC electronic mailing list? If so, please send an email to tocbrc@nrcce.wvu.edu.



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COMBUSTION BYPRODUCTS RECYCLING CONSORTIUM

Ashlines

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Reclamation Center at
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in cooperation with the
U.S. Department of
Energy-National Energy
Technology Laboratory
www.netl.doe.gov

To promote and support the commercially viable and environmentally sound recycling of coal combustion byproducts for productive uses, through scientific research, development, and field testing

CBRC History & Status: Eight Years of Identifying Markets for Millions of Tons of Waste

Once viewed as a useless, dirty, unsightly, and copious liability, coal combustion byproducts (CCBs) are now regarded as a largely untapped, recyclable resource with tremendous industrial market potential. In recent years, CCBs have been used successfully as a structural fill for an airport runway extension, as a safe backfill for an abandoned mine pit, and as a treatment for acid mine drainage. Other promising CCB demonstration projects are using fly ash to replace foundry sand and flue gas desulfurization (FGD) scrubber sludge to manufacture countertops, tiles, and other materials for the construction industry. High-carbon CCBs and FGD byproducts have been used to fabricate a permeable roadway base material, FGD soil supplements are boosting soybean and alfalfa crop yields, and FGD sludge briquettes are helping to control beach erosion. And that's just a sample.

(continued on page 2)



CBRC-supported investigators at Energy Industries of Ohio Casting Development Center are investigating the feasibility of using CCBs as a substitute for foundry sands, thus replacing a portion or all of the virgin silica sand used for foundry mounds and cores. The materials will be tested in a "live fire" production environment at General Motors Corporation's Powertrain Casting Plant in Defiance, Ohio. Actual molds and/or cores will be made from both currently available ashes and ashes that contain higher carbon content, expected to result from new environmental requirements. The photo above is of a compression test at the point of failure. (02-CBRC-E10)

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VISIT THE CBRC WEBSITE AT [HTTP://WWW.NRCCE.WVU.EDU/PROGRAMS/CBRC](http://www.nrcce.wvu.edu/programs/cbrc)

CBRC History & Status: Eight Years of Identifying Markets for Millions of Tons of Waste (continued from page 1)

Fact 1: Each year, the U.S. electric utility industry generates about 100 million tons of coal combustion byproducts. Just over half of this amount is fly ash, approximately one-fourth is sludge from wet flue gas scrubbers, another 16 percent is boiler ash (a heavier, coarser solid removed from the bottom of a boiler), and about 7 percent is boiler slag (a hard, glassy material made from boiler ash that has been melted by the heat of the combustor). Currently, only about a third of this coal ash and just over one fourth of the scrubber waste is recycled in commercially beneficial uses. The largest amount is fly ash that is typically used as a Portland cement replacement in concrete and concrete products. The remainder, more than 70 million tons a year, is disposed of in impoundments and landfills.¹

Fact 2: The U.S. relies on oil and natural gas from the Middle East, a market that has become increasingly unstable, expensive, and volatile. If we had to rely exclusively on domestic supplies of fossil fuels to meet our energy demands, according to calculations based on Energy Information Administration (EIA) data, at current reserve and production rates, the U.S. has approximately 9.5 years proven reserves of natural gas, 12.2 years proven reserves of

oil, and 247 years proven reserves of coal.²

Observation: That figure of 100 million tons of CCBs being produced annually in the U.S. may, in the near future, get much bigger. And, strict limits on NO_x emissions, mandated by the 1990 Clean Air Act have resulted in utility burner/boiler modifications that frequently yield higher carbon concentrations in fly ash, which restricts its use as a concrete ingredient—historically ash’s biggest commercial market. If newer, “clean coal” combustion and gasification technologies are adopted, their byproducts may add to the CCB management challenge. The time is ripe for innovation, research, and investment in the recycling and industrial application of CCBs.

Brief History of CCB Utilization and the CBRC

Dam construction was the first large market for using fly ash as a substitute for Portland cement. One of the first large-volume uses of fly ash was in the construction of the Hungry Horse Dam in Montana in 1949. Not until 1958, though, did a group of researchers start working on problems related to the under-utilization of coal ash. The National Ash Association (NAA) was formed 9 years later, shortly after the first Ash Utilization Symposium in 1967. In 1985, the American Coal Ash Associa-

tion (ACAA) succeeded the NAA, choosing a perfect symbol—the phoenix—for its logo.³

In 1992, *Use of Coal Combustion By-Products: Status and Opportunities in Region 8*, a report by Bryggman and Nillick prepared for the U.S. Department of Energy, identified typical markets for CCBs in DOE’s Region 8 (Colorado, Montana, North and South Dakota, Utah, and Wyoming). Positive response to that report led to the formation of the Western Region Ash Group (WRAG) in 1994.⁴

In the eastern U.S., West Virginia is a major coal producer and has played a prominent role in coal-related research. It was a natural choice, then, that in 1998, with support from the U.S. Department of Energy’s National Energy Technology Laboratory (DOE-NETL) in Morgantown, West Virginia, the Combustion Byproducts Recycling Consortium (CBRC) was established in Morgantown also, at West Virginia University (WVU). The CBRC is headquartered at the West Virginia Water Research Institute (WVWRI), located at WVU’s National Research Center for Coal & Energy (NRCCE). The Consortium’s director, Dr. Paul Ziemkiewicz has worked with CCBs since the early 1980s and been a member of the WVU research community and director of the WVWRI for 18 years.

(continued on page 3)

CBRC History & Status: Eight Years of Identifying Markets for Millions of Tons of Waste (continued from page 2)

The CBRC Today

The mission of the CBRC is to identify beneficial uses for those approximately 100 million tons of coal combustion byproducts that are generated every year. The Consortium supports innovative ideas, and its projects—performed by universities and businesses research teams—are demonstrating that CCBs have many high-volume applications.

The CBRC continues to be funded and overseen by DOE NETL and is supported by the ACAA, the Interstate Mining Compact Commission, and numerous state and corporate sponsors. To meet its goals, the CBRC provides seed money to researchers to develop innovative applications for CCBs, while testing the economic and environmental viability of these applications.

No byproduct recycling technology, however, is likely to be adopted by industry unless it is more cost-effective than disposal. Therefore, the utility industry—as producer and owner of CCBs—pro-

vides guidance to the CBRC R&D program, as well as government agencies and private-sector organizations that may have use for CCBs. The CBRC synthesizes information from these organizations and uses it to develop a balanced R&D program that addresses the needs of both producers and end-users of CCBs.

CBRC's Structure: National Steering Committee and Regional Centers

The CBRC's National Steering Committee (NSC) is its key decision-maker. Among its many functions, the NSC sets priorities based on regional recommendations, evaluates proposals, and recommends proposals to DOE-NETL for funding consideration. The types of coals burned by electric utilities and the technologies employed for emission control greatly affect the characteristics of the byproducts that are produced. Recognizing that these characteristics often vary from region to region and that

regional prioritization of research needs is determined by transportation costs and state regulations governing CCB disposal and utilization, the NSC works with regional advisors and reviewers from the Eastern, Midwestern, and Western regions of the U.S., with each region developing its own research priorities.

Each region develops its own specific research priorities based on its own particular needs, with all three regions supporting projects with a market potential for high-volume beneficial utilization of CCBs and investigations into the impacts of changing air quality standards on the composition and quality of fly ash and FGD byproducts. Environmental impacts, technology development, and long-term economic benefits for producers and end-users are integral to every undertaking.

Progress to Date

Between 1998 and 2005, the CBRC funded 42 projects, totally over \$8 million (nearly \$4.1 million in federal funds, and more than \$4.4 million in cost share.) Many of the technologies developed through CBRC research have been selected for large-scale demonstrations, and several technologies have been adopted by the government as agency policy or by industry as commercial processes. The following list provides a sampling of CBRC-supported research, by region.

“if we’re going to add to the utilization rate, we also need to identify new markets, and that means finding applications that make the most of the unique properties of CCBs, applications for which there are few competing materials in the marketplace right now.”

(continued on page 4)

CBRC History & Status: Eight Years of Identifying Markets for Millions of Tons of Waste (continued from page 3)

CBRC Regional Research

Northeast Region

- In Preston County, West Virginia, a demonstration project has reclaimed 35 acres of land degraded by strip mining by amending the site's soil using fly ash and planting five species of hardwood trees. Ultimately, the project is testing whether it is economically advantageous for industry and landowners to recycle CCBs and restore abandoned mine lands, thus converting a degraded habitat into an environmental commodity. (99-EC-E17)
- At Rostraver Airport near Pittsburgh, Pennsylvania, CBCs from a nearby power plant were used as structural fill to expand the airport's runway. The favorable engineering properties of the low-permeability cementitious (LPC) CCB material produced at the Elrama power station made it uniquely qualified to meet the Westmoreland County Airport Authority's objective. This project is one of the largest projects of its type using coal combustion byproducts and serves as an excellent example of an environmentally friendly solution to CCB management. (00-CBRC-E41)
- In another project funded by the CBRC, Energy Industries of Ohio recently demonstrated the suitability of fly ash as a re-



At Rostraver Airport near Pittsburgh, Pennsylvania, CBCs from a nearby power plant were used as structural fill to expand the airport's runway. The favorable engineering properties of the low-permeability cementitious (LPC) CCB material produced at the Elrama power station made it uniquely qualified to meet the Westmoreland County Airport Authority's objective. This project is one of the largest projects of its type using coal combustion byproducts and serves as an excellent example of an environmentally friendly solution to CCB management. (00-CBRC-E41)

placement for traditional foundry sands, which have certain negative qualities including cost; varying dust contents; health risks; and excavation, cleaning, and segregating requirements. (02-CBRC-E10 and 00-CBRC-E42)

- Also in Ohio, one of the first CBRC-funded research teams demonstrated that FGD byproducts provide sulfur and trace mineral nutrition for alfalfa and soybean crops. (99-EC-E08)

- Because excessive ammonia, or even the presence of an ammonia odor, can severely affect the ability to utilize and sell fly ash for any purpose, CBRC researchers in Pennsylvania and Kentucky characterized and compared the ammonia content of fly ash from different power plants that operate SCR (selective catalytic reduction) and SNCR (selective noncatalytic reduction) systems for controlling NOx emissions. Their project in-

(continued on page 5)

CBRC History & Status: Eight Years of Identifying Markets for Millions of Tons of Waste (continued from page 4)

cluded investigations of ammonia release, including leaching and thermal studies; an evaluation of the potential impacts on plant equipment, air quality, and water quality (surface and ground); ash disposal operations; and ash marketing. (99-EC-E06)

- In Homestead, Florida, CBRC researchers mixed Class F fly ash with yard waste and biosolids to grow tomatoes, thus determining the beneficial effects of CCBs on the physical and chemical properties of typical nutrient-poor Florida soils and the growth of Florida-grown vegetables. (99-EC-E11).
- CBRC researchers at Louisiana State University have proven the feasibility of using light-weight stabilized FGD sludge briquettes as a fill material to control beach erosion (00-CBRC-M11)

Midwest Region

- In Illinois, researchers at Southern Illinois University at Carbondale (SIUC) have designed utility poles made from CCBs. They estimate that currently 250,000 wooden poles with an average height of from 30–40 feet and another 1 million poles averaging 15–30 feet high are used annually in the Midwest alone. To replace 250,000 wooden poles with CCB-fabricated poles would save that many trees and uti-

lize from 77,500 to 100,000 tons of CCBs at a rate of 400–600 pounds of CCBs per pole. (99-EC-M07)

- Also at SIUC, CBRC researchers have studied fly ash boron concentrations (99-ECM-04) and fabricated countertops, tiles, and other structural materials from FGD scrubber sludge. (99-EC-M01)
- In Wisconsin, CBRC researchers have fabricated four concrete mixtures using high-carbon CCBs and FGD byproducts, which can be used in permeable roadway base construction. (99-EC-M06)

Western Region

- The Varra Coal Ash Project is an ongoing study to determine the feasibility of using coal ash to reclaim flooded gravel mine quarries in Weld County, Colorado. The use of coal ash as fill in saturated environments has been discouraged by most regulatory agencies; it took 4 years to obtain required permits to conduct this study to assess potential impacts of large-scale coal ash reclamation on groundwater resources. Analytical data generated from the Varra project indicate that the leaching characteristics of the coal ash used in the study

(continued on page 6)

The introduction of fly ash and bottom ash into the foundry industry could create a new use for CCBs and perhaps solve some the the problems associated with the use of natural sand, the traditional base material of foundry molding and core mixtures. This photo is of a pour test using iron at General Motors Corporation's Powertrain Casting Plant in Defiance, Ohio, where fly ash from First Energy is being used in place of silica sand. (02-CBRC-E10)



CBRC History & Status: Eight Years of Identifying Markets for Millions of Tons of Waste
(continued from page 5)



Researchers at the Southern Illinois University of Illinois at Carbondale have developed technology for converting sulfate-rich FGC scrubber sludge into decorative building materials like the sample countertop tiles shown at left. (00-CBRC-M11)

are relatively benign and that large-scale ash reclamation may be feasible at this location and meet drinking water standards. (00-CBRC-W02)

- Specific fly ashes from Colorado bituminous and Wyoming sub-bituminous coals have been proven to capture from 75% to 98% of mercury. A study conducted in Pueblo, Colorado investigated the feasibility of employing these fly ash materials as mercury sorbents on a slipstream from a full-scale generating unit. An economic analysis showed that for the flue gas conditions and plant configuration of the host site, this use of fly ash-derived sorbents would be cost-competitive with the injection of activated carbon. This application of fly ash-derived sorbents for mercury

control is anticipated to allow the continued sale of this CCB. (00-CBRC-W4)

The CBRC Vision for the Future

By 2010, the CBRC hopes to

- increase the overall ash utilization rate to 50% by 2010,
- increase the current rate of flue gas desulfurization byproduct use,
- continue to examine the environmental impact of CCB use and disposal, and
- increase the number of uses for CCBs considered allowable under state regulations.

According to William Aljoe, the US DOE NETL's contracting officer representative to the CBRC, "The three biggest markets for CCBs are (1) cement and con-

crete, (2) structural fill, and (3) mine reclamation, and these represent the biggest opportunity for the CBRC to reach its goal of increasing overall utilization of CCBs to 50% by 2010."

"And," adds Paul Ziemkiewicz, CBRC Director, "if we're going to add to the utilization rate, we also need to identify new markets, and that means finding applications that make the most of the unique properties of CCBs, applications for which there are few competing materials in the marketplace right now."

Bearing these goals for 2010 in mind, the National Steering Committee met in February 2006 to select projects for its current funding cycle. Of the 19 full proposals submitted, 10 were selected for funding, with projects ranging from 1-3 years in duration, and project total values ranging from approximately \$24,987 to \$222,682. The CBRC awarded approximately \$1.5 million, with a commitment of over \$¾ million in total cost share.

(continued on page 7)

CBRC History & Status: Eight Years of Identifying Markets for Millions of Tons of Waste

(continued from page 6)

CBRC 2006 Project Awards

The NSC chose five concrete-related projects, two agricultural projects, one in situ treatment of acid mine drainage, one project on brick manufacturing, and one project on CCB marketing strategies. The following are the 10 projects the NSC chose to recommend to DOE-NETL for funding. Awards will be made in yearly increments based upon performance and DOE funding availability:

- **05-CBRC-M09**, “Cold In-Place Recycling of Asphalt Pavements Using Self Cementing Fly Ash”; principal investigator: Anil Misra, University of Missouri. A demonstration of this fly ash pavement use was conducted in August 2004 on approximately 2.5 miles of low-traffic roadway. This project will build upon those results and establish the parameters for engineering design of rehabilitated road pavements with a fly ash-stabilized recycled asphalt base layer. CBRC award: \$24,987.
- **05-CBRC-W8**, “Evaluation of the Durability and Commercial Potential of 100 Percent Fly Ash Concrete”; principal investigator: Jerry Stephens, Montana State University. Portland cement is the binder material in traditional concretes for construction applications, but although it is an excellent performer, Portland cement production is an energy-intensive process. The objective of this project is to determine the long-term durability and possible economic benefits of using 100 percent fly ash concrete in construction applications. Due to recent domestic shortages of Portland cement, as well as cost increases, concrete producers are motivated to explore fly ash binders. CBRC award: \$95,900.
- **05-CBRC-M16**, “In Situ Stabilization of Gravel Roads with CCBs”; principal investigator: Tuncer B. Edil, University of Wisconsin-Madison. This project will test the feasibility of using low-cost, rapid-application, self-cementing CCPs to stabilize deteriorating gravel roads, of which, the investigators estimate there to be 1.6 million miles or 53% of all roads in the U.S. CBRC award: \$130,362.
- **05-CBRC-W04**, “Using Class C Fly Ash to Mitigate Alkali-Silica Reactions in Concrete”; principal investigator: Bruce Dockter, University of North Dakota Energy & Environmental Research Center. This multiyear investigation will evaluate the performance of several Class C fly ashes (>10% CaO) as a means to mitigate alkali-silica reactions (ASR) in concrete. CBRC award: \$150,000.
- **05-CBRC-M20**, “New Technology-Based Approach to Advance Higher Volume Fly Ash Concrete with Acceptable Performance”; principal investigator: Karthik Obla, National Ready Mixed Concrete Association. Surveys indicate that the average fly ash content in all ready-mixed concrete is only about 10%. This project suggest novel science-based approaches to address this low percentage by upping high fly ash concentrations during warm weather applications when optimal strength gain and setting time can be achieved. CBRC award: \$199,680.
- **05-CBRC-M23**, “Manufacturing Building Products with Fly Ash and Advanced Coal Combustion”; principal investigator: Mei-In Melissa Chou, Illinois State Geological Survey (ISGS). For the past several years, researchers at the ISGS have been working with the brick industry to develop high-quality, marketable, fired bricks that use high volumes of Class F fly ash as a raw material. The purpose of this project is to demonstrate the use of CCBs in the production of high-quality fired bricks and innovative autoclaved aerated concrete (AAC) blocks. CBRC award: \$51,000.

(continued on page 8)

CBRC History & Status: Eight Years of Identifying Markets for Millions of Tons of Waste (continued from page 7)

- **05-CBRC-E08**, "Field Testing of Arsenic and Mercury Bioavailability Model from Land-Applied CCBs"; principal investigator: Paul A. Pier, Tennessee Valley Authority. This project will investigate the environmental effects of CCB use, including the potential bioavailability of contaminants to soil organisms, plants, and possibly animals and humans. CBRC award: \$46,000.
- **05-CBRC-M22**, "Community-based Social Marketing: The Tool to Get Target Audiences to Use CCBs"; principal investigator: Richard Buggeln, University of Tennessee Center for Industrial Services. The overarching goal of this project is to demonstrate the utility of community-based social marketing (CBSM) as a method for implementing sustainable agricultural uses of FGD-gypsum by farmers, and in so doing, develop a model that can be expanded and applied to other CCB markets. CBSM is based on motivations for human behavior and is an alternative to traditional information-based campaigns. CBRC award: \$200,193.
- **05-CBRC-W03**, "Evaluation of CCBs for In Situ Treatment of Acid Mine Drainage"; principal investigator: Geoffrey A. Canty, CC Environmental, LLC. This project will follow-up the investigation of a 1994 alkaline injection technology (AIT) project in an abandoned coal mine in eastern Oklahoma, which has been under study for 11 years. This monitoring is necessary to fully evaluate the treatment effectiveness. CBRC award: \$26,940.
- **05-CBRC-M22**, "National Network of Research and Demonstration Sites for Agricultural and Other Land Application Uses of FGD Products"; principal investigator: Warren Dick, The Ohio State University. With many electric utilities in the process of bringing new scrubbers on line, the amount of FGD products to be generated in the future in the U.S. will be greatly increased. This project proposes to establish a national network of sites for research/demonstration of beneficial agricultural and other land application uses of FGD products. CBRC Award: \$222,682.

More Information

The CBRC's website at <http://www.wvri.nrcce.wvu.edu/programs/cbrc> features program news, factsheets, project reports, contact information, a calendar of events, and publications, including the *Ashlines*, which is available in electronic format only (Adobe Acrobat). To be placed on the CBRC electronic mailing list, send an email to cbrc@nrcce.wvu.edu. For more information about the Combustion Byproducts Recycling Consortium and to view RFPs and project reports for any of the projects mentioned in this article, visit the Consortium's website, or contact the CBRC Consortium

Manager, Tamara Vandivort, at Tamara.Vandivort@mail.wvu.edu or at 304.293.2867.

Notes

1. U.S. Department of Energy, Fossil Energy, Coal Byproducts Research, January 18, 2006. http://www.fossil.energy.gov/programs/powersystems/pollution/controlsoverview_coalbyproducts.html.
2. Bayless, Charles, "Energy for West Virginia," presented at the Ninth Annual Industries of the Future-West Virginia (IOF) Symposium, November 8, 2005, Charleston, WV. Proceedings to be published in Spring 2006. Mr. Bayless calculated the estimated remaining years of proven reserves by dividing current proven reserves by current production rates, based on data from the U.S. Department of Energy, Energy Information Administration (EIA). A

Power Point presentation of "Energy for West Virginia" is available online at <http://iofww.nrcce.wvu.edu/>.

3. Manz, Oscar and Debra Pflughoeft-Hassett, "Historical Perspective of Coal Ash Marketing and Promotion in the USA," paper presented at the World of Coal Ash Conference, April 11-15, 2005, Lexington, Kentucky.
4. "WRAG Partnership Benefits the CCB Industry," *Ashlines*, Vol. 1, No. 4 (Winter 2000). More information about the Western Region Ash Group (WRAG) can be found on the WRAG Web site at www.WRASHG.org.



Calendar

Sept. 25–28, 2006

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Pittsburgh, PA

www.engr.pitt.edu/pcc

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June 11–13, 2007

Sustainable Construction Materials and Technologies

Coventry University, Coventry, UK

www.uwm.edu/dept/cbu/coventry.html

This conference will highlight case studies and applied research that show new and innovative ways of achieving sustainability of construction materials and technologies. Papers have been invited on all the different materials used in construction, including cementitious materials (fly ash, wood ash, silica fume, slag, natural pozzolans, and others); aggregates; admixtures, concrete; timber; masonry; metals; plastics; glass; bitumen; lime; and gypsum, and on paints, adhesives, preservatives, and preservation processes.

Sponsored by Coventry University and University of Wisconsin-Madison Center for By-Products Utilization

CBRC contacts

Program Manager

William Aljoe, U.S. Department of Energy-National Energy Technology Laboratory, 412/386-6569, aljoe@netl.doe.gov

National Center

Paul Ziemkiewicz, Ph.D., *Director*
Tamara Vandivort, *Consortium Manager*
CBRC National Center located at the National Mine Land Reclamation Center at West Virginia University, 304/293-2867, pziemkie@wvu.edu or tvandivo@wvu.edu

National Steering Committee Chair

Paul Ehret, Kentucky Department of Natural Resources, 317/232-4020, paul.ehret@ky.gov

Eastern Regional Chair

Cheri Miller, Tennessee Valley Authority, 423/751-4419, ecmiller@tva.gov

Midwestern Regional Chair

Kimery Vories, U.S. Office of Surface Mining, 618/463-6463, kvories@osmre.gov

Western Regional Chair

Richard Halverson, Headwaters Resources, 206/575-1981, rhalverson@isgresources.com

Eastern Regional Technical Director

James C. Hower, Ph.D., University of Kentucky, 859/257-0261, hower@caer.uky.edu

Midwestern Regional Technical Director

Y. Paul Chugh, Southern Illinois University at Carbondale, 618/536 6637, chugh@engr.siu.edu

Western Regional Technical Director

Deborah Pflughoeft-Hassett, University of North Dakota, 701/777-5181, dphassett@undeerc.org

National Steering Committee Members

Jackie Bird, *Member-at-Large*
Ohio Coal Development Office, 614/466-3465, jbird@aqda.state.oh.us

John Glassock, Synthetic Materials Synmat, 727/367-0402, jrg@synmat.com

David Goss, American Coal Ash Association, 720/870-7897, DCGoss@ACAA-USA.org

Howard Humphrey, *Ex-Officio*, American Coal Ash Association, 614/846-1726, hhumphrey@columbusrr.com

Jimmy Knowles, South Eastern Fly Ash Group, 803/794-3230, jknowles@SEFAGroup.com

David Meadows, USACE-Huntington District, 304/529-5243, david.f.meadows@usace.army.mil

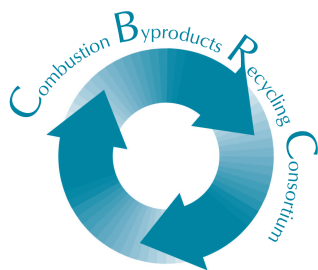
Bonnie Robinson, EPA-Office of Solid Waste, 423/751-4419, robinson.bonnie@epa.gov

James Roewer, Utility Solid Waste Activities Group, 202/508-5645, jim.roewer@uswag.org

Dan Wheeler, Illinois DCCA Office of Coal Development and Marketing, 217/558-2645, dwheeler@lidceo.net



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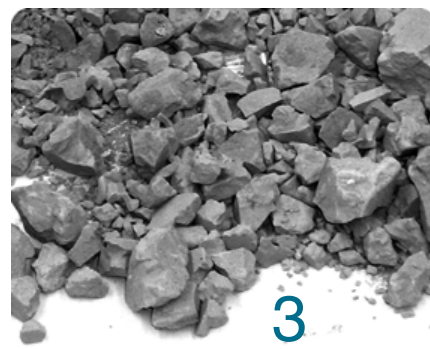
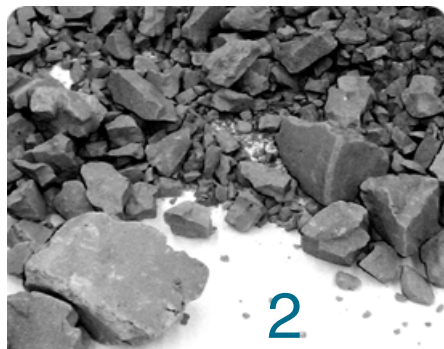
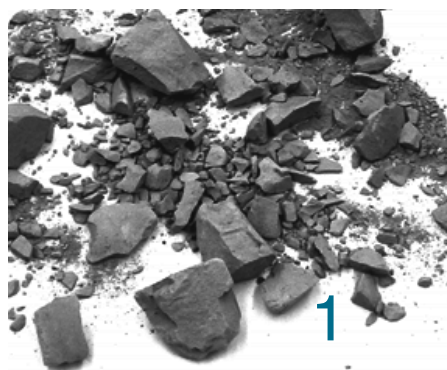
COMBUSTION BYPRODUCTS RECYCLING CONSORTIUM

Ashlines

a program of the
National Mine Land
Reclamation Center at
West Virginia University,
in cooperation with the
U.S. Department of
Energy-National Energy
Technology Laboratory
www.netl.doe.gov

To promote and support the commercially viable and environmentally sound recycling of coal combustion byproducts for productive uses, through scientific research, development, and field testing

New Construction Applications for Fly Ash: Crushed Aggregates from Class C Fly Ash



Three different samples of aggregates from Class C fly ash, made by different methods, after 20 blows from a 2.5kg rammer. The aggregates made using procedure one have an applicable grain-size distribution. Moreover, procedure one is expected to be more economical because it is a less energy-intensive process than the other two, which require sintering at 850°C.

Class C fly ash is produced in abundance by utilities that burn subbituminous coal from Wyoming. While this type of ash is widely used in a variety of construction and building materials, very few efforts have been made to take advantage of the self-cementing nature of class C fly ash for synthetic aggregate production. Instead, most existing synthetic aggregate applications require expensive high-temperature treatments.

The use of this high-calcium coal combustion byproduct (CCB) as a substitute for cement could provide an innovative and readily available raw material for highway and other construction activities.

Anil Misra and his research team at the University of Missouri have completed a project in which the self-cementing property of class C fly ash was exploited to develop lightweight aggregates that could be used for a wide variety of construction activities.

After determining that extruded aggregates made with hydrated class C fly ash do not meet highway specifications, Misra went on to explore the feasibility of using the ash for crushed aggregates. He found that both dry scrubber class C ash and hydrated class C ponded ash have potential for use in crushed aggregates.

The properties of the aggregates produced from class C ash suggest their suitability for use as

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VISIT THE CBRC WEBSITE AT [HTTP://WWW.NRCCE.WVU.EDU/PROGRAMS/CBRC](http://www.nrcce.wvu.edu/programs/cbrc)

New Construction Applications for Fly Ash: Crushed Aggregates from Class C Fly Ash (continued from page 1)

backfill behind retaining structures, as decorative rocks, and as a granular base course—or a base layer below the pavement—for highways. Aggregates made with fly ash could also be used in specialty concrete and in other applications where low-strength rocks are commonly used.

Why study the self-cementing property of class C fly ash?

Class C fly ash has properties that are very similar to those of natural hydraulic cement. It contains sufficient calcium and other compounds to induce a cementitious reaction in the presence of water, meaning that class C fly ash can serve as a cementing agent.

Prior to this study, very few efforts had been made to take advantage of the self-cementing property of ash for the purpose of producing aggregates. Most of the existing methods for producing aggregates from fly ash employ a high-temperature sintering process. A few studies on the production of unsintered aggregates have yielded encouraging results. Based on these findings and knowledge about the properties of class C fly ash, the project team speculated that aggregates with adequate mechanical properties for various construction activities could be created without the expense of high-temperature treatments.

For this study fly ash from the plants of Kansas City Power and Light Company (KCPL) was used to produce aggregates. The KCPL

class C fly ash has low loss-on-ignition (LOI) and fineness values, which make it an excellent cement surrogate.

The uniformity of the KCPL ash serves as another advantage in that it helps ensure consistent outputs. Class C fly ashes, particularly the Western coal ashes, show small variability in almost all measures of physical and chemical characteristics. The low variability can be attributed to the effort of power plants to control the quality of their combustion byproduct, as well as the low natural variability of western coal.

Misra and his team used class C scrubber ash from the KCPL plants to produce extruded aggregates, and they used both KCPL scrubber ash and class C ponded ash to produce crushed aggregates.

Extruded aggregates

The project team first explored the possibility of producing extruded aggregates from a fly ash mixture. A mortar mix was selected by testing the strength of cubes made of mixes with varying ratios of water:fly ash and sand:fly ash. The optimal mortar mix was found to have a water-fly ash-sand proportion of 0.3:1.0:2.0, yielding an average strength of 14.6 MPa after seven days of curing in a controlled environment. The trials revealed that compression strength and modulus of elasticity are tied to variables such as curing time and the humidity and temperature in the curing environment.

A next step was to evaluate the potential of three fibers—glass, polymer, and cellulose—to enhance the mortar by replacing a portion of the sand in the mixture described above. The plastic and cellulose fibers tend to decrease the strength while increasing the modulus of elasticity, but the glass fibers increase both the strength and modulus of elasticity of the mixture. Mixtures in which 15% of the sand was replaced with glass fibers yielded the best strength.

Batches were extruded from a variety of fly ash mixtures, and the physical properties of the resulting aggregates were evaluated. The optimal mixture yielded aggregates that generally have the properties necessary for base course and subgrade construction materials; however, their soundness and durability performance does not meet standard specifications. The high absorption capacity of the extruded aggregates, which could be linked to sand content, was determined to be a possible cause of low sulfate resistance.

Reducing the sand content did not adequately diminish the susceptibility to sulfate attack, so the sand was completely eliminated from the mix to produce crushed aggregates from compacted samples.

Crushed aggregates

Three methods for producing crushed aggregates from compacted samples were evaluated. In the preferred procedure—procedure 1—fly

(continued on page 3)

New Construction Applications for Fly Ash: Crushed Aggregates from Class C Fly Ash (continued from page 2)

ash is mixed with water to 20% moisture content, placed in a mold and compacted at 1000 psi for one minute, with 600 psi seating pressure applied for 10 minutes to achieve proper compaction and to ensure that there is minimal rebound upon removal of seating pressure. The fly ash mix is then cured for seven days at 38°C and 75% humidity, dried at room temperature for 24 hours, and then crushed with 20 blows by a 2.5 kg rammer.

This procedure produces aggregates of an appropriate grain size and is expected to be more economical to produce than the other two processes, which are identical processes except that after drying at room temperature the aggregate is then fired in a furnace at a temperature of 850°C. In the second process, the fly ash was baked for 2 hours, and in the third process, it was baked for 4 hours.

Compact briquettes were produced and crushed using the described method. The resulting aggregates fall within the category of lightweight aggregates with a

specific gravity of 1.73-1.75 and a maximum compacted dry density of approximately 1.6 Mg/m³. The California Bearing Ratio was used as a measure of the mechanical strength of the samples, yielding values between 28 and 52, depending upon the compaction moisture content. Even at a CBR value of 28, the compacted aggregate material would provide a suitable road base or sub-base.

Ponded fly ash crushed aggregates

The success in creating crushed aggregates from dry scrubber class C fly ash indicated that hydrated ponded class C fly ash could also yield serviceable crushed aggregates. Tests on crushed aggregates derived from ponded ash revealed a low density, but this would not rule out the aggregates as a lightweight road base or sub-base material. CBR values were in the range of 40 to 90, sufficient for road base or sub-base.

Samples cured for fourteen days provided higher strength and CBR

values than those cured for seven days, indicating that the ponded ash has some residual cementation capacity. It is expected that strength values for ponded ash would increase beyond fourteen days, thereby improving the aggregates performance over time.

Summary and conclusions

While the study's findings suggest limitations for use of unsintered class C fly ash in extruded aggregates, they offer encouragement for the use of this type of ash in the production of lightweight crushed aggregates. Both dry scrubber class C fly ash and hydrated class C ponded ash can be converted into lightweight crushed aggregates using a method that does not involve high-temperature sintering. The resulting aggregates have properties that indicate their suitability for use as road bases, embankment fills, and backfills behind retaining walls. These outcomes indicate the potential value of exploiting the self-cementing capacity of class C fly ash for crushed aggregate production.

For more information about this project (#00-CBRC-M04), or to view the final report, please visit the CBRC web site at <http://www.wri.nrcce.wvu.edu/programs/cbrc/> or contact the CBRC at cbrc@wvu.edu.



“Both dry scrubber class C fly ash and hydrated class C ponded ash can be converted into lightweight crushed aggregates using a method that does not involve high-temperature sintering. The resulting aggregates have properties that indicate their suitability for use as road bases, embankment fills, and backfills behind retaining walls.”

Meet the CBRC Directors



William Aljoe
CBRC Program Manager
Contracting Officer's Representative
U.S. Department of Energy
National Energy Technology Laboratory

William Aljoe is the program manager for the U.S. Department of Energy National En-

ergy Technology Laboratory, which funds CBRC projects and oversees its activities.

As program manager, Aljoe works directly with the consortium manager to ensure that the program is developing satisfactorily and in adherence to the cooperative agreement between the National Mine Land Reclamation Center and the DOE-NETL. He advises the CBRC of the annual funding available for its activities and helps update national research priorities.

The program manager is also responsible for a variety of specific tasks. He assists with the development of requests for proposals and with the selection of research projects. While he does not vote in National Steering Committee elections or in NSC proposal selections, he can provide input to the NSC that can affect their pre-proposal or full proposal selections.

Aljoe's role includes publicizing and promoting the CBRC's work within the DOE and maintaining the CBRC web page on the NETL's Website. He also performs other duties essential to fulfilling DOE-NETL requirements and improving CBRC operations.

Q: What is your role with the CBRC?

A: As the contracting officer's representative to the CBRC, my role is to oversee all of the organization's activities under its cooperative agreement with the U.S. Department of Energy Technology Laboratory. I attend the CBRC National Steering Committee meetings and am responsible for defining the national priorities that go into the CBRC's requests for project proposals. I function as a de facto member of the

steering committee. The CBRC requests for proposals have both regional and national priorities that need not coincide, so independent of what the regions issue as their priorities, my job is to set the national priorities that go into the solicitation of project proposals. The CBRC National Steering Committee then decides, by joint consensus, which projects to fund.

Q: What do you believe is the future of CCBs and the role of CBRC?

A: What I see in the future is expansion of CCB utilization in markets (reuse or recycling markets) in which these byproducts already have a toehold. That's where I believe the greatest progress can be made. There are markets out there that are already exposed to these materials—that aren't seeing them for the first time. There is potential for expansion in these markets where you don't have to educate people from scratch. You merely need to reinforce and find new matches for uses that are already in play. In my view, the three biggest markets for CCBs are

- *Cement and concrete.* There is nothing holding back the use of byproducts in cement and concrete other than transportation costs—finding the right CCB material to be used in cement and concrete at a location where the price is competitive with other materials, and that's an evolutionary process.
- *Structural fill.* All the different CCBs can and have been used at one time or another in structural fills. Not everybody in the construction industry is familiar with these applications, but there are enough demonstrated successes out there that it's easy to find an example of where the materials were used successfully. That should provide comfort to folks who haven't directly used them before.
- *Mine reclamation.* The third largest application would have to be an expansion of the use of CCBs in mine reclamation, whether that be remediation of mine sites that have been abandoned or place-

Meet the CBRC Directors *(continued)*

ment of materials directly from a power station to a mine that is still active. Abandoned mines have already been left and don't have anybody responsible for their care except the states where the property resides. CCBs will continue to provide a cost-effective way to reclaim these abandoned mine lands. The responsibility to reclaim these sites falls to the states at some point or another, and byproducts make this reclamation possible at a cost that is much less than what the states would have to pay using other materials.

For active mines, where a mining company is responsible for the environmental performance or the eventual environmental impacts of the mining operation, byproducts can be placed on that mine site. Again, byproducts allow the mining companies to reclaim the land in a more cost-effective manner than the use of non-byproducts.

I would say those are the three biggest markets, but they're all existing markets. Within all these markets, there are specific instances and specific nuances where the materials haven't been used before in exactly the same way. How the CBRC can help out is by completing the picture to expand existing uses.

The three markets I mentioned represent the biggest opportunity for the U.S. Department of Energy to reach its stated goal, which is to increase the overall utilization rate of CCBs to 50 percent nationwide by 2010. The most likely way we will reach that goal is by expanding utilization in these three existing large-volume markets.

By the same token, we don't want to ignore other opportunities. We can do more than just explore the existing markets—there's always room for new ideas and uses that could expand into large markets that the CBRC can't afford to ignore. We need to reflect a balance between innovative, novel uses, and tried-and-true uses in each request for proposals.

Aljoe has been a DOE employee since 1997. He worked with CCBs as a project manager until 2001 and was instrumental in the initial development of the CBRC, originally called the Emission Control Byproducts

Consortium. From 2001 to 2004, he took time away from CCBs to develop the DOE-NETL's Air Quality Research Program, which included a broad array of research projects on the impact of power plant emissions on air quality. Late in 2004, he returned to manage the CBRC effort and provide overall coordination for DOE-NETL's CCB research and development program.



Paul Ziemkiewicz, CBRC Director
National Mine Land Reclamation
Center, West Virginia Water Research
Institute, West Virginia University

As the director of the CBRC, **Paul Ziemkiewicz** coordinates with the DOE program manager and the CBRC's National Advisory Committee to direct

and manage the program. Ziemkiewicz assists in developing research projects and reviews RFPs and proposals. He votes in National Steering Committee decisions and in the NSC pre-proposal and full proposal selections. His role as director also requires Ziemkiewicz to communicate with the press, discuss steering committee recommendations with the NSC chair, and solicit members to serve on the NSC.

Q: What is your role with the CBRC?

A: As director of CBRC, I have both a technical and a managerial role. Technically, my role is to remain current with the technical status of the technology, our projects' technological advances, and emerging priorities. These then translate into priority and proposal recommendations to the Steering Committee and DOE-NETL. Managerially, my role is to make sure that the National Mine Land Reclamation Center is staffed and organized to provide outstanding service to DOE-NETL and the CCB community and stakeholders across the country.

Meet the CBRC Directors *(continued)*

Q: What do you believe is the future of CCBs and the role of the CBRC?

A: I think we need to develop new markets for CCBs. That means finding new uses and applications. We have a number of what I would call mature research areas. For example, construction applications, such as concrete, are big CCB users right now. Wallboard manufacturing using flue gas desulfurization (FGD) solids is probably close to being a mature application. Certainly, these applications will continue to grow as important uses of CCBs.

But, if we're really going to add significantly to the utilization rate, we also need to find new applications and markets. And that means finding applications that make the most of the unique properties of CCBs—applications for which there are few competing materials in the market place.

Paul Ziemkiewicz began his work with CCBs as an employee of the Alberta Department of Energy in Canada in the early 1980s, a time when the provincial government was shifting from natural gas to coal as the primary means of electricity generation. Ziemkiewicz participated in research on the environmental implications of disposing of ash in mines. Specifically, he studied the leaching of ash, its effect on groundwater, and the potential environmental hazards.

In 1988 Ziemkiewicz came to West Virginia University, where he encountered similar issues with ash disposal. He was interested in the ash's alkalinity as a possible answer to the region's problem with acid mine drainage. His current work focuses on ways to pair these two problems to create a solution that addresses both CCB disposal and acid mine drainage.



Tamara Vandivort, Consortium Manager, CBRC National Center, West Virginia University

Tamara Vandivort is the CBRC's consortium manager. She facilitates communication among the various players of the CBRC, submits reports to funding agencies, and prepares press releases. Vandivort has a variety of other responsibilities essential to CBRC operations and the dissemination of program information and research findings.

Q: What is your role with the CBRC?

A: As consortium manager of the CBRC, I serve as the hub of the wheel in terms of tying all the program components together. I facilitate communications between DOE-NETL, the National Steering Committee, research contractors, and external agencies. I coordinate the activities of the National Steering Committee and work with it to develop the requests for proposals, evaluation criteria, proposal reviews, and selections. I prepare the overall program proposal for submission to DOE-NETL; develop dissemination strategies; oversee the CBRC Web site and newsletter, *Ashlines*; negotiate subcontracts with researchers; collect all project deliverables; and develop reports for DOE-NETL.

Q: What do you believe is the future of CCBs and the role of the CBRC?

A: I've managed the Consortium since December, 1999, and over the years the program has matured to a fine-tuned machine. The National Steering Committee has been very stable and is comprised of experts in the field from utilities, federal, and state agencies, and not-for-profit organizations. The Steering Committee is very active and involved in the program and has played a vital role in making the program as successful as it has become. While there is still some reluctance in the public mind to accept ash as an everyday com-

Meet the CBRC Directors *(continued)*

ponent in their lives, the reality is that it is becoming just that—an everyday component.

For instance, research supported by the CBRC alone has resulted in ash utilization in road base construction, paving materials, surface mine reclamation, soil remediation, wallboard, countertops, bricks, lagoon liners, marine structures, transmission poles, and building products.

While the regulatory arena wrestles with the public perceptions to safely use ash in environmental ways, the coal-burning utility industry is still producing in excess of 100 million tons per year of fly ash that has to go somewhere. Landfills are no longer the answer. It is critical that this valuable byproduct be utilized for valuable purposes. The CBRC program promotes just that. However, funding for the CBRC program has declined over time; whereas, the needs to find uses for this byproduct are growing as the amount of byproduct keeps increasing.

Tamara Vandivort is an environmental geologist and program coordinator for the West Virginia Water Research Institute. In addition to managing the CBRC, Vandivort manages the Water Resources Research program and coordinates the activities of the West Virginia Advisory Committee for Water Research. She also serves as secretary/treasurer for the West Virginia Water Gaging Council, secretary/treasurer for the Ohio River Basin Consortium for Research and Education, and principal investigator for watershed-based research projects on water and wastewater in the state of West Virginia.



CBRC Regional Directors

The regional directors facilitate the accomplishment of CBRC goals and objectives as developed by DOE-NETL, the national CBRC office, and the National Steering Committee. They communicate directly with regional contractors and the CBRC to develop and realize high-quality research and development projects that address priorities and goals at both the national and regional levels.

The directors provide technical expertise to the CBRC, offer technical oversight of regional projects, and facilitate information sharing between their regions and the national office. They do not vote in NSC elections or NSC proposal selections.



Y. Paul Chugh, *Midwestern Regional Director, Southern Illinois University-Carbondale*

Y. Paul Chugh is the Midwestern Regional Director of the CBRC.

Q: What is your role with the CBRC?

A: As director of the CBRC's Midwestern Region, my role is to promote utilization of CCBs in an economic and environmentally friendly manner in the region, through research needs identification; by nurturing professionals to seek funds for identified research and field demonstrations; and through technical information transfer to individuals, industry, and state agencies.

Q: What do you believe is the future of CCBs and the role of the CBRC?

A: It is my opinion that CCB issues are not going to go away soon. With additional air quality controls planned for coal-burning power plants, the quality of CCBs is likely to deteriorate, and we will need to do additional research and field demonstrations and remove regulatory barriers to maintain utilization at the current levels.

I believe the CBRC's thrust over the next five years should be to focus energies in large-volume management of CCBs. The impacts of impending mercury regulations on wallboard manufacturing and other beneficial uses of CCBs must be characterized and dealt with. New large-volume uses, such as development of soils for use in landfills, should be developed and field demonstrated.

Meet the CBRC Directors *(continued)*

Over the last five years, the CBRC has focused on exploratory research. It should now review some of the ideas that have been developed and move promising technologies to field implementation and commercialization.

Y. Paul Chugh has a broad background in engineering with emphasis on rock mechanics, geotechnical engineering, and mining engineering. In the early 1990s, he became interested in developing CCB-based artificial supports in mines. During the same time period, he developed the Coal Combustion Residues Program for the state of Illinois. For the last 12 years, Chugh has studied large-volume management strategies for CCBs and worked on product development. Three of his products have reached the commercialization stage, and he holds two patents for CCB management practices.

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Debra Pflughoeft-Hassett, Western Region Director, Energy and Environmental Research Center, University of North Dakota

Debra Pflughoeft-Hassett is the Western Region Director of the CBRC.

Q: What is your role with the CBRC?

A: I see my role with CBRC as twofold: I'm an advisor to the National Steering Committee, helping it to understand what the Western Region's issues are and how the region's ash industry works relative to the viewpoint of the national industry and the issues and concerns of other regions. My second role is to act as a sort of technical advisor to the principal investigators for CBRC projects in the Western Region. When they have technical questions, I help them find answers, and I act as a liaison between them and the national office on technical issues.

Q: What do you believe is the future of CCBs and the role of the CBRC?

A: The area of CCB recycling or reuse is basically being opened up. I think that we have great potential for meeting the goal of utilizing 50 percent of the produced byproducts, but that also means there is a lot of work to do. I think the CBRC can play a significant role, because we can only achieve a certain increase with the given information we have and because byproducts are changing primarily due to emission regulations. CCBs are changing on a regular basis, so there needs to be continued work not only on the properties of those materials but also on how those materials can be utilized in the existing products and how new products can be developed around those properties.

The combustion byproducts industry is tapping into a resource that has much left to offer and that has significant increases to make in its utilization potential. I think partnering a government agency or program with industry, as the CBRC does, is the best way to accomplish the type of research that is going to help us make great strides toward increased utilization.

Debra Pflughoeft-Hassett is a chemist with extensive experience researching reuse options and environmental impacts of CCBs. While studying at the University of North Dakota, she worked for Oscar Manz, a well-known researcher in the field of coal ash utilization. In 1977, she began work with Manz studying groundwater quality for a project on the placement of fly ash in mines. The project piqued her interest and exposed her to the different properties and potential uses of ash.

After she graduated, Pflughoeft-Hassett continued working on a wide variety of projects dealing with the disposal and reuse of ash and the potential impact on groundwater and surface water. After Manz retired, Pflughoeft-Hassett succeeded him as program manager for CCB research at the University of North Dakota. She now heads the Coal Ash Resources and Research Consortium at North Dakota's Energy and Environmental Research Center (EERC).

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Meet the CBRC Directors *(continued)*



James Hower, Director, CBRC Eastern Region, Center for Applied Energy Research, University of Kentucky

James Hower is the Eastern Regional Director of the CBRC

Q: What is your role with the CBRC?

A: I oversee the CBRC projects in the Eastern Region and provide feedback to the CBRC National Steering Committee regarding content of the requests for proposals. I help review the pre-proposals and proposals and give my opinion about what should be funded.

Q: What do you believe is the future of CCBs and the role of the CBRC?

A: I believe that CCBs will certainly remain a viable resource. The challenge may be the perception that there's going to be more mercury in CCBs, even though there is mercury in them now. The increase in mercury probably won't be substantial, if there's an increase at all, but there's going to be a public perception of a problem, which may then become a problem for the industry.

Another challenge will be meeting the U.S. Department of Energy's goal of 50 percent utilization what with the modifications/additions to the clean air rules that just came out in March 2005. The rule changes point to more back-end pollution control, es-

pecially more scrubbing. So there's going to be more FGD products produced. That could end up really saturating the market in places it's already relatively saturated. Achieving 50 percent CCB utilization is already a challenge with the current 100 million tons being produced. But the tonnage you need to get to 50 percent utilization is itself a moving target.

I hope that the CBRC continues to encourage the large-scale use of environmentally sound disposal practices and large-scale reuse projects. I would like to see the CBRC continue that role and to continue funding innovative ideas. I would like to see it remain one of the leading groups at the cutting edge funding new ideas.

James Hower runs the Applied Petrology Laboratory at the University of Kentucky Center for Applied Energy Research, in Lexington. He conducts microscopic analysis of coals, fly ash, and other substances. Much of his work for the last twelve years has focused on CCBs.

Every five years Hower's research group conducts a survey of all the power plants in Kentucky to learn the quantity of coal used, the quantity of ash produced, and the type of challenges the plants expect to face in the next years. The group also collects coal, fly ash, bottom ash, and other materials at each of the plants and examines them to create five-year snapshots of power plants in Kentucky. Hower says the survey often provides his group with insight into upcoming problems, which they then study more closely.



Combustion Byproducts Recycling Consortium (CBRC) at a Glance—1998-2006

| <u>Category</u> | <u>Number</u> |
|---|---------------|
| Projects Funded | 42 |
| Research dollars awarded by DOE NETL | \$4.1 million |
| Matching funds contributed (over 100% of DOE \$\$) | \$4.4 million |
| States with CBRC projects | 18 |
| Researchers involved with CBRC projects | 50 |
| Students trained | 30 |
| Papers generated | 30 |
| Presentations given | 40 |
| Final reports completed and on CBRC web site | 30 |
| Quarterly newsletters, <i>Ashlines</i> , published and released | 23 |
| RFP's developed and released | 5 |

CBRC Success Stories At-a-Glance, 1998-2006

The CBRC National Steering Committee and regional directors have done an exceptional job of bringing critical issues facing CCBs management into focus, identifying pertinent research priorities, and allowing only those projects to be funded that are in line with those critical issues. These members and directors have been steady and consistent over time and have been an excellent filter media in terms

of selecting proposals for funding consideration to the U.S. Department of Energy, National Energy Technology Laboratory.

Strong Matching Support

Even though the matching requirement is 25%, to date, matching support has exceeded 100% (\$4.4 million in matching funds to the \$4.1 million provided by the U.S.

Department of Energy, National Energy Technology Laboratory).

Ash Utilization

The Midwest regional director evaluated ash utilization within the region and compared it to national averages for different byproducts. Ash utilization within the region has kept pace with national averages.

Distribution of CBRC Research Projects by American Coal Ash Association (ACAA) Coal Combustion Byproducts (CCB) Breakdown Categories

| <u>American Coal Ash Association Category</u> | <u>CBRC Projects Addressing Each Category</u> | <u>Total Number of CBRC Projects</u> |
|---|--|--------------------------------------|
| Concrete/Concrete Products/Grout | 99-E04; 99-E06; 99-E16 | 3 |
| Cement/Raw Feed for Clinker | | 0 |
| Flowable Fill | 00-M5 | 1 |
| Structural Fills/Embankments | 00-E24; 00-E41; 99-E24; 00-M11 | 4 |
| Road Base/Sub-base/Pavement | 01-E10 | 1 |
| Soil Modification/Stabilization | 99-M5 | 1 |
| Mineral Filler in Asphalt | | 0 |
| Snow and Ice Control | | 0 |
| Blasting Grit/Roofing Granules | | 0 |
| Mining Applications | 99-W4; 02-E6; 00-E15; 00-E37; 00-W2; 99-W1; 99-E15; 99-E17; 00-M9 | 9 |
| Wallboard | 01-M12; 99-W2 | 2 |
| Waste Stabilization/Solidification | | 0 |
| Agriculture | 99-E08; 99-E11; 02-W09; 01-M23 | 4 |
| Aggregate | 00-M4 | 1 |
| Miscellaneous/Other | 02-E10; 01-E09; 00-E42; 99-E13; 00-M12; 02-W12; 01-M21; 01-W01; 00-M14; 99-M01; 99-M04; 99-M06; 99-M07; 99-W05; 00-W04; 00-W10 | 16 |

CBRC Success Stories At-a-Glance, 1998-2006

Field Demonstration and Performance Evaluation of Large Volume Noncompliant F Fly Ash Road Sub-base

In Illinois, a CBRC project utilized 70,000 cubic yards of high-LOI (loss on ignition), ponded F-fly ash for road sub-base construction. The state and industrial funding for the project exceeded \$400,000. The savings to the road construction project amounted to \$100,000 and to the utility company over \$1 million dollars in not having to construct another ash pond.

Development of Novel Construction Materials

Novel construction materials developed with CBRC support and over \$400,000 in state and industrial matching support include

- tiles and siding materials using sulfate or sulfite scrubber sludge,
- paperless wallboard using sulfate-rich scrubber sludge, and
- utility poles using fly ash as fillers in polymers.

Impact on Regulatory Environment for CCB Utilization

Four Western Region projects have had direct contact with regulatory offices. Those responding say that the projects of note smoothed the way for future projects. One note of interest is the final report of a multiyear project at the University of North Dakota that has investigated the performance of several Class C fly ashes as a means to mitigate alkali-silica reactions in concrete. The report has been re-

quested by several Department of Transportation representatives.

Adsorption of Trace Elements from Leachate During Transport in Host Soils and Rocks

A project partly funded by the CBRC provided the Office of Surface Mines (OSM) and state regulatory authorities appropriate data for dealing with permitting issues. The data developed was presented at several public hearings at the state and national levels and was positively received. The state and industry provided over \$150,000 in matching support.

Mercury in CCBs and its Impacts on CCBs Management

The knowledge base developed in CBRC projects with respect to mercury and its impacts on CCB management has assisted Midwestern researchers in dealing with mercury speciation in solid and liquid wastes. Federal, state, and industrial matching support for studies of mercury have been over \$200,000.

Impact on Use of High-Carbon Ashes; Ammoniated Ashes; High-Mercury Content Ash

A CBRC-supported research project conducted by a private firm, ADA Technologies, evaluated high-carbon ash as a mercury sorbent for mercury emission control. That project did not result in a commercial endeavor, but the information gained was indispensable to other groups working on mercury emission controls. Another industry project, supported by the

CBRC and conducted by AeRock, addressed the use of fly ash that was not suitable for standard concrete applications and FGD material.

Environmental Performance of Surface Mine Backfilling with CCBs

A multiyear study that is investigating the leaching and transport of trace elements such as boron, arsenic, and selenium has drawn national attention and is providing data that is invaluable for future similar projects in surface and underground mine backfilling. State and industrial matching support for this project has been over \$300,000.

CCBs Management for Agricultural Land Applications

Numerous CBRC projects have demonstrated potential for enhancing agricultural land applications by boosting soil nutrients.

Demonstration of Cattle Feedlots Using Sulfite-rich Scrubber Sludge and FBC Byproducts

A CBRC project has successfully demonstrated the performance of commercially viable, high-strength feedlot pads. The power plant is modifying the plant to commercialize the technology. Over \$400,000 was provided by the states and industry as matching support.

For more information on any of these projects, contact the CBRC at cbrc@wvu.edu.



Calendar

Sept. 25–28, 2006

23rd Annual International Pittsburgh Coal Conference

Pittsburgh, PA

www.engr.pitt.edu/pcc

The Twenty-Third Annual International Pittsburgh Coal Conference will focus on environmental emissions issues and technologies surrounding the continued use of coal and the development of future coal-based energy plants to achieve near-zero emissions of pollutants, reduced costs, and high thermal efficiency while producing a suite of products to meet future energy market requirements. Technical, business, and policy-related papers will be presented at the conference.

October 24-25, 2006

20th Western Fuels Symposium

International Conference on Lignite, Brown, and Subbituminous Coals

Denver, Colorado

<http://www.undeerc.org/wfs/>

The goal of the Twentieth Symposium on Western Fuels is to provide a forum in which industry, government, and research organizations can share up-to-date information on the role of lignite, brown, and subbituminous coals in meeting future energy demands. Low-rank fuels have unique properties that present challenges and opportunities related to meeting future environmental regulations and in the development and application of advanced technologies.

June 11–13, 2007

Sustainable Construction Materials and Technologies

Coventry University, Coventry, UK

www.uwm.edu/dept/cbu/coventry.html

This conference will highlight case studies and applied research that show new and innovative ways of achieving sustainability of construction materials and technologies. Papers have been invited on all the different materials used in construction, including cementitious materials (fly ash, wood ash, silica fume, slag, natural pozzolans, and others); aggregates; admixtures, concrete; timber; masonry; metals; plastics; glass; bitumen; lime; and gypsum, and on paints, adhesives, preservatives, and preservation processes.

Sponsored by Coventry University and University of Wisconsin-Madison Center for By-Products Utilization

CBRC *contacts*

Program Manager

William Aljoe, U.S. Department of Energy-National Energy Technology Laboratory, 412/386-6569, aljoe@netl.doe.gov

National Center

Paul Ziemkiewicz, Ph.D., *Director*
Tamara Vandivort, *Consortium Manager*
CBRC National Center located at the National Mine Land Reclamation Center at West Virginia University, 304/293-2867, pziemkie@wvu.edu or tvandivo@wvu.edu

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Paul Ehret, Kentucky Department of Natural Resources, 317/232-4020, pehret@ky.gov

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Kimery Vories, U.S. Office of Surface Mining, 618/463-6463, kvories@osmre.gov

Western Regional Chair

Richard Halverson, Headwaters Resources, 206/575-1981, rhalverson@isgresources.com

Eastern Regional Technical Director

James C. Hower, Ph.D., University of Kentucky, 859/257-0261, hower@caer.uky.edu

Midwestern Regional Technical Director

Y. Paul Chugh, Southern Illinois University at Carbondale, 618/536 6637, chugh@engr.siu.edu

Western Regional Technical Director

Deborah Pflughoeft-Hassett, University of North Dakota, 701/777-5181, dphassett@undeerc.org

National Steering Committee Members

Jackie Bird, *Member-at-Large*
Ohio Coal Development Office, 614/466-3465, jbird@aqda.state.oh.us

John Glasscock, Synthetic Materials Synmat, 727/367-0402, jrg@synmat.com

David Goss, American Coal Ash Association, 720/870-7897, DCGoss@ACAA-USA.org

Howard Humphrey, *Ex-Officio*,
American Coal Ash Association, 614/846-1726, hhumphrey@columbusrr.com

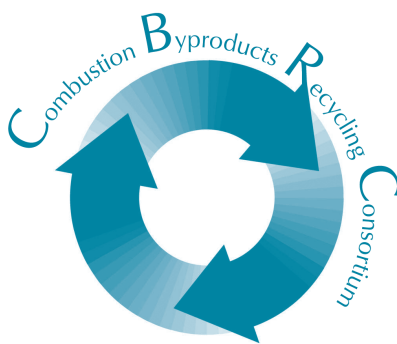
Jimmy Knowles, South Eastern Fly Ash Group, 803/794-3230, jknowles@SEFAGroup.com

David Meadows, USACE-Huntington District, 304/529-5243, david.f.meadows@usace.army.mil

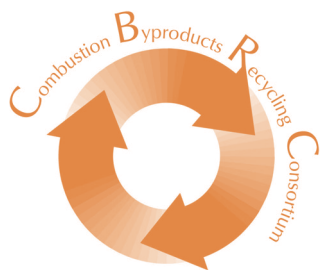
Bonnie Robinson, EPA-Office of Solid Waste, 423/751-4419, robinson.bonnie@epa.gov

James Roewer, Utility Solid Waste Activities Group, 202/508-5645, jim.roewer@uswag.org

Dan Wheeler, Illinois DCCA Office of Coal Development and Marketing, 217/558-2645, dwheeler@lidceo.net



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Volume 6, Number 3

Fall 2005

COMBUSTION BYPRODUCTS RECYCLING CONSORTIUM

Ashlines

a program of the
National Mine Land
Reclamation Center at
West Virginia University,
in cooperation with the
U.S. Department of
Energy-National Energy
Technology Laboratory
www.netl.doe.gov

To promote and support the commercially viable and environmentally sound recycling of coal combustion byproducts for productive uses, through scientific research, development, and field testing

Forging Ahead with CCB Research: Can Fly Ash Replace Sand in Foundry Operations?

Robert Purgert, P.I.

Foundries in the United States use about 100 million tons of sand per year in their operations, which is roughly the same amount of coal combustion byproducts (CCBs) produced annually. Since natural sand has some disadvantages for use in the foundry industry and CCBs are potential substitutes for sand, interchangeability, plus supply-and-demand would seem to be suggesting that foundries research the benefits of CCBs over natural sand.

The introduction of fly ash and bottom ash into the foundry industry could create a new use for CCBs and perhaps solve some of the problems associated with the use of natural sand, the traditional base material of foundry molding and core mixtures.

Natural sand has three major drawbacks in foundry use:

1. Because grains of natural sand, like any granular material, are nonhomogeneous in size and shape, they have different dust contents.
2. Natural sand must be excavated, cleaned, and segregated before use.
3. Natural sand poses a potential health risk for workers and is being scrutinized as a potential



Pouring gray iron into sand molds with cores made of fly ash.

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Calendar & Calls for Papers

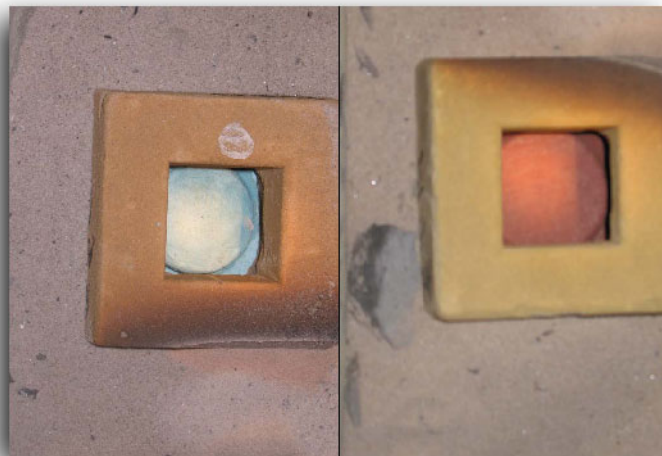
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Contacts

VISIT THE CBRC WEBSITE AT [HTTP://WVWR.NRCCE.WVU.EDU/PROGRAMS/CBRC](http://wvwr.nrcce.wvu.edu/programs/cbrc)

Forging Ahead with CCB Research: Can Fly Ash Replace Sand in Foundry Operations? (continued from page 2)

Cores with blue and pink coatings nested in dry sand molds prior to pour.



cause of silicosis in workers exposed to crystalline silica (quartz), which is common in foundry sands.

Under a program funded by the Combustion Byproducts Recycling Consortium (CBRC), the Energy Industries of Ohio has just completed a project designed to demonstrate the suitability of fly ash as a replacement for traditional foundry sands. This study elaborates on the findings of an earlier CBRC project (#00-CBRC-E42).

Project costs were shared by a project team that included the General Motors Company (GM) casting plant in Defiance, Ohio; Oak Ridge National Laboratory; Edison Materials Technology Center; Foundry Research Institute of Krakow, Poland; Kent State University; FirstEnergy Corporation; and the Dayton Power & Light Company.

The study explored the feasibility of substituting CCBs for foundry sands, specifically, by re-

placing fly ash for the virgin silica sand typically used in the foundry molds and cores employed by the automotive industry.

Background

During the earlier CBRC project, researchers determined that CCBs could be used in a number of applications as substitutes for traditional foundry sands in the production of metal castings. Foundry sands are used to make molds and cores that approximate the shapes of the metal product or cast. Molten metal is poured into the mold to form a cast metal part or component. The mold defines the outside areas of the casting, and the core shapes the interior passageways and openings.

Previous studies established that CCBs were suitable as replacements for foundry sands in both mold and core applications. Molds made from CCBs were successfully used under laboratory conditions to make castings of both ferrous and

nonferrous alloys. A significant finding was the ability to substitute 100% ash for traditional foundry sand in the chemically bonded (or dry sand) types of applications that are often used for making cores.

The outcomes of the initial project highlighted a need for further study to refine production techniques and formulas for the ash and binder systems. Another important activity identified for the next phase was to ensure that actual production techniques could be used with little modification.

Objectives

The recently completed project was undertaken to demonstrate the use of fly ash in applications similar to those used for actual production. Automotive industry iron castings were chosen as a subject because of their widespread use and the quantity of sand used each year in their production. Automotive castings also have stringent quality require-

(continued on page3)

Forging Ahead with CCB Research: Can Fly Ash Replace Sand in Foundry Operations?

(continued from page 2)



Iron castings in sand molds with fly ash cores.

ments, which makes them a good test subject for determining the production readiness of the fly ash molds and cores.

Selection of Ash Mixtures and Binding Systems

Fly ash from the FirstEnergy Eastlake Plant in the United States and, for comparison, from the Skawina Power Plant located near the Foundry Research Institute of Krakow, Poland, were used in the study.

To contrast the ash with that used in the earlier phase of the project, detailed investigations of its chemical composition; phase constitution; density distribution; and individual fractions, toxicity, and thermal characteristics were conducted.

A binding system was then chosen to ensure that the cores and molds closely approximated those being used in the production process at the General Motors casting

plant in Defiance, Ohio. In an effort to match the high degree of permeability of the GM cores and molds, a binding system of organic and inorganic binders was determined to be the most suitable.

The technological properties of various fly ash mold and core mixtures were tested, and the three most promising chemical compositions and fabrication methods were then employed in a number of trials on the casting of gray and ductile irons.

Casting Trials

The trials took place at the Energy Industries of Ohio Casting Center, a full-scale working foundry. Cores made of fly ash were used in sand molds to make iron castings. Both the molds and cores closely approximated those used in the actual production process at GM.

Macroscopic examinations of the castings to check the surface

conditions and gas content revealed that the permeability coupled with the high-calcium content of the ash caused considerable out-gassing, which affected the surface quality of the castings. This was directly attributed to the high calcium content of the ash used in this study compared with that of the ash used in the first analysis.

Final trials took place in the late summer of 2005. Sample cores were prepared for testing, and a visit to the GM casting plant was made to review the test plan and observe the actual process. During this visit, it was noted that a coating was applied to the sand cores prior to use in the casting molds. The coating was needed to achieve the desired smooth surface finish and to reduce permeability of the core. This detail is significant for two reasons:

1. Fly ash has a relatively very fine grain size when made into cores. This creates a very fine

(continued on page 4)

Forging Ahead with CCB Research: Can Fly Ash Replace Sand in Foundry Operations? (continued from page 3)

surface finish, which may make it unnecessary for GM to coat the cores in the future.

2. When the ash is mixed with a single binder system, the permeability is reduced significantly; again, possibly negating the need for the coating. Initially in this study the intent had been to increase permeability to match the GM cores as closely as possible.

Subsequent trials demonstrated that fly ash cores could be produced with the traditional inorganic binder system and coated with the types of coatings currently used by GM.

Tests and a demonstration for GM officials were conducted, during which the cores did indeed hold up to the process, but considerable out-gassing was again noted. This time the gasses were released in a concentrated jet, probably at the point of the weakest area of the coating shell.

Conclusions

After analyzing the differences between these findings and those of the earlier study, it was concluded that the type of fly ash plays a significant role in determining its suitability for use in casting applications. The fly ash used in the initial study was from Dayton Power & Light and was wet collected. The ash used for this series of tests was from FirstEnergy's Eastlake plant and was dry collected.

From this attempt to create production-type casting materials, it was concluded that certain types of fly ash offer the ability to replace foundry sand systems for making cores and molds, even in applications for high-temperature castings such as iron. However, the following technical obstacles first must be addressed prior to commercialization:

- To reduce out-gassing, the ash must contain a low level of calcium.
- The ash should be of a size distribution that would not require

changes to screens and vents used in current sand systems.

- A binder system that will permit ease of knock-out after casting must be defined. The cores made from 100% fly ash required a greater amount of binder than traditional sands, resulting in a high binder volume, which made it more difficult to remove the castings.

In addition to defining the suitability of certain ashes for metal casting, this project revealed that ashes and binder systems can impact a wide array of engineering characteristics in the cores, including the level of permeability. Another significant finding was that the surface finish of castings made with fly ash cores has certain advantages that may eliminate the need for applying expensive coatings to the cores and then waiting for them to dry prior to casting.

This project highlights the need for further study of fly ash as a substitute for foundry sand and demonstrates several potential advantages of employing ash in the metal casting industry. A subsequent project is planned for identifying the optimal binding systems and binder volumes for fly ash cores.

For more information about this project (#02-CBRC-E10), or to view the final report, please visit the CBRC web site at <http://www.wri.nrcce.wvu.edu/programs/cbrc/> or contact the CBRC at cbrc@wvu.edu.



“The introduction of fly ash and bottom ash into the foundry industry could create a new use for CCBs and perhaps overcome some of the disadvantages of natural sand, the traditional base material of foundry molding and core mixtures.”

Calendar

February 23, 2006
Ramada Inn
Marquette, MI

Workshop on Recycling Opportunities for Fly Ash and Other Coal Combustion Products in Concrete and Construction Materials

The purpose of this workshop is to bring participants up to date on the latest information about recycling applications for coal combustion products in concrete and other construction materials. Presentations will give important information on technical, environmental, and economic advantages of using coal ash in ordinary, everyday construction applications. The workshop will be of interest to the construction industry, concrete producers and manufacturers, contractors, and to utilities and other industries producing coal combustion by-products, as well as architects, engineers and academic researchers.

Workshop registration fee of \$35 (\$45, if registering after February 17) includes hand-outs, refreshments, and lunch. Complete information about the conference, including agenda and speaker information, at: www.cbu.uwm.edu. Call 414/229-4105 or email tarun@uwm.edu.

Sponsored by UWM Center for By-Products Utilization; We Energies; Mineral Resources Technologies, a Cemex Company; and co-sponsored by Michigan Technological Institute and Wisconsin Public Service Corporation.

Calls for Papers

Sustainable Construction Materials and Technologies

Coventry University, Coventry, UK
Monday June 11–Wednesday, June 13, 2007
www.uwm.edu/dept/cbu/coventry.html

Abstracts of 200-300 words to be submitted by email to by March 2006 to p.claisse@coventry.ac.uk.

This conference will highlight case studies and applied research that shows new and innovative ways of achieving sustainability of construction materials and technologies. Papers are invited on all the different materials used in construction, including cementitious materials (fly ash, wood ash, silica fume, slag, natural pozzolans, and others); aggregates; admixtures, concrete; timber; masonry; metals; plastics; glass; bitumen; lime; and gypsum. Papers on paints, adhesives, preservatives, and preservation processes are also welcome.

23rd Annual International Pittsburgh Coal Conference

Pittsburgh, PA
Monday, Sept. 25–Thursday, September 28, 2006
www.engr.pitt.edu/pcc

Papers may be contributed in all subject areas dealing with coal technologies and related policy issues. Submit a one-page abstract by email on or before March 1, 2006 to pcc@engr.pitt.edu

CBRC contacts

Program Manager

William Aljoe, U.S. Department of Energy-National Energy Technology Laboratory, 412/386-6569, aljoe@netl.doe.gov

National Center

Paul Ziemkiewicz, Ph.D., *Director*
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James C. Hower, Ph.D., University of Kentucky, 859/257-0261, hower@caer.uky.edu

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Jimmy Knowles, South Eastern Fly Ash Group, 803/794-3230, jknowles@SEFAGroup.com

David Meadows, USACE-Huntington District, 304/529-5243, david.f.meadows@usace.army.mil

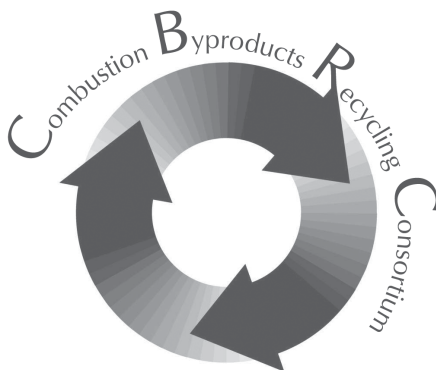
Bonnie Robinson, EPA-Office of Solid Waste, 423/751-4419, ecmiller@tva.gov

James Roewer, Utility Solid Waste Activities Group, 202/508-5645, jim.roewer@uswag.org

Dan Wheeler, Illinois DCCA Office of Coal Development and Marketing, 217/558-2645, dwheeler@commerce.state.il.us

National Steering Committee Meets to Select Pre-Proposals

The National Steering Committee met September 16, 2005 in Pittsburgh, PA to select pre-proposals from which to invite applicants to submit full proposals. Of the 52 pre-proposals received, 19 applicants were invited to submit full proposals by December 15, 2005. The Steering Committee will meet in early 2006 to select which full proposals should be recommended to the U.S. Department of Energy-National Energy Technology Laboratory for funding.



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Summer 2005

COMBUSTION BYPRODUCTS RECYCLING CONSORTIUM

Ashlines

a program of the
National Mine Land
Reclamation Center at
West Virginia University
in cooperation with the
U.S. Department of
Energy - National Energy
Technology Laboratory
www.netl.doe.gov

To promote and support the commercially viable and environmentally sound recycling of coal combustion byproducts for productive uses through scientific research, development, and field testing.

CCB Utilization and Disposal: A State-by-State Comparison

Bruce A. Dockter, P.I.

Engineers, scientists, and regulators who work with coal combustion byproducts (CCBs) are familiar with their state CCB regulations and local utilization and disposal practices. But few have the time or resources to investigate CCB practices outside their own region—for example, to compare what different state agencies require or what technologies and innovative uses are employed in other parts of the country.

In 2004, the Combustion Byproducts Recycling Consortium (CBRC) funded a study by the University of North Dakota's Energy and Environmental Research Center to compare CCB practices around the nation. According to Bruce A. Dockter, principal investigator, the project had two main goals. The first was to present a state-by-state accounting of department of transportation (DOT) specifica-



Study compares state department of transportation specifications for CCBs.

tions governing the use of CCBs.

Because most transportation and materials engineers cannot fully research all the current coal ash utilization technologies, the study compiled this information to

allow these professionals to become familiar with other department practices and to identify areas where specifications need to be developed within their own transportation offices.

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CCB Utilization and Disposal: A State-by-State Comparison

(continued from page 1)

The results from this project will help familiarize DOT engineers and officials with coal ash use applications around the country. It also will help the coal ash industry to develop a plan to work with these departments and individuals in expanding their knowledge while expanding coal ash markets.

The second goal of the project was to establish a comparison of state environmental laws and regulations as they pertain to CCB utilization and/or disposal. As a result of the interpretation of the Bevill Amendment, CCB utilization and disposal are not regulated at the federal level, but instead have been left to the states. Many states have enacted laws and adopted regulations, or both, governing the utilization and disposal of CCBs. These laws and regulations vary widely.

As part of the study, a state-by-state survey of state laws and regulations authorizing beneficial reuse of CCBs was conducted. It provides an overview of state solid waste laws and regulations governing reuse of CCBs. Although not intended to identify landfill or similar disposal requirements, the results will be useful to persons familiar with "beneficial use" regulations for CCBs in their particular state and will assist in the exchange of regulatory guidance to enhance the use of CCBs.

Although the findings of both project objectives are similar in their presentation (state-by-state comparisons), their contents are very distinct. Therefore, the project findings are presented in a two-

volume final report. Both volumes can be downloaded in their entirety from the CBRC Web site at <http://www.wri.nrcce.wvu.edu/programs/cbrc/>. The following is a short summary of the project findings.

Survey of State DOT Specifications for CCBs

In August 1992, a survey letter was sent to all highway departmental offices in the U.S. and Canada to look at the differences between state and provincial DOT specifications for CCB utilization. Since that time, numerous changes have occurred in these departments, so it was decided that an update was needed. An extensive survey was begun in 2004 to obtain specifications from all state DOT offices. All information for the survey was obtained through Internet searches and personal contacts within departments.

Although specifications and practices varied among states, several similarities were noted. The specifications used in all reported cases for fly ash were ASTM International (American Society for Testing and Materials) C618 and AASHTO (American Association of State Highway and Transportation Officials) M295. The title for both specifications is "Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete." Under both classification systems, fly ash is defined as "a finely divided residue that results from the combustion of ground or powdered coal."

In addition to concrete, numerous states have used fly ash as a mineral filler in asphaltic concrete and soil stabilization, with many more states beginning to use fly ash in flowable mortar applications.

Another material often cited for use as a cement supplement was ground granulated blast furnace slag. At one time, slag was generally only used as a blasting grit, skid, or traction applications, or as aggregate in asphaltic concrete. However, now many DOTs allow its use in the production of Portland cement concrete.

Most states included specifications for the allowable use of blended hydraulic cements. The specifications for these were ASTM C595 and AASHTO M240. The descriptions and definitions of these cements varied considerably.

The use of silica fume was often grouped into the same category as fly ash and ground granulated blast furnace slag as a mineral admixture in Portland cement concrete. The specifications for silica fume are AASHTO M307 "Microsilica for Use in Concrete and Mortar" and ASTM C1240 "Use of Silica Fume as a Mineral Admixture in Hydraulic-Cement Concrete, Mortar, and Grout." Generally very small amounts of silica fume were specified for used in a concrete mix design. These specified amounts were usually from 3 to 10 percent of the total cementitious material.

Methods

Specifications on the use of CCBs in their construction procedures were requested. As was

(continued on page 3)

CCB Utilization and Disposal: A State-by-State Comparison

(continued from page 2)

the case in the 1992 survey, there were three main specification criteria:

- physical and chemical specifications for CCBs,
- applications that utilize CCBs and their corresponding specifications,
- quantities of CCBs which may be allowed in each application

The first step was to evaluate existing specifications as they appeared on Internet Web sites. The most utilized Web site was <http://fhwapap04.fhwa.dot.gov/nhswp/index.jsp>, which is maintained by the U.S. Federal Highway Administration (FHWA). This site consists of a searchable library of highway specifications from across the country. It also features discussion forums to enhance communication and interaction in the development and use of various types of construction specifications.

The FHWA Web site is not necessarily complete with all specification updates, so other DOT sites had to be utilized. Two of these other Internet sources of DOT specifications were <http://www.transdata.com/dots.htm> and <http://www.fhwa.dot.gov/webstate.htm>. These sites established links directly to DOT offices.

These DOT Web sites were often a good source of establishing personal contacts as well as checking specification updates. A summary was made for each state as to its existing specifications for CCB utilization.

After a state summary was completed, an e-mail copy was

sent to an appropriate representative from that state. The e-mail message was designed to accomplish two objectives: the first was to determine if there were any current specification updates that were not reflected on the available Web sites, and the second was to establish a personal contact, with an e-mail address, within each transportation office.

The information is presented in two forms in the project report. First, specific guidelines are given in a summarized text format. Second, the data are also presented in a series of tables allowing quick reference between states and comparison of their different specifications. This facilitates evaluation of similarities and experiences in coal ash utilization on a state-by-state basis. This information is intended to be used as a means of basic comparison and not to serve as a comprehensive design manual. In addition, a contact name with personal information is included in the appendix for each DOT office.

Results and Discussion

As mentioned previously, although specifications and practices varied between states, several similarities were noted. The specifications used in all reported cases for fly ash were ASTM C618 and AASHTO M295. The title for both specifications is "Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete." Under both classification systems, fly ash is defined as "a finely divided residue that results from the combustion of ground or powdered coal." Likewise, pozzolans are defined as "siliceous or siliceous

and aluminous materials which in themselves possess little or no cementitious value but will, in finely divided form, and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties."

These materials are then divided into three classifications: Class N, Class F, and Class C. Class N materials are raw or calcined natural pozzolans which may or may not be processed by calcination to induce satisfactory properties. Class F fly ash is normally produced from burning anthracite or bituminous coal and has pozzolanic properties. Class C fly ash is normally produced from lignite or subbituminous coal. This last class of fly ash, in addition to having pozzolanic properties, also has some cementitious properties.

Excerpts from the two classification systems, ASTM C618 and AASHTO M295, are given in Tables 1 and 2, respectively. The specification from AASHTO M295 is based on a previous ASTM C618 specification from 1996. Since that time, ASTM C618 has been updated to the more recent version portrayed in this report.

Transportation departments will often change their specification from the indicated ASTM C618 and AASHTO M295 to reflect regional practices and preferences. One example of this is the requirement for loss on ignition (LOI). The lowest maximum level of LOI allowed by either specification is 5 percent.

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Table 1—ASTM C618-03 Chemical and Physical Specifications

| Chemical Requirements | Mineral Admixture Class | | |
|--|-------------------------|------------------|-----------------|
| | N | F | C |
| Silicon Dioxide, Aluminum Oxide, Iron Oxide ($\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$), min., % | 70.0 | 70.0 | 50.0 |
| Sulfur Trioxide (SO_3), max., % | 4.0 | 5.0 | 5.0 |
| Moisture Content, max., % | 3.0 | 3.0 | 3.0 |
| Loss on Ignition, max., % | 10.0 | 6.0 ^A | 6.0 |
| ^A The use of Class F pozzolan containing up to 12.0% loss on ignition may be approved by the user if either acceptable performance records or laboratory test results are made available. | | | |
| Physical Requirements | | | |
| | N | F | C |
| Fineness: Amount Retained When Wet-Sieved on 45 μm (No. 325) sieve, max., % ^A | 34 | 34 | 34 |
| Strength Activity Index: ^B with Portland Cement at | | | |
| 7-day, min. % of control | 75 ^C | 75 ^C | 75 ^C |
| 28-day, min. % of control | 75 ^C | 75 ^C | 75 ^C |
| Soundness Water Requirement, max., percent of control | 115 | 105 | 105 |
| Autoclave Expansion or Contraction, max., % | 0.8 | 0.8 | 0.8 |
| ^A Care should be taken to avoid the retaining of agglomeration of extremely fine material. | | | |
| ^B The strength activity index with Portland cement is not to be considered a measure of the compressive strength of concrete containing the fly ash or natural pozzolan. The mass of fly ash or natural pozzolan specified for the test to determine the strength activity index with Portland cement is not considered to be the proportion recommended for the concrete to be used in the work. Strength activity index with Portland cement is a measure of reactivity with a given cement and may vary as to the source of both the fly ash or natural pozzolan and the cement. | | | |
| ^C Meeting the 7- or 28-day strength activity index will indicate specification compliance. | | | |
| ^D If the fly ash or natural pozzolan will constitute more than 20% by weight of the cementitious material in the project mix design, the test specimens for autoclave expansion shall contain that anticipated percentage. | | | |

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Table 2—AASHTO M295-98 Chemical and Physical Specifications

| Chemical Requirements | Mineral Admixture Class | | |
|--|------------------------------------|------------------------------------|------------------------------------|
| | N | F | C |
| Silicon Dioxide, Aluminum Oxide, Iron Oxide ($\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$), min., % | 70.0 | 70.0 | 50.0 |
| Sulfur Trioxide (SO_3), max., % | 4.0 | 5.0 | 5.0 |
| Moisture Content, max., % | 3.0 | 3.0 | 3.0 |
| Loss on Ignition, max., % | 5.0 | 5.0 | 5.0 |
| Available Alkalies, as Na_2O , max., percent ^A | 1.5 | 1.5 | 1.5 |
| ^A Applicable only when specifically required by the purchaser for mineral admixture to be used in concrete containing reactive aggregate and cement to meet a limitation on content of alkalies. | | | |
| Physical Requirements | | | |
| | N | F | C |
| Fineness: Amount Retained When Wet-Sieved on 45 μm (No. 325) sieve, max., % ^A | 34 | 34 | 34 |
| Strength Activity Index: ^B with Portland Cement at 7 day, min. % of control 28 day, min. % of control | 75 ^C 75 ^C | 75 ^C 75 ^C | 75 ^C 75 ^C |
| Soundness Water Requirement, max., percent of control | 115 | 105 | 105 |
| Autoclave Expansion or Contraction, max., % | 0.8 | 0.8 | 0.8 |
| ^A Care should be taken to avoid the retaining of agglomeration of extremely fine material. | | | |
| ^B The strength activity index with Portland cement is not to be considered a measure of the compressive strength of concrete containing the mineral admixture. The strength activity index with Portland cement is determined by an accelerated test and is intended to evaluate the contribution to be expected from the mineral admixture to the longer strength development of concrete. Strength activity index with Portland cement is a measure of reactivity with a given cement and may vary as to the source of both the mineral admixture and the cement. | | | |
| ^C Meeting the 7- or 28-day strength activity index will indicate specification compliance. | | | |
| ^D If the fly ash or natural pozzolan will constitute more than 20% by weight of the cementitious material in the project mix design, the test specimens for autoclave expansion shall contain that anticipated percentage. | | | |

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However, many states specified LOI values to be much lower. Delaware, New York, North Carolina, Rhode Island, and the District of Columbia indicated a maximum allowable LOI of 4 percent. Still others, such as Arizona, Hawaii, Indiana, Idaho, Illinois, Kentucky, Missouri, Minnesota, New Jersey, New Mexico, North Dakota, Oregon, Ohio, South Dakota, Utah, Washington, and Wisconsin, accepted even lower maximum LOI values.

A similar situation also existed in the case for maximum levels of moisture content and fineness in states where DOT specifications are more restrictive than ASTM C618 or AASHTO M295. According to these specifications, the maximum retainment allowed on the number 325 mesh sieve is 34 percent, and the maximum acceptable moisture content is 3.0 percent. Several states such as Alaska, Indiana, New Mexico, Oregon, and South Dakota, were more restrictive in either one or both of these parameters.

Additionally, state specifications may undergo a series of alterations dependent on changes in national standards and field experiences. Other isolated differences in state specifications from national standards included maximum allowable autoclave expansion, maximum level of magnesium oxide (MgO), and a minimum calcium oxide (CaO) level. In Colorado, fly ash would only be accepted from a preapproved source, not at all an unusual DOT requirement, but preapproval required submission of a report from the supplier documenting the

results of testing the fly ash from that source in accordance with the toxicity characteristic leaching procedure (TCLP).

Fly ash use as a partial cement replacement in concrete was the most frequently indicated application. In most instances, 15 percent partial replacement of cement in a concrete mixture is allowed. The amount of fly ash used in place of the cement would either be added on a pound-for-pound basis or as additional weight.

The most common practice was to replace 15 percent of the cement with 20 percent fly ash. This was a practice originally specified in FHWA publications many years ago and was commonly incorporated into state DOTs across the country. However, in the past several years, many states have allowed for larger levels of replacement, depending on the applications. Other partial replacement levels were based on weight ratios varying from 1.0 to 1.35 portions of fly ash for every 1.0 portion of cement.

In states that have access to both Class C and Class F fly ash, the percentage of partial replacement and the amount of fly ash used as the replacement material would often be dependent on the fly ash classification. It was also commonly specified that the blending of different ash sources was prohibited.

In addition to concrete, numerous states have used fly ash as a mineral filler in asphaltic concrete and soil stabilization, with many more states beginning to use fly ash in

flowable mortar applications.

In the cases of fly ash for use in asphalt, the test procedure ASTM D242, "Mineral Filler for Bituminous Paving Mixtures," was commonly cited. This specification assesses fly ash for retainment on the No. 30-, 50-, and 200-mesh sieves and for organic impurities and plasticity indexes.

In soil stabilization, ASTM C593, "Fly Ash and Other Pozzolans for Use with Lime," is generally cited as a material specification. ASTM C593 provides evaluation criteria for fly ash by durability testing according to compressive and vacuum saturation strengths. In soil stabilization applications, it is the CaO contained in the fly ash that is being exploited for its potential engineering use. Thus there is usually a minimum level of CaO associated with fly ash being used in this application.

There are several forms of what could be considered soil stabilization, such as cement treated base, subgrade stabilization, subbase stabilization, and base course. States with some type of specification for soil stabilization include Arkansas, Illinois, Indiana, Mississippi, Nebraska, North Dakota, Oklahoma, Pennsylvania, Tennessee, Texas, Virginia, and Wisconsin, as well as Washington, D.C., and the federal lands highways.

Flowable mortar fill, also known as controlled low-strength materials (CLSM) and control density fill, is a low-strength

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flowable slurry for use as an economical fill or backfill material. It is generally placed by pouring from a commercial ready-mix concrete truck. The applications of CLSM mixtures include sewer trenches, utility trenches, bridge abutments, conduit trenches, retaining walls, foundation subbases, subfootings, floor slab bases, abandoned underground storage tanks and wells, and voids under pavement.

Flowability can be measured by the standard slump cone method for concrete (ASTM C143) with measurements generally at 8 inches or higher. Another method of measuring flowability is ASTM C934, "Flow of Grout for Preplaced Aggregate Concrete Flow Cone Method). CLSM are self-leveling and can be placed with minimal effort and no vibration or tamping. Long-term compressive strengths can vary from 50 to 1,200 psi.

Flowable CLSM mixtures are an economical alternative because of the savings of labor and time over placing and compacting soil or granular materials. This technology was once considered relatively new, and few state transportation departments have specifications for flowable mortar applications. However, several now have standing specifications for CLSM and flowable density fills, which often specify the use of fly ash as one of the constituents.

Another material often cited for use as a cement supplement was ground granulated blastfurnace slag (GGBF slag). At one time, slag was generally only used as blasting grit, in skid or traction

applications, or as aggregate in asphaltic concrete. However, now many DOTs allow its use in the production of Portland cement concrete. The replacement levels of cement with GGBF slag varied from 20 to 50 percent. It was also not uncommon to allow it to be blended with fly ash in concrete.

The materials specification cited for GGBF slag was ASTM C989 or AASHTO M302, "Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars." Three main definitions are listed under this specification. Blast-furnace slag is the nonmetallic product that is developed in a molten condition simultaneously with iron in a blast furnace. Granulated blastfurnace slag is the glassy granular material formed when molten blast-furnace slag is rapidly chilled as by immersion in water. Slag is granulated blast-furnace slag that is ground to cement fineness.

The two most common specified grades of GGBF slag were Grades 100 and 120. Most states included specifications for the allowable use of blended hydraulic cements. The specifications for these were ASTM C595 and AASHTO M240. The descriptions and definitions of these cements varied considerably.

A Type IS cement (Portland blast-furnace slag cement) was an intimate blending of cement and granulated blast-furnace slag in which the slag constituent is between 25 and 70 percent of the mass of Portland blast-furnace slag cement. A Type I(SM) cement

(slag-modified Portland cement) is a cement in which the slag constituent is less than 25 percent of the mass of the slag-modified Portland cement.

A Portland-pozzolan (Type IP) cement consisted of an intimate and uniform blend of Portland or Portland blast-furnace slag cement and fine pozzolan, in which the pozzolan constituent is between 15 and 40 percent of the mass of the Portland-pozzolan cement. A Type I (PM) cement (pozzolan-modified Portland cement) is a blend of Portland cement, or Portland blast-furnace slag cement and fine pozzolan, in which the pozzolan constituent is less than 15 percent of the mass of the Portland-modified Portland cement.

The use of silica fume was often grouped into the same category as fly ash and GGBF slag as a mineral admixture in Portland cement concrete. The specifications for silica fume are AASHTO M307, "Microsilica for Use in Concrete and Mortar," and ASTM C1240, "Use of Silica Fume as a Mineral Admixture in Hydraulic-Cement Concrete, Mortar, and Grout." Generally very small amounts of silica fume were specified for use in a concrete mix design. These specified amounts were usually from 3 to 10 percent of the total cementitious material.

Several states made references to not allowing the blending of two or more sources of fly ash and to only allowing the use of ash that had been evaluated by Cement and Concrete Reference Laboratories

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(CCRL). It is customary for DOTs to use the CCRL evaluation report as a means of rating their own laboratory testing capabilities and personnel. In several state DOTs, it is a customary practice to use cutoff dates for when fly ash is not to be used in concrete pavements. The cutoff dates are dependent on the region of country but can generally begin in early fall and extend to late spring.

DOT Survey Project Conclusions

All states had in place specifications pertaining to CCBs and their applications. The single most noted application is the partial replacement of cement in concrete. For this reason, the most commonly referenced specifications were ASTM C618 or AASHTO M295. Both are designed as methods of verifying if an ash can be used as a partial cement replacement in concrete. It was common practice for transportation departments to often change their specification from the indicated ASTM C618 and AASHTO M295 to reflect regional practices.

The most significant changes in DOT specifications from 1992 were the additions of specifications for CLSM, GGBF slag, and blended cements. During the earlier comparison study, most states were aware of CLSM applications, but few had in-place specifications for its uses. The specified use of blended cements is an indication of the increased use of fly ash within the cement industry, as is also the case for GGBF slag.

Some states have or are currently in the process of adopting updated specifications for utilizing CCBs. Differences between DOT specifications still varied greatly between states, even neighboring ones. A transition in material specifications to performance specifications will gradually blur the lines between state specifications.

State Environmental Regulations Survey

Extensive research for part two of this project began in 2004, and information was obtained from numerous sources through February 2005. The laws and regulations of each state were reviewed to identify statutory or regulatory provisions authorizing the beneficial reuse of CCBs. Information was collected through Internet and Westlaw searches.

Additionally, a survey letter was sent to all the states requesting copies of any legal authority upon which the state relies to authorize beneficial reuse of CCBs. In many cases, personal contact was also made with state agencies.

Based on the information obtained, a summary of the CCB laws and regulation in each state was prepared and presented in volume 2 of the final project report, available with volume 1 for download from the CBRC Web site. The report provides an overview of state solid waste laws and regulations governing reuse of CCBs. It will be useful to persons familiar with "beneficial use" regulations for CCBs in their particular state and will assist in the exchange of regulatory guidance to enhance the use of CCBs.

Disclaimers

The report also includes several disclaimers. It is not intended to identify landfill or similar disposal requirements. Although the report seeks to accurately describe authorized CCB reuses in the states, the reader is cautioned to seek appropriate technical, environmental, and legal advice with respect to any actions that may be undertaken concerning the management and use of CCBs in any state. The report does not constitute legal or technical advice. Further, it is not intended to advise the reader regarding legal or regulatory requirements applicable to CCB reuse projects in any state and should not be relied upon for this purpose.

The report summarizes state laws, regulations, policies, and/or agency guidance regarding the use of CCBs. It is important the reader recognize that information presented in this section of the report is merely a summary overview of various state requirements. The reader should carefully review and understand the briefly stated limitations of this report as well as the formal disclaimer of warranties and limitation of liabilities.

States Define CCBs Differently

For consistency, this report utilizes the term CCBs. The term is intended to generically refer to fly ash, bottom ash, boiler slag, flue gas desulfurization sludge, or fluidized-bed combustion material. The reader must recognize that

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each state has different approaches to classification of CCBs and that these respective classifications may limit or expand allowable uses of CCBs.

For example, in Pennsylvania, CCBs are referred to as coal ash, which is defined to include fly ash, bottom ash, and boiler slag. Conversely, some states include within the definition of CCB wastes that have been combusted with other materials, such as petroleum coke, tire-derived fuel, and/or wood. In some cases, these distinctions are noted in the report. However, the reader should not assume that use of the term CCB infers that all types of CCBs are included within the scope of a particular state's regulations.

Summary of State CCB Regulations

CCB reuse options are determined by state law. CCBs are generally exempt from hazardous waste regulations, and the states have elected to regulate these materials as solid, special, or industrial wastes. States that do not exempt CCBs from hazardous waste regulations require testing to determine hazardousness, and if shown to be nonhazardous, the CCBs are regulated as solid waste.

Most states currently do not have specific regulations addressing the use of CCBs, and requests for CCB uses are handled on a case-by-case basis or under generic state recycling laws or regulations. Many states have "generic" laws and regulations that authorize limited reuse and recycling of hazardous and/or solid wastes.

These generic laws do not apply specifically to CCBs or any other materials. In general, under these regulations, materials are not considered solid wastes when they can be recycled by being:

- used or reused as ingredients in an industrial process to make a product, provided the materials are not being reclaimed;
- used or reused as effective substitutes for commercial products; or
- returned to the original process from which they are generated, without first being reclaimed. (The materials must be returned as a substitute for raw materials feedstock, and the process must use raw materials as principal feedstocks.)

A number of states have adopted laws and regulations or issued policies and/or guidance specifically pertaining to CCB use. The CCB uses authorized within these states vary widely. Some states authorize liberal use of CCBs, while others authorize CCB use only in limited applications. In addition, the level of regulatory control and oversight varies significantly.

CCB uses presenting the greatest concern to state regulators are those which involve land application, such as use of CCBs in agricultural applications, structural fills, mine applications, and embankments. Some states consider these applications to be waste disposal and not reuse or recycling.

Finally, other states have elected to adopt "industrial solid waste beneficial use" rules intended to authorize use of a variety of materials such as coal ash, paper mill sludge, and foundry sand. These reuse rules with application to multiple materials may represent a growing trend.

Table 1 in volume 2 of the final report summarizes the use of CCPs that are "authorized" or "allowed" on a state-by-state basis. A detailed, state-by-state summary and discussion as presented in the remainder of this report.

Results and Discussions Federal Regulation of CCBs

The principal federal statute under which hazardous and solid wastes are regulated is the Resource Conservation and Recovery Act (RCRA), 42 U.S.C. § 6901-6991. RCRA establishes a comprehensive cradle-to-grave system for regulating hazardous wastes. Specifically, Subtitle C of RCRA and its implementing regulations impose requirements on the generation, transportation, storage, treatment, and disposal of hazardous wastes. To trigger these requirements, a material must be a "solid waste," and the solid waste must be "hazardous."

Subtitle D of RCRA pertains to State or Regional Solid Waste Plans. Wastes that are not considered hazardous under Subtitle C fall under Subtitle D and are subject to regulation by the states as solid waste. As originally drafted, RCRA did not specifically

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address whether CCBs fell under Subtitle C as a hazardous waste or Subtitle D as a solid waste.

In 1980, Congress enacted the Solid Waste Disposal Act Amendments to RCRA. Under the amendments, certain wastes, including CCBs, were temporarily excluded from Subtitle C regulation. This regulatory exemption is commonly referred to as the "Bevill Exemption," 42 U.S.C. §6921(b)(3)(A)(i). As a result, CCBs fell under Subtitle D and became subject to regulation under state law as solid waste.

As the Bevill Exemption was temporary, the amendments further directed that the U.S. Environmental Protection Agency (EPA) produce a report regarding CCBs and to pursue appropriate regulation, 42 U.S.C. §6982(n). In accord with this mandate, EPA issued its first report to Congress in 1988 titled *Waste from the Combustion of Coal Electric Utility Power Plants* (EPA/5-30-SW-88-002). This EPA report concluded that CCBs generally do not exhibit hazardous characteristics, and that regulation of CCBs should remain under state Subtitle D authority.

Following litigation against EPA by the Bull Run Coalition because EPA failed to timely issue a regulatory determination as stated in its 1988 report to Congress, EPA entered into a consent decree with the Bull Run Coalition which included a time frame for EPA to issue a formal recommendation regarding regulation of CCBs. Pursuant to the consent decree, EPA issued a final regulatory determination applicable to fly ash, bottom ash,

boiler slag, and FGD material which became effective September 2, 1993, 58 *Federal Register* 42, 466 (August 9, 1993). The rule states that regulation of CCBs generated by coal-fired electric utilities and independent power producers as hazardous waste is unwarranted and that the materials will remain exempt from regulation as a hazardous waste under RCRA.

EPA has narrowly interpreted this exemption. According to EPA, the exemption applies only to coal-fired electric utilities and independent power producers. It does not include CCBs generated at any other industrial activity (in *re*: *Wheland Foundry*, EAB, No. 93-2, December 22, 1993). Further, fluidized-bed combustion wastes, low-volume wastes (boiler blowdown, coal pile runoff, cooling tower blowdown, demineralizer regenerant rinses, metal and boiler cleaning wastes), and pyrites and comanaged wastes (referred to as remaining wastes) are not covered by the rule. EPA decided that more study was needed on these remaining wastes before an exemption determination could be made.

EPA was initially scheduled to complete a study of remaining wastes by September 30, 1998, and issue a final regulatory determination regarding these wastes by April 1, 1999, pursuant to the consent decree in the Bull Run Coalition litigation. Based on this obligation, EPA's study of fluidized-bed combustion wastes, low-volume wastes (boiler blowdown, coal pile runoff, cooling tower blowdown, demineralizer

regenerant rinses, metal and boiler cleaning wastes), and pyrites and comanaged wastes (referred to as remaining wastes) were subsequently discussed in a March 31, 1999, Report to Congress. The report indicated that fluidized-bed combustion wastes, low-volume wastes, and remaining wastes should continue to maintain their "Bevill Exemption" and that regulation under Subtitle C was not warranted.

Based on extensions of the consent decree mentioned above, EPA was to issue a final regulatory determination addressing fluidized-bed combustion wastes, low-volume wastes, and remaining wastes by April 10, 2000. In early March, EPA circulated a draft regulatory determination which indicated that, contrary to the 1999 Report to Congress, these wastes would be regulated under Subtitle C. EPA's stated basis for this shift in position was that remaining wastes did present environmental concerns, particularly concerns regarding groundwater leaching and the effects on drinking water standards, as well as effects associated with mercury exposure.

The ACAA, as well as other shareholder groups, did not agree that regulation of CCBs as hazardous was warranted and met with EPA to discuss concerns associated with the draft approach. After much debate and discussion among EPA, industry, and environmental groups (as well as an extension of the consent decree), EPA issued its final regulatory

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determination April 25, 2000, which was published in the *Federal Register* on May 22, 2000 (65 *Federal Register* 32213).

The final regulatory determination states that fluidized-bed combustion wastes, comanaged wastes, and coal combustion wastes from nonutilities, petroleum coke combustion wastes, coburning of coal and fuel, and oil and natural gas combustion will not be regulated under Subtitle C and would continue to maintain their "Bevill Exemption."

However, in determining if low-volume wastes are subject to Subtitle C regulation, EPA divided the low-volume wastes into two new categories: uniquely associated wastes and nonuniquely wastes. EPA took the position that when uniquely associated low-volume wastes are comanaged, those wastes would continue to be exempt from regulation under Subtitle C. However, if these wastes are managed independently and if they exhibit hazardous characteristics, they are subject to Subtitle C regulation. EPA defined these uniquely associated low-volume wastes to include coal pile runoff, coal mill rejected and waste coal, air heater and precipitation wastes, flow and yard drains and sumps, wastewater treatment sludge, and boiler fireside chemical cleaning waste.

EPA defined nonuniquely associated wastes as boiler

blowdown, coal pile runoff, cooling tower blowdown, demineralizer regenerant rinses, metal and boiler cleaning wastes (which was the historical definition for all low-volume wastes). Under EPA's final regulatory determination, when these nonuniquely associated wastes are comanaged or managed independently, they are not automatically exempt from regulation under Subtitle C, but must rather go through a RCRA hazardous waste determination.

The determination also indicated that EPA would be looking to the states to ensure proper regulation for certain CCB applications. In particular, EPA expressed the view that CCBs disposed in landfills or surface impoundments, or used to fill surface or underground mines, should be regulated by the states. Alternatively, EPA stated it would develop federal regulations of these applications under Subtitle D of RCRA. EPA indicated in the regulatory determination that, in developing/reviewing regulations, it would look at the extent to which CCBs caused actual or potential damage to human health and/or the environment, the environmental effects of filling mines with CCBs, the adequacy of existing regulations, and the effects of mercury exposure from these activities. EPA further indicated any federal regulations would be developed through notice and comment rulemaking.

State Regulation of CCBs

As a result of the federal law developments described above, CCB reuse options are determined by state law. CCBs are generally exempt from hazardous waste regulations, and the states have elected to regulate these materials as solid, special, or industrial wastes. States that do not exempt CCBs from hazardous waste regulations require testing to determine hazardousness, and if shown to be nonhazardous, the CCBs are regulated as solid waste.

Most states currently do not have specific regulations addressing the use of CCBs, and requests for CCB uses are handled on a case-by-case basis or under generic state recycling laws or regulations. Many states have "generic" laws and regulations, which authorize limited reuse and recycling of hazardous and/or solid wastes. These generic laws do not apply specifically to CCBs or any other materials. In general, under these regulations, materials are not considered solid wastes when they can be recycled by being:

- used or reused as ingredients in an industrial process to make a product, provided the materials are not being reclaimed;
- used or reused as effective substitutes for commercial products; or
- returned to the original process from which they are generated,

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without first being reclaimed. (The materials must be re-turned as a substitute for raw materials feedstock, and the process must use raw materials as principal feedstocks.)

The following materials remain regulated solid wastes, even if the recycling involves use, reuse, or return to the original process:

- materials used in a manner constituting disposal or used to produce products that are applied to the land;
- materials burned for energy recovery, used to produce a fuel, or contained in fuels;
- materials accumulated speculatively; and
- inherently waste-like materials.

In addition, there is little consistency among the states regarding the use of CCBs in mine applications. Some states have detailed regulations for reuse of CCBs in mine applications (some of which are discussed in the project report). Other states address this common use of CCBs by reference to fly ash and flue gas desulfurization (FGD) material as materials, which may be permitted as “discharges” to the mine upon approval by the state mining agency.

In general, the legal and technical requirements for mine applications are complex. For this reason, these regulations are not discussed in detail in the final report but are noted so further research can be done in the event the reader is interested in the potential application of these regulations to a proposed project. There may be significant changes in the regulations applicable to mine reuse applications. EPA has identified this as an area where greater regulation is warranted.

State Regulations Survey Project Conclusions

A number of states have adopted laws and regulations or issued policies and/or guidance specifically pertaining to CCB use. The CCB uses authorized within these states vary widely. Some states authorize liberal use of CCBs, while others authorize CCB use only in limited applications. In addition, the level of regulatory control and oversight varies significantly.

CCB uses presenting the greatest concern to state regulators are those which involve land application, such as use of CCBs in agricultural applications, structural fills, mine applications, and embankments. Some states consider these applications to be waste disposal and not reuse or recycling.

Finally, other states have elected to adopt “industrial solid waste beneficial use” rules intended to authorize use of a variety of material such as coal ash, paper mill sludge, and foundry sand. These reuse rules with application to multiple materials may represent a growing trend.

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For more information about this project (#02-CBRC-W12), or to view the final report, please visit the CBRC Web site at <http://www.wri.nrcce.wvu.edu/programs/cbrc/>. Or contact the CBRC at cbrc@wvu.edu.



CBRC CONTACTS

Calendar of Events

November 29–30, 2005

2005 Byproducts Beneficial Use Summit

Philadelphia, Pennsylvania

Contact:

info@byproductsummit.com
www.byproductsummit.com/
2005\

December 4–7

International Congress Fly Ash India 2005

New Delhi, India

Contact:

flyash.conference@gmail.com,
www.flyashindia.tifac.org.in

December 6–8

Power-Gen International 2005 Conference & Exhibition

Las Vegas, Nevada

Contact:

http://pgi05.events.pennnet.com/

April 11–15

World of Coal Ash—2005

Lexington, Kentucky

Contact:

Gretchen Tremoulet
(859) 257-0355
gtremoulet@caer.uky.edu
www.worldofcoalash.org/

April 22

The Ohio State University Coal Combustion Products Extension Program Seminar

Columbus, Ohio

Contact:

Dr. Tarunjit S. Butalia
(614) 688-3408
butalia.1@osu.edu

Program Manager

William Aljoe, U.S. Department of Energy -
National Energy Technology Laboratory
412/386-6569; aljoe@netl.doe.gov

National Center

Paul Ziemkiewicz, Ph.D., *Director*
Tamara Vandivort, *Consortium Manager*
CBRC National Center located at the
National Mine Land Reclamation Center at
West Virginia University, 304/293-2867,
pziemkie@wvu.edu or tvandivo@wvu.edu

National Steering Committee Chair

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Resources, 317/232-4020, pehret@indy.rr.com

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nooga, Tenn., 423/751-4419, ecmiller@tva.gov

Midwestern Regional Chair

Kimery Vories, U.S. Office of Surface Mining,
618/463-6463, kvories@osmre.gov

Western Regional Chair

Richard Halverson, Headwaters Resources,
206/575-1981, rhalverson@isgresources.com

Eastern Regional Technical Director

James C. Hower, Ph.D., University of Kentucky,
859/257-0261, hower@caer.uky.edu

Midwestern Regional Technical Director

Y. Paul Chugh, Southern Illinois University at
Carbondale, 618/536 6637, chugh@engr.siu.edu

Western Regional Technical Director

Deborah Pflughoeft-Hassett, University of North
Dakota, 701/777-5181, dphassett@undeerc.org

NSC Committee Members

Jackie Bird, Ohio Coal Development Office,
614/466-3465, jbird@aqda.state.oh.us

John Glasscock, Synthetic Materials Synmat,
727/367-0402, jrg@synmat.com

David Goss, American Coal Ash Association,
720/870-7897, DCGoss@ACAA-USA.org

Howard Humphrey, American Coal Ash Association,
614/846-1726, hhumphrey@columbusrr.com

Jimmy Knowles, South Eastern Fly Ash Group,
803/794-3230, jknowles@SEFAGroup.com

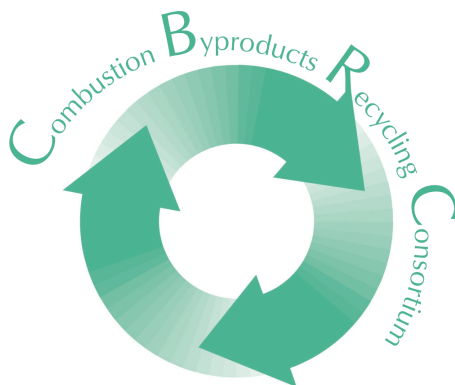
David Meadows, USACE-Huntington District,
304/529-5243, david.f.meadows@usace.army.mil

James Rower, Utility Solid Waste Activities Group,
202/508-5645, jim.rower@uswag.org

Andy Wittner, U.S. EPA, 703/308-0496
Wittner.Andrew@epamail.epa.gov

Dan Wheeler, Illinois DCCA Office of Coal
Development and Marketing, 217/558-2645,
dwheeler@commerce.state.il.us

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Volume 6, Number 1

Spring 2005

COMBUSTION BYPRODUCTS RECYCLING CONSORTIUM

Ashlines

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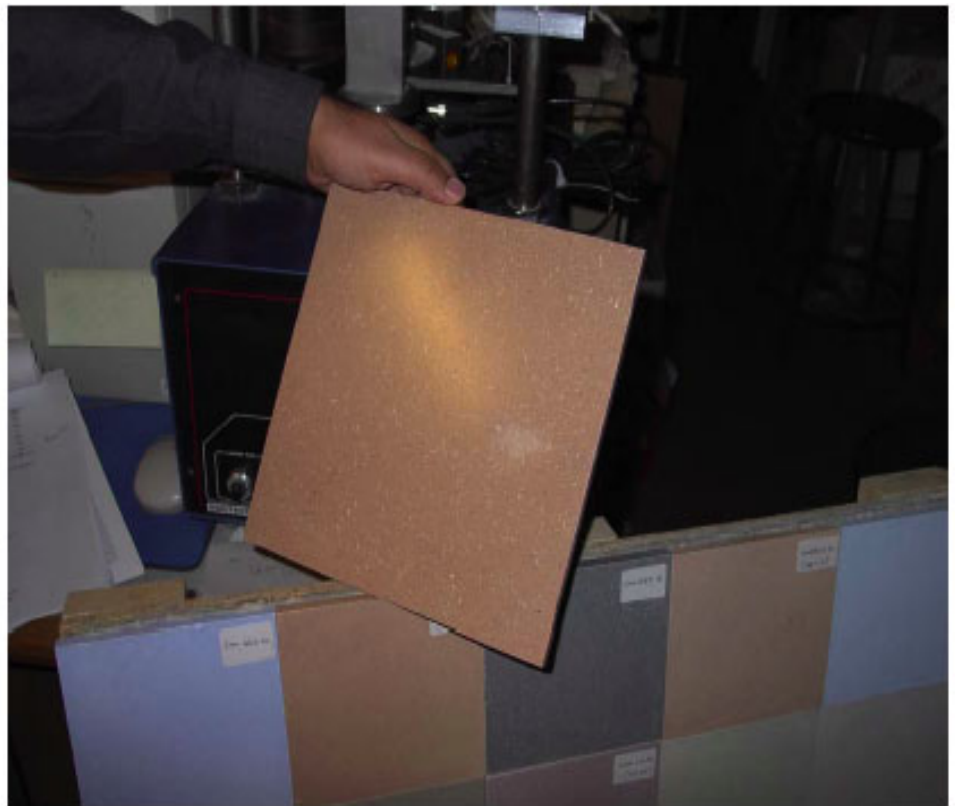
To promote and support the commercially viable and environmentally sound recycling of coal combustion byproducts for productive uses through scientific research, development, and field testing.

Tile, Countertops, and Structural Materials from Sulfate-Rich FGD Scrubber Sludge

V. M. Malhotra and Y. P. Chugh, PIs

One day, a family, maybe even yours, will return home each evening to a house covered in sulfate-rich, flue gas desulfurization (FGD) scrubber sludge materials. The kids will wash up in a bathroom lined with tiles made of scrubber sludge, while the adults prepare and serve the evening meal on a scrubber sludge countertop. And this will all be far more lovely than it sounds.

V. M. Malhotra and Y. P. Chugh, professors at the Southern University of Illinois at Carbondale, have completed a two-year project to develop technology for converting sulfate-rich, FGD scrubber sludge into value-added decorative building materials. The research was funded by the Combustion Byproducts Recycling Consortium (CBRC), the Illinois Department of Commerce



Sample of size 10" x 10" x 0.125" siding fabricated from sulfate-rich scrubber sludge.

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Tile, Countertops, and Structural Materials from Sulfate-Rich FGD Scrubber Sludge *(continued from page 1)*

and Economic Opportunity through the Office of Coal Development, and the Illinois Clean Coal Institute.

Malhotra and Chugh sought to establish technology for fabricating cost-effective but marketable materials, like countertops and decorative tiles, from the sludge. In addition, they explored the feasibility of forming siding material from the sludge. By the end of the project, they generated several structural and decorative materials of various colors with potential market value.

Background

About 29 million tons of FGD scrubber sludge is currently produced in the U.S. Most of it is disposed of in the landfills near power plants. In Illinois, Indiana, and Western Kentucky, 6 million tons of wet scrubber sludge are currently produced. About 7,000 MW of additional capacity is expected to be wet scrubbed in the near future in response to the Clean Air Act Amendments of 1990, and this will further increase the amount of wet scrubber sludge produced annually.

Since only about five percent of wet scrubber sludge is utilized nationally, and the wallboard industry may be able to absorb only a portion of high-quality gypsum sludge, alternative utilization strategies must be developed to effectively utilize FGD wet scrubber sludge.

In 1989, 21.9 billion square feet of gypsum-based products were utilized in the U.S. along with 1.20 billion square feet of tile materials. The gypsum and tile

business together generated about 4.7 billion dollars in 1994 (U.S. *Industrial Outlook* 1994, U.S. Department of Commerce).

FGD technology commonly uses sorbents such as CaCO_3 or CaO to scrub SO_2 gas from the flue gases generated by coal burning power plants. Although FGD technology is successful in reducing the SO_x emission, it generates a large quantity of solid residue, called FGD scrubber sludge. FGD residue is generally composed of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ (gypsum) or $\text{CaSO}_3 \cdot n\text{H}_2\text{O}$, depending upon the FGD technology used.

The disposal of about 29 million tons of scrubber sludge is a serious economic problem for the coal utilities. A number of commercial applications of scrubber sludge have been proposed [1–9]. For example,

- road base construction,
- manufacture of wallboard,
- agriculture, and
- friction materials.

Notwithstanding the proposed applications, a large portion of it ends up in landfills. The limited utilization of the sludge has been due to fluctuations in its composition and properties.

The processes involved in manufacturing a commercial product using gypsum commonly employ higher pressures and temperatures. In fact, the hemihydrate phase ($\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$), called plaster, is used as the starting material because of its cementitious

properties. A homogeneous paste of this plaster is prepared by mixing it with water in a definite proportion. The paste hardens to generate a highly porous material whose physical and engineering properties are strongly governed by

- the water-to-plaster ratio,
- the water temperature,
- impurities,
- additives and accelerators,
- mode of mixing, and
- extent of mixing.

Thus, the processing parameters have a profound effect on the shapes, sizes, and compaction of the gypsum crystals formed. In fact, most of the physical and engineering properties of these materials are governed by the microstructure of the hardened gypsum, because of the interlocking of the crystals [7–12].

If FGD scrubber sludge is to be used in the manufacturing of structural materials, then it is necessary to study how temperature, pressure, and other parameters affect the crystal growth habits of scrubber sludge, especially sulfate-rich sludge. In addition, technology is required to overcome the deleterious effects of organic and inorganic components, often present in scrubber sludge, in the fabrication of materials.

These organic and inorganic impurities/components are difficult, if not economically prohibitive, to separate from sludge. Hence, strategies are needed to form materials from FGD scrubber sludge, which are

not affected by the presence of these impurities and/or components.

If the countertop and tile materials developed by this research project were able to compete in the high-end gypsum product market, high-end tabletop market, and tile markets, and were able to capture 5 percent of the rapidly growing export market, this would translate into 5 million tons of sludge utilization. This potential market would generate 600 jobs (3 percent of the current 20,000 workers) with an annual turnover of 250 million dollars. Thus, the successful development of the proposed structural composite materials should not only generate new markets for coal combustion residues but should also strengthen the utilization of Midwestern coal.

Specifically, the developed materials would benefit in the following ways:

- by reducing the cost of scrubber sludge disposal;
- by generating new structural material markets for coal combustion byproduct-based materials, specifically FGD residue;
- by providing the technological base for industry to locate in the Midwestern area, especially hard hit by the Clean Air Act, and, therefore, generating additional jobs in the region which currently do not exist;

- by converting FGD byproducts into marketable items, thus, converting byproducts into valuable, sellable raw material;
- by utilizing the wet scrubber sludge and the associated revenue generated, encouraging further use of scrubbers for SO₂ control; and
- by lowering the requirement to cut trees, thus preserving our forests.

Objectives

The goal of this project was to develop technology for the conversion of sulfate-rich scrubber sludge into value-added decorative materials; i.e., countertops, decorative siding, and decorative tiles. Specifically, the project had the following objectives:

- to design, assemble, and utilize high-temperature, high-pressure molding dies for fabricating large-size composites (up to 8-inch size) from FGD scrubber sludge (the experimental setup was to be capable of applying at least 200,000 lbs of force with controlled temperature up to 350°C);
- to develop protocols and engineering procedures for the development and fabrication of value-added materials from sulfate-rich scrubber sludge;
- to enhance the mechanical strength of materials produced from sulfate-rich scrubber sludge (the fabricated composites' strength was to be com-

pared with commercially available materials);

- to optimize the type of fibers used and their content for enhanced durability and textural appearance of the material;
- to establish procedures for different surface treatment so that our materials would not scratch under normal conditions;
- to fabricate our composites in at least six different colors and patterns; and
- to conduct explorative experiments to establish the feasibility of forming wood-substitute siding materials from sulfate-rich scrubber sludge.

To meet the project objectives of developing decorative materials, the following six tasks were proposed:

- *Task 1*—Focus mainly on optimizing the mixes to be used for countertops, decorative tiles, and siding materials. Another important step in this task was to enhance cross-linking between sludge crystallites and the binders.
- *Task 2*—Focus on maintaining the highly twinned crystal growth behavior of scrubber sludge particles in the materials, yet allow the impregnation

(continued on page 4)

Tile, Countertops, and Structural Materials from Sulfate-Rich FGD Scrubber Sludge *(continued from page 3)*

of the polymer to form smooth textured composites. In addition, an attempt at altering physical and chemical parameters for the fabrication of composites was made so that enhanced mechanical strength of the decorative composites ensued.

- *Tasks 3 and 4*—Subject the composites formed under tasks 1 and 2 to various mechanical performance tests and analyze the ensuing data.
- *Task 5*—Perform an economic analyses of the structural products.
- *Task 6*—Explore strategies for commercializing the products, which showed potential.

Summary and Conclusions

The following was accomplished during the course of this project:

- The FTIR measurements were conducted on the as-received polymer to identify the vibrational oscillators, which could be used to measure the concentration of the polymer and cured structure of the polymer in our countertop composites.
- The differential scanning calorimetry (DSC) measurements on as-received polymer suggested that the countertop composites should be formed

at $T > 60^{\circ}\text{C}$ and not at $T < 55^{\circ}\text{C}$ as recommended by the supplier. In fact, this was born out subsequently after forming the composites at $T > 60^{\circ}\text{C}$.

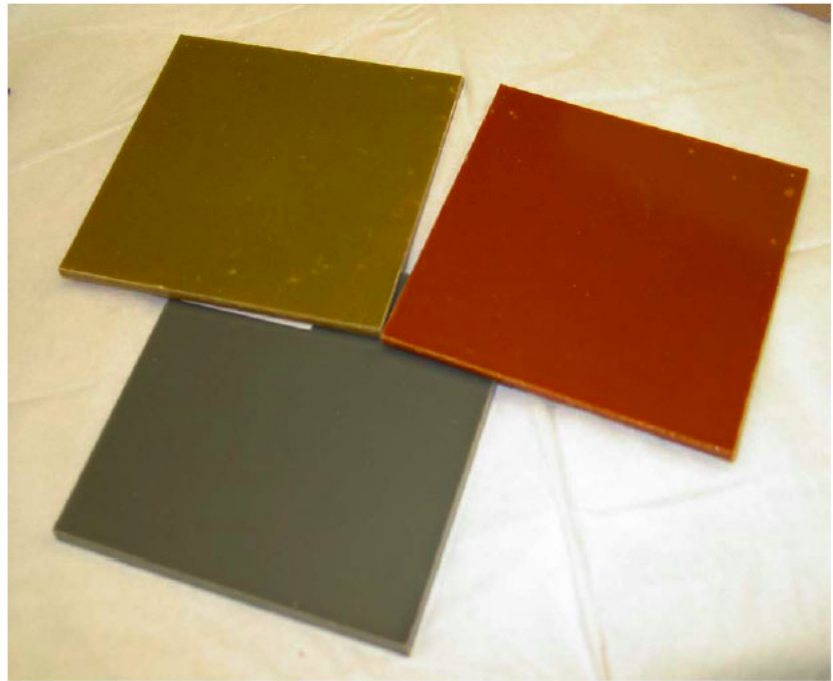
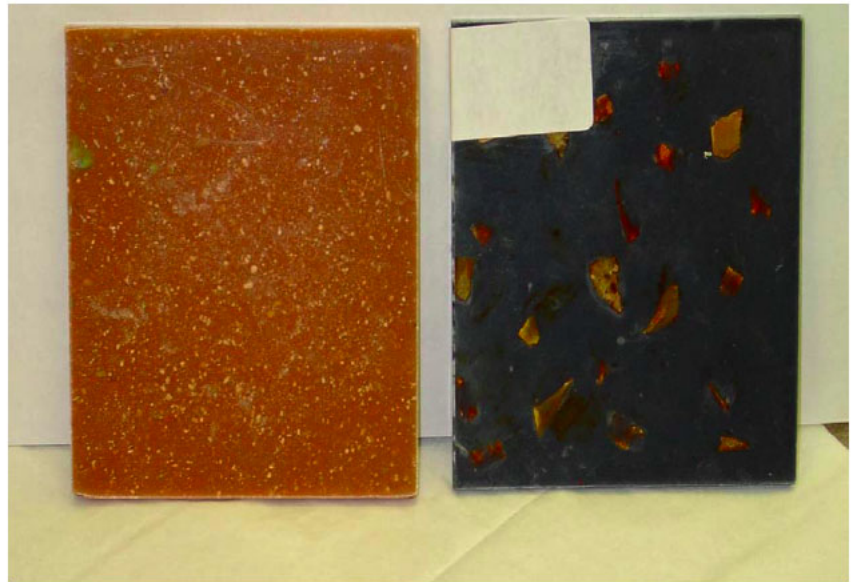
- The researchers evaluated how the fiber content in the countertop materials affected the strength of the formed composites.
- They also studied how the orientation of the fibers within our countertop composites affected their mechanical strength. The results suggested that though a sandwich configuration gave the highest flexural strength, the incorporation of the fiber mesh at the bottom would facilitate the installation of the countertops on pre-existing countertops.
- The researchers probed how the formation temperature controlled the strength of the formed material and concluded that higher formation temperature ($T < 110^{\circ}\text{C}$) imparted better strength to the countertop material formed from sulfate-rich scrubber sludge.
- They also studied how the degree of cure affected the mechanical strength of the composite materials. It appeared that post-curing, in fact, decreased the strength of the countertop material.
- The researchers formed countertop composites using

conventional molding technique in which they varied the concentration of the sludge from 10 to 50 weight-percent. However, the sludge was treated to control its crystallization in the composite during molding. It appeared the flexural strength of the composites was comparable or better than the flexural strength of commercial products with similar filler concentration.

- The researchers designed and built a vacuum die to form countertop composites under mild vacuum. Using this die, they formed countertop composites in which they varied the concentration of scrubber sludge. The concentration of the sludge in the composite was varied between 50 and 75 weight percent. It appeared that we could use up to 65 weight percent scrubber sludge in our composites and yet obtain comparable flexural strength to that of commercial products. However, it is believed the commercial products contain only 33 percent inorganic phase.
- The researchers explored whether the countertop composite's resistance to scratching could be further enhanced by forming the composites from block copolymers. In this approach, they incorporated a polymer in addition to the polymer that

was used to form countertops. The results indicated that a second polymer could be added to further improve scratch resistance without degrading the strength of the countertops. In fact, 5 weight percent of the second polymer could accomplish this without reducing the scrubber sludge crystallites in the materials.

- Flexural strength measurements on the decorative tiles indicated that the particle size of the polymer had a crucial effect on the strength of the material; i.e., the smaller the particle size of the polymer the larger was the flexural strength of the composite.
- Experiments suggested that 2 weight percent decorative granules could be incorporated in the tile composites without compromising the strength of the material.
- The researchers have completed the fabrication of 64 decorative tiles from scrubber sludge. Four of the tiles were mounted on a commercial backing board using commercial adhesive. Results suggested that sludge-derived tiles could be mounted on currently existing commercial backing boards.
- Strength and fabrication measurements suggested that a significant amount of waste and broken countertops could be recycled.



Countertops fabricated from scrubber sludge and waste material.

- Strength and fabrication measurements suggested that a significant amount of broken tiles could be used to design different patterns in the decora-

tive tiles. The researchers believe this approach would considerably reduce the waste and disposal costs of the fabrication process.

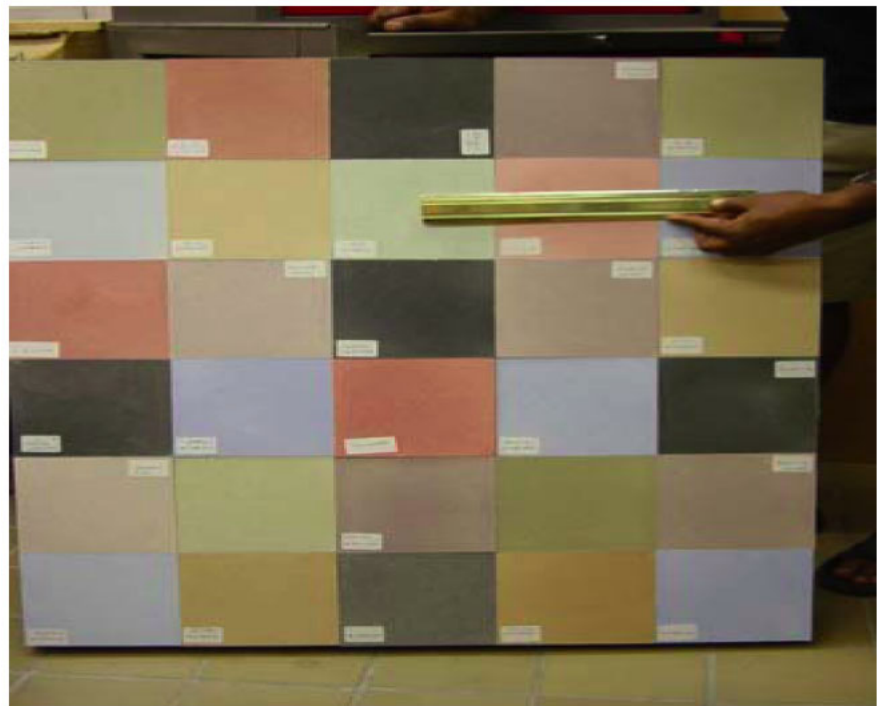
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Tile, Countertops, and Structural Materials from Sulfate-Rich FGD Scrubber Sludge (continued from page 5)

- The researchers fabricated 4" x 4" x 0.2" countertop composites in 11 different colors and patterns.
- The countertop composites were upscaled to 6" x 6" x 0.2" size. At least four different colored countertop composites were fabricated. The researchers have now successfully fabricated 64 pieces of countertop, thus establishing the viability of forming countertop materials from scrubber sludge.
- The researchers examined whether aging affected the strength of the countertops and tiles. The flexural strength measurements suggested that a year of aging did not affect the strength.
- Stability of the tiles in water was also tested. After continuous immersion in water for more than a month, disintegration of the tile or swelling has not been observed.
- The leachate obtained from countertop and decorative tile using the ASTM D3987 procedure suggested that the concentration of selenium and arsenic were below the detection limits.
- The detailed economic analysis indicated that the countertop product would be approximately 10 times cheaper than the current high-end countertops. Decorative tiles would cost about \$0.85 per tile.



Decorative tiles made from sulfate-rich scrubber sludge and waste or broken tiles.



Different color tiles fabricated from sulfate-rich scrubber sludge were mounted on a commercial Durock board.

Acknowledgements

This research was supported with funding from the CBRC, the Illinois Department of Commerce and Economic Opportunity through the Office of Coal Development, and the Illinois Clean Coal Institute.

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For more information about this project (#99ECM01) or to view the final report, please visit the CBRC Web site at <http://www.wvri.nrcce.wvu.edu/programs/cbrc/>. Or contact the CBRC at cbrc@wvu.edu.



Request for Preproposals

The Combustion Byproducts Recycling Consortium (CBRC), a program of the National Mine Land Reclamation Center in cooperation with the U.S. Department of Energy National Energy Technology Laboratory, has announced a request for preproposals. Applications are due by **4:30 p.m. EST, July 31, 2005**

Each year, over 100 million tons of solid byproducts are produced by coalburning electric utilities in the U.S.. One of the CBRC's objectives is to develop and demonstrate technologies to address issues related to the recycling of byproducts associated with coal combustion processes. A goal of CBRC is that these technologies, by the year 2010, will lead to an overall ash utilization rate from the current 34 to 50 percent.

For more information on the CBRC program and for the preproposal application procedures and forms, please access the CBRC Web site at: <http://www.wvri.nrcce.wvu.edu/programs/cbrc/>, or contact the CBRC at West Virginia University at (304) 293-2867 or at cbrc@wvu.edu.

Calendar of Events

August 17–19

Coal-Gen 2005, Revival of the Fittest

San Antonio, Texas

Presented by PennWell

Contact: Registration Department
1421 S. Sheridan Road
Tulsa, OK 74112-6600 USA
Fax (888) 299-8057
coal-gen@pennwell.com,
www.coal-gen.com

August 31–September 1

Coal Combustion Product Optimization

Denver, Colorado

www.euci.com/conferences/august_05/coal_combustion_0805.php

September 18–22

22nd Annual International Pittsburgh Coal Conference “Coal, Energy, and the Environment”

Pittsburgh, Pennsylvania

Contact: (412) 624-7440
pcc@engr.pitt.edu
www.engr.pitt.edu/pcc

December 4–7

International Congress Fly Ash INDIA 2005

New Delhi, India

Contact: flyash.conference@gmail.com, www.flyashindia.tifac.org.in

CBRC CONTACTS

Program Manager

William Aljoe, U.S. Department of Energy -
National Energy Technology Laboratory
412/386-6569; aljoe@netl.doe.gov

National Center

Paul Ziemkiewicz, Ph.D., *Director*
Tamara Vandivort, *Consortium Manager*
CBRC National Center located at the
National Mine Land Reclamation Center at
West Virginia University, 304/293-2867,
pziemkie@wvu.edu or tvandivo@wvu.edu

National Steering Committee Chair

Paul Ehret, Kentucky Department of Natural
Resources, 317/232-4020, pehret@indy.r.com

Eastern Regional Chair

Cheri Miller, Tennessee Valley Authority, Chatta-
nooga, Tenn., 423/751-4419, ecmiller@tva.gov

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Kimery Vories, U.S. Office of Surface Mining,
618/463-6463, kvories@osmre.gov

Western Regional Chair

Richard Halverson, Headwaters Resources,
206/575-1981, rhalverson@isgresources.com

Eastern Regional Technical Director

James C. Hower, Ph.D., University of Kentucky,
859/257-0261, hower@caer.uky.edu

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Y. Paul Chugh, Southern Illinois University at
Carbondale, 618/536 6637, chugh@engr.siu.edu

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Deborah Pflughoeft-Hassett, University of North
Dakota, 701/777-5181, dphassett@undeerc.org

NSC Committee Members

Jackie Bird, Ohio Coal Development Office,
614/466-3465, jbird@aqda.state.oh.us

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727/367-0402, jrg@synmat.com

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720/870-7897, DCGoss@ACAA-USA.org

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614/846-1726, hhumphrey@columbusrr.com

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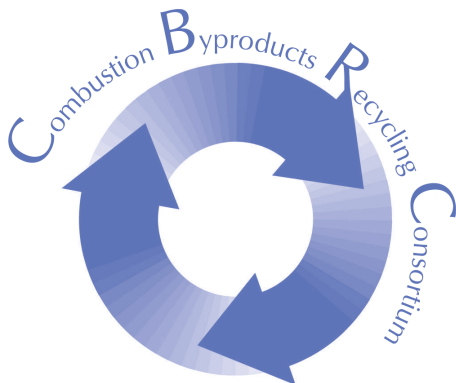
David Meadows, USACE-Huntington District,
304/529-5243, david.f.meadows@usace.army.mil

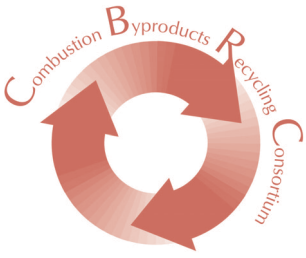
James Rower, Utility Solid Waste Activities Group,
202/508-5645, jim.rower@uswag.org

Andy Wittner, U.S. EPA, 703/308-0496
Wittner.Andrew@epamail.epa.gov

Dan Wheeler, Illinois DCCA Office of Coal
Development and Marketing, 217/558-2645,
dwheeler@commerce.state.il.us

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Winter 2004

COMBUSTION BYPRODUCTS RECYCLING CONSORTIUM

Ashlines

To promote and support the commercially viable and environmentally sound recycling of coal combustion byproducts for productive uses through scientific research, development, and field testing.

a program of the National
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Center at West Virginia
University [www.nrcce.
wvu.edu/nmlrc](http://www.nrcce.wvu.edu/nmlrc), in
cooperation with the U.S.
Department of Energy -
National Energy
Technology Laboratory
www.netl.doe.gov

Environmental Effects of Large-Volume FGD Fill: Rostraver Airport Runway Safety Area

By Phillip E. Glogowski, P.I.

This article describes the use of low permeability cementitious (LPC) material as structural fill material for the construction of a 250-foot-high embankment to create a safety area at the end of an existing airport runway. The Elrama Power Station, owned by Orion Power MidWest and managed by Reliant Energy, located near Pittsburgh, Pennsylvania, produces the LPC material.

The Rostraver Airport was constructed on a flattened hilltop in Westmoreland County, Pennsylvania. With steep side slopes of 10 to 50 percent, the steep drop at the end of the runway did not allow a sufficient margin of safety for planes taking off and landing. This geometry created a risk for air traffic in that a suitable margin of protection was not provided to the pilots on approach or in the event of an overshoot or aborted takeoff.



FGD byproducts from a nearby power plant were used to expand this runway at Pennsylvania's Rostraver Airport.

To improve the conditions, a 300-foot runway safety area extension, meeting FAA standards, was designed. The safety area

extension required that a 250-foot-high side hill fill be constructed. The structural fill embankment required approximately 560,581

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Flue Gas

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Environmental Effects of Large-Volume FGD Fill: Rostraver Airport Runway Safety Area (continued from page 1)

tons of LPC material. The favorable engineering properties of LPC material produced at the Elrama Power Station make the LPC material uniquely qualified to meet the Westmoreland County Airport Authority's objective.

LPC material is a stabilized product that consists of flue gas desulfurization byproduct (FGD) (calcium sulfite and calcium sulfate), fly ash, quicklime, and, in some cases, bottom ash. The LPC material generally has a minimum 60 to 66 percent solids content that is suitable for conventional construction methods for loading, hauling, and placement. The LPC material has a low permeability of about 1×10^{-6} centimeters per second (cm/sec), and normally has a construction life of two to three days before the pozzolanic reaction between the lime and fly ash begins to harden the material to a consistency that makes it difficult to compact.

To construct the Rostraver embankment, the LPC material was spread in 1- to 2-foot-thick vertical lifts and compacted to a minimum dry density of 97 percent of Standard Proctor Maximum Density (ASTM D698, Method A). The top 3 feet of the LPC material embankment will be compacted to at least 100 percent of the maximum Standard Proctor dry density.

The project included both construction and environmental monitoring activities. As described below, the construction monitoring activities reviewed all aspects of site preparation, fill placement and compaction, and soil cover

placement and vegetation. The environmental monitoring plan addressed sampling and testing of sedimentation pond influent and effluent, dustfall, and surface and groundwater.

Sedimentation Pond Influent and Effluent Monitoring

The sedimentation pond was constructed in the fall of 2000, and monitoring began January 2001. The sedimentation pond monitoring was performed twice a month and will continue until the Pennsylvania Department of Environmental Protection (PaDEP) grants approval for the pond's removal.

The influent monitoring points to the sedimentation pond consisted of sampling and testing the embankment toe drain discharge and the discharge from a spring drain that was encountered in the toe area of the embankment. The construction of the toe drain was started in November 2000, and one background sample was collected in December 2000. The toe drain was sampled six times during the first six months of the project, and as required by the project approvals, has been sampled quarterly thereafter. The spring drain was constructed during the early spring of 2001 and first sampled in May 2001 and, as required, has been sampled quarterly since that time.

The analysis of the data from these sampling points indicates that the project limit criteria have been satisfied and that the project

has not impacted the groundwater quality in the area.

Dustfall Monitoring

Dustfall monitors were installed at the site to determine the impact of the project on air quality. Dustfall buckets 1 through 8 were installed two months prior to the beginning of construction of the LPC material embankment to generate background particulate data. Dustfall bucket 9 was installed after the completion of the sedimentation pond, and dustfall bucket 10 was installed in August 2001 to monitor dustfall at the entrance to the site.

The dustfall buckets were sampled monthly during construction activities in accordance with ASTM Method D139-98 standard method for collection and measurement of dustfall.

Water Quality Monitoring

Prior to construction of the runway safety area extension embankment and emergency access road, a water quality monitoring program was implemented at eight private residence water supply points, five surface water locations, and one on-site spring. Each monitoring location was sampled a minimum of five times prior to LPC material placement in order to develop background data.

After fill placement began in January 2001, all monitoring locations have been sampled on a quarterly basis. Since construction ceased in September 2003, a post construction monitoring plan was developed, which eliminated

sampling points considered highly unlikely to be impacted by the migration of groundwater, and which reduced the amount of sampling to twice per year. This post construction monitoring will continue for a period of at least five years. The six monitoring points, as well as the private water supply locations, are sampled and analyzed for 21 parameters.

Analysis of the background and quarterly test results has concluded that, to date, there are no impacts of the water quality in the vicinity of the project due to the use of coal combustion byproducts at the project site.

Construction Monitoring

Construction monitoring was performed by GAI using both visual methods and material sampling and testing in the field and laboratory. The monitoring included subgrade inspection, quality assurance, and quality control testing of the soil cover, bottom ash underdrain material, and LPC material. Material placement performance was monitored by nuclear density testing (ASTM 3017) and moisture testing in the laboratory (ASTM D2216).

Field compaction monitoring was used as a method to assure that the LPC material is properly compacted to at least 97 percent of maximum laboratory Standard Proctor Dry Density (ASTM D698). On occasion, when unsatisfactory field test results were obtained, the LPC Material was dried in-place and recompact until the placement criteria was satisfied. This procedure ensured that the structural fill embankment will achieve strengths comparable to those developed by the laboratory test specimens, and thus satisfy slope stability criteria.

Summary

The Rostraver Airport Safety Extension Project is an excellent example of the beneficial use of coal combustion byproducts. The implementation of Reliant Energy's general permit facilitated the PaDEP approval of the project. Because of the critical nature of the project, extensive efforts were expanded to include identification of wetlands and streams, and preparation of detailed environmental monitoring, operations, and E&S plans.

The detailed design of the site involved stability analyses and the preparation of technical specifications and construction drawings. To date, environmental monitoring has indicated that the use of the LPC material and bottom ash in the construction of the runway safety area extension embankment has had essentially no effect on the surrounding environment.

This project is one of the largest projects of its type using coal combustion byproducts and will serve as an excellent example of cooperation among all the parties involved to provide an environmentally friendly solution to coal combustion management.

For more information about this project or to download the final project report (00CBRC41), please visit the CBRC Web site at <http://www.wri.nrcce.wvu.edu/cbrc/>. Or contact the CBRC at cbrc@nrcce.wvu.edu.



National Steering Committee Meets in April

The CBRC National Steering Committee will be meeting in April to finalize the next request for preproposals and determine a date for its release. It is anticipated that the RFP will be released this spring. For more information on the upcoming RFP and program news, log onto the CBRC web site at: <http://www.wri.nrcce.wvu.edu/cbrc>.

CBRC Exhibit at the WOCA Conference

The CBRC will have a booth at the World of Coal Ash Conference in Lexington, Kentucky, April 11-15, 2005. Stop by for more information on the program, how to sign up for the free newsletter, *Ashlines*, and /or to receive an announcement about the upcoming request for proposals.

Development of Fly Ash-Derived Sorbents To Capture CO₂ from Power Plant Flue Gas

By M. Mercedes Maroto-Valer, P.I., John M. Andrésen, Co-P.I., Yinzhi Zhang, and Zhe Lu



The costs of separation and capture of CO₂ are estimated to be about three-fourths of the total cost of ocean or geological sequestration, where the processes involved are very energy intensive and the amine solutions used in the proc-

ess have very limited lifetimes.

Recently, new solid-based sorbents are being investigated, where the amine groups are bonded to a solid surface, resulting in an easier regeneration step. However, the supports used thus

far, including commercial molecular sieves and activated carbons, are very expensive and hinder the economical viability of the process. Therefore, there is a need to find cost-effective precursors that can compete with the expensive commercial sorbents. For these new precursors to compete effectively with commercial sorbents, they must be inexpensive and easily converted into high-surface materials.

The unburned carbon in the fly ash meets satisfactorily all these conditions. First, it can be easily obtained from the utility industries as a byproduct. Second, the conventional production of activated carbons consists of a two-step process that includes a devolatilization of the raw materials, followed by an activation step.

In contrast, only a one-step activation process is required for unburned carbon since it has already gone through a devolatilization process while in the combustor, as shown previously by the proposers. Accordingly, this research program focuses on the development of fly ash derived sorbents to capture CO₂ from flue gas of power plants.

In this research project, fly ash carbon samples collected from

different combustion systems were activated using the protocols previously developed by the authors, and the resultant activated fly ash samples were amine impregnated. The activated and treated fly ash samples were tested for CO₂ capture and release, and their capacities were compared to those of commercial activated carbons.

For this work, a total of ten fly ash samples were collected from different combustors with different feedstocks, including bituminous coal, PRB coal and biomass. These samples presented a wide range of LOI value, from 0.66 to 84.0 percent, and different burn-off profiles.

The samples also spanned a wide range of total specific surface area and pore volume. These variations reflect the difference in the feedstock, types of combustors, collection hopper, and the beneficiation technologies the different fly ashes underwent.

The fly ash samples were activated by steam using a process previously developed by the authors. Nitrogen adsorption isotherms were used to characterize the resultant activated samples. The cost-saving, one-step, activation process applied was successfully used to increase the surface area and pore volume of all the fly ash samples.

The activated samples present very different surface areas and pore volumes due to the range in physical and chemical properties of their precursors. Furthermore, one

activated fly ash sample, was loaded with amine-containing chemicals (monoethanolamine-MEA, diethanolamine-DEA, methyldiethanolamine-MDA and polyethylenimine-PEI), which were used to modify the sorbents produced from fly ash.

The impregnation significantly decreased the surface area and pore volume of the parent activated fly ash samples.

The CO₂ capacities of the fly ash derived sorbents before and after impregnation were determined at different temperatures. Chemical impregnation can improve the CO₂ adsorption of fly ash samples and their activated counterparts where the MEA impregnated activated sample presents the highest CO₂ adsorption capacities of 68.6 mgCO₂/g at 30°C and 49.8 mgCO₂/g at 70°C, respectively.

Moreover, after loading PEI, the CO₂ adsorption capacity can be high as 93.6 mg/g at 75°C. In addition, the impregnation of chemicals can reduce the surface area and the total pore volume of the activated carbons due to the blocking of both micro- and mesopores. Therefore, chemically attached amino groups in fly ash derived sorbents may have a great potential when used in flue gases and the selection of the chemical is a critical step.

Finally, in this work, a comparison of the CO₂ capture by fly

ash derived sorbents with commercial sorbents was also conducted. The CO₂ adsorption capacity of some of the samples prepared in this project was close to 7 percent by weight, which is comparable to, and even better than, the published values of 3 to 4 percent.

For more information about this project or to download the final project report (01CBRCE9), please visit the CBRC Web site at <http://www.wri.nrcce.wvu.edu/cbrc>. Or contact Dr. M. Maroto-Valer, P.I., at mercedes.maroto-valer@nottingham.ac.uk.



Calendar of Events

April 11–15

World of Coal Ash

Lexington Center's Heritage Hall
Lexington, Kentucky

Contact: Gretchen Tremoulet
(859) 257-0355, gtremoulet@caer.uky.edu, or Michael MacDonald
(720) 870-7897, info@acaa-usa.org

April 17–21

The 30th International Technical Conference on Coal Utilization and Fuel Systems

Clearwater, Florida

Sponsored by the U.S. Dept. of
Energy, the Coal Technology
Association, the American Society
of Mechanical Engineers, in coop-
eration with the National Energy
Technology Laboratory.

Contact: Barbara Sakkestad,
BarbaraSak@aol.com,
www.coaltechnologies.com

May 18–20

Spring Coal Conference

Scottsdale Plaza Resort,
Scottsdale, AZ

Sponsored by the American Coal
Council (ACC)

Contact: Janet Gellici, Executive
Director, ACC, Pheonix, AZ
(602) 485-4737, Fax (602) 485-4847
info@americancoalcouncil.org,
www.americancoalcouncil.org

August 17–19

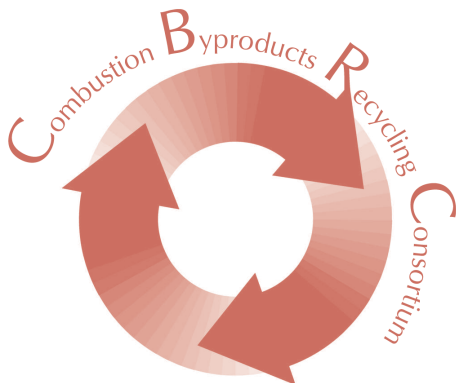
Coal-Gen 2005, Revival of the Fittest

San Antonio, Texas

Presented by PennWell

Contact: Registration Department
1421 S. Sheridan Road
Tulsa, OK 74112-6600 USA
Fax (888) 299-8057
coal-gen@pennwell.com,
www.coal-gen.com

Ashlines is published by the Combustion Byproducts Recycling Consortium, headquartered at West Virginia University in Morgantown, WV. Would you like to be on the CBRC electronic mailing list? If so, please send an e-mail to cbrc@nrcce.wvu.edu.



CBRC CONTACTS

Program Manager

William Aljoe, U.S. Department of Energy -
National Energy Technology Laboratory
412/386-6569; aljoe@netl.doe.gov

National Center

Paul Ziemkiewicz, Ph.D., *Director*
Tamara Vandivort, *Consortium Manager*
CBRC National Center located at the
National Mine Land Reclamation Center at
West Virginia University, 304/293-2867,
pziemkie@wvu.edu or tvandivo@wvu.edu

National Steering Committee Chair

Howard Humphrey, American Coal Ash
Association, Columbus, Ohio, 614/846-1726,
hhumphrey@columbus.rr.com

Eastern Regional Chair

Cheri Miller, Tennessee Valley Authority, Chatta-
nooga, Tenn., 423/751-4419, ecmiller@tva.gov

Midwestern Regional Chair

Tom Robl, Ph.D., University of Kentucky,
859/257-0272, robl@noah.caer.uky.edu

Western Regional Chair

Jacob Gonzales, TXU Energy, Dallas, Texas,
214/812-8328, jake.gonzales@txu.com

Eastern Regional Technical Director

James C. Hower, Ph.D., University of Ken-
tucky, 859/257-0261, hower@caer.uky.edu

Midwestern Regional Technical Director

Y. Paul Chugh, Southern Illinois University at
Carbondale, 618/536 6637, chugh@engr.siu.edu

Western Regional Technical Director

Deborah Pflughoeft-Hassett, University of North
Dakota, 701/777-5181, dphassett@undeerc.org

NSC Committee Members

Jackie Bird, Ohio Coal Development Office, 614/466-
3465, jbird@odod.state.oh.us

Taylor Eighmy, University of New Hampshire, 603/
862-1065, taylor.eighmy@unh.edu

Paul Ehret, State of Indiana, 317/232-4020,
pehret@dnr.state.in.us

Dave Goss, American Coal Ash Association, 720/
870-7897, DCgoss@acaa-usa.org

Dave Meadows, USACE-Huntington District, 304/
529-5243, david.f.meadows@usace.army.mil

Jim Rower, Utility Solid Waste Activities Group,
202-508-5645, jim.rower@uswag.org

Kimery Vories, Office of Surface Mining, 618/463-
6463 ext.103, kvories@mcrgw.osmre.gov

Andy Wittner, USEPA, 703-308-0496
Wittner.Andrew@epamail.epa.gov

Dan Wheeler, Illinois Office of Coal Development and
Marketing, 217-558-2645, dwheeler@commerce.state.il.us



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COMBUSTION BYPRODUCTS RECYCLING CONSORTIUM

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Mine Land Reclamation
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cooperation with the U.S.
Department of Energy -
National Energy
Technology Laboratory
www.netl.doe.gov

To promote and support the commercially viable and environmentally sound recycling of coal combustion byproducts for productive uses through scientific research, development, and field testing.

High-Carbon CCBs and FGD Byproducts in Permeable Roadway Base Construction

By Tarun R. Naik and Rudolph N. Kraus

The presence of excess water in pavement structure is known to be the primary cause of pavement distress. Extended exposure to water can lead to pumping, D-cracking, faulting, frost action, shrinkage, cracking, and potholes (Cedergren, 1994).

Out of these parameters, pumping is known to be the most dominating mechanism of pavement distress. The water that infiltrates through the pavement is trapped within the pavement structure when draining capabilities of the pavement base is low. When high-pressure is applied to these pavements from heavy traffic loads, pumping occurs in the presence of water. This causes erosion of the base because fines get pumped out along with the water.

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High-Carbon CCBs and FGD Byproducts in Permeable Roadway Base Construction (continued from page 1)

Consequently, a loss in pavement support occurs, leading to early failure of pavement. This can be avoided by using free-draining pavement base (Baumgardner, 1992; PCA, 1991; Kozeliski, 1992; Grogan, 1992; Hall, 1994; and Naik and Ramme, 1997).

With a view to meet current and future U.S. Environmental Protection Agency (EPA) air quality standards, utilities are utilizing supplemental flue gas treatments to reduce emissions. These treatments either alter the quality of the coal combustion byproducts (CCBs), or generate another type of "waste" material.

Two processes typically used are flue gas desulfurization (FGD) to reduce SO_x emissions and low-NO_x burners to reduce NO_x emissions. FGD products are high-sulfite and/or sulfate products, and low-NO_x burners generate high-carbon CCBs.

Approximately 23 million metric tons of FGD products were generated in 1998 in the U.S. with a utilization rate of ten percent. (This has gone up to 19 percent in 2000.) Consequently, most of FGD products are landfilled at high disposal costs and potential future environmental liabilities to the producer. To avoid these costs, there is a need to develop beneficial uses of these products.

This project was undertaken to develop high-volume applications of such CCBs in manufacture of permeable base materials for highways, roadways, and airfield pavements. Use of FGD products and high-carbon or variable carbon CCBs in

permeable base course is expected to utilize significant quantities of these products. It will also help to reduce the cost of installing permeable base materials for pavement, which will lead to increased use of such permeable bases for highways, roadways, and airfield pavements. Reducing the cost of permeable base materials is expected to expand its use in many other types of construction (e.g., parking lots, industrial facility floors, material handling yards, etc.) with increased pavement life and increased utilization rate of CCBs, especially underutilized and/or nonspecified CCBs.

Literature Review

Past investigations have established that drainage under rigid (i.e., concrete) or flexible (i.e., asphalt) pavements is required in producing durable pavements. To help solve this problem, porous base pavements are used (Naik and Ramme, 1997). A properly designed and constructed porous base eliminates pumping, faulting, and cracking. Therefore, the base is designed to have the necessary permeability and stability. It is estimated that the use of a porous base would add to pavement service life by up to 70 percent for Portland cement concrete and asphaltic pavements (Naik and Ramme, 1997).

As a paving material, porous concrete is raked or slip-formed into place with a conventional spreader or paving equipment and then roller-compacted, similar to asphaltic concrete. Vibratory

screeds or hand rollers can be used for smaller project work. In order to maintain porous properties. The surfaces should not be closed or sealed; therefore, troweling and finishing are neither done nor desired.

The compressive strength of different mixtures typically range from 500 to 4,000 psi, or can be even higher. Drainage rates commonly range from 2 to 18 gallons per minute per square foot (Kosmatka and Panarese, 1988).

Porous bases are divided into two classes: treated and untreated. A treated porous base employs a binder that typically consists of either cement or asphalt. An untreated subbase contains more smaller size particles in order to provide stability through aggregate interlock. A porous base must be capable of maintaining both permeability and stability. In order to have improved stability, an untreated subbase should contain 100 percent crushed aggregate (Baumgardner, 1992).

The coefficient of permeability for treated base depends upon several factors, such as aggregate gradation and fines content. Due to the coarse gradation and small amount of binder used in the manufacture of treated base, they are quite porous by design. The coefficient of permeability for the untreated porous base is normally lower than that for the treated porous base materials due to greater amount of fines required for the untreated porous base.

A porous base system is composed of three major elements: permeable base, separator or filter layer, and edge drain system. A

typical cement-treated porous base is composed of 86 percent aggregate, 10 percent cement, and 4 percent water (Kozeliski, 1992). Information on design, construction, and material requirements are available in the literature (Baumgardner, 1992; Kozeliski, 1992; Grogan, 1992; Zhou et al., 1993; Mathis, 1989; and Forsyth et al., 1989).

Although the thickness of porous bases generally varies between 4 to 12 inches, an 8-inch thickness of the porous base is the most commonly used (Croveti and Dempsey, 1993; Strohm et al., 1967; and Moynahan and Steinberg, 1974).

The importance of adequate pavement drainage has been identified since the early days of road construction (Croveti and Dempsey, 1993). To help solve drainage problems, open-graded porous materials have been used in Portland cement pavements for many years. To handle heavy traffic loads, the trend of using dense-graded materials dominated during the 1960s and 1970s, which resulted in decreased use of porous materials (Croveti and Dempsey, 1993).

However, a renewed interest in the use of porous materials for pavement construction has occurred during the past two decades. In a survey conducted by the National Asphalt Institute, 30 states indicated use or planned use of asphalt-treated porous base materials under pavement (Zhou et al., 1993). A number of investigations (Strohm et al., 1967; and Moynahan and Steinberg, 1974) have supported the use of open-graded porous bases for efficient drainage. Croveti and Dempsey (1993) showed that various parameters such as cross slope, longitudinal grade, and drainage layer width and thickness can influence the permeability and performance of open-graded porous materials (OGPM).

In 1988, the Federal Highway Administration (Munn, 1990) surveyed ten different states that had installed porous base pavements. Of these, the most experienced states were California, Michigan, New Jersey, and Pennsylvania. The remaining six were Iowa, Kentucky, Minnesota, North Carolina, West Virginia, and Wisconsin. These states developed their design data largely based upon the information of the four most experienced states.

Out of the 10 states surveyed, seven states used untreated porous base, and the remaining three (California, North Carolina, and West Virginia) used treated porous base. Five of the seven states using untreated porous base had dense-graded materials with reduced amounts of fines. The other two states, Wisconsin and Kentucky, employed larger AASHTO No. 57 or an equivalent size, which resulted in higher permeability of the base.

Grogan (1992) reported that subsurface pavement layers are virtually impermeable in the case of dense-graded materials. When these layers become saturated, they remain saturated for the majority of the pavement life. These saturated layers cause pumping, erosion, subgrade weakening, and freezing/thawing damage. Use of properly designed and constructed porous bases reduces or practically eliminates these problems, thus improving pavement performance.

The improved performance will translate into dollar savings through increased life and reduced maintenance requirements for the pavement. Based on investigations (Forsyth et al., 1989; and Munn, 1990) in California, a minimum life increase was estimated to be 33 percent for asphaltic concrete pavement and 50 percent for

Portland cement concrete pavements incorporating porous bases compared to undrained pavements. Hall (1990) reported that factors such as cement content, truck traffic, sublayer stability, segregation, and surface irregularities are important in affecting performance of the porous material.

Studies conducted by several state agencies were summarized by Munn (1990). Two eight-year-old pavements on porous bases in California did not exhibit any cracking, whereas corresponding undrained pavements showed 18 and 47 percent cracking.

Nondestructive testing of porous base pavements in Iowa revealed a greater support relative to undrained pavements. The increased support is equivalent to a thickness of three to five inches of additional pavement.

In Michigan, porous base test sections built in 1975 did not show any faulting or cracking and had less D-cracking compared to control sections of bituminous and dense-graded sections.

In Minnesota, a jointed reinforced concrete pavement on porous base built in 1983 experienced only one mid-panel crack in its 59 panels, while undrained sections adjacent to either end showed 50 percent mid-panel cracks.

Performance of Pennsylvania's porous base sections built in 1979 to 80 were rated much better than that of dense-graded aggregate sections. In Pennsylvania, a porous base between Portland cement concrete pavement and the dense-graded aggregate subbase was standardized in 1983.

Wisconsin (Hall, 1994) estimates that the use of a cement stabilized base would add 25

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High-Carbon CCBs and FGD Byproducts in Permeable Roadway Base Construction (continued from page 3)

percent more service to concrete pavements.

Recent nondestructive testing in Iowa (Brown, 1996) have shown excellent performance of porous base pavements. New Jersey (Mathis, 1989) found similar rutting for porous base pavements constructed in 1979 to 1980 for either thicker or thinner sections. Also, there was less deflection, no faulting or pumping, and reduced frost penetration on concrete pavements.

In 1990, porous base concrete pavement became standard in nine different states (Kozeliski, 1992). The use of porous bases is rapidly increasing in the U.S. Kozeliski (1992) reported the successful application of open-graded cement treated base material in the construction of a parking lot for an office building, a driveway of a home, and ground cover of a refinery. Kuennen (1993) described construction of a high-quality, high-durability, drainable concrete pavement incorporating 18 percent fly ash of total cementitious materials.

Porous concrete also can be used in other types of concrete construction. Porous concrete can be used in load-bearing walls in buildings and in filling panels in framed structures. No-fines concrete is not normally used in reinforced concrete, but, if this is required, the reinforcement has to be coated with a thin layer (about 1/8 in.) of cement paste in order to improve the bond characteristics and to prevent corrosion. The easiest way to coat the reinforcement is by shotcreting (Neville, 1995).

Porous concrete can be used

in building wall construction to take advantage of its thermal insulating properties. For example, a 10-inch-thick porous concrete wall can have an R value of 5, compared to 0.75 for normal concrete. Porous concrete is also lightweight (95 to 110 pcf) and has low shrinkage properties (Malhotra, 1976; and Concrete Construction, 1983).

Meininger (1988) reported that due to the large size of the pores, porous concrete is not subject to capillary suction. Therefore, porous concrete is highly resistant to freezing and thawing, provided that the pores are not saturated. If saturated, freezing would cause a rapid deterioration. High absorption of water, however, makes porous concrete unsuitable for use in foundations and in situations where it may become saturated with water and then exposed to freezing temperatures. The water absorption can be as high as 25 percent by volume.

Coating and painting exterior walls reduce the sound-absorbing properties of porous concrete.

Project Outline

To meet the objectives of the project, the entire work was organized in two major phases, each one year in duration. These two phases were subdivided into the following tasks:

Phase 1-Year 1: Laboratory Activities

- **Task 1:** acquisition, characterization, and evaluation of materials;

- **Task 2:** development of base course mixture proportions;
- **Task 3:** testing and evaluations;
- **Task 4:** CCBs and FGD utilization criteria and base course specifications;
- **Task 5:** base course design criteria and construction guidelines; and
- **Task 6:** reports.

Phase 2: Field Demonstration and Technology Transfer

- **Task 7:** field demonstrations, testing, and evaluation;
- **Task 8:** demonstration technology transfer;
- **Task 9:** optimization of construction specifications; and
- **Task 10:** reports.

Characterization of Materials

Testing of all base course mixture constituent materials, such as fine aggregate, coarse aggregate, cement, and CCBs, was completed. These materials were tested and evaluated for physical and chemical properties using ASTM or other applicable test methods as described below.

(Please refer to the final project report—#99ECM06—available on the CBRC Web site at <http://www.wri.nrcce.wvu.edu/programs/cbrc/> for complete data and test results for this project.)

Fine Aggregate

One source of concrete sand for laboratory mixing was acquired from a local concrete producer. Physical properties of the sand were determined per ASTM C 33 requirements for the following: unit weight (ASTM C 29), specific gravity and absorption (ASTM C 128), fineness (ASTM C 136), material finer than #200 sieve (ASTM C 117), and organic impurities (ASTM C 40).

Test results for the fine aggregate are shown in the final report. All aggregate met the ASTM C 33 requirements for fine aggregate.

Coarse Aggregate

One source of coarse aggregate for laboratory mixing was acquired from a local concrete producer. Physical properties of the aggregate were determined per ASTM C 33 requirements for the following: unit weight (ASTM C 29), and specific gravity and absorption (ASTM C 128). Test data for the coarse aggregate are shown in the final report. The coarse aggregate met all the ASTM C 33 requirements.

Gradation of the coarse aggregate for prototype manufacturing and full-scale manufacturing is shown in the final report. The aggregate for field mixtures met the grading requirements of ASTM C 33, except for percent passing a 3/8-inch sieve.

Cement

Type I cement for laboratory mixtures was acquired from one source. Its physical and chemical properties were determined per ASTM C 150 requirements. It was tested for physical properties, such as compressive strength (ASTM C 109), autoclave expansion (ASTM C 151), fineness (using both ASTM C 204 and ASTM C 430), time of setting

(ASTM C 191), air content (ASTM C 185), and specific gravity (ASTM C 188).

The physical properties of the cement are given in the final report. The chemical properties determined were oxides, loss on ignition (LOI), moisture, available alkali, and mineral species of the cement. The test data are shown in the final report. Both physical and chemical properties of the cement met the ASTM C 150 requirements.

Coal Combustion Products (CCBs)

Three sources of CCBs were obtained for the project. These include two high-carbon, sulfate-bearing CCBs, designated as CCP-1 and CCP-2, and a variable carbon fly ash designated as CCP-3. Each CCB source was tested for physical and chemical properties in accordance with ASTM C 311.

The following physical properties were determined: fineness (ASTM C 325), strength activity index with cement (ASTM C 109), water requirement (ASTM C 109), autoclave expansion (ASTM C 151), and specific gravity (ASTM C 188). The physical properties of CCBs are given in the final report.

The chemical properties determinations included measurement of basic chemical elements, oxides, moisture content, available alkali, and mineral species of CCBs. The basic chemical elements of CCB samples were determined using instrumental neutron activation analysis. The neutron activation analysis method exposes the sample to neutrons, which results in the activation of many elements. This activation consists of radiation of various elements. For the ash sample, gamma ray emissions were detected.

Many different elements may be detected simultaneously based on

the gamma ray energies and half-lives. The elemental analysis results are shown in the final report.

The presence of oxides was determined for the CCB materials using the X-Ray Fluorescence (XRF) technique. SO₃ was determined by using analysis of sulfur via double dilution XRF. The chemical analysis results are given in the final report.

The CCB samples were also analyzed to determine the type and amount of minerals present. The mineral species found in the CCB samples are shown in the final report.

Casting, Curing, and Testing of Specimens

All concrete mixtures were mixed in a rotating-drum concrete mixer in accordance with ASTM C 192. Coarse aggregate was added first to the mixer, and it was allowed to rotate for about one minute. Then fine aggregate and cement were added to the mixer. These ingredients were mixed dry for two minutes. Thereafter, water was added, and all the ingredients in the mixer were mixed for three minutes followed by a three-minute rest, followed by an additional two-minute mixing. The resulting mixture was used in making concrete test specimens.

Fresh concrete was tested for air content (ASTM C 138), unit weight (ASTM 138), and temperature (ASTM C 1064). Ambient air temperature was also measured and recorded.

For Series 1 mixtures, cylindrical specimens (6 x 12 in.) were made in accordance with ASTM C 192 using the rodding method of consolidation. For Series 2 through 9 mixtures, RCC specimens were prepared in accordance with ASTM C 1435.

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High-Carbon CCBs and FGD Byproducts in Permeable Roadway Base Construction (continued from page 5)

For Series 2 mixtures, freshly mixed concrete was molded in cylindrical steel mold (6 x 12 in.) with the help of a vibrating hammer having a mass of 10 kg (22 lb). The hammer was equipped with a circular plate (tamping plate) attached to a shaft that was inserted into the chuck of the hammer. Concrete in the mold was compacted in three lifts (layers) with the vibratory hammer. For each lift, enough concrete was placed in the mold to fill one-third of its volume after compaction. Each layer was compacted by placing the tamping plate on to the concrete while the hammer was operated for approximately 20 seconds.

For Series 3 through 9 mixtures, freshly mixed concrete was molded in cylindrical steel molds (4 x 8 in.) for compressive strength (ASTM C 39) and splitting tensile strength (ASTM 496) measurements; and in beam molds (3 x 4 x 16 in.) for measurements of flexural strength (ASTM C 78), shrinkage (ASTM C 157), sulfate resistance (ASTM C 1012), and freezing-and-thawing resistance (ASTM C 666) with the help of the vibrating hammer. For each 4 x 8-in. cylinder, concrete in the mold was compacted in two lifts (layers) with the vibratory hammer. For each lift, enough concrete was placed in the mold to fill one-half of its volume after compaction. Each layer was compacted by placing a circular tamping plate on to the concrete while the hammer was operated for approximately 20 seconds.

For each 3 x 4 x 16 in.-beam specimen, concrete in the mold was compacted in one lift with the

vibratory hammer. For each specimen, enough concrete was placed in the mold to fill its entire volume after compaction. The concrete layer in the mold was compacted by placing a rectangular tamping plate on to the concrete while the hammer was operated for about 10 seconds.

All test specimens were cured in their molds for one day and then demolded from the molds. These specimens were then subjected most curing in accordance with ASTM C 192 until the time of test.

Mixture Proportions, Results, and Discussions

Overview

Based on the literature search and the characterization of constituent materials, various mixtures were proportioned. Nine series of concrete mixtures were proportioned, manufactured in the laboratory, and evaluated.

The mixture proportions were developed via the use of a two-step experimental optimization process. The first step involved developing optimum mixture proportions for base course materials without the use of CCBs. The second step of this experimental program involved the use of the three sources of CCBs using candidate mixture proportions developed in the first step of the optimization process.

Mixtures for the second step in the optimization process were completed for each of the three sources of CCBs. Fresh and hardened concrete properties of

the base course materials, such as density, air content, and temperature, were measured.

(Please refer to the final project report, #99ECM06, at <http://www.wri.nrcce.wvu.edu/programs/cbrc/> for a complete discussion of the mixtures tested and detailed results.)

Prototype Manufacturing

To achieve maximum drainage capability for a base course, mixture proportions for prototype concrete were based on the mixture proportions that had been used in Series 7 for producing open-graded structure. Although, all three sources of ashes were considered suitable for producing permeable base course, CCP-3 ash was selected for the prototype manufacturing and subsequent full-scale field demonstration. CCP-3 ash was selected to promote the use of the locally available ash since the source of CCP-3 ash was located near the field manufacturing site.

Also, in mixture Series 7 to 9 investigations, base course materials containing CCP-3 ash showed higher strength than those containing CCP-1 or CCP-2 ash. This implies that with the use of CCP-3 ash, lower amount of cement can be used for achieving a given level of base course strength compared with the use of CCP-1 or CCP-2 ash.

Cement replacement rates, with CCP-3 ash, of 0, 16, 37, and 45 percent were used in four prototype mixtures. To achieve open-graded base course, fine aggregate was not used.

Compressive strength of the base course mixtures ranged from 985 to 1,545 psi at 28 days. As the cement replacement rate increased, compressive strength decreased. However, the strength of the mixtures with highest rate of cement replacement (45 percent) was still considered satisfactory.

Flexural strength ranged from 255 to 325 psi at 28 days. Flexural strength was relatively insensitive to cement replacement rate.

Full-Scale Manufacturing and Technology Transfer Activities

After prototype manufacturing, a technology transfer educational workshop and construction demonstration was held using a base course mixture. The technology transfer workshop was conducted in Green Bay, Wisconsin, on September 19, 2002. The technology transfer workshop consisted of a half-day of lectures on the use of permeable base course materials using CCBs, followed by the construction demonstration. The lectures consisted of presentations by Tarun R. Naik, P.I., on the engineering properties and mixture proportions of the permeable base course materials from the results of this project; Bruce W. Ramme, principal engineer, WE Energies, on field applications for permeable base course materials containing high- or variable-carbon ash; and James A. Crovetto, associate professor, Marquette University, on design and construction considerations for pavements using open-graded base course materials.

The workshop was attended by 33 people—a diverse group interested in implementing permeable base course technology. Attendees included representatives of the Wisconsin Department of Transpor-

tation, Wisconsin Department of Administration, utilities, fly ash marketing companies, City of Milwaukee, City of Mequon, Outagamie County, City of Algoma, concrete products manufacturers, and others.

A copy of the workshop program announcement is included in the final report as Appendix 1.

The construction demonstration consisted of placement of porous base course, approximately 24 ft. x 230 ft in area and 8 in. in thickness. For adequate drainage, drain tiles were provided under the porous base course. A filter fabric was used under the porous concrete.

Coarse aggregates layer was not used underneath the porous concrete. Saw cuts were provided for the porous concrete at 20-ft. intervals along the length. The 24-ft. width did not have saw cuts. The entire area had 4-in. asphalt surfacing.

To minimize the cement content and maximize economy while providing adequate strength, a full-scale permeable base course mixture was proportioned based on the proportions for the MF4 prototype mixture. Cement replacement rate with CCP-3 ash was 49 percent by mass. A section of a typical base course, constructed for comparison, had 14-inch-thick layer of coarse aggregates as a base course underneath 4-in. asphalt pavement.

Compressive and flexural strengths of the porous base course were 575 and 110 psi, respectively, at 28 days. These strengths were considered satisfactory for the performance of the base course.

Summary and Conclusions

The experimental investigations completed in the laboratory were composed of two parts. The first

part described experimental investigation pertaining to the characterization of constituent materials. The second part dealt with development of mixture proportions, and manufacturing and testing of mixtures for base course materials.

Various constituent materials, such as fine aggregate, coarse aggregate, cement, and CCBs, were tested and evaluated using applicable ASTM standards or other applicable standards. Both coarse and fine aggregates met the ASTM C 33 requirements. The cement conformed to the ASTM C 150 requirements. Three sources of CCBs (designated as CCP-1, CCP-2, and CCP-3) were selected for this investigation. CCP-1 and CCP-2 did not meet the ASTM C 618 requirements for coal fly ash for use as mineral admixtures in concrete because these are FGD materials containing high sulfite/sulfates. CCP-3 conformed to the ASTM C 618 requirements for Class C fly ash. Both CCP-1 and CCP-2 contained high amounts of sulfate and unburnt carbon as measured by LOI.

Mixture proportions for the base course materials were developed using a two-step experimental optimization process. The first step involved developing mixture proportions for permeable base course materials without CCBs. The optimum mixtures developed from the first step of the experimental process were used for developing mixture proportions for the second step of the optimization process. The second step of the mixtures included various combinations of CCBs for developing mixtures for base course materials.

A total of 56 concrete mixtures were proportioned, manufactured,

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High-Carbon CCBs and FGD Byproducts in Permeable Roadway Base Construction (continued from page 7)

and tested in nine different series of laboratory experiments over the course of this two-year project. Of these, 26 mixtures were proportioned for the first step of optimization. All concrete mixtures were tested and evaluated for fresh and hardened concrete properties using applicable ASTM standards. The fresh concrete properties measured were air content, unit weight, and temperature. Ambient air temperature was also recorded.

For the first step of optimization, hardened concrete properties measured were density and compressive strength. For this step of investigation, the effects of amount of cement and water to cementitious materials ratio on the performance of permeable base course mixtures were also investigated. Based on the compressive strength results, three candidate mixtures were selected, which formed the basis for mixture proportioning for the second step of optimization.

For the second step of the optimization process, a total of 30 mixtures were proportioned using CCP-1, CCP-2, and CCP-3. Three series of mixtures were developed: one open-graded base course structure (Series 7), one intermediate-graded (Series 9), and one dense-graded (Series 8) base course structure. Each series of mixtures incorporated all three sources of CCBs material used for this project. Each of the three series of mixtures was evaluated for long-term (up to one year from the date of manufacturing).

Each mixture was tested for strength and durability-related

properties. The strength properties include compressive strength, tensile strength, and flexural strength. The durability-related properties included drying shrinkage, resistance to sulfate exposure, and resistance to rapid freezing and thawing.

Based on the mixture proportions established in the laboratory, four prototype open-graded base course mixtures containing CCP-3 ash as a partial replacement of cement were manufactured at a commercial ready-mixed concrete plant. A full-scale base course mixture, manufactured with 49 percent replacement of cement with CCP-3 ash, was produced for a construction demonstration. The base course mixture was proportioned to maximize drainage capability and economy. The base course used for the full-scale manufacturing exhibited adequate strength.

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For more information about this project, including the final project report (99ECM06), please visit the CBRC Web site at <http://www.wri.nrcce.wvu.edu/cbrc/>. Or, contact Tarun Naik, P.I., at tarun@uwm.edu.



Calendar of Events

April 11-15

World of Coal Ash

Lexington Center's Heritage Hall
Lexington, Kentucky

Contact: Gretchen Tremoulet
(859) 257-0355, gtremoulet@caer.uky.edu, or Michael MacDonald
(720) 870-7897, info@acaa-usa.org

April 17-21

The 30th International Technical Conference on Coal Utilization and Fuel Systems

Clearwater, Florida

Sponsored by the U.S. Dept. of
Energy, the Coal Technology
Association, the American Society
of Mechanical Engineers, in coop-
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Contact: Barbara Sakkestad,
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May 18-20

Spring Coal Conference

Scottsdale Plaza Resort,
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August 17-19

Coal-Gen 2005, Revival of the Fittest

San Antonio, Texas

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CBRC CONTACTS

Program Manager

William Aljoe, U.S. Department of Energy -
National Energy Technology Laboratory
412/386-6569; aljoe@netl.doe.gov

National Center

Paul Ziemkiewicz, Ph.D., *Director*
Tamara Vandivort, *Consortium Manager*
CBRC National Center located at the
National Mine Land Reclamation Center at
West Virginia University, 304/293-2867,
pziemkie@wvu.edu or tvandivo@wvu.edu

National Steering Committee Chair

Howard Humphrey, American Coal Ash
Association, Columbus, Ohio, 614/846-1726,
hhumphrey@columbus.rr.com

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nooga, Tenn., 423/751-4419, ecmiller@tva.gov

Midwestern Regional Chair

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859/257-0272, robl@noah.caer.uky.edu

Western Regional Chair

Jacob Gonzales, TXU Energy, Dallas, Texas,
214/812-8328, jake.gonzales@txu.com

Eastern Regional Technical Director

James C. Hower, Ph.D., University of Ken-
tucky, 859/257-0261, hower@caer.uky.edu

Midwestern Regional Technical Director

Y. Paul Chugh, Southern Illinois University at
Carbondale, 618/536 6637, chugh@engr.siu.edu

Western Regional Technical Director

Deborah Pflughoeft-Hassett, University of North
Dakota, 701/777-5181, dphassett@undeerc.org

NSC Committee Members

Jackie Bird, Ohio Coal Development Office, 614/466-
3465, jbird@odod.state.oh.us

Taylor Eighmy, University of New Hampshire, 603/
862-1065, taylor.eighmy@unh.edu

Paul Ehret, State of Indiana, 317/232-4020,
pehret@dnr.state.in.us

Dave Goss, American Coal Ash Association, 720/
870-7897, DCgoss@acaa-usa.org

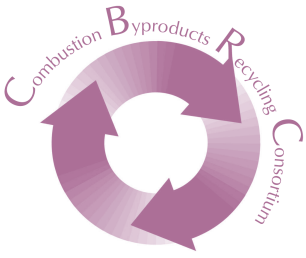
Dave Meadows, USACE-Huntington District, 304/
529-5243, david.f.meadows@usace.army.mil

Jim Rower, Utility Solid Waste Activities Group,
202-508-5645, jim.rower@uswag.org

Kimery Vories, Office of Surface Mining, 618/463-
6463 ext.103, kvories@mcrgw.osmre.gov

Andy Wittner, USEPA, 703-308-0496
Wittner.Andrew@epamail.epa.gov

Dan Wheeler, Illinois Office of Coal Development and
Marketing, 217-558-2645, dwheeler@commerce.state.il.us



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COMBUSTION BYPRODUCTS RECYCLING CONSORTIUM

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Effects of Large-Scale CCB Applications on Groundwater

Louis M. McDonald and Jennifer Simmons

Coal combustion byproducts (CCBs) in surface and deep coal mines have the potential to affect the environment slowly but permanently. For neutralizing acid mine drainage (AMD), CCBs have distinct advantages, including their availability, alkalinity, and pozzolonic activity. As such, CCBs have been used to fill mine voids and strip pits, encapsulate acidic materials in backfills, cap reclaimed surface mines, and neutralize acidic impoundments.

Nearly all CCB uses at mine sites have a single purpose, to eliminate or reduce acidic drainage from the site. All CCBs contain elements, some of them of environmental significance, which may leach into groundwater. The potential for leaching depends on the chemical composition of the

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Effects of Large-Scale CCB Applications on Groundwater

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CCB, the chemistry of the water in contact with the CCB, and because CCBs dissolve to neutralize acidity, the amount of contact time.

However, there have been few studies conducted to show the effects of CCBs on groundwater chemistry. It may take decades to exhaust the alkalinity of CCBs and to observe any adverse effects of CCBs on the environment. Therefore, it is essential that we have accurate, cost-effective methods to characterize metal leaching potential of CCBs, particularly when they are to be placed in AMD.

The Mine Water Leaching Procedure (MWLP)

There have been several methods proposed to determine the metal leaching potential of CCBs. These have used one or more complexing agents, and/or various concentrations of sulfuric, hydrochloric or nitric acids. While valuable, these approaches ignore any potential effects, positive or negative, of other components of AMD that may affect metals leaching from CCBs.

The mine water leaching procedure (MWLP) was developed specifically to account for the effects of AMD on metal leaching. It aims to quantify the time-dependent concentrations of metals leached from a specific ash when in contact with a specific AMD. The MWLP procedure continues until all alkalinity has been exhausted from the CCB.

The objectives of this research were to identify cases where CCBs

had been placed in mine environments and summarize their effects on subsequent water quality, and to use the MWLP to characterize metal release from specific CCB-AMD combinations.

AMD/CCB Exhaustion Study

The MWLP was used with the modification that less CCB was added (Simmons et al., 2001). Other CCB leaching characterization procedures have used 0.5M acetic acid (Flemming et al., 1996), water (Dreesen et al., 1977; Querol, et al., 2001), simulated AMD (Bhumbla et al., 1996; Morgan et al., 1997), citric acid, hydrochloric acid, ammonium hydroxide or various concentrations of nitric acid (Dreesen et al., 1977). The MWLP is the only procedure that matches CCB with the specific mine water it is expected to be in contact with in the environment.

A known amount of each CCB and 2 L of either AMD or distilled, deionized water (DDIW) was added to labeled, acid-washed containers. All CCBs were used as received. Containers were sealed and then agitated for 18 hours at 30 rpm on a rotating platform.

Samples were collected after every 18-hour agitation cycle. Container contents were filtered through 0.7 μ , acid-rinsed TCLP filter paper using a stainless steel pressure filtration unit at or below 40 psi. Solids were rinsed back into corresponding containers with additional AMD, and the agitation cycle repeated until alkalinity was exhausted from the CCB. CCB alkalinity exhaustion

was indicated when filtrate pH was equal (or nearly equal) to initial AMD pH.

Two filtrate samples were collected in 250-mL bottles. One was acidified for inorganic constituents (Sb, As, B, Ba, Be, Cd, Cr, Pb, Hg, Se, Ag, Cu, Ni, Tl, V, Zn, Mo, Fe, Mn, Al, Ca, Mg, and sulfate). An unacidified sample was analyzed for pH, alkalinity, and acidity. Inorganic constituents were determined in initial AMD and after selected agitation cycles using U.S. Environmental Protection Agency (EPA)-approved methods in EPA-certified commercial laboratories.

AMD treatments were replicated twice. A DDIW control was included for all treatments at least once. Solid CCB samples were digested at 95° C on a block digester in concentrated HNO₃ and the inorganic constituents determined as described above.

MWLPs 2 and 5 had the same AMD source and were used to test the effect of ash source on inorganic constituent concentrations by analysis of variance (ANOVA) using MWLP cycle and ash source as categorical variables. MWLPs 1 and 3 had the same ash source, as did MWLPs 4a and 4b and so were used to test the effect of AMD source on inorganic constituent concentrations by ANOVA using MWLP cycle and AMD source as categorical variables.

Because the number of MWLP cycles was variable, only the first and last cycles were included in this analysis. AMD source was a categorical variable and means in the two cycles were separated using Scheffe's Test.

Case Studies/Literature Review

Available case studies on field applications of CCBs were summarized for CCB use—noting whether there was a CCB analysis, pre- and post-CCB use water quality, monitoring time, elements of concern not measured, and whether the application was considered a success. Reports from conference proceedings and peer-reviewed literature were included.

Conclusions

Although most researchers considered their use of CCBs in mine environments a success, only one long-term study could be found, and in no study was water quality followed to CCB alkalinity exhaustion. Also, some elements known to be of concern during the initial phases of CCB dissolution (B, Mo, Se, As) and others identified in this study (Sb, Cr, Pb, Tl, Be, Cd) were not measured in some studies.

In laboratory tests (MWLP procedure) CCBs in contact with distilled, deionized water (DDIW) water was alkaline, at least pH 7.1, but more typically above pH 9 and sometimes as high as pH 11.7. Elements of concern in the DI water control samples include Sb, Cr, Pb, Tl, Be and Cd, all of which exceeded drinking water standards in at least one MWLP.

Other elements present in the DDIW water treatment at relatively high concentrations include As and B. The highest observed As concentration was 0.022, which

*It is suggested
that CCBs not be placed in
close proximity to
primary drinking water
supplies, especially where
CCBs are not likely to
contact AMD.*

exceeds the 2006 As standard of 0.010 mg L⁻¹. The highest observed B concentration was 2.71 mg L⁻¹. Boron is frequently observed at elevated concentrations in CCB leachates, but the metals Cd, Pb and Cr are not typically thought of as problems in high pH waters. However, in all cases, Cd, Pb and Cr concentrations were below their hydroxide solubility product minima, indicating that pH dependent precipitation as metal hydroxides was not controlling solution phase concentrations.

When CCBs were in contact with AMD, at alkalinity exhaustion some elements decreased in concentration and some increased in concentration, compared to the initial AMD water quality. Trace elements that decreased in concentration but still exceeded drinking water standards included Ni, Be and Cu. Those elements of concern that increased in concentration, indicating that the ash was a net source for these elements, included Mn, Cr, Pb, Ni and Cd. Nickel concentrations in

solution at alkalinity exhaustion exceeded drinking water standards in all seven MWLPs; Cr and Pb exceeded drinking water standards in 3 MWLPs.

There were statistically significant effects from AMD source on MWLP results when the same CCBs were used, but the results were not consistent for each element. CCBs could be a source or a sink for B, Pb and Zn, depending on the specific CCB-AMD combination.

During the course of the MWLP procedure, Mn, Ni, Zn, Pb, Cu, Be, Cr and Cu concentrations increased in at least one CCB-AMD combination. A separate laboratory experiment indicated that CCBs could be a source of Zn, Cu and Ni at alkalinity exhaustion in solutions with low initial iron concentrations, but could remain a sink for these elements in solutions with high initial iron concentrations.

These results indicate that, as expected, at alkalinity exhaustion CCBs can release metals to solution. This suggests that careful planning and monitoring are necessary to prevent alkalinity exhaustion. When leachates were very alkaline (in contact with DDIW), elements such as B, Mn, Zn and Pb were present in leachates, sometimes in excess of drinking water standards. Further study of the geochemical controls on metal availability when CCBs are in contact with circumneutral water, including groundwater, is needed. It is suggested that CCBs not be placed in close proximity to primary drinking water supplies,

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especially where CCBs are not likely to contact AMD.

Because metals release depends on the specific CCB-AMD combination, this work suggests that CCBs should be tested for their potentials to release metals under the specific conditions where they are to be placed. When CCBs are to be placed in AMD, metals leaching behavior should be tested in waters comparable to what is expected at the site, rather than simple acid containing solutions. Iron concentrations in the AMD appear to play a role in metal source—sink behavior.

Additional study is warranted into the specific mechanisms by which metals are retained or released during the AMD leaching process. When CCBs are not likely to come into contact with AMD, characterization of metals leaching behavior, particularly for B, Mn, Zn, and Pb is still indicated. Given the relationship between CCB source and metals leaching, leaching characterization should be repeated whenever CCB source changes.

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For more information about this project, including the complete project report, please visit the CBRC Web site at <http://www.wri.nrcce.wvu.edu/cbrc>, or contact Louis McDonald at lmcdona4@wvu.edu.



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hiedyv@infocastinc.com
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April 11-15

World of Coal Ash Lexington Center's Heritage Hall Lexington, Kentucky

Contact Gretchen Tremoulet
(859) 257-0355
gtremoulet@caer.uky.edu
or Michael MacDonald
(720) 870-7897
info@acaa-usa.org

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August 17-19, 2005

Coal-Gen 2005, Revival of the Fittest, San Antonio, Texas Presented by PennWell

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1421 S. Sheridan Road
Tulsa, OK 74112-6600 USA
Fax (888) 299-8057
coal-gen@pennwell.com
www.coal-gen.com

CBRC CONTACTS

Program Manager

Lynn Brickett, U.S. Department of Energy -
National Energy Technology Laboratory
412/386-6574; brickett@netl.doe.gov

National Center

Paul Ziemkiewicz, Ph.D., *Director*
Tamara Vandivort, *Consortium Manager*
CBRC National Center located at the
National Mine Land Reclamation Center at
West Virginia University, 304/293-2867,
pziemkie@wvu.edu or tvandivo@wvu.edu

National Steering Committee Chair

Howard Humphrey, American Coal Ash
Association, Columbus, Ohio, 614/846-1726,
hhumphrey@columbus.rr.com

Eastern Regional Chair

Cheri Miller, Tennessee Valley Authority, Chattanooga, Tenn., 423/751-4419, ecmiller@tva.gov

Midwestern Regional Chair

Tom Robl, Ph.D., University of Kentucky,
859/257-0272, robl@noah.caer.uky.edu

Western Regional Chair

Jacob Gonzales, TXU Energy, Dallas, Texas,
214/812-8328, jake.gonzales@txu.com

Eastern Regional Technical Director

James C. Hower, Ph.D., University of Kentucky, 859/257-0261, hower@caer.uky.edu

Midwestern Regional Technical Director

Paul Chugh, Southern Illinois University at
Carbondale, 618/536 6637, chugh@engr.siu.edu

Western Regional Technical Director

Deborah Pflughoeft-Hassett, University of North
Dakota, 701/777-5181, dphassett@undeerc.org

NSC Committee Members

Jackie Bird, Ohio Coal Development Office, 614/466-3465, jbird@odod.state.oh.us

Taylor Eighmy, University of New Hampshire, 603/862-1065, taylor.eighmy@unh.edu

Paul Ehret, State of Indiana, 317/232-4020,
pehret@dnr.state.in.us

Dave Goss, American Coal Ash Association, 720/870-7897, DCgoss@acaa-usa.org

Dave Meadows, USACE-Huntington District, 304/529-5243, david.f.meadows@usace.army.mil

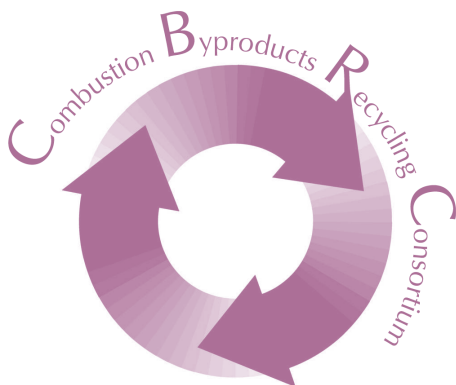
Jim Rower, Utility Solid Waste Activities Group, 202-508-5645, jim.rower@uswag.org

Kimery Vories, Office of Surface Mining, 618/463-6463 ext.103, kvories@mcrgw.osmre.gov

Andy Wittner, USEPA, 703-308-0496
Wittner.Andrew@epamail.epa.gov

Dan Wheeler, Illinois Office of Coal Development and
Marketing, 217-558-2645, dwheeler@commerce.state.il.us

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COMBUSTION BYPRODUCTS RECYCLING CONSORTIUM

Ashlines

To promote and support the commercially viable and environmentally sound recycling of coal combustion byproducts for productive uses through scientific research, development, and field testing.

a program of the National
Mine Land Reclamation
Center at West Virginia
University www.nrcce.wvu.edu/nmlrc, in
cooperation with the U.S.
Department of Energy -
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Use of CCBs for In-Situ Treatment of Acid Mine Drainage

Geoffrey A. Canty, Ph.D., and Jess W. Everett, Ph.D., P.E.

Acid mine drainage is a common problem near active and former coal and hard rock mining operations. When geologic formations containing pyrite react with water and air, sulfuric acid and dissolved metals can be released to local waters, devastating aquatic plant and animal life.

In 1994, a demonstration project investigated the effectiveness of using coal combustion byproducts (CCBs) for the in-situ treatment of acidic mine water. The project was conducted at an abandoned coal mine located in southeast Oklahoma, 160 miles southeast of Oklahoma City near the town of Red Oak. The mine is located in the Interior Province, Western Region Coal Field, or more specifically, in the Howe-Wilburton Coal District. The mine was a down-dip slope



operation that undermined approximately 46.5 acres.

In 1997, alkaline injection technology (AIT) was performed at the site with initially positive results. However, the amount of alkalinity

added was limited and resulted in a short duration of treatment.

In 1999, the Combustion Byproducts Recycling Consortium (CBRC) awarded a grant, which

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Use of CCBs for In-Situ Treatment of Acid Mine Drainage

(continued from page 1)

allowed researchers to further investigate AIT's effectiveness for treating acid mine drainage at the site. In December 2001, 2500 tons of fluidized bed combustion (FBC) ash was injected into the Red Oak mine. The results of the 2001 injection are the focus of this report, from pre-injection to 24 months after injection.

AIT Is Cost-Effective

AIT involves introducing alkaline coal combustion byproducts (CCBs) into a mine void to impart alkalinity, increase pH, and precipitate metals; thus, improving the quality of acid mine drainage.

Initially, acid mine drainage treatments relied on established engineering practices employing active chemical and physical processes to mine waters outside of the mine void. For example, combined neutralization and precipitation is a reliable and effective treatment option still employed in many situations, but it tends to be impractical for abandoned mine sites where there are limited funds or support for chemical inputs, equipment, and personnel requirements.

Over the past two decades, alternative treatment methods that "passively" address acid mine drainage have been developed and refined to treat mine water in a relatively cost-effective manner. Such passive treatments as treatment wetlands, sequential alkaline producing systems (SAPS), anoxic limestone drains (ALDs), and the numerous associated hybrid derivatives have been successful for specific mine water conditions. Mine chemistry and the physical setting can limit passive treatments.

AIT can be used in situations where other passive systems are not suited because of mine chemistry constraints. AIT can also be used in combination with other treatment options.

Project Results

Before the 2001 project, the water at the mine site had an average pH of 4.75, zero alkalinity, and average iron, manganese, and aluminum concentrations of 179 ppm, 6.7 ppm, and 3 ppm, respectively.

The results of the 2001 AIT demonstration project on water quality are described as taking place in three phases. Figure 1 on page 3 and Figure 2 on page 4 illustrate the results for alkalinity, pH, iron, manganese, and aluminum during Phases 1 and 2. The mine has not yet entered Phase 3.

During the injection process, the start of Phase 1, mine chemistry was drastically altered within a relatively short time. As the injection proceeded over a period of days, the pH and alkalinity increased relatively sharply, approaching maximum values of 12.45 and 1340 ppm as CaCO_3 , respectively. The increase in pH and alkalinity was undoubtedly due to overwhelming the major acidity species, free H^+ and H_2CO_3^* , by OH^- . Iron, manganese, and aluminum concentrations decreased to below 1 ppm shortly after injection.

Phase 1

As was observed during the 1997 injection, the duration of Phase 1 was short-lived. As soon

as injection stopped, alkalinity decreased sharply. Within 6 days after injection, the alkalinity was less than half, and within 14 days less than a quarter, of the values observed during the injection. The precipitous drop leveled off temporarily at ~200 ppm as CaCO_3 before decreasing at a more gradual rate. The pH values decreased gradually initially. It was not until several weeks later that pH values began to decrease relatively sharply.

The reactions occurring within Phase 1 were governed by the presence of OH^- , available in elevated concentrations. Concentrations of OH^- were significant until several weeks after the end of the injection. Carbon dioxide and carbonic acid present in mine water affected by the FBC ash injection were consumed in reactions with hydroxide. This depletion set up an imbalance, causing carbon dioxide to transport from the mine headspace and non-affected mine volume into the affected mine volume. The quantity of OH^- was large enough, initially, to minimize changes in pH and alkalinity.

Phase 2

Phase 2 represents the transition from the extreme disruption of the mine chemistry by the alkaline CCB injection to the recovery and re-establishment of the carbonate system within the mine, as controlled by the partial pressure of carbon dioxide (P_{CO_2}) in the mine headspace. Phase 2 is described as two sub-phases. During Phase 2a, which lasted approximately 9 months after

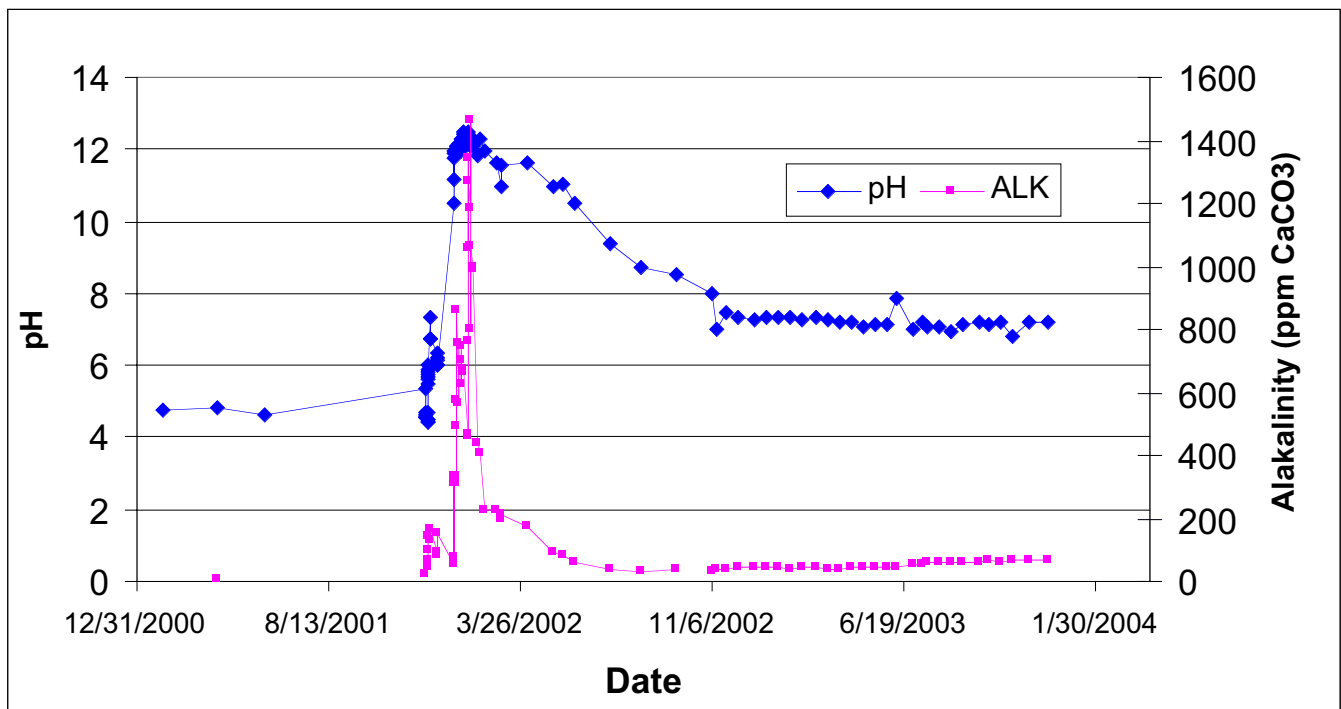


Figure 1—Alkalinity and pH values verses time. The relevant project period is from December 2001 through December 2003. Treatment phases are represented by the vertical dashed lines.

injection, hydroxide alkalinity associated with the injected slurry was converted to carbonate alkalinity (CO_3^{2-}). It lasted from early February through mid-November.

The alkalinity dropped precipitously immediately after the injection until it appeared to stabilize at ~200 ppm for roughly 2 months. Soon after, the alkalinity decreased steadily to ~30 ppm and remained constant for an additional 3 months.

The drop in alkalinity appears to be a function of pH and precipitation of metal-hydroxides, metal-carbonates, and potentially some sulfate compounds. Within the same period, pH decreased by approximately 0.014 unit/day, leveling off in the range of 7.3 to 7.4. It is assumed that a temporary equilibrium was established while carbonate was being converted to bicarbonate.

As of September 2004, the

mine system was in Phase 2b of treatment, which began roughly in mid to late November 2002. Equilibrium was established between the alkaline material introduced into the mine and the carbonate system, as controlled by the P_{CO_2} in the mine headspace.

Phase 2b is distinguished by slightly decreasing pH and a gradual increase in alkalinity. Alkalinity increased, from a low of 30 ppm as CaCO_3 after the injection to approximately 66 ppm roughly 17 months later. As bicarbonate became the more important species, there was an observed increase in alkalinity. Alkalinity continued to gradually increase at a rate of 0.13 ppm per day. The pH decrease observed during Phase 2a tapered substantially in Phase 2b. There was a modest, decreasing trend, roughly 0.1 units over a 12-month period (0.0003 units/day), from 7.3 to 7.2.

Metals were also influenced

by the change in alkalinity and pH during Phase 2. The concentration of iron and manganese appeared to increase steadily once the pH dropped below 8 and is predicted to increase to some threshold in the future. As of December 2003, iron and manganese concentrations were 30 ppm and 1.25 ppm, respectively. In contrast, aluminum concentrations were below the PQL. Aluminum forms a hydroxide solid within this pH range and is not influenced by the carbonate ligand. Aluminum levels are not likely to increase until the pH returns to preinjection levels (i.e., <5) at some time in the future.

Phase 3

During Phase 3, it is predicted that the mine system will reach equilibrium between the added alkaline material and the P_{CO_2} in

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Use of CCBs for In-Situ Treatment of Acid Mine Drainage

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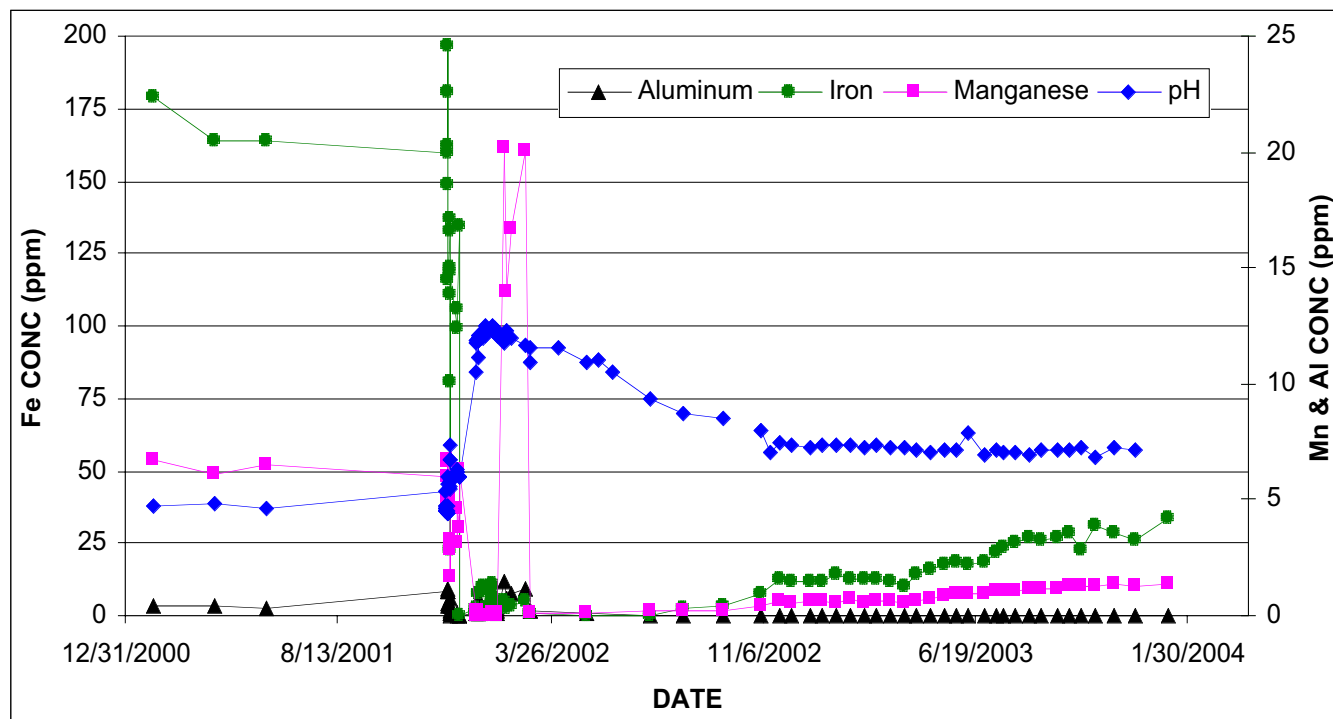


Figure 2—Concentrations of iron, aluminum, manganese, and pH versus time. The relevant project period is from December 2001 through January 2004. Treatment phases are represented by the vertical dashed lines.

the headspace; i.e., the H_2CO_3^* concentration will be at or near pre-injection levels. Over time, the available alkalinity will decrease because of flushing and consumption due to the continuous formation of acid. At the end of Phase 3, which is of unknown duration, the mine will return to pre-injection conditions.

Conclusions

From an acid mine drainage treatment perspective, the 2001 injection has been completely effective as of the date of writing. The mine discharge is net alkaline;

consequently, the receiving environment pH is circumneutral. Iron concentration has increased as described in Phase 2, but an oxidation impoundment immediately downstream of the discharge has been effective at removing precipitated iron floc, with significant improvement of the immediate environment.

Historically, the receiving stream was devoid of fish, and the macroinvertebrate community was severely impaired downstream of the mine discharge. Since the AIT demonstration, the habitat has

improved significantly, the macroinvertebrate community has improved, and fish were collected for the first time in 10 years of monitoring. Consequently, treatment achieved to date by AIT, in combination with an oxidation impoundment, has been successful.

In addition to the metals relevant to acid mine drainage treatment (iron, aluminum, and manganese), there is concern over the use of CCBs in environmental settings because of the potential release of toxic metals, metalloids, and mutagenic compounds. Trace



AIT staging area. CCB transport trucks download fluidized bed combustion ash for the injection slurry.

elements in the discharge were assessed.

The concentration of nickel and zinc were below 2001 preinjection levels and the federal criterion maximum concentration (CMC) and criterion continuous concentration (CCC) levels. The metalloids arsenic, boron, and selenium were investigated because they are commonly associated with CCBs. The median arsenic level was lower than the CMC (0.34 ppm) and CCC (0.15 ppm). The postinjection median boron concentration was below the Canadian guideline for freshwater aquatic communities (1.2 ppm), the Canadian drinking water guideline (5 ppm), and the recommended level for the protection of agricultural crops (0.5 to 1 ppm).

The postinjection median selenium concentration was 0.25 ppm, which was much greater than the CCC (0.005 ppm) and the MCL (0.05 ppm). This could be an issue for AIT application near sensitive receiving environments or drinking water aquifers. Copper and chromium concentrations were below the PQL for both metals (<0.01 and <0.02 ppm, respectively).

AIT has proven to be effective at reducing acidity and metal loads. Depending on the longevity of the treatment, AIT could be used in abandoned mine situations where any treatment would be welcomed. Alternatively, AIT could prove to be a beneficial pretreatment for more established passive systems. Using AIT in

series with a SAPS or ALD system could improve the overall efficiency of the passive treatment system. The alkalinity imparted to the water and the reduction in metals load may decrease the sizing requirements and prevent aluminum and ferric iron precipitation concerns.

For more information about this project and the complete project report, please visit the CBRC Web site at <http://www.wri.nrcce.wvu.edu>. Refer to project # ECW04-99. Geoff Canty can be contacted at cbrcenvironmental@sbcglobal.net.



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CBRC CONTACTS

Program Manager

Lynn Brickett, U.S. Department of Energy -
National Energy Technology Laboratory
412/386-6574; brickett@netl.doe.gov

National Center

Paul Ziemkiewicz, Ph.D., *Director*
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tucky, 859/257-0261, hower@caer.uky.edu

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Paul Chugh, Southern Illinois University at
Carbondale, 618/536 6637, chugh@engr.siu.edu

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Dakota, 701/777-5181, dphassett@undeerc.org

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3465, jbird@odod.state.oh.us

Taylor Eighmy, University of New Hampshire, 603/
862-1065, taylor.eighmy@unh.edu

Paul Ehret, State of Indiana, 317/232-4020,
pehret@dnr.state.in.us

Dave Goss, American Coal Ash Association, 720/
870-7897, DCgoss@acaa-usa.org

Dave Meadows, USACE-Huntington District, 304/
529-5243, david.f.meadows@usace.army.mil

Jim Rower, Utility Solid Waste Activities Group,
202-508-5645, jim.rower@uswag.org

Kimery Vories, Office of Surface Mining, 618/463-
6463 ext.103, kvories@mcrgw.osmre.gov

Andy Wittner, USEPA, 703-308-0496
Wittner.Andrew@epamail.epa.gov

Dan Wheeler, Illinois Office of Coal Development and
Marketing, 217-558-2645, dwheeler@commerce.state.il.us



Volume 4, Number 4

Winter 2003

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Leaching of Heavy Metals from Fly Ash-Stabilized Soils Used in Highways

Md Sazzad Bin-Shafique, Craig H. Benson, and Tuncer B. Edil

The use of fly ash is generally governed by regulations and guidelines promulgated by state environmental regulatory agencies [Kyper 1992]. In Wisconsin, fly ash use is regulated by Ch. NR 538 of the Wisconsin Administrative Code. NR 538 encourages beneficial use of industrial byproducts to an extent that is consistent with protection of public health and the environment.

According to NR 538, byproducts are classified into five "categories" that define applications where the byproducts can be used. Byproducts are assigned into categories based on the concentration of potential contaminants from elemental analysis and/or from water leach tests.



NR 538 defines twelve "methods" in which byproducts can be used, and the categories of byproducts suitable for each method. Using fly ash to stabilize soil in confined geotechnical fill, such as road subbase, is Beneficial Use Method 5. Industrial byproducts falling into categories 1 to 4 can be used for method 5,

with category 4 being the least stringent. To qualify for Category 4, fly ash has to be tested for five species (Cd, Cr, Se, Ag, and SO₄²⁻) and concentrations of these species must not exceed the limits set in NR 538.

From a regulatory perspective, fly ash only needs to be tested for the required species using a water

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Leaching of Heavy Metals from Fly Ash-Stabilized Soils Used in Highways

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leach test (WLT) following ASTM D 3987. Site-specific tests, such as properties of the soil, depth to groundwater, and properties of the stabilized subbase, are not required. The primary objective of this study was to go beyond that required in NR 538, and to conduct an in-depth geoenvironmental assessment of the potential for groundwater contamination by fly ash stabilized soil.

Four different tasks were conducted as part of this assessment: (1) water leach testing, (2) laboratory column testing, (3) field lysimeter testing, and (4) numerical modeling. The final report, available on the CBRC Web site, describes the work conducted on these tasks.

Materials

Soils

Soil samples were collected from four different locations in Wisconsin. Locations of the sampling sites are shown in Figure 1. These sites were selected so that soft subgrade soils having a broad range of properties could be tested. Personnel from the Wisconsin Department of Transportation assisted in locating the sampling sites. The samples were collected from a depth of 0.2 to 0.3 m along the roadway at each site.

Index properties, compaction characteristics, classifications, and California bearing ratio (CBR) are shown for each soil in Table 1. Joy silt loam and Plano silt loam are low plasticity clays. Lacustrine

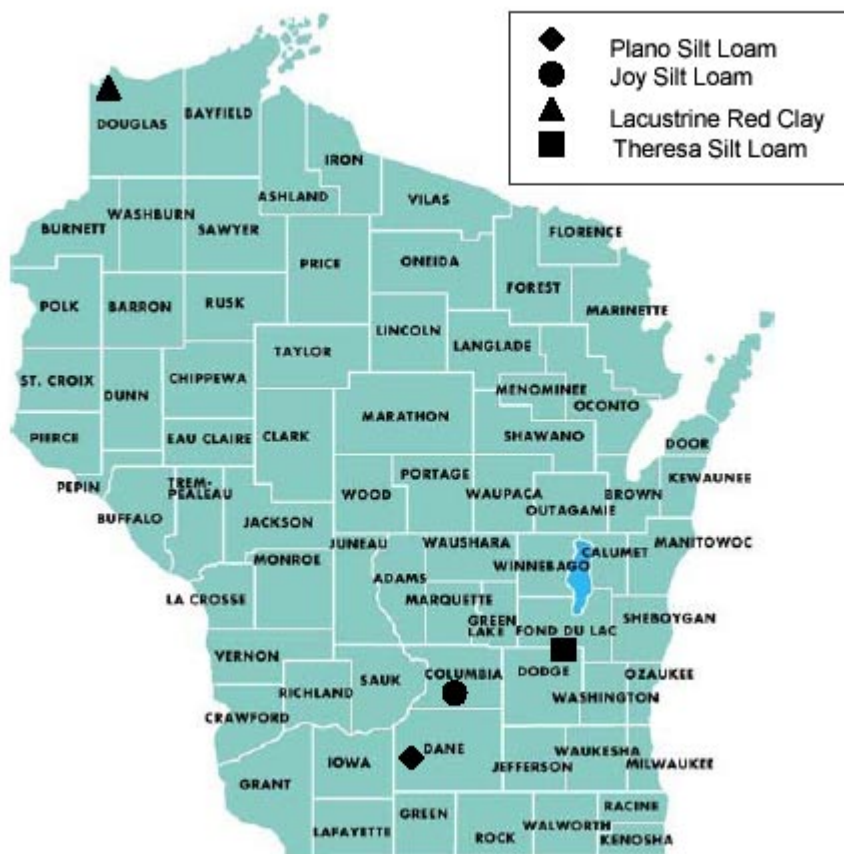


Figure 1—Location of Soil Sampling Sites

red clay is a highly plastic clay and Theresa silt loam is an organic highly plastic clay. The CBR tests were performed at the natural water content for all soils following ASTM D 1883. The dry unit weight of the CBR specimens is also shown in Table 1. The CBR ranges from 1 to 3, which indicates that all are very soft soils.

Particle size distribution curves for the soils are shown in the final project report (CBRC). The particle size distributions are

similar for the Joy silt loam, Plano Silt loam, and Theresa silt loam. The Lacustrine red clay is finer than the other soils. The percent fines (P200) varies between 94 and 97 percent, and the 2 μ m clay fraction varies between 20 and 65 percent.

The maximum dry unit weight and optimum water content, determined using standard Proctor compaction, range between 13.5 and 16.5 KN/m³ and 19 to 29 percent, respectively.

Table 1—Index Properties, Compaction Characteristics, Classifications, and CBRs of Soils

| Soil | Sampling Location | Liquid Limit | Plasticity Index | Specific Gravity | LOI (%) | Classification | | CBR | w _N (%) | γ _{d(CBR)} (kN/m ³) | w _{OPT} (%) | γ _{dmax} (kN/m ³) |
|---------------------|---------------------------------|--------------|------------------|------------------|---------|----------------|---------|-----|--------------------|--|----------------------|--|
| | | | | | | USCS | AASHTO | | | | | |
| Joy Silt Loam | STH 60 near Lodi, WI | 39 | 17 | 2.70 | 1 | CL | A - 6 | 3 | 25 | 15.1 | 19 | 16.5 |
| Plano Silt Loam | Scenic Edge in Cross Plains, WI | 44 | 20 | 2.71 | 2 | CL | A -7- 6 | 1 | 27 | 14.6 | 19 | 16.2 |
| Lacustrine Red Clay | STH 13 near Cloverland, WI | 69 | 38 | 2.71 | 2 | CH | A-7-6 | 2 | 35 | 13.3 | 24 | 15.7 |
| Theresa Silt Loam | STH 28 near Mayville, WI | 61 | 19 | 2.24 | 10 | OH | A-7-5 | 1 | 35 | 12.8 | 29 | 13.5 |

Notes: LOI = Loss on ignition, w_N = Natural water content, γ_{d(CBR)} = Dry unit weight for CBR samples, w_{OPT} = Optimum water content, and γ_{dmax} = Maximum dry unit weight.

The compaction curves are also provided in the final project report. Similar maximum dry unit weights were obtained for the Joy silt loam, Plano Silt loam, and Lacustrine red clay. The maximum dry unit weight for Theresa silt loam is appreciably lower than that of the other soils, due to its higher organic content.

Cation exchange capacity (CEC) and paste pH of the soils are shown in Table 2. Joy silt loam has the lowest pH (6.9) and also the lowest cation exchange capacity (9.9 meq/100g). Lacustrine red clay has the highest pH (7.4) as well as the highest cation exchange capacity (35.3 meq/100g).

Fly Ash

Physical properties and chemical composition of the fly ashes are shown in Table 3 on page 4. Columbia fly ash classifies as Class C fly ash following ASTM C 618. Columbia fly ash contains 23 percent lime and has self-cementing capabilities. Dewey fly ash has high organic content (16 percent) and classifies

Table 2—Adsorption-Related Chemical Properties of Soils and Fly Ash

| Sample | pH | CEC (meq/100g) |
|---------------------|------|----------------|
| Joy silt loam | 6.9 | 9.9 |
| Plano silt loam | 7.1 | 14.2 |
| Lacustrine red clay | 7.4 | 35.3 |
| Theresa silt loam | 7.1 | 27.6 |
| Columbia fly ash | 11.7 | 102.2 |
| Dewey fly ash | 10.1 | 49.3 |
| King fly ash | 11.0 | 77.5 |

Note: Cation exchange capacity (CEC) is estimated at the corresponding pH. Chemical analyses were conducted by Soil and Plant Analysis Laboratory at UW-Madison.

as an “off-specification” fly ash, implying that it does not meet the Class C criteria in C 618 and is not suitable for use in concrete. Dewey fly ash has 10 percent lime and has self-cementing properties. King fly ash also classifies as off-specification because its organic content (5.4 percent) and SO₃ content (6.4 percent) exceed the criteria in

ASTM C 618. King fly ash has 24 percent lime content and has self-cementing capabilities.

Chemical compositions of the fly ashes are compared with the composition of typical Class C and F fly ashes in Table 4. The Columbia and King fly ashes have lime contents similar to

(continued on page 4)

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(continued from page 3)

typical Class C fly ash. The lime content of Dewey fly ash is close to that of typical Class F fly ash. The SO_3 content, which causes rapid hydration, is much higher (12 percent) for Dewey fly ash than any of the other fly ashes, including typical Class C (3.3 percent) and F fly ashes (0.6 percent). All three fly ashes have Al_2O_3 and Fe_2O_3 contents comparable to that of Class C fly ash, and SiO_2 content lower than the typical Class C and F fly ashes.

Dewey fly ash has the lowest pH (10.1) as well as the lowest cation exchange capacity (49.3 meq/100g), and Columbia fly ash has the highest pH (11.7) and the highest cation exchange capacity (102.2 meq/100g). The pH and the cation exchange capacity of King fly ash fall between those for the Columbia and Dewey fly ashes.

Particle size distributions of the fly ashes are shown in the final project report. All three ashes contain a broad range of particle sizes in the silt and clay range. Particle size distributions of the King and Dewey ashes are more widely distributed, and these ashes contain coarse as well as fine particles. Columbia fly ash contains some uniform silt size particles and a wide range of smaller particles. The percent fines (P200) varies from 64 to 98 percent. Columbia fly ash has the highest percent fines (98 percent) and Dewey fly ash has the lowest (64 percent). King fly ash has an intermediate fines content (85 percent)

Table 3—Physical Properties and Chemical Composition of Fly Ashes

| Fly Ash | Classification (ASTM 618) | Specific Gravity | Moisture Content (%) | Loss on Ignition (%) | Lime (CaO) Content (%) | Other Oxides ($\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$) (%) | Sulfur Trioxide Content (%) |
|----------|---------------------------|------------------|----------------------|----------------------|------------------------|---|-----------------------------|
| Columbia | C | 2.70 | 0.09 | 0.7 | 23.0 | 55.5 | 3.7 |
| Dewey | Off-spec | 2.53 | 0.23 | 16.2 | 9.8 | 38.7 | 11.8 |
| King | Off-spec | 2.68 | 0.44 | 5.4 | 23.7 | 49.5 | 6.4 |

NA = Not available

Table 4—Chemical Composition of Fly Ashes

| Chemical Species | Percent of Composition | | | | |
|-------------------------|-------------------------------|----------------------------|---------------------------|------------------------------|------------------------------|
| | Columbia Fly Ash ¹ | Dewey Fly Ash ¹ | King Fly Ash ² | Typical Class C ³ | Typical Class F ³ |
| CaO (lime) | 23.1 | 9.8 | 23.7 | 24 | 9 |
| SiO_2 | 31.1 | 19.8 | 27.3 | 40 | 55 |
| Al_2O_3 | 18.3 | 13.0 | 16.3 | 17 | 26 |
| Fe_2O_3 | 6.1 | 6.0 | 5.9 | 6 | 7 |
| MgO | 3.7 | 3.1 | 1.8 | 5 | 2 |
| SO_3 | 3.7 | 11.8 | 6.4 | 3 | 1 |

¹ From chemical analyses provided by Alliant Energy (see Appendix B)

² From chemical analyses provided by Xcel Energy

³ From *Fly Ash Facts for Highway Engineers* (1995)

Stabilized Soil

Compaction curves for the soil-fly ash mixtures were determined using the Harvard Miniature Compaction procedure (ASTM D 4609-94). The compaction effort was intended to simulate standard Proctor effort (ASTM D 698). The first set of mixtures was compacted immediately after mixing with water (no delay). Another set of mixtures was compacted two hours after mixing with water (2-hour delay)

to simulate the typical duration between mixing and compaction that occurs in the field. Mixtures were prepared with fly ash contents of 10, 15, and 20 percent with Joy silt loam and 12, 16, and 20 percent with Plano silt loam. The compaction curves are provided in the final project report.

Compaction characteristics of the soil-fly ash mixtures prepared with Plano silt loam and Joy silt loam are shown in Table 5. The

Table 5—Compaction Characteristics of Fly Ash-Stabilized Soils

| Soil Type | Fly Ash Type | Fly Ash Content (%) | Stabilized Soil-No delay | | Stabilized Soil- 2-hr delay | | Soil Alone | |
|-----------------|--------------|---------------------|--------------------------------------|---------------|--------------------------------------|---------------|--------------------------------------|---------------|
| | | | γ_{dmax} (kN/M ³) | W_{opt} (%) | γ_{dmax} (kN/M ³) | W_{opt} (%) | γ_{dmax} (kN/M ³) | W_{opt} (%) |
| Plano Silt Loam | Columbia | 12 | 16.2 | 19 | 15.6 | 21 | 16.2 | 20 |
| | | 16 | 16.2 | 20 | 15.5 | 21 | | |
| | | 20 | 16.0 | 20 | 15.5 | 22 | | |
| Joy Silt Loam | Columbia | 10 | 16.6 | 18 | 16.1 | 20 | 16.5 | 19 |
| | | 15 | 16.5 | 19 | 15.9 | 20 | | |
| | | 20 | 16.4 | 20 | 15.8 | 21 | | |

Note: First set of soil-fly ash mixtures was compacted immediately after mixing with water and indicated as "no delay" samples. A second set of soil-fly ash mixtures was compacted two hrs after mixing with water and indicated as "2-hr delay" samples.

maximum dry unit weight and optimum water content for the soils alone are also shown in Table 5. For both soils, the maximum dry unit weight and optimum water content for the "no delay" soil-fly ash mixtures are comparable with that for the soil alone. In contrast, the maximum dry unit weight for the "2-hour delay" soil-fly ash mixtures is lower than that for the soil alone, and optimum water content of the soil-fly ash mixtures is slightly higher (1 percent) for both soils. Additionally, the maximum dry unit weight decreases and the optimum water content increases as the fly ash content increases.

The maximum unconfined strength of design mixtures was obtained at 1 percent wet of optimum water content [Edil et al. 2002]. Thus the water content used in the field was specified as optimum water content 2 percent.

Methods

Water Leach Tests

Water leach tests (WLTs) were conducted on fly ashes to assess their leaching behavior and to determine if the fly ashes were suitable for soil stabilization in accordance with NR 538. The WLTs were conducted following ASTM D 3987-85. Water leach tests were also conducted on soil alone, soil-fly ash mixtures having different fly ash contents, fly ashes spiked with known amounts of different metals, and soil-fly ash mixtures prepared with spiked fly ash.

Water Leach Tests on Fly Ash, Soil Alone, and Soil-Fly Ash Mixtures

The WLTs were conducted by adding 70 g of crushed solid (soil or fly ash alone or soil-fly ash mixture) passing a US No. 4 Standard sieve to 1400 mL of ASTM Type II deionized water in a 2 L sealed container. The mixture was then agitated continuously in a tumbler at a rate of 29

rotations/min for 18 hours at room temperature (25° C). Afterwards, the mixture was allowed to settle for 5 minutes, and then the aqueous phase was separated by decantation. The pH of the aqueous phase was measured immediately. The leachate was then filtered through a 0.45- μ m filter paper and stored for chemical analysis. Preservation of the leachate samples and subsequent chemical analyses of leachates are described later.

Soil-fly ash mixtures were also prepared for the WLTs using each of the soils and fly ashes, and with different fly ash contents (by dry weight). The mixtures that were used for the WLTs are shown in Table 6. These fly ash contents were also used for column testing. To prepare the soil-fly ash mixtures, the soil was air dried and crushed to pass a US No. 4 Standard sieve. Then a 2-kg sample of soil and fly ash (the proportion depends on fly

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ash content) was mixed homogeneously on a tray, and the required amount of tap water was sprayed on the mixture to achieve a molding water content 2 percent dry of optimum water content. The molding water was mixed into the dry soil-fly ash mixture until the mixture appeared homogeneous. A portion of each mixture was used to prepare a column leaching test specimen. The remainder was stored in a sealed plastic bag for seven days before the WLT.

Water Leach Tests on Spiked Fly Ash and Soil-Spiked Fly Ash Mixtures

WLTs with spiked fly ash were conducted to determine how higher metal concentrations affect leaching of metals. WLTs were conducted on the spiked fly ash and soil-spiked fly ash mixtures using the procedure described in previously. Only Columbia fly ash was used for the tests on spiked fly ash and soil-spiked fly ash mixtures.

The fly ash was spiked by dissolving the mass of metal salts required to achieve the target concentration (Table 4.2) in 1400 ml of ASTM Type II deionized water. WLTs were then conducted using this water as the leachant. Four different sets of metal concentrations were used to simulate different levels of metals in the fly ash.

All tests conducted on soil-spiked fly ash mixtures had a fly ash content of 10 percent, so that

Table 6—Soil/Fly Ash Mixtures Used for WLTs

| Type of Soil | Type of Fly Ash | Fly Ash Content (%) |
|---|-----------------|---------------------|
| Low plasticity clay (Joy silt loam) | Columbia | 5 |
| | | 10 |
| | | 15 |
| | | 20 |
| | King | 10 |
| | | 20 |
| | Dewey | 10 |
| | | 20 |
| High plasticity clay (Lacustrine red clay) | Columbia | 10 |
| | | 20 |
| | King | 10 |
| | | 20 |
| | Dewey | 10 |
| | | 20 |
| Organic clay (Theresa silt loam) | Columbia | 10 |
| | | 20 |
| | King | 10 |
| | | 20 |
| | Dewey | 10 |
| | | 20 |
| Silica sand | Columbia | 10 |
| | | 20 |
| | King | 10 |
| | | 20 |
| | Dewey | 10 |
| | | 20 |

all other chemical constituents would remain unchanged. The soil was air dried and crushed to pass a US No. 4 Standard sieve, and 2 kg of soil and fly ash sample was mixed homogeneously on a tray.

The metals were added to fly ash by dissolving the mass of metal salts required to achieve the target concentration in water, and then the water was sprayed on the mixture to achieve a molding water content of 2 percent dry of optimum. The molding water was mixed into the dry soil-fly ash mixture until the mixture appeared homogeneous. A portion of each mixture was then used to prepare a column test specimen. The remainder was stored in a sealed plastic bag for seven days before the WLT.

Column Tests

Prior to conducting the column tests, hydraulic conduc-

tivity tests were conducted on soil and soil-fly ash mixtures to identify molding water contents that resulted in specimens permeable enough to permit convenient sample collection. The hydraulic conductivity of a soil-fly ash mixture prepared with 10 percent Columbia fly ash and Joy silt loam from the STH 60 site is illustrated in the final project report for molding water contents ranging between 17.6 percent and 21.6 percent.

The specimens for the hydraulic conductivity tests were prepared in standard Proctor mold using standard Proctor compaction effort. The hydraulic conductivity decreases sharply as the molding water content is increased beyond optimum water content (19 percent) of the soil. Thus, all specimens were prepared at molding water content approximately 2 percent dry of optimum water content so that

sufficient volumes of effluent could be collected in a reasonable timeframe.

Experimental Setup

Column leaching tests were conducted to provide a more realistic assessment of leaching from soil-fly ash mixtures and to determine leaching and transport parameters, such as initial effluent concentration (i.e., initial pore fluid concentration), effective porosity, partition coefficient, and dispersion coefficient for the soil-fly ash mixtures. Column leaching tests were also conducted on soil alone. The specimens were placed in flexible-wall permeameters operated in an up-flow mode [Das et al. 1989]. A photograph of the experimental set-up is shown in Figure 2.

Hydraulic gradients between 7 and 10 were applied to make sample collection convenient. These gradients are larger than

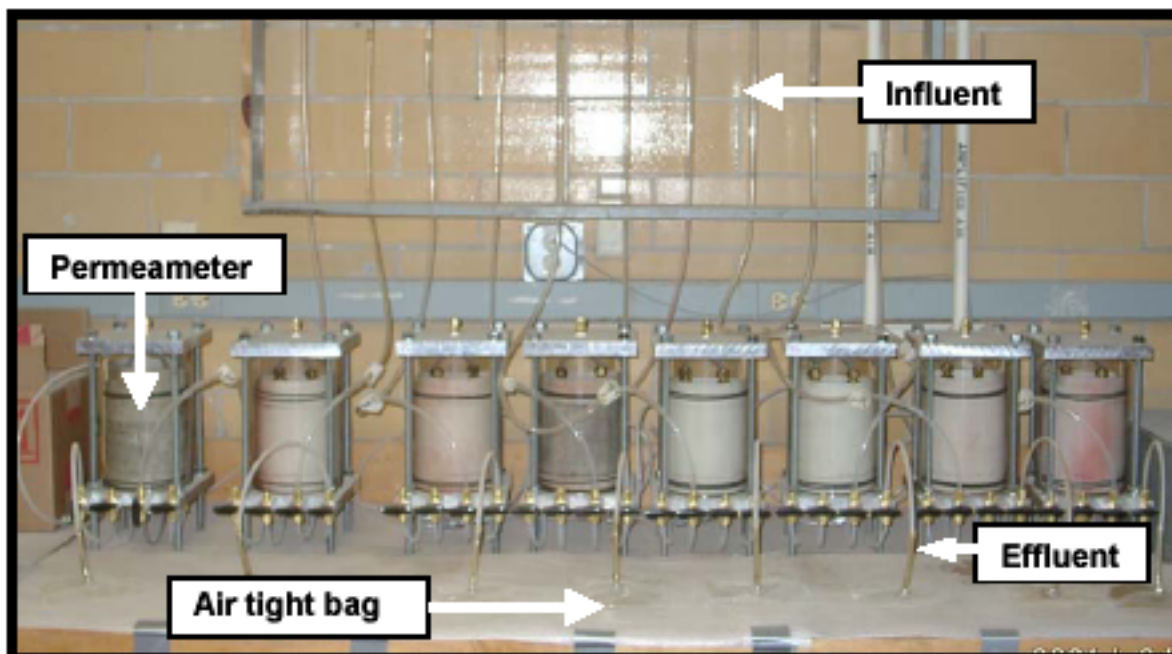


Figure 2—Experimental Setup for Column Test

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exist in the field (typically about 1). However, Creek et al. [1992] report that metal leaching from fly ashes is independent of flow rate. Thus, the larger gradients are believed to have little impact on the test results. The cell pressure was 15 kPa and the pore water pressure ranged from 8 to 12 kPa.

A 0.1-M LiBr solution was used as the influent liquid to provide an influent with comparable ionic strength to percolating water [Karczewska et al. 1996, Papini 1999]. The solution was prepared with LiBr salts (99.9 percent pure) dissolved in ASTM Type II water. Bromide was used as an independent tracer. Lithium was selected because it is not considered in the environmental analysis, is unlikely to be present in the soil, and has a lower preference for adsorption compared to the metals of concern in this study (Cd, Cr, Se, and Ag). The influent solution was exposed to the atmosphere for several days to achieve pH 6 prior to use, which is comparable to the pH of water in the natural environment [Chichester and Landsberger 1996, Huang et al. 1998].

Effluent from the column test (i.e., leachate) was collected in airtight sampling bags. Leachate was removed from the bags every 0.4 to 0.6 pore volumes of flow and a portion of leachate (50-55 mL) was collected for chemical analysis. The pH, volume, and time of collection of the leachate were recorded. Leachate samples

were preserved and subjected to chemical analysis following the methods described later in this article.

Column Tests on Subgrade Soils

Column tests were also conducted on subgrade soils using the set up described previously, except with an influent liquid simulating effluent from fly ash stabilized soil. The purpose of these tests was to evaluate transport through an underlying unstabilized subgrade above the groundwater table. Transport parameters of the subgrade soil are necessary to estimate the concentration of metals at the groundwater table.

The synthetic leachate used as the influent liquid was prepared by adding metals (Cd = 20 µg/L, Cr = 200 µg/L, Se = 100 µg/L, Ag = 20 µg/L) to a 0.1 M LiBr solution. This solution simulates the typical initial leachate obtained from the soil-fly ash mixtures. The pH of the influent solution was adjusted to 9.5 using calcium hydroxide and hydrochloric acid to simulate the high pH of the effluent from the soil-fly ash mixtures. Readjustment of the pH was required several times during the column tests.

Type of Specimens

Two types of specimens were tested in the column leaching tests: Type-F and Type-S. Type-F specimens were prepared with

conventional soil-fly ash mixtures and soil alone. Type-S specimens were prepared with soil-fly ash mixtures using fly ash spiked with metals. Type-F specimens were tested to determine transport parameters for soil-fly ash mixtures as well as the subgrade soil.

Type-S specimens were tested for three reasons: to determine if a relationship exists between the initial effluent concentration from the column leaching tests and the concentration from the water leach test and to examine if the release pattern still follows instantaneous desorption at higher metal concentrations.

Type-F specimens were prepared with soil-fly ash mixtures at the fly ash contents shown in Table 7. Specimens with 0 percent fly ash were also tested to evaluate leaching from soil alone. The soil-fly ash mixtures were prepared and moistened following the method described previously. The moistened mixtures were compacted within one hour after mixing with water using standard Proctor effort (ASTM D 698). After compaction, the specimens were extruded from the compaction molds, sealed in polyethylene, and cured for 7 days at room temperature. The column leaching tests were initiated immediately after the curing period.

Four Type-S specimens were prepared using the four metals concentrations used for WLTS the tests (Table 7). Type-S specimens were prepared only with Colum-

Table 7—Targeted Concentration of Fly Ash Spiked with Metals

| Species | Spike-A Concentration (mg/kg) | Spike-B Concentration (mg/kg) | Spike-C Concentration (mg/kg) | Spike-D Concentration (mg/kg) |
|--------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Cadmium | 0.5 | 1.0 | 2.0 | 3.0 |
| Chromium (T) | 5.0 | 10.0 | 20.0 | 40.0 |
| Selenium | 3.0 | 6.0 | 12.0 | 30.0 |
| Silver | 1.0 | 2.0 | 3.0 | 5.0 |

T = Total chromium

bia fly ash at a fly ash content of 10 percent. Type-S specimens were prepared following essentially the same procedures used for the Type-F specimen, except the compaction water was spiked with metals to achieve the target concentrations in Table 7.

Column Tests on Subgrade Soils

Four specimens were prepared with four different subgrade soils (Joy, Plano, Lacustrine, and Theresa) for the column tests conducted with subgrade soil alone using synthetic leachate as the influent liquid. These specimens were prepared using the same procedures used for the Type-F specimen.

Data Processing

Effective porosities and dispersion coefficient were obtained by fitting the Ogata-Banks [1961] equation to bromide concentrations in effluent of from column leaching test. The Ogata-Banks solution of the advection-dispersion-retardation equation is:

$$\frac{C_e(L, T)}{C_i} = \frac{1}{2} \left\{ \operatorname{erfc} \left(\frac{R - T}{2(TR/P_L)^{1/2}} \right) + \exp(P_L) \operatorname{erfc} \left(\frac{R - T}{2(TR/P_L)^{1/2}} \right) \right\}$$

where

C_e = the effluent concentration,
 C_i = the influent concentration,
 R = the retardation factor,
 T = the pore volume leached,
 $P_L (= vL/D)$ = the column Peclet number, and
 erfc = the complimentary error function.

Transport properties of metals in subgrade soils were also obtained by fitting the Ogata-Banks equation to the metal concentrations in the effluent of the column tests.

Retardation factors for the metals (Cd, Cr, Se, and Ag) were obtained by fitting van Genuchten's [1981] analytical leaching model to the metal concentration in the effluent of the column leaching tests:

$$\frac{C_e(L, T)}{C_o} = 1 - \frac{1}{2} \left\{ \operatorname{erfc} \left(\frac{R - T}{2(TR/P_L)^{1/2}} \right) + \exp(P_L) \operatorname{erfc} \left(\frac{R - T}{2(TR/P_L)^{1/2}} \right) \right\}$$

where

C_o = the initial concentration in the pore fluid of the porous matrix equilibrium with the solid phase concentration.

Concentrations were assigned to the average pore volumes of flow between the time when the sample was collected and the time when the previous sample was collected, as recommended by Shackelford [1994].

Field Tests

Lysimeters were installed at the STH 60 and Scenic Edge field sites to determine the amount of liquid passing through the stabilized layer and to characterize the concentrations of Cd, Cr, Se, and Ag in leachate under field conditions. A photograph of the lysimeters being installed at STH 60 is shown in Figure 3.

The lysimeters were constructed with 1.5-mm thick textured HDPE geomembrane overlain by a geocomposite drainage layer (geonet with a non-woven geotextile heat bonded to both sides) used to direct the leachate to a sump. Schedule 40 PVC pipe (31 mm diameter) was used to connect the sump in each lysimeter to a 120-L tank buried adjacent to the pavement and below the frost depth. The tank was insulated with extruded polystyrene insulation to prevent freezing of the leachate during the winter.

Leachate is removed from the tanks every 3 to 5 weeks using a suction pump. The volume of leachate is measured in a 20-L bucket during pumping. Leachate

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samples for chemical analysis are collected from the outlet pipe when approximately 40 to 50 percent of the leachate has been pumped from the tank. After pumping each tank, the pump and the associated hoses are washed by allowing the pump to run with deionized water for 2 to 3 minutes to prevent cross-contamination. Preservation and chemical analyses of the leachate samples are described later.

Lysimeters at STH 60 Site

Two equal size (3.50 m x 4.75 m) lysimeters were installed in the fly ash stabilized test section

at the STH 60 site. The layout of these lysimeters is shown in Figure 4. One lysimeter was installed along the centerline of the roadway; the other was along the shoulder. Two other lysimeters having the same size were installed at similar locations in a control section where no fly ash stabilization was employed.

Concentrations of bromide were determined by ion chromatography (IC) following the instructions provided with the instrument. A Dionex-600 Ion Chromatographer equipped with an ED 50 Electrochemical Detector, GP50 Gradient Pump, and a

LC 25 Chromatography Oven, was used for bromide analysis.

Summary of Method for Analysis of Metals

EPA Method 1669 was followed for sample collection, filtration, and preservation. To avoid contamination and interferences, several measures were taken according to Part 4.0 [Method 1669], such as minimizing exposure, wearing gloves, using metal-free apparatus, and ensuring a clean environment. Immediately after leachate collection, samples were filtered through a 0.45 µm filter paper

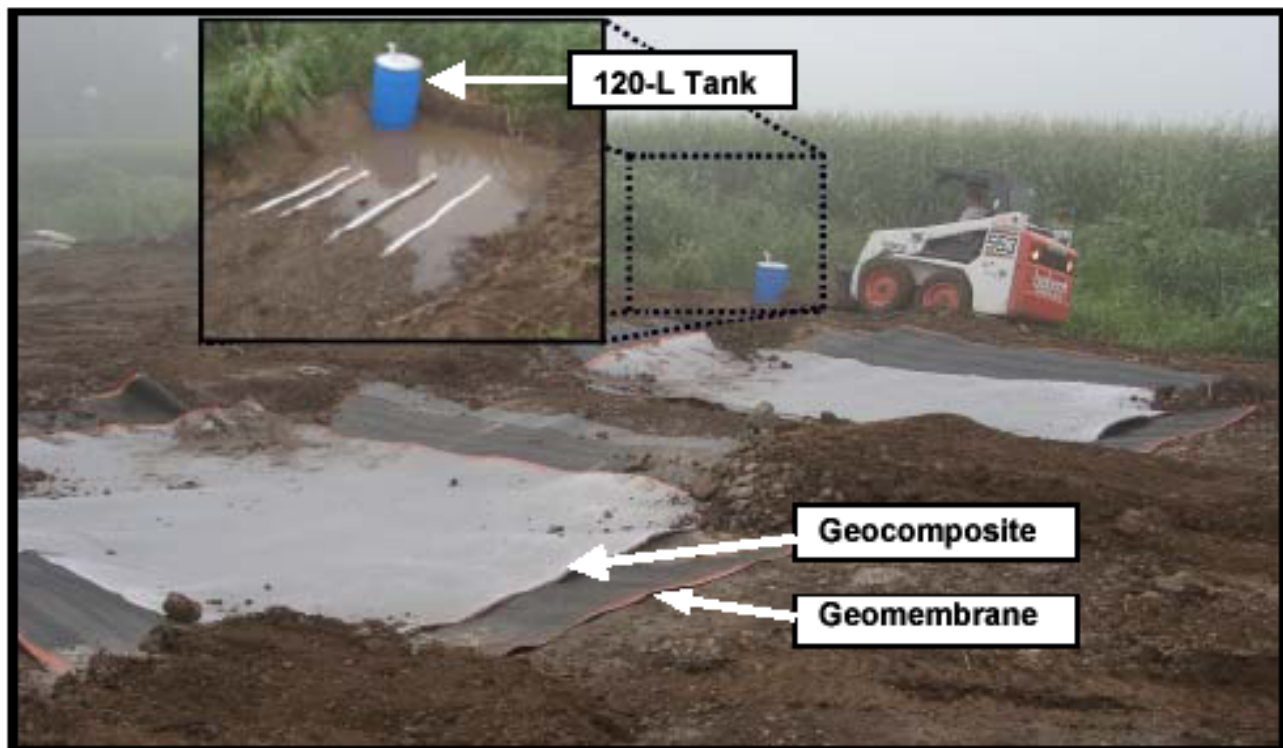


Figure 3—Construction of Lysimeters at STH 60 Site

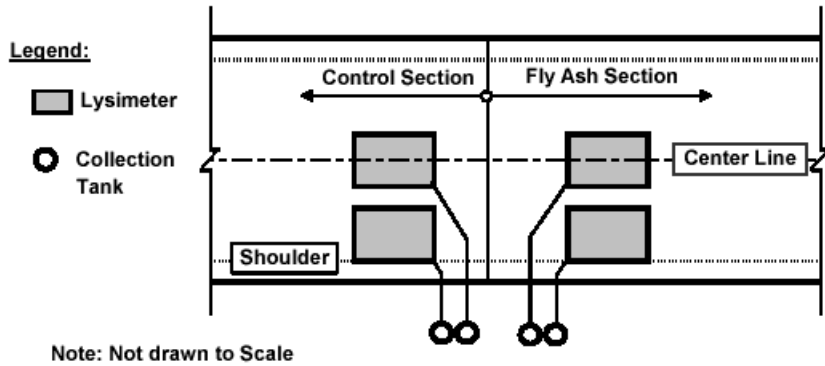


Figure 4—Layout of Lysimeters at STH 60 Site

and acidified with concentrated 0.5 percent HNO_3 to bring the sample pH <2.

Samples were collected in new 60-mL high-density polyethylene bottles that were washed with acid solution (2 percent HNO_3) before use. The sampling bottles were sealed to prevent volume change and evaporation. All samples were preserved at 4°C before chemical analysis.

Preparation of Standard Solution

Stock solutions obtained from Aldrich Chemical Company were used for all calibrations. The stock solution was diluted using ASTM Type I water containing 0.5 percent HNO_3 . Calibration standards were prepared fresh each time. A blank and at least three standards were prepared within the appropriate range.

Instrument Parameters

Instrument parameters such as drying time, ashing time, and wavelength were adapted from the standard method for each element. Other operating parameters, such as atomizing time and temperature and purge gas atmosphere, were chosen as

suggested by the instrument manufacturer.

Analysis

Chemical analysis was performed according to methods corresponding to specific elements. Before each use of the AA spectrometer, the instrument was configured, tuned, and calibrated for the metals of interest. A separate graphite tube was used for each element. Laboratory blanks were tested along with standard solutions. Equipment blanks and bottle blanks were also tested. Three replicates of each sample were measured.

Calibration Method for Metals Analysis

The instrument was optimized and initialized at zero before calibration. A standard solution was measured for five times for a stability check of the instrument. The instrument was assumed to be stable when the relative standard deviation (RSD) of the absorbance signals was <5 percent for all 5 replicates. The calibration points were obtained from the calibration blank and calibration standards, and a new rational curve was fit (auto-

matically by the data station) to the data, which was used as a calibration curve. A new calibration curve was created after measuring 20 samples.

Three replicates of each sample were measured. The RSD of the concentrations estimated from the calibration curve for replicates was calculated automatically by the data station. If the RSD was higher than 10 percent, the measurement was discarded and another measurement was made. After measuring two samples, a calibration blank was analyzed to ensure no carryover of the metal of interest and to check if the analytical system was free from contamination. The calibration curve was also verified with a standard solution after analyzing four samples. After measuring 10 samples, the calibration curve was resloped by analyzing the calibration blank and the mid-point calibration standard. A new calibration curve was created if the reslope varied 10 percent of the original slope.

Conclusion

The primary objective of this study was to conduct an in-depth assessment of leaching of heavy metals from fly ash stabilized soil used in highway construction. An additional objective was to estimate the potential for groundwater contamination in a typical highway containing a stabilized layer. To achieve these objectives, four different tasks were undertaken: (1) water leach testing (WLT), (2) laboratory column testing, (3) field lysimeter testing,

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and (4) numerical modeling. Detailed results and numerical modeling are presented in the final report available on the CBRC Web site at <http://www.wri.nrcce.wvu.edu/cbrc>.

Water Leach Testing

Concentrations of metals in leachate from soil-fly ash mixtures prepared with various soil and fly ashes at different fly ash content tend to be lower (1.5 to 2.5 times) than those from fly ash alone. The concentrations of metals in the leachate from soil-fly ash mixtures varies non-linearly with fly ash content and cannot be estimated based on a simple dilution calculation. The non-linear behavior is attributed to the variation in pH with fly ash content, and the effect of pH on the partition coefficient.

Leaching potential of a metal from a soil-fly ash mixture depends on the metal concentration in the fly ash as well as in the soil, pH of the leachate, the cation exchange capacity (CEC) of the soil, and the type of fly ash. The pH of the leachate increases as the lime content of the fly ash increases.

Laboratory Column Testing

Column leaching tests conducted on soil-fly ash mixtures showed that the hydraulic conductivity, pH of the effluent, and initial effluent concentration of the soil-fly ash mixture increase with increasing fly ash content, but the partition coefficient is essentially independent of fly ash

content. For compacted soil-fly ash mixtures, the effective-to-total porosity varies between 0.65 and 1.08, and the longitudinal dispersivity varies between 0.05 L and 0.24 L, where L is the length of the column.

The initial effluent concentration from the column leaching tests on soil-fly ash mixtures prepared with various soils and fly ash at different fly ash contents is non-linearly related to the concentration obtained from WLTs on similar soil-fly ash mixtures and with the concentration from WLTs on fly ash alone. Non-linearity exist because the pH of the leachate varies with fly ash content, which affects adsorption of metals. In contrast, if the fly ash content is fixed, and the fly ash is spiked with different metal concentrations, initial effluent concentrations from column leaching tests on soil-fly ash mixtures are linearly related to the concentration obtained from the WLTs on soil-fly ash mixtures. A linear relationship exists for spiked fly ashes because the pH remains constant when the fly ash content is fixed.

The release pattern of metals from the soil-fly ash mixtures appears to be adsorption-controlled. Adsorption of metals is highly dependent on the pH of the pore fluid. However, the pH of the soil-fly ash mixtures appears to be persistent for at least 30 pore volumes of flow, which corresponds to at least 30-yr of flow in the field.

Column tests conducted on subgrade soils (i.e., soil without fly ash) with synthetic fly ash

leachate used as the permeant liquid showed that the partition coefficient of metals for soil-fly ash mixtures is similar to that of the soil alone, and is slightly higher for soils with higher CEC. That is, the partition coefficient depends primarily on the type of soil rather than the fly ash. The column tests also showed that the effective-to-total porosity ratio varies between 0.89 and 1.02, and the longitudinal dispersivity varies between 0.06 L and 0.11 L for compacted fine-grained subgrade soils.

Field Tests

Lysimeters installed at two field sites were used to monitor the water flux and concentration of metals in leachate from fly ash stabilized soil layer and a control section. The average annual flux through the stabilized sections is approximately 4 to 6 percent of the average annual precipitation, and is comparable to that from the control section. Concentrations of most of metals of concern are higher in the fly ash stabilized section than the control section. The concentrations have decreased slightly over time as water has passed through the fly ash stabilized layer.

Concentrations of metals in leachate collected in the lysimeters usually are two times higher than those from WLTs. The concentrations are slightly higher at the Scenic Edge site, where the fly ash content is higher. Concentrations of metals in leachate from the field agree well with concen-

trations in the effluent from the column leaching tests, which suggests that the transport parameters obtained from the column leaching tests can be used to predict field conditions.

Numerical Modeling

A numerical model was developed to simulate leaching and contaminant transport for typical field scenarios where the subgrade is stabilized with fly ash. Simulations conducted using transport parameters obtained from the column tests and Darcy fluxes measured in the field showed that the maximum concentration decreases by a factor of five within the first meter beneath the fly ash stabilized layer, and then decreases gradually at deeper depths. The maximum concentration at a given depth is independent of the retardation factor, and decreases as the dispersion coefficient of subgrade soil increases and the thickness of the stabilized layer decreases.

For an advection-dominated transport scenario, the maximum concentration is independent of Darcy flux, and the time to reach the maximum concentration is inversely proportional to the Darcy flux. The time to reach the maximum concentration increases linearly with depth when the flow is uniform. The time to reach maximum concentration at a particular depth is independent of the thickness of the stabilized layer, and increases as the dispersion coefficient of the subgrade soil decreases and the retardation factor of the subgrade soil increases.

Graphs generated from the results of the numerical simulations are presented that can be

used to quantify the maximum relative concentration at a particular depth and the time required to achieve the maximum concentration. The only required parameter is the initial effluent concentration, which depends primarily on the type of fly ash and can be estimated from a water leach test. To determine the time required to achieve the maximum concentration at a given depth, the Darcy flux and the retardation factor are required. The retardation factor depends primarily on the type of soil being stabilized, but does not vary significantly for fine-grained soils. Thus, quick and reasonable predictions can be made using a conservative estimate of the retardation factor and Darcy flux.

Practical Implications

According to NR 538 Section of the Wisconsin Administrative Code, the potential for leaching of heavy metals from fly ash stabilized soil is estimated from a water leach test on bulk fly ash. However, the leaching potential of heavy metals is lower for fly ash stabilized soil than for bulk fly ash. Water leach tests on soil-fly ash mixtures intended for use in field construction may provide more realistic estimates of the leaching potential.

Concentration of metals in leachate collected from the lysimeters installed beneath the fly ash stabilized soils were significantly higher than those in leachate from the water leach test.

However, prediction made with the numerical model of contaminant transport show that the concentration of metals that exists when the leachate reaches the groundwater table depends

significantly on field conditions, and generally is much lower than the concentration measured at the base of the stabilized layer. Thus to evaluate the impact on groundwater, an index test is not sufficient. A systematic evaluation must be conducted to assess each case. The design charts presented in Section 6 of the final report can be used to make such an evaluation. A conservative, yet realistic evaluation can be made with this procedure using only the result of a water leach test performed on the intended soil-fly ash mixture.

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For more information about this project, refer to the final project report on the CBRC Web site at <http://www.wvri.nrcce.wvu.edu/cbrc> or contact Tuncil Edil, P.I., at edil@engr.wisc.edu.



Calendar of Events

September 1, 2004

The abstract deadline for the World of Coal Ash conference is September 1. For information about submitting abstracts, visit the conference Web site at www.worldofcoalash.org/presenters/callforpapers.html.

For sponsorship and exhibit opportunities, see www.worldofcoalash.org/sponsorship/exhibitorinfo.html.

September 13-17, 2004

21st Annual International Pittsburgh Coal Conference: Coal

Energy and the Environment
Osaka, Japan

This conference is being held in Japan this year because "As the world's largest importer of coal, Japan has been extensively utilizing coal in steel production as well as power generation . . ."

For more information, contact the conference secretary at (412) 624-7440 or by e-mail at pcc@engr.pitt.edu, or visit the conference Web site at www.engr.pitt.edu/pcc.

Ashlines is published by the Combustion Byproducts Recycling Consortium, headquartered at West Virginia University in Morgantown, WV. Would you like to be on the CBRC electronic mailing list? If so, please send an e-mail to cbrc@nrcce.wvu.edu.

CBRC CONTACTS

Program Manager

Lynn Brickett, U.S. Department of Energy - National Energy Technology Laboratory
412/386-6574; brickett@netl.doe.gov

National Center

Paul Ziemkiewicz, Ph.D., Director
Tamara Vandivort, Consortium Manager
CBRC National Center located at the National Mine Land Reclamation Center at West Virginia University, 304/293-2867, pziemkie@wvu.edu or tvandivo@wvu.edu

National Steering Committee Chair

Howard Humphrey, American Coal Ash Association, Columbus, Ohio, 614/846-1726, hhumphrey@columbus.rr.com

Eastern Regional Chair

Cheri Miller, Tennessee Valley Authority, Chattanooga, Tenn., 423/751-4419, ecmiller@tva.gov

Midwestern Regional Chair

Tom Robl, Ph.D., University of Kentucky, 859/257-0272, robl@noah.caer.uky.edu

Western Regional Chair

Jacob Gonzales, TXU Energy, Dallas, Texas, 214/812-8328, jake.gonzales@txu.com

Eastern Regional Technical Director

James C. Hower, Ph.D., University of Kentucky, 859/257-0261, hower@caer.uky.edu

Midwestern Regional Technical Director

Paul Chugh, Southern Illinois University at Carbondale, 618/536 6637, chugh@engr.siu.edu

Western Regional Technical Director

Deborah Pflughoeft-Hassett, University of North Dakota, 701/777-5181, dpflughoeft@undecr.org

NSC Committee Members

Jackie Bird, Ohio Coal Development Office, 614/466-3465, jbird@odod.state.oh.us

Taylor Eighmy, University of New Hampshire, 603/862-1065, taylor.eighmy@unh.edu

Paul Ehret, State of Indiana, 317/232-4020, pehret@dnr.state.in.us

Dave Goss, American Coal Ash Association, 720/870-7897, DCgoss@acaa-usa.org

Dave Meadows, USACE-Huntington District, 304/529-5243, david.f.meadows@usace.army.mil

Jim Rower, Utility Solid Waste Activities Group, 202-508-5645, jim.rower@uswag.org

Kimery Vories, Office of Surface Mining, 618/463-6463 ext.103, kvories@mcrgw.osmre.gov

Andy Wittner, USEPA, 703-308-0496
Wittner.Andrew@epamail.epa.gov

Dan Wheeler, Illinois Office of Coal Development and Marketing, 217-558-2645, dwheeler@commerce.state.il.us



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To promote and support the commercially viable and environmentally sound recycling of coal combustion byproducts for productive uses through scientific research, development, and field testing.

Controlling Beach Erosion Using FGD Sludge Products

*Kelly A. Rusch, Ph.D., P.I.,
Roger K. Seals, Ph.D., and
Tingzong Guo, Ph.D.*

Our nation's coastal regions are an invaluable source of natural resources, biological diversity and recreational pleasure. However, coastal erosion is claiming these valuable lands at an alarming yearly rate. The reasons for increased coastal erosion are many and range from increased population growth in the coastal areas to historic decisions to straighten rivers, which has resulted in the loss of alluvial sediment transport to sensitive areas.

Additionally, as barrier islands erode away due to increased storm surges and natural erosion processes, the coastline itself has become more vulnerable. Coastal wetlands are being lost at a rate of 33.5 square miles per year, or one



Aerial view of Louisiana coastline.

acre every 24 minutes (Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority, 1998).

The Gulf and southern Atlantic Coasts are seeing the greatest erosion problems. Louisiana, which

contains approximately 42 percent of the nation's wetlands, is losing about 80 percent of the total area being lost yearly. If this trend continues, it could cost the U.S. \$33.6 billion in lost public use value over the next 50 years (National Coastal Wetlands Conservation

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**CBRC Selects
2004 Projects**

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**Contacts/
Calendar**

VISIT THE CBRC WEBSITE AT [HTTP://WWW.NRCCE.WVU.EDU/CBRC](http://www.nrcce.wvu.edu/cbrc)

CBRC Selects Projects for 2004

On October 23, 2003, the Combustion Byproducts Recycling Consortium (CBRC) National Steering Committee met in Lexington, Kentucky, to select which projects to fund for 2004. (See the contacts list on page 17 for the names and affiliations of CBRC National Steering Committee members.)

There were 59 preproposals received in response to the CBRC request for proposals. Of those 59, 17 were invited to submit full proposals. Six of the 17 full proposals were then selected by the steering

committee to recommend to the U.S. Department of Energy (DOE) for funding. The DOE is to fund all six.

These six new projects are scheduled to start April 1, 2004.

Details on each project will be featured in Winter 2004 issue of *Ashlines*. Also refer to the CBRC's Web site at <http://www.nrcce.wvu.edu/cbrc> for news and final reports from all CBRC sponsored projects.



| Project No. | Title | P.I. | Organization/Affiliation |
|-------------|---|---------|---|
| 00-CBRC-M9 | Field and Laboratory Studies of Arsenic Species and Boron in CCB Leachates and Attenuation by Mine Spoil Material and Evaluation of Long-Term Environmental Performance of the Coal Ash Minefilling of the Universal Surface Mine Pit | Muraka | Ish, Inc. |
| 00-CBRC-E10 | Commercialization of Production Foundry Molds Made From CCBs for High Volume Automotive Applications | Purgert | Energy Industries of Ohio |
| 02-CBRC-E6 | Prediction of the Effects of Placing CCBs in Contact with Mine Spoil | Gutta | West Virginia University |
| 02-CBRC-W9 | Power Plant Combustion Byproducts for Improved Crop Productivity of Agricultural Soils | O'Neill | Agricultural Center at Farmington, New Mexico |
| 02-CBRC-W12 | Engineering and Environmental Specification for State Agencies for Utilization and Disposal of Coal Combustion Products | Dockor | University of North Dakota |
| 02-CBRC-M12 | Manufacturing Fired Bricks with Class F Fly Ash from Illinois Basin Coals | Chou | Illinois State Geological Survey |

Controlling Beach Erosion Using FGD Sludge Products

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Grant Program, 2000; and Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority, 1998).

As important, the loss of coastal areas has started to threaten entire communities and cities. A good example of the seriousness of the issue was summarized in a recent *Time* magazine article titled "The Big Easy on the Brink." As stated in the article, "New Orleans will be the next lost city of Atlantis if measures are not taken to slow down and minimize the coastal erosion process" (Cohen, 2000).

While New Orleans may be a special case, it serves as a global example of the ramifications of coastal erosion and lost wetlands. Recognizing the national significance of lost wetlands, the U.S. Congress passed the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA, Breau Act) (Public Law 101-646, Title III) to contribute federal monies yearly to wetland restoration projects. Additionally, since the CWPPRA's inception in 1990, the U.S. Fish and Wildlife Service has been working with coastal states to acquire, restore, manage and enhance coastal wetlands through a matching grants program. To date, approximately \$32 million dollars have been awarded to 23 coastal states and U.S. territories, with 40,000 acres of coastal wetlands being acquired, restored or enhanced (Louisiana Coastal Restoration, 2000).

The entire nation is experiencing wetland lost and coastal erosion problems. However, since Louisiana has the largest percentage of wetlands, much focus has been

placed on this state. The State of Louisiana legislature passed the Louisiana State and Local Coastal Resources Management Act in 1978. In 1989, the Louisiana Legislature passed Act 6 of the second extraordinary session (R.S. 49:213-214) and a subsequent constitutional amendment that created the Coastal Restoration Division within the Louisiana Department of Natural Resources.

Thus, Louisiana has a commitment to restore wetlands and decrease the amount of barrier island loss. Loss of these valuable entities has far-reaching implications that go beyond lost recreational lands. The barrier islands and wetlands also provide unique habitats for thousands of flora and fauna and provide protection from storm surges created by tropical storm and hurricane conditions.

The wetlands and coastal areas associated with Louisiana serve as a nursery for many of the Gulf Coast aquatic organisms. Thus, loss of these areas will have a devastating impact on the entire Gulf region.

Five federal partners (the Natural Resources Conservation Service, National Marine Fisheries, U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, and U.S. Army Corps of Engineers) along with the State of Louisiana, develop, budget, and approve construction projects based on four basic engineering techniques:

- structural,
- sedimentary,
- hydrologic, and
- vegetative.

The structural techniques minimize erosion and soil breakdown

caused by wave and tidal action. The sedimentary techniques create new wetlands or protect existing wetlands. The hydrologic technique controls water so that it benefits wetlands growth. And, the vegetative techniques reinforce existing wetlands and minimize soil erosion.

A number of engineering approaches have been used to counteract erosion along populated coastlines. Traditional protective measures have included structures such as seawalls, revetments, groins and detached breakwaters. These structures are made of stone, limestone, concrete and steel (Whiteneck and Lester, 1989), all of which are relatively expensive.

Within Louisiana, the majority of material used as rip-rap and for dike construction is limestone mined and barged from Arkansas at a cost of \$36 to \$52 per ton of material (in place), with needed quantities in the tens of thousands of tons per project (LADNR, 2000). Shoreline erosion dike construction generally consists of a 4-ft.-wide crown with a 2 or 3:1 ratio back slope, and a 3 or 4:1 ratio front slope (water side). Normally, the dikes are 2 to 3 ft. above the water line. The end result is the need for tremendous amounts of limestone.

Besides cost, one of the problems with the use of limestone rip-rap is the excessive settlement of the embankment due to the consolidation of the underlying soils created by the limestone weight burden. Thus, the use of lightweight materials can potentially minimize this problem.

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Controlling Beach Erosion Using FGD Sludge Products

(continued from page 5)

Coal combustion byproduct (CCB) fill material could be used in conjunction with geogrid material as the light-weight core material, with limestone used as an armoring. This configuration would dramatically cut costs by reducing the amount of needed limestone and would reduce the overall weight burden. The development of economically competitive alternative fill materials using waste FGD sludge and class C fly ash would not only provide a use of these byproduct materials, but would also result in the establishment of a marketable industry.

The Coal Combustion Recycling Consortium (CBRC) in conjunction with the U.S. Department of Energy sponsored research conducted at Louisiana State University (LSU) to specifically explore the use of waste FGD sludge and

The Study

Of the more than 90 million tons of CCBs produced by the utility industry every year, greater than 20 million tons is FGD byproducts (ACAA, 1998). As the demand for cleaner burning increases, more utilities are using forced oxidation, resulting in more waste FGD sludge produced. There are three kinds of FGD byproducts:

1. refined FGD gypsum (93 percent $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ and 7 percent $\text{CaSO}_3 \cdot 0.5\text{H}_2\text{O}$),
2. FGD gypsum (70 to 93 percent $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ and 7 to 30 percent $\text{CaSO}_3 \cdot 0.5\text{H}_2\text{O}$), and
3. FGD sludge (60 to 70 percent $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ and 30 to 40 percent $\text{CaSO}_3 \cdot 0.5\text{H}_2\text{O}$).

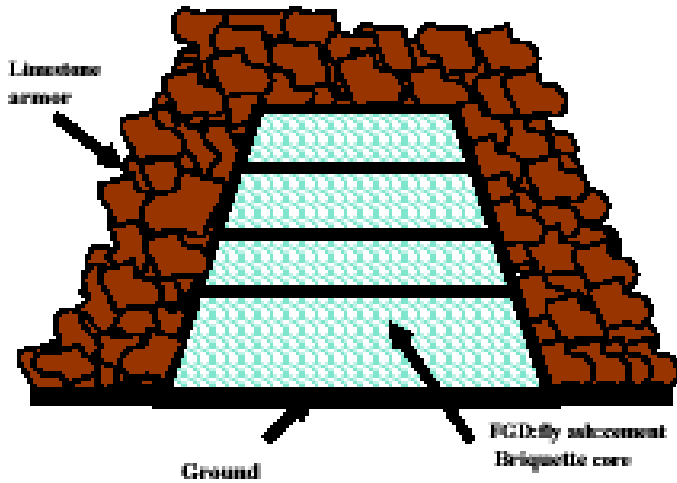


Figure 1—Ground FGD Fly Ash Cement Briquette Core with Limestone Armor

The first two kinds of FGD gypsum have been used for wall-board and cement additives, and, therefore, have commercial value. FGD sludge is a solid waste with no commercial value. The utility industry has to pay for its disposal. As of December 1994, there were at least 157 coal-fired boiler units at 92 power plants that had operating wet scrubbing systems. These plants are located in at least 32 states (U.S. DOE, 1995). Although efforts have been focused on the reuse of FGD byproducts (mainly for terrestrial applications, such as road bases, bituminous mixtures, concrete admixtures, etc.), only small amounts are currently used.

In 1998, 1.5 million tons of FGD byproduct was used to produce wallboard and 0.2 million tons of FGD byproduct was used to replace gypsum in the cement production. The other major uses included mining application (0.15 million tons), road base/subbase (0.08 million tons), and agriculture (0.05 million tons) (Robbins et al.,

2000; ACAA, 1998; Smith, 1998,1985, and 1982; Amaya et al., 1997; Prusinski et al., 1995; and EPRI, 1995).

The remainder of the material is disposed of in holding ponds or landfills. Stabilization or fixation and placement in landfills is the most common method of disposal (U.S. DOTD, 2000).

The use of CCBs for aquatic applications has not been pursued as extensively as terrestrial applications. However, some early work done in the 1980s demonstrated the feasibility of using FGD: fly ash composites for artificial reef material (NYSEROA, 1985; and Parker and Woodhead, 1983).

Coal waste blocks were constructed using a fly ash to FGD ratio of 1:1 to 3:1, and resulting in a volume of 16,000 cm^3 . The blocks were fabricated using conventional concrete block making equipment and cured, resulting in a cured strength of 2000 kPa. The blocks were placed in the sea near Long Island, New York, to form an artificial reef. The reef had a relief

of approximately 1 m. and a length of 70 m., and covered 1,200 m². Following two years of monitoring, the reef had a well-established epifaunal community encrusting the blocks. No accumulation of trace metals was found in organisms associated with the reef, suggesting the compatibility of stabilized coal waste usage within the aquatic environment (Woodhead and Parker, 1983; George et al., 1983; and Rose, 1983).

While these results demonstrate the feasibility of using fly ash/waste FGD composites within the aquatic environment, they were not used in weight bearing situations. Little literature is available on the use of waste FGD sludge and class C fly ash in mechanically stabilized marine structures. This use must not only consider the environmental suitability of placing this material in the environment, but also the structural/geotechnical properties to assure the material can provide strength to the structure.

Portland type II cement was chosen as a binding agent with sulfate resistance. The Class C fly ash was chosen because it is a low cost binding agent. The Class C fly ash can also prevent the formation of ettringite that can cause rupture development of cement stabilized FGD briquettes. The selection of mixture ratios and compaction pressure is more critical for the fabrication of composites for marine use than for terrestrial use due to the highly soluble nature of gypsum (CaSO₄, approximately 4 g/L in full strength saltwater) (Jame, 1992), which is a major component of waste FGD sludge.

Thus, in the development of waste FGD sludge briquettes for marine applications, one must consider not only the mechanical/

physical properties of the composite, but also the utilization of admixtures to encapsulate the material and prevent it from dissolving once submerged.

Objectives

The overall goal of this study was to determine the feasibility of utilizing CCBs (waste FGD sludge and class C fly ash) as construction materials in coastal protection structures. The specific objectives of this research were the following:

1. to refine the mixture composition for stabilized FGD sludge briquettes consisting of waste FGD sludge, class C fly ash, and Portland type II cement; and
2. to evaluate the pertinent environmental (long-term environmental impact from dynamic leaching, TCLP required by U.S. EPA), geotechnical engineering properties (specific gravity, compaction and sieve analysis) and salt water survivability of the stabilized FGD sludge briquettes.

Methodology

Raw Materials and Fabrication

Raw flue gas desulfurization (FGD) sludge was obtained from Big Bend Electric Company, Tampa, Florida. The FGD was oven-dried at 45 to 50°C for 6 to 12 hours, depending on moisture content. The oven temperature was checked twice a day and adjustments made if necessary. The dried FGD was crushed and passed through a 1.46-mm sieve. Type II Portland cement used was obtained from the River Cement Co., St. Louis, Missouri and class C fly

ash from Bayou Ash Inc., Erwinville, Louisiana.

FGD Block Fabrication

Blocks of ten different composite combinations using FGD, class C fly ash, and Portland Type II cement were fabricated for screening purposes. The initial ten stabilized ingredient combinations (Table 1), which were selected using factorial design method. Fabrication of blocks was done in the Louisiana State University (LSU) concrete lab. Dried, ground FGD passed through a 1.46 mm sieve, dried Portland type II cement and class C fly ash were combined according to the compositions in Table 1. The ingredients were homogenized and mixed with water equivalent to 8 percent of the dry mixture.

Eighty-nine grams of the resulting mixture were poured into a 3.9-cm-diameter steel mold and compacted to a 3.6-0cm-long cylinder under a pressure of $9.8 \cdot 10^7$ N/m² using a static press. The composites were allowed to cure at room temperature and 100 percent humidity for over two weeks before testing. The mean mass of all FGD blocks was 87.1 g, with a solid density of 2.05 g/cm³.

Briquette Fabrication

Stabilized FGD briquettes for investigating the feasibility of using FGD composites as coastal protection materials were fabricated by K.R. Komerack Briquetting and Research, Inc., Anniston, Alabama. The five best composite combinations from the screening phase were briquetted (Table 2). The FGD briquettes had an average biomass of 29.5 g and a solid density of 2.0 g/cm³.

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Controlling Beach Erosion Using FGD Sludge Products

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Chemical Characterization

Dynamic Leaching Test

A dynamic leaching test was performed to evaluate the long-term environmental effects of the stabilized solid wastes. A variation of the dynamic leach test (ANS, 1986) was performed for both the screening and final evaluation studies.

During the screening process, leachate from FGD blocks was collected and analyzed for calcium and sulfate, which is used as indicators of the dissolution potential of the block/briquette. During final evaluation of the selected briquettes, leachate from the FGD briquettes was collected and analyzed for calcium and sulfate. The leachate volume to surface area ratio was 8:1. The composites were placed in 550 mL of 20 ppT artificial seawater (Instant Ocean™). The leachant was completely exchanged at intervals of 0.80, 0.29, 1, 2, 3, 4, 5, 8, 11, 14, 21 and 28 days. The experiments were performed in duplicate. The data from the leaching tests were used as the basis for the diffusion model.

Toxicity Characteristic Leaching Procedure (TCLP)

The TCLP (U.S. EPA, 1990c) test is designed to simulate the leaching a waste would undergo if disposed in an unlined sanitary landfill. The extraction fluid volume to crushed FGD briquette volume was 20:1.

One hundred grams of the crushed briquette were agitated with 2000 mL of extraction fluid (acetic acid solution having a pH of 2.88+/-0.05) for 20 hours, and then the liquid was passed through 7 µm glass fiber filter to obtain the TCLP extract. The extract was digested

Table 1—Composition of the initial ten stabilized FGD sludge/class C fly ash/Portland type II cement combinations, which underwent a dynamic leaching test for screening.

| FGD Sludge (%) | Class C fly ash (%) | Portland type II cement (%) |
|----------------|---------------------|-----------------------------|
| 77 | 20 | 3 |
| 73 | 25 | 2 |
| 72 | 25 | 3 |
| 69 | 30 | 1 |
| 68 | 30 | 2 |
| 67 | 30 | 3 |
| 64 | 35 | 1 |
| 63 | 35 | 2 |
| 62 | 35 | 3 |
| 60 | 40 | 0 |

Table 2—Five composite combinations selected of the screening were briquetted for further testing.

| FGD: Class C fly ash: Portland type II cement | Water (%) | Average Briquette Weight (g) | Amount (lb) |
|---|-----------|------------------------------|-------------|
| 77%:20%:3% | 5.0 | 29.91 | 69 |
| 64%:35%:1% | 8.0 | 30.46 | 69 |
| 63%:35%:2% | 8.0 | 29.98 | 69 |
| 69%:30%:1% | 8.0 | 28.77 | 69 |
| 67%:30%:3% | 8.0 | 28.52 | 69 |

with nitric acid using the U.S. EPA 3015 method; the digested extract was analyzed for As, Cr, Cd, Pb, Se. If the TCLP extract contains any one of the 40 Toxicity Characteristics (TC) constituents in amounts equal to or greater than that specified in 40CFR 261.24 (1992), then the waste will be declared a hazardous waste.

Sulfate, Calcium and Metal Concentration Measurements

Leachate from the dynamic leaching tests was analyzed for calcium, sulfate. The leachate was analyzed for alkalinity in accordance to *Standard Methods* (APHA, 1998). The extraction fluid from TCLP was analyzed for cadmium, chromium, lead, selenium and arsenic using ICP.

Physical Characterization

Surface Hardness

A cone penetrometer (Model No. WF 21510, Humboldt Mfg., Inc.) was used to measure the penetration depth of the dry, leached FGD briquettes following the *British Standard Methods of Testing Soils for Engineering Purposes* (BS 1377:1977).

The inverse of the penetration depth was used as a measurement of the surface hardness. Hardness at 6 different points was measured for the briquettes and its average value was used to calculate surface hardness of the briquettes.

Porosity Measurement

The porosity of the briquettes was measured by weight loss and effective diffusion coefficients. The FGD briquettes were immersed in tap water for 24 hours and then weighed (W1). The briquettes were then dried in oven at 50°C for 24

hours and then weighed (W2). The difference in the weights W1 and W2 is the weight of water filled by the pore spaces.

The weight of water in the pores can be converted by divided by density of water. The porosities were calculated as pore water volume divided by composite volume.

Geotechnical Characterization

Compaction Characteristics

This test was carried out for briquettes as similar to that carried out for coarse aggregates (ASTM D698-00a). Raw FGD exhibits thixotropic properties hence compaction criteria are not specified in ASTM standards.

The time interval between wetting and compaction in the laboratory was similar to that anticipated during construction.

Sieve Analysis

The sieve analysis was conducted on the crushed materials obtained from the compaction tests giving the complete picture of physical degradation the briquettes will undergo when subject to the worst case loading.

Field Submergence

To study the survivability and dissolution potential for the FGD composites in the natural saltwater environment, five FGD briquettes of each selected combination were submerged in a bay located at Port Fourchon, Louisiana. The briquettes were tied with colored tags and placed in autoclaving baskets (Nalgene Brand) and suspended in the water column subjecting them to natural currents and tides and maximizing the interaction potential with various aquatic organisms. Monthly observations were made to determine

deterioration of the briquettes.

Market Analysis

The initial economic analysis performed at LSU for the PG briquetting process was used as a foundation of the economic analysis of the stabilized FGD sludge briquettes. The analysis assumes a 4,500,000-ton FGD sludge briquettes per year production facility located near Tampa, Florida. All cost figures are in the year of 2002.

Data Analysis

Diffusion of calcium and sulfur from the FGD blocks/briquettes is an indicator of dissolution rate. Determination of the effective diffusion coefficients is needed to predict the long-term stability of the briquettes in the marine environments. Duedall et al. (1983) developed a diffusion model based on Fick's second law of diffusion

Equation 1

$$\frac{\partial C}{\partial t} = D_e \left(\frac{\partial^2 C}{\partial x^2} \right),$$

for $0 < x < \infty$ and $0 < t$,

where

C = the ion concentration with C_0 being the initial concentration of the species,

D_e = the effective diffusion coefficient of ions in the FGD briquette,

x = the one-dimensional coordinate system for the briquette extended from the water interface at $x=0$ to the briquette center at $x=+\infty$, and

t = time.

This model is one-dimensional for ions in solidified briquettes and

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Controlling Beach Erosion Using FGD Sludge Products

(continued from page 7)

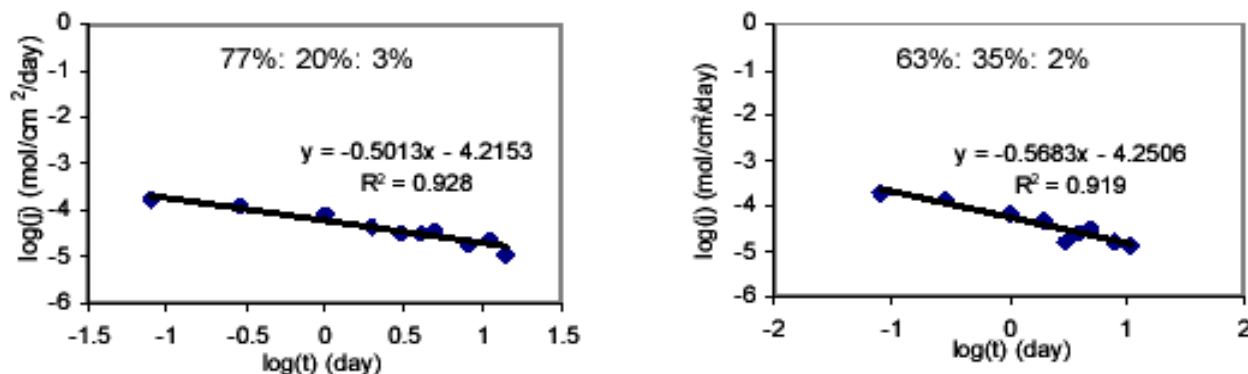


Figure 2—Calcium effective diffusion coefficients for 77 percent, 20 percent, 3 percent, and 63 percent, 35 percent, 2 percent FGD/class C Fly Ash/Portland Type II Cement Composite Blocks was Estimated by Plots of Log (J) vs. log (t).

in well-stirred aqueous systems. It assumes a uniform distribution of diffused ions in the briquette and a flux of the ions across the water-water interface that is proportional to the concentration at the interface.

The initial and boundary conditions for the one dimensional diffusion equation are

Equation 2

Initial Condition: $C(x,0) = C_0$

Boundary Condition 1 (as x approached infinity):

$$De \left(\frac{\partial C}{\partial x} \right) = hC \quad \text{for } x=0 \text{ or } \lim_{C \rightarrow C_0} \frac{1}{C} \frac{\partial C}{\partial x} \rightarrow \frac{h}{D_e}$$

where

h = the transfer coefficient $\lim_{C(x,t) \rightarrow C_0} C$

Boundary Condition 2 (as x approaches infinity):

The solutions for the above equation where release of the parameter of interest is controlled by diffusion in the briquettes, $h \rightarrow \infty$, are

Equation 3

$$C(x,t) = C_0 \operatorname{erf} \left(\frac{x}{2\sqrt{D_e t}} \right)$$

$$J = C_0 \sqrt{\frac{D_e}{\pi t}}$$

where

J = the daily flux of ions.

The diffusion coefficient ($m^2 \sec^{-1}$) can be obtained from the equation $De = \pi t (J / C_0)^2$. This model is widely applied for diffusion coefficient calculations (Edwards and Duedall, 1985; Cote,

Results and Discussion

Block Fabrication and Screening

The one-dimensional diffusion model in combination with the leaching data was used to calculate the effective diffusion coefficients (D_e) for calcium and sulfur (sulfate and sulfite). The diffusion coefficients were then used in conjunction with an economic analysis to select appropriate combinations for further testing.

Calcium Effective Diffusion Coefficients and Effective Diffusion Depths for FGD Blocks

Representative illustrations of logarithmic plots of J (Ca^{2+} , daily flux) vs. time are shown Figure 2. The slopes of the regression equations (Table 3) fell within the range of the theoretical values for diffusion (-0.5) and dissolution (-0.8). Effective diffusion coefficients for the ten composites ranged from 1.34 to $3.41 \times 10^{-13} m^2$

Table 3—The effective calcium diffusion coefficients and effective diffusion depths ($t=1$ year and 30 years) were estimated for the FGD: Class C fly ash: Portland type II cement composite blocks subjected to the 28-day dynamic leaching study.

| FGD Sludge (%) | Class C fly ash (%) | Portland type II cement (%) | D_e ($m^2 s^{-1} \times 10^{-13}$) | Intercept | Slope | Mean D_e ($m^2 s^{-1} \times 10^{-13}$) | Mean X_e (mm) ($t=1$ year) | Mean X_e (mm) ($t=30$ years) |
|----------------|---------------------|-----------------------------|--|-----------|--------|---|-------------------------------|---------------------------------|
| 77 | 20 | 3 | 1.579 | -4.215 | -0.501 | 2.068 | 3.58 | 19.64 |
| 77 | 20 | 3 | 2.556 | -4.108 | -0.581 | | | |
| 73 | 25 | 2 | 3.208 | -4.084 | -0.631 | 3.086 | 4.41 | 24.16 |
| 73 | 25 | 2 | 2.965 | -4.108 | -0.650 | | | |
| 72 | 25 | 3 | 3.672 | -4.093 | -0.624 | 3.393 | 4.71 | 25.84 |
| 72 | 25 | 3 | 3.114 | -4.035 | -0.664 | | | |
| 69 | 30 | 1 | 3.860 | -4.069 | -0.610 | 3.452 | 4.65 | 25.51 |
| 69 | 30 | 1 | 3.045 | -4.120 | -0.515 | | | |
| 68 | 30 | 2 | 1.867 | -4.2329 | -0.430 | 2.231 | 3.73 | 20.48 |
| 68 | 30 | 2 | 2.595 | -4.1614 | -0.725 | | | |
| 67 | 30 | 3 | 2.416 | -4.1834 | -0.649 | 2.486 | 3.96 | 21.69 |
| 67 | 30 | 3 | 2.555 | -4.1721 | -0.685 | | | |
| 64 | 35 | 1 | 1.933 | -4.2517 | -0.816 | 1.638 | 3.20 | 17.53 |
| 64 | 35 | 1 | 1.342 | -4.3309 | -0.774 | | | |
| 63 | 35 | 2 | 2.086 | -4.242 | -0.614 | 2.046 | 3.59 | 19.67 |
| 63 | 35 | 2 | 2.005 | -4.250 | -0.568 | | | |
| 62 | 35 | 3 | 2.986 | -4.171 | -0.624 | 3.079 | 4.40 | 24.14 |
| 62 | 35 | 3 | 3.173 | -4.157 | -0.606 | | | |
| 60 | 40 | 0 | 2.633 | -4.212 | -0.751 | 2.225 | 3.75 | 20.57 |
| 60 | 40 | 0 | 1.870 | -4.286 | -0.756 | | | |

• s^{-1} , while effective diffusion depths ranged from 17.53 to 25.64 mm for 30 years submergence. These values are comparable to the values from previous research (10^{-13} to $10^{-14} m^2 \cdot s^{-1}$) for Phosphogypsum/Class C fly ash/Portland type II cement composites (Guo et al, 2000, Rusch et al, 2001a).

Sulfur (sulfate + sulfite) Effective Diffusion Coefficients and Effective Diffusion Depths for FGD Blocks

Representative illustrations of logarithmic plots of J (S, daily flux) vs. time are shown in Figure 3. The slopes of the regression equations (Table 4) fell within the range of the theoretical values for diffusion

(-0.5) and dissolution (-0.8). The effective diffusion coefficients for the ten composites ranged from $1.02 m^2 \cdot s^{-1}$ to $2.45 \times 10^{-13} m^2 \cdot s^{-1}$ while effective diffusion depths ranged from 13.89 to 36.53 mm for 30 years submergence (Table 4). These values are slightly higher than the calcium effective diffusion coefficients obtained in this study but are comparable to the values from previous research (10^{-13} to $10^{-14} m^2 \cdot s^{-1}$) for Phosphogypsum: Class C fly ash: Portland type II cement composites (Rusch et al, 2001a). FGD dissolves to form Ca^{2+} , SO_3^{2-} and SO_4^{2-} . SO_3^{2-} can be oxidized into SO_4^{2-} , which is still in the

solution state. Ca^{2+} , on the otherhand, may undergo minimal reactions to form calcite. Thus, sulfur may be considered a better indicator than calcium for the FGD sludge dissolution process.

Selection of Best Composite for Further Testing

Effective diffusion coefficients (D_e) and economics were the two criteria used to determine which of the initial ten compositions were to be subjected to further testing. The limestone used in Louisiana Coastal protection projects average cost of \$36 to \$52/ton. Thirty percent of the average limestone cost is chosen as economic criteria (\$13/ton). The composites must have met at least one of the D_e (calcium, or sulfur) and the target economic value (\$13/ton) to be included in the further experiments.

Based on saltwater submergence experiments from previous results, it was found that 63 percent, 35 percent, 2 percent phosphogypsum/class C fly ash: Portland Type II cement composites can survive for more than two years (Guo et al., 2001). Thus, the Ca^{2+} and SO_4^{2-} effective diffusion coefficients for this composite were used as the maximum allowable levels for selecting FGD: Class C fly ash: Portland type II cement composites for further testing.

The effective diffusion coefficients for Ca^{2+} and SO_4^{2-} are 1.51×10^{-13} and $1.63 \times 10^{-13} m^2 \cdot s^{-1}$, respectively (Rusch, 2001b). Considering the deviations, the maximum allowable values for Ca^{2+} and S (sulfate + sulfite) for FGD selection were selected to be 2.0×10^{-13} and $2.1 \times 10^{-13} m^2 \cdot s^{-1}$, respectively.

(continued on page 10)

Controlling Beach Erosion Using FGD Sludge Products

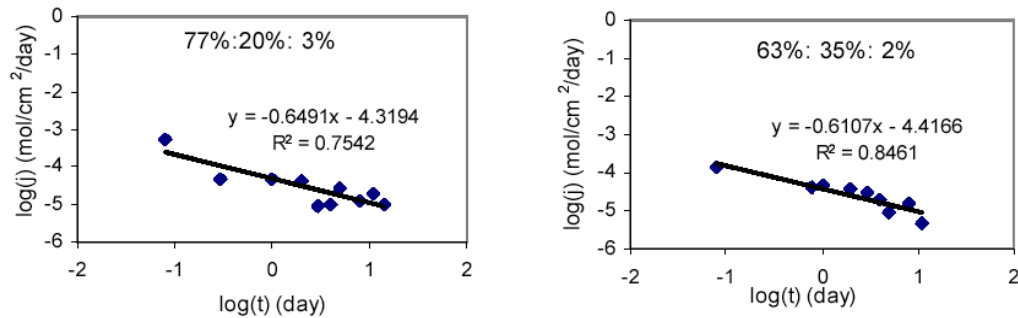


Figure 3—Sulfur Effective Diffusion Coefficients for 77%:20%:3% and 63%:35%:2% FGD: Class C Fly Ash:Portland Type II Cement Composite Blocks was Estimated by Plots of Log (J) Vs log (t).

Table 4.—The Effective Sulfur Diffusion Coefficients and Effective Diffusion Depths (t = 1 year and 30 years) Were Estimated for the FGD: Class C fly Ash/Portland type II Cement Composites Subjected to the 28-Day Dynamic Leaching Study.

| FGD Sludge (%) | Class C fly ash (%) | Portland type II cement (%) | Intercept | Slope | D_e (m ² s ⁻¹ × 10 ⁻¹³) | Mean D_e (m ² s ⁻¹ × 10 ⁻¹³) | Mean X_e (mm) (t=1 year) | Mean X_e (mm) (t=30 years) |
|----------------|---------------------|-----------------------------|-----------|--------|---|--|----------------------------|------------------------------|
| 77 | 20 | 3 | -4.319 | -0.649 | 0.978 | 1.296 | 2.83 | 15.54 |
| 77 | 20 | 3 | -4.210 | -0.813 | 1.615 | | | |
| 73 | 25 | 2 | -4.143 | -0.692 | 2.447 | 2.348 | 3.84 | 21.08 |
| 73 | 25 | 2 | -4.161 | -0.727 | 2.250 | | | |
| 72 | 25 | 3 | -4.273 | -0.788 | 1.342 | 2.174 | 3.63 | 19.89 |
| 72 | 25 | 3 | -4.097 | -0.739 | 3.007 | | | |
| 69 | 30 | 1 | -4.218 | -0.638 | 1.941 | 2.143 | 3.67 | 20.13 |
| 69 | 30 | 1 | -4.176 | -0.564 | 2.350 | | | |
| 68 | 30 | 2 | -4.146 | -0.782 | 2.776 | 2.304 | 3.79 | 20.77 |
| 68 | 30 | 2 | -4.236 | -0.817 | 1.833 | | | |
| 67 | 30 | 3 | -4.240 | -0.956 | 1.854 | 1.643 | 3.21 | 17.59 |
| 67 | 30 | 3 | -4.297 | -0.768 | 1.432 | | | |
| 64 | 35 | 1 | -4.140 | -0.523 | 1.638 | 1.051 | 6.67 | 36.53 |
| 64 | 35 | 1 | -4.193 | -0.870 | 1.634 | | | |
| 63 | 35 | 2 | -4.379 | -0.706 | 1.107 | 1.022 | 2.53 | 13.89 |
| 63 | 35 | 2 | -4.416 | -0.610 | 0.936 | | | |
| 62 | 35 | 3 | -4.287 | -0.636 | 1.746 | 1.683 | 3.25 | 17.84 |
| 62 | 35 | 3 | -4.303 | -0.544 | 1.620 | | | |
| 60 | 40 | 0 | -4.764 | -0.543 | 3.290 | 2.451 | 3.87 | 21.21 |
| 60 | 40 | 0 | -4.815 | -0.505 | 1.612 | | | |

Table 5.—The application of the D_e and economic criteria resulted in the selection of five FGD Sludge/Class C fly ash/Portland type II cement combinations for further testing.

| FGD (%) | Class C fly ash (%) | Portland type II cement (%) | Selected by Ca ²⁺ | Selected by Sulfur | Estimated Cost (\$/ton) |
|---------|---------------------|-----------------------------|------------------------------|--------------------|-------------------------|
| 77 | 20 | 3 | Yes | Yes | 10.15 |
| 64 | 35 | 1 | Yes | Yes | 12.26 |
| 63 | 35 | 2 | Yes | Yes | 12.94 |
| 69 | 30 | 1 | No | Yes | 11.10 |
| 67 | 30 | 3 | No | Yes | 12.46 |
| 68 | 30 | 2 | No | Yes | 11.78 |
| 73 | 25 | 3 | No | No | 10.62 |
| 72 | 25 | 3 | No | No | 11.30 |
| 62 | 35 | 3 | No | No | 13.62 |
| 60 | 40 | 0 | No | No | 12.73 |

The economic analysis framework developed for a phosphogypsum briquetting plant was expanded and updated for FGD (Rusch et al., 2001). The estimated costs of the ten stabilized FGD block combinations are listed in Table 5. The first five combinations met the criteria for selection for further testing.

Briquette Fabrication and Testing—Final Analysis

Briquetting solid wastes has the advantages of low production cost and easy handling. Therefore, the commercial application of solid wastes has to be in the form of briquettes.

Sulfur (sulfate + sulfite) Effective Diffusion Coefficients and Effective Diffusion Depths of the Stabilized FGD Briquettes

The logarithmic plots of J (S, flux) vs. time are shown in Figure 4. The effective diffusion coefficients of sulfur for the five selected FGD briquettes ranged from 2.63 m² • s⁻¹ to 4.16 • 10⁻¹³ m² • s⁻¹, while effective diffusion depths ranged from 11.8 to 25.1 mm for 30 years submergence (Table 6). These

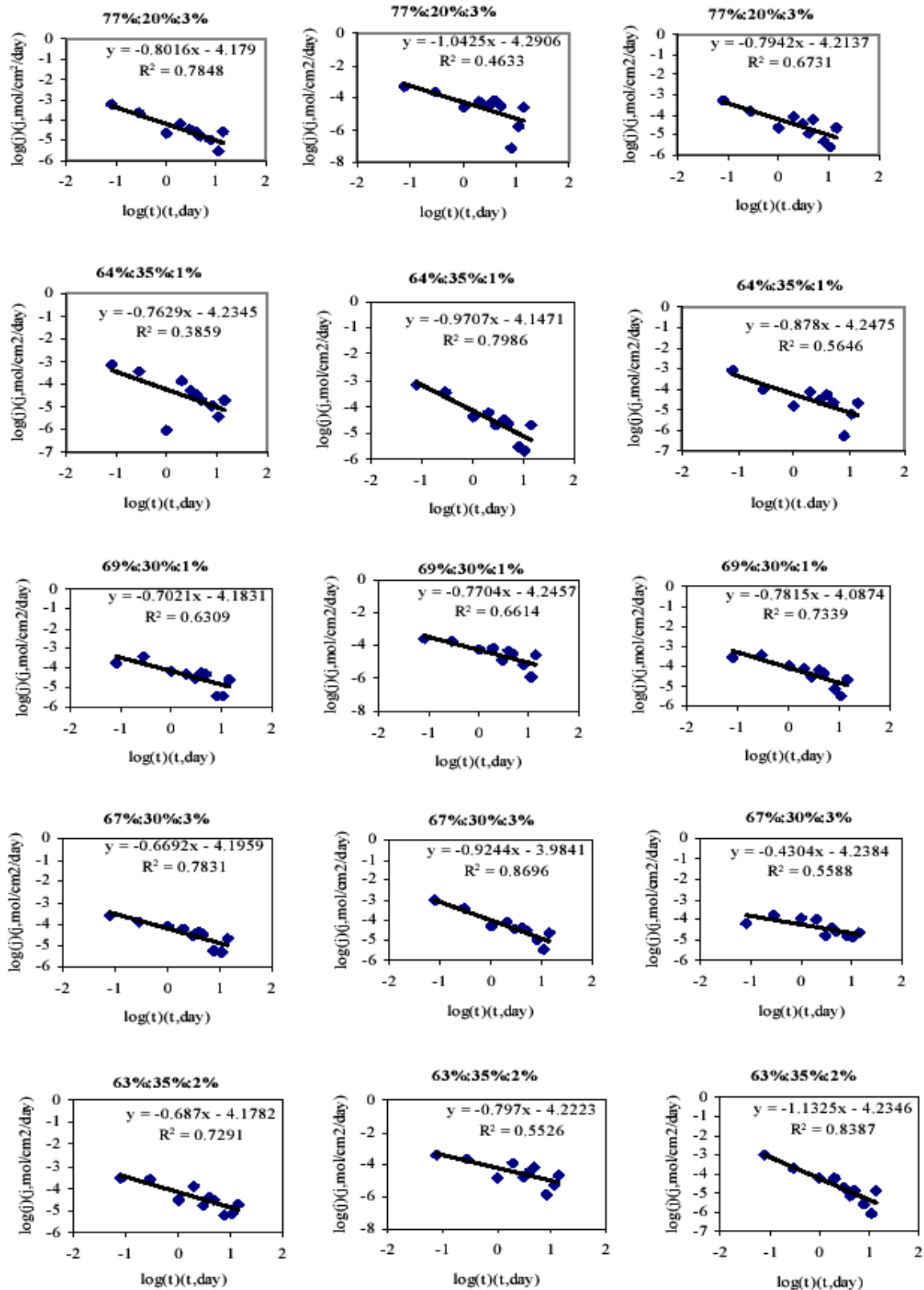


Figure 4—Sulfate effective diffusion coefficients for five FDG/class C fly ash/Portland type II cement briquettes were estimated by plots of $\log(I)$ vs. $\log(t)$.

(continued on page 12)

values are 1.3- 4 times higher than the sulfur effective diffusion coefficients of the FGD blocks obtained in this study but are comparable to the values from previous research (10^{-13} to 10^{-14} $\text{m}^2 \cdot \text{s}^{-1}$) for Phosphogypsum/class C fly ash/Portland Type II cement composites (Rusch et al, 2001a) and other research (10^{-13} to 10^{-14} $\text{m}^2 \cdot \text{s}^{-1}$) from Duedall (1983). The leachate was not analyzed for calcium due to limited funding hence the effective diffusion coefficients for calcium are not available.

TCLP Test

The ICP analysis results of the TCLP leachate solution are shown in Table 7. The Cd, Pb, Cr, Se and As concentrations in the leachate are far below the maximum concentrations that can be classified as hazardous materials.

Surface Hardness

The surface hardness is estimated for the dried FGD/class C fly ash/Portland type II cement briquettes subjected to the 28-day dynamic leaching study are listed in Table 8. When binding agent content is high, the surface hardness is high. These readings imply that the surface hardness may be used as an indicator for surface dissolution potential for the FGD briquettes.

Comparison of the Porosities from Weight and Effective Diffusion Coefficient

Porosities can be obtained many ways. The porosities obtained during this study were calculated from weight and effective diffusion coefficient measurements.

There is a relationship between effective diffusion coefficient and porosity: $D_e = D_o \phi^2$ (Ullman and Aller 1982). Where D_e is the ion effective diffusion coefficient in the porous media; D_o is the ion diffu-

Table 6—The effective sulfate, (SO_4^{2-}) diffusion coefficients and effective diffusion depths ($t = 1$ year and 30 years) were estimated for the FGD: class C fly ash: Portland type II cement composite briquettes subjected to the 28-day dynamic leaching study.

| FGD (%) | Class C fly ash (%) | Portland type II cement (%) | D_e ($\text{m}^2 \cdot \text{s}^{-1} \times 10^{-13}$) | Average ($\text{m}^2 \cdot \text{s}^{-1} \times 10^{-13}$) | X_e (mm) ($t=1$ year) | X_e (mm) ($t=30$ years) |
|---------|---------------------|-----------------------------|--|--|--------------------------|----------------------------|
| 77 | 20 | 3 | 6.57 | 3.22 | 4.22 | 23.13 |
| 77 | 20 | 3 | 1.31 | | | |
| 77 | 20 | 3 | 1.78 | | | |
| 64 | 35 | 1 | 2.19 | 4.16 | 4.97 | 27.23 |
| 64 | 35 | 1 | 7.01 | | | |
| 64 | 35 | 1 | 3.27 | | | |
| 63 | 35 | 2 | 2.46 | 2.63 | 4.06 | 22.28 |
| 63 | 35 | 2 | 2.42 | | | |
| 63 | 35 | 2 | 3.00 | | | |
| 69 | 30 | 1 | 1.98 | 2.87 | 4.21 | 23.10 |
| 69 | 30 | 1 | 4.03 | | | |
| 69 | 30 | 1 | 2.62 | | | |
| 67 | 30 | 3 | 2.32 | 3.38 | 4.45 | 24.37 |
| 67 | 30 | 3 | 5.98 | | | |
| 67 | 30 | 3 | 1.84 | | | |

Table 7—Analysis of TCLP extracts of FGD: class C fly ash:/Portland Type II cement briquettes for presence of various metals by ICP.

| Elements | 77%:20% :3% (ppm) | 64%:35% :1% (ppm) | 63%:35% :2% (ppm) | 69%:35% :1% (ppm) | 67%:30% :3% (ppm) | Maximum Conc. USEPA (ppm) |
|----------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|---------------------------------|
| Arsenic | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | 5.0 |
| Cadmium | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | 1.0 |
| Chromium | 0.08 | 0.076 | 0.083 | 0.07 | 0.076 | 5.0 |
| Lead | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | 5.0 |
| Selenium | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | 1.0 |

Table 8—The surface hardness, which was measured at six different points on the leached briquettes, showed that surface hardness is approximately proportional to the amount of binding agents.

| FGD (%) | Class C fly ash (%) | Portland type II cement (%) | Surface Hardness (mm^{-1}) Average of Six points (mm^{-1}) | Overall Average (mm^{-1}) |
|---------|---------------------|-----------------------------|--|---|
| 77 | 20 | 3 | 75.4 | 81.9 |
| 77 | 20 | 3 | 84 | |
| 77 | 20 | 3 | 81.9 | |
| 64 | 35 | 1 | 64.9 | 67.7 |
| 64 | 35 | 1 | 65.3 | |
| 64 | 35 | 1 | 67.7 | |
| 63 | 35 | 2 | 69.8 | 98.8 |
| 63 | 35 | 2 | 89.1 | |
| 63 | 35 | 2 | 98.8 | |
| 69 | 30 | 3 | 89.3 | 97.3 |
| 69 | 30 | 3 | 98.8 | |
| 69 | 30 | 3 | 97.3 | |
| 67 | 30 | 1 | 96.2 | 79.2 |
| 67 | 30 | 1 | 82.1 | |
| 67 | 30 | 1 | 79.2 | |

sion coefficient in the saltwater; ϕ is the porosity. The sulfate ion diffusion coefficients in salt water is $9.8 \cdot 10^{-10}(\text{m}^2 \cdot \text{s}^{-1})$ (Li and Gregory, 1974). The comparison of the porosities from weight and effective diffusion coefficient measurements (Table 9) show about 36 percent (from sulfate) of porosities is effective porosities.

Specific Gravity Test

This test was performed to relate gravimetric and volumetric quantities of the mechanically stabilized fill material. Specific gravity of the briquettes, which are to be used as fill materials in the coastal relief construction works, was calculated according to the test method for specific gravity of coarse aggregate (ASTM C127). The results for the test conducted on the five composite combinations are listed in Table 10. The results show that all ingredient combinations behave similarly.

Sieve Analysis

The crushed materials obtained from the FGD briquette compaction tests were subjected to the sieve analysis, giving the complete picture of physical degradation the briquettes will undergo when subject to the worst case loading. The results of sieve analysis are listed in Figure 5.

The percentage change of the D_{10} [$\Delta D_{10} = (D_{10i} - D_{10})/D_{10i}$] and D_{50} [$\Delta D_{50} = (D_{50i} - D_{50})/D_{50i}$] are listed in Table 11, where subscript i represents the original briquettes before compaction test. The results show that all ingredient combination behave similarly.

Table 9—The comparison of the porosities from different sources showed that about 36 percent (from sulfate) of porosities is effective.

| FGD (%) | Class C Fly ash (%) | Portland type II Cement (%) | Porosity (%) | |
|---------|---------------------|-----------------------------|------------------------------|--------------------|
| | | | From $D_e(\text{SO}_4^{2-})$ | Weight measurement |
| 77 | 20 | 3 | 2.59 | 5.24 |
| 77 | 20 | 3 | 1.16 | 4.34 |
| 77 | 20 | 3 | 1.35 | 4.64 |
| 64 | 35 | 1 | 1.50 | 4.77 |
| 64 | 35 | 1 | 2.67 | 4.96 |
| 64 | 35 | 1 | 1.83 | 4.97 |
| 63 | 35 | 2 | 1.59 | 4.47 |
| 63 | 35 | 2 | 1.57 | 5.27 |
| 63 | 35 | 2 | 1.75 | 4.86 |
| 69 | 30 | 1 | 1.42 | 4.59 |
| 69 | 30 | 1 | 2.03 | 5.04 |
| 69 | 30 | 1 | 1.63 | 4.73 |
| 67 | 30 | 3 | 1.54 | 4.44 |
| 67 | 30 | 3 | 2.47 | 4.71 |
| 67 | 30 | 3 | 1.37 | 5.24 |

Table 10—Calculation of specific gravity of briquettes for use as fill materials.

| FGD (%) | Class C Fly ash (%) | Portland type II Cement (%) | Specific Gravity | Average |
|---------|---------------------|-----------------------------|------------------|---------|
| 77 | 20 | 3 | 2.040 | 2.033 |
| 77 | 20 | 3 | 2.020 | |
| 77 | 20 | 3 | 2.006 | |
| 64 | 35 | 1 | 2.007 | 2.019 |
| 64 | 35 | 1 | 2.034 | |
| 64 | 35 | 1 | 2.016 | |
| 63 | 35 | 2 | 2.030 | 1.980 |
| 63 | 35 | 2 | 1.906 | |
| 63 | 35 | 2 | 2.004 | |
| 69 | 30 | 1 | 2.022 | 2.031 |
| 69 | 30 | 1 | 2.032 | |
| 69 | 30 | 1 | 2.009 | |
| 67 | 30 | 3 | 2.050 | 2.066 |
| 67 | 30 | 3 | 2.086 | |
| 67 | 30 | 3 | 2.066 | |

Table 11— ΔD_{50} and ΔD_{10} were calculated from sieve analysis.

| Composite Combination | ΔD_{50} (%) | Average ΔD_{50} (%) | ΔD_{10} (%) | Average ΔD_{10} (%) |
|-----------------------|---------------------|-----------------------------|---------------------|-----------------------------|
| 77%:20%:3% | 0.843 | 0.843 | 0.992 | 0.993 |
| 77%:20%:3% | 0.843 | | 0.995 | |
| 64%:35%:1% | 0.843 | 0.869 | 0.987 | 0.988 |
| 64%:35%:1% | 0.895 | | 0.990 | |
| 63%:35%:2% | 0.738 | 0.791 | 0.984 | 0.986 |
| 63%:35%:2% | 0.843 | | 0.987 | |
| 69%:35%:1% | 0.843 | 0.817 | 0.987 | 0.983 |
| 69%:35%:1% | 0.791 | | 0.979 | |
| 67%:30%:3% | 0.791 | 0.791 | 0.953 | 0.953 |
| 67%:30%:3% | 0.791 | | 0.953 | |

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Controlling Beach Erosion Using FGD Sludge Products

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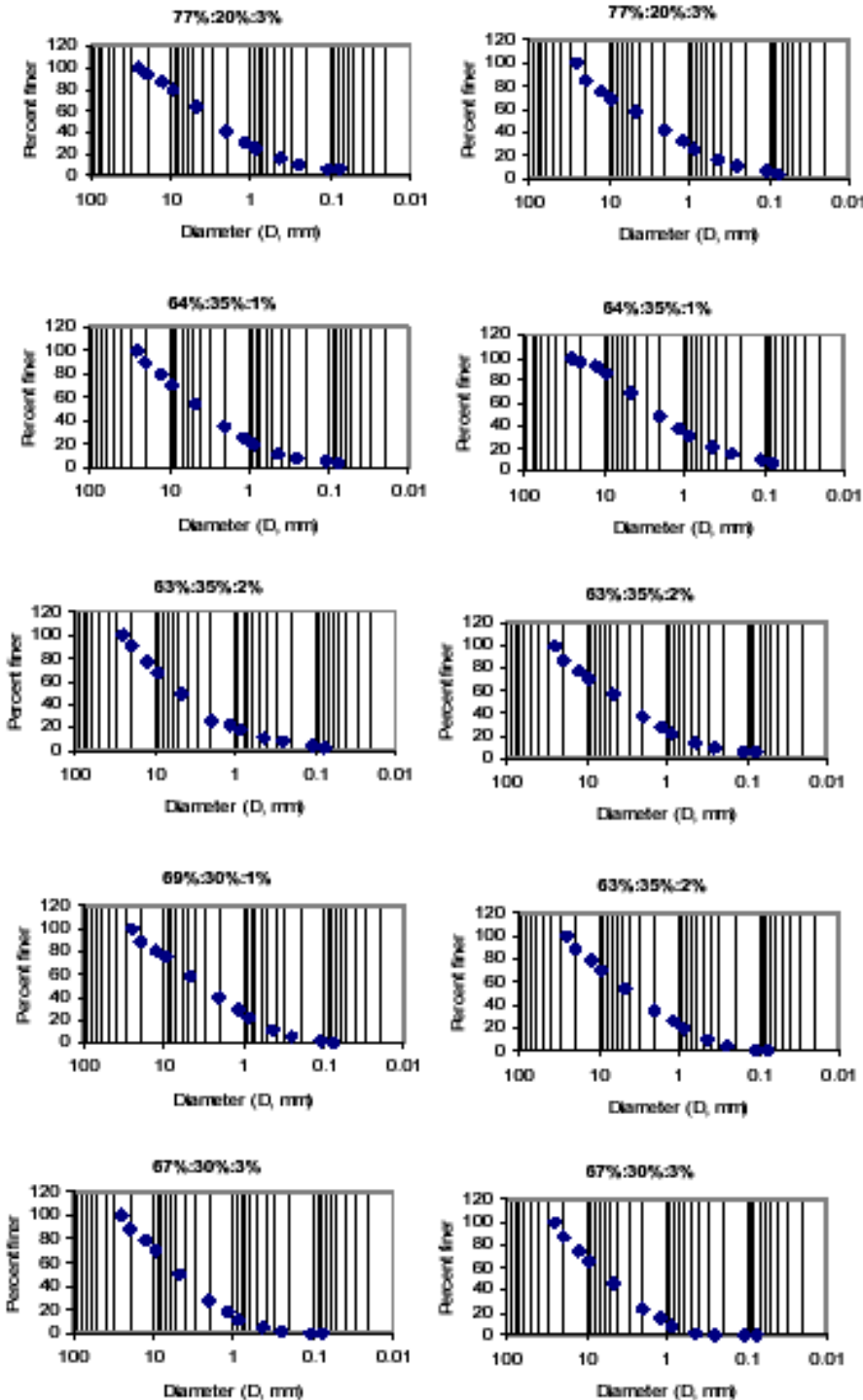


Figure 5—Plots of particle gradation obtained from sieve analysis.

Field Submergence

The briquettes were submerged in a bay located at Port Fourchon, Louisiana. The summary of the observations from a four-month submergence study is given in Table 12. The long-term submergence results are not available.

The FGD composite briquettes designated with “poor” status showed significant degradation by size and came out of the tied tags. Briquettes designated as “good” showed only slight degradation; whereas the “excellent” briquettes are staying firmly with the tags with very little sign of decrease in dimensions.

Conclusions

1. The effective sulfur (sulfate + sulfite) diffusion coefficients of the stabilized FGD/class C fly ash/Portland type II cement blocks is $1.02 - 2.14 \text{ (m}^2\text{s}^{-1} \bullet 10^{-13})$ while the effective sulfur diffusion coefficient of the stabilized FGD/class C fly ash/Portland type II cement briquettes is $1.34 - 3.96 \text{ (m}^2\text{s}^{-1} \bullet 10^{-13})$. The higher effective diffusion coefficient for the briquettes indicate that the fabrication conditions for the FGD briquettes is not optimal.
2. The field salt water submergence experiment shows that 64:35:1 percent, 63:35:2 percent, and 69:30:1 percent FGD/class C fly ash/Portland type II cement briquettes have survived for more than 4.5 months.
3. TCLP test shows that the mcontent of Cr, Cd, As, Pb and

Table 12—Status of FGD briquettes after four months of field saltwater submergence.

| FGD (%) | Class C fly ash (%) | Portland type II cement (%) | Status | Cost (\$/ton) |
|---------|---------------------|-----------------------------|-----------|---------------|
| 77 | 20 | 3 | Good | 10.15 |
| 64 | 35 | 1 | Excellent | 12.26 |
| 63 | 35 | 2 | Excellent | 12.94 |
| 69 | 30 | 1 | Excellent | 11.10 |
| 67 | 30 | 3 | Poor | 12.46 |

Se in the TCLP extraction fluid is far below the maximum concentration limits set by U.S. EPA for declaring a waste to be hazardous.

- The geotechnical tests conducted so far on the briquettes show all that all stabilized briquettes behave similarly.
- The economic analysis shows that 64:35:1 percent, 63:35:2 percent, and 69:30:1 percent FGD/class C fly ash/Portland type II cement briquettes can be manufactured on a large scale for less than \$13/ton.

These results indicate the feasibility of using light-weight stabilized FGD briquettes as conventional structural fill material in the coastal protection projects.

Acknowledgements

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For more information about this project, contact Kelly A. Rusch, Ph.D., P.I., Louisiana State University, at krusch@lsu.edu, or (225) 578-8528.



CBRC CONTACTS

Program Manager

Lynn Brickett, U.S. Department of Energy - National Energy Technology Laboratory
412/386-6574; brickett@netl.doe.gov

National Center

Paul Ziemkiewicz, Ph.D., *Director*
Tamara Vandivort, *Consortium Manager*
CBRC National Center located at the National Mine Land Reclamation Center at West Virginia University, 304/293-2867, pziemkie@wvu.edu or tvandivo@wvu.edu

National Steering Committee Chair

Howard Humphrey, American Coal Ash Association, Columbus, Ohio, 614/846-1726, h Humphrey@columbus.rr.com

Eastern Regional Chair

Cheri Miller, Tennessee Valley Authority, Chattanooga, Tenn., 423/751-4419, ecmiller@tva.gov

Midwestern Regional Chair

Tom Robl, Ph.D., University of Kentucky, 859/257-0272, robl@noah.caer.uky.edu

Western Regional Chair

Jacob Gonzales, TXU Energy, Dallas, Texas, 214/812-8328, jake.gonzales@txu.com

Eastern Regional Technical Director

James C. Hower, Ph.D., University of Kentucky, 859/257-0261, hower@caer.uky.edu

Midwestern Regional Technical Director

Paul Chugh, Southern Illinois University at Carbondale, 618/536 6637, chugh@engr.siu.edu

Western Regional Technical Director

Deborah Pflughoeft-Hassett, University of North Dakota, 701/777-5181, dphassett@undeerc.org

NSC Committee Members

Jackie Bird, Ohio Coal Development Office, 614/466-3465, jbird@odod.state.oh.us

Taylor Eighmy, University of New Hampshire, 603/862-1065, taylor.eighmy@unh.edu

Paul Ehret, State of Indiana, 317/232-4020, pehret@dnr.state.in.us

Dave Goss, American Coal Ash Association, 720/870-7897, DCgoss@acaa-usa.org

Dave Meadows, USACE-Huntington District, 304/529-5243, david.f.meadows@usace.army.mil

Jim Rower, Utility Solid Waste Activities Group, 202-508-5645, jim.rower@uswag.org

Kimery Vories, Office of Surface Mining, 618/463-6463 ext.103, kvories@mcrgw.osmre.gov

Andy Wittner, USEPA, 703-308-0496
Wittner.Andrew@epamail.epa.gov

Dan Wheeler, Illinois Office of Coal Development and Marketing, 217-558-2645, dwheeler@commerce.state.il.us

Calendar of Events

May 23-29, 2004

8th CANMET/ACI International Conference on Fly Ash, Silica Fume, Slag, and Natural Pozzolans in Concrete.

Treasure Island Hotel. Las Vegas, NV
Sponsored by: Committee for the Organization of CANMET/ACI Conferences (ACI

Council)Canada Centre for Mineral and Energy Technology (CANMET) American Concrete InstituteInstitute for Research in Construction Electric Power Research Institute

For more information, visit www.uwm.edu/Dept/CBU/8thCANMET.html.

Ashlines is published by the Combustion Byproducts Recycling Consortium, headquartered at West Virginia University in Morgantown, WV. Would you like to be on the CBRC electronic mailing list? If so, please send an e-mail to cbrc@nrcce.wvu.edu.



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COMBUSTION BYPRODUCTS RECYCLING CONSORTIUM

Ashlines

To promote and support the commercially viable and environmentally sound recycling of coal combustion byproducts for productive uses through scientific research, development, and field testing.

a program of the National Mine Land Reclamation Center at West Virginia University www.nrcce.wvu.edu/nmlrc, in cooperation with the U.S. Department of Energy - National Energy Technology Laboratory www.netl.doe.gov

FIRST SEARCH—The First Place to Look for Coal Ash Information

T. Berland Buckley, P.I.

With over 600 publications from more than 40 publishers, the FIRST SEARCH database is the industry's most comprehensive resource for coal combustion byproduct (CCB) information. Developed by the University of North Dakota Energy and Environmental Research Center (EERC), with funding from the Combustion Byproducts Recycling Consortium (CBRC) and the Western Region Ash Group, the FIRST SEARCH database contains abstracts and full paper instructions for an array of CCB publications. The FIRST SEARCH database is now available at www.undeerc.org/carrc/firstsearch.

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VISIT THE CBRC WEBSITE AT [HTTP://WWW.NRCCE.WVU.EDU/CBRC](http://www.nrcce.wvu.edu/cbrc)

FIRST SEARCH Database

(continued from page 1)

At the time this database project was proposed to CBRC, there was no system in place that allowed for universal information sharing within in the CCB industry. By providing a forum to support technology transfer between producers, regulators, and end users, the FIRST SEARCH database plays a key role in removing barriers at the national, state, and local levels to beneficially utilize CCBs.

From the home page (shown on page one) the database can be quickly searched using the "Quick Search" tool. Or by using the "Advanced Search" tool, the database can be searched for a specific title, author, source/publisher, or abstract text. Users may also browse all publications in alphabetical order by title. Unless prohibited by copyright issues, each publication contains an abstract. All publications link to full electronic text, or a method is provided to acquire the full text. In many instances, the complete text is provided free of charge by following the full text instructions.

Papers published after 1995 were sought for inclusion in the database, although there are a select number of publications in the database prior to 1995. Upon CBRC's recommendation, papers from Southern Illinois University-Carbondale, the University of Kentucky, CBRC, the U.S. Department of Energy National

All publications link to full electronic text, or a method is provided to acquire the full text. In many instances, the complete text is provided free of charge by following the full text instructions.

Energy Technology Laboratory, and the Ohio Coal Development office were specifically targeted. Other major sources of publications included Elsevier, the American Coal Ash Association, the Office of Surface Mining, and the Energy & Environmental Research Center (EERC). Several journal articles are also included.

In addition to the Internet database, an electronic data entry system was created to perform automatic updates. This system will allow a database administrator to continue adding publications to the database after the close of the project. Any new

information added to the database will still require appropriate copyright approvals.

The EERC's *WebTrends* Log Analyzer software was also installed on the database (this software was not purchased with project funds). This Web traffic-tracking software measures a variety of variables including how many visitors hit the database home page, how many pages a user visits, and how much time a user spends in the database. Customized Web traffic reports will be available to project sponsors.

The EERC continues to seek funding to expand database content and anticipates that the automated updating system will allow easy and instant updates at minimal cost.

Visit the FIRST SEARCH database at www.undeerc.org/carrclfirstsearch. Please contact Tera Berland Buckley by phone at (701) 777-5296 or by e-mail at tbuckley@undeerc.org if you have any questions or comments about the database.



High-Performance Masonry Units from 100% Fly Ash: A Synergistic Approach

H. C. Wu, P.I.

Michigan's Wayne State University (WSU) recently completed a study that investigates the potential use of fly ash to make masonry units. Several well-developed processes, mechanical pressing, hydrothermal, carbonation, fiber reinforcement, and chemical activation, were integrated in an innovative way to make high performance masonry units from fly ash with a small amount of chemical additives. The properties of the fly ash materials were evaluated. These samples have achieved very high strength and ductility.

The following conclusions can be drawn:

1. Class C and Class F ash can be solidified by the hydrothermal hot-pressing process developed from this project. Generally speaking, Class C is much more active than Class F, leading to better performance.
2. NaOH is an effective activator for fly ash. A very high splitting tensile strength of 11.0 MPa has been achieved. Mechanical properties of the ash samples increase with increasing NaOH contents and heating temperatures.
3. The addition of discontinuous fibers increases the ductility of

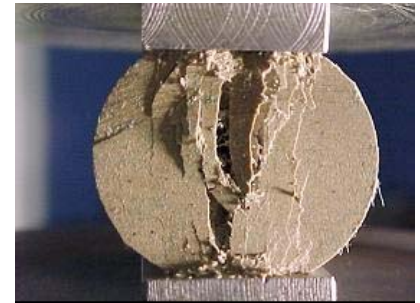
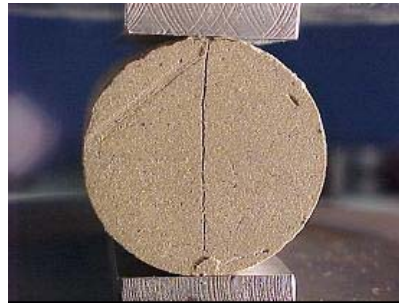


Figure 1: Different failure modes of Class C samples during testing. (Without fiber [left] and with 1.0 % fiber [right])



Figure 2: Different failure modes of Class C samples after testing. (Without fiber [left] and with 1.0 % fiber [right])

the ash samples significantly. A "ductile" failure resembling steel yielding is observed instead of a typical brittle failure (see Figures 1 and 2).

The fly ash samples developed from this project show extremely positive short-term performance as building materials. Other issues, however, need to be studied in the future, especially the long-term

durability, microstructure and chemical analysis of fly ash products.

Further information can be obtained by contacting Professor H.C. Wu of WSU (phone: 313-577-0745 or e-mail: hcwu@eng.wayne.edu).



CBRC CONTACTS

Program Manager

Lynn Brickett, U.S. Department of Energy -
National Energy Technology Laboratory
412/386-6574; brickett@netl.doe.gov

National Center

Paul Ziemkiewicz, Ph.D., Director
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pzziemkie@wvu.edu or tvandivo@wvu.edu

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Association, Columbus, Ohio, 614/846-1726,
hhumphrey@columbus.rr.com

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Dakota, 701/777-5181, dphassett@undeerc.org

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3465, jbird@odod.state.oh.us

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Paul Ehret, State of Indiana, 317/232-4020,
pehret@dnr.state.in.us

Dave Goss, American Coal Ash Association, 720/
870-7897, DCgoss@aca-usa.org

Dave Meadows, USACE-Huntington District, 304/
529-5243, david.f.meadows@usace.army.mil

Jim Rower, Utility Solid Waste Activities Group,
202-508-5645, jim.rower@uswag.org

Kimery Vories, Office of Surface Mining, 618/463-
6463 ext.103, kvories@mcrgw.osmre.gov

Andy Wittner, USEPA, 703-308-0496
Wittner.Andrew@epamail.epa.gov

Dan Wheeler, Illinois Office of Coal Development
and Marketing, 217-558-2645,
dwheeler@commerce.state.il.us

Calendar of Events

April 18-22, 2004

Annual Meetings of the Ameri-
can Society of Mining and
Reclamation / West Virginia
Surface Mine Drainage Task
Force in Morgantown, WV.

For additional information,
contact Jeff Skousen at (304)
293-6256 or jskousen@wvu.edu.
See the website at <http://www.wvu.edu/~agexten/landrec/land.htm>

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Pozzolans in Concrete. Treasure
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Mineral and Energy Technology
(CANMET) American Concrete
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Construction Electric Power
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May 23-29, 2004

8th CANMET / ACI Interna-
tional Conference on Fly Ash,

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Control of Ettringite Swelling

Barry E. Sheetz and Steven Kwan, P.I.s

Fluidized bed combustion (FBC) of coal or coal mining wastes was widely adopted because of its clean burning characteristics with respect to emission of SO_x . The technology, in all of its variations, involves the burning coal in a carrier bed of finely ground limestone.

The operational temperatures of this technology are high enough to cause the decomposition of the limestone to CaO and CO_2 , which, depending upon the partial pressure of carbon dioxide, occurs at temperatures as high as $800^\circ C$. This temperature is significantly lower than the combustion process for pulverized coal at approximately $1,400^\circ C$. Burning sulfur-bearing fuels in FBC units results in the release of SO_x , which in turn reacts within the combustor with the free anhydrous lime to form $CaSO_4$, anhydrite.

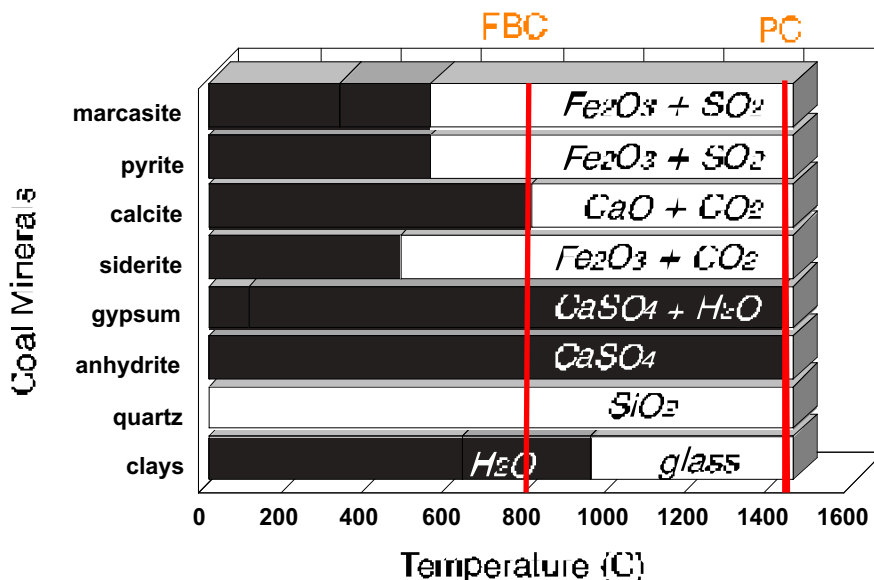


Figure 1—Thermal Stability of Minerals Typically Found in Coal

Coal combustion byproducts from these facilities usually contain excess CaO and residual thermally altered mineral matter from the coal. Figure 1 summarizes the alteration process of the most common mineral phases of coal

that occur during the combustion process. Typical bulk chemical compositions for FBC ash derived from different fuel sources are summarized in Table 1 on page 2.

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Control of Ettringite Swelling

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Table 1—Typical Bulk Chemical Compositions of FBC Fly Ashes as a Function of Source (after Sheetz et al., 1997)

| Oxide | High-BTU | Anthracite Refuse | Bituminous Refuse |
|--------------------------------|----------|-------------------|-------------------|
| SiO ₂ | 24.00 | 58.00 | 34.00 |
| Al ₂ O ₃ | 6.05 | 20.4 | 2.15 |
| Fe ₂ O ₃ | 2.05 | 5.74 | 5.98 |
| CaO | 42.00 | 4.11 | 30.00 |
| MgO | 0.45 | 0.62 | 0.62 |
| Na ₂ O | 0.07 | 0.59 | 0.11 |
| K ₂ O | 0.51 | 2.56 | 1.49 |
| SO ₃ | 20.8 | 1.1 | 13.00 |
| L.O.I. | 2.03 | 3.31 | 10.0 |

Table 2—Mineralogy of Various Forms of FBC Ash (after Sheetz et al., 1997)

| High-BTU | Refuse Burning | |
|--|----------------------------|--|
| | Anthracite | Bituminous |
| quartz (SiO ₂) | quartz (SiO ₂) | quartz (SiO ₂) |
| anhydrite (CaSO ₄) | | anhydrite (CaSO ₄) |
| calcite (CaCO ₃) | | |
| portlandite (Ca(OH) ₂ *) | | portlandite Ca(OH) ₂ * |
| ettringite Ca ₆ Al ₂ (SO ₃) ₃ O ₉ ·32H ₂ O | | ettringite Ca ₆ Al ₂ (SO ₃) ₃ O ₉ ·32H ₂ O |
| calcium sulfide (CaS) | | |

*formed from reaction with atmospheric moisture and CaO

From the data in Table 1, it can be inferred that the "high-BTU" and the "bituminous refuse" ashes will exhibit enhanced chemical reactivity based on the presence of relatively large amounts of CaO. Table 2 details the typical mineralogical composition of the same ashes.

Ettringite, Ca₆Al₂(SO₃)₃O₉·32H₂O, a double salt of gypsum and calcium aluminate, is present in the partially hydrated high-sulfur-bearing ashes and contributes to some unique properties of this class of ash. Ettringite is formed from the chemical interaction of the anhydrite and residual dehydroxylated clays (aluminosilicates) in the residual thermally altered minerals found in coal.

However, the molar volume of ettringite is larger than the sum of the molar volumes of its solid constituents. This growth can lead to a deleterious effect on the mechanical properties of the material. This class of fly ash has cementitious and pozzolanic properties, which can result in self-cementing behavior or can be tailored into producing mechanical properties comparable to modern high-performance concretes; i.e., unconfined compressive strength in excess of 6,000 psi. (Sheetz et al. 1993).

The initial cementitious behavior of these fly ashes is derived from the hydration of anhydrite, similar to hardening of "plaster of Paris," and ettringite formation. In an aluminosilicate-starved system, strength will be gained for several months, but when the pore fluids are depleted in sulfate, the ettringite becomes unstable relative to monocalcium aluminosulfate hydrate. The mechanical properties (strength) dramatically diminish as documented by early U.S. Bureau of Mines reports.

In ash systems where sufficient aluminosilicates are present, a second stage of pozzolanic reactions occur similar to that observed in Portland cement in which C-S-H forms. It is the presence of this second hydration reaction that maintains the long-term mechanical properties of FCB-based fly ash grouts.

The growth of ettringite within the matrix of any solidified body can pose a significant structural problem. First, the total volume is greater than the combined volume of the solid reactants. Second, morphologically, ettringite crystallizes into a needle-like habit with a large aspect ratio. The growth of these needle-like crystals can exert substantial dilative stresses on the object which results in microcracking, swelling, and eventual failure. The growth of ettringite is responsible for the noted swelling behavior of high sulfur-bearing FBC ashes when they become wet and is responsible for at least one train derailment and the sinking of an ocean going barge. The tales of rail car expanding 6 feet on the centerline and the horror stories of the necessity of using jack hammers to remove ash from rail cars are indeed true.

Ettringite may also be a significant deleterious component in ordinary Portland cement and has been the focal point of a major legal battle and intense scientific discussion for the last decade. Concrete rail ties were found to deteriorate, some while remaining in the storage yard of the manufacturer awaiting shipment. Deterioration was attributed to an ill-defined and, as of yet, poorly understood phenomena dubbed delayed ettringite formation (DEF), (Heinz & Ludwig, 1987). DEF has subsequently been identified as significantly contributing to sub-

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going barge.*

stantial deterioration of larger pre-cast objects; i.e., box beam members in Texas highway construction, all of which have experienced some form of accelerated curing at elevated temperatures (Lawrence et al., 1987).

The actual mechanism by which DEF functions is still a hotly contested topic of discussion in the Portland cement concrete sector.

Methodology

Thermodynamic Stability of Ettringite

Empirical evidence for the stability of ettringite can be drawn from several different sources. Scheetz et al. (1997) in studies of FBC-derived cementitious grouts for acid mine drainage control observed that the use of NaOH as an activator for the pozzolanic reaction resulted in a cementitious body that did not contain ettringite. In contrast, nonactivated control samples in that study routinely exhibited ettringite as one of the hydration products in the hardened

grouts.

In studies attempting to delineate the mechanism of DEF formation, Brown and Bothe (1997) have called attention to the difficulty of ettringite formation in the presence of high concentrations of alkali hydroxides. More recently, studies at Imperial College in the UK by Famy (1999) have demonstrated that DEF can be significantly delayed if test specimens were stored in a curing solution that was comparable to the chemistry of the pore fluids in the concrete, thus eliminating activity gradients between inside and outside of the test specimens.

The consequence of the elimination of the activity gradients is that transport (leaching) of alkali from the pore fluids to the surrounding curing solution is minimized. Zhang (1999) had demonstrated that alkalis were removed from the pore fluids stoichiometrically with hydroxyls. That is to say, alkali hydroxides were being removed from the pore fluids during leaching. These studies have demonstrated that if the alkali hydroxides leach out of the test specimens, DEF follows. If the alkali hydroxides do not leach out, the concretes remain stable and DEF does not occur.

The observations that alkali hydroxide concentrations are important is further supported by the analysis of failures in large pre-cast structures that have not experienced leaching but, nonetheless, experienced DEF failure. For these large structures, Meland et al. (1997) have associated the presence of alkali silica reactivity [ASR] as a necessary precursor to DEF.

(continued on page 4)

ASR is a deleterious reaction that occurs in concrete in which reactive forms of silica in the aggregates interact with the alkalis in the pore fluids to form pockets of alkali silicate gel around the aggregates. These gels, according to Meland et al. (1997), serve as a “sink” for alkali hydroxides decreasing their availability in the pore fluids of the concrete. As the pH drops, the stability field for ettringite is encountered, and it begins to form causing the observed DEF deterioration.

From these data it is clear that within the normal pH range of Portland cement pore solutions [~13.5], ettringite is not a stable phase. By keeping the pH of the pore fluid high, DEF is prevented along with its deleterious effect on concrete. If mechanisms are available that disturb the buffering capacity of the pore fluids by removing hydroxyls, the pH decreases, and, at some lower value, the pore fluid composition moves into the stability field for ettringite, which then causes ettringite to grow.

The observation of ettringite growth in FBC ash would then suggest that the pH of this system, buffered at 12.45 by $\text{Ca}(\text{OH})_2$, is within the stability field for ettringite. Scheetz et al. (1997) used NaOH to activate their FBC fly ash grout. Their data show the absence of ettringite formation. Therefore, it is suggested that the stability region for ettringite in complex chemical systems begins somewhere between calcium oxide containing FBC (~12.4) and portland cement pore solutions (~13.5).

Brown (1993) constructed a phase diagram showing solution compositions for phases in the system $\text{CaO-Al}_2\text{O}_3\text{-CaSO}_4\text{-H}_2\text{O}$ that

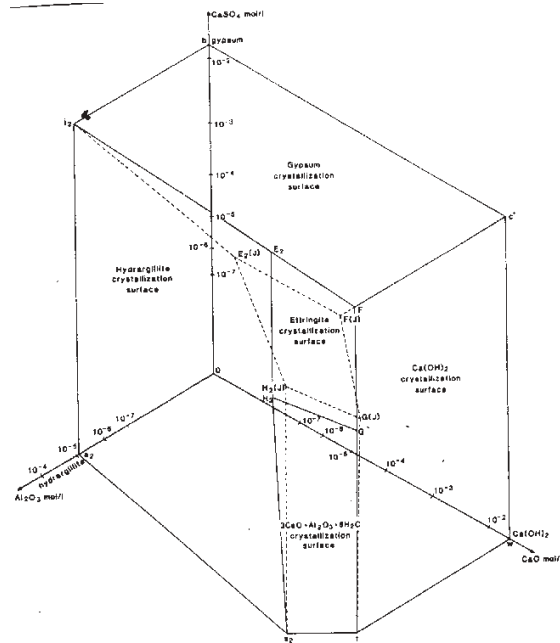


Figure 2—Stability Field of Ettringite in the System $\text{CaO-Al}_2\text{O}_3\text{-CaSO}_4\text{-H}_2\text{O}$ at 20°C. (Brown, 1994)

located the stability field for ettringite. These data suggest that by controlling the bulk chemistry of the material, it is possible to minimize the effect of DEF. Hampson and Bailey (1982), nearly a decade before Brown (1993), have shown that in pure systems, as the pH drops below that buffered by portlandite, ettringite becomes stable, Figure 2.

The Approach

The observations presented above strongly support the interpretation that ettringite growth in FCB ash composites can be modified by the control of pH, as originally reported by Scheetz et al.

(1994). The literature on chemically “pure” systems suggests that a small increase, above that established by portlandite, may be sufficient to destabilize ettringite relative to gypsum and portlandite and hydrargillite. Sodium hydroxide is the alkali hydroxide of choice for this study based on its cost and ready availability. It can be mixed with the conditioning water during transport and compaction or with the mixing water if the ash is to be used as a cementitious grout.

The global objective of this project is to take the fundamental thermodynamic understanding for the stability of ettringite and apply it to “real world” ash systems and

demonstrate that, in practice, the deleterious swelling associated with the formation of ettringite can be controlled.

Experimental Methods

In as far as possible, ASTM standardized methods were employed in this study. The initial starting ash was characterized for its quantitative mineralogical composition, the magnitude of expansion that might be anticipated from its hydration, and an understanding of the pore fluid compositions which develop in the ash. Subsequent to the treatment process, characterization was focused on the identification of the formation of ettringite and the impact that the treatment processes had on the expansion of the ettringite/ash composites.

Results

Ash Characterization

Mineralogical Composition by QXRD—Rietveld analysis of x-ray diffraction data on the anhydrous ash has been conducted to identify the quantitative mineralogy makeup of the ash (Table 3). Data was collected on a SCINTAG PADV diffractometer with CuK α radiation operated at 30 kV and 30 ma.

The analyses show the presence in the raw ash of about 7 percent free lime and a relative large percentage, 17.8, of larnite, the calcium silicate responsible for the long-term development of strength in Portland cement concrete. Additionally, akermanite was identified. Akermanite is generally never reported for this class of ash because the other compounds in the ash totally mask each and every peak of

Table 3—Results of Quantitative Mineral Analysis of Culver FBC Ash

| <i>Wt %</i> | <i>Phase</i> | <i>Mineralogical formula</i> |
|-------------|--------------|------------------------------------|
| 38.5 | quartz | SiO ₂ |
| 7.15 | lime | CaO |
| 17.8 | Ca-silicate | CaSiO ₃ |
| 26.6 | anhydrite | CaSO ₄ |
| 1.5 | carbon | C |
| 5.5 | akermanite | CaMgSi ₂ O ₇ |
| 2.9 | calcite | CaCO ₃ |

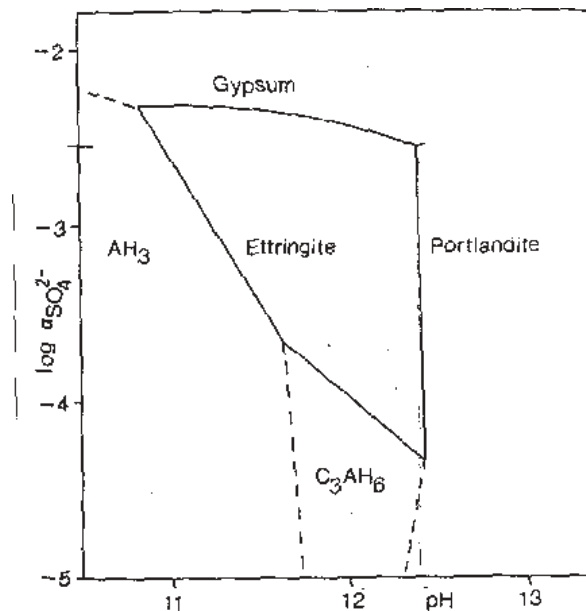


Figure 3—Activity Diagram for the System CaO-Al₂O₃-CaSO₄-H₂O at 20°C. (Hampson and Bailey, 1982)

(continued on page 6)

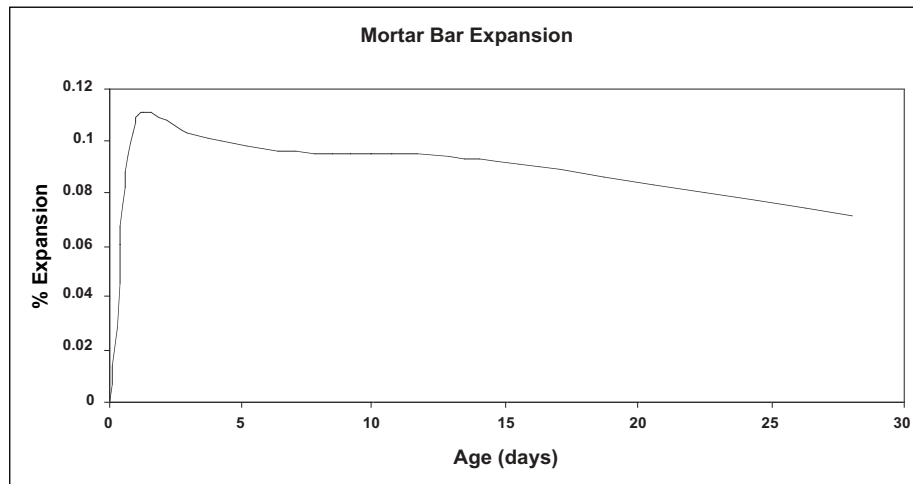


Figure 4—28-Day Mortar Bar Expansion Recorded for FBC Ash-GROUT Mixtures

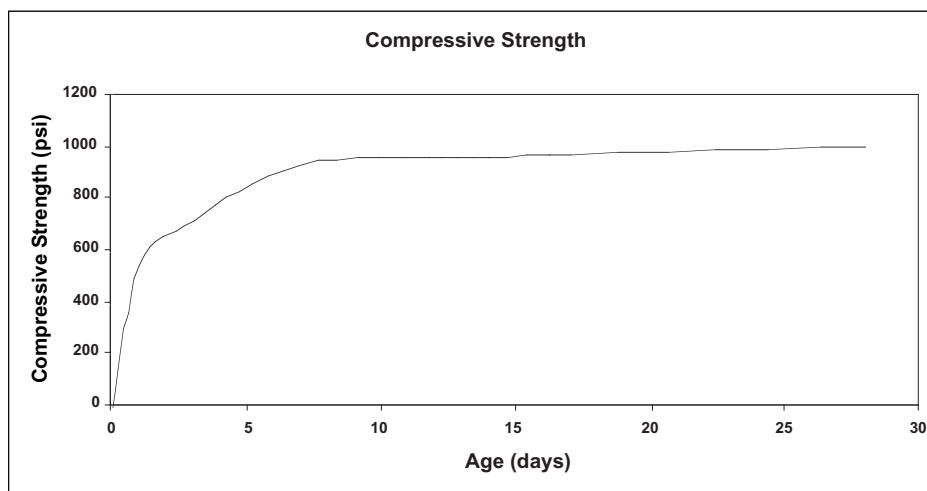


Figure 5—Compressive Strength Development in FBC Ash-Grouts as a Function of Time of Curing

akermanite. Only with careful quantitative analyses can its presence be confirmed. Ettringite was not observed in the unhydrated ash but in the hydrated grout mixtures.

Expansion Bar

The FBC ash was formulated into 1x1-inch expansion bars and were cast using a water/cement ratio of 0.6. The w/c ratio was extraordinarily high due to the high reactivity of the FBC ash. The samples were

subjected to standard ASTM mixing and curing methods. Expansion of the fly ash grout prisms exceeded 0.1 percent within the first 5 days of mixing. The expansion data are reported in Figure 4 .

Strength Determination

Mechanical properties testing was conducted on grouts made from taking the FBC ash and mixing it with water according to ASTM C 109 procedures at a water

to cementitious solids ratio of 0.6. These 2 x 2-inch cube specimens were cured at laboratory ambient conditions in moist air for 1,3,7,14 and 28 days before testing. The ash-based grouts resulted in an unconfined compressive strength of 950 psi (Figure 5).

Pore Fluid Analyses

Samples of the hydrated fly ash grout were processed to extract pore fluids from the hardened

Table 4—FBC Pore Solution Composition

| mg/L | 1D | 5D | 7D | 21D | 28D |
|-----------------|------|------|------|------|------|
| Al | 1 | 4 | 4 | 7 | 5 |
| B | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Ba | 0.5 | 0.5 | 0.5 | 3 | 3 |
| Ca | 370 | 210 | 215 | 380 | 410 |
| Co | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Cr | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Fe | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| K | 2790 | 2880 | 2730 | 3500 | 3600 |
| Mg | 0.5 | 0.5 | 0.5 | 7 | 6 |
| Mn | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Mo | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Na | 430 | 400 | 380 | 710 | 740 |
| Ni | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Si | 1390 | 960 | 850 | 2330 | 1740 |
| Sr | 23 | 16 | 16 | 13 | 14 |
| Ti | 0.5 | 0.5 | 0.5 | 1 | 1 |
| V | 0.5 | 0.5 | 0.5 | 1 | 2 |
| Zn | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| F | 0.3 | 6.8 | 5.7 | 3.1 | 4.7 |
| Cl | 380 | 490 | 450 | 540 | 560 |
| NO ₂ | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| NO ₃ | 3 | 36 | 32 | 21 | 29 |
| PO ₄ | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| SO ₄ | 3400 | 4200 | 3200 | 5500 | 5900 |

specimens at 1, 5, 7, and 28 days (Table 4). The analyses of these solutions were used to monitor the alkali additions to grouts in order to take the bulk composition beyond the stability field of ettringite.

Ameliorated Ash Characterization

Expansion Bar

NaOH was added to the fly ash grout in an attempt to drive the chemistry of the system from

the stability field of ettringite. 0.5, 1, 2, 3 and 4 percent of the total dry weight of NaOH was added to the grout mix. Similar to previous experiments, 1 x 1-inch expansion bars were cast in order to measure the expansion due to the formation of ettringite, if any, using standard ASTM methods. Shown in Figure 6 on page 8 are the expansion data.

The data plotted in Figure 6 for the expansion/shrinkage of the test bars exhibits maximum shrinkage of the fly ash grout at about 1 percent NaOH.

X-ray Diffraction

Powder X-ray diffraction was used to track the existence of ettringite in the samples. Periodic scans were taken with time. Shown in figure 7 are the x-ray diffraction patterns of samples with differing amounts of added NaOH. Although the diffraction pattern span a wide range of 2q angles, only the low angles are shown where ettringite has its characteristic peaks.

(continued on page 8)

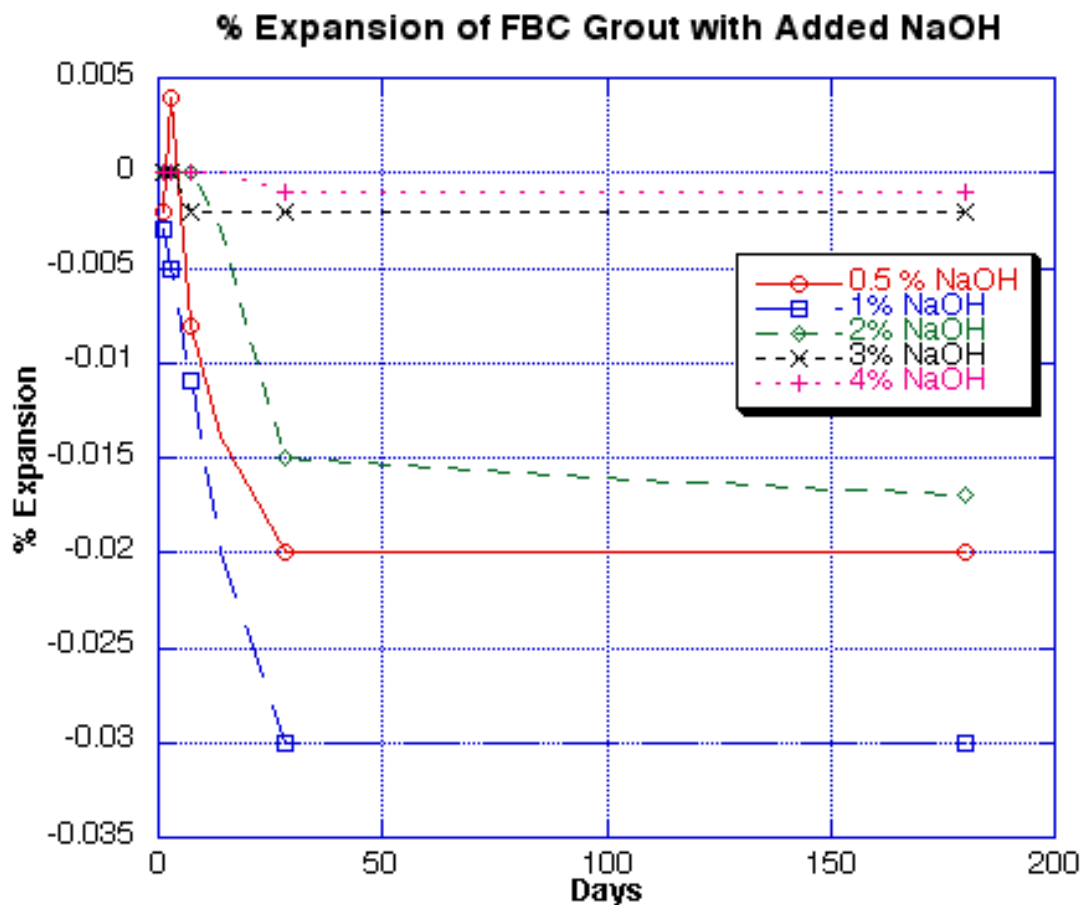


Figure 6—Percent Expansion of FBC Ash Grout with added NaOH as a Function of Time

Scanning Electron Microscopy

Scanning electron microscopy images of the samples were taken in order to visually verify the existence of ettringite. These are shown in Figure 8.

Discussion

Ettringite Suppression

The data support the observations that the solubility of gypsum, a principal component of the ash, is suppressed in terms of the calcium concentration but the concentra-

tions of sulfate in solution approach 1050 mmolar. Both alkalis, sodium and potassium, are present in the pore fluids at 2000 and 195 mmolar, respectively. The former ion represents the alkali addition of the experiment. At these concentrations, the pH of the pore fluids should exceed the 12.5 stability limits for ettringite. What is observed in the analyses of the fluids is that the pH is gradually approaching this limit over the concentration range of this phase of the study.

Scanning electron microscopy characterization of the ash composites confirm the x-ray diffraction and differential scanning calorimetry studies that indicate the presence of ettringite. The SEM data however reveal that what ettringite, that is forming, is doing so as a low density form with many of the individual needles growing into the void space without gaining purchase on the main structure of the composite. Shown in Figure 8 are typical SEM image of the ettringite development in samples containing up to 5 wt. percent NaOH.

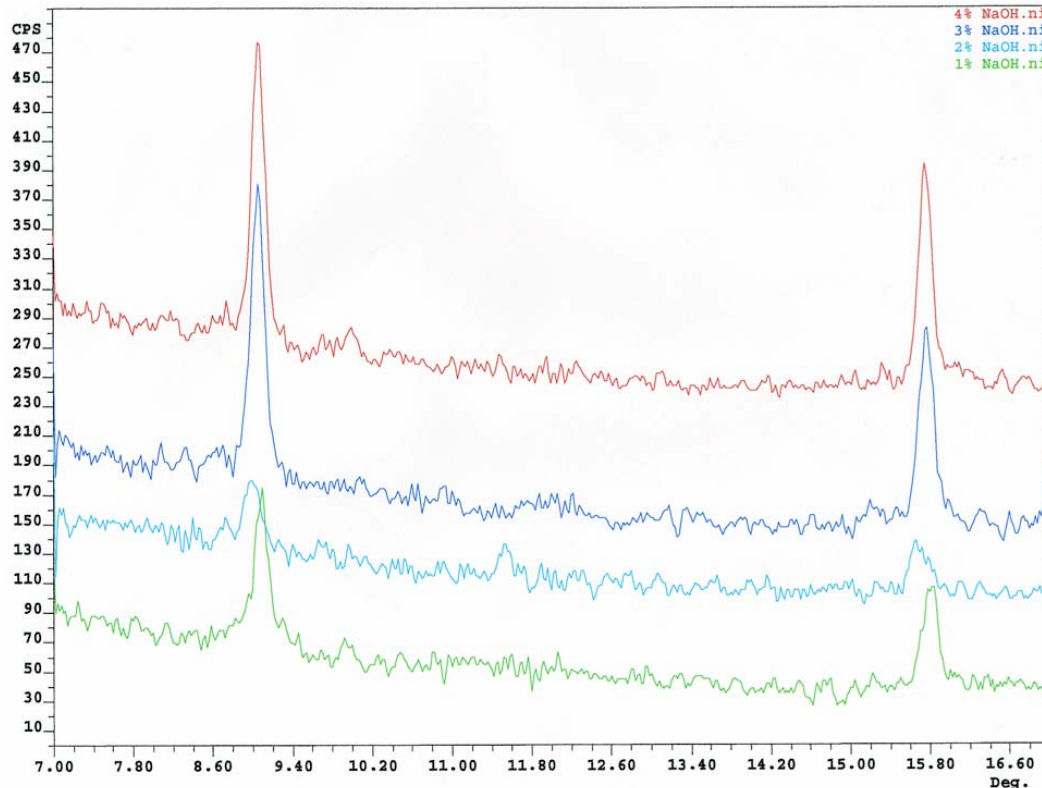


Figure 7—X-Ray Diffraction Patterns of FBC Ash Grouts With Added NaOH

Although SEM and XRD conclusively show the existence of ettringite, measured expansion data for the test specimens show either zero or negative expansion throughout the test interval of 6 months (Figure 6). This behavior points to the formation of a low density ettringite that does not exert enough expansive force to cause any deleterious effects on FBC ash grouts. These data also suggest a pessimism in the concentration of alkali responsible for the retardation of expansion. This type of behavior is not uncommon in portland cement chemistry but was not anticipated for this chemical system.

Determination of the strength data suggested that within a week of preparation, all of the test specimens with the varying alkali dosing achieved working strength of approximately 1,400 psi, a 56% increase over the control ash.

Economic and Safety Considerations

The technological approach to minimizing the swelling of consolidated FBC ash as a result of ettringite formation appears to be successful. There are, however, several economic issues that result from an attempt to implement the technology. The work to date has shown that swelling can be eliminated by the addition of sodium hydroxide to the mix water for making a fly ash grout from FBC ashes. In field applications, the form in which the sodium hydroxide is purchased will have a strong influence on how readily the solid dissolves. The majority of forms in which sodium hydroxide is available are pellets which range from pea-size to small bricketts. These will have the advantage of being easier to handle from the perspec-

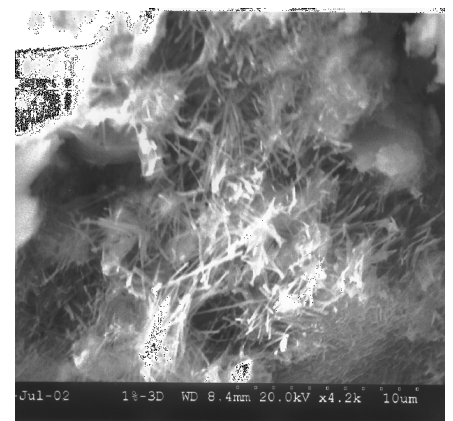


Figure 8. SEM Images of FBC Ash-Grouts with Added NaOH.

tive of dust generation but will require longer to dissolve into solution. After extensive searching, a 'flake' form was located and purchased for \$0.49/pound. This

(continued on page 10)

form has the advantage of readily dissolving but has the potential to contribute to dust formation during handling thus necessitating the use of protective clothing and breathing apparatus.

The research effort found that the addition of 0.5 percent to 5 percent by mass was adequate in controlling the expansion. This range of additions would add an additional \$4.90 to \$49.00 per ton of ash placed to the handling costs in addition to the special handling that may be necessary. An alternative to this cost would be the direct purchase of aqueous sodium hydroxide solutions that are commonly used for AMD control. This option has not been explored during this study.

Conclusion

The results of the laboratory study have demonstrated that the expansive force of ettringite formation in hardened FBC ash compacts can be controlled. The study suggests that the pure system ettringite phase relationship is not directly transferable to real world ash systems.

Although the stability of ettringite was not totally controlled, it was moderated to a point that expansion may now be engineered. Alkali hydroxide solutions are routinely utilized for AMD control on mine sites but at a cost. The crude economic analyses conducted in this study suggest that an added cost of \$4.90 per ton would be necessary to achieve control over the expansion. The cost is likely far too large for routine use but for value added application it may certainly be within the project budgets.

Acknowledgement

Culver Power in Ebensburg, Pennsylvania, is gratefully acknowledged by the authors for their interest in the project and the contribution of ash to the research.

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For more information about this project, contact Barry E. Sheetz at 814/865-3539 or se6@psu.edu, Materials Research Laboratory, Materials Research Institute, Pennsylvania State University, or contact the CBRC at <http://www.wri.nrcce.wvu.edu/cbrc>.



CBRC CONTACTS

Program Manager

Lynn Brickett, U.S. Department of Energy -
National Energy Technology Laboratory
412/386-6574; brickett@netl.doe.gov

National Center

Paul Ziemkiewicz, Ph.D., Director
Tamara Vandivort, Consortium Manager
CBRC National Center located at the
National Mine Land Reclamation Center at
West Virginia University, 304/293-2867,
pziemkie@wvu.edu or tvandivo@wvu.edu

National Steering Committee Chair

Howard Humphrey, American Coal Ash
Association, Columbus, Ohio, 614/846-1726,
hhumphrey@columbus.rr.com

Eastern Regional Chair

Cheri Miller, Tennessee Valley Authority, Chatta-
nooga, Tenn., 423/751-4419, ecmiller@tva.gov

Midwestern Regional Chair

Tom Robl, Ph.D., University of Kentucky,
859/257-0272, robl@noah.caer.uky.edu

Western Regional Chair

Jacob Gonzales, TXU Energy, Dallas, Texas,
214/812-8328, jake.gonzales@txu.com

Eastern Regional Technical Director

James C. Hower, Ph.D., University of Kentucky,
859/257-0261, hower@caer.uky.edu

Midwestern Regional Technical Director

Paul Chugh, Southern Illinois University at
Carbondale, 618/536 6637, chugh@engr.siu.edu

Western Regional Technical Director

Deborah Pflughoeft-Hassett, University of North
Dakota, 701/777-5181, dphassett@undeerc.org

NSC Committee Members

Jackie Bird, Ohio Coal Development Office, 614/466-
3465, jbird@odod.state.oh.us

Taylor Eighmy, University of New Hampshire, 603/
862-1065, taylor.eighmy@unh.edu

Paul Ehret, State of Indiana, 317/232-4020,
pehret@dnr.state.in.us

Dave Goss, American Coal Ash Association, 720/
870-7897, DCgoss@acaa-usa.org

Dave Meadows, USACE-Huntington District, 304/
529-5243, david.f.meadows@usace.army.mil

Jim Rower, Utility Solid Waste Activities Group,
202-508-5645, jim.rower@uswag.org

Kimery Vories, Office of Surface Mining, 618/463-
6463 ext.103, kvories@mcrgw.osmre.gov

Andy Wittner, USEPA, 703-308-0496
Wittner.Andrew@epamail.epa.gov

Dan Wheeler, Illinois Office of Coal Development
and Marketing, 217-558-2645,
dwheeler@commerce.state.il.us

Calendar of Events

April 18-22, 2004

Annual Meetings of the Ameri-
can Society of Mining and
Reclamation / West Virginia
Surface Mine Drainage Task
Force in Morgantown, WV.

Technical Sessions will include:
Acid Mine Drainage, Passive
Treatments, Geochemistry,
Forestry & Wildlife, Stream
Restoration, Mine Closure,
Revegetation, Hydrology,
Wetlands, Ecology, Case

Studies, Tailings, Abandoned
Mine Lands, Water Manage-
ment, Soils and Overburden,
Reclamation Success / Bond
Release, Invasive and Native
Species, and Watershed
Groups.

For additional information,
contact Jeff Skousen at (304)
293-6256 or jskousen@wvu.edu.
See the website at [http://
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Volume 3, Number 4

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COMBUSTION BYPRODUCTS RECYCLING CONSORTIUM

Ashlines

To promote and support the commercially viable and environmentally sound recycling of coal combustion byproducts for productive uses through scientific research, development, and field testing.

a program of the National
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FGD Byproducts Can Help Boost Soybean and Alfalfa Crops

Liming Chen and Warren A. Dick, PI

Sulfur (S) is one of the elements essential for plant growth. It is a macronutrient and, like N, P, K, Ca, and Mg, must be available in relatively large amounts for good crop growth.

In a study titled *Flue Gas Desulfurization Byproducts Provide Sulfur and Trace Mineral Nutrition for Soybean and Alfalfa*, researchers examined the potential benefits of FGD byproducts and biosolids to crop production from spring 2000 to 2002. Gypsum was also tested as an S source. Results were compared to an unamended control treatment. Environmental impacts based on accumulation of toxic elements or heavy metals such as arsenic (As) in plant tissue, soil, and subsoil solution were also studied.

This article summarizes the project's results. For a complete discussion of the literature, methods, and results, as well as data from the project, please refer to the final project report available online at the CBRC's Web site at <http://www.nrcce.wvu.edu/cbrc>.

Sulfur's Importance to Crops

Sulfur is a constituent of the amino acids cysteine and methionine and hence of protein. Both of these amino acids are precursors of other sul-



Sulfur deficiencies can influence the feed value of alfalfa.

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FGD Byproducts Can Boost Soybean and Alfalfa Crops

(continued from page 1)

fur-containing compounds such as coenzymes and secondary plant products. Sulfur is a structural constituent of these compounds or acts as a functional group directly involved in metabolic reactions.

Under conditions of S deficiency, protein synthesis is inhibited (Marschner, 1986). During the early years of commercial fertilizer use, nearly all fertilizer elements were in the sulfate form. During the same years, sulfate was also abundantly supplied to the soil by rain, snow, and dust. Thus it was difficult to visualize that S deficiency would ever become a problem in many soils.

Sulfur deficiencies became more numerous and serious when heavy rates of highly purified fertilizers of N, P, and K not in the sulfate form began to be applied to soils (Tucker, 1993; Marschner, 1986).

S Deficiencies Widespread

In recent years, deficiencies of S have become more common in North America and worldwide, including Australia and the regions of Scandinavia. This is attributed to (1) intensive cropping systems and higher yielding varieties and hybrids that result in more S removal from the soil each year; (2) higher analysis fertilizers that contain little or no S; (3) less S deposition from the atmosphere; and (4) declining levels of organic matter (Tucker, 1993; Waddoups, 1971).

The increasing need for S in various cropping situations has translated into greater demand for S fertilizers. The use of gypsum as a soil

amendment in agriculture reached approximately 2 millions tons in 2001 (USGS, 2002). Much of this use was as a soil conditioner and S nutrient source.

In the United States, positive yield responses to application of S fertilizers have been reported for different crops and grasses even prior to 1970 (Olson et al., 1971). In North Carolina, S containing fertilizers increased the yield of cotton, tobacco, and coastal bermudagrass, and the yields of coastal bermudagrass were increased by more than 60 percent. Many fields across the coastal plains in North Carolina require a sulfur application to achieve optimum yields (Tucker, 1993).

Sulfurcontaining fertilizers increased cotton and other crop yields in South Carolina, Georgia, and Florida. In Georgia, it is necessary to apply S fertilizer to all cotton grown in the state (Olson et al., 1971). As yields of corn, sugar beets, and clover have increased, the use of S fertilizers in Ohio has also increased (Olson et al., 1971).

On soils having low organic matter (< 2 percent) or on soils which are coarse textured and have been heavily leached, there is a high probability that the sulfur content of the soil is low. When analysis of a soil demonstrates a need for S, a crop response to S supplementation is likely (Johnson and Hudak, 1999).

Wheat is a crop that typically requires a relatively high amount of supplemental S. One reason for this need is that wheat experiences its most rapid growth during early spring when the rate of S release from soil organic matter is quite slow. On coarse, sandy soils, especially those low in organic

matter, wheat can be expected to have a yield response to added S.

Alfalfa also has a relative high requirement for S. Sulfur deficiency of alfalfa has been reported in Ohio, Indiana, Michigan, Wisconsin, and Virginia during the 1960s and 1970s (Beaton and Fox, 1971). Sulfur deficiencies not only decrease alfalfa yields, but also influences the feeding value of the alfalfa.

Sulfur deficiency has been reported to decrease the photosynthetic rate of soybean and decrease yield in the field by up to 20 percent (Agrawal and Mishra, 1994; Sexton et al., 1997). A deficiency of the S-containing amino acids cysteine and methionine limits the nutritional value of soybean protein (Sexton et al., 1997).

Substantial acreages of farmland in western Canada are S deficient, and the yields of alfalfa and soybean were significantly increased by S fertilizer treatments (Beaton and Soper, 1986). Alfalfa yields were increased by gypsum application in sandy loams but not in silt loams in Minnesota (O'Leary and Rehm, 1989).

Flue gas desulfurization (FGD) byproduct applied to alfalfa in the upper Midwest at agronomic rates did not affect yields, but FGD byproduct treatment increased the S content of alfalfa plants relative to alfalfa grown on untreated soil (Sloan et al., 1997). Alfalfa yields did not respond to elemental S or gypsum application in central Maryland and Prince Edward

(continued on page 6)

CBRC NEWS

CBRC Announces Steering Committee Changes

In 2002, David Goss accepted a position with the American Coal Ash Association (ACCA) and resigned his post as chair of the CBRC National Steering Committee (NSC). Goss will continue to serve as a NSC member.

ACCA's Howard Humphrey has replaced Goss as the NSC Chair. Humphrey previously served as the NSC's Eastern Region Chair.

Nominations were taken from NSC

members for a new Eastern Chair, and the CBRC is pleased to announce that Cherie Miller of the Tennessee Valley Authority (TVA) has accepted the post. Miller has been employed by TVA for 22 years and has been involved in all aspects of coal combustion product management and use. She is currently the senior member of TVA's byproduct marketing staff. She also is a member of the AACA Executive Committee and is

on the technical committee for the University of Kentucky's 2003

International Ash Symposium.



Cherie Miller



CBRC Requests Your Assistance in Locating Publications for Its Database

As part of an effort funded by the Combustion Byproducts Recycling Consortium (CBRC) and the Western Region Ash Group, the University of North Dakota Energy & Environmental Research Center is developing a Web-based searchable database of publications related to coal combustion byproducts. Your assistance in locating publications related to CCBs is requested.

The database will include abstracts of published papers with a full citation for each paper. Database users will be provided with further instructions regarding where to find the full document. If applicable, and with the applicable permissions, each abstract will link directly to the full paper on the organization's/publisher's Web site.

This effort has the potential to significantly impact the manner in which information is shared in the coal ash industry, and your participation will greatly enhance the value of the

database. Abstracts can be added to the database directly from your Web site (if applicable), or e-mailed directly to Tera Berland at tberland@undeerc.org, or by regular mail to

Tera Berland
Energy & Environmental
Research Center
15 North 23rd Street
Grand Forks, ND 58201

Electronic formats are preferred. Please include a complete citation (author[s], date, organization/publisher, etc.). If you would like to further discuss participation in this database, please contact Tera Berland at 701-777-5296.

For more information, refer to CBRC Project 01-CBRC-W1: Development of a Database of CCB Publications; Principal Investigator: Tera Berland, University of North Dakota on the cbrc web site at <http://www.wri.nrcce.wvu.edu/cbrc>.



Please include the following language with abstracts submitted to the CBRC Database:

Approval is hereby given for abstracts from our organization that relate to coal combustion byproducts to be incorporated into the described Web-based database.

Approval is also given to provide a direct link to our organization's Web site.

Approved by: _____

Date: _____

CBRC NEWS

CBRC Receives Applications in Response to RFP 2002

The request for preproposals (RFP) for 2002 was released October 9, 2002. The RFP was placed on the CBRC Web site and postcards were mailed to everyone on the CBRC's mailing list announcing the RFP and providing instructions for downloading it off the Web site. Electronic notices were also sent to the mailing list of *Ashlines* readers. The due date for applicants to submit pre-proposals was Dec. 9, 2002.

Eight continuation applications and 59 new applications

were received. The breakdown is as follows:

| | |
|-------------------|----|
| Eastern Region | 24 |
| Midwestern Region | 22 |
| Western Region | 13 |

The National Steering Committee met in St. Petersburg, Florida, on January 30, 2003 to select preproposals from those received.

Two continuation applications and 14 new applications were selected and invited to submit full proposals. Full proposals are due

from these selected applicants by May 30, 2003. The breakdown of new applications selected is as follows:

| | |
|-------------------|---|
| Eastern Region | 5 |
| Midwestern Region | 4 |
| Western Region | 5 |



Below and Right: CBRC National Steering Committee met in St. Petersburg, Florida, to evaluate and select preproposals.



Above: CBRC Program Manager Lynn Brickett (left) and Consortium Manager Tamara Vandivort

WVU Receives Award from DOE-NETL To Continue CBRC Program

The award for Phase IV of the CBRC program was successfully negotiated between the U.S. Department of Energy-National Energy Technology Lab (DOE-NETL) and West Virginia University. A total of \$836,997 in federal funds was

awarded from DOE-NETL to support six new projects, three continuation projects, and administration at three regional centers and the national center.

In addition, matching funds from nonfederal sources in the amount of

\$923,847 have been committed to the nine projects. This brings the current phase of the CBRC program to a total value of \$1,760,844.

The nine projects funded with FY03 funds include the following:

Continuation Projects

| | |
|-------------|--|
| 00-CBRC-M9 | Environmental Performance Evaluation of Filling and Reclaiming a Surface Coal Mine with Coal Combustion Byproducts Principal Investigator: Ishwar Murarka, Ish Inc. |
| 00-CBRC-E41 | Environmental Effects of large Volume FGD Fill Principal Investigator: Phillip Glogowski, GAI Consultants, Inc. |
| 00-CBRC-M4 | Crushed Aggregates from Class C Fly Ash Principal Investigator: Anil Misra, University of Missouri |

New Projects

| | |
|-------------|--|
| 01-CBRC-W1 | Development of a Database of CCB Publications Principal Investigator: Tera Berland, University of North Dakota |
| 01-CBRC-E10 | Full-Scale Testing of Coal Combustion Product Pavement Sections Subjected to Repeated Wheel Loads Principal Investigator: Tarunjit Butalia, Ohio State University |
| 01-CBRC-M21 | The Impact of Absorption on the Mobility of Arsenic and Selenium Leached from Coal Combustion Products Principal Investigator: Bradley Paul, Southern Illinois University |
| 01-CBRC-M12 | The Effect of Mercury Controls on Wallboard Manufacture Principal Investigator: Sandra Meischen, Tennessee Valley Authority |
| 01-CBRC-E9 | Development of Fly Ash Derived Sorbents to Capture CO ₂ from Flue Gas of Power Plants Principal Investigator: Mercedes Maroto-Valer, Pennsylvania State University |

For more information on these and other CBRC projects, please visit our Web site at <http://wwwri.nrcce.wvu.edu/cbrc>

FGD Byproducts Can Boost Soybean and Alfalfa Crops

(continued from page 2)

Island in Canada (Vough et al., 1986; Gupta and MacLeod, 1984).

Sulfur is usually present in relatively small amounts in soils and most of this S is in organic forms. Sulfur deficient soils are often low in organic matter, coarse-textured, well-drained, and subject to leaching (Waddoups, 1971).

The S status of Ohio's soils is not well-defined, and the effect of adding S on the growth of crops has not been extensively researched. At the Wooster (Ohio) site, annual SO₄ deposition gradually decreased from 34.8 kg ha⁻¹ in 1979 to 16.9 kg ha⁻¹ in 1999 (National Atmospheric Deposition Program, 2002).

Based on the S status model used by McGrath and Zhao (1995) in England, many regions in Ohio need supplemental S for optimum growth of crops. Therefore, crop response to S application on some agriculture soils in Ohio is expected.

The Role of FGD Byproducts

Plants take up S from soils in the form of divalent sulfate anions (SO₄²⁻). The organic form must be transformed to sulfate by a largely biological process before utilization by plants. Therefore, most of commercial S fertilizers are mineral forms such as sulfate, trisulfate or elemental S. These forms are rapidly converted to sulfate that is easily taken up by plants.

In the United States, use of high sulfur coal for energy often requires the SO₂ produced during burning be removed via some type of scrubbing technology to meet the clean air regulations. The materials that are

produced during scrubbing are given the generic name of flue gas desulfurization (FGD) byproducts.

FGD byproducts are typically composed of three components varying in proportion and composition which depends on the coal, sorbent, and scrubbing process used. These components are (1) the SO₂ reaction products, which are primarily CaSO₃ and CaSO₄, (2) unreacted sorbent, and (3) coal combustion ash.

Because of the unspent sorbent component, FGD byproducts are usually highly alkaline and have significant neutralization potential. Several studies have shown that this property enables FGD byproducts to be used as alkaline amendments for agricultural soils (Terman et al., 1978; Stout et al., 1979; Korcak, 1980; Stehouwer et al., 1995; Ritchey et al., 1996; Stehouwer et al., 1996; Chen et al., 2001).

Technologies for SO₂ scrubbing that can be retrofitted onto existing facilities are needed if the Phase II regulations of the Clean Air Act are to be met. Many of these expensive retrofit technologies achieve only 40 to 50 percent SO₂ removal.

A retrofitable duct-injection technology using vermiculite or perlite as a carrier for the Ca(OH)² sorbent has been developed by Sorbent Technologies, Inc (Twinsburg, OH). The technology has a demonstrated SO₂ removal rate of 80 to 90 percent (Nelson et al., 1998). This process creates a new type of dry FGD byproduct that contains CaSO₃, and CaSO₄, Ca(OH)², fly ash, and vermiculite or perlite. This S, like that in commercial fertilizers, is readily available to plants. Therefore, FGD by-

products should be good substitutes for commercial S fertilizers

In addition to S, FGD byproduct provides many other elements essential for plant growth. These elements are often referred to as micronutrients because they are required in lesser amounts than the major nutrients (i.e., N, P, and K). However, their presence in FGD can be beneficial and improve overall plant growth.

Environmental Concerns

FGD byproducts, however, also contain some trace elements of environmental concern (Fowler et al., 1992). For example, arsenic (As), a regulated element, also has been detected in FGD byproducts. Even though the total As content in FGD byproduct is very low, the As solubility in FGD byproducts is high.

Many different products have been developed from FGD byproducts and tested (Dick et al., 2000). One such product, made by mixing biosolids and FGD byproduct, is called N-ViroSoil (N-Viro International Corporation, Toledo, OH). The N-Viro Soil process uses the residual-free lime contained in dry FGD byproduct to react with the water in the biosolids creating heat through an exothermic reaction. The heat generated from this reaction aids in the disinfection of biosolids.

These materials contain different minerals that are valuable in agriculture and help to maintain plant health. Sulfur, N, P, K, Mg, B and other trace nutrients are contained in the N-Viro Soil product. By using FGD byproduct materials to treat biosolids, N-Viro Soil can offer a

more valuable product than traditional biosolids or FGD alone.

Objectives

In this study, the researchers hypothesized that the vermiculite FGD byproduct and N-Viro Soil have the potential to be effective sources of S and other nutrients for crops. The research objectives were (1) to determine the suitability of the FGD byproduct and N-Viro Soil for agricultural use during production of alfalfa and soybean; and (2) to assess their potential environmental impacts based on accumulation of toxic elements or heavy metals on the quality of alfalfa tissue, soybean grain, soils and subsoil solutions.

Materials and Methods

Experiments in 2000

Two research sites were chosen for field experiments to test whether soils and plants are deficient in S and other trace minerals. One site is located near Wooster (in northeast Ohio and containing a Wooster silt loam) and the other near Fremont (in northwest Ohio and containing a Fremont sand). The Wooster site field had been maintained in a corn-soybean rotation with soybean grown in 1998 and corn in 1999, the year before the 2000 study.

The Fremont site field had been used for vegetable production with cabbage grown in 1999. The two fields had no S fertilizer applied during the past several years.

Before treatments, surface (0 to 20 cm) soil samples were collected, air-dried and analyzed to determine fer-

tility status, pH, lime requirements and concentrations of elements essential for growth of higher plants.

Sulfur sources for the field tests were vermiculite FGD byproduct, N-Viro Soil and gypsum. The FGD byproduct was obtained from Sorbent Technologies Corporation (Twinsburg, OH) and contained sulfate/sulfite, unused lime, and vermiculite. N-Viro Soil was provided by N-Viro International Corporation (Toledo, OH). Commercial agricultural gypsum, commercial name Nutrasoft Pelletized Gypsum, was produced by Rex International (Thomasville, NC).

Characteristics of the FGD byproduct, N-Viro Soil and gypsum were determined as described by Stehouwer et al. (1995).

Alfalfa and soybean were used as test crops. Plot sizes were 3 x 6 m for alfalfa and 6 x 6 m for soybean and were arranged in a randomized block design with three replications. Plots were supplied with P and K fertilizers based on soil test results and the Ohio Agronomy Guide (1995) recommendations at the beginning of the experiment.

Soybean was planted in 38-cm rows at a population of 350,000 seeds ha⁻¹ on June 3, 2000 at the Fremont site and on June 12, 2000, at the Wooster site. Alfalfa was planted using a seeding rate of 14 kg ha⁻¹ in 20-cm rows on July 7, 2000, at the Wooster site. Immediately after seeding, the FGD byproduct and N-Viro Soil were applied at rates equivalent to 16 and 67 kg S ha⁻¹ and the gypsum was applied at a rate of 16 kg S ha⁻¹ for alfalfa and at rates of

16 and 67 kg S ha⁻¹ for soybean. The experimental design included an unamended control (i.e. zero S) treatment.

Because alfalfa was planted late and it takes time for alfalfa to become fully established, alfalfa was harvested only one time in 2000 (on September 8). In general, alfalfa was harvested at the late bud or early bloom stage by clipping a randomly selected 1 m² area from each plot. Samples were dried at 60°C for 5 days, weighed and ground to pass a 1-mm sieve.

Concentration of total N in alfalfa tissue was analyzed using an automated Kjeldahl method adopted for measuring protein content in animal feed (JAOAC, 1976). Concentrations of other elements in the alfalfa were determined by inductively coupled plasma (ICP) emission spectrometry after digestion with a mixture of HClO₄ - HNO₃ (Isaac and Johnson, 1985).

Soybean at the Wooster site was harvested by a small combine from the center 23 m² area of each plot on October 13, 2000. Soybean grain was ground to pass a 1-mm sieve and elemental concentrations of elements were determined by the methods previously described for alfalfa.

Soybean at the Fremont site was not harvested in 2000 because *Phytophthora* root rot severely reduced growth. *Phytophthora* root rot is a common soybean disease in Ohio and it was especially evident at the Fremont site in 2000 because of

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the heavy rains in the area in May and June. Total rainfall for May was 5.08 inches and for June it was 7.49. This amount of rainfall was 41 and 87 percent, respectively, more than the long-term averages at this site.

Three months after treatments were applied at the Fremont site (i.e., in September 2000), subsoil solution samples were collected using suction lysimeters. These lysimeters were placed 60 cm below the surface of the soybean plots treated with FGD byproduct and N-Viro Soil (at the 67 kg S ha⁻¹ rate) and in the unamended control plots. The ceramic lysimeters were 6 cm long and 4.8 cm in diameter and were obtained from Soilmoisture Equipment Corporation (Goleta, CA). Total concentrations of elements in the subsoil solution were determined by ICP emission spectrometry and anion concentrations were determined by ion chromatography.

Four months after applying treatments (i.e., in October), five cores (2.5-cm diameter) from the 0 to 15 and 15 to 30 cm soil layers were collected from the plots of the control and high S rate application in the two soybean fields and then bulked to create two samples (a 0- to 15-cm sample and a 15- to 30-cm sample) per plot. Soil samples were air-dried, crushed, passed through a 2-mm sieve, and extracted with Mehlich-3 solution (Mehlich, 1984). Extracted elements were then determined by the ICP emission spectrometry.

Experiments in 2001

Field studies in 2001 for alfalfa were conducted on three fields. At the Wooster site, the same field that

had been used in 2000 was again selected for study. The same treatments were applied to the same plots on April 2, 2001. In addition, we selected two established stands of alfalfa in different regions of Ohio. One was located in Wayne County and the other in Hancock County. These new sites did not have a recent history of S fertilizer application.

FGD byproduct, N-Viro Soil or gypsum were broadcast applied to plots (3 x 6 m in size) at rates of 0, 8, 16, and 24 kg S ha⁻¹ in early April 2001 (April 4 at the Hancock County site and on April 9 at the Wayne County site). The experimental design was a randomized complete block with four replications. Before applying treatments, soil samples from the 0-20 cm soil layer were collected and analyzed.

Alfalfa was harvested three times from the Wooster site and the Hancock County site and four times from the Wayne County site during May to September. All harvests were taken between the late bud and early bloom stage of maturity. Alfalfa was harvested by clipping a randomly selected 1 m² area from each plot.

Soybean experiments in 2001 were conducted on silt loam soils located in Clark County, Ohio, and at the Wooster site. These sites were no-tillage corn/soybean rotation fields where soybean had been grown in 1999 and corn in 2000. No S fertilizer had been applied to these fields during the past several years. Before application, soil samples (0 to 20 cm soil layer) were collected and analyzed and plots were supplied with P and K fertilizers based on soil test

results and the Ohio Agronomy Guide (1995).

The FGD byproducts, N-Viro Soil or gypsum were broadcast applied to plots (6 x 6 m in size) at 0, 6, and 17 kg S ha⁻¹. The experimental design was a randomized complete block with four replications. Materials were applied on April 25 at the Clark County site and on May 14 at the Wooster site.

Soybean was planted in 38-cm rows at a population of 350,000 seeds ha⁻¹ on April 30 at the Clark County site and on May 11 at the Wooster site. Soybean was harvested by a small combine from a 12 m² area in the center of each plot on October 3, 2001 at the Clark County site and from a 9.7 m² center of each plot on November 1, 2001 at the Wooster site.

Data Analysis

The results obtained for each of the dependent variables in this study were analyzed statistically using a model that included treatment and replication as independent variables. Data were subjected to analysis of variance (ANOVA) using the PROC GLM statement of SAS statistics program (SAS, Cary, NC). When ANOVA generated a significant F-value ($P \leq 0.05$) for treatments, treatment means were compared by the Least Significant Different (LSD) test using the appropriate error term to calculate the LSD value.

Results and Discussion

The study results are presented in a way that tests differences in parameter values for the treated

plots versus the control plots. (Complete results including data from the experiments are presented in the final report available on the CBRC's Web site at <http://www.wri.nrcce.wvu.edu/cbrc>.)

When testing potential environmental impacts, it is a change from the natural baseline condition that is most important. For crop yield data, an increase in yield in the treated plots compared to the unamended control plots provides evidence that S, and/or trace elements, are contributing to better plant nutrition and improved crop yields.

Alfalfa Field Results for 2000

Mean dry weight yields of alfalfa harvested from the Wooster site are averages of the 16 and 67 kg S ha⁻¹ application rate treatments and clearly show a positive yield response when FGD byproduct, N-Viro Soil, or gypsum were applied to this site. There were no significant differences in alfalfa yields, however, among the treatments indicating the FGD byproduct or N-Viro Soil can be used as substitutes for gypsum in providing S to soil.

The low application rate of S to this soil was sufficient for improving growth of alfalfa. At the 16 kg S ha⁻¹ application rate, mean alfalfa yields were increased 16.9 percent to 42 percent by the FGD byproduct, N-



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Viro Soil, or the gypsum treatment compared to the unamended control.

These data strongly suggest that the alfalfa was responding to S (and possibly other trace minerals) because the 16 kg S ha⁻¹ application rate is not high enough to significantly affect other soil properties. In addition, the gypsum treatment would be expected to contribute lower amounts of essential trace elements than the other treatments because of its purer form and because less material is needed to achieve the target S application rates. Thus, we conclude the primary treatment response is due to S.

Other factors, however, may have affected yield at the higher rate. For example, the N-Viro Soil brought about higher alfalfa yields for the 67 kg S ha⁻¹ rate than for the 16 kg S ha⁻¹ rate. The N-Viro Soil provides additional benefits due to inputs of alkalinity and N.

In contrast, the alfalfa yields for a the FGD byproduct were higher for the 16 kg S ha⁻¹ rate than for the 67 kg S ha⁻¹ rate. These results are in agreement with the studies of O'Leary and Rehm (1989). They applied gypsum to two sandy loam soil in Wisconsin at rates of 28 to 112 kg S ha⁻¹. Yields responded to S treatment, but not to an increase in S application rate.

A study by Sloan et al. (1997) has also indicated that FGD byproducts can serve as a ready B source for alfalfa production, particularly late in the growing season when native soil B availability decreases.

Concentration in alfalfa of Ca, a major element in the various treatments, was slightly decreased by the application of FGD byproducts at the 16 kg S ha⁻¹ application rate as compared to the unamended control. There were no significant affects by

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the other treatments or when the soil was treated with the FGD byproduct at the rate of 67 kg S ha⁻¹.

Goodroad et al. (1989) similarly found concentrations of Ca in soft red winter wheat (*Triticum aestivum* L.) were decreased when application rates of S were increased. One explanation for these results is that addition of S to soils, deficient in this element, stimulates crop growth more than uptake of S, thereby diluting its concentration in plant tissue. However, O'Leary and Rehm (1989) have observed that S concentrations in crops generally increased with addition of S to soil.

Inspection of the data shows that the only other elements whose concentrations in alfalfa tissue were significantly affected by treatment were Mg, Mn, N, and P which were all reduced when soil was treated with FGD byproduct at the 16 kg S ha⁻¹ application rate. Again this seems due to increased growth (a 42 percent yield increase) causing a dilution in the plant tissue.

One other significant treatment affect, as compared to the control treatment, was a decrease in Mn concentration when N-Viro Soil was applied at the 67 kg S ha⁻¹ rate.

Surprisingly, none of the treatments significantly changed S concentrations in the alfalfa tissue. Our results are similar to those of Spiers and Braswell (1989) who also observed that S treatments reduced Ca and Mg concentrations in the leaves of blueberries. Goodroad et al. (1989) found that Mn concentrations

in soft red winter wheat were decreased when soil was amended with S fertilizer.

Aluminum, As, and Ba concentrations in alfalfa were not affected by the FGD byproduct N-Viro Soil or gypsum treatments as compared to the unamended control. Concentrations of Se were significantly decreased by all the treatments. Cadmium concentrations in alfalfa were significantly increased, compared to the unamended control, when soil was treated with FGD byproduct at the high application rate and Pb concentrations were also increased by FGD byproduct at the low application rate. Chromium concentrations were significantly increased by gypsum.

Soybean Field Results for 2000

Soybean grain yields were increased when FGD byproduct, N-Viro Soil, or gypsum were applied to soil at the Wooster site. These results are averages of the 16 and 67 kg S ha⁻¹ application rate treatments as compared to the unamended control. Only the N-Viro Soil treatment significantly increased yields at the $P \leq 0.05$ level, but at the 10 percent level of significance, all treatments caused a significant yield increase compared to the unamended control. There were no consistent rate effects on soybean yields with all treatments increasing yield from 3.4 to 11.6 percent.

The only significant effects of FGD byproduct, N-Viro Soil, and gypsum treatments on concentrations

of essential plant nutrients (both major and minor nutrients) in soybean grain harvested from the Wooster site were observed for Ca, K, Mg, and S concentrations, which were significantly decreased when compared to the unamended control. Calcium concentrations were decreased in soybean grain from plots treated with the high rate of FGD byproduct. Potassium concentrations were decreased by both of the N-Viro Soil treatments and by the high rate of gypsum. Magnesium concentrations were decreased by the high rate of FGD byproduct and by the high rate of N-Viro Soil. Finally, S was decreased by the high rate of the N-Viro Soil and by the low rate of gypsum. No other effects on essential plant nutrient concentrations were observed when FGD byproduct, N-Viro Soil, or gypsum were applied to soil as S sources.

Concentrations, in soybean grain harvested from the Wooster site, of Ba were significantly ($P \leq 0.05$) decreased when plots were treated at the high rate of FGD byproduct and N-Viro Soil and at the low rate of gypsum as compared to the unamended control. Concentrations of Cr were increased by the high rate of FGD byproduct. Concentrations of Al, As, and Pb were not affected by the FGD byproduct, N-Viro Soil, or gypsum treatments. Cadmium and Se concentrations were always below the detection limits of 0.12 mg kg⁻¹ for Cd and 6.0 mg kg⁻¹ for Se.

Soil Quality Data from Soybean Plots in 2000

Four months after applying treatments to the Wooster site soil and after soybean harvest, concentrations of most essential plant elements in the 0 to 15 cm soil layer of the treated plots were found to be similar to those in the unamended control plots. We used a Mehlich-3 extractant which is weakly acidic and extracts elements that are thought to be in a plant-available form. Zinc concentrations in both soil layers were increased by application of FGD byproduct at the 67 kg S ha⁻¹ rate as compared to the unamended control.

The high rate of FGD byproduct and N-Viro Soil also significantly increased concentrations of Fe in the 15 to 30 cm soil layer. The high rate of N-Viro Soil increased concentrations of Mn in both soil layers and the low rate of FGD byproduct increased concentrations of Cu in the 15 to 30 cm soil layer. Finally, the high application rate of FGD byproduct was found to increase B concentrations in both soil layers.

Since none of these elements were affected by the gypsum treatment, these elements are thought to have been derived from the fly ash portion of the FGD byproduct or from both fly ash and biosolids in the N-Viro Soil.

The Fremont site soil, which contains more sand than the Wooster site soil, and thus has more potential for elements to leach, showed several elements were affected by treatments in the 15- to 30-cm soil layer. The high application rate of the N-Viro Soil treatment significantly ($P \leq 0.05$)

increased Ca, Fe, B and Ni concentrations in soil as compared to the unamended control, and the low rate also increased concentrations of B and Mn. The high application rate of FGD byproduct significantly increased B and Ni concentrations.

Only B and Zn concentrations were changed in the 0- to 15-cm surface soil layer as compared to the unamended control. The low rate of the N-Viro Soil treatment caused an increase in Zn. B concentrations were increased in the surface soil layer by both rates of N-Viro Soil, the high rate of FGD byproduct, and the gypsum treatment.

The one element that would be predicted to be most affected in soil by the various treatments is S. This is because the various treatments applied S to soil in the readily available sulfate form which can be easily extracted by the Mehlich-3 extractant. Sulfur concentrations in the 0- to 15-cm soil layer of the Wooster site soybean field were increased significantly ($P \leq 0.05$) by the application of FGD byproduct at the 67 kg S ha⁻¹ rate. In the Fremont site soil, the high rates of FGD byproduct and N-Viro Soil significantly increased S concentrations above that of the unamended control.

In the 15- to 30-cm soil layer, concentrations of S in both the Wooster and Fremont site soils were significantly increased by all treatments except for the low rate of FGD byproduct. The concentrations of B in soil at both the Wooster site and the Fremont site where soybeans were grown were, as previously mentioned, increased significantly

by the high rate application of FGD byproduct (i.e., 67 kg S ha⁻¹). Concentrations of B in soil treated with some fly ash materials can reach phytotoxic levels (Sutton and Dick, 1987).

However, the results from this study indicate that the alfalfa tissue and soybean seeds did not accumulate B. Many reports indicate foliar B applications can improve soybean yield (Gascho and McPherson, 1997; Reinbott and Blevins, 1995; Schon and Blevins, 1990).

Boron applied to soil at low rates can also increase soybean yields. When B was applied to a silty clay loam soil at a rate of 2.8 kg ha⁻¹, soybean yields were increased by about 12 percent (Reinbott and Blevins, 1995). In Georgia, broadcast applications of B to a loamy sand soil with low levels of soil test B at rates ranging from 0.28 to 1.12 kg ha⁻¹ also increased soybean yields in that state by 4 percent (Touchton and Boswell, 1975).

Concentrations of elements, in the Wooster site soil, potentially toxic to plants or regulated by the Resource Conservation and Recovery Act (RCRA) were measured. Relatively few changes in Mehlich-3 extractable concentrations of elements were affected by treatments. Al, Cd, and Se were not affected by any of the treatments in the Wooster soil when compared to the unamended control. The FGD byproduct only affected Pb concentrations, which was increased in the 15- to 30-cm soil layer, when this material was applied to the Wooster soil at the 16 kg S ha⁻¹ rate. Application of N-Viro Soil increased the concentrations of

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As and Cr in both soil layers and the Ba concentrations in the 15 to 30 cm soil layer. Application of gypsum did not affect the Mehlich-3 extractable soil concentrations of any of the elements measured.

The Fremont soil again showed more effects of treatment and more effect at depth than did the Wooster soil due to its greater content of sand and potential for elements to leach. In the surface 0- to 15-cm soil layer, N-Viro Soil at the low application rate, significantly decreased Cd concentrations but increased Cr concentrations. The high application rate of N-Viro Soil at the high application rate also increased Al and Cr concentrations. The gypsum treatment decreased Cd concentrations in the surface soil layer.

In the subsurface (i.e., 15- to 30-cm) soil layer, the high rate of FGD byproduct and N-Viro Soil increased Al concentrations and gypsum decreased Ba concentrations. All treatments, except the low rate of FGD byproduct, significantly increased Cr concentrations in the 15- to 30-cm soil layer.

Soil Solution Quality Data from Soybean Plots at the Fremont Site in 2000

Only the concentration of S was significantly ($P \leq 0.05$) increased by application of FGD byproduct at the rate of 67 kg S ha⁻¹ at the Fremont site in 2000. It is expected that this soluble S would be primarily in the form of SO₄⁻² and this seems to be confirmed when only anionic S was measured.

Nitrate-N concentrations were all

found to average more than the 10 mg L⁻¹ regulatory level for safe drinking water. The source of this N was not identified but did not seem to be caused by the two S treatments.

The unamended control had average concentrations that were equivalent to or even higher than that for the two S treatments. FGD byproduct contains only very small amounts of N, and thus the observed soil nitrate levels that exceed the regulatory level cannot be due to N inputs by this treatment. The biosolids, that are part of the N-Viro Soil, would contain N, but even for this treatment the levels in the soil solution were similar to those for the control plots.

Some possibilities that could explain, at least partially, the high nitrate levels in the soil solution are (1) fertilizer N inputs for the previous year's vegetable crop production and (2) input by the soybean crop itself. Soybean is a legume crop and can take atmospheric dinitrogen (N₂) and convert it to plant available forms. This N is then introduced to soil when roots or other plant residues decay.

The concentration of B was increased by the treatment of FGD byproduct, but this increase was not statistically ($P \leq 0.05$) significant. None of the elements regulated by RCRA and elements potentially toxic to plants were increased by FGD byproduct and N-Viro Soil applications.

Alfalfa and Soybean Field Results for 2000

Alfalfa yields were also increased in 2002 when FGD

byproduct, N-Viro Soil, or gypsum were applied to established alfalfa stands. The most responsive site was the Wooster site which was a new planting of alfalfa in 2000. Average yield increases, above that for the unamended control, ranged from 15 to 33 percent.

At the Wayne County site, the yield of alfalfa was lower compared to other sites. This was attributed, in part, to a lower level of available K in the soil. Optimum soil test for most crops in Ohio is 100 to 200 mg K kg⁻¹ soil (Ohio Agronomy Guide, 1995), but at this site it was only 73 mg K kg⁻¹ soil. Alfalfa has a relative high K requirement, and low K in the soil limited the growth of the crop.

There was no response of alfalfa yields to different rates of S addition to soil. Sulfur is generally needed in only relatively small amounts to reach sufficiency. The data suggest that a recommendation rate of approximately 20 kg S ha⁻¹ would achieve maximum yields in most soils.

Combining data for 2001 from all three sites provides further strong support that S additions can significantly boost alfalfa yields. Increases for the three treatments ranged from 4.0 to 11.3 percent. This level of increase is more than sufficient to justify the expense of adding S in the forms of FGD byproduct, N-Viro Soil, or gypsum.

The project data also strongly suggest that the alfalfa is responding to S and not some other essential trace elements in the materials applied. Concentrations of many trace elements

were generally lower in the gypsum compared to the other treatments. In addition, because treatments were based on rates of S to be applied to soil, the higher S analysis in gypsum meant that actual amount of material applied had to be greater for FGD byproduct (50 percent more) and N-Viro Soil (five times more). Thus if there were trace element responses, the FGD byproduct and N-Viro Soil treatments should have resulted in greater yields than the gypsum treatment.

For the 2001 soybean experiment, analysis of variance indicated no significant differences in soybean grain yields when comparing the control versus the S application treatments or when comparing results for the various S application rates. A severe drought occurred in the Wooster area in June and July of 2001 and limited the growth of soybean at this site. There also seemed to be sufficient S in the soil at the Clark County site so that treatment responses were not evident.

A recent study from British Columbia, Canada (Kishchuk and Brockley, 2002), indicated that S additions to lodgepole pine (*Pinus contorta*) sites deficient in S, resulted in a much greater N fertilizer response. The interaction of S and N is something we did not study, but it is hypothesized that similar results could exist for agronomic crops.

Sulfur is a component of two essential amino acids (cysteine and methionine) and if S is limiting, protein synthesis would be negatively impacted and responses to addition of N would be reduced. Such an interaction would often not be observed unless

specific experiments were conducted to test for it. This would seem to be a fruitful area for future study.

Conclusions and Recommendations

1. Some soils in Ohio need supplemental S for optimum growth of crop. Soils that will respond to S inputs are expected to be those with low organic matter concentrations and low concentrations of S in Mehlich-3 extracts.
2. Alfalfa had a greater positive response than soybean when S treatments were applied to Ohio soils.
3. FGD byproduct and N-Viro Soil are good S sources for improving growth of crops in Ohio. They have the same capacity as gypsum to increase yields of alfalfa and soybean.
4. The FGD byproduct and N-Viro Soil may also provide additional growth benefits by supplying trace nutrients essential for plants.
5. Additions of S at the 20 kg ha⁻¹ rate would be sufficient to meet the needs of most crops growing in S deficient soils.
6. Concentrations in soil of trace elements essential for plant growth were generally unaffected or slightly increased when plots were treated with FGD byproduct and N-Viro Soil.
7. Elements regulated by the Resource Conservation and Recovery Act (RCRA) did not

accumulate in alfalfa tissue and soybean grain to a level that would impose any use restrictions. On the contrary, many of the elements were reduced in concentrations by the various treatments.

8. Interaction studies of S and N should be conducted to better assess growth responses to S additions. Establishing such an interaction would provide further incentive to farmers to apply S to their soils and could also allow a reduction in N fertilizer application rates, thus improving environmental quality.

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If you have questions about this project, view the final project report at the CBRC's Web site at <http://www.nrcce.wvu.edu/cbrc>. Refer to project 99ECE08. Or contact the principal investigator, Warren A. Dick, at the Ohio State University at (330)263-3877, or by e-mail to dick5@osu.edu.



CBRC CONTACTS

Program Manager

Lynn Brickett, U.S. Department of Energy -
National Energy Technology Laboratory
412/386-6574; brickett@netl.doe.gov

National Center

Paul Ziemkiewicz, Ph.D., Director
Tamara Vandivort, Consortium Manager
CBRC National Center located at the
National Mine Land Reclamation Center at
West Virginia University, 304/293-2867,
pzziemkie@wvu.edu or tvandivo@wvu.edu

National Steering Committee Chair

Howard Humphrey, American Coal Ash
Association, Columbus, Ohio, 614/846-
1726, hhumphrey@columbus.rr.com

Eastern Regional Chair

Cherie Miller, Tennessee Valley Authority,
Nashville, Tennessee, 432/751-4419,
ecmiller@tva.gov

Midwestern Regional Chair

Tom Robl, Ph.D., University of Kentucky,
859/257-0272, robl@noah.caer.uky.edu

Western Regional Chair

Jacob Gonzales, TXU Energy, Dallas, Texas,
214/812-8328, jake.gonzales@txu.com

Eastern Regional Technical Director

James C. Hower, Ph.D., University of Kentucky,
859/257-0261, hower@caer.uky.edu

Midwestern Regional Technical Director

Paul Chugh, Southern Illinois University at
Carbondale

Western Regional Technical Director

Deborah Pflughoeft-Hassett

UND Committee Members

Jackie Bird, Ohio Coal Development Office

Taylor Eighmy, University of New Hampshire

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Group

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Andy Wittner, USEPA

Dan Wheeler, Illinois Office of Coal Develop-
ment and Marketing

Calendar of Events

May 20, 2003

Seminar and Construction Demon- stration on the Use of Flowable Slurry Containing Coal Ash

Chicago, Illinois.

Sponsored by the Illinois Clean
Coal Institute UWM Center for
By-Products Utilization and
Ozinga Chicago RMC, Inc.

For more info or to register, call
414-229-4105, e-mail

tarun@uwm.edu or

rudik@uwm.edu, and visit

<http://www.cbu.uwm.edu>.

TRB Committee on Waste Manage- ment Summer Workshop

Portsmouth, NH

Hosted by Recycled Materials

Resource Center

For more info: <http://www.rmrc.unh.edu/summer2003> or
contact Taylor Eighmy at 603-
862-1065, or e-mail
t.eighmy@rmrc.unh.edu.

Sept. 15-19, 2003

Twentieth Annual International Pittsburgh Coal Conference

The Westin Convention Center
in Downtown Pittsburgh

Hosted by: University of Pitts-
burgh School of Engineering;
Dominion Center for Environ-
ment and Energy

For more info: phone 412-624-
7440; email: pcc@enr.pitt.edu;

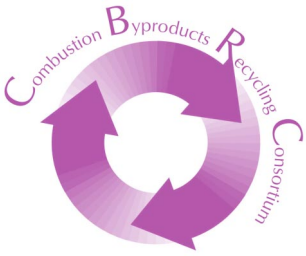
Web site: [www.enr.pitt.edu/](http://www.enr.pitt.edu/pcc)
[pcc](http://www.enr.pitt.edu/pcc).

Ashlines is published by the Combustion Byproducts Recycling Consortium, headquartered at West Virginia University in Morgantown, WV.

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Land Reclamation Center, West Virginia University, P.O. Box
6064, Morgantown, WV 26506-6064** OR fax the information to 304/
293-7822.





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wvu.edu/nmlrc](http://www.nrcce.wvu.edu/nmlrc), in
cooperation with the U.S.
Department of Energy -
National Energy
Technology Laboratory
www.netl.doe.gov

To promote and support the commercially viable and environmentally sound recycling of coal combustion byproducts for productive uses through scientific research, development, and field testing.

A Landfill Cost Model for CCPs

Deborah A. Kosmack, P.I., David A. Lewandowski, Gary F. Brendel, P.E., and Robert A. Barnes, P.E.

Ohio generates approximately 10 million tons of coal combustion byproducts (CCPs) from coal-fired electric generating power plants each year. Some of these plants have flue gas desulfurization (FGD) scrubbers and others do not.

The number of plants that include scrubbers is projected to increase to meet the Phase II sulfur dioxide emission requirements of the Clean Air Act Amendments of 1990. The quantities of fly ash and bottom ash will increase with the projected increase in electricity demand in the United States. Thus, disposal or use of CCPs will become an increasingly important environmental and economic issue.

Power plant operators must meet environmental requirements while producing the lowest cost electric power in a deregulated, competitive electric power market. Waste dis-



Aerial view of a CCP landfill in the northeastern U.S.

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VISIT THE CBRC WEBSITE AT [HTTP://WWW.NRCCE.WVU.EDU/CBRC](http://www.nrcce.wvu.edu/cbrc)

The Cost of Landfilling CCPs

posal, in either on-site or off-site landfills, can be a significant cost.

Existing landfill sites have a fixed capacity that is rapidly being exhausted. New landfills will be constructed under more stringent environmental requirements, with higher levels of public awareness, and with fewer potential sites available. All of these factors will increase the cost of developing landfills.

Generators need accurate cost information to make the most economical and environmentally sound decision on CCP disposition when existing landfill capacities are exhausted. Alternative-use developers also need information to use as a benchmark in evaluating new processes and concepts. A cost model will allow a power plant or alternative-use developer to evaluate the economic trade-off between landfill disposal and beneficial uses of the CCPs.

Fly ash and FGD sludge have uses in concrete manufacture, as roadbed materials and in the production of manufactured aggregate. Landfill disposal cost estimates may also affect the decision on the type of scrubber a power generator may install to reduce sulfur dioxide emissions. For example, a limestone forced oxidation scrubbing system may show better overall economics if it produces salable gypsum for use in wallboard versus having to landfill the byproducts.

Objectives

The overall objective of this work was to produce and disseminate a

flexible, user-friendly computer model that predicts the capital and operating costs of new landfills for disposal of a variety of coal combustion and FGD scrubber byproducts. The model provides the user the flexibility of either specifying design and cost parameters or using default values built into the program.

The specific objectives addressed in developing the computer model included:

- Account for various types of landfill topography.
- Predict the waste products generated from a power plant based upon power plant parameters, coal parameters, and scrubber parameters.
- Assess the cost of disposal of fly ash, bottom ash, and FGD sludge from coal-fired power plant accounting for different physical properties of the materials.
- Develop the model in a platform that is widely accepted.
- Develop a user's manual to describe the model and provide step-by-step instructions to run the model.
- Disseminate and publicize the model to maximize its use.

Approach

A comprehensive literature review was conducted to gather information on the fundamentals of constructing landfills and the specific design criteria that are used today. Then, an extensive review of the environmental regulations in the Ohio coal market area (Ohio, Pennsylvania, Kentucky) was con-

ducted. This is a primary factor affecting landfill design and cost.

The regulations vary from state to state, especially regarding the construction of the liner. Some states allow a natural liner (clay), others require a synthetic liner, and still others require a double liner. The user selects the state code to be used for the design. The model has the flexibility to allow the user to override specific criteria of the codes.

Consultations with engineering and construction firms that specialize in the design and construction of landfills for this type of application were conducted. GAI Consultants, Inc. and Trumbull Corporation provided a detailed review of the landfill design and construction, from site selection through construction and operation.

Drawings of existing landfills were reviewed, capital costs associated with each step of construction were analyzed, cost ranges were established, and the variables that affected these costs were identified. Landfills under construction were visited to gain firsthand information on design and construction techniques.

An advisory board consisting of members from the electric power industry, government agencies, and academicians also was formed to review the details of the model as they were being developed. From the above-listed resources, cost ranges for the components of the direct and indirect capital costs, operating and maintenance costs, and post-closure costs were identified.

Capabilities

The model provides the user the capability of calculating landfill costs based upon user-specified information. The user is provided with the option of either directly entering quantities of various coal combustion byproducts or calculating these quantities based upon user specified power plant characteristics.

Some specific parameters that can be input are power plant size, heat rate, coal sulfur and ash contents, and coal heating value. The quantities of scrubber byproducts, fly ash, and bottom ash generated are calculated from the scrubber type, coal properties, and power plant characteristics selected. If limestone natural oxidation or wet lime scrubbing is the selected FGD option, the program calculates the amount of fly ash and lime required to fixate the sludge prior to landfill disposal.

Based on the volume of CCPs, the area (acreage) of the landfill can be calculated using the known bulk densities of the various CCPs, the type of topography selected, standard engineering practice, state regulations, maximum allowable slopes for stable cuts, and intermediate and final cover requirements. By establishing the volume and acreage, the quantities of material to be removed and added to the landfill site can be calculated. This calculation is key in developing the costs for the entire landfill.



A CCP landfill under construction in the northeastern U.S.

The model calculates direct capital costs and indirect costs. Indirect costs include engineering design fees, permits, surveys, inspections, and administration fees required during the landfill construction phase. The direct and indirect costs are added to generate the total installed capital cost of the landfill.

The model calculates operating and maintenance costs and post-closure costs. Operation includes activities ongoing at the landfill site as well as transportation costs to haul the waste material from the power plant to the landfill. On-site activities include grading, compaction, water for dust suppression, monitoring well sample collection, cover addition, etc. Operating activities and costs considered include both equipment costs and manpower costs.

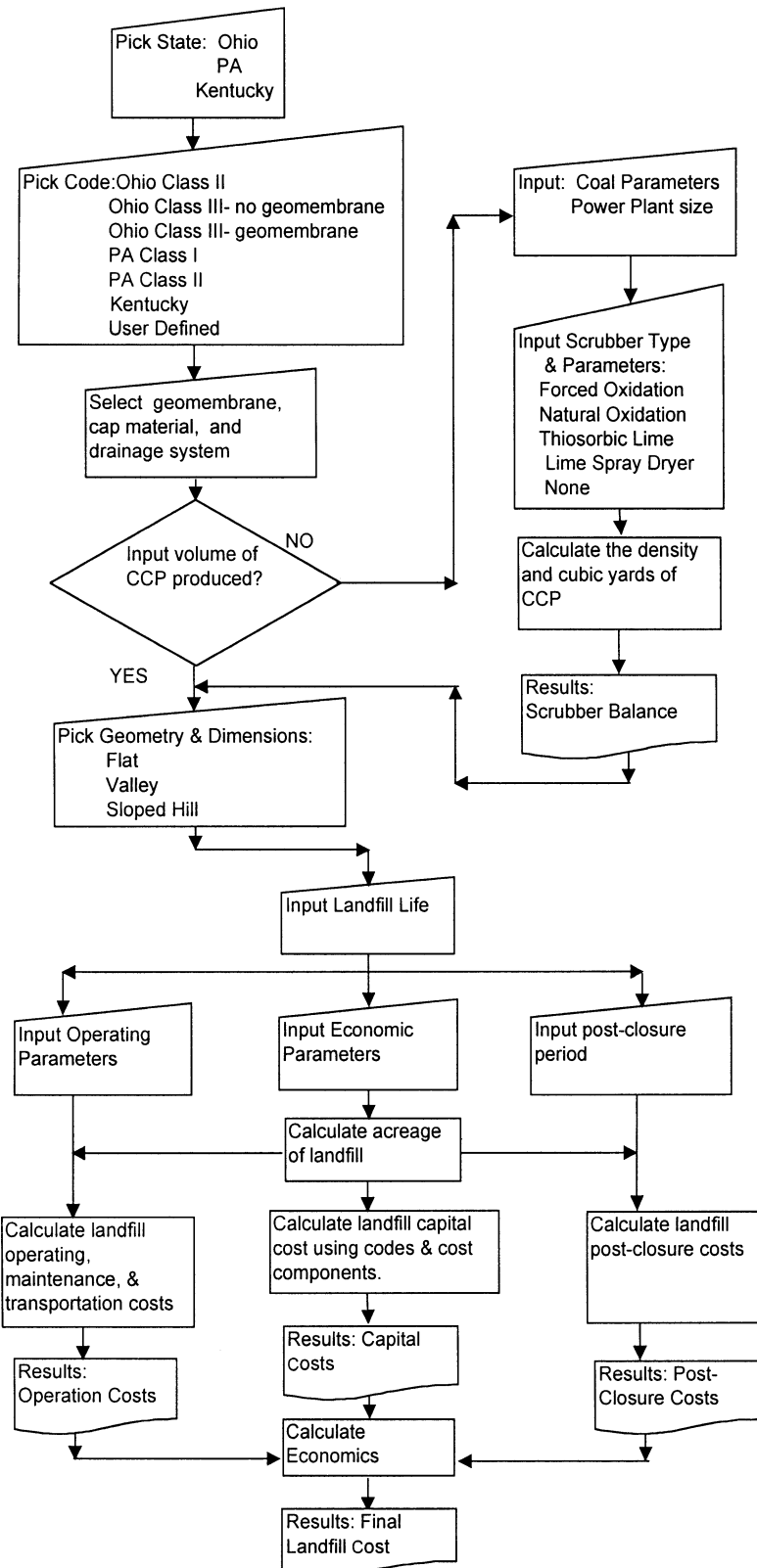
Loading and transportation of the combustion byproducts are part of the day-to-day operation. Factors that are accounted for in determining the cost of transportation are the number of trips a truck can make, type of truck, type of roads, and size of truck. Post-closure costs include expenses that will occur after the landfill is closed. This includes groundwater monitoring and site maintenance for a specified duration dictated by code regulations.

The program provides the option of treating the landfill as a commercial operation (in which costs are analyzed as an investment decision) and establishing a landfill disposal price to meet a specified return on investment. Cost factors developed for the model are based on year 2001

(continued on page 4)

Figure 1

Flow Chart for OCDO Landfill Cost Model



costs. To account for costs escalating in the future, a cost index is provided in the model. The *Chemical Engineering* cost index and the construction cost index from *Engineering News Record* are provided. Inclusion of cost indices and provisions for adding user-defined costs prolongs the shelf-life of the model.

The model also provides for a staged construction option in which the landfill is constructed in a series of stages or cells. This approach minimizes upfront capital costs and spreads the cost of subgrade preparation, liner/leachate collection system installation, and final cover placement over the life of the project.

Because there are many factors that affect the cost of a landfill, the estimate is only as good as the data that have been provided for a particular site. The model results provide an estimate that is considered to be plus or minus 25 percent of the final costs. If a landfill were to be constructed, a detailed engineering estimate that includes the specific details of the site would have to be conducted.

Results

The completed model was created in a Microsoft Excel 2000 Workbook format, with interfaces and supporting code developed in Visual Basic. It consists of 26 spreadsheets that are organized into four main sections: capital costs, scrubber analysis, operating and maintenance activities, and post-closure activities.

Within each of these categories are data input sheets, and results sheets. Code regulation sheets, landfill geometry calculation sheets, a project summary sheet, and an economics sheet are components of the complete model. The flow chart in Figure 1 on page 4 illustrates the critical inputs needed for the calculations and the results that are generated.

When the model is opened the user is directed to the Menu worksheet. This worksheet has a series of buttons that step the user through the model and provide limited error messages when appropriate. The user is guided through a series of five steps to calculate landfill costs based on the criteria input by the user. In general, critical input data are entered in step 1, optional input data are entered in step 2, design and cost calculations are performed in step 3, results are viewed in step 4, and results are printed in the last step. To input the required critical data in step one, the model is programmed with changing screen interfaces based on options selected by the user in an interactive manner. A particular screen will remain active until the user presses OK or Exit. The user-interface screen contains data input boxes, option selection check boxes, or both.

To operate the Landfill Cost Model, the user must have a computer equipped with 32MB or more of RAM, running Microsoft Word 2000 and Microsoft Excel 2000. There is a brief list of instructions in the model to help the user get started and perform the basic steps of

operation. A separate user's manual goes through a step-by-step procedure to run the model and provide the basis for the calculations performed and costs developed. This documentation is created in Microsoft Word 2000 and is on the CD-ROM that contains the program.

After the model file has been copied onto the user's computer, the model can be opened and closed as a regular Microsoft Excel 2000 file. All Excel commands can be used. The workbook is protected so that the only cells that can be changed are the input data. It is strongly recommended that users save any changes or test cases as separate files.

The model will run only one case at a time. The program output summarizes the design parameters, capital costs, operating and maintenance costs, post-closure costs, and total calculated costs based on desired internal rate of return (IRR).

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The advisory committee, with their affiliation, consisted of Bob Brown of OCDO, Tarunjit S. Butalia, P.E., Ph.D., of OSU, Annette DeHavilland of Ohio EPA, Scott Heidenreich, R.S., of Ohio EPA, Dirk J. Krouskop of MeadWestvaco, Carl S. Togni, P.E., and Dana Limes of American Electric Power, and Gary

Haney of FirstEnergy.

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For More Information

Information published about the landfill cost model is available from the Ohio Coal Combustion Products Pilot Extension program at The Ohio State University (OSU) as an OSU Extension fact sheet. Users can download the model from the Ohio CCP Web site at <http://ccpohio.eng.ohio-state.edu/ccpohio>, or from the OCDO Web site at <http://www.odod.state.ohio.us/tech/coal/html/landfill.htm>. The model also is available on CD-ROM free of charge from the lead author, D.A. Kosmack, at CONSOL Energy Inc., Research and Development, 4000 Brownsville Road, South Park, PA 15129. Or call (412) 854-6592, fax (412) 854-6613, or e-mail deborahkosmack@consolenergy.com.



Effects of Fly Ash and Portland Cement on the Long-Term Excavatability of Flowable Fill

DeL.K. Crouch, Ph.D., P.E., P.I., Vernon J. Dotson, E.I.T., and Tim Dunn

This project examined twenty-three different excavatable flowable fill (EFF) mixtures placed in trenches simulating utility cuts. Excavation of the trenches was planned for approximately two years after placement; at that time the qualitative excavatability was to be correlated with compressive strength development of the EFF.

However, funding for the project was terminated after the first year. All EFF mixtures were tested for flow, unit weight, gravimetric air content, and suitability for load application.

Nine EFF mixtures were used to access the impact of Portland cement content and ASTM C 618 Class F fly ash content. Portland cement contents of 30, 45, and 60 pounds-per-cubic-yard and ASTM C 618 Class F fly ash contents of 300, 370, and 440 pounds-per-cubic-yard was used to evaluate the impact of component proportions.

Proportions for the EFF mixtures were chosen using Kentucky Transportation Cabinet and Tennessee Ready Mixed Concrete Association (TRMCA) recommendations as well as a previous Tennessee Technological University research mixture. Six EFF mixtures were used to assess the impact of Portland cement content and high-unburned carbon fly ash content.

Portland cement contents of 45 and 60 pounds-per-cubic-yard and high-unburned carbon fly ash contents of 370, 440, 510 pounds-per

cubic-yard were used to evaluate the impact of component proportions.

The influence of aggregate type on EFF mixtures was evaluated by

Table 1. Proportions and Plastic Properties

| Mixture | Date Placed | PC | Fly Ash (lbs/CY) | Aggregate (lbs/CY) | Water (lbs/CY) | Flow (" | Ball Drop (hrs) | Air (%) | Unit Weight (pcf) |
|-----------------------------|-------------|-----|------------------|--------------------|----------------|---------|-----------------|-----------------------|-------------------|
| 1 KTC | 3/12/01 | 30 | 300 (F) | 3000 (R) | 550 | Shear | 22 | 0 | 131.8 |
| 2 | 3/12/01 | 30 | 370 (F) | 2560 (R) | 501 | Shear | 21 | 0 | 135 |
| 3 | 3/12/01 | 30 | 440 (F) | 2508 (R) | 491 | 9.5 | 21 | 0 | 132.3 |
| 4 | 3/12/01 | 45 | 300 (F) | 2603 (R) | 510 | 10.5 | 20 | 0 | 131.6 |
| 5 TRMCA | 3/12/01 | 45 | 370 (F) | 2552 (R) | 499 | 11 | 19 | 0 | 131 |
| 6 | 5/14/01 | 45 | 440 (F) | 2499 (R) | 490 | 11 | 20 | 7 | 121.8 |
| 7 | 5/16/01 | 60 | 300 (F) | 2595 (R) | 508 | Shear | 19 | 0 | 130 |
| 8 | 5/16/01 | 60 | 370 (F) | 2538 (R) | 500 | Shear | 18 | 0 | 131.8 |
| 9 TTU CAP | 5/16/01 | 60 | 440 (F) | 2492 (R) | 498 | 18 | 19 | 0 | 131.6 |
| 10 | 5/15/01 | 45 | 370 (H) | 2697 (R) | 515 | Shear | 19 | 2 | 128.9 |
| 11 | 5/15/01 | 60 | 370 (H) | 2600 (R) | 509 | 8.5 | 18 | 3 | 126.6 |
| 12 | 5/15/01 | 45 | 440 (H) | 2557 (R) | 500 | 14 | 71 | 2 | 129.2 |
| 13 | 5/15/01 | 60 | 440 (H) | 2560 (R) | 494 | 15.5 | 66 | 3 | 127.8 |
| 14 | 5/15/01 | 45 | 510 (H) | 2527 (R) | 481 | 15 | 69 | 3 | 128.2 |
| 15 | 5/15/01 | 60 | 510 (H) | 2520 (R) | 479 | 16 | 66 | 5 | 125.8 |
| 16 | 5/14/01 | 45 | 370 (F) | 2552 (L) | 499 | 11 | 48 | 2 | 132.4 |
| 17 Crushed Sandstone Sand | 5/14/01 | 45 | 370 (F) | 2362 | 593 | Shear | 22 | 3 | 122.4 |
| 18 Masonry Sand | 5/14/01 | 45 | 370 (F) | 2190 | 641 | 12.5 | 44 | 2 | 121 |
| 19 RGI Screenings | 5/14/01 | 45 | 370 (F) | 2611 | 448 | 10.5 | 23 | 0 | 135.2 |
| 20 Foundry 1 | | | | | | | | | |
| 21 Foundry 2 | | | | | | | | | |
| 22 TDOT | 5/14/01 | 100 | 250 (F) | 2800 (R) | 500 | Shear | 21 | 5 | 126 |
| 23 MBT MB AE 90 (A) | 5/15/01 | 100 | 0 | 2439 (R) | 340 | 8.75 | 46 | 28.3 (G) 25 (V) | 98.6 |
| 24 W. R. Grace Darafill (A) | 5/15/01 | 100 | 0 | 2316 (R) | 270 | 6.25 | 20 | 24.3 (G) 21 (V) | 106.7 |
| 25 MBT Rheofill (A) | 5/15/01 | 80 | 0 | 2501(L) | 375.3 | 7.25 | 67 | 25.9 (G) 22.25 (V) | 103.8 |

G = Gravimetric air content
R = River Sand Fine Aggregate
H = High Carbon Ash
A = Air-entrained Mixture

V = Volumetric air content
L = Limestone Manufactured Sand
F = Class F Fly Ash

Table 2. Compressive Strength Development

| Mixture | Date Placed | 7-day (psi) | 28-day (psi) | 63-day (psi) | 98-day (psi) | 140-day (psi) | 182-day (psi) | 238-day (psi) | 301-day (psi) | 364-day (psi) |
|---------------------------|-------------|-------------|--------------|--------------|--------------|---------------|---------------|---------------|---------------|---------------|
| 1 KTC | 3/12/01 | 5 | 6 | 8 | 9 | 9 | 10 | 9 | 8 | 9 |
| 2 | 3/12/01 | 6 | 10 | 12 | 15 | 13 | 15 | 13 | 12 | 16 |
| 3 | 3/12/01 | 7 | 13 | 20 | 20 | 19 | 21 | 20 | 22 | 20 |
| 4 | 3/12/01 | 9 | 20 | 24 | 40 | 37 | 45 | 43 | 45 | 43 |
| 5 TRMCA | 3/12/01 | 8 | 17 | 18 | 21 | 24 | 35 | 39 | 32 | 41 |
| 6 | 5/14/01 | 17 | 20 | 37 | 38 | 56 | 65 | 61 | 52 | 45 |
| 7 | 5/16/01 | 10 | 17 | 38 | 56 | 66 | 74 | 99 | 79 | 80 |
| 8 | 5/16/01 | 17 | 27 | 52 | 60 | 69 | 81 | 86 | 90 | 76 |
| 9 TTU CAP | 5/16/01 | 28 | 40 | 78 | 108 | 111 | 145 | 126 | 137 | 101 |
| 10 | 5/15/01 | 22 | 34 | 45 | 41 | 68 | 83 | 75 | 87 | 74 |
| 11 | 5/15/01 | 27 | 41 | 55 | 81 | 108 | 115 | 122 | 144 | 139 |
| 12 | 5/15/01 | 12 | 20 | 23 | 24 | 23 | 21 | 30 | 29 | 28 |
| 13 | 5/15/01 | 28 | 31 | 47 | 43 | 63 | 50 | 68 | 83 | 63 |
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| 23 MBT MB AE 90 | 5/15/01 | 11 | 16 | 19 | 22 | 24 | 25 | 39 | 38 | 35 |
| 24 W. R. Grace Darafill | 5/15/01 | 32 | 36 | 45 | 50 | 51 | 73 | 78 | 74 | 79 |
| 25 MBT Rheofill | 5/15/01 | 11 | 17 | 18 | 20 | 24 | 26 | 36 | 42 | 44 |

using five different aggregate types in the EFF mixture recommended by TRMCA (45 pounds-percubic-yard Portland cement and 370 pounds-per-cubic-yard ASTM C 618 Class F fly ash). In addition, four comparison EFF mixtures will also be used in the study (1 Tennessee Department of Transportation and 3 air-entrained EFF mixtures).

The results of the research obtained prior to termination of the

project by CBRC are shown in Tables 1 and 2.

Acknowledgements

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recommendations expressed herein are those of the author(s) and do not necessarily reflect the views of WVU or DOE.

For more information about this CBRC Project #CBRCM05, and for a copy of the final project report, visit the CBRC Web site at <http://www.wvori.nrcce.wvu.edu/cbrc>.



CBRC CONTACTS

Program Manager

Lynn Brickett, U.S. Department of Energy -
National Energy Technology Laboratory
412/386-6574; brickett@netl.doe.gov

National Center

Paul Ziemkiewicz, Ph.D., Director
Tamara Vandivort, Consortium Manager
CBRC National Center located at the
National Mine Land Reclamation Center at
West Virginia University, 304/293-2867,
pziemkie@wvu.edu or tvandivo@wvu.edu

National Steering Committee Chair

David Goss, Xcel Energy, Denver, Colorado,
303/308-2734, david.goss@xemkt.com

Eastern Regional Chair

Howard Humphrey, American Coal Ash
Association, Columbus, Ohio, 614/846-
1726, hhumphrey@columbus.rr.com

Midwestern Regional Chair

Tom Robl, Ph.D., University of Kentucky,
859/257-0272, robl@noah.caer.uky.edu

Western Regional Chair

Jacob Gonzales, TXU Energy, Dallas, Texas,
214/812-8328, jake.gonzales@txu.com

Eastern Regional Technical Director

James C. Hower, Ph.D., University of Kentucky,
859/257-0261, hower@caer.uky.edu

Midwestern Regional Technical Director

Paul Chugh, Southern Illinois University at
Carbondale

Western Regional Technical Director

Deborah Pflughoeft-Hassett

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Jackie Bird, Ohio Coal Development Office

Taylor Eighmy, University of New Hampshire

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Dave Meadows, USACE-Huntington District

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Calendar of Events

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in Downtown Pittsburgh

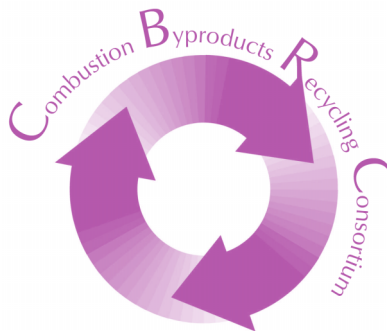
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Volume 3, Number 2

Summer 2002

COMBUSTION BYPRODUCTS RECYCLING CONSORTIUM

Ashlines

To promote and support the commercially viable and environmentally sound recycling of coal combustion byproducts for productive uses through scientific research, development, and field testing.

a program of the National Mine Land Reclamation Center at West Virginia University www.nrcce.wvu.edu/nmlrc, in cooperation with the U.S. Department of Energy - National Energy Technology Laboratory www.netl.doe.gov

CCP Grouts: Stomach Lining for Sick Mines

Paul Petzrick, P.I., Ray Hemmings, Lenny Rafalko, and Heather Wattenbach

Each day, in the shadow of Maryland's highest point, the Kempton Mine Complex belches forth 3.5 million gallons of acid (pH 3.0) mine water. Now comes the Maryland Power Plant Research Program (MPPRP) with a bold proposal to use local coal combustion products (CCPs) to prevent the air, water, and pyrites from getting together to produce their bile—all part of the MPPRP's aggressive program to fully utilize the CCPs produced within the state.

Power plants in Maryland currently produce about 1.5 million tons per year of CCPs, and growth to 2 million tons per year is expected. Currently, only about 30 percent of these CCPs are used beneficially; the remaining 70 percent being landfilled. The landfilling of CCPs consumes valuable land and has the potential to adversely affect Maryland's aquatic resources.

In 1995, the MPPRP and the Maryland Department of the Environment Bureau of Mines established the

Western Maryland Coal Combustion Products/Acid Mine Drainage Initiative.¹ The initiative, which is jointly funded by public and private sectors, spearheads Maryland's research and development of beneficial large-volume uses of CCPs to reduce acid formation in Maryland's abandoned underground coal mines. The initiative emphasizes the prevention of acid formation rather than treatment of acid mine waters.

In 1996, the initiative's first project, the Winding Ridge Project, injected 5,600 cubic yards of a 100 percent CCP-based grout into an underground coal mine, and successfully reduced acid formation in that mine by as much as 90 percent.²⁻⁴ The Siege of Acre Project is one of several projects underway or planned by the MPPRP to use CCP-based grouts to



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CCP Grouts: Stomach Lining for Sick Mines

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reduce acid formation in Maryland's 450 abandoned coal mines.

In general, the MPPRP's strategy is to demonstrate that grouts made of CCPs can be used as a replacement for ordinary cement mixtures in most geotechnical engineering applications. Mine restoration has focused on acid mine drainage (AMD) but will eventually address subsidence and disruption of water patterns in watersheds disturbed by underground mining.

Objectives

The Siege of Acre Project is a field-scale experiment designed to evaluate the impact on acid production of covering pyritic mine pavement and high sulfur mine debris left in abandoned mines. The impermeable covering proposed is a hydraulically-placed fluid grout composed of mine water and locally available CCPs.

The Kempton Mine Complex covers about 12 square miles in Maryland and West Virginia, and discharges AMD at a rate of approximately 3.5 million gallons per day into Laurel Run, the first major tributary to the North Branch of the Potomac River. The Siege of Acre segment of the Kempton Complex forms the northern extremity of the mine workings in Maryland (refer to the map on page 1). In particular, it includes an isolated straight run of three tunnels, each 750 feet long by 16 feet wide, running up dip from the northern edge of the mine pool. As an experimental site, this section is directly representative of several hundred acres of subaerial mine pavement along the western

edge of the Kempton mine pool, and subaerial pavement in other Upper Freeport mines in Maryland and neighboring states.

Project Tasks

The Siege of Acre Project is planned to be completed in two phases for an important technical reason: if there is no reliable flow of low pH water off the pavement in this segment of the mine the experiment could not be conducted. Thus, phase I was planned to determine the exact location and orientation of the mine tunnels and provide access to monitor water (if any was found) coming off the pavement in this segment of the mine.

Phase I of the project was completed during 2001 and 2002 with the help of Department of Energy funds provided under a subcontract with West Virginia University, contract agent for the Combustion Byproducts Recycling Consortium (CBRC). The three tasks of phase I included careful mapping and drilling to find the mine tunnels under 140 to 175 feet of overburden, determining their exact orientation, preparations for baseline water quality monitoring, and preliminary design of the grout using locally produced combustion products.

The investigation to determine the exact location and orientation of the mine was a challenge worthy of extensive discussion, especially in view of the recent accident at the Quecreek Mine in Pennsylvania, which was associated with interpreting an old mine map. The initial drilling locations to find the Siege of Acre tunnels were identified by a rigorous review of the 50-year-old

historical mine map. This map was known to have been prepared over a 30-year period of progressively mining north from Davis, West Virginia, and then jumping ahead to Kempton, Maryland, in 1912.

From the 420-foot shafts in Kempton, the mine continued its northward march two miles to the Siege of Acre segment until closed in 1950. The closest reference points to the Siege of Acre tunnels identified on both the mine map and the surface are an airshaft and a power borehole 4,000 feet from the experimental site. It also was known that the best of mine mapping in this period employed rather crude survey methods compared to modern lasers and global positioning systems and were subject to changing magnetic declinations.

After extensive field reconnaissance and careful surveying of suspected subsidence depressions, it was estimated that distances on the mine map had to be foreshortened by a factor of .00875 (35 feet over the 4,000 feet to the closest reference points), but it was impossible to estimate the degree of rotation needed to precisely place the Siege of Acre segment of the mine relative to the surface. Drilling at a location determined to have the highest probability of hitting a tunnel resulted in hitting the tunnel below the surface of the mine pool. This hole has been retained for sampling the mine pool in the area, initially the depth of water in it provided a reference point for drilling a second hole into the tunnel above mine pool.

Downhole camera observations in the second and subsequent holes guided additional drilling until the

exact geometry of all three tunnels was established. At the time of initial drilling in November 2001, no water was observed coming off the pavement at the proposed site for the experiment. Since the area had endured an unusual drought over the summer, it was decided to observe the tunnels for several months to determine if the initial observation was an anomaly.

Camera observations since December 2001 have shown water flowing under the hole drilled into the southwest tunnel so the experiment can proceed. Baseline water quality monitoring is underway at the site.

Grout Mix Design

The laboratory investigation conducted by Hemmings & Associates using locally available CCPs focused on the specifics of the mine geometry and conditions observed by the downhole cameras. The CCP materials selected for the grouts were fluidized bed combustion (FBC) ash and pulverized coal fly ash (PFA) from the North Branch and Mount Storm power plants, respectively, both located close to the Kempton Mine Complex.

A grout formulation has been developed using these materials to provide a competent fluid grout that will spread and flow long distances through the debris on the mine floor where slopes vary from 15 to 19 percent. The ability to design a grout with an angle of repose comparable to the slope of the mine floor is crucial to economy in drilling injection holes and, at the same time, not have the grout flow away into the mine pool.

Because of the complexity of the abandoned mine workings and

debris, the CCP-based grouts are being designed to be adaptable to a variety of anticipated conditions underground with the following generalized performance criteria:

- rheological properties to provide sufficient fluidity to ensure good pumpability,
- optimum fissure and/or mine debris penetration and lateral transport underground,
- adequate durability to withstand possible low-pH water flowing on it for long periods of time, and
- *in-situ* characteristics to prevent acid formation or leaching of heavy metals in the abandoned mine workings.

The all important consideration is that the CCP grouts should be stable and compatible with the mine water present on the mine floor. This is particularly important with respect to the ability of the grout to retain its chemical integrity against potential dissolution and release of metals into either groundwater or surface water.

Rheologically, the PFA-FBC grouts exhibit good fluidity, with stable Bingham flow and cohesiveness in the solids content (Cw) range Cw = 65 to 71 percent. Above this range, the grouts quickly start to exhibit pseudoplastic flow with reduced fluidity as a consequence of rapidly increasing yield stress, plastic viscosity, and thixotropy.

Below Cw = 65 percent, there is a tendency towards solid-liquid separation, which could lead to problems during pumping and placement. Because of the higher fines content of the PFA compared to the FBC material, grouts with a higher proportion of PFA tend to be

more cohesive at a given Cw, with slightly higher yield stress and plastic viscosity.

Physically, compressive strengths for the grouts can be targeted in the range 100 pounds per square inch (psi) to over 2,000 psi to meet the needs of widely different exposure conditions underground. While compressive strength is not an important consideration in the conventional sense for this application, it is considered to be an important surrogate for durability. The grouts are surprisingly well-behaved from a design perspective, with strength potential being controlled predictably by the water to FBC (w/fbc) ratio—exactly analogous to the water to solids content (w/c) ratio controlling strength in concrete technology.

To a first approximation, the FBC material, therefore, plays the role of the primary cement for the system. It is evident that, with the possible exception of bulk filling of dry areas near the upper ends of the tunnels, the grouts will need to contain at least 25 wt percent of the FBC material (on a dry basis) to achieve adequate durability (*in-situ* strength).

Mechanistically, the development of strength in the grouts is the result of a complex sequence of sulfo-pozzolanic and silico-pozzolanic reactions involving the residual lime alkalinity, anhydrite and amorphous dehydroxylated clays/shales present in the FBC material, and the aluminosilicate glass in the PFA. The significant product from these reactions is the calcium sulfoaluminate ettringite, which has good cementitious properties and, therefore,

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Fly Ash as an Aggregate for Foundry Sand Mold and Core Production

Jerzy Sobczak and Robert M. Purgert, P.I.

Coal remains the major fuel burned for power production in the U.S. In 1998, power production from coal generated nearly 45 million tons of fly ash and over 10 million tons of bottom ash as part of the coal combustion byproduct waste stream. This material is composed of noncrystalline oxides of silicon (SiO_2), aluminum (Al_2O_3), iron (Fe_2O_3), calcium (CaO), and minor quantities of other metal oxides (i.e., magnesium, sodium, titanium, and potassium).

The precise composition of fly and bottom ash varies depending on the source of the coal being burned. The physical properties of the ash vary with the type and uniformity of the coal, the operating parameters of the power plant, and the collection methods employed to separate the ash from the combustion stream. Although some portion of this ash is used in beneficial applications, primarily in the construction industry, significant portions are disposed of in landfills.

Fly Ash Can Benefit Foundry Industry, Workers

The foundry industry in the U.S. comprises approximately 3,000 independent companies found in

all 50 states. While 85 percent of these companies are small businesses employing fewer than 100 people, the industry as a whole provides well-paying jobs for over 200,000 people each year.

With the exception of die casting, sand molds and cores are used in nearly every casting process practiced in the U.S. with foundries using about 100 million tons of sand per year in their operations. Only the largest foundries generate the amounts needed to justify the capital equipment necessary to reuse this sand in foundry applications or to process the sand into a relatively clean material for use in construction applications. Every year, 8 to 10 million cubic yards of this sand are placed in landfills at a yearly cost of 100 to 250 million dollars.

Aside from the disposal costs associated with casting sands, the biggest concern surrounding its use in the foundry industry is employee exposure to crystalline silica. Common foundry sands are composed of crystalline silica (quartz) materials. As such, prolonged exposure to dusts from these sands can cause silicosis. This is particularly true when very fine grades of sand are handled.



The Occupational Safety and Health Agency (OSHA) has proposed lowering the allowable workplace exposure of crystalline silica by 50 percent to 0.05 mg/m^3 . This level of exposure might be difficult to achieve at many foundries. In addition, the record keeping, reporting, training, and medical surveillance required under the new standards would be extremely time consuming and costly.

Fly Ash Can Replace Foundry Sand

High silica sand is an extremely good material for casting molds because it has the ability to withstand the temperature of the molten metal, can absorb and transmit heat, and has sufficient permeability to allow gasses generated during casting to pass between the particles without causing casting defects. Fly ash and bottom ash have many of the

same attributes. These materials have a very high melting point, can absorb and transmit heat during pouring, and have the ability to allow gases to pass through a compacted mass.

Foundry sands are processed within strict particle size distributions to tailor the properties of the material to the intended casting process. The major difficulty with fly or bottom ash is the fact that it currently is generated in a manner that is optimized for coal combustion. The particle size distribution that results is determined by combustion criteria without any thought for the properties required to use the resultant ash in any secondary application.

However, it was found that it is possible to determine and modify the particle size distribution of fly ash or bottom ash in such a manner that the resulting material could be acceptable as a replacement for foundry sand in some applications.

This project determined that fly ash could act as a replacement for foundry sand and has been justified in a number of ways.

Fly Ash Advantages

First, the use of fly ash would eliminate a portion of the total amount of material being sent to landfills. Granted the fly ash or bottom ash so used would be landfilled in the same manner as the foundry sand currently in use. However, since the ash would be landfilled in any event, total volume of landfill material would be reduced by the quantity of sand replaced.

Secondly, the most problematic sand material handled by foundries are those fine-grained sands with American Foundry Society (AFS) grade fineness numbers higher than 90. These sands have nearly 80 percent of their grains smaller than 140 U.S. Mesh. This is the sand that poses the greatest threat of dusting during handling and of inhalation by foundry workers. Since fly ash is extremely fine, it possibly can replace these very fine sands. The noncrystalline nature of these ash materials could also reduce or eliminate the concern for crystalline silica exposure in applications using fine foundry sands.

Third, ash products have a considerably lower bulk density than virgin sands. If they prove commercially suitable as a replacement for sands, the resulting molds will be much lighter than comparable sand molds. Handling the molds would become easier for foundry workers and injuries related to handling the molds would be reduced.

Fourth, because fly ash's low density, it may provide a much higher insulating value than typical foundry sands. This increased insulation would make it possible to pour thinner sections, particularly in light metal (e.g., aluminum and magnesium) castings without encountering freeze-off during the pour. This possible benefit of fly ash use should be more fully explored in future studies.

Findings

The Energy Industries of Ohio demonstrated that fly ash could be used as a replacement and filler for foundry sands for both mold and core applications. Molds made from fly ash were successfully poured in both ferrous and nonferrous alloys. For green sand applications, fly ash in varying amounts was found to be suitable as a substitute for traditional foundry sand.

An even more significant finding was the ability to use fly ash in chemically bonded (dry sand) types of applications substituting for 100 percent of the traditional foundry sand. The benefit for using fly ash in these types of applications lend themselves to being used for cores that are currently produced, used once, and then landfilled in many automotive applications.

The project's demonstration of the the acceptability of fly ash as a substitute for foundry sand points the way to a very promising new application for fly ash.

For more information about this CBRC Project #CBRCE42, visit the CBRC Web site at www.wvwrri.nrcce.wvu.edu/cbrc, or contact the CBRC at (304) 293-2867.



CBRC CONTACTS

Program Manager

Lynn Brickett, U.S. Department of Energy -
National Energy Technology Laboratory
412/386-6574; brickett@netl.doe.gov

National Center

Paul Ziemkiewicz, Ph.D., Director
Tamara Vandivort, Consortium Manager
CBRC National Center located at the
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West Virginia University, 304/293-2867,
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Association, Columbus, Ohio, 614/846-
1726, hhumphrey@columbus.rr.com

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Jacob Gonzales, TXU Energy, Dallas, Texas,
214/812-8328, jake.gonzales@txu.com

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Andy Wittner, USEPA

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ment and Marketing

CCP Grouts: Stomach Lining for Sick Mines

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is the primary binding agent for the grouts. However, ettringite is expansive, and if it continues to form to the point of breaking up the chemical matrix, the grout will become soluble in water.

Normally, as the grouts mature, there is an increasing contribution to the cementing action from calcium silicate hydrates and aluminosilicate hydrates, closely related to the binding phases in portland cement concrete. Continued strength gain and ettringite formation in this particular PFA-FBC system is restricted by the relatively low lime availability in the North Branch FBC ash so durability of the grout is not expected to be a problem but it is being monitored *in-situ* at Winding Ridge and will be the subject of accelerated weathering experiments at Temple University.

The Path Forward

Completion of phase 1 of the Siege of Acre Project has provided an excellent basis for continuing pre-injection monitoring, planned grout injection, and post injection monitoring. PPRP has made a preproposal to CBRC for assistance in funding phase II of the project with the intention of completing grout injection in 2003 or 2004.

Acknowledgements

Funding from CBRC made this start on the Siege of Acre Project possible. The Maryland Environmental Trust Fund provided the state cost share. Every contractor and agency involved went above the letter of their contract or commitment to meet the

challenges of the project. The project team is especial grateful to the Maryland Department of the Environment Bureau of Mines and the landowner, Western Pocahantas Properties, LLC, for their cooperation, and to Dr. Peter Dunbar, Director of PPRP and administrator of the Maryland Environmental Trust Fund.

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For more information about this CBRC Project #CBRC15, visit the CBRC Web site at www.wvri.nrcce.wvu.edu/cbrc, or contact the principal investigator, Paul Petzrick, at (410) 260-8669; e-mail ppetzrick@dnr.state.md.us.



Calendar of Events

November 27–29, 2002

Biennial Energy Science and Technology Conference. University of Melbourne-Parkville Campus. Organized by the Australian Institute of Energy. Write to Dr. Brian Young, Conference Chairman, Australian Institute of Energy, PO Box 88, Vermont VIC 3133, Australia, or fax to (03) 9873-8481, or

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CBRC Headquarters
WVU Research Corporation
WVU NRCCE
P.O. Box 6064
Morgantown, WV 26506-6064





Volume 3, Number 1

Spring 2002

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Ashlines

To promote and support the commercially viable and environmentally sound recycling of coal combustion byproducts for productive uses through scientific research, development, and field testing.

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Center at West Virginia
University www.nrcce.wvu.edu/nmlrc, in
cooperation with the U.S.
Department of Energy -
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Fly Ash Evaluated as Mercury Sorbent in Power Plants

James Butz, ADA Technologies, Inc., P.I.

On December 14, 2000, the U.S. Environmental Protection Agency (EPA) announced its intention to regulate the emission of mercury from coal-fired power plants. This statement has resulted in renewed interest in technologies for the removal of mercury, the most common of which is the use of sorbents injected into the flue gas stream.

Recent research into the removal of vapor-phase mercury from coal-fired flue gas streams has shown that some native fly ash materials have an affinity for mercury, to the point where these fly ashes capture virtually all the mercury present at some generating facilities. Specific fly ashes from Colorado bituminous and Wyoming subbituminous coals have been measured to remove from 75

to 98 percent of the mercury in full-scale generating units. Investigations of the properties of these fly ashes have revealed that most of the mercury was present in the smallest size fraction.

ADA Technologies, Inc., was awarded a project to investigate the feasibility of employing these fly ash materials as mercury sorbents. The planned testing was performed on a slipstream from a full-scale generating unit at Xcel Energy's Comanche Station in Pueblo, Colorado. Candidate fly ash materials were obtained from three other Xcel generating facilities.

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Fly Ash Evaluated as Mercury Sorbent in Power Plants

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Materials and Methods

The fly ash testing was performed in a pilot plant built and installed under an earlier contract with the U.S. Department of Energy. (Refer to the photo on page 1.) Testing was performed to evaluate the use of activated carbon for the removal of mercury from a slipstream from Comanche Station's Unit 2. The slipstream was extracted from the host unit upstream of the plant particulate control equipment. The unit was outfitted with a reverse-gas baghouse particulate control system.

The fly ash-derived sorbent under test was injected upstream of the baghouse at a location to provide a nominal one-second residence time in the gas flow before entering the baghouse. Ports installed on the pilot plant ducting allowed measurement of mercury content upstream of the injection location and at the outlet of the baghouse. Mercury measurements for these tests were made with a commercial portable mercury analyzer.

Candidate fly-ash-derived sorbents were manufactured from three fly ash materials supplied by Xcel Energy. Two were from plants burning a Colorado bituminous coal, and the third was from a site burning a Wyoming subbituminous (Powder River Basin) coal. Two of the fly ash materials contained alkali sorbents injected at the generating sites for reduction of SO₂ emissions. One alkali material was lime from a spray dryer absorber, and the second was sodium sesquicarbonate injected

directly into the flue gas for SO₂ control. The fly-ash-derived sorbents were created by grinding to generate materials with 90 percent of the mass in particles less than 20 micrometers in diameter. A few hundred pounds of each candidate fly ash were processed for the planned testing.

Fly-ash-derived sorbents were injected into the pilot gas flow at two rates: 22 lb. per million actual cubic feet and 7.3 lb. per million actual cubic feet. These rates were selected to represent the maximum practical rate and a reduced rate at which the test sorbents could be injected. The maximum rate represented a nominal 10 percent increase in mass loading for the host site, a level at which the performance of the existing particulate control equipment would not be substantially affected. The flue gas was maintained at 300°F for all of the tests.

Results and Conclusions

All three fly ash materials showed significant incremental removal of vapor-phase mercury, ranging from 53 percent to 85 percent at the high injection rate and about 23 percent at the low rate. The pilot gas flow was also monitored to determine if there was any reduction in SO₂ levels due to the alkali compound content of the test sorbent materials. No measurable change was observed.

An economic analysis was completed to compare the estimated cost of fly-ash-derived sorbents with the projected use of activated carbon for control of mercury emissions

from a 100-MW generating facility. The cost model used was based upon an analysis originally presented in the EPA's 1997 *Mercury Study Report to Congress*. The modeling showed that the use of fly-ash-derived sorbents was projected to be cost-competitive with the injection of activated carbon for flue gas conditions and the plant configuration of the host site. The fly-ash-derived sorbents were assumed to be available in quantity at a price of \$50 per ton, although the analysis showed that there was only a minor sensitivity of the unit cost for mercury removal as a function of the price of the processed fly ash sorbent.

The major factor in considering the use of fly-ash-derived sorbents may well be their effect on the marketability of the collected native fly ash plus sorbent at plants where mercury control must be implemented. The injection of activated carbon could result in a collected fly ash plus sorbent product that must be landfilled rather than sold as a pozzolan. On the other hand, the use of a fly-ash-derived sorbent that is mostly a silicate or alumina product would mean that the carbon content of the collected matter is low, and it could be sold on the open market. This aspect of the use of fly-ash-derived sorbents merits further investigation.

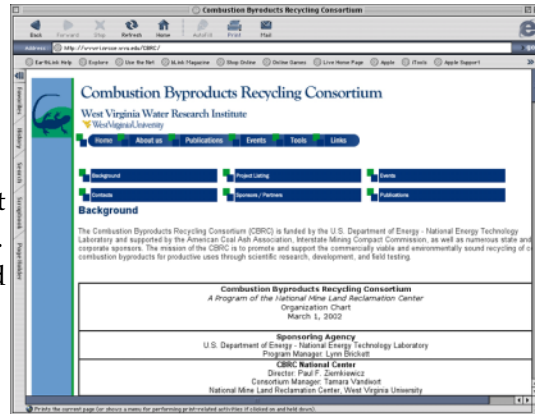
For more information about this project, contact the principal investigator, James Butz, ADA Technologies, Inc., at (303) 792-5615 or at james.butz@adatech.com.



CBRC News

CBRC Web Site Has New Look, Location

The original CBRC Web site has moved and is now a page located on the West Virginia Water Resources Institute (WVWRI) Web site at <http://wvwri.nrcce.wvu.edu>. The Web page was redesigned and has a new look, but all the features on the original site, such as *Ashlines* issues and CBRC news, are still available.



Visitors who use the CBRC's former URL will be automatically routed to the new page.

CBRC To Announce 2002 RFPs

The CBRC expects to announce requests for proposals for 2002 projects in late summer/early fall on the CBRC's new Web site at <http://wvwri.nrcce.wvu.edu>. Please

check the site regularly for information and instructions on how to submit a proposal.

Ashlines Says Goodbye to Paper and Ink

How many past issues of *Ashlines* (even those you read more than once and distributed around the office) do you suppose are fly ash now? It's impossible to say. But this should happen less often now that *Ashlines* is published exclusively online. Hard copies of the newsletter will no longer be printed and mailed to subscribers. Instead, readers can choose to print the newsletter only when needed and at their convenience. The newsletter will be located at CBRC's Web site

at <http://wvwri.nrcce.wvu.edu>.

Becoming an online subscriber to *Ashlines* is easy. Simply e-mail a request to be placed on the CBRC Listserv to cbrc@nrcce.wvu.edu. Please include your name, address, phone, fax, and e-mail address. Or, you can fill out the form provided on page 4 and fax or mail it to the address provided. Subscriptions are free and the listserv also keeps you updated on other CBRC news including requests for proposals.



CBRC CONTACTS

Program Manager

Lynn Brickett, U.S. Department of Energy - National Energy Technology Laboratory
412/386-6574; brickett@netl.doe.gov

National Center

Paul Ziemkiewicz, Director
Tamara Vandivort, Consortium Manager
CBRC National Center located at the National Mine Land Reclamation Center at West Virginia University, 304/293-2867, pziemkie@wvu.edu or tvandivo@wvu.edu

National Steering Committee Chair

David Goss, Xcel Energy, Denver, Colorado,
303/308-2734, david.goss@xemkt.com

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Howard Humphrey, American Coal Ash Association, Columbus, Ohio, 614/846-1726, hhumphrey@columbus.rr.com

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859/257-0272, robl@noah.caer.uky.edu

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Jacob Gonzales, TXU Energy, Dallas, Texas,
214/812-8328, jake.gonzales@txu.com

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James C. Hower, University of Kentucky,
859/257-0261, hower@caer.uky.edu

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Jim Rower, Utility Solid Waste Activities Group

Kimery Vories, Office of Surface Mining

Andy Wittner, USEPA

Dan Wheeler, Illinois Office of Coal Development and Marketing

Calendar of Events

August 19–20, 2002

Midwest Industrial Byproducts Beneficial Use Summit. Sponsored by the U.S. Environmental Protection Agency Region 5 and the National Council for Air and Stream Improvement. Metcalfe Federal Building, 77 W. Jackson Blvd., Chicago. Visit www.ncasi.org/summit.html for agenda and registration.

November 27–29, 2002

Biennial Energy Science and Technology Conference. University of Melbourne-Parkville Campus. Organized by the Australian Institute of Energy. Write to Dr. Brian Young, Conference Chairman, Australian Institute of Energy, PO Box 88, Vermont VIC 3133, Australia, or fax to (03) 9873-8481, or e-mail to melb@aie.org.au, or visit the Web site at www.aie.org.au.

January 27–30, 2003

Products (CCPs)

Sponsored by the American Coal Ash Association and the American Coal Ash Association Educational Foundation. Don CeSar Hotel. St. Petersburg, Florida. Contact the American Coal Ash Association at (703) 317-2400 or at info@acca-usa.org, or visit the Web site at www.acaa-usa.org.



Ashlines is published by the Combustion Byproducts Recycling Consortium, headquartered at West Virginia University in Morgantown, WV.



Would you like to be on the CBRC electronic mailing list?

If so, complete this form and mail it to: **CBRC Mailing List, National Mine Land Reclamation Center, West Virginia University, P.O. Box 6064, Morgantown, WV 26506-6064** OR fax the completed form to 304/293-7822 OR send email to cbrc@nrcce.wvu.edu

Name: _____

Mailing Address: _____

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COMBUSTION BYPRODUCTS RECYCLING CONSORTIUM

Ashlines

To promote and support the commercially viable and environmentally sound recycling of coal combustion byproducts for productive uses through scientific research, development, and field testing.

a program of the National
Mine Land Reclamation
Center at West Virginia
University www.nrcce.wvu.edu/nmlrc, in
cooperation with the U.S.
Department of Energy -
National Energy
Technology Laboratory
www.netl.doe.gov

CBRC Selects Nine Research Projects for Funding in 2002

The Combustion Byproducts Recycling Consortium (CBRC), a five-year national program funded by the U.S. Department of Energy-National Energy Technology Laboratory (DOE-NETL) and managed by the National Mine Land Reclamation Center (NMLRC), has selected nine research projects for funding. This year, the DOE-NETL will award approximately \$835,000 to the CBRC to fund the projects selected by the CBRC National Steering Committee as part of their continuing efforts to promote and support

the commercially viable and environmentally sound recycling of coal combustion byproducts (CCBs).

The CBRC is divided into three regional areas: Western, Midwestern, and Eastern Regions. The national center is located at West Virginia University's NMLRC and is directed by Paul Ziemkiewicz. Regional centers are located at the University of North Dakota, Southern Illinois University-Carbondale, and the University of Kentucky.

Since its inception in 1998, the CBRC has received \$2,659,035 in funding from DOE-NETL and has funded 30 projects nationwide through a series of requests for proposals with a 25 percent minimum cost-share requirement. To date, \$3,019,698 in cost-share has been applied

to these projects.

Funding of these nine new projects marks the entry of the fourth phase of the five-year program and takes the CBRC closer to meeting its goal to double the current rate of flue gas desulfurization byproducts use and to increase by 25 percent the number of uses considered "allowable" under state regulations by 2005.

Phase IV projects address the use of CCBs in a variety of ways. Project topics include determining environmental effects of using large volumes of CCBs to reclaim surface mines, testing CCBs for road pavements, and CCB use in wall board manufacture.

For more information on the nine 2002 projects or previous projects funded by the CBRC, call (304) 293-2867 or visit the CBRC Web site at <http://cbrc.nrcce.wvu.edu>.

NOTICE

This is the last paper issue of Ashlines. To sign up to receive electronic notices of Ashlines release to the CBRC Web site, see page 8.

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VISIT THE CBRC WEBSITE AT [HTTP://CBRC.NRCCE.WVU.EDU](http://CBRC.NRCCE.WVU.EDU)

CBRC Phase IV Projects

Project 00-CBRC-M04: Crushed Aggregates for Class C Fly Ash

Anil Misra, Ph.D., P.I.

Utilities in the Midwest produce voluminous quantities of self-cementing class-C fly ash as a result of burning subbituminous coal from Wyoming. Owing to their self-cementing nature, these fly ashes can be used as cement surrogates. In this research project, the investigators intend to exploit the self-cementing nature of these fly ashes to develop lightweight aggregates that can be used for a wide variety of construction activities.

Hydrated class-C fly ash can have compressive strength comparable to low-strength rocks. For example, 7-day air-cured samples of class-C fly ash-sand mortar have compressive strengths of 10 MPa and above. Furthermore, compressive strengths of some hydrated class-C ashes have been reported to be as high as 15 MPa with a specific gravity of less than 2. Additives such as kiln dust, lime, and fibers may enhance the strength and other mechanical properties of hydrated class-C fly ash.

This indicates that class-C fly ash could be used as granular base course for highways, as backfill behind retaining structures, as decorative rocks, in specialty concrete, and in other applications. Hydrated class-C ponded ash also may be reclaimed from ponds to produce crushed aggregates.

The researchers will evaluate two types of crushed aggregates produced by using (1) laboratory-cured mixtures of class-C fly ash, fibers, and, sand and (2) reclaimed hydrated ponded class-C fly ash. An optimal mix proportion will be developed for the ash-fiber-sand aggregates. The 7-day unconfined compressive strength test on 2-inch cube samples will be used as a criterion to optimize the mix proportions.

Mixtures will be selected to produce crushed aggregate material in the laboratory based upon the unconfined compressive strength and visual examination of sample hardness. A variety of tests will be performed to characterize the various properties of the crushed aggregates. The aggregates will be evaluated for application as pavement base course material, as backfill material, and as aggregates for Portland cement concrete by investigating their compaction behavior, California Bearing ratio (CBR), shear strength behavior, and behavior in Portland cement concrete.

The researchers will evaluate aggregates reclaimed from ponded ash for application in road bases. Ponded ash aggregates will be specially evaluated for residual cementation capacity and pozzolanic activity.

For more information about this project, contact the CBRC or the principal investigator, Anil Misra, associate professor of civil engineering, University of Missouri-Kansas City, at (816) 235-1285 or misraa@umkc.edu.

Project 01-CBRC-E09: Development of Fly Ash- Derived Sorbents to Capture CO₂ From the Flue Gas of Power Plants

M. Mercedes Maroto-Valer, Ph.D., P.I.

Coal is the most abundant fossil fuel in the U.S., and the reduction of CO₂ emissions from coal-fired units is imperative to mitigating global climate change and, consequently, to guaranteeing the key role of coal in the 21st century. The costs of separation and capture of CO₂ are estimated to be about three-fourths of the total cost of ocean or geological sequestration, where the processes involved are very energy-intensive, and the amine solutions used in the process have very limited lifetimes.

Recently, new solid-based sorbents are being investigated where the amine groups are bonded to a solid surface, resulting in an easier regeneration step. However, the supports used thus far, including commercial molecular sieves and activated carbons, are very expensive and hinder the economical viability of the process. There is a need to find cost-effective precursors that can compete with the expensive commercial sorbents.

To compete effectively, the precursors must be inexpensive and easily converted into high-surface materials. The unburned carbon in fly ash meets all these conditions satisfactorily.

This research program will focus on the development of fly ash carbon-derived sorbents to capture CO₂ from power plant flue gas. The proposed fly ash carbon derived sorbents will represent an affordable alternative to

existing methods using specialized activated carbons and molecular sieves, which tend to be expensive and therefore hinder the viability of the CO₂ sorption process.

In this project, researchers will activate fly ash carbon samples collected from different combustion systems and the resultant activated fly ash samples will be amine impregnated. The activated and treated fly ash samples will be tested for CO₂ capture and release, and their capacities will be compared to those of commercial activated carbons.

Finally, to assess whether the proposed CCB utilization is more cost-effective than landfilling, the researchers will conduct a preliminary economic assessment to evaluate the economic viability of the proposed CCBs as CO₂ sorbents.

This research will have an environmental and economic impact for both the coal and utility industries, since utilities could simultaneously increase their CCB utilization, as well as reduce their CO₂ emissions.

For more information about this project, contact the CBRC or the principal investigator, M. Mercedes Maroto-Valer, assistant professor energy and geo-environmental engineering and program coordinator for sustainable energy, Pennsylvania State University, at (814) 863-1333 or mmm23@psu.edu.

Project 00-CBRC-E41: Environmental Effects of Large-Volume FGD Fill

Phillip E. Glogowski, P.I.

The goal of this research project is to investigate the environmental effects associated with use of fixated

flue-gas desulfurization (FGD) material for structural fills requiring large volumes of fill material.

A 472,000-ton embankment being constructed from Fall 2000 to 2002 at the Rostraver Airport near Pittsburgh, Pennsylvania is proposed as the site of a field demonstration. The embankment is being constructed to fulfill the Federal Aviation Administration requirement for a 300-foot runway safety area at the end of the paved runway.

A detailed preconstruction, construction, and postconstruction environmental monitoring program will be conducted to investigate air and water quality impacts. Environmental monitoring consists of the following:

- surface water quality testing,
- groundwater quality testing, and
- air quality testing.

For more information about this project, contact the CBRC or Phillip E. Glogowski, engineering manager, GAI Consultants, Inc., at (412) 856-6400 or p.glogowski@gaiconsultants.com.

Project 01-CBRC-M12: The Effect of Mercury Controls on Wallboard Manufacture

Sandra Meischen, Ph.D., P.I.

Pending U.S. Environmental Protection Agency (EPA) regulations are anticipated to mandate 90 percent mercury removal efficiency from utility flue gas. Little data is currently available on the fate and form of mercury in the FGD material and its use in wallboard manufacture.

Consequently, the doubling of mercury in the FGD material and its

effect on wallboard manufacture is a concern that could limit the growing byproduct use of FGD material.

This project will examine thermal decomposition profiles and selective leaching techniques to identify minute quantities of mercury compounds in FGD material and wallboard. Analysis will be accomplished with CVAFS method capable of measuring mercury at the picogram level.

The FGD material will be prepared from simulated flue gas containing elemental mercury. The mercury will be oxidized by a TVA-patented oxidation catalyst and trapped in a laboratory wet-FGD control apparatus. The mercury volatility and leaching potential will be measured for the FGD material produced. Mercury volatility of the FGD material also will be monitored as it undergoes a laboratory-scale wallboard manufacture process.

This data will address the commercial viability of FGD material as a result of mercury controls that focus on wet-FGD to remove oxidized mercury.

For more information about this project, contact the CBRC or the principal investigator, Dr. Sandra Meischen, scientific specialist, Tennessee Valley Authority, at (256) 386-3539 or simeischen@tova.gov.

Project 01-CBRC-M23: Qualifying CCBs for Agricultural Land Application

David J. Hassett, P.I.

The goal of this University of North Dakota Energy and Environmental Research Center (EERC) project is to determine the environmental appropriateness of CCBs for agricultural land applications. The project will determine

CBRC Selects Nine Research Projects for Funding in 2002 (cont. from page 3)

the appropriateness of mixed CCBs (bottom ash, fly ash, and FGD material) recovered from wet storage for agricultural land application.

CCBs reclaimed from disposal, individual ash samples before wet storage, untreated and field-treated soil samples, and Duck Creek Power Station ash pond water will be evaluated in a laboratory setting. Evaluation will involve analyses of the received materials and leachate chemistry of the as-managed ash and soil samples. This will include major, minor, and trace constituent analysis and sulfate/sulfite determination.

Constituents to be included in the analyses will be determined through a screening test. A synthetic groundwater leaching test will be used.

A specific mixed ash will be evaluated in the proposed effort, but the protocols will be designed to be broadly applicable. Results will be evaluated against appropriate federal and state rules and guidelines and compared to other agricultural soil amendments.

The impact of this project will be national. Agricultural application is one of the largest potential unrealized CCB utilization applications. This project also could help utilities, marketers, and regulators to develop a template for understanding and qualifying individual CCBs for agricultural application.

For more information about this project, contact the CBRC or the principal investigator, David J. Hassett, Senior Research Advisor, EERC, at (701) 777-5192 or dhassett@undeerc.org.

Project 01-CBRC-WI: Development of a Database of CCB Publications

Tera D. Berland, P.I.

The goal of this EERC project is to develop a searchable Web-based database of publications related to high-volume uses of CCBs. Articles contained in the database will support environmentally acceptable, cost-effective uses of CCBs and focus on the CBRC's priority areas of civil and structural engineering uses, agriculture applications, mine land reclamation, and construction materials. The database will serve as a national baseline project encompassing priorities from each region.

Target users for this database include those already involved in the coal ash industry and the larger, potential audience outside the industry. Projected benefits are to enhance and increase opportunities for existing ash applications and to initiate and develop new and innovative applications.

For more information about this project, contact the CBRC or the principal investigator, Tera D. Berland, Research Specialist, EERC, at (701) 777-5296 or tberland@undeerc.org.

Project 01-CBRC-E10: Full-Scale Testing of Coal Combustion Product Pavement Sections

Tarunjit S. Butalia, P.I.

CCBs can be used in a variety of highway- and construction-related applications. The use of fly ash in concrete applications is well established, however, information concern-

ing the performance of these materials as part of a full-scale pavement structure have been lacking.

In this study, The Ohio State University will design, construct, and conduct accelerated testing on full-scale pavement systems using realistic loading magnitudes and durations and will present the findings and recommendations to the appropriate government agencies.

The accelerated pavement loading tests under controlled conditions of temperature and moisture will allow the research team to predict the 10-year highway traffic response of CCB pavements in time frames of 4 to 6 months, time periods typical of laboratory experiments.

It is expected that a minimum of six complete travel lanes will be constructed and tested during the proposed three-year duration of the project. Small-scale laboratory tests will be conducted prior to full-scale testing to adequately characterize the chemical, physical, and engineering properties of the materials to be used in the pavement test sections.

The full-scale pavement sections will be subjected to typical service loads using standard single, standard duals, and wide-based tires. Environmental conditions to be tested will include both surface and subsurface moisture infiltration into the structural sections.

Monitoring will include deflections, vertical stresses, and horizontal as well as vertical strains throughout the pavement section, and temperature, moisture, frost depth, and pore pressures in the pavement base, subbase, and subgrade. Researchers will pay particular attention to measuring surface and subsurface leachate

quantity and quality and to recording the incidence and extent of visible surface distress, such as rutting and cracking.

This study will allow researchers to compare the environmental and engineering response of CCB-based pavement sections with those made of conventional materials

For more information about this project, contact the CBRC or the principal investigator, Dr. Tarunjit S. Butalia, Research Scientist, The Ohio State University, at (614) 688-3408 or butalia.l@osu.edu.

Project 00-CBRC-M09: Field and Laboratory Studies of Arsenic Species in CCB Leachates and Attenuation by Mine Spoil Material and Environmental Performance Evaluation of the Coal Ash Filling of the Universal Mine Site

Ishwar P. Murarka, P.I.

In its May 2000 regulatory determination, the EPA expressed concerns about the placement of CCBs directly into groundwater in surface and underground mines. EPA identified arsenic as a chemical of particular concern along with the potential for increased leaching of coal ash due to the acidic conditions in mine waters.

The lack of reliable scientific results to alleviate these concerns continues to create obstacles in increasing or even retaining the current use of CCBs in active and inactive mines. Millions of tons of CCBs can be used in mine filling annually, making this a very attrac-

tive, large-volume beneficial use application of CCBs.

This project is a continuation of work funded by the CBRC in 2000. This year's research will have two components. The first consists of collecting and analyzing groundwater samples from the 16-groundwater wells installed at the Universal Ash site previously in the project.

Groundwater samples will be collected quarterly from the wells and two surface water sampling locations to establish the hydrology and extent of groundwater plume containing coal ash-derived leachate constituents. Groundwater transport and fate modeling as well as statistical analysis of the temporal and spatial data will be completed. The monitoring data combined with the laboratory results also will provide the basis for evaluating the extent of acid mine drainage amelioration by the coal ash leachate at the Universal site.

The second research component will be to conduct field and laboratory studies on arsenic speciation, leaching, attenuation, and long-term fate in groundwater at the Universal site. The leaching, attenuation, and fate of boron also will be addressed. The research on arsenic will examine the synergistic interactions between dissolved ferrous iron in acid mine drainage and the coprecipitation/adsorption of arsenic contained in the ash leachate.

The boron and arsenic studies will utilize laboratory batch and column systems to establish the geochemistry involved. Appropriate geochemical modeling and analyses of the water quality data will be done to understand the environmental chemistry of arsenic and boron applied to filling of surface coal mines with coal ash.

For more information about this project, contact the CBRC or the principal investigator, Ishwar P. Murarka, Chief Scientist, Ish Inc., at (408) 720-0474 or ishinc@pacbell.net.

Project 01-CBRC-M21: The Impact of Adsorption on the Mobility of Arsenic and Selenium Leached from CCBs

Bradley C. Paul, Ph.D., P.I.

In their spring 2000 determination on CCBs, the EPA delayed a ruling on whether CCBs placed in loose-fill field applications (mine haulback) would constitute hazardous waste. Based upon the last hearings, it can be anticipated that the EPA and private individuals interested in bulk CCB applications will be closely examining the risk posed by a water table intersecting a loose fill and, particularly, the potential transport of trace contaminants, such as arsenic and selenium. In EPA's last ruling, arsenic was the element that came closest to indicating a significant environmental hazard.

Current assessment practices assume that arsenic and selenium, once released from CCBs, will remain mobile in the environment and will be carried forward by the water supply with only dilution and dispersion to mitigate the concentrations. Although the work is limited, studies that do exist suggest that arsenic and selenium are adsorbed by the soils and thus cannot be transported great distances except in the presence of an infinite source of contaminants, of which CCBs are not.

To investigate this potential for a major overstatement of risk from CCBs, researchers will develop a series of adsorption isotherms for Midwestern

(continued on page 6)

The CBRC Welcomes New National Steering Committee Members



Jacob Gonzales, Western Regional Chair

For the past 10 years, Jacob Gonzales has managed TXU's Coal Combustion Product Utilization Program, including the negotiation and management of their CCP marketing contracts. Gonzales has spent nearly all his time for

the past 20 years in the support of projects for fossil-fueled power plants in design, supervision, and management roles.

"I think the CBRC's present efforts to address

industry concerns about mercury and other regulatory activities that can negatively affect CCPs are appropriate," says Gonzales. "I also believe that a major barrier to increasing CCP utilization, particularly in the Western Region, is transportation costs. Most of the plants in the West are in rural communities far removed from major metropolitan areas where CCPs are needed."

Gonzales says he would like to see the CBRC receive more project proposals from marketing and business interests to explore such issues as transportation, logistics costs, and market incentives.

Howard Humphrey, P.E. Eastern Regional Chair

Howard Humphrey, who retired from the American Electric Power Service Corporation (AEP) in 1999, has held various engineering and engineering management positions in ash, coal, and materials handling. In addition to his work with the CBRC, he is active with the American Coal Ash Association (ACAA) and works as a private consultant.

"I have been reviewing proposals for the Eastern Region since the inception of the CBRC's predecessor

organization," says Humphrey. "The chairman of the ACAA proposed my position on the National Steering Committee.

"I support the current direction of the CBRC and am pleased to be a part of the team that is dedicated to this effort."



James Hower Eastern Regional Technical Director

James Hower has been working at the University of Kentucky's Center for Applied Energy Research for over 23 years.

"For the past 10 years,

part of my research has involved studies of CCBs," says Hower. His studies have included the production and quality of CCBs in Kentucky (conducted every five years), investigations of carbon content in ash before and after conversion to low-NOx burners, and studies of the Hg content of coals and fly ashes.

"I trust the steering committee will utilities, ash marketers, and users of both through the proper solution and proper management of the research

to address the needs of the Hower says. "We can do this on of proposals and through nducted."

Tom Robl Midwestern Regional Chair

Paul Robl has been working with CCBs for over 20 years. Previously, he worked with the TVA on limestone for AFBC application and with CONSOL and Ohio Edison on the lime injection technology. For the past 10 years, much of his work has been on CCBs from PCC-fired boilers operating on bituminous coal. He also served as technical chair of the 1999 and 2001 International Ash Symposiums.

"The CBRC program serves to provide seed money for startup projects," says Robl. "This is a very important function not met by other parts of the DOE program. I hope to see the amount of available funding increased." He also believes that the impending regulations for mercury control may also impact CCBs and should be addressed. "The program also can help build bridges between consumers, producers, and regulators," Robl says.



CBRC Selects Nine Research Projects for Funding in 2002 (cont. from page 6)

materials to quantify the extent to which arsenic and selenium are quickly immobilized into the environment. With the help of an advisory board from utility, coal, highway, and regulatory groups, a set of 8 samples, characteristic of materials that will be encountered around CCB fills, will be selected. These samples will be prepared and tested using EPA protocol for development of adsorption isotherms for both arsenic and selenium.

Simple models of contaminant transport for typical sites will be constructed and then run with and without the adsorption isotherms applied. The purpose will be to illustrate the impact of adsorption on the anticipated magnitude of any contami-

nation plumes that may develop. The data will then be available for others to use in site-specific modeling studies as needed.

Information from the project will be distributed back to industry and regulators, first through the advisory board, then through additional channels, including conferences and publications. Finally, the information will be made available to regulators and at hearings to help shape regulatory outcomes that are based upon real and accurate risk assessment.

For more information, contact the CBRC or the principal investigator, Dr. Bradley C. Paul, Southern Illinois University at Carbondale, at (618) 453-7923 or paul_b@engr.siu.edu.



CBRC CONTACTS

Program Manager

Lynn Brickett, U.S. Department of Energy - National Energy Technology Laboratory
412/386-6574; brickett@netl.doe.gov

National Center

Paul Ziemkiewicz, Director
Tamara Vandivort, Consortium Manager
CBRC National Center located at the National Mine Land Reclamation Center at West Virginia University, 304/293-2867, pziemkie@wvu.edu or tvandivo@wvu.edu

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James C. Hower, University of Kentucky, 859/257-0261, hower@caer.uky.edu

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Andy Wittner, USEPA

Dan Wheeler, Illinois Office of Coal Development and Marketing

Calendar of Events

November 27–29, 2002

Biennial Energy Science and Technology Conference. University of Melbourne-Parkville Campus. Organized by the Australian Institute of Energy. Write to Dr. Brian Young, Conference Chairman, Australian Institute of Energy, PO Box

88, Vermont VIC 3133, Australia, or fax to (03) 9873-8481, or e-mail to melb@aie.org.au, or visit the Web site at www.aie.org.au.

January 27–30, 2003

Products (CCPs)

Sponsored by the American Coal Ash Association and the

American Coal Ash Association Educational Foundation. Don CeSar Hotel. St. Petersburg, Florida. Contact the American Coal Ash Association at (703) 317-2400 or at info@acca-usa.org, or visit the Web site at www.acaa-usa.org.



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WVU Research Corporation
WVU NRCCE
P.O. Box 6064
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COMBUSTION BYPRODUCTS RECYCLING CONSORTIUM

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Lowering the Foam Index in Fly Ash Used for Concrete

by Robert LaCount, P.I., et al.¹

Commercially, fly ash is often used as a replacement for some of the Portland cement in concrete products. Surfactants, used to entrain air in the concrete mixtures, improve the workability of the mixtures and the durability of the concrete products to freeze-thaw cycles (Dodson, 1990).

Inefficient combustion and the use of low-NO_x burners in coal-fired boilers has resulted in variable increases in the unburned carbon content of fly ash (Baltrus, Wells, et al., 2001). When high-carbon fly ashes are used in concrete, often an increase in the amount of surfactant is required. These variations in carbon content and amount of surfactant required directly impact the sale of fly ash for use with cement to produce concrete products. Even when fly ash meets loss on ignition (LOI) specifications, variation in the adsorption properties of the fly



ash may result in changes in the amount of surfactant required (Freeman et al., 1997). The foam index (FI) test, which involves titration of a portion of the concrete mixture with an aqueous solution of the surfactant until a stable foam results, is used to determine the

amount of surfactant required in the concrete.

FACTORS AFFECTING AIR ENTRAINMENT

Factors affecting air entrainment in

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the concrete mixtures have been identified. For example, as the carbon content of the pozzolans increase, the level of entrained air decreases (Dodson, 1990). Freeman et al. (1997) examined the interactions of carbon-containing fly ash with surfactants and found that the interactions are time dependent and that the degree of interaction correlates only roughly with carbon content.

Gao et al. (1997) examined the interaction between several fly ash carbons and carbon blacks and an air-entraining admixture (AEA) and found that surfactant interaction increased with an increase in carbon surface area. Yu et al. (2000) found that a low specific area fly ash containing 17 wt percent carbon produced by co-firing coal and petroleum coke had no measurable surfactant adsorptivity.

Hill et. al. (1998) examined a number of fly ash samples using thermal and optical microscopy methods. They found that:

- differential thermal analysis was not a useful prognostic tool for performance of fly ash in air entrained mortar;
- optical characterization of the forms of carbon in fly ash did not relate fly ash performance to mortar air entrainment, but it did indicate that a significant portion of carbon in fly ash is submicron in size; and
- potential effects of carbon chemistry on surfactant adsorption capacity cannot be identified using surface areas determined with an inert gas such as nitrogen.

A better prediction of surfactant performance with different fly ash samples may help to minimize variability in concrete products.

Gao et al. (2001) reported ozonation for chemical modification of the carbon surfaces in fly ash as a route to reducing the adsorptivity of fly ash carbon toward surfactants.

CHARACTERIZING FLY ASH

One approach for characterization of fly ash carbon is to focus on partial oxidation to selectively remove each carbon form followed by characterization of the carbon form or forms remaining in the fly ash residues. LaCount et al. (1997), using this approach, characterized the carbon in several fly ash samples using a controlled-atmosphere programmed-temperature oxidation (CAPTO) instrument and found oxidation generally occurring in four different temperature zones.

Several of the oxidation temperatures are well above those of coals, activated carbons, and other chars, but significantly below the oxidation temperature of graphite. The amount of carbon dioxide evolving in each temperature range was evaluated. That work prompted progressive partial oxidation and pyrolysis studies of numerous fly ash samples followed by foam index (FI) measurements to assess any change in surfactant adsorption properties of each

partially oxidized or pyrolyzed residue (LaCount et al., 1998 and 2001).

A major decrease in FI occurred between room temperature and approximately 400°C prior to significant loss of carbon and resulted in further work described in this paper.

Baltrus, LaCount, and Kerns (2001) and Baltrus and LaCount (2001) optimized an ultraviolet-visible spectrophotometric method for measuring the adsorption of air-entraining surfactants on the components of cement. It was found that FI was a poor means for measuring adsorption capacity in high carbon fly ashes due to an insufficient equilibration time used in the foam index measurements.

A better understanding of the variation in interactions of air entraining surfactants with unburned carbon forms and the mineral components in fly ash concrete mixtures may lead to improved methodology for maintaining the level of air as the concrete cures. A better prediction of surfactant performance with different fly ash samples may help to minimize variability in concrete products.

PROJECT OBJECTIVES

The initial goal of the present work was to thermally treat commercially important fly ash samples under both oxidative and inert conditions as a route to decrease surfactant adsorption by the fly ash. In order to evaluate the effectiveness of the thermal treatments in lowering surfactant adsorption, both the untreated and thermally treated samples were characterized using both FI and conductance measurements.

The overall objective of this work is to develop a method that will decrease

the interaction between fly ash and the surfactants used to entrain air in concrete products, thus increasing the amount of fly ash suitable for use in concrete products.

Thermally treated fly ash samples that have a decreased interaction with air entraining surfactants as evidenced by a significantly lower FI value will be prepared in quantities suitable for the preparation of concrete test samples. Concrete test samples prepared from these thermally treated products will be evaluated for the amount of entrained air as well as compressibility and the data compared with that from concrete test samples prepared using the untreated fly ashes.

Previously, two different fly ash samples derived from eastern bituminous coals had been thermally treated under both oxidizing and inert conditions to a range of temperatures from 100°C to 769°C, and each residue was characterized using CAPTO and FI (LaCount et al., 2001). The CAPTO results indicated the presence of at least four different carbon forms in the untreated fly ash samples. In all cases, a decrease in FI values was observed.

A significant decrease in the FI values occurred prior to significant loss of carbon indicating that factors other than carbon content may play a role in determining a sample's FI. In order to identify those factors, the thermally treated fly ash residues were examined by X-ray photoelectron spectroscopy (XPS), X-ray diffraction (XRD), scanning electron microscopy (SEM), and petrographic analysis. XPS has previously been used to distinguish the presence of various graphitic carbon

types in the untreated fly ash (LaCount et al., 2001). The types of carbon were found to vary as a function of oxidation temperature.

All of the bulk carbon was removed by oxidation to 769°C. SEM measurements of the untreated and oxidized fly ash samples showed no change in morphology of the ash after oxidation. Petrographic analysis showed no difference in carbon anisotropy at the various temperatures prior to the complete oxidation of carbon.

To ensure that the decrease in FI observed above was applicable to other fly ashes, a series of 13 different fly ashes derived from eastern bituminous coals were thermally treated to 500°C and 800°C under both oxidative and inert conditions and were characterized using FI and conductance (LaCount et al., 2001). In all cases the FI values of the thermally treated fly ash samples were lower in comparison to those of the untreated samples.

Additionally, the conductance of samples thermally treated to 800°C under inert conditions was found to be lower than that of the untreated fly ash samples, indicating that the thermal treatments may lessen the solubility of ions that can interfere with the surfactant in the FI measurement.

Based on the previous observations that FI values of thermally treated fly ashes are significantly lower than those of untreated fly ash samples, an additional series of six commercially important fly ash samples were subjected to similar treatments and used for further study of the relation between FI, conductance, and their behavior under CAPTO. These results are described below.

Each untreated fly ash is being used to generate quantities of thermally treated fly ash required for the preparation and testing of concrete samples. These results will be described in a future report.

EXPERIMENTAL PROCEDURES *CAPTO Characterizations of Fly Ash Samples*

All untreated and thermally treated fly ash samples were characterized using CAPTO. The carbon forms and total carbon content were determined from the overall CO₂ evolution profiles.

A 250-mg sample of each fly ash was thoroughly mixed with 12 g of tungsten trioxide and positioned in a quartz combustion tube to ensure gas plug flow through the sample. A 100 cm³ min⁻¹ flow of gas (10 percent oxygen/90 percent argon or 100 percent argon) through the sample was maintained as the combustion tube was heated from room temperature to 1,050°C at a temperature ramp of 3°C min⁻¹. The resultant H₂O, CO₂ and SO₂ evolution gases, are swept from the combustion tubes through a secondary furnace, maintained at 1,050°C to ensure complete oxidation and consistent temperature/equilibrium conditions, into FTIR gas cells.

An FTIR was used to measure the distinctive H₂O, CO₂, SO₂ patterns evolving from the sample. Integration of the gas evolution patterns provided the forms and total hydrogen, carbon, and sulfur content of the sample.

CAPTO Thermal Treatments

Six fly ash samples of commercial importance were selected for oxidization

(continued on page 4)

and pyrolysis to 500 and 800°C in quantities suitable for the preparation of concrete test samples. The carbon content of two of the samples was between 7 and 9 percent; two contained between 4 and 6 percent carbon; and two contained between 0 and 2 percent carbon.

Thermal treatment of fly ash samples for FI measurements was accomplished using CAPTO with 5-g samples of fly ash positioned in quartz combustion tubes. Oxidation treatments were completed using 10 percent oxygen/90 percent argon, and the pyrolysis treatments were completed using a 100 percent argon gas stream. The residues were then recovered from the combustion tubes and both FI and conductive measurements were completed.

Thermal Treatment of Fly Ash for Concrete Test Samples

Quantities of fly ash for concrete test samples were prepared in batch quantities (300 to 400g) using the same experimental parameters as those employed in the CAPTO thermal treatments.

Foam Index

FI measurements were completed in duplicate using representative samples of the residue recovered from each oxidation or pyrolysis experiment as well as the untreated fly ash samples. A modification of the FI test described by Dodson (1990), Gao et al. (1997), and others was used.

Two grams of each untreated or thermally treated fly ash sample was mixed with 5 mL of distilled water in a 15 mL i.d. 24 mm x 45 mm vial, and

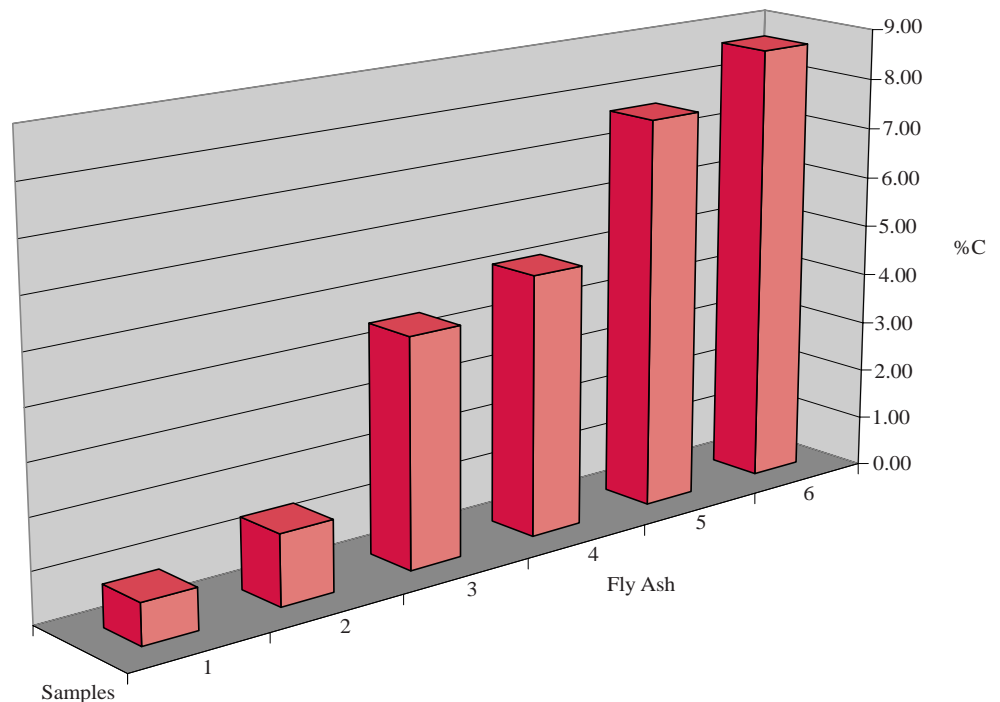


Figure 1—Percent Carbon for Fly Ash Samples

shaken for 1 minute. A mixture of Darex® II surfactant (W.R. Grace & Co.) in distilled water (1:40) was added to the mixture in 0.05 mL increments using a 2-mL microburet.

The vial was shaken for 15 seconds, placed upright, opened, and the center portion of the foam layer observed using a microscope light source positioned at the side of the vial above the fly ash and below the foam layer. A stable foam that persisted for 15 seconds, and obscured all but a small fraction of light transmitted at the center of the foam layer was designated as the endpoint.

Conductance

Conductance measurements were performed to determine the relative solubility of conductive ions in a number of the fly ash samples before and after pyrolysis. The measurement was carried out by placing 0.1 g of fly

ash in a 100-mL beaker to which 25 mL of deionized water was added along with a Teflon-coated stirring bar. The mixture was stirred for 10 minutes and filtered. The filtrate was then tested using a conductance meter.

RESULTS AND DISCUSSIONS

Figure 1 on page 5 shows the carbon content of the six fly ash samples selected for this study. Note that two low carbon content (0.81 and 1.39 percent), two medium carbon content (4.49 and 5.13 percent) and two higher carbon content samples (7.70 and 8.69 percent) are included in the selection.

The FI results for the fly ash samples treated under inert conditions to the two different temperatures are summarized in figure 2. Note that a significant decrease in FI resulted when the samples were treated to 500°C. In all cases the fly ash samples thermally treated to 800°C under argon flow show an even lower FI

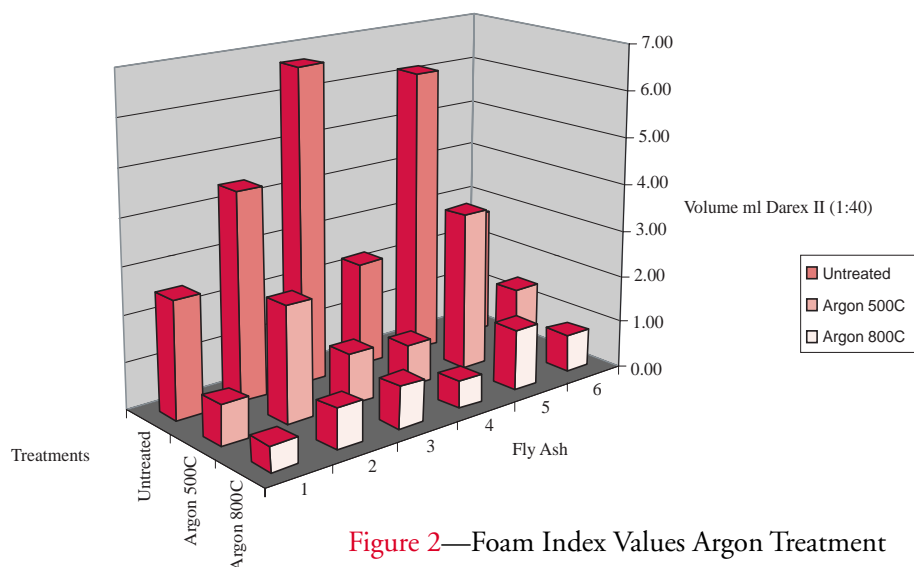


Figure 2—Foam Index Values Argon Treatment

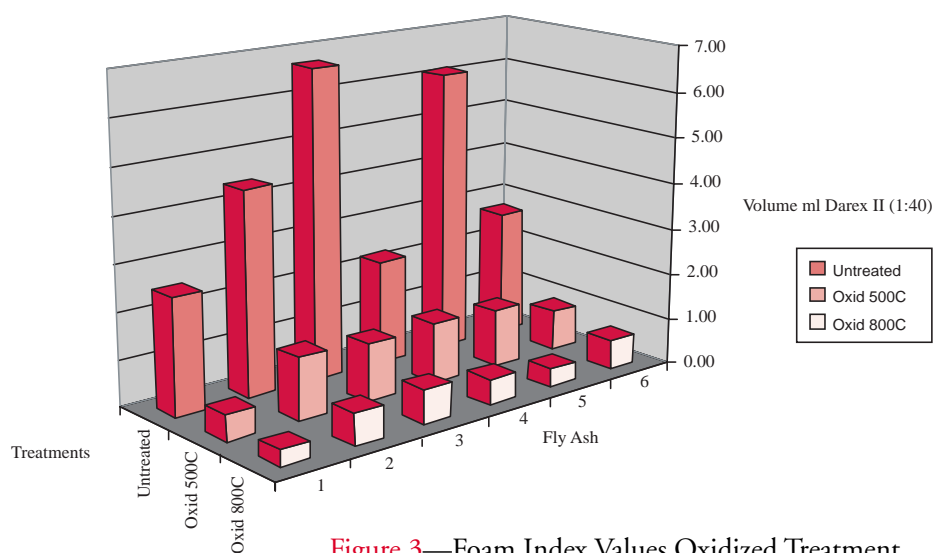


Figure 3—Foam Index Values Oxidized Treatment

value. These lower FI values are observed even though loss of carbon content during this thermal treatment is minimal.

The results of oxidative thermal treatment are shown in figure 3. Note that the same trend observed in figure 2 is retained in this plot. However, samples 2 and 5 show a further significant decrease in FI under oxidative thermal treatment to 500°C compared to the thermal treatment under argon

flow. Additionally, sample 5 in figure 3 treated to 800°C under oxidative conditions also shows a further significant decrease in FI compared to the corresponding treatment under argon flow. It is of interest to note that only three of the oxidized samples showed significantly lower FI values compared to the FI values obtained from thermal treatment under argon flow where carbon loss is minimal.

Darex® II, the surfactant used in the

FI titrations reported here, is an alkaline solution of fatty acid salts, and the surfactant properties of such “soaps” are affected by alkaline earth ions such as calcium and magnesium. Any affect that thermal treatment may have on the solubility of such ions in solution was determined by measuring the conductance of solutions exposed to the untreated and treated fly ashes.

Conductance results are shown in Table 1. Note that the conductance is lower in all cases after thermal treatments under inert conditions. However, the magnitude of the decrease shows no apparent correlation with changes in FI. This may be due to the fact that conductance is also affected by ions other than calcium and magnesium that have no effect on the surfactant.

The decrease in conductance is probably due to incorporation of some of the previously soluble ions into insoluble structures induced by thermal treatment. However, the thermal treatment likely does not render all of the calcium and magnesium insoluble.

CONCLUSIONS

These experiments indicate that both unburned carbon and soluble ions such as calcium and magnesium can have an impact on FI. Their relative effects are most likely, dependent on the properties of the carbon and mineral components of the fly ash and not their relative proportions in the ash.

Thermal treatment of the fly ashes under oxidative as well as inert atmosphere conditions clearly has an impact on FI. Conductance measurements of fly ash thermally treated under inert conditions does suggest a decrease in the solubility of

(continued on page 6)

ions that can interfere with the surfactant in the FI test, thus lowering the FI values. The ions that are rendered insoluble may be incorporated into amorphous "glass like" phases.

Thermally treated fly ashes prepared in this study are now being used in the preparation of concrete test samples.

We are continuing to examine the effects of treatment to higher temperatures and other possible modes of surfactant adsorption by fly ash.

NOTE

¹The following authors contributed to this report: Robert LaCount, P.I., John P. Baltrus, Timothy L. Banfield, J. Rodney Diehl, Keith A. Giles, Douglas G. Kern, Tiffany A. Leyda, Patrice J. Pique

ACKNOWLEDGEMENTS

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The authors thank W.R. Grace & Co. for samples of Daravair® 1000 and Darex® II AEAs.

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Table 1—Conductance for Fly Ash Samples, Untreated and after Pyrolysis

| Sample | Conductance, ($\mu\text{S/g ash}$) Untreated | Conductance, ($\mu\text{S/g ash}$) Pyrolysis to: | |
|--------|---|---|--------|
| | | 500° C | 800° C |
| 1 | 160.1 | 127.5 | 113.6 |
| 2 | 127.5 | 99.5 | 84.7 |
| 3 | 125.0 | 118.6 | 70.7 |
| 4 | 163.8 | 108.6 | 84.2 |
| 5 | 73.5 | 58.0 | 21.7 |
| 6 | 175.9 | 141.9 | 135.8 |

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For more information on this project, contact Robert LaCount, principal investigator, at (412) 386-5175.



CBRC National Steering Committee Selects Preproposals

The National Steering Committee met on October 25, 2001 in Lexington, Kentucky to select which preproposals and which continuation projects to invite to submit full proposals. The committee selected 12 of the new preproposals and six continuation projects for a total of 18 researchers invited to submit full proposals to the CBRC.

Full proposals will be accepted by these 18 only and are due December 17, 2001. The Steering Committee will review the proposals and meet in February, 2002 to determine which of

the submitted proposals will be funded.

The following new proposals were selected:

- East: 4
- Midwest: 4
- West: 4

The following continuation projects were selected:

- East: 2
- Midwest: 4.



CBRC Well Represented at Annual International Coal Conference

The 18th Annual International Pittsburgh Coal Conference will be held in Newcastle, New South Wales, Australia, December 3-7, 2001. The CBRC will be well represented by members of the National Steering Committee and researchers.

Tarunjit Butalia, Ohio State University, will moderate the Coal Combustion Byproducts Utilization session. Kimery Vories, USDI Office of Surface Mining and member of the CBRC National Steering Committee, will give a presentation titled *Coal Mining and Reclamation in the U.S.A. with Coal Combustion Byproducts: An Overview*. Robert LaCount, Waynesburg College and a CBRC researcher, will give

the presentation, *Treatments for Lowering Foam Index in High-Carbon Fly Ashes for Concrete Applications*, which is featured in this issue. Ishwar Murarka of Ish, Inc. and a CBRC researcher will present *A Case Study on the Use of Coal Fly Ash for Reclaiming a Surface Coal Mine Pit*. Finally, Tamara Vandivort of the National Mine Land Reclamation Center at West Virginia University and CBRC Consortium Manager will give a presentation on the CBRC program titled, *The United States Combustion Byproducts Recycling Consortium*.



CBRC CONTACTS

Program Management

Lynn Brickett, CBRC Program Manager
U.S. Department of Energy -
National Energy Technology Laboratory
412/386-6574; brickett@netl.doe.gov

National Center

Paul Ziemkiewicz, Director
Tamara Vandivort, Consortium Manager
CBRC National Center located at the
National Mine Land Reclamation Center
West Virginia University
pziemkie@wvu.edu or tvandivo@wvu.edu
304/293-2867

Regional Centers

Debra Pflughoeft-Hassett, Director
Western Regional Center located at the Univer-
sity of North Dakota
dphassett@undeerc.org; 701/777-5261

Y. Paul Chugh, Director
Midwestern Regional Center located at
Southern Illinois University at Carbondale
chugh@engr.siu.edu; 618/536-6637

D. Courtney Black, Director
Eastern Regional Center
located at West Virginia University
dblack@wvu.edu; 304/293-2867, ext. 5447

National Steering Committee

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217/785-2001

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Ohio Coal Development Office
jbird@odod.state.oh.us; 614/466-3465

Calendar of Events

March 18–19, 2002

Workshop on the Use of Fly Ash and other Coal Combustion Products in Concrete and Construction Materials. Sponsored by UWM Center for By-Products Utilization and Wisconsin Electric Power Company. Holiday Inn—City Centre, Milwaukee. Contact Rudolph N. Kraus at (414) 229-4105, or visit www.uwm.edu/Dept/CBU.

April 16–18

Coal Combustion Byproducts and Western Coal Mines: A Technical Interactive Forum. Sponsored by U.S. DOI, Office of Surface Mining, U.S. Department of Energy's National Energy Technology Laboratory (NETL), and others. Golden, CO. Register at www.mcrc.osmre.gov/ccb, or contact Kimery Vories at (618) 463-6463, ext 103, or by e-mail to kvories@osmre.gov.

May 14

2002 Conference on Unburned Carbon on Utility Fly Ash. Pittsburgh, PA, and

May 15–16

2002 Conference on Selective Catalytic Reduction (SCR) and Selective Non-Catalytic Reduction (SNCR) for NO_x Control. Pittsburgh, PA. Sponsored by NETL. Contact Karen Lockhart at (412) 386-4763 or by e-mail to karen.lockhart@netl.doe.gov.

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Summer 2001

COMBUSTION BYPRODUCTS RECYCLING CONSORTIUM

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Omega Mine Project: CCB Injection Used to Reduce Acid Mine Drainage

by Dave Broschart and
GAI Consultants, Inc.

In the 1980s, the Omega Mining Corporation, Inc., opened the Omega 100 mine along U.S. Route 119, six miles south of the city of Morgantown, West Virginia. The mine is in the Upper Freeport Coal Seam, which is approximately 4.5 feet thick, at depths varying from approximately 70 to 190 feet. The dip of the seam is to the northwest at approximately 9 percent.

During the mine's operation, it discharged acid drainage, which impacted the Owl Creek watershed located downdip of the mine. This watershed lies generally to the west of U.S. Route 119 (refer to Figure 1 on page 2). It already had been impacted by acid mine drainage from older mining operations in the area.

In July, 1989, after the Omega Mine closed, accumulation of water



Photo courtesy of the West Virginia Department of Environmental Protection

A Chinese delegation was among several groups to tour the Omega Mine site.

in the mine resulted in additional acid mine drainage discharges into the Cobun Creek watershed north of the mine (generally east of U.S. Route 119). Cobun Creek flows into a reservoir that provides water to the city of Morgantown.

After discovering the acid mine drainage discharges north of the mine, horizontal relief drains were installed to lower the water level in the mine in order to reduce the discharges into the Cobun Creek watershed.

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Collection points were established to direct the acid mine drainage discharge to a central treatment facility. Following bond forfeiture when the Omega Mining Company declared bankruptcy, a local citizens group operated the treatment facility.

In early 1995, when bond forfeiture funds were exhausted, the West Virginia Division of Environmental Protection (WVDEP) took over treating the acid mine drainage from the site. Treatment costs (labor and materials) were approximately \$300,000 per year.

Others Join the Effort

Concurrent with other activities at the site during the early 1990s, several public and private entities completed feasibility studies for injecting coal combustion byproducts (CCBs) in the Omega Mine to reduce the acid mine drainage.

An agreement was reached in March 1996 between WVDEP; Monongahela Power Company, a subsidiary of Allegheny Energy Supply (Allegheny Energy); Anker Energy Corporation (Anker); Consol, Inc. (Consol); United States Office of Surface Mining Reclamation and Enforcement (OSMRE); and the Electric Power Research Institute (EPRI) to contribute funds for the project.

Water quality data indicated that the majority of the acid mine drainage came from the north lobe of the mine. The north lobe encompasses approximately 26 acres of the 170-acre mine. The agreement dictated that only the north

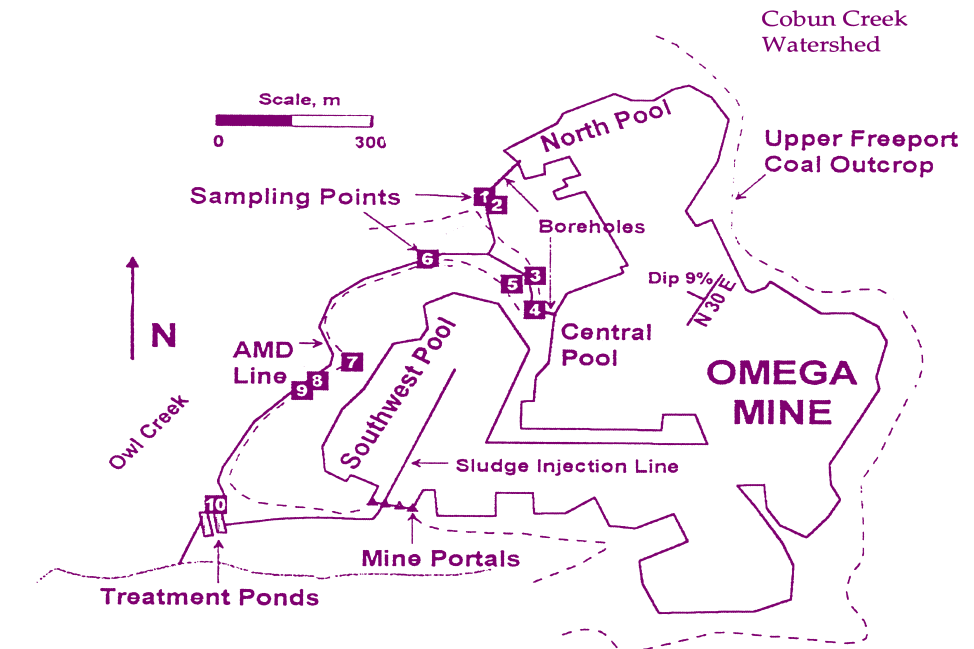


Figure 1—Omega Mine Map

Source: GAI Consultants, Inc.

lobe of the mine would be grouted with CCBs.

The agreement provided that CCBs from Allegheny Energy (Class F fly ash) and Anker (hauler of fluidized bed combustion [FBC] ash from the Morgantown Energy Associates [MEA] power station) would be evaluated for use in the grout mixes. The U.S. Department of Energy (USDOE) joined as a project sponsor in the spring of 1998 to monitor water quality.

Although the Omega Mine was a post-1977 deep mine bond forfeiture site, the WVDEP Abandoned Mine Lands (AML) Section took over administration of the design and construction contract. This was due to the AML Section's expertise with subsurface grouting projects, having completed more than a hundred subsurface grouting projects to prevent mine subsidence. GAI Consultants, Inc. (GAI) was selected as the project designer.

Project Objectives

The project objectives were to develop a suitable mix of coal combustion byproducts available from two of the project sponsors, Allegheny Energy and Anker, to reduce acid mine drainage and prevent subsidence by filling the north lobe of the Omega Mine.

This represents a potential beneficial use of the coal combustion byproducts that would reduce the amount of material going to disposal sites. The general requirements for such a grouting material are that it possess (a) sufficient fluidity to ensure optimum mine room penetration, (b) the ability to provide physical support to abate surface subsidence, and (c) in situ characteristics that reduce acid mine drainage emanating from the abandoned mine workings.

An additional consideration was that the injected materials should be compatible with the water present in the underground mine workings. This is particularly important with respect to its ability to retain strength for subsidence control, while at the same time, retaining chemical integrity against the release of toxic agents (e.g., metals) into the groundwater system.

The mine injection program had four goals:

1. to fill the voids in the north lobe of the Omega Mine to reduce contact of water and air with acid forming material, and a secondary requirement that the grout have some alkaline leaching potential to help treat acid mine drainage;
2. to achieve a grout mix which would set to sufficient strength to prevent mine subsidence;
3. to use a mixture of fly ash and FBC materials to demonstrate the synergistic attributes of the

- combined materials; and
4. to use a grout mix that would flow without separation and develop reasonable strength and dimensional stability.

Project Tasks

GAI's work consisted of the following:

- site reconnaissance,
- subsurface investigation,
- report on pre-injection water quality,
- laboratory testing program to select suitable injection mix,
- mine injection plan,
- technical specifications for the injection program,
- periodic monitoring of the injection work,
- analysis of pre- and post-injection water quality,
- sampling the injected material and testing for unconfined compressive strength and permeability,

- post-injection benthic survey, and
- report on the project including evaluation of the results.

The WVDEP's work consisted of the following tasks:

- water sampling and testing,
- a pre-injection benthic survey,
- overall management of the work, and
- monitoring of the injection work.

The USDOE's work consisted of the following:

- water sampling and testing, and
- geophysical research.

The OSMRE's work consisted of:

- borehole video camera inspection of the mine pre- and post-injection.

In addition, aspects of this project have been presented at various conferences as part of EPRI's technology transfer program.

Grout Mix Design

An extensive laboratory testing program was conducted to evaluate both fly ash and FBC ash or mixtures of the two for injection into an abandoned deep mine to reduce acid mine drainage.

The test program indicated that a blend of the two candidate materials provided an acceptable grout mix. The FBC ash had the potential to provide strength to the grout while the fly ash enhanced



Source: GAI Consultants, Inc.

Expanded FBC ash and recommended grout mix.

(continued on page 4)

Omega Mine Project (cont. from page 3)

the fluidity of the grout. The addition of two percent cement provided dimensional stability to the hardened grout.

It was recommended that a grout blend be used consisting of 49 percent FBC ash and 49 percent fly ash, plus 2 percent cement with enough water added to produce a grout having a flow cone value of 60 seconds. This mix demonstrated the synergistic attributes of combined fly ash and FBC ash, would flow long distances without separation, and would develop reasonable strength and dimensional stability.

These characteristics provided confidence that the grout would fill 26 acres of the mine and encapsulate acid forming materials.

Mine Grouting

The program at the Omega Mine is by far the largest CCB injection project to date undertaken to reduce acid mine drainage. Almost 61,000 cubic meters (80,000 cy) of CCB grout were injected into 26 acres of the mine.

A grout barrier was formed at the south side of the north lobe to prevent mine water from flowing down the relatively steep dip (9 percent) into the north lobe, which is the lowest portion of the mine. Injection hole locations were determined from study of the mine maps.

There was no set hole spacing. Due to the openness of the mine and steep dip of the mined seam, injection hole spacing in first mined areas was generally in excess of 100 ft. In second mined areas, hole spacing was reduced to

The program at the Omega Mine is by far the largest CCB injection project to date undertaken to reduce acid mine drainage.

as little as 50 ft, since site exploration (both borings and video camera) indicated that fallen roof material could impede movement of the grout.

Due to the openness of some portions of the mine, grout moved up to 1,500 ft, primarily because of the relatively steep dip of the mine. In previous work, CCB grouts moved over 100 ft, and the flowing grout moved slowly, like pancake batter (EPRI, 1996).

From borehole video views of the grout, flow in the Omega Mine was fast and turbulent. The maximum grout take in one hole of 7,812 cubic meters (10,218 cy) is an indication of the ability of the grout to flow. The total quantity of the FBC fly ash mix injected into 156 primary grout holes was 47,185 cubic meters (61,716 cy), an average of 302 cubic meters (395.6 cy) per hole.

Secondary holes were pressure grouted in October of 1998. Of the 46 holes that were pressure grouted, 18 had takes of only 0.7-1.5 cubic meters (1 or 2 cy). The total volume injected under pressure was 995 cubic meters (1302 cy) an average take of 22 cubic

meters (28 cy) per hole. In contrast the average take of the FBC fly ash grout in 156 primary injection holes was 302 cubic meters (396 cy) per hole.

The total cost for drilling and injecting 60,500 cubic meter (79,130 cy) of grout was \$1,946,592 or \$24.60 per cubic yard.

The cost of using CCB grout for mine filling is competitive with typical mine grouting using a fly-ash cement grout, if suitable materials are available within a reasonable haul distance from the mine.

Effectiveness of Filling

The volume of grout injected into the north lobe, approximately 61,000 cubic meters (80,000 cy) is equivalent to 100 percent of the void volume in the first mined area and 75 percent of the mined void volume in the second mined area, where fallen roof material partially filled the mine void and would prevent grout from filling all voids.

The pressure grouting conducted in October 1998 near the end of the injection program indicates many portions of the mine had been previously filled by grout.

Nine exploratory holes were drilled in the north lobe late in the injection program using a rotary air rig. Eight encountered grout with no loss of air. This indicates the mine was filled at these locations. The other exploration hole encountered a 0.3m (1 ft) void and lost air, but air flow returned while drilling below the void. Subsequent pressure grouting of this hole resulted in a take of 92.5 cubic meters (121 cy).

Four core borings drilled approximately one year after grouting

showed good roof contact by the CCB grout. Video camera observations in these holes confirmed good roof contact and showed good distribution of the injected grout. No voids were found.

Acid Mine Drainage Abatement

Reduction in acid mine drainage usually infers some sort of water treatment to change the chemistry of the mine water and/or its discharge. Various treatment methodologies, such as percolation over and through limestone in air, or through limestone under water in anoxic drains, dumping limestone fines near headwaters, and various kinds of other chemical dosing, all work to some extent. However, these methods require replenishing limestone or various chemicals as they are consumed in treatment.

Work conducted in recent years in acid mine drainage reduction from mines and spoil piles has indicated that the best way to reduce acid mine drainage is to prevent the reaction from occurring rather than trying to treat the results (EPRI et al., 1996).

Filling of the mine voids reduces or eliminates air and/or oxygenated water from reaching the acid-mine-drainage-forming materials, thus preventing the generation of acid mine drainage.

Using a material which will set and develop some strength further limits acid mine drainage production by decreasing the permeability of the material (grout) thus further limiting air and water movement. Complete filling of the mine

workings results in limiting acid mine drainage formation by creating a barrier between acid forming materials in the mine and air or water (EPRI et al., 1996). Acid forming materials above the mine roof may continue to produce acid mine drainage.

Testing of four grout core samples recovered from the mine a minimum of 9 to 10 months after injection showed a permeability range of 6.2×10^{-7} to 8.9×10^{-8} cm/sec. Thus, the hardened grout is relatively impervious, and with its dimensional stability, should encapsulate acid forming materials and greatly reduce future formation of acid mine drainage.

The greatly reduced flows from the north lobe following the grouting in 1998 could not be evaluated due to a drought in 1999. However, precipitation in 2000 was slightly above normal and the flows at points 1, 3, 4, and 5 have been reduced (refer to Figure 1 on page 2).

It was anticipated that the flow from the central mine pool would increase, but the observed increase has been slight (about 2 percent).

The quality of water flowing from the north lobe has not changed significantly. With injection of almost 61,000 cubic meters (80,000 cy) of grout, mostly highly alkaline, the lack of buffering of the acid mine drainage is disappointing.

Apparently the ground water flows around the filled mine or encapsulated acid forming materials without being greatly affected by the chemistry of the hardened grout.

The reactivation of acid mine drainage seepage into the Cobun

Creek watershed in March 1999 appears related to the mine filling on the basis of timing and water quality. This acid mine drainage is similar to that flowing from the north lobe. However, the combined seepage flow is generally low and does not add greatly to total acid load. However, significant flows occur shortly after high precipitation events and rapid snow melts.

The source of the poor quality water from the Cobun Creek seeps and the north lobe is uncertain. A possible source is precipitation moving downward to thin pyritic seams or zones in the mine roof where the water becomes acidic before reaching the grouted mine. However, the monitoring wells installed above the mine in 1999 generally indicate good water quality within a few feet of the mine roof.

In spite of essentially no change in mine water quality, the greatly reduced flows from the north lobe (point 1 on Figure 1) result in a reduction in daily acid load of 75 percent. Taking into account the increased flow and unchanged quality of the flow from the central pool, the reduction in the daily acid load from the three largest sources of acid mine drainage from the Omega Mine is 58 percent.

Subsidence Control

Injection of CCB grout with the procedures utilized resulted in virtually complete filling of the mine voids and is likely to provide excellent subsidence control. The fact that the hardened grout was

(continued on page 6)

Omega Mine Project (cont. from page 5)

found to have significant unconfined compressive strength coupled with a low permeability indicates it will provide good roof support while resisting passage of water, thus limiting the potential for chemical degradation. The strength, ability to fill the mine, and dimensional stability exhibited by the FBC-fly ash grout indicate that it is an excellent material for subsidence control.

Summary

The injection program met its goal of reducing the contact of water and air with acid forming materials in the mine. Acid forming minerals above the mine roof appear to be contributing to acid

mine drainage flows.

The secondary goal of buffering the acid mine drainage by alkaline leaching did not occur. However, the great amount of acid forming materials that are now encapsulated will not contribute to future acid mine drainage.

A laboratory test program indicated that the grout mix selected satisfied the project goals. The mixture of FBC ash, fly ash, and cement provided sufficient strength, flowability, and stability. Injection of CCB grout with the procedures utilized resulted in virtually complete filling of the mine voids and is likely to provide excellent subsidence control.

It is anticipated that the materi-

als now contributing to acid mine drainage formation will eventually be exhausted and water quality will improve as has been observed in the study of discharges from abandoned mines.

Reference

EPRI, et al. 1996. *Fluid Placement of Fixated Scrubber Sludge in Abandoned Deep Mines to Abate Surface Subsidence and Reduce Acid Mine Drainage*. Final Report. (November) EPRI TR-107053, Palo Alto, California.

For more information on this project, contact Dave Broschart, principal investigator, at 304-457-4583.



Demonstration Shows Coal Ash Improves Feedlots

Coal ash from power plants provides farmers and ranchers with an environmentally safe, low-cost option to significantly improve animal health and safety conditions in livestock feedlots.

Preliminary results of one of the largest, most comprehensive and definitive studies confirm that coal ash effectively stabilizes soils in feedlots. The three-year project, being conducted by the University of North Dakota Energy and Environmental Research Center (EERC) and the North Dakota State University (NDSU) Carrington Research Center (CREC), demonstrates the engineering and environmental performance of coal ash.

"Our goal was to provide large-

scale commercial feeding operations, farmers, and ranchers with a safe, cost-effective method to improve feeding areas and pen conditions," said EERC director, Gerald Groenewold.

"The project proves that coal ash can significantly improve animal feeding areas, resting areas, and equipment traffic areas," said Debra Pflughoeft-Hassett, manager of the Coal Ash Resources Research Consortium (CARRC) at the EERC.

Livestock producers in North Dakota and the region want a low-cost alternative to using concrete in feedlots. The majority of North Dakota's 12,000 beef producers and 800 dairy producers have at least some areas subject to concentrated

traffic by livestock. Earthen pens and equipment traffic areas do not withstand this pressure, particularly when wet. As the integrity of the pen or alleyway surfaces break down, mud and poor drainage affect animal weight gain, health, and regular maintenance operations, such as manure removal. Fly ash mixtures used in the study proved to be a significant improvement over concrete.

For more information, contact Pflughoeft-Hassett at (701) 777-5261 or via e-mail to dphassett@undeerc.org.





Calendar of Events

December 3–7, 2001

18th Annual International Pittsburgh Coal Conference.

New Castle City Hall. New Castle, New South Wales. Australia.

For more information, contact Marguerite Link at the University of Pittsburgh at (412) 624-7440, or by e-mail at pcc@engr.pitt.edu.

March 4–7, 2002

"Keeping the Lights On!" The 27th International Technical Conference on Coal Utilization and Fuel Systems in Clearwater, Florida. Presented by the American Society of Mechanical Engineers—Fuels and Combustion Technologies Division, the Coal Technology Association, and the U.S. Department of Energy.

For more information, contact Barbara A. Sakkestad at (301) 294-6080, via e-mail at BarbaraSak@aol.com, or visit www.coaltechnologies.com.

May 14, 2002

2002 Conference on Unburned Carbon on Utility Fly Ash. Marriott City Center Hotel, Pittsburgh, PA. Sponsored by the

U.S. Department of Energy's National Energy Technology Laboratory.

Call for Papers. Abstracts of approximately 100 words must be submitted in electronic format by December 31, 2001.

For more information, contact Karen Lockhart at (412) 386-4763 or by e-mail to karen.lockhart@netl.doe.gov.

May 15–16, 2002

2002 Conference on Selective Catalytic Reduction (SCR) and Selective Non-Catalytic Reduction (SNCR) for NO_x Control. Marriott City Center Hotel, Pittsburgh, PA. Sponsored by the U.S. Department of Energy's National Energy Technology Laboratory.

Call for Papers. Abstracts of approximately 100 words must be submitted in electronic format by December 31, 2001.

For more information, contact Karen Lockhart at (412) 386-4763 or by e-mail to karen.lockhart@netl.doe.gov.

CBRC CONTACTS

Program Management

Lynn Brickett, CBRC Program Manager
U.S. Department of Energy -
National Energy Technology Laboratory
412/386-6574; brickett@netl.doe.gov

National Center

Paul Ziemkiewicz, Director
Tamara Vandivort, Consortium Manager
CBRC National Center located at the
National Mine Land Reclamation Center
West Virginia University
pziemkie@wvu.edu or twandivo@wvu.edu
304/293-2867

Regional Centers

Debra Pflughoeft-Hassett, Director
Western Regional Center located at the
University of North Dakota
dphassett@undeerc.org; 701/777-5261

Y. Paul Chugh, Director
Midwestern Regional Center located at
Southern Illinois University at Carbondale
chugh@engr.siu.edu; 618/536-6637

D. Courtney Black, Director
Eastern Regional Center
located at West Virginia University
dblack@wvu.edu; 304/293-2867, ext.
5447

National Steering Committee

David Goss, Interim Chair
Xcel Energy
david.goss@xemkt.com; 303/308-2734

Chairs of Regional Advisors/ Reviewers

Andrew Stewart, Interim Chair
Western Regional Advisors/Reviewers
PPE, Inc.
Eden Prairie, Minnesota
952/974-3954

Michael Murphy, Chair
Midwestern Regional Advisors/Reviewers
Illinois Department of Commerce and
Consumer Affairs, Office of Coal Develop-
ment mmurphy@commerce.state.il.us;
217/785-2001

Jackie Bird, Chair
Eastern Regional Advisors/Reviewers
Ohio Coal Development Office
jbird@odod.state.oh.us; 614/466-3465

CBRC National Steering Committee to Select Preproposals

This year, the CBRC solicited preproposals instead of full proposals. Fifty-two preproposals were received in all by the due date of September 5. The following is a breakdown by region:

- 24 from the Midwest,
- 15 from the East, and
- 13 from the West.

The National Steering Committee will meet on October 25 to select preproposals. Those selected will be invited to submit full proposals.

Both preproposals and full proposals are to be reviewed by the National Steering Committee. The preproposals were solicited based

on the same regional priorities as last year.

For a full listing of these priorities, visit the CBRC Web site at

<http://cbrc.nrcce.wvu.edu>.

Selected proposals will be highlighted in the next *Ashlines* issue.



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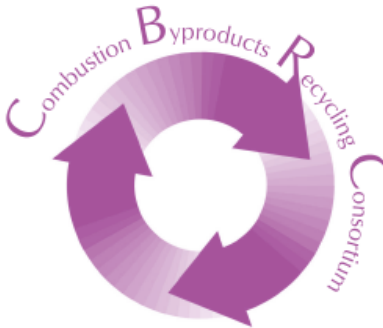
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Ashlines

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Effects of PFBC Byproducts on Water Quality

by Ralph J. Haefner

Many abandoned coal mines in Ohio and the Appalachian coal region are characterized by acid mine drainage. These mines typically require alkaline amendments, such as lime, to raise the pH of the soil so that vegetation can be reestablished (Barton, 1978). The coal combustion byproducts from coal-burning utilities may be beneficial in reclaiming abandoned coal mine sites. For example, flue-gas desulfurization (FGD) byproducts have pHs of 10 to 12 and a calcium carbonate equivalent of up to 60 percent (Stehouwer et al., 1995). Thus, a potential use exists for these materials to act as a neutralizing agent in acidic environments.

However, before beneficial uses of FGD byproducts can be supported by the electric-power industry and regulatory agencies, environmental data must be collected to show their effects on water quality. Specifically, questions remain

regarding the transport and fate of major elements such as sulfur and trace elements such as arsenic, selenium, and boron, which may be derived from the FGD byproduct.

This article summarizes a report titled *Water Quality Monitoring at an Abandoned Mine Site Reclaimed With Pressurized Fluidized Bed Combustion By-Product*, in which a method for distinguishing leachate derived from PFBC byproduct in ground water impacted by acid mine drainage is described. The report documents the effects of the use of a dry coal-combustion byproduct on water quality in the reclamation of an abandoned coal mine in Ohio. It presents the results and conclusions of data collection efforts from September 1994 through March 2001.

The pressurized fluidized bed combustion (PFBC) byproduct used in the study was generated at American Electric Power's experi-

mental Tidd Plant in Brilliant, Ohio. The byproduct is not strictly an FGD byproduct. Chemical reactions in the FGD process are similar to the pressurized fluidized bed combustion (PFBC) process; thus, the PFBC byproduct is chemically and physically comparable to FGD byproducts. The report presents the results and conclusions of data-collection efforts from April 2000 through March 2001 and focuses on the chemistry of interstitial water, ground water, and spring water.

Methods

A seven-acre abandoned surface coal mine site (referred to as the Fleming site) was reclaimed with PFBC byproduct as a surface amendment in 1994. Before reclamation, local residents lodged complaints regarding erosion and sedimentation along a nearby road. Springs were discharging acid mine drainage with pH less than 4 and

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high concentrations of dissolved solids, including iron and sulfate.

Instruments were installed at the site after reclamation in late 1994 and in early 1995 so that changes in water quality could be assessed through time. Thirty-five soil-suction lysimeters in five clusters were installed to monitor interstitial-water quality within the shallow unsaturated zone. Twenty monitoring wells in 13 well clusters were installed to monitor ground water levels and water quality at depths ranging from 15 to 100 feet. Three sampling sites were selected at downgradient springs to monitor the quality of spring water flowing from the site.

Workers at The Ohio State University School of Natural Resources did soil tests and chemical analyses of PFBC byproduct and determined that the mine spoil at the site required approximately 125 tons per acre of PFBC byproduct to attain a neutral pH of 7 (Stehouwer et al., 1996). In addition, the spoil at the mine site lacked organic matter necessary for successful plant growth. Therefore, approximately 50 tons per acre of yard-waste compost were added at the time of PFBC byproduct application.

Water samples were collected from the lysimeters, monitoring wells, and springs during the period 1995-2000. Onsite measurements of water characteristics included water temperature, alkalinity, pH, reduction-oxidation potential, specific conductance, and dissolved-oxygen concentration. Laboratory analyses included measurements for concentrations of major and trace elements and sulfur-isotope ratios ($\delta^{34}\text{S}$).

As of June 2000, the site was still undergoing hydrologic and geochemical changes, as documented by rises in water levels in wells and changes in water quality between June 1995 and June 2000. Although the Fleming site was mined more than 25 years before the onset of this investigation, reclamation in 1994 likely caused a disturbance of the chemical and hydrologic flow regime.

Water levels in wells rose approximately 1.5 to 2 ft from 1995 to 2000. Ground water flow directions during earlier phases of study (1995 and 1996) were generally from north to south; however, the potentiometric surface changed slightly during subsequent years (1997 through 2000). A ground water mound directed ground water flow in northerly, easterly, and southerly directions away from the mound. Possible causes of changes in the ground water levels and flow directions included raising of the outlet elevation for a sediment pond southeast of well cluster 5 and (or) changes in topography due to recharge patterns.

Water Chemistry

Previous work published in Dick and others (1999) and Haefner (1998) describe the properties and constituents that can be used to evaluate differences between water types at the Fleming site. These include specific conductance, pH, selected major ions and trace elements (calcium, magnesium, sulfate, and boron), magnesium-to-calcium (Mg:Ca) mole ratios, and sulfur-isotope ratios ($\delta^{34}\text{S}$).

Tracers of PFBC Byproduct

For this study, magnesium-to-calcium (Mg:Ca) mole ratios were selected for analysis because the PFBC byproduct was known to contain elevated concentrations of magnesium. Additionally, sulfur-isotope compositions of solid-phase materials (PFBC byproduct, spoil, and aquifer materials) and water were examined to see if differences could be determined between sulfate derived from oxidation of mine spoil and sulfate present in the PFBC byproduct.

Figure 1 shows that sulfur-isotope ratios for interstitial waters in the application areas have been influenced by PFBC byproduct. The majority of application-area interstitial waters have sulfur-isotope ratios that are greater than -5 per mil, whereas all other water samples have sulfur-isotope ratios that are less than -5 per mil. The sources of sulfate in interstitial water were estimated with a mixing model of sulfur-isotope ratios (Haefner, 2001). Mixing-model results indicated that most of the sulfate in application-area interstitial water was derived from PFBC byproduct leachate.

Sulfur-isotope ratios in control-area interstitial waters were similar to those measured in ground water. For all sampling rounds, downgradient ground waters sulfur-isotope ratios were consistently more negative than those for upgradient ground waters.

In previous reports (Haefner, 1998; Dick et al., 1999), it was noted that sulfate concentrations increased in upgradient and downgradient ground waters between sampling

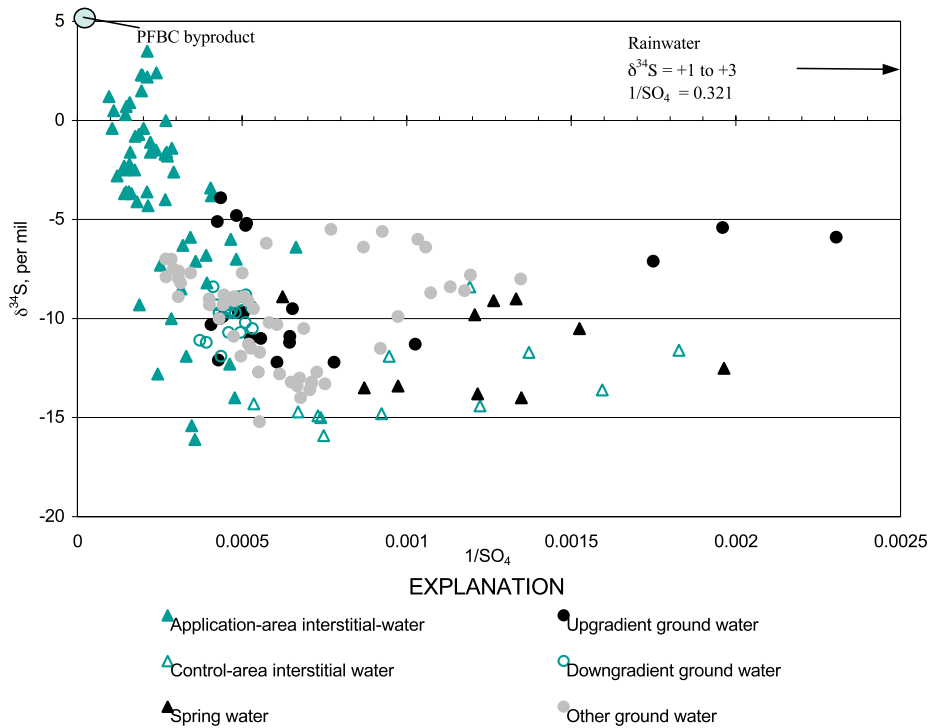


Figure 1—Sulfur-isotope composition as a function of the inverse of dissolved sulfate for water samples from the Fleming abandoned mine site, Tuscarawas County, Ohio.

rounds; however, the sulfur-isotope ratios of sulfate in these samples remained relatively constant and was approximately -10.0 per mil. Therefore, the dominant source of sulfate in ground water at the mine site is likely from oxidation of sulfide in mine spoil. Increases in sulfate concentrations during the study period in both upgradient and downgradient ground waters is indicative of sulfate derived from oxidation of pyrite in mine spoil that was disturbed and regraded during reclamation.

For this field application, the difference in Mg:Ca mole ratios and sulfur-isotope ratios between leachate derived from PFBC byproduct and leachate derived from spoil or aquifer materials was detectable. This was because the feed coal and sorbent used to create the byproduct came from a different mine and, therefore, had different chemical and isotopic characteristics than the coal and aquifer materials

at the site. If the coal and sorbent used in the PFBC process was from a local source, these methods of geochemical fingerprinting would not have been possible.

Summary and Conclusions

The two main processes of interest in this water quality study are (1) dissolution and leaching of PFBC byproducts applied to the surface of the study area, and (2) the generation of acid mine drainage (AMD) in spoil left at the surface of the site after mining ceased. Addition of alkaline PFBC byproduct was intended to increase pH, thereby reducing the solubility of major and trace elements in water.

Water quality was assessed on the basis of analyses of samples collected six times since 1995. Interstitial water containing leachate derived from PFBC byproduct contained elevated concentrations of calcium, magnesium, sulfate, boron, and strontium. The influence of PFBC byproduct on

water quality was evident from increased pH and lower concentrations of aluminum, iron, manganese, nickel, and zinc in application-area interstitial waters as compared to control-area interstitial waters. Elevated concentrations of boron in application-area interstitial waters may result in phytotoxicity in some plants, especially if PFBC byproducts or other coal-combustion byproducts are applied at higher rates than the rates applied in this study.

Ground water chemistry was dominated by high concentrations of sulfate, iron, and manganese. Median concentrations of most major elements in downgradient ground waters were similar to concentrations in upgradient ground waters. Water quality from springs showed not only the effects of acid-mine drainage, but also the effects of oxidation upon exposure to the atmosphere.

Magnesium-to-calcium mole ratios were distinctly higher in samples of interstitial waters collected from the application area (median of 4.9) than in interstitial-water samples collected in a control area (median of 0.91). Magnesium-to-calcium mole ratios for ground waters were similar to those obtained from control-area interstitial waters and were generally less than 1.2.

Sulfur-isotope ratios of water samples obtained at the site provide the following important results:

- Sulfur-isotope ratios in application-area interstitial waters are relatively positive as compared to control-area interstitial

(continued on page 4)

waters, showing the influence of sulfate derived from the PFBC byproduct.

- Upgradient and downgradient ground waters and spring waters are similar in sulfur - isotope composition to control area interstitial waters.
- Sulfur -isotope signatures of solid-phase materials and water samples collected at the site indicate that sulfate in ground water is derived from oxidation of pyritic mine spoil; and that ground water has not been significantly influenced by sulfate derived from PFBC byproduct leachate.

For this field application, the use of Mg:Ca mole ratios and sulfur - isotope ratios to distinguish leachate derived from PFBC byproduct from leachate derived from spoil or aquifer materials was successful because the feed coal and sorbent used to create the byproduct came from a different mine and, therefore, had different chemical and isotopic characteristics than the coal and aquifer materials at the site.

Other trace elements derived from the PFBC byproduct that could affect water quality include arsenic and selenium. Concentrations of these elements in interstitial waters were well below maximum contaminant levels (MCLs) for drinking water set by the U.S. Environmental Protection Agency. Concentrations of these elements rarely exceeded reporting limits.

The quality of interstitial water has clearly shown the influence of the PFBC byproduct leachate;

The quality of interstitial water has clearly shown the influence of the PFBC byproduct leachate; however, no changes in ground water quality can be attributed to addition of the byproduct.

however, no changes in ground water quality can be attributed to addition of the byproduct. Water quality in interstitial waters within the PFBC byproduct application area had elevated pH and specific conductance along with elevated concentrations of calcium, magnesium, sulfate, boron, and strontium. There were no exceedences of U.S. Environmental Protection Agency MCLs for drinking water for arsenic or selenium or any other trace elements. Increases in pH caused a decrease in concentrations of aluminum, iron, manganese nickel, and zinc.

The use of Mg:Ca ratios and sulfur-isotope ratios as tracers of PFBC byproduct were important to determine the influence of the byproduct leachate on water. Magnesium-to-calcium mole ratios from ground water were similar to those obtained from outside the PFBC application area, indicating that PFBC byproduct leachate has not reached ground water.

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For more information on this project, contact Ralph Haefner, principal investigator, at 614-430-7751 or rhaefner@usgs.gov. Also, check the CBRC Web site at <http://cbrc.nrcce.wvu.edu> this fall for a complete copy of the final report on this project.



Removing Ammonia from Fly Ash

by Edward K. Levy, Sc.D.

As the utility industry gears up for the next major round of NO_x reductions, it is widely anticipated that a significant number of units will be equipped with either selective noncatalytic reduction (SNCR) or selective catalytic reduction (SCR) technologies. For coal-fired applications, both techniques use either an ammonia or urea-based reagent.

In all cases, some ammonia reaches the stack as part of the flue gas and some is adsorbed onto the fly ash. There is widespread concern the presence of ammonia on the ash will adversely affect ash utilization. Much of the ammonia present on ash is in the form of ammonium sulfate or ammonium bisulfate.

This article summarizes a report titled "Ammonia Removal From Fly Ash in a Bubbling Fluidized Bed," which presents results from a project funded by the Combustion Byproducts Recycling Consortium and a group of electric utilities. The project demonstrates that ammonia can be driven from dry fly ash by heating the ash in a fluidized bed to cause thermal decomposition of the ammonium compounds. The report presents data on the ash temperatures required to accomplish this.

Background

Tests of fly ash contaminated by ammonium salts show that, in normal situations, the ammonia is not a problem unless the ash is moistened. Van der Bruggen et al. (1995) performed laboratory tests in which concrete was prepared using fly ash containing from 100 to 300 mg/kg of

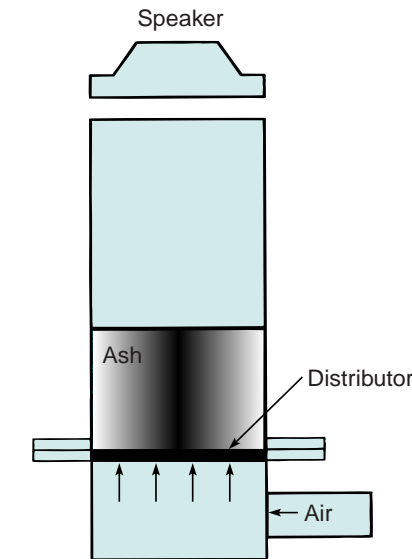


Figure 1 – Laboratory Batch Fluidized Bed

ammonium. Ammonia concentrations were continuously measured in the ambient air during the preparation of the concrete and the pouring of the concrete floors. The results show, for some situations, unsafe concentrations of ammonia were measured in the vicinity of the wet concrete. The problem of the ammonia odor increased in severity with higher concentrations of ammonium in the ash and in applications in which concrete was being mixed or poured in enclosed areas.

It seems likely, based on the experiments reported in Van der Bruggen et al., that the presence of ammonium salts on fly ash will be a deterrent to the utilization of fly ash for some high volume applications. This problem will become much more serious with more widespread installation of SCR and SNCR technologies.

Fluidization of Fly Ash

Fluidized beds are widely used in industry because, when operated with the right range of conditions, they exhibit excellent heat transfer, solids mixing, and gas contacting characteristics. In one type of fluidized bed, the particles are contained in a vessel and are supported by a gas distributor.

At low flow rates of fluidizing gas, the particle bed is in a packed state. As the gas velocity increases to a critical value, bubbles are formed at the distributor. These rise vertically through the bed, creating a turbulent-like motion and very good solids mixing. The gas velocity at which bubbles first appear is referred to as the minimum bubbling velocity, U_{mb} . At conditions above minimum bubbling, as gas velocity, U_o , is increased, bubble frequency and bubble size increase, with more vigorous mixing occurring in the bed. Previous tests with fly ash in a fluidized bed in our laboratory have shown that because of the very fine size distribution of fly ash particles, the particles tend to be attracted to one another. This leads to a clustering of the particles in the bed which, in turn, makes it difficult to achieve stable fluidization with active bubbling.

To get around this problem, we use an acoustic field to agitate the bed material. Figure 1 shows a laboratory-scale batch fluidized bed with a loud speaker positioned at the top of the bed.

(continued on page 6)

Removing Ammonia From Fly Ash (cont. from page 5)

Bubble measurements performed inside the bed with a reflective type fiber optic probe show the effects of bed process conditions and the acoustic field on bubbling.

In a series of experiments with fly ash, the sound pressure level caused by the loud speakers was varied up to 140 dB and the excess air velocity ($U_o - U_{mb}$) was held at a fixed value. The data show intermittent bubbling activity at low dB levels, with the bubble frequency increasing and becoming much more regular as the dB level increased.

The ammonia removal process requires vigorous and consistent bubbling, and we are using results from experiments like these to determine the best bed process conditions for this application.

Experiments on Ammonia Removal

The experiments on ammonia removal were performed in a 6-inch diameter bed fluidized with air. Electric resistance heaters submerged in the bed were used to heat the ash, and a loud speaker positioned at the top of the bed, helped to promote active bubbling. Thermocouples positioned in the bed measured ash temperature at several locations. As the ash temperature increased, samples of ash were periodically removed and these were subsequently analyzed for ammonium content. The ammonia measurements were performed using an ammonia ion selective electrode. The measurement procedure requires a sample of ash be placed in a sulfuric acid solution. The ammonium compounds in the

ash dissolve, making it possible for the electrode to detect the ammonia level.

Three different ashes were tested. For one ash, the initial ammonia concentrations were in the 700 to 850 ppm range. The results show reductions in ammonia began to occur in the 300 to 450 °F range, depending on process conditions. The ash ammonia content was reduced to 30 per cent of the initial at 600°F.

A similar set of tests was performed on ash from a second power plant. In this case, the initial ammonia content ranged from 600 to 1100 ppm. Ammonia release began at lower temperatures with a residual ammonia content of the ash at 20 per cent of the initial at around 650°F and at less than 5 per cent of the initial at around 700°F.

Finally, tests were performed on ash from a third plant with an initial ammonia concentration of approximately 500 ppm. The concentration was reduced to about 20 per cent of the initial at 700 °F. Ammonia removed from the ash is carried from the bed with the fluidizing gas.

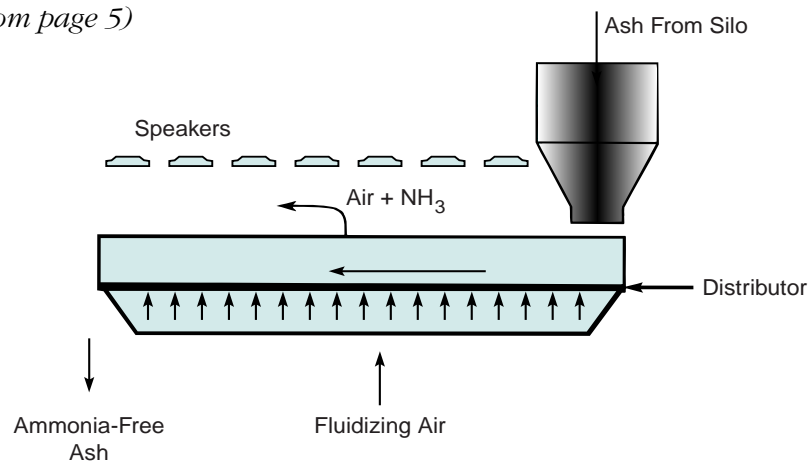


Figure 2—Inclined Fluidized Bed

Conclusions

The data from the three ash experiments show that ammonia can be removed from dry ash by heating the ash in a bubbling fluidized bed, with the assistance of acoustics to promote bubbling fluidization. The bed used in those experiments was a small, laboratory-scale batch bed. However, a full-scale commercial process will need to operate continuously, and we propose to accomplish steady operation using an inclined fluidized bed.

In the case of the inclined bed (see figure 2), dry ash is fed to the bed at one end and is heated as the ash flows along the surface of the distributor. Ammonia-free ash is removed at the far end of the bed. The inclined bubbling fluidized bed seems to be the ideal type of reactor for this application. It is of simple construction, with no moving parts. It permits continuous operation. Finally, because of extremely low fluidizing air velocities, energy requirements for heating and the cost of solids-air separation can be kept to a minimum.

Design calculations were per-

The CBRC Welcomes Rhonda



The Combustion Byproducts Recycling Consortium (CBRC) is pleased to announce a

new addition to its staff. Rhonda Rice joined the CBRC in July 2001 as an administrative assistant.

"I will be handling all contract administration matters for the CBRC," says Rice. "These will

include paying invoices and making sure CBRC subcontractors stay in compliance with their contracts."

Rice comes to the CBRC from West Virginia University's Health Sciences Center where she held a similar position in the Department of Community Medicine.

Rice also has worked in the coal industry and with utility companies, which makes her uniquely qualified to work with so many of the CBRC's participants.



Removing Ammonia From Fly Ash (cont. from page 3)

formed for a system processing 25 tons of ash per hour. It was assumed the ash is heated using electrical resistance heaters immersed in the bed. At \$0.04/kWh for electricity, the energy costs for ash heating ranged from \$2.14 to \$3.05/ton, depending on ash inlet temperature.

We are in the process of designing such a system for both laboratory and field testing. This will handle up to 1,000 lb/hr. Design studies for commercial scale units are also in progress.

Acknowledgments

This report was prepared with the support of the U.S. Department of Energy (DOE), National Energy Technology Laboratory through its Cooperative Agreement No. DE-FC26-98FT40028 with West Virginia University (WVU) Research Corporation. However, any opinions, findings, conclusions, or recommendations expressed herein are those of the author(s) and do not neces-

sarily reflect the views of WVU or DOE.

The authors are also grateful to Cinergy Corporation, Ontario Power Generation, PPL Generation, Public Service Electric & Gas Company, and PG&E National Energy Group for their support of this study.

Reference

van der Bruggen, F. W., et al. 1995. Problems encountered during the use of ammonium contaminated fly ash. *Proceedings EPRI/EPA 1995 Joint Symposium on Stationary Combustion NO_x Control*.

For more information on this project, contact Edward K. Levy, Sc.D., principal investigator, at (610) 758-4090 or at ek10@lehigh.edu. Also, check the CBRC Web site at <http://cbrc.nrcce.wvu.edu> this fall for a complete copy of the final report on this project.



CBRC CONTACTS

Program Management

Lynn Brickett, CBRC Program Manager
U.S. Department of Energy -
National Energy Technology Laboratory
412/386-6574; brickett@netl.doe.gov

National Center

Paul Ziemkiewicz, Director
Tamara Vandivort, Consortium Manager
CBRC National Center located at the
National Mine Land Reclamation Center
West Virginia University
pziemkie@wvu.edu or tvandivo@wvu.edu
304/293-2867

Regional Centers

Debra Pflughoeft-Hassett, Director
Western Regional Center located at the
University of North Dakota
dphassett@undeerc.org; 701/777-5261

Y. Paul Chugh, Director
Midwestern Regional Center located at
Southern Illinois University at Carbondale
chugh@engr.siu.edu; 618/536-6637

D. Courtney Black, Director
Eastern Regional Center
located at West Virginia University
dblack@wvu.edu; 304/293-2867, ext. 5447

National Steering Committee

David Goss, Interim Chair
Xcel Energy
david.goss@xemkt.com; 303/308-2734

Chairs of Regional Advisors/ Reviewers

Andrew Stewart, Interim Chair
Western Regional Advisors/Reviewers
PPE, Inc.
Eden Prairie, Minnesota
952/974-3954

Michael Murphy, Chair
Midwestern Regional Advisors/Reviewers
Illinois Department of Commerce and
Consumer Affairs, Office of Coal Develop-
ment mmurphy@commerce.state.il.us;
217/785-2001

Jackie Bird, Chair
Eastern Regional Advisors/Reviewers
Ohio Coal Development Office
jbird@odod.state.oh.us; 614/466-3465

Calendar

September 30 – October 5, 2001

11th International Conference on Coal Science: Exploring the Horizons of Coal.

San Francisco, California. Sponsored by The International Energy Agency (IEA) and the National Energy Technology

Laboratory (NETL). Coal Combustion Byproducts Session: Thursday, October 4, from 1:30–4:00 p.m. For more information visit <http://www.netl.doe.gov/events/01conferences/iccs/iccs01.html>.

October 22 – 24, 2001
International Ash Symposium.

Lexington, Kentucky. University of Kentucky's Center for Applied Research and the U.S. Department of Energy. Symposium will cover all aspects of coal combustion byproduct utilization. For more information contact Geaunita Caylor at (859) 257-2820 or gcaylor@engr.uky.edu.

Would you like to be on the CBRC mailing list?

If so, complete this for me and mail it to: **CBRC Mailing List, National Mine Land Reclamation Center, West Virginia University, P.O. Box 6064, Morgantown, WV 26506-6064** OR fax the completed form to **304/293-7822** OR send email to **cbrc@nrcce.wvu.edu**

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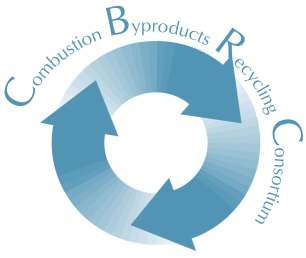
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Ashlines

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Department of Energy -
National Energy
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www.netl.doe.gov

Can Coal Ash Be Used as Fill in Saturated Areas?

by J. L. Adams and J. W. Warner

In Colorado, researchers are proposing to use coal Ash in the large-scale reclamation of a gravel quarry to determine its feasibility as beneficial fill material in water table conditions. The study, named the Varra Coal Ash Burial Project, has the following objectives:

- to determine the leaching characteristics of coal ash with respect to varying water quality conditions;
- to document local background water quality;
- to measure the permeability and porosity of various types of coal ash used in the project;
- to determine the affects of coal ash burial on local hydrology and water quality;
- to determine the physical characteristics of coal ash in saturated media;
- to evaluate the economic feasibility of mine land reclamation using coal ash; and

- to present socioeconomic issues regarding solid waste disposal in a nontraditional disposal site.

The project will be accomplished by submitting required permits and conducting bench scale leaching tests and a small-scale ash burial and water quality monitoring program. The permits are required because coal ash is classified as a solid waste and as such is subject to regulation under RCRA. The laboratory testing and proposed field tests are being conducted to fulfill permit requirements and to provide assurance to all parties involved that the placement of coal ash below the water table at this specific site will not cause adverse environmental impacts.

Coal Ash Source and Handling

The ash proposed for use in the Varra Test Project in Weld County, Colorado, will come from the Cherokee Generating Station in Denver. The plant has four pulverized coal-

fired boilers all of which burn coal from Moffat, Routt, or Delta Counties. The chemical and physical properties of the coal (and resulting ash) do not change significantly from year to year.

Local Geology/Hydrogeology

The proposed field study area for the project is an active gravel quarry located near the Saint Vrain Creek in Weld County. The surficial geology of the area as documented by Colton, 1978, varies between wind blown deposits of clay, silt and sand, and sandy to gravelly alluvium, which are Holocene in age.

A U.S. Geological Survey investigation documented groundwater occurrence and movement near the study area. Underflow calculations in the vicinity indicate that the average hydraulic conductivity varies between 97 and 147 feet per day.

The effects on groundwater quality and hydrology as a result of coal ash burial will be evaluated by

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placing roughly 400 tons of coal ash within a trench excavated to at least seven feet below the water table. The coal ash will be placed so that the water table surface intersects the coal ash, even during seasonal fluctuations.

The coal ash will be buried in a trench measuring 10 feet in width, 100 feet in length and roughly 10 feet in depth. The trench will be constructed perpendicular to the direction of groundwater flow and will consist of two ash deposits separated by undisturbed soil. The separation between the two trenches will be no more than ten feet to show that preferential pathways between and around the less permeable ash will result in a higher groundwater flux in the more permeable zones immediately adjacent to the ash. This may allow natural process to abate or reduce any effects of elemental leaching. Approximately one foot of native soil will be placed over the entire trench.

Concerns regarding the affects of coal ash burial on groundwater flow at the study area were evaluated by use of a two-dimensional analytical groundwater flow model created with TWODAN Windows software. The model was used to simulate groundwater flow conditions with the proposed trench in place.

A uniform flow field was defined in the model with an unconfined aquifer. The hydraulic conductivity of the aquifer at the Varra site was estimated at 100 to 150 feet per day. A hydraulic conductivity of 125 feet per day was used in the model. The aquifer thickness was modeled as 20 feet. A 100-foot long trench was placed in the uniform flow field and a plot was generated showing the water table contours and flow path lines.

This will be the first permitted project in Colorado (and possibly the nation) approving the placement of coal fly ash in a drinking water aquifer.

Accomplishments

The various testing regimes document hydraulic and leaching characteristics of coal ash. Permeabilities of coal ash varied over three orders of magnitude. The hydraulic conductivity of bottom ash closely approximated recycled concrete and recycled asphalt and is comparable to permeabilities associated with medium- and coarse-grained sands. Fly ash samples were three orders of magnitude less permeable than bottom ash and non-ash samples and have permeabilities comparable with silt and clay.

Analytical solutions indicate that deposition of impermeable materials in a transmissive aquifer will not cause significant hydraulic gradient changes. Groundwater flow will be diverted around or beneath less permeable materials. In addition, the ability to draw water downstream of a properly engineered ash burial will not be affected to any significant degree. In fact, the reclamation of open water bodies by coal ash can substantially reduce consumptive groundwater losses and provide other benefits as well.

Large-scale ash deposits can be placed with very permeable channels or pathways making it feasible to channel a majority of groundwater flux through small localized

channels with out significant changes to hydraulic gradients or water quality. As long as the leaching of elements from the ash is slow enough, it may be possible to safely deposit ashes of any composition in saturated environments. CGRS proposed that the results of a unique leaching study be used to evaluate liabilities of coal ash burial in wet systems. The CDPH&E accepted the unique leaching studies in lieu of more traditional leaching tests such as TCLP.

The results of initial laboratory testing indicate that the total leachability of coal ash is comparable to inert materials such as recycled asphalt. Comparisons of leachates from short-term leaching tests to primary and secondary drinking water standards indicate that reuse of coal ash in saturated environments may be feasible with proper environmental and engineering controls.

The CDPH&E approved the Varra permit submittal with minor clarifications required. This will be the first permitted project in Colorado (and possibly the nation) approving the placement of coal fly ash in a drinking water aquifer. During the first quarter of 2001, the response to the state's comment letter will be prepared and the CD application process with Weld County will continue.

Field placement of coal ash will proceed in 2001 with continued funding from CBRC.

For more information on this project, contact Joby Adams at 970-493-7780 or joby@cgrs.com.



The CBRC Promotes CCB Use to State and Federal Regulatory Agencies

Ishwar P. Murarka, Ish Inc.

THE COMBUSTION BYPRODUCTS RECYCLING CONSORTIUM (CBRC) began in the fall of 1998 as a five-year U.S. Department of Energy (DOE) funded program. The firm of Ish Inc. was awarded a CBRC grant in response to RFP1999 solicitation.

Ish Inc. proposed to assemble and synthesize, in a scientifically sound manner, available information on the use of coal combustion byproducts (CCBs) for reclaiming and filling surface mine pits and underground coal mines.

The research is, therefore, structured to

- (1) search for and acquire available data from case studies where CCBs have been or are currently being used to fill surface and deep mines;
- (2) synthesize and critically analyze the collected information through statistical, graphical, geochemical, and hydrologic methods; and
- (3) carry out technology transfer activities through presentations at meetings and conferences to disseminate information synthesized in this project.

Potential Benefits and Regulatory Issues

Deposition of CCBs in mined lands can serve two purposes offering large environmental and social benefits.

The first purpose of CCB placement in mines is to reclaim mine lands for productive land use in an economic and environmentally sound manner. The second is to eliminate the need for converting lands near power plants to landfills and impoundments.

However, perceptions and lack of reliable scientific data continue to create large obstacles in increasing or even retaining the current use of CCBs in active and inactive mines. Several million tons of CCBs can be beneficially used in mine-filling operations on an annual basis.

Since the initiation of this research project, use of CCBs in filling of coal mines is receiving very high scrutiny both from environmental groups and from the U.S. Environmental Protection Agency (EPA). In its regulatory determination (May 22, 2000), EPA has decided to establish national regulations under Subtitle D of RCRA or upgrade SMCRA controls for coal combustion wastes used to fill surface or underground mines to ensure protection of human health and the environment.

EPA specifically noted that it has considerable concern about certain current practices; e.g., placement directly into groundwater. This research project is expected to provide available scientific information that the EPA can utilize in developing its regulations.

Results from this Research

During the last six months, the researchers have been searching for and acquiring available data on surface water and groundwater quality from coal mine sites, which have received CCBs. Several coal mine facilities have been identified from review of public comments submitted into the RCRA docket file on EPA's determination on wastes from the combustion of Fossil Fuels.

These submissions indicate that Pennsylvania and Indiana have the most mines used for CCBs. In addition, states of Arizona, Colorado, Illinois, Kentucky, Maryland, Montana, New Mexico, North Dakota, Ohio, Oklahoma, Texas, West Virginia, and Wyoming have coal mine sites where CCBs are being deposited in the mines.

Altogether 100 projects have been identified where coal mines either have or are currently placing CCBs in the active or inactive mines. Both surface and underground coal mines are involved. These projects cover a span of CCB use practices, such as mine-reclamation, ash disposal, stabilization, grouting, abatement of acid-mine drainage, subsidence control, and capping of acid producing mine spoils.

As a result of the contacts with various owners, operators, researchers, and state regulators, significant amounts of water quality data and

(continued on page 4)

CBRC CONTACTS

Program Management

Lynn Brickett, CBRC Program Manager
U.S. Department of Energy -
National Energy Technology Laboratory
412/386-6574; brickett@netl.doe.gov

National Center

Paul Ziemkiewicz, Director
Tamara Vandivort, Consortium Manager
CBRC National Center located at the
National Mine Land Reclamation Center
West Virginia University
pziemkie@wvu.edu or tvandivo@wvu.edu
304/293-2867

Regional Centers

Debra Pflughoeft-Hassett, Director
Western Regional Center located at the
University of North Dakota
dphassett@undeerc.org; 701/777-5261

Y. Paul Chugh, Director
Midwestern Regional Center located at
Southern Illinois University at Carbondale
chugh@engr.siu.edu; 618/536-6637

D. Courtney Black, Director
Eastern Regional Center
located at West Virginia University
dblack@wvu.edu; 304/293-2867, ext. 5447

National Steering Committee

David Goss, Interim Chair
Xcel Energy
david.goss@xemkt.com; 303/308-2734

Chairs of Regional Advisors/ Reviewers

Andrew Stewart, Chair
Western Regional Advisors/Reviewers
PPE, Inc.
Eden Prairie, Minnesota
952/974-3954

Michael Murphy
Midwestern Regional Advisors/Reviewers
Illinois Department of Commerce and
Consumer Affairs, Office of Coal Development
mmurphy@commerce.state.il.us; 217/785-2001

Jackie Bird, Chair
Eastern Regional Advisors/Reviewers
Ohio Coal Development Office
jbird@odod.state.oh.us; 614/466-3465

The CBRC Promotes Coal Combustion Byproduct Use (cont. from page 3)

some CCBs characterization data have been accumulated for a number of sites. However, hydrologic data are generally lacking, which will limit analysis for changes in groundwater flow due to the placement of coal ash.

Organizations have completed a number of demonstration projects using finite quantities of CCBs in a mined site and are monitoring the engineering and environmental performance of the CCB applications. Most of these projects showed some benefit from the CCBs. In some of the situations, no benefits were seen when CCBs were utilized.

The Midwestern ash site in Indiana is one example of a case study where fly ash has been used to fill an open mine pit created by the surface mining of coal. Over 1.2 million tons of coal ash from a nearby power plant have been placed to nearly fill the open pit over a ten-year period. The coal ash is placed dry, and the final grade consists of a soil cover with grass. Monitoring of groundwater and surface water for approximately 34 parameters has been performed quarterly for the past 10 years at several locations at the site. Data have also been collected on the bulk chemical composition and laboratory generated leachates for the CCBs on a quarterly basis. The coal ash is alkaline and has a pH of about 9.0.

Acid mine drainage (AMD) was present at the Midwestern ash site due to the exposure and oxidation of pyrite in coal. One of the monitoring locations at the Midwestern site is the water from mine seep located about 800 ft downgradient of the ash-fill area. The monitoring data show significant improvements in the water quality of the mine seep and include near elimination of acidity; neutralization of pH, reduction in iron, manganese, and reduction in sulfate. However, these monitoring data also show an increase in Boron concentrations in the mine seep water. Time series data plots and trends have been utilized to identify these changes in water quality.

Over the remaining three months of the project, all acquisition, summarizing, and analyzing of assembled data will be completed and a technical report will be prepared to present the findings. Presentations at a number of conferences are planned to disseminate the results of this research project to regulators, CCB generators, marketers, and users.

For more information on this CBRC project, contact the principal investigator, Ishwar Murarka at 408-720-0474 or ishinc@ix.netcom.com.



The New Year Brings Personnel Changes to the CBRC

Lynn Brickett as new DOE-NETL Program Manager

On January 1, 2001, the new year also introduced a new Department of Energy-National Energy Technology Laboratory (DOE-NETL) Program Manager, Lynn Brickett. She is currently a Project Manager in the Environmental Projects Division at the DOE'S NETL Pittsburgh office and has been working in the environmental area for 7 years. She began her career working for the former Bureau of Mines where she did a variety of research including active and passive treatment of AMD, microbiological metal leaching research, underground mine ecology and ore passivation studies. Lynn came to DOE-NETL in 1997 when the Bureau closed. She worked in the Environmental Science and Technology in-house research group. Her research areas included: coal combustion by-products and in-situ bioremediation of contaminated soils and sediments. She holds a B.S. in Environmental Science and a M.S. in Environmental Science and Management from Duquesne University.

Lynn replaces Scott Renninger who has moved on into mercury issues that DOE-NETL is addressing.



needed role. Hopefully, our paths will cross again in the future. Until then, I wish you good health, prosperity and enjoyment in your lives." Robert Dolence.

Dave Goss Replaces Dolence as Interim Chair

Dave Goss, who has served as Western Regional Chair since the inception of the CBRC and whose term is scheduled to end this December, has agreed to step down early as Western Regional Chair and serve as Interim Chair for the National Steering Committee.

Paul Ziemkiewicz, Director of the CBRC states that "Goss has been a very valuable member of the NSC and we are fortunate to have him as Interim NCS Chair."

Goss's interim position will be effective immediately and continue until the NSC meets later this fall to elect a Chair for a two-year term.



Andrew Stewart as Interim Western Regional Chair

Andrew Stewart has agreed to serve as the Interim Western Regional Chair in Dave Goss's place. Stewart worked for Cooperative Power (now Great River Energy) for more than 16 years in various positions, from plant engineer to manager of the ash program. He now heads up his own engineering and ash management consulting firm. He has served in national leadership roles for the American Coal Ash Association (ACAA), is an honorary member of the European Association for the Utilization of Coal Combustion Byproducts, and was one of the founders of the Western Region Ash Group (WRAG).

Stewart's interim position will be effective immediately and continue until the NSC meets later this fall to elect a Western Region Chair for a three year term.

"I think Andy's previous utility experience, plus his strong technical background in environmental and construction activities gives him a well rounded perspective." Dave Goss.

Robert Dolence Steps Down as Chair of the National Steering Committee



Robert Dolence has stepped down as Chair of the National Steering Committee. In January,

2001, he resigned as Deputy Secretary for Mineral Resources in Pennsylvania's Department of Environmental Protection, and he has accepted a position with Science Applications International Corporation (SAIC), an employee-owned technology "portal" company servicing the private and public sectors. He represented the Interstate Mining Compact Commission (IMCC) to the CBRC.

"I had a lot of fun and professional gratification working with the CBRC. Your mission is an important one and I wish you all the success in fulfilling this much

WRAG Partnership Benefits the CCB Industry

THE COAL COMBUSTION BYPRODUCTS (CCB) INDUSTRY IS DIVERSE AND INFLUENCED BY COUNTLESS REGIONAL AND NATIONAL FACTORS AND ISSUES. Because CCBs have such varied and far-reaching technical and environmental potential, it is difficult for individuals or single companies to acquire and maintain adequate CCB expertise in all necessary areas. For this reason, Western Region Ash Group (WRAG) was formed to help interested parties join forces for the common good of the CCB industry and the environment.

How WRAG Began

Although one of the first notable uses of coal fly ash was in the construction of the Hungry Horse Dam in Montana in the early 1940's, the CCB industry was really developed in the East and Midwest with bituminous ashes as its focus. Later, when ashes from sub-bituminous coals became more abundant, it was clear that these differences affected markets, economics, geographic realities and technical needs.

In 1992, Tim Bryggman and Jim Nallick worked under an Associated Western Universities Fellowship to assemble a report for the U.S. Department of Energy titled *"Use of Coal Combustion By-Products: Status and Opportunities in Region 8."* Region 8 includes Colorado, Montana, North Dakota, South Dakota, Utah, and Wyoming. The report provided summary information describing CCBs and the typical regional markets.

Based on positive feedback to the

. . . technical seminars on the physical and environmental properties of CCBs have permitted more producers and contractors to use them in construction projects because regulators better understand the benign nature of the material.

report from state energy officers, a small group of regional CCB industry representatives formed the DOE Region 8 Ash Promotional Group in January, 1994 and developed a mission statement. Volunteers compiled a database of CCBs generated and used in the DOE Region 8 on a state-by-state basis, and they assembled state regulatory information and identified regional markets and market impediments. A minimal membership fee was established, and a tentative agreement was made for the group to meet 2 or 3 times per year.

Since the first organization meeting, this group has evolved into the Western Region Ash Group (WRAG) serving the Western United States with a volunteer executive committee consisting of co-chairs elected in alternating years, a secretary, and a treasurer. The early meetings of the Region 8 Fly Ash group largely consisted of producers and market-

ers with a few interested parties involved in research and academic activities. The meetings were informal and normally consisted of roundtable discussions of common issues between members.

WRAG's membership has changed significantly in the past few years. More organizations and individuals have become involved in WRAG as CCBs have become more widely accepted and receive national attention through environmental issues.

The lines that seemed to divide viewpoints have blurred to the point where CCBs are promoted almost without distinction as to marketplace and location. WRAG members now include producers, marketers, cement manufacturers, researchers, testing organizations, transportation (trucking and railroad) companies, individual entrepreneurs and inventors, contractors, universities, other CCB interest groups and regulators. Complimentary memberships are provided to state and federal agencies that have been involved in the regulation or promotion of CCB use.

How WRAG Has Helped

WRAG has found that open dialogue with and seminars hosted for the benefit of local and state agencies that review CCB use enhances understanding and often resolves misconceptions. For example, technical seminars on physical and environmental properties of CCBs have permitted more producers and contractors to use them in construc-

tion projects because regulators better understand the benign nature of the material.

WRAG has also changed its meeting format from informal roundtable sessions with members, to specific topical meetings that include a variety of technical speakers. At each meeting, experts from throughout the U.S., not just the West, are invited to present information on emerging technologies, research results and examples of CCB use. Meetings have been hosted jointly with or co-hosted by groups such as the Energy and Environmental Research Center, the American Society for Surface Mining and Reclamation, the American Coal Ash Association and the Texas Coal Ash Users Group.

WRAG's accomplishments in the last seven years include:

- technical forums and workshops
- focused on regional markets
- twice annual membership meetings and member roundtable discussions of technical and regulatory issues
- facilitated operation of the Western Region Combustion Byproducts Recycling Consortium (CBRC)
- an internet web page (www.WRASHG.org)
- comments to EPA on the RCRA determination for fossil fuel wastes
- joint meeting with the Texas Coal Ash Utilization Group

WRAG's meetings and workshops typically draw between 40 to 60 attendees indicating that there is merit in the effort. Membership retention is high because there is

ample opportunity to participate, and the cost of membership has remained low.

The key to sustaining WRAG in the future centers around two things: communication and dedicated volunteers. WRAG has provided a vehicle for the ash industry to understand its own needs and work toward improvements. Through WRAG, the western ash industry has developed an identity and a voice in the overall ash industry, so the issues of the western region can be better addressed by organizations at any level.

For more information about WRAG, access the WRAG Web site at www.WRASHG.org.



Clarification of "Fly Ash, Pigs & Tomatoes" printed in the Summer 2000 issue

The article stated that "two of the top 73 major coal-powered utilities (Florida Power Corporation and Tampa Electric Company) in the U.S. are located in Florida and producing tons of Class F daily, which they need to dispose of." Representatives of both Florida Power and Tampa Electric notified the CBRC that all fly ash resulting from electricity production at their facilities is sold for beneficial reuse. Yuncong Li and Peter Stoffella, researchers on this Eastern Region CBRC project, have offered the following clarification based on information from DOE and the American Coal Ash Association:

"According to the US Department of Energy, power plants in the United States used over 640 million tons of coal in 2000. Two of the top 73 major consumers of

coal powered utilities are located in Florida (Florida Power Corporation and Tampa Electric Company). The production of coal fly ash exceeds the current beneficial use for such ash, resulting in the need for disposal including landfilling and ponding of ash. According to the data released by the American Coal Ash Association on the national level, only 33 percent of ash produced is being utilized in 1999."

For more information on the CBRC project "Utilization of Fly Ash and Urban Yard Waste as Soil Amendments to Improve Soil Fertility," contact the principal investigators, Yuncong Li or Peter Stoffella at 561-468-3922 or send email to yunli@gnv.ifas.ufl.edu or stoffella@gnv.ifas.ufl.edu.



Calendar

May 13-16, 2001

16th International Conference on Fluidized Bed Combustion.

Reno, Nevada. Session on Ash Management and Use. Sponsored by American Society of Mechanical Engineers (ASME) and the Council of Industrial

Boiler Owners (CIBO). For more information visit "events" on <http://www.netl.doe.gov/> or <http://www.asme.org/conf/fbc/>.

May 16-18, 2001

2001 Conference on Unburned Carbon (UBC) on Utility Fly Ash and Selective Catalytic (SCR)

and 2001 Conference on Selective Non-Catalytic Reduction (SNCR) for NOX Control.

Pittsburgh, PA. For more information visit "events" on www.netl.doe.gov or contact karen.lockhart@netl.doe.gov

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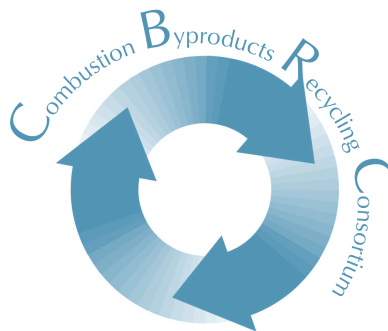
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Ashlines is published by the Combustion Byproducts Recycling Consortium, headquartered at West Virginia University in Morgantown, WV.

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COMBUSTION BYPRODUCTS RECYCLING CONSORTIUM

Ashlines

To promote and support the commercially viable and environmentally sound recycling of coal combustion byproducts for productive uses through scientific research, development, and field testing.

a program of the National
Mine Land Reclamation
Center at West Virginia
University www.nrcce.wvu.edu/nmlrc, in
cooperation with the U.S.
Department of Energy -
National Energy
Technology Laboratory
www.netl.doe.gov

Save the Trees! *Utility poles made from coal combustion byproducts could save millions!*

THEY'RE EVERYWHERE!
THEY'RE EVERYWHERE! Look out your window and you'll probably see them: utility poles. The utility industries (electric, telephone, cable, and municipalities) use wooden poles for installing cables, lights, and transmission lines. CBRC investigators Dr. Y.P. Chugh et al at Southern Illinois University at Carbondale (SIUC) report that an estimated 250,000 poles with an average height of 30 to 40 feet and another one million poles averaging 15 to 30 feet high are used annually in the Midwestern U.S. alone.

Chugh and his colleagues, Dr. D. Deb, Dr. Navin Chand, and H. Wilcox are working on designing utility poles made of coal combustion byproducts (CCBs) and leaving trees alone. Each pole would use about 400 to 600 pounds of CCBs, which are waste products from coal combustion. In the U.S., over 100 million tons of CCBs are generated every year with only about 30 percent used

for beneficial purposes. In the CCRB researchers' experimental utility pole project, the CCBs are mixed into a grout that is combined with different types of polymers (PVCs), which are used as a binding agent for the grout. Glass or other material fiber may be added to improve flexural strength. Thus, it is expected that the final product will be comparable or superior to its wooden counterpart.

Timbering can cause landslides and compromise air and water quality. Pondered CCBs (CCBs landfilled in large ponds) can contaminate groundwater. Thus, utility poles made from CCBs benefit the environment and industries that generate CCBs. In addition to the obvious saving of trees and the recycling of problematic industrial waste, CCB-based utility poles would have several advantages over wooden poles:

1. They are fireproof and termite proof.
2. They do not have to be treated with creosote for weatherproof-

ing, which can cause water pollution from rainwater runoff.

3. They are cheaper to install than wooden poles.
4. They are not as easily damaged by animals and humans.

If the Midwest region were to replace the 250,000 wooden poles it uses in one year with CCB-fabricated poles, it would save that many trees and utilize from 87,500 to 100,000 thousand tons of CCBs.

For commercial development, however, four of the challenges in developing CCB-fabricated poles are to:

1. perfect a pole that tapers towards the top like standard wooden utility poles, to minimize weight and cost, and with adequate shear, compressive, and flexural strengths to withstand bending loads and wind;
2. develop a pole that can be manufactured for under \$200—the approximate price of a 35-foot wooden pole;

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VISIT THE CBRC WEBSITE AT [HTTP://CBRC.NRCCE.WVU.EDU](http://CBRC.NRCCE.WVU.EDU)

3. determine how ultraviolet rays will impact the long-term life of a PVC-encased utility post and build into the design prevention of UV damage; and
4. develop a grout to mix with the PCVs that will utilize the maximum amount of CCBs while creating the desired utility pole characteristics.

The researchers have determined that their basic CCB utility pole grout must have the following properties:

- *compressive strength*: 2,000 to 3,000 psi
- *flexural strength*: 6,000 to 8,000 psi
- *elastic modulus*: 100,000 psi
- *density*: 45 to 60 pcf
- *failure behavior*: flat or slow strain-softening

Two types of CCBs—Grand Tower (GT) F-type ash and SIU fluidized-bed combustion (FBC) spent bed ash—are being used for the study. The ashes are being mixed with three grades of polyurethane provided by polymers manufacturers. In general, CCBs with finer ash particles provide higher compressive strength and elastic modulus as compared to samples composed of coarser ash particles. Grout mixes containing 60 - 65 percent of fly ash yield uniaxial compressive strengths ranging from 743 to 2,265 psi, with elastic modulus of 15,613 to 74,102 psi.

CCB chemical composition also plays an important role in grout development. In general, variations in silica and calcium oxide content affect how the CCBs bond with different polymers. This variation in chemical composition of CCBs creates different physical properties of the com-

posites. The chemical composition of the fly ash also determines how much polymer must be added to the grout.

To date, the CBRC researchers have developed 81 mixes of polymers and grouts. The ultimate goal is to identify the mix with the highest compressive and elastic modulus strength, highest percentage of CCBs, cheapest resin (polymer), and good post failure behavior.

Once a suitable material is developed, the researchers will use numerical analysis, mainly finite element method (FEM) to analyze the structural performance of the fabricated poles under different load conditions. Laboratory testing of large-size (6-foot) poles will also be performed to evaluate buckling behavior. Based on the results of the FED analysis and laboratory data, mix designs will be modified, if necessary.

The researchers have also determined that PVC pipe or another encasement is essential to improve both compressive and flexural properties of the polymeric grout. In some cases, the ultimate strength of specimens was found to be greater than the yielding strength, which would make the CCB-fabricated poles of superior quality than their wood counterparts.

The 12 35- to 40-foot CCB-based poles will be fabricated by a manufacturing company with experience in building large-scale structures from polymer-based products. The company chosen will manufacture the poles with an outer layer composed of polyester and 10 to 20 percent CCB. This layer will increase the flexural strength. The inside of the poles will be made of a material that is 70 to 80 percent CCBs and polyester

(or other inexpensive polymer). A polyester foaming process will be used to reduce the bulk density of the inner material. Currently, no suitable process exists for foaming polyester for this project, so the manufacturing also involves developing such a process and then mixing the “whipped” polyester with the CCBs to develop a low-density grout for the interior of the poles. According to the companies interested in manufacturing the poles, design and development of this essential process will be the most difficult part of the production.

Once the 12 prototype full-size CCB utility poles are manufactured, the CBRC researchers will then test and characterize the engineering performance of the poles and document their performance in the field in conjunction with local electric utility companies. Long-term goals include designing a pilot scale facility for fabricating poles and developing an industrial partnership for eventual commercialization.

For more information on CBRC project #ECM-07, *Development of Coal Combustion Byproducts-Based Utility Poles for Electric Utility Industry*, contact the principal investigator, Dr. Paul Chugh at Southern Illinois University-Carbondale; 618/536-6637; chugh@engr.siu.edu.



Good News for Boron

IN FLY ASH AND CCB CIRCLES, BORON TRADITIONALLY HAS GOTTEN A BAD RAP. Boron is an important plant nutrient that is naturally concentrated in plant tissues, including ancient plants that became fossilized into coal. Boron is considered a salt former and tends to be elevated in the sea and in stagnant water bodies associated with most coal deposition. Many of the fine clays and soils washing into the ancient coal-forming swamps were capable of adsorbing boron from the water, and many of the surrounding shales that were deposited around the coal were formed from boron-adsorbing clays and sediments. As a result of these natural processes, boron is a significant trace element in most coal, and when coal is burned in power plants, the ash residue produced can contain high concentrations of boron. It may be concentrated in the finer materials such as fly ash and scrubber product by both natural and combustion-related processes. Although boron is essential for plant life, high levels can cause bowel and stomach upset in humans. Release of boron is of environmental concern because it can adsorb onto and accumulate in irrigated soils.

Boron oxidizes at low temperatures and is mostly vaporized in the burning of coal. This vaporized boron moves with the hot gases of combustion and the fine particles of fused fossil dirt and soil until the temperature of the gas stream has dropped sufficiently to allow condensation. When this occurs, the boron is deposited on the fine particulate matter in the gas stream. This fine particulate

Most fly ashes are more likely to fail environmental tests on the basis of boron concentration than any other element.

matter is removed from the flue gas stream with baghouses and electrostatic precipitators as fly ash. This fly ash can have high levels of boron. In fact, most fly ashes are more likely to fail environmental tests on the basis of boron concentration than any other element, and if they do fail, even the most beneficial use and recycling efforts for coal combustion byproducts (CCBs) are thwarted.

CBRC researcher Bradley Paul at Southern Illinois University at Carbondale (SIUC) suspects that boron fails the shake tests—that is, the traditional way of testing by mixing the fly ash in solution, shaking it for a given amount of time, and then measuring the boron concentration in suspension—because it is wrongly assumed that the concentration remains the same in perpetuity. In reality, fly ash will generally leach high in boron during a shake test because the most soluble boron is on the surface and once it has washed off of the fresh fly ash, there is no more easy boron to leach, and concentrations drop.

Another problem with measuring boron concentration, according to Paul, is that conservative groundwater modeling assumes that contaminants released from a source are conserved and move through the groundwater system, affected only by

dilution and dispersion. In the case of boron, such an assumption is especially out of place. If one of the concentration mechanisms for bringing boron into material associated with coal was adsorption of boron from water by ancient clays and soils, then in this setting it seems especially contradictory to assert that boron will move through the ground for hundreds or thousands of feet with no adsorption reactions occurring with the surrounding ground and yet, when the water emerges at the surface and runs through irrigation furrows, the boron will suddenly become active and start adsorbing on the soil. Despite this obvious contradiction, almost no work has been done to define the adsorptive capacity of soils and rock from boron. This is the work Paul and his researchers are doing.

In their research, Paul et al have discovered that boron is actually one of the elements *least* adsorbed by many types of soil and rock. The low adsorption of boron they found compared to what other researchers have reported for other more-studied ions is most likely because boron is generally found as an anion in solution as opposed to a cation. When many clays, soils, and rocks are beginning to decay, they form laminated chemical structures with plates of negative charges between these layers. In these negatively charged areas, metal cations can be attracted and trapped. Since boron is most often an anion, not a cation, it cannot be captured between these planes with negative charges. The significant implication here is that most other trace elements of concern with

(continued on page 6)

CBRC CONTACTS

Program Management

Scott Renninger, CBRC Program Manager
U.S. Department of Energy -
National Energy Technology Laboratory
304/285-4790; scott.renninger@netl.doe.gov

National Center

Paul Ziemkiewicz, Director
Tamara Vandivort, Consortium Manager
CBRC National Center located at the
National Mine Land Reclamation Center
West Virginia University
pziemkie@wvu.edu or tvandivo@wvu.edu
304/293-2867

Regional Centers

Debra Pflughoeft-Hassett, Director
Western Regional Center located at the
University of North Dakota
dphassett@undeerc.org; 701/777-5261

Y. Paul Chugh, Director
Midwestern Regional Center located at
Southern Illinois University at Carbondale
chugh@engr.siu.edu; 618/536-6637

D. Courtney Black, Director
Eastern Regional Center
located at West Virginia University
dblack@wvu.edu; 304/293-2867, ext. 5447

National Steering Committee

Robert Dolence, Chair
Interstate Mining Compact Commission
dolence.robert@dep.state.pa.us

Chairs of Regional Advisors/ Reviewers

David Goss, Chair
Western Regional Advisors/Reviewers
Public Service Company of Colorado
dgoss@psc.co.com; 303/571-7075

Michael Murphy
Midwestern Regional Advisors/Reviewers
Illinois Department of Commerce and
Consumer Affairs, Office of Coal Development
mmurphy@commerce.state.il.us; 217/785-2001

Jackie Bird, Chair
Eastern Regional Advisors/Reviewers
Ohio Coal Development Office
jbird@odod.state.oh.us; 614/466-3465

CBRC 2000 Awards

Sixty-nine proposals were received in response to CBRC's Request for Proposals (RFP) 2000. The National Steering Committee (NSC) met on November 2, 2000 in Denver, CO to discuss the reviewers' evaluations of the proposals. The NSC made their funding recommendations to the Department

Title

PI

Siege of Acre

Paul Petzrick

Environmental Performance Evaluation of
Filling and Reclaiming a Surface Coal Mine
with Coal Combustion Byproducts

Ishwar Murarka

Environmental Effects of Large-Volume
FGD Fill

Phillip Glogowski

The Use of Fly Ash as an Aggregate for
Foundary Sand Mold and Core Production

Thomas Cobett

Long Term Excavatability of Flowable Fill
Containing Coal Combustion Byproducts

L. K. Crouch

Development of CCB Fill Materials for Use as
Mechanically Stabilized Marine Structures

Kelly Rusch

Evaluation of Flyash Admixtures for Final
Cover and Composite Liner Applications

James Carlson

Effects of Large-Scale CCB Applications on
Groundwater: Case Studies

Shiv Dube

Laboratory and Field Demonstration of the
Control of Ettringite Swelling

Barry Scheetz

Crushed Aggregates from Class C Fly Ash

Anil Misra

Varra Coal Ash Burial Project

Joby Adams

Pilot Testing of Fly Ash-Derived Sorbents for
Mercury Control in Coal-Fired Flue Gas

James Butz

High Performance Masonry Units from 100%
Fly Ash: Synergistic Approach

Hwai-Chung Wu

C a l e n d a r

of Energy-National Energy Technology Laboratory (DOE-NETL). Thirteen proposals have been selected for funding in 2001 (five Eastern Region; five Midwestern Region; and three Western Region) and are listed below:

| Submitting Organization | State | CBRC \$\$ |
|------------------------------------|-------|-----------|
| MD Dept. of Natural Resources | MD | \$50,000 |
| Ish Inc. | CA | \$42,500 |
| GAI Consultants, Inc. | PA | \$45,500 |
| Energy Industries of Ohio | OH | \$42,100 |
| Tennessee Technological University | TN | \$49,476 |
| Louisiana State University | LA | \$81,694 |
| Sunflower Electric Power Corp. | KS | \$49,575 |
| West Virginia University | WV | \$97,791 |
| Pennsylvania State University | PA | \$40,667 |
| University of Missouri | MO | \$37,751 |
| CGRS Inc. | CO | \$45,761 |
| ADA Technologies, Inc. | CO | \$87,819 |
| Wayne State University | MI | \$66,921 |

January 22-26, 2001

"Greening the Globe with CCP's," 14th International Symposium on Management and Use of Coal Combustion Products (CCP's). San Antonio, TX. Sponsored by the American Coal Ash Association and ACAA Educational Foundation. For more information contact: ACAA, 6940 South Kings Highway, Suite 207, Alexandria, VA 22310-3344; phone: 703-317-2400
email: emarshall@acaa-usa.org
<http://www.ACAA-USA.org>

Symposium Preview (from their flyer):

"ACAA and the ACAA Educational Foundation will welcome more than 400 participants from 30 countries to hear about the work of some 100 authors of published papers. Their success in developing technically sound, commercially competitive and environmentally safe applications of CCPs is reflected in the theme of the 2001 symposium, "Greening the Globe with CCPs."

Several CBRC participants will be at the conference, including CBRC Program Manager Scott Renninger, Consortium Manager Tamara Vandivort, Western Regional Director Debra Pflughoeft-Hassett, Western Region Chair Dave Goss, and members of the National Steering Committee, including Sam Tyson and Bill Aljoe.

CCBs (e.g., arsenic, cadmium, lead, and mercury) are all cations and can be expected to be adsorbed much more strongly than boron. Thus, results reported for boron probably represent a worse case scenario as far as potential for any trace elements being transported through groundwater supplies.

In their study, the CBRC researchers have characterized 11 soil and rock samples. Previous research (Goldberg and Glaubig, 1986) determined that the capacity for most soils to adsorb boron was a function of pH: for pH values much below 5, the ability to adsorb boron is minimal, whereas at a pH of around 10, the value is maximum. The average pH of the samples the CBRC researchers tested was 7.27, slightly below the maximum of the boron-pH adsorption range. Since CCBs in the Midwest are most frequently alkaline, their placement in contact with groundwater and soil in areas such as mine sites might increase the likelihood that soils would adsorb boron by moving the soil pH toward the alkaline side, where adsorption is more likely to occur.

Paul et al found that when boron is transported by groundwater, it can be expected to move on average at the same speed as the groundwater, but dispersion can cause some of the boron to move slower or faster. When adsorption is present, some of the boron is captured or adsorbed onto active sites on the soil or rock. Since adsorption is a reversible process, individual boron ions may

Assumptions that boron can move through groundwater without interaction with the aquifer mass and then suddenly become active and begin adsorbing onto soils when used in irrigation contradict logic and actual test results.

exchange off or onto sites, allowing boron to still move forward but at greatly delayed rates of travel and with reduced amounts of boron in the water. The amount by which the rate of boron travel is reduced is called its *retardation factor*, and the area and extent of boron adsorption over time is called its *plume*. A retardation factor of 1 means no adsorption or retardation, while a retardation factor of 4 would mean that the boron would advance at only one-fourth the rate of groundwater movement.

Conclusions

The CBRC researchers have concluded that conventional modeling and assessment tools for appraising the risk of boron contamination from CCBs appears to be exaggerated.

Assumptions that shake tests on fresh CCBs will indicate long-term leachate concentrations are contrary to fact. When placed in containment transport models, these errors result in both greater extent of contamination plumes and distinct overprediction of the concentrations likely to occur in the field. Assumptions that boron can move through groundwater without interaction with the aquifer mass and then suddenly become active and begin adsorbing onto soils when used in irrigation contradict logic and actual test results. When placed into computer models, failure to acknowledge adsorption results in overprediction of the size of the resulting plumes. The models used in this study are still likely to overpredict the extent of boron plumes because they

1. fail to consider the lesser hydraulic conductivity of fine CCBs,
2. used boron concentration decay curves that were slower than field observations, and
3. considered retardation impacts only, without regard to the amount of boron that may be removed from the water supply at any point in time.

For more information on CBRC project # ECM-04, *Boron Transport from Coal Combustion Product Utilization and Disposal Sites*, contact the principal investigator Dr. Bradley Paul at Southern Illinois University-Carbondale, 618/453-7923; paul_b@engr.siu.edu.

Michael Murphy Elected to CBRC Midwestern Regional Chair

AT THE NOVEMBER 2, 2000 NATIONAL STEERING COMMITTEE meeting in Denver, Colorado, Michael Murphy, Chief of the Illinois Department of Commerce & Community Affairs (DCCA) Office of Coal Development & Marketing was nominated and elected Chair of the Midwestern Region. Murphy replaces Wayne Bahr who retired in July.

Mike Murphy is a native of Springfield who has spent his career in a wide variety of news, media relations, and marketing positions. A graduate of the University of Michigan-Ann Arbor, Murphy worked for 19 years as a newspaper reporter and columnist, capturing several regional and national awards for writing and reporting. He covered agriculture, business, and politics for newspapers in Champaign and Springfield, Ill.

Murphy, 50, began his government career in 1990 as press secretary for then-Illinois Lieutenant Governor George H. Ryan. He was chief spokesman for Ryan's 1990 campaign for secretary of state. Murphy served four years as press secretary and four years as communications director in the Illinois Secretary of State's office.

After Ryan was elected governor, Murphy joined the Department of Agriculture in February 1999 as head of a division that oversaw media relations, horse racing, county fairs, the Illinois State Fair, DuQuoin State Fair, and other special events on the grounds of the two fairs.



Murphy joined Director Pam McDonough's executive staff at DCCA on January 1, 2000, as head of an office that oversees Illinois' \$20 million-a-year program that supports the state's critical coal development and coal marketing efforts.

Married and the father of two teenage daughters, Murphy is the author of *Building on the Legacy*, a book about Springfield and Sangamon County, and has written numerous articles on business and sports for regional and national magazines. He has served on the boards of several community organizations and has coached youth sports, on and off, for 20 years.

Beneficial Use of Recycled Materials in Transportation Applications

*Washington, DC
November 13-15, 2000*

This 2½-day event will be the first international conference hosted in the United States that exclusively addresses the use of recycled materials generated from transportation, industrial, municipal, and mining processes in transportation applications. It will bring together experts from North America, South America, Europe, and Asia to discuss, in both panel and technical sessions, relevant research, technical management, and institutional issues associated with the use of these byproduct materials. The conference is intended for researchers, material generators, processors, end users, equipment suppliers, regulatory officials, engineers, recyclers, and technical consultants involved in the management of recycled materials that have potential for use as substitute construction materials. More info at

www.rmrc.unh.edu/2001Conf/overview.asp

Sponsored by The Recycled Materials Resource Center in partnership with the Federal Highway Administration

CHECK THE CBRC WEBSITE
at:

<http://cbrc.nrcce.wvu.edu>
for abstracts on recently funded
CBRC projects. New CBRC

projects (listed on pages 4-5)
expand the combustion
byproducts recycling research
program into five new states:
Maryland, Tennessee, Louisiana,

Kansas, and Missouri. Keep
checking our website, too, for
news on the CBRC program,
upcoming conferences, and re-
search results of CBRC projects.

Happy New Year from the CBRC!

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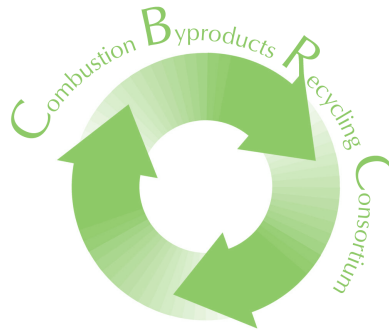
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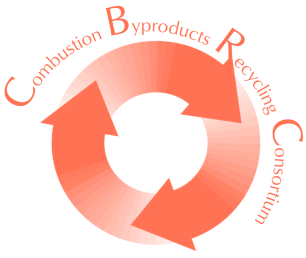
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Summer 2000

COMBUSTION BYPRODUCTS RECYCLING CONSORTIUM

Ashlines

To promote and support the commercially viable and environmentally sound recycling of coal combustion byproducts for productive uses through scientific research, development, and field testing.

a program of the National
Mine Land Reclamation
Center at West Virginia
University www.nrcce.wvu.edu/nmlrc, in
cooperation with the U.S.
Department of Energy -
National Energy
Technology Laboratory
www.netl.doe.gov

Fly Ash, Pigs & Tomatoes

IS THAT A KIND OF SUMMER MEAL LIKE SPAM, CORN ON THE COB, AND TOMATOES? Not exactly, but CBRC researchers in Florida are putting tomatoes on the table and helping utilize fly ash in the process, while CBRC researchers in Ohio are lining swine manure-holding ponds with flue gas desulfurization byproducts.

Fly Ash-Grown Tomatoes

In Homestead, Florida, CBRC researchers Yuncong Li, Peter Stofella, Jiangiang Zhao, Herbert Bryan, and Zhenli He are mixing Class F fly ash (referred to herein as Class F) with yard waste and sewage sludge (referred to herein as 'biosolids') and growing tomatoes. The objective of their project is to evaluate the effects

of this mixture on the physical and chemical properties of soil and on the growth of vegetables grown in typical Florida soils.

Class F as a soil amendment for agricultural purposes is a potentially large market. Class F can improve soil texture, modify soil pH, and supply essential plant nutrients for crop production. Class F alone, though, is a poor source of macronutrients (nitrogen, phosphorous, and potassium.) Yard waste, on the other hand, contains enormous amounts of macronutrients.

Composted yard waste can improve soil structure and fertility, biologically control weeds and soil-

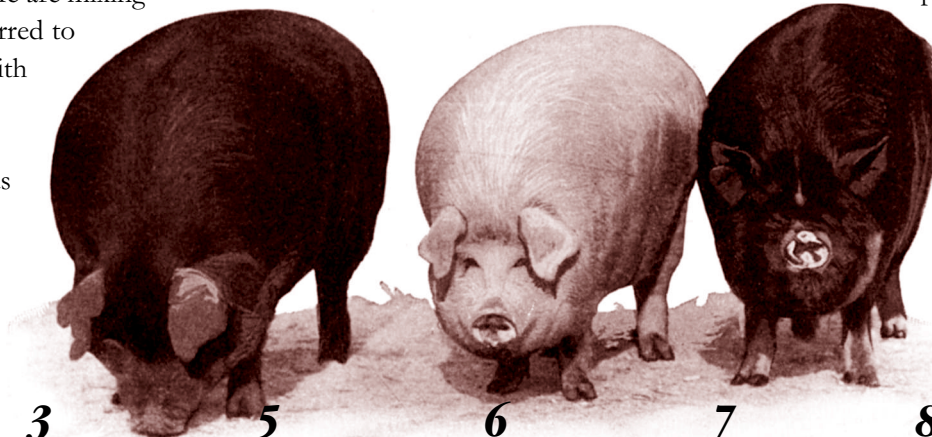
borne pathogens, and increase water-holding capacity and soil organic matter. Soil microbial activity is increased by introducing biosolids to the Class F-yard waste mix.

Most Florida soils have low nutrient-holding and low exchangeable cation capacities, and frequent applications of fertilizer are necessary to supply nutrients to crops. By adding a compost of Class F, yard waste, and biosolids, soil fertilization with commercial chemicals—which is costly and labor intensive—could be reduced.

Class F contains over 40 elements and most of the trace elements that are essential for plant growth. The

application of fly ash as a soil nutrient for plant growth has been studied before with corn, beans, and rice and has been shown to increase

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VISIT THE CBRC WEBSITE AT [HTTP://CBRC.NRCCE.WVU.EDU](http://CBRC.NRCCE.WVU.EDU)

Tomatoes (cont. from page 1)

potassium, calcium, magnesium, manganese, copper, iron, and zinc in the soil. Fly ash was also demonstrated to increase the content of boron in alfalfa and in corn, and molybdenum in alfalfa.

Other studies have demonstrated that a mixture of fly ash and biosolids significantly increases the nutrient uptake and yield of tall wheat grass (*Agropyron elongatum*) and that it improved the yields of collard and mustard greens. Other studies have demonstrated that soil microbial activity was increased by mixing soil, fly ash and biosolids.

The CBRC Florida researchers have found the use of Class F as a soil amendment to be especially attractive because:

1. poor soil is a major limitation to crop yield in Florida;
 2. two of the top 73 major coal-powered utilities (Florida Power Corporation and Tampa Electric Company) in the US are located in Florida and producing tons of Class F daily, which they need to dispose of;
 3. a composted mixture of Class F and biosolids was available from Florida-N-Viro in Sarasota; and,
 4. Florida recently mandated that yard waste cannot be landfilled, and the city of St. Petersburg was eager to find disposal applications for the urban yard debris it had collected and composted.
- Why not mix all four compo-



Sample of the first harvest of tomatoes grown by CBRC researchers Yuncong Li et al, CBRC Project No. ECE11. The researchers are using a mixture of fly ash, yard waste, and municipal biosolids as a soil amendment to improve Florida's crop yield.

nents: soil, fly ash, yard waste compost, and biosolids? And why not grow tomatoes, a big Florida crop with a yield that can be readily weighed and sampled?

It made sense to Yuncong Li and his colleagues that a soil amendment of Class F, yard waste compost, and biosolids mix might be just what Florida needed. "There are approximately 10 million acres of farmland in Florida," says Li, "If the application rate were 10 tons of fly ash/yard waste compost per acre in a 50-50 mix, a total of 50 million tons of each of these waste materials could be utilized every year as a soil enhancement."

"Now that's what we call recycling," said Courtney Black, CBRC project manager in Morgantown, West Virginia. "We are expecting this study to generate the management practices for using Class F, yard waste, and biosolids compost as soil amendments in Florida. Consequently, it could lead to a large-volume use of Class F and yard waste in agriculture, not only in Florida, but elsewhere where these

practices can be put in place, or 'tweaked' to fit other growing conditions and other crops in other parts of the country and throughout the world."

Researcher Bryan worked on a pilot research project (1995-97) at the Tropical Research and Education Center in Homestead, Florida, to compost municipal solid waste. The project established a compost facility and developed criteria for composting organic waste. The CBRC project is using this facility to mix together the Class F and biosolids compost from Sarasota and the composted yard debris from St. Petersburg. The new compost composition is a 1:1:1 ratio of fly ash, biosolids, and yard debris.

The CBRC researchers have been monitoring, testing, and sampling the soil and tomatoes, and monitoring the subsurface water quality. They harvested tomatoes on May 1, 11, and 30, 2000.

Findings

The researchers found that the

(continued on page 5)

Effects of Ammonia Adsorption from NO_x Reduction Technologies on Fly Ash

TEN YEARS AGO, THE US ENVIRONMENTAL PROTECTION AGENCY'S CLEAN AIR ACT AMENDMENTS MANDATED REDUCTIONS IN EMISSIONS OF NO_x from coal-fired electric utility boilers. Hence, a flurry ensued in the fitting and retrofitting of utility boilers with technologies that reduce NO_x emissions from coal-fired electric utility boilers. Today, two of the most prominent commercially available technologies for this purpose are selective catalytic reduction (SCR) and selective noncatalytic reduction (SNCR) systems or a combination of these two, all of which use a reagent—usually ammonia—to react with the NO_x and reform it into molecular nitrogen and water.

Fine and dandy, BUT . . . unreacted ammonia is carried with the flue gases through the boiler's duct system, with a large part deposited as ammonium bisulfate in the fly ash collected by the electrostatic precipitator (ESP). As much as 70 to 80 percent of the unreacted ammonia is retained in the fly ash. These traces of ammonia are adsorbed on the fly ash, with potentially undesirable effects on air quality, water quality, ash disposal, and ash sales.

Trace amounts of ammonia left after burning with SCRs may exceed stack limits for ammonia and/or particulates and Occupational Safety and Health Administration (OSHA) limits at ash facilities and/or at the property line. Trace amounts of ammonia may also affect ESP performance and the operation of loss-on-

ignition (LOI) monitors and continuous emissions monitoring (CEM) equipment. Plus, ammonia may affect the efficiency of flue gas desulfurization (FGD) equipment. An increase in nitrate/nitrite concentrations (precipitated by the introduction of ammonia) in ash pond effluents could violate the limits set by the National Pollutant Discharge Elimination System (NPDES) program. These limits are particularly troubling for ash facilities that are located on water bodies that have already been listed as impaired due to excessive nitrogen (nutrient) loadings.

Ammonia concentrations in ash ponds could also exceed levels that would violate water quality standards, resulting in the imposition of effluent limits. In this case, an ammonia fix to meet the U.S. Environmental Protection Agency's (EPA's) Clean Air Act Standards degrades the water quality so that it will not meet the water effluent standards set by the same agency. And, the odor of ammonia, even when it is not harmful to health, can adversely affect the operation of an ash disposal facility. Excessive ammonia, or even the presence of an ammonia odor in fly ash, could severely impact the ability to utilize and sell it for any purpose, no matter how good the end result or end product.

Enter CBRC researchers. In their project no. ECE06, "Effects of Ammonia Adsorption on Fly Ash due to Installation of SCR Technology," Gary Brendel and Joseph Bonetti of GAI Consultants in

Excessive ammonia, or even the presence of an ammonia odor in fly ash could severely affect the ability to utilize and sell it for any purpose, no matter how good the end result or end product.

Monroeville, Pennsylvania; Robert Rathbone at the Center for Applied Energy Research in Lexington, Kentucky; and Robert N. Frey, Jr. with Air/Compliance Consultants in Pittsburgh, Pennsylvania are characterizing the ammonia content of fly ash from two typical power stations in the eastern U.S. Their project includes an investigation of ammonia release, including leaching and thermal studies, and an evaluation of the potential impacts on plant equipment, air quality, water quality (surface and ground), ash disposal operations, and ash marketing, using fly ash produced at power plants that currently operate SCR or SNCR systems for NO_x reduction.

As a control, they are also studying fly ash from three power plants that burn similar coal but do not inject

(continued on page 4)

Ammonia on Fly Ash (cont. from page 3)

ammonia for NO_x reduction. All of the plants currently burn low-sulfur central Appalachian coal and produce low-calcium oxide class F fly ash.

To date, the researchers have reviewed available information and data from published and unpublished sources; conducted extensive sampling and data analysis of the fly ash samples they collected; and examined SCR equipment for the effects of ammonia, focusing on air preheaters, SCR catalysts, CEM systems, ammonia storage systems, particulate and acid gas control systems, ash air quality, and the beneficial uses of the ash produced. Their testing has included analysis of ash properties for the power plants with and without SCR systems, and ammonia release from fly ash, conducted in both closed-vessel and open-vessel testing. Some of their findings and predictions are listed below.

From closed-vessel and open-vessel testing, the researchers concluded that

- most of the ammonia present on fly ash is highly water soluble and is completely dissolved into solution within several hours.
- pH exerts the dominant influence on ammonia speciation in solutions of fly ash and water.
- SCR/SNCR fly ash that produces a high pH in aqueous solution will also produce ammonia odors when wetted, unless the NH₃ is present on the ash in very low concentrations or is diluted. Ammonia odors from low-pH fly ash will be negligible.
- NH₄⁺ ion is stable in fly ash/water mixtures at low pH and is

The potential for ammonia release from ponds, landfills, piles, and impoundments containing fly ash appears to be driven by the pH effect of ammonia in aqueous solution.

not out-gassed. However, conversion of at least a portion of it to nitrate is likely in the natural environment because of the presence of nitrifying bacteria.

Ash Handling

- No operating facility or vendor contacted identified any reported changes to the existing ash handling system after the addition of SCR. Several facilities evaluated the potential for dissolved ammonia to impact surface and groundwater and possibly switching from a wet-based ash-handling system to a dry one. Sites have generally opted to maintain unit operations in their current configuration. Sites currently selling ash appear to have not noticed a significant impact on ash quality or beneficial use potential.

Ambient Air Impact

- The potential for ammonia release from ponds, landfills, piles, and impoundments containing fly ash appears to be driven by the pH effect of ammonia in

aqueous solution. In general, if the pH is below 7-8, no odors or significant releases are observed, and as the pH increases above 9-10, all of the ammonia present in solution is released with the potential for significant near-field odors. Process operations, ash storage, and disposal appear to have minimal impact on ambient air quality, however, for the sources operating with low pH ash management systems.

Surface Water

- For both study sites, the addition of SCR units is predicted to increase ammonia as N concentrations but remain well below the acceptable surface water quality standards for ammonia. Ammonia as N loading, however, is predicted to increase to a rate that will exceed the current loading standard of 6 to 11 pounds, and nitrate-nitrogen concentrations are predicted to increase with the addition of SCR technology but not to exceed the existing limits.

Ground Water

- Exceedences of the US EPA's current nitrate as N drinking water standard of 10 mg/L are not anticipated at one site but are predicted to exceed these standards at the other site.

For more information on the researchers' findings, contact the principal investigator, Gary Brendel at 412/856-6400. Check the CBRC website at <http://cbrc.nrcce.wvu.edu> for more information on the CBRC and its projects.



Tomatoes (continued from page 2)

application of Class F-yard waste-biosolids compost

- significantly increased total marketable tomato yield by 35 to 71%.
- at the rate of 50 mt/ha is probably the optimal amount for tomato production in south Florida.
- increased early fruit yield more than 50% with high application rates (50 and 75 mt/ha). (Early fruits often have high marker values.)
- increased the amount of large fruits compared to control plots.

- showed increased soil water-holding capacity.
- increased soil temperatures.
- showed no indication of leaching of trace metals into groundwater. (Preliminary results show less nitrate and phosphate leaching in Class F-biosolids-yard waste compost-amended plots compared to traditional fertilizer-treated plots.)

The researchers expect to find that nutrient concentrations will be higher in soil and tissue samples from fly ash-biosolids-yard waste compost plots than from the control plots, but at the time of this printing, they were not

finished collecting and analyzing these data. They are also in the process of quantifying the amount of nutrients and trace metals released from fly ash-biosolids-yard waste compost during the year.

For more information on project no. ECE11, contact the principal investigators, Yuncong Li or Peter Stoffella, at 561/468-3922, or send email to yunli@gnv.ifas.ufl.edu or stoffella@gnv.ifas.ufl.edu. Check the CBRC website at <http://cbrc.nrcce.wvu.edu> for more information.



CBRC Midwestern Position Open



WAYNE BAHR, CHAIR OF THE CBRC MIDWESTERN REGIONAL ADVISORS/ REVIEWERS has retired from the Illinois Department of Commerce and Community Affairs Office of Coal Development and Marketing. Bahr has also chosen to step down from his position of Chair of the Midwestern Regional Advisors/Reviewers, effective July 31, 2000. Bahr has been an active member of the Consortium and will be missed. Arrangements are currently being made to find a replacement for this position.

Would you like to be on the CBRC mailing list?

If so, complete this form and mail it to: **CBRC Mailing List, National Mine Land Reclamation Center, West Virginia University, P.O. Box 6064, Morgantown, WV 26506-6064** OR fax the completed form to **304/293-7822** OR send email to **cbrc@nrcce.wvu.edu**

Name: _____

Mailing Address: _____

email: _____ fax: _____ phone: _____

☐ I would like to receive a free copy of *Asblines*, the CBRC newsletter.
I prefer to receive ☐ electronic OR ☐ hard copies of future CBRC newsletters

CBRC CONTACTS

Program Management

Scott Renninger, CBRC Program Manager
U.S. Department of Energy -
National Energy Technology Laboratory
304/285-4790
scott.renninger@netl.doe.gov

National Center

Paul Ziemkiewicz, Director
Tamara Vandivort, Consortium Manager
CBRC National Center located at the National
Mine Land Reclamation Center
West Virginia University
pziemkie@wvu.edu or tvandivo@wvu.edu
304/293-2867

Regional Centers

Debra Pflugboeft-Hassett, Director
Western Regional Center located at the
University of North Dakota
dphassett@undeerc.org
701/777-5261

Y. Paul Chugh, Director
Midwestern Regional Center located at Southern
Illinois University at Carbondale
chugh@engr.siu.edu
618/536-6637

D. Courtney Black, Director
Eastern Regional Center
located at West Virginia University
dblack@wvu.edu
304/293-2867, ext. 5447

National Steering Committee

Robert Dolence, Chair
Interstate Mining Compact Commission
dolence.robert@dep.state.pa.us

Chairs of Regional Advisors/ Reviewers

David Goss, Chair
Western Regional Advisors/Reviewers
Public Service Company of Colorado
dgoss@psco.com
303/571-7075

Position Open, Chair
Midwestern Regional Advisors/Reviewers

Jackie Bird, Chair
Eastern Regional Advisors/Reviewers
Ohio Coal Development Office
jbird@odod.state.oh.us
614/466-3465

CBRC Researchers at The OSU Line Swine Manure Containment Facilities with Scrubber Sludge

IN OHIO, CBRC RESEARCHERS AT THE OHIO STATE UNIVERSITY (OSU) are evaluating the long-term durability and effectiveness of using scrubber sludge (stabilized FGD material) as a raw material in the construction of low permeability liners for animal manure holding ponds. The current research efforts, sponsored by the Combustion Byproducts Recycling Consortium, Ohio Department of Development, and several other co-sponsors, have focused on the monitoring of a full-scale FGD-lined manure containment facility.

Laboratory tests conducted on scrubber sludge have shown that many of these materials function effectively as a hydraulic barrier (to the flow of liquids) due to their low permeability. Research conducted at OSU for the past decade has shown that lime-enriched scrubber sludge has laboratory permeability values comparable to that of natural clays.

The actual permeability of a field-constructed liner, however, is a function of the construction process. To evaluate the effect of construction processes on the behavior of an FGD liner, a full-scale FGD-lined pond facility (one million gallons capacity) was designed and built in the summer of 1997 at The Ohio Agricultural Research and Development Center

near South Charleston, Clark County, Ohio. The facility was constructed to answer two critical questions about the behavior of a field-constructed FGD liner: (a) what is the actual permeability of the liner? and (b) what is the quality of the leachate from the liner?

Water was held in the facility for the first year. At the end of the first year, some of the water was

replaced with swine manure. Since December of 1997, swine manure has continued to be added and removed from the pond depending on manure storage versus field-spreading needs of the swine research center. Monitoring of the facility consists of measuring the actual permeability of the field-compacted liner as well as water quality measurements for the liquid in the pond and leachate coming out of the liner.

Monitoring of the facility for over three years has shown that the FGD material liner has low permeability (permeability coefficient in the range of 10^{-7} cm/sec), and the quality of leachate flowing through the FGD liner generally meets the National Primary Drinking Water Regulations. The leachate from the liner is relatively small, better than the manure contained within the pond, and is non-toxic.

The use of scrubber sludge for lining manure storage ponds offers

If successful, this research project could allow some coal combustion by-products to enter a market that is now dominated by expensive clay and synthetic liners.

C a l e n d a r

opportunities for economic development in the Appalachian region because many areas of the region

have little or no water-holding nor manure-holding capacity. The use of scrubber sludge in the construction of livestock water- and manure-holding ponds can be instrumental in the establishment of animal prep facilities. Preliminary economic analysis of the cost data for constructing manure storage ponds has shown that scrubber sludge-lined facilities offer savings of about \$2-\$5 per square foot over clay or geomembranes. If successful, this research project could allow some coal combustion by-



Sunset over the OSU swine manure storage demonstration facility lined with scrubber sludge (project no. ECE24).

products to enter a market that is now dominated by expensive clay and synthetic liners.

The OSU research team consists of William E. Wolfe, Tarunjit S. Butalia, Hal Walker, and Earl Whitlatch. More information on the project can be obtained by contacting Dr. Butalia at (614) 688-3408 or by e-mailing butalia.1@osu.edu. Check the CBRC website at <http://cbrc.nrcce.wvu.edu> for more information on project no. ECE24.

CBRC Project Papers to be Presented at Upcoming Conferences

This September, the following two CBRC project papers will be presented at the Seventeenth Annual International Pittsburgh Coal Conference:

“A Feasibility Study for the Beneficial Use of Coal Ash as Fill Material in Saturated Conditions,” by Joby Adams, CGRS, Inc. and James Warner, Colorado State University.

“Effects of Ammonia from NO_x Reduction Technologies on Fly Ash” by Gary Brendel, GAI Consultants, Inc., Robert Rathbone, University of Kentucky, and Robert N. Frey, Jr., Air/Compliance Consultants, Inc.

Both papers are being presented at the Coal Combustion Byproduct Utilization session on Thursday, September 14, 2000.

For more information on conferences, see the sidebar at right, and check the CBRC website <http://cbrc.nrcce.wvu.edu/calendar> regularly for changes and additions.

September 11 - 15, 2000

Seventeenth Annual International Pittsburgh Coal Conference, Radisson Hotel Green Tree, Pittsburgh, PA. Hosted by University of Pittsburgh School of Engineering, Engineering Center for Environment & Energy. The theme of this year's conference is “Coal-Energy and the Environment.” For an agenda or to register for this conference, contact: Marguerite Link, University of Pittsburgh, 1130 Benedum Hall, Pittsburgh, PA 15261; 412/624-7440 (phone); 413/624-1480 (fax); pcc@engrng.pitt.edu

November 14 - 15, 2000

Western Region Ash Group and the Western Region CBRC Joint Meeting, Holiday Inn - Denver Southeast, Denver, CO. The meeting will include progress reports of current Western Region CBRC projects. For more information on this meeting, contact Dave Goss at 303/571-7075; dgoss@psco.com

January 22-26, 2001

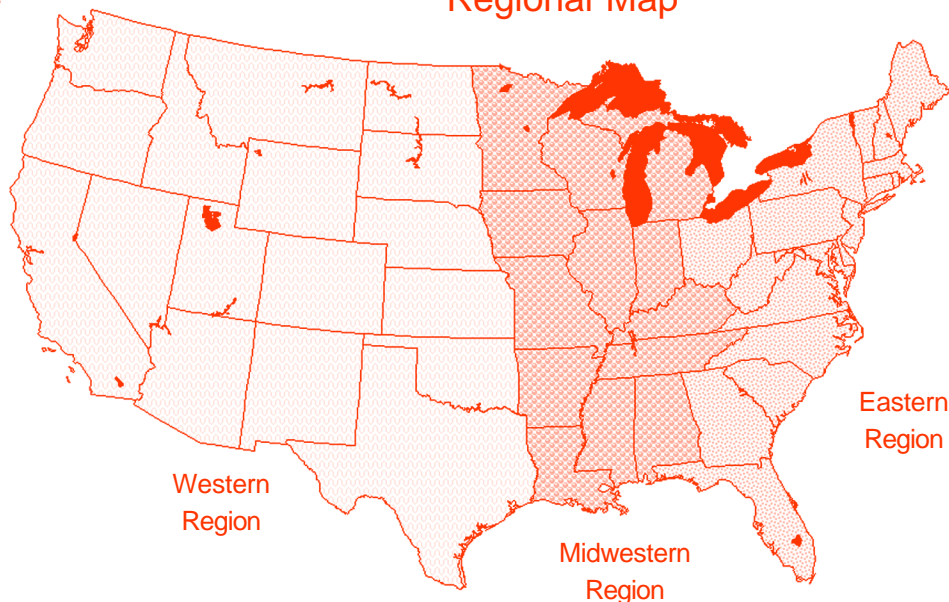
"Greening the Globe with CCP's," 14th International Symposium on Management and Use of Coal Combustion Products (CCP's). San Antonio, TX.

Sponsored by the American Coal Ash Association and ACAA Educational Foundation. For more information contact: ACAA, 6940 South Kings Highway, Suite 207, Alexandria, VA 22310-3344; 703/317-2400; info@acaa-usa.org

RFP 2000 Big Success!

THE REQUEST FOR PROPOSALS ISSUED BY THE COMBUSTION BYPRODUCTS RECYCLING CONSORTIUM (CBRC) in May 2000 was very successful. Proposals are currently being evaluated by reviewers in each region. Reviewers are members of the CBRC Regional Advisors/Reviewers and are typically from industry, state regulatory agencies, and academia. Each proposal is evaluated by three reviewers designated by the National and Regional Centers. In November 2000, the CBRC National Steering Committee (NSC) will meet to determine which projects will be funded. The NSC will base its determinations on the evaluation results submitted by the reviewers. The Department of Energy - National Energy Technology Laboratory (DOE-NETL) will be providing not less than \$1 million to fund the highest scored proposals. For more information on the proposal

Combustion Byproducts Recycling Consortium Regional Map



process, log onto the CBRC web site at <http://cbrc.nrcce.wvu.edu> or call 304/293-2867. Following is the timeline for the proposal process.

July 31, 2000—Proposals due to the CBRC National Center.

August 4, 2000—Proposals mailed to reviewers for evaluation.

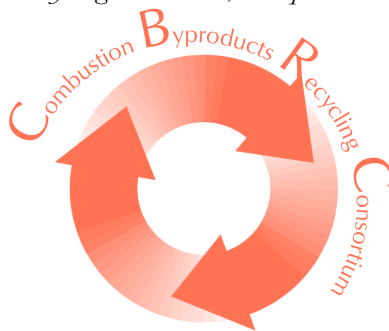
November 2000—CBRC National Steering Committee makes funding decisions.

November 30, 2000—Applicants notified of the results.

February 2001—Recipients receive funding.

Asblines is published by the Combustion Byproducts Recycling Consortium, headquartered at West Virginia University in Morgantown, WV.

CBRC Headquarters
WVU Research Corporation
WVU NRCCE
P.O. Box 6064
Morgantown, WV 26506-6064



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COMBUSTION BYPRODUCTS RECYCLING CONSORTIUM

Ashlines

To promote and support the commercially viable and environmentally sound recycling of coal combustion byproducts for productive uses through scientific research, development, and field testing.

a program of the
National Mine Land
Reclamation Center in
cooperation with the
U.S. Department of
Energy - National
Energy Technology
Laboratory

Vision 2000: Welcome to the CBRC

Consortium Gets New Name

AT THE MARCH 2, 2000 NATIONAL STEERING COMMITTEE MEETING, the Committee voted to change the name of the Emissions Control By-products Consortium (ECBC). Since the mission of the Consortium is to promote and support the commercially viable and environmentally sound recycling of coal combustion byproducts for productive uses through scientific research, development, and field testing, the Committee felt that a name more in line with its mission was needed. Therefore, the former name, *Emissions Control By-products Consortium* has been

replaced with *Combustion Byproducts Recycling Consortium*.

Welcome to the CBRC

The Combustion Byproducts Recycling Consortium (CBRC) began in the fall of 1998 as a five-year program. The CBRC's mission is to promote and support the commercially viable and environmentally sound recycling of coal combustion byproducts for productive uses through scientific research, development, and field testing. The CBRC is

funded by the U.S. Department of Energy - National Energy Technology Laboratory and is managed by the National Mine Land Reclamation Center at West Virginia University in Morgantown, West Virginia. The first request for proposals (RFP 1999) generated 34 proposals; 18 of which

(continued on page 2)

Who's who in the CBRC: front row, left to right: William Aljoe, Samuel Tyson, David Meadows, Robert Dolence, Scott Renninger, Kimberly Vories. Back row, left to right: Debra Pflughoeft-Hassett, Wayne Bahr, Scott Roberts, Jackie Bird, David Goss, D. Courtney Black, Paul Ziemkiewicz



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VISIT THE CBRC WEBSITE AT CBRC.NRCCE.WVU.EDU



Robert Dolence, CBRC National Steering Committee Chair, 2000-2001.

Robert Dolence is deputy secretary for Mineral Resources Management at the Commonwealth of Pennsylvania's Department of Environmental Protection. This position is a governor's appointment and reports to the Cabinet Secretary. The responsibilities are statewide and include five bureaus with a total of 580 employees, covering program areas of oil and gas management, coal mining and industrial mineral mining and reclamation, abandoned mine reclamation, and deep mine safety.

Previously, Dolence worked for the U.S. Department of Energy at the then Pittsburgh Energy Technology Center (PETC). Prior to joining DOE, Dolence was employed by the U.S. Department of the Interior's Office of Surface Mining (OSM). Dolence has also worked in various capacities in industry from consulting work through production and reclamation as a mining engineer.

The CBRC is pleased to welcome Bob Dolence as chair of the National Steering Committee.

Welcome (continued from page 1)

were funded in the range of \$18,765 to \$116,180 per project. The sum total of funding available for RFP 2000 will not be less than \$1 million and will be awarded by the U.S. Department of Energy—National Energy Technology Laboratory. RFP 2000 is expected for release May 1, 2000.

This is the first edition of CBRC's quarterly newsletter, *Asblines*. This issue contains additional information on the CBRC, RFP 2000, and current

projects. We hope that you find this information useful and informative. For more information on the CBRC, visit our web site at <http://cbrc.nrcce.wvu.edu>.



Tamara Vandivort, Consortium Manager; Paul Ziemkiewicz, Ph.D., Director; Scott Renninger, Program Manager

National Steering Committee Meets to Discuss Vision 2000

The National Steering Committee (NSC) for the Combustion Byproducts Recycling Consortium (CBRC) met March 2, 2000 in Pittsburgh, Pennsylvania to discuss the direction for the CBRC in the year 2000, the Consortium's second year. In the morning session, Paul Ziemkiewicz, Director of the CBRC, began the meeting with a welcome and introduction of all those present. Organizations represented at the meeting included the Office of Surface Mining, U.S. Department of Energy, Pennsylvania Department of Environmental Protection, Illinois Office of Coal Development & Marketing, Ohio Coal Development Office, Interstate Mining Compact Commission, U.S. Army Corps of Engineers, Public Service Company of Colorado, and the American Coal Ash Association.

Tamara Vandivort, consortium manager for the CBRC, gave a program status report. Vandivort reported that the second phase of funding arrived from DOE-NETL on February 29, 2000. Project support

from DOE contributions for this second phase totals \$819,978; non-federal contributions total \$972,214; for a grand total of \$1,792,192. This second phase supports ten CBRC projects. There are now a total of eighteen CBRC-funded projects.

Vandivort reported that researchers were contacted in January as to the status of their project funding.



CBRC Regional Advisors/Reviewers: David Goss, Chair, Western Region; Jackie Bird, Chair, Eastern Region; Wayne Bahr, Chair, Midwestern Region.

In February, the first draft of the request for proposals (RFPs) for the year 2000 was sent to all members of the NSC and to the regional directors for comment. Vandivort also discussed the content for *Asblines*, and the CBRC internet web site, which has been recently updated.

CBRC Structure

The CBRC is divided into three regions: Western, Midwestern, and Eastern. Project status reports for the three regions were given by the

(continued on page 5)

RFP 2000 Expected for Release May 1, 2000

THE CBRC'S PRIMARY GOAL IS TO DEVELOP AND DEMONSTRATE TECHNOLOGICAL SOLUTIONS related to the utilization of byproducts associated with coal combustion processes. It is hoped that by the year 2005, these technologies will lead to a doubling of the current rate of flue gas desulfurization byproduct use, a 10% increase in the overall national rate of byproduct use, and a 25% increase in the number of uses considered "allowable" under state regulations.

The fifty United States make up three specific CBRC regions. Each region has identified priorities that, if met, should increase the utilization of coal combustion byproducts (CCBs) within that region. Although many priorities are shared between regions, proposals will be evaluated separately by region in order to help that region meet its own priorities. The map below shows which states fall within these three CBRC regions.

Last year 18 awards were granted. It is anticipated that a similar number of awards will be granted to applicants in any of the fifty United States and its territories through this request for proposals. The sum total of funding available will not be less than \$1 million and will be awarded by the U.S. Department of Energy - National Energy Technology Laboratory. Requests for up to two years funding may be made,

and if awarded, funds will be made available yearly for up to two years depending upon satisfactory progress. All funds awarded are intended to support activities in the region within which the applicant's project falls and may include salaries, travel, equipment, materials, and services. Awarded funds may not include fees or profit.

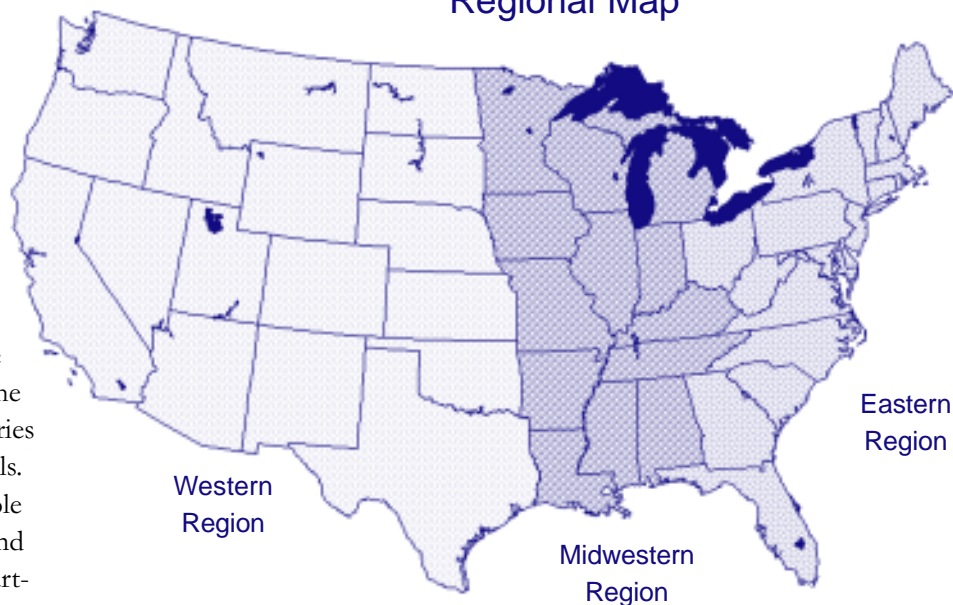
A minimum cost-share of 25% is required and the applicant must provide some portion of this percentage. The remainder may come from academic, industry, or other sources. The higher the percentage of cost-share provided, especially if from the

applicant, the more favorably the application will be considered.

The CBRC will be requesting proposals for research expected to be funded February, 2001. For more information on the RFP, please visit our web site at <http://cbrc.nrcce.wvu.edu> or call the National CBRC Center located at the National Mine Land Reclamation Center at West Virginia University 304/293-2867. If you wish to be placed on the mailing list for the RFP 2000 or for this newsletter, please call 304/293-2867, email cbrc@nrcce.wvu.edu, or complete and mail the form on page 5.



Combustion Byproducts Recycling Consortium Regional Map



CBRC Consortium Structure



National Center

Paul Ziemkiewicz, Director
Tamara Vandivort, Consortium Manager
CBRC National Center located at the
National Mine Land Reclamation Center
West Virginia University

Regional Centers

Debra Pflughoeft-Hassett, Director
Western Regional Center located at the
University of North Dakota

Y. Paul Chugh, Director
Midwestern Regional Center located at
Southern Illinois University at Carbondale

D. Courtney Black, Director
Eastern Regional Center
located at West Virginia University

Chairs of Regional Advisors/ Reviewers

David Goss, Chair
Western Regional Advisors/ Reviewers
Public Service Company of Colorado

Wayne Bahr, Chair
Midwestern Regional Advisors/ Reviewers
Illinois Department of Commerce &
Community Affairs

Jackie Bird, Chair
Eastern Regional Advisors/ Reviewers
Ohio Coal Development Office



National Steering Committee Members

Robert Dolence, NSC Chair, *Pennsylvania Department of Environmental Protection*
William Aljoe, U.S. DOE - *National Energy Technology Laboratory*
Greg Conrad, *Interstate Mining Compact Commission*
Taylor Eighmy, *University of New Hampshire Recycled Materials Resource Center*
Fred Fox, *Office of Surface Mining*
David Meadows, *U.S. Army Corp of Engineers*
Scott Renninger, U.S. DOE - *National Energy Technology Laboratory*
James Roewer, *Edison Electric Institute*
Dennis Ruddy, *U.S. EPA Office of Solid Waste*
Samuel Tyson, *American Coal Ash Association*
Kimery Vories, *Office of Surface Mining*
Regional Advisors/ Reviewers Chairs: David Goss, Wayne Bahr, and Jackie Bird

How the Consortium Structure Works



THERE ARE THREE MAJOR ELEMENTS OF THE CBRC: the National Steering Committee (NSC), regional advisors/reviewers for each of the three regions, and program management.

The National Steering Committee is the key element of the CBRC. All decisions on how the CBRC conducts business are made by consenses of the NSC. Critical roles and responsibilities of the NSC include approving overall CBRC structure and timetables; selecting, from its membership, regional advisors/reviewers, and chairpersons; authorizing RFPs; and making project funding decisions.

Regional advisors/reviewers identify research priorities for the region for use in the RFP; review, score, and rank proposals received in accordance with research priorities; review technical progress on projects that are funded; and report important results to the NSC.

Each regional center is located at a university. Directors of the regional centers manage the CBRC projects for their particular region and facilitate communications with the National Center consortium manager, regional chair, and regional advisors/reviewers.

The National Mine Land Reclamation Center (NMLRC) at West Virginia University serves as the national center for CBRC. The national center management includes soliciting members to serve on the NSC; developing the RFP, the RFP proposal evaluation procedures, and the RFP dissemination strategies; and awarding and administering research contracts assuring that contractors meet all performance, reporting, and budget requirements.

Oversight is provided by the U.S. Department of Energy - National Energy Technology Laboratory.

CBRC Structure (continued from page 2)

respective regional directors, Debra Pflughoeft-Hassett, Y. Paul Chugh, and D. Courtney Black. The regional directors discussed the objectives of the CBRC projects respective to their particular regions, anticipated research and development strategies, and what they foresee for their regions.

Scott Renninger, program manager with the Department of Energy-National Energy Technology Laboratory (DOE-NETL) presented the CBRC Vision for 2000. Renninger announced that DOE-NETL will be contributing at least \$1 million to the CBRC for RFP 2000, and would like to expand the CBRC program to include a minimum of two additional states per region with CBRC-funded projects from RFP 2000 proposals. Renninger's desire is to work toward expanding the program to at least one CBRC-funded project in every state. Renninger also emphasized the importance of disseminating project results through the CBRC newsletter, web site, and forums.

An election was held for the chair of the NSC. Robert Dolence was nominated and elected NSC chair and

will serve from March 2, 2000 to March 1, 2001. Dolence is deputy secretary of the Mineral Resources Management Department of Environmental Protection for the Commonwealth of Pennsylvania. He also represents the Interstate Mining Compact Commission. As NSC chair, Dolence will be responsible for coordinating the activities of the NSC and communicating NSC recommendations to the CBRC national center's director and to the DOE-NETL program manager.

Of utmost importance for discussion was the issuance of RFP 2000. Last year, 34 proposals were received, and 18 were awarded funds ranging from \$18,765 to \$116,180.

This year, as the CBRC becomes more widely publicized, even more proposals are expected. In anticipation of the greater number of proposals, the NSC is working to maximize the efficiency of both RFP dissemination and the proposal review process.

Other topics for discussion included opportunities for improvement in the CBRC program, roles and responsibilities of each position within the Consortium, revised proposal evaluation forms, and a proposed timeline. This meeting gave the NSC participants an opportunity to further refine strategies for making the CBRC a strong research program to beneficially recycle coal combustion byproducts.



Y. Paul Chugh, Ph.D., Director, Midwestern Regional Center; Debra Pflughoeft-Hassett, Ph.D., Director, Western Regional Center; D. Courtney Black, Director, Eastern Regional Center.



Would you like to be on the CBRC mailing list?

If so, complete this form and mail it to: **CBRC Mailing List, National Mine Land Reclamation Center, West Virginia University, P.O. Box 6064, Morgantown, WV 26506-6064** OR fax the completed form to **304/293-7822** OR send email to **cbrc@nrcce.wvu.edu**

Name: _____

Mailing Address: _____

email: _____ fax: _____ phone: _____

I would like to receive a free copy of ☐ CBRC newsletter ☐ RFP 2000

I prefer to receive ☐ electronic OR ☐ hard copies of future CBRC newsletters



C a l e n d a r

April 25, 2000

Spring Meeting

Western Region Ash Group (WRAG)

Holiday Inn-Denver Southeast
3200 South Parker Road
Aurora, CO

*For an agenda, registration form, and
directions contact:*

Mary Ratliff
623-581-1836 or
diulusdh@phoenix-cement.com

RFP 2000 Program Schedule

May 1, 2000

RFP 2000 Released

July 31, 2000

Proposal Application Deadline

Sept. 30, 2000

Proposal Reviews Completed

Oct. 31, 2000

Funding Decision Made

Nov. 15, 2000

Applicants Notified of Decision

Feb. 2001

Awards Distributed

1999 Research Area Priorities by Region

Note: It is currently anticipated that research area priorities by region will remain the same for RFP 2000. However, any modifications to these priorities will be included in the RFP 2000 and on the CBRC website: <http://cbrc.nrcce.wvu.edu>

Western

1. Develop information or processes to promote the increased use of coal combustion products (CCPs) to state regulators and government agencies in applications such as mine land reclamation, structural fills, and other more nontraditional uses.
2. Research the use of ash blends and potential applications of blended ashes.
3. Develop markets and uses for flue gas desulfurization (FGD) fly ash.
4. Develop information on or demonstrate uses of CCPs in mine land reclamation that address issues of air and water quality and the reduction of landfill space by such use.
5. Develop methods or technologies for making use of high-carbon fly ash.
6. Develop methods or technologies for increased use of bottom ash.

Midwestern

1. Develop beneficial large-volume applications of conventional CCPs and FGD byproducts (wet/dry scrubber byproducts, fluidized-bed combustion residues) in construction, building products, roads, agriculture, etc.
2. Develop beneficial large-volume use applications for CCPs with

high unburned carbon and/or contaminated with ammonia.

3. Identify impacts of changing air quality standards on CCPs and FGD byproducts.
4. Develop technical, environmental, and economic assessment tools for management of CCPs and FGD byproducts.
5. Develop efficient handling and transportation of CCPs and FGD byproducts, including dust control.

Eastern

- 1) Address the issues to CCPs quality and reuse from federally mandated requirements to reduce nitrogen oxide (NOx) emissions including ammonia carryover into ash from NOx-reduction technologies and increased unburned carbon in ash due to loss on ignition (LOI).
- 2) Develop unique utilization of all types of CCPs (fly ash, bottom ash, FGD sludge, etc.) in large volume applications (or R&D of issues that prevent such use), such as civil and structural engineering uses, agricultural applications, mine land reclamation, and treatment for biosolids.
- 3) Develop standards and their incorporation into state and federal environmental and transportation specifications.
- 4) Develop value-added products from CCPs including high-tech applications in auto and/or aerospace industry, and materials research.



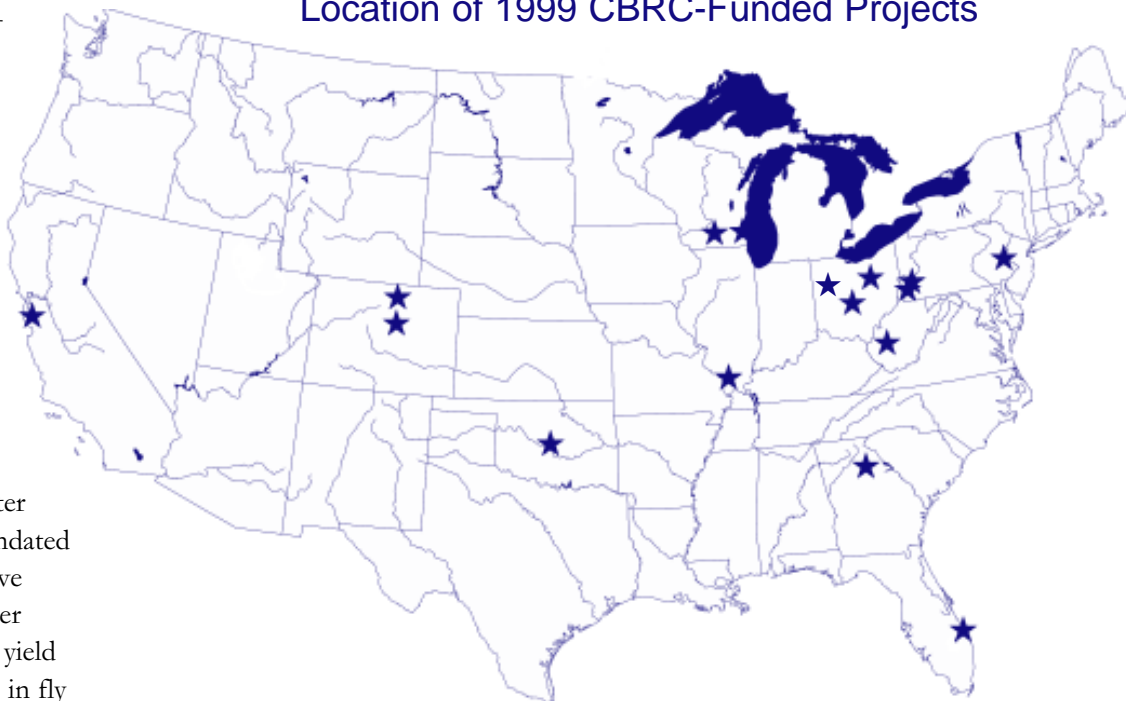
CBRC Funded Projects—RFP 1999

| Recipient | <i>Principal Investigator</i> PI | Title | Amount |
|--------------------------|--|--|---------------|
| <i>Western Region</i> | | | |
| Varra Corp. | J. Adams | Varra Coal Ash Burial Project | \$18,765 |
| AeRock, Inc. | J. Hunt | Fiber-Fly-Ash-Based Wall-Panel Development | \$45,052 |
| OK Cons. Com. | G. Canty | The Use of Coal Combustion Byproducts for In-situ Treatment of Acid Mine Drainage | \$85,890 |
| Ish, Inc. | I. Murarka | Promote Increased use of Coal Combustion Products to State Regulators and Government Agencies | \$45,000 |
| <i>Midwestern Region</i> | | | |
| S. Illinois Univ. | V. Malhotra | Development of Structural Materials from Sulfate-Rich Wet Scrubber | \$116,180 |
| S. Illinois Univ. | B. Paul | Boron Transport from Coal Combustion Product Utilization and Disposal Sites | \$66,795 |
| Univ. of Wisconsin | T. Edil | Soil Stabilization and Drying by Use of Fly Ash | \$101,310 |
| Univ. of Wisconsin | T. Naik | Development and Demonstration of High-Carbon CCP's and FGD By-Products in Permeable Roadway Base Construction | \$66,190 |
| S. Illinois Univ. | Y. Chugh | Industry-Government-University Cooperative Research Program for Development of Coal Combustion Products-Based Transmission Poles for Electric Utility Industry | \$113,880 |
| <i>Eastern Region</i> | | | |
| Waynesburg College | R. LaCount | Economical Treatment of High Carbon Fly Ash to Produce a Low Foam Index Products with Carbon Content Retained | \$68,673 |
| GAI Consultants | G. Brendel | Effects of Ammonia Absorption on Fly Ash due to Installation of SCR Technology | \$84,969 |
| Ohio State Univ. | W. Dick | Flue Gas Desulfurization By-products provide Sulfur and Trace Mineral Nutrition for Alfalfa and Soybean | \$48,650 |
| Univ. of Florida | P. Stoffella | Utilization of Fly Ash and Urban yard Waste as Soil Amendments to Improve Soil Fertility | \$75,466 |
| Univ. of Georgia | K. Das | Odor and HAP Control in Waste Treatment Processes Using Coal Combustion Ash (CCA) | \$59,553 |
| USGS | R. Haefner | Water Quality Monitoring at an Abandoned Mine Site Reclaimed with Pressurized Fluidized Bed Combustion By-products | \$60,000 |
| Lehigh Univ. | E. Levy | Ammonia Removal from Fly Ash in a Bubbling Fluidized Bed | \$83,188 |
| WV DEP | J. Johnston | Proposal for Hydrogeologic Evaluation of Strata above the North Lobe of the Omega Mine | \$25,071 |
| Ohio State | W. Wolfe | Use of Clean Coal Technology Products in the Construction of Low Permeability Liners | \$25,258 |

1999 CBRC Projects

EACH YEAR, OVER 100 MILLION TONS OF SOLID BY-PRODUCTS are produced by coal-burning electric utilities in the United States in response to regulatory restrictions on emissions of air pollutants. For example, annual production of flue gas desulfurization (FGD) by-products continues to increase as a result of more stringent sulfur emission restrictions. In addition, stricter limits on NO_x emissions mandated by the 1990 Clean Air Act have resulted in utility burner/boiler modifications that frequently yield higher carbon concentrations in fly ash, which restricts the use of the ash as a cement replacement. If newer, “clean coal” combustion and gasification technologies are adopted, their byproducts may also present a management challenge.

Location of 1999 CBRC-Funded Projects



In order to meet CBRC's objective of developing and demonstrating technologies to create solutions for constructive uses of byproducts associated with coal combustion processes, 18 projects were funded

from RFP 1999. The stars on the map above indicate project location within the United States. Recipient, principal investigator, project title, and CBRC award amounts are listed in the table on page 7.

CBRC Headquarters
WVU NRCCE
P.O. Box 6064
Morgantown, WV 26506-6064



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