

INJECTION OF FGD GROUT TO ABATE  
ACID MINE DRAINAGE IN UNDERGROUND COAL MINES

by

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**Abstract.** The objective of this project is to demonstrate the technical feasibility of injecting cementitious alkaline materials in the form of fixated flue gas desulfurization (FGD) material to reduce and mitigate acid mine drainage in a small abandoned deep mine in Coshocton County, Ohio. The project will attempt to demonstrate if a grout consisting of FGD and water can economically seal off seepage from old mine works and reduce or eliminate acid mine drainage. By attempting to seal and fill primarily the lower, down-dip areas of the mine, we will attempt to establish a practical procedure which can be economically applied to larger mines where full scale filling would be cost prohibitive due to the quantities required. In addition to the design of the grout mix and the mine seal, the research project will be studying the following aspects of the use of FGD in this application:

- Impact of FGD on ground and surface water quality
- Effect of AMD chemistry on acid neutralizing capacity of FGD
- Weathering Kinetics of FGD grout subject to AMD conditions
- Effect on physical properties of FGD caused by AMD weathering
- Sulfur Isotopic Characterization of the site coal, FGD, acid mine water, and groundwater samples

Introduction

Acid Mine Drainage (AMD) from abandoned underground coal mines in Ohio is a concern for both residents and regulatory agencies. Effluent from these mines is typically characterized by low pH and high iron and sulfate concentrations and may contaminate local drinking-water supplies and streams. The objective of this project is to demonstrate the technical feasibility of injecting cementitious alkaline materials, such as Flue Gas Desulfurization (FGD) material to mitigate current adverse environmental impacts associated with AMD in a small, abandoned deep mine in Coshocton County Ohio. The Flue Gas Desulfurization material was provided from American Electric Power's (AEP) Conesville Plant. It was injected as a grout mix that used fixated Flue Gas Desulfurization material and water. Grouting was done between September, 1997 and January, 1998.

The subject site for this study is located on the border of Coshocton and Muskingum Counties, Ohio, approximately 1.5 miles south-southwest of the town of Wills Creek. The study is being performed at an underground mine designated as Mm-127 in the Ohio Department of Natural Resources register, also known as the Roberts-Dawson Mine. The mine operated in the mid-1950's, during which approximately 2 million cubic feet of coal was removed. Effluent discharging from the abandoned mine entrances has low pH in the range of 2.8 - 3.0 that drains directly into Wills Creek Lake. The mine covers approximately 14.6 acres. Approximately 20,000 tons of FGD material were provided from AEP's Conesville Power Plant located approximately 3 miles northwest of the subject site.

This project is being funded largely by the Ohio Coal Development Office. American Electric Power is the prime sponsor of the project. The Ohio Department of Natural Resources, Division of Mining and

Reclamation, the U.S. Department of Energy - Federal Energy Technology Center, the Ohio State University, Dravo Lime Company, the U.S. Department of Interior - Office of Surface Mining are the cosponsors of the project.

### Fixated FGD Material

The byproduct of scrubbers at AEP's Conesville Power Plant is in a slurry form primarily made of Calcium Sulfit (80%) and Calcium Sulfate (20%). This slurry is de-watered to a cake with a solids content of approximately 35%-40%. This product in its semi-solid cake form is extremely difficult to handle and therefore, is mixed with fly ash and lime for fixation or stabilization so it can be transported to a landfill for disposal or to a utilization project for beneficial reuse. At Conesville Plant, normally, the filter cake is mixed with dry fly ash in a pugmill, with a 1:1 (FA:CAKE) ratio. Then, approximately 2% to 5% quick lime is added to the final mix. The final product is normally placed on a curing pad for several days prior to the final haul to a landfill or a utilization project. For this project, the plant was adjusted to produce 1.25:1 and 1:1 FA:CAKE material, with 5% added quicklime. The material was used within a few hours of its production.

### Acid Mine Drainage

Acid mine drainage affects hundreds of miles of streams in Ohio resulting in adverse impacts to biota, water quality and manmade structures. This directly affects Ohio's economy by limiting recreational use, reducing property values, increasing water treatment costs for human consumption, and increasing expenditures for road, bridge, and sewer maintenance.

Unreclaimed abandoned mine land is the primary source of AMD in Ohio. Water quality impacts typically associated with AMD sites include low pH, elevated chemical constituents and increased sedimentation. Ohio EPA has estimated that over 3,000 miles of stream have been adversely impacted in Ohio by uncontrolled AMD. Mining related discharges have been identified as the fourth leading source of aquatic life use impairment in Ohio, behind point source discharges, habitat modifications and agricultural practices. Low pH conditions are the seventh leading cause of aquatic life use impairment.

AMD from the proposed project site enters the lower segment of the Wills Creek drainage basin. Approximately one-half of this segment does not support the aquatic life use attainment. Ohio EPA has identified

uncontrolled discharges from surface and subsurface mines as significant contributing factors to this nonattainment.

There have been various approaches to abate AMD with limited success. Traditional abatement techniques involve either treatment of the surface discharges or sealing the mine to prevent the discharges. Conventional treatment technology includes limestone drains, sediment pond/chemical treatment systems, and passive wetlands. However, these systems are costly to build, require perpetual maintenance and do not address the problem at the source. Mine seals that eliminate the production of AMD by flooding the underground workings are generally a more effective approach. However, mine sealing is difficult to conduct cost effectively and usually addresses only the discharge from a particular portal or down dip side of the mine. The increased hydraulic pressure often causes leaking through the outcrop barriers between the mine workings and the surface.

### Project Objectives

The primary objective of the project is to demonstrate the technical feasibility of injecting cementitious alkaline material in the form of FGD material to reduce and mitigate acid mine drainage in a small, abandoned deep mine in Coshocton County, Ohio. The project will attempt to demonstrate if a grout consisting of FGD material and water can economically seal off seepage from old mine works and neutralize acid mine water. By attempting to seal and fill primarily the lower, down-dip areas of the mine, we will attempt to establish a practical procedure which can be economically applied to large mines where full scale filling would be cost prohibitive due to the quantities required.

Also, the impact of FGD on the ground and surface water, the ability of FGD grout to seal the mine and stop or reduce AMD production, the effects of AMD chemistry on Acid Neutralizing Capacity of FGD, and the effects on physical properties of FGD caused by AMD weathering will be studied in this project.

### Methods

#### Field Demonstration

The objective in this phase of the project is to seal the down dip area of the mine with a hydraulic seal consisting of a viscous mixture of FGD material and water with a slump of 4"-6"; as measured by a standard concrete testing procedure under ASTM-C143. This seal

is expected to cause the water level in the mine to increase and eventually flood the mine works. Once the mine works become flooded, the source of oxygen to the pyrite impurities in the coal will be cut off and therefore, the production of AMD will stop. However, there will be a possibility for the mine water to seep out of the mine through other outcrops, which would not promote the desired mine inundation and would simply transfer the AMD seepage from the existing outcrop openings in the downdip area to new seepage points. A similar but more fluid grout mix with a slump of about 8"-10" was injected in the up-dip area of the mine to mix with and neutralize the acidic water and encapsulate pyritic materials. It is hoped that the mine water that may seep through the newly developed seepage locations will have minimal contact with pyritic material and therefore will have better quality.

The FGD material was delivered to the site by dump truck, and was mixed with water using a paddle type mixer to produce either the thicker mine seal mix or the more fluid infill grout, as needed. The mine voids were accessed by drilling 318 vertical grout injection holes from the ground surface down to the mine elevation. Grout was pumped to the hole locations using heavy duty, positive displacement concrete pumps, and was conveyed into the mine voids by gravity flow through a pipe inserted into each hole. Twenty holes were pressure grouted. The holes were seal grouted to top of ground upon completion and temporary casings were removed. Grout penetration within the mine was monitored during the work using a down-hole video camera inserted in nearby grout holes.

To facilitate initial seal grouting near the existing mine openings, horizontal bypass drain pipes were installed after excavation of the existing earthen mine seal material. Engineered earthen seals were placed over the bypass pipes prior to grouting. The bypass pipes temporarily conveyed flowing mine drainage water while the grouting was under way. The intent was to valve off the bypass drain pipes when grout was observed flowing out of them, but this did not occur. After most of the grouting had been completed, several of the bypass pipes were pressure grouted and valved off to effect final sealing of the mine. When the seal grouting had been completed, the operation switched over to placement of the thinner, infill grout in the up-dip areas of the mine.

Implementation of the grouting was complicated by the presence of an unmapped abandoned mine area contiguous with the project area at its southern end. The unmapped area was shown as an outline enclosing about 7 acres on the old mine maps, and identified as "inined

out". No details were available. Evidence of a partially backfilled old mine entry was present, and was designated as entry No. 4 during this project. Water flow from entry No. 4 was initially only a trickle, but increased substantially after compressed air from nearby exploratory drilling flowed out from it during pre-construction activities.

Although not in the original project scope, bypass drain pipes and an engineered earthen seal were installed at entry No. 4, but its bypass drain pipes were pressure grouted at the end of the project in an attempt to seal the area.

Supervision of the project was done by American Electric Power construction employees, who monitored site conditions and enforced the technical specifications. Grout samples were obtained twice daily for laboratory strength testing; more frequent testing was done routinely during each shift to maintain the grout consistency (slump) within the specified range. Detailed boring records were maintained for each grout hole which include drilling data and grout injection information. The site was inspected visually daily during grout injection to check for grout leaks onto the ground surfaces. This did not occur. Lined temporary waste pits were constructed for pipe flushing water, waste grout and minor washdown water.

#### Laboratory Testing

##### Grout Mix Design

Several candidate grout mixes were prepared at AEP Civil Engineering Laboratory in Groveport, Ohio, using FGD material. Portions of each trial batch mix were poured into dry molds, and the rest were tremied into containers of mine water to simulate injection into a loaded mine void. The samples were stored in a climate controlled concrete curing room at the laboratory and were subjected to strength testing a time intervals of 7, 28, and 91 days after batching.

The list of candidate grout mixes was reduced after initial results were in, and two final mixes were selected for the project. Hardened samples of the seal mix design were tested by Toxicity Characteristic Leaching Procedure (TCLP) testing method using the natural samples of mine water to determine the characteristics for arsenic, barium, cadmium, chromium, lead, mercury, selenium and other parameters. Tables 1 and 2 show the results of strength testing and TCLP testing. Leachate from FGD was far below Ohio EPA's Drinking Water Standards for the Primary Parameters.

**Conesville FGD Material Grout - Table 1**

Selected Mix Designs	Water Added To Get Slump	How Samples Were Made	Slump, in	Unit Wt. Pcf	7 Days psi	14 Days psi	28 Days psi	91 Days psi
<b>Infill Grout</b>								
1FA:1FC, 5% Lime	2.3 gal water to 25 gal FGD	Rodded into 6 x 12" cycles	10	95.2	8.3	22.7	67.3	87.6
		Pumped into dry container			6.9*	18.8*	81.1*	127.6
		Pumped into container of mine water			5.5*	10.7*	53.7*	85.5
<b>Mine Seal Grout</b>								
1.25FA:1FC, 5% Lime	0 (as mixed at Conesville)	Rodded into 6 x 12" cycles	5.5	101.6	29.8	109.3	258.1	368.2
		Pumped into dry container			20.3*	86.2*	253.4*	392.2
		Pumped into container of mine water			12.8*	64.8*	219.7*	328.1

\*Note: \*.8x5.6" cylinders trimmed from sample which was pumped into container.

**Conesville FGD Grout - Modified TCLP Leachate Test Results - Table 2**

Constituent	Units	Drinking Water Std.	Mine Water	Low Ash Grout	High Ash Grout
Acidity	MG/L	NA	158	<1	<1
Aluminum	MG/L	0.05-0.2	2.88	0.89	1.12
Arsenic	MG/L	0.05	<0.004	0.01	0.018
Barium	MG/L	2	<0.00021	<0.0005	0.196
Cadmium	MG/L	0.005	<0.0005	63	<0.0005
Chloride	MG/L	250	<1	0	63
Chromium	MG/L	0.1	0.002	0	0.005
Iron	MG/L	0.3	45.3	0.01	0.01
Lead	MG/L	0.05	<0.0003	<0.002	<0.002
Mercury	MG/L	0.002	<0.00002	<0.0002	<0.0002
Magnesium	MG/L	N/A	22.3	3.0	1.7
Magnesium	MG/L	0.05	3.65	<0.01	<0.01

## Weathering Studies

This phase of the study is being conducted by the Ohio State University. In this study samples of FGD material will be reacted with natural samples of mine-drainage water collected at the field site, and with model mine-drainage waters prepared in the laboratory. Grout samples will be reacted with the acidic solutions for up to 18 months. Changes in the solution-phase chemistry will be monitored throughout this period with Inductively Coupled Plasma, Graphite Furnace Atomic Absorption, and potentiometric methods. Solution and solid-phase samples will be taken after 1 day, 2 days, 1 week, 2 weeks, 4 weeks, and subsequently, monthly (after exposure of the grouts to the acidic solutions). Solid-phase characterization will consist of SEM, Infrared and X-ray diffraction analyses of the surface layers of the grout to examine the changes in chemistry and mineralogy resulting from exposure to the acidic mine-drainage solutions.

The solid-phase characterization will be used along with data on the changes in solution composition to calculate the effects of the mine-drainage waters on the dissolution kinetics of the site-specific FGD grouts. An 18 month period will be necessary to assess the long-term stability of the FGD grouts.

Cores of the FGD grouts will be collected by the AEP drilling crews at designated time intervals, and will be brought to the laboratory and examined by x-ray diffraction, FTIR and electron microscopy. Resulting information will be used to assess the changes in mineralogy in the FGD grouts as they react in-place in the treated mine environments.

## Acid Neutralization Studies

In an effort to understand the processes that influence the acid neutralizing capacity (ANC) of the FGD material, Ohio State University will conduct a series of both laboratory batch experiments and computer modeling using chemical equilibrium programs such as MINEQL or MINREQ. In many effluents from old coal mines, the principle acidic species is produced from the oxidation of metallic sulfide species (e.g., pyrite, sphalerite, etc.). As a consequence, the proton donors resulting from these reactions are comprised of Fe(III) aquo-complexes and their hydrolysis derivatives ( $\text{Fe}(\text{OH})^{+2}$  is particularly important). Moreover, Fe(II) can also exist given the slow oxidation kinetics of this species at low pH (Hering and Morel, 1993). Additionally, the low pH associated with mine drainage waters promotes the dissolution of aluminosilicate

minerals resulting in a large concentration of dissolved  $\text{Al}^{+3}$ . As the AMD waters increase in pH, hydrolysis of the metal species will occur. One consequence of this reaction is the formation of amorphous iron and aluminum oxide and hydroxide precipitates. If these precipitates form on the FGD they could affect the ANC properties of this material. Thus, in order to understand the ANC role that the FGD material plays in the remediation scheme, we must consider both proton exchange and other metal hydroxide species (particularly iron). Ohio State will investigate these issues in detail.

## Sulfur Isotopic Characterization

Sulfur isotopic characterization of site coal, FGD grout, acid-mine drainage, and groundwater samples will be carried out by the Geological Sciences Department of the University of Indiana. This study will define the unique characterization of FGD material for future groundwater detection or tracing.

## High Resolution Tritium Analysis

Tritium analysis to a resolution of  $\pm 5$  pci/I will be conducted by Quanterra Environmental Services, in Richland, Oregon. This will enable the determination of flow time from surficial sources to the groundwater monitoring station, providing improved estimates for physical characteristics of the flow medium. This will enable better calibration of the numerical groundwater flow model.

## Site Hydrogeologic Characterization

Approximately 5 to 10 exploratory borings have been drilled to characterize the geologic setting and groundwater levels at the site. These borings have also been geophysically logged to provide detailed stratigraphic and hydrologic information. Twenty three monitoring wells have been installed across the site for the purposes of monitoring the Freeport Sandstone aquifer, the Middle Kittanning No. 6 Coal and the underlying Clarion Sandstone aquifer. Seventeen of these wells are sampled for water quality. A total of nine piezometers were installed in the Middle Kittanning No 6 Coal and overlying Freeport Sandstone. Select monitoring wells have been instrumented with Stevens recorders to provide continuous water level measurements for storm-event monitoring through the aquifer(s) and the deep mine.

A site specific numerical computer flow model is being developed and will be utilized to analyze this multilevel aquifer system. The numeric flow model will

be calibrated against field measurements of hydraulic conductivities and potentiometric maps derived from static water levels as observed in the project's monitoring wells. Tritium, a naturally occurring isotope of hydrogen, will also be analyzed to provide independent analysis of flow and travel time through the hydrogeologic system. Upon calibration, the model will be calibrated against field measurements of hydraulic conductivities and potentiometric maps derived from static water levels as observed in the project's monitoring wells. Tritium, a natural occurring isotope of hydrogen, will also be analyzed to provide independent analysis of flow and travel time through the hydrogeologic system. Upon calibration, the model may be used to project and simulate the establishment of new groundwater flow paths and travel times as a direct consequences of injecting low hydraulic conductivity FGD grout into portions of the deep mine. The numeric flow model will be used to compute volumetric discharge through the mine and the flux of chemically treated groundwaters exiting the mine to the receiving streams. The numeric flow model will be capable of simulating three dimensional "particle tracks" which represent the movement of solutes through the FGD materials and aquifer(s). The results of the modeling efforts will combine with chemical loading rates to compute the buffering capacity of the treated groundwater/mine discharge.

#### Groundwater And Surface Water Monitoring

##### Groundwater

A series of 23 wells have been installed to characterize the geology and hydrogeology of the site. Approximately one third of the wells have been installed in permeable materials or sandstone overlying the Number 5 coal. Another third of the wells have been completed in the FGD material used to fill the mine voids. The rest of the wells have been completed in the sandstone or shale materials underlying the Number 6 coal. The wells were installed in clusters such that the deepest boreholes were logged for variations in lithology. The wells were completed using standard practices used for permeable and for fine-grained materials (FGD). The materials recovered from the cores were typed and descriptions recorded using standard practices for soil and rock.

The monitoring wells will be used to provide water quality information ungradient of the mine, within the mine itself, and near the mine. This will enable statistical comparisons to be made regarding changes in water quality resulting from emplacement of the FGD

material. Several of the wells have been located northwest of the mine where groundwater flow is likely to be to the southeast toward the mine. These wells provide upgradient information.

Some wells have been positioned near the highwall of the old strip mine on the southwestern side of the underground mine. Some wells have been positioned within the area of underground mining. And finally some wells have been installed near the seeps on the northwestern side of the underground mine. These three well clusters all represent downgradient positions and/or positions near groundwater discharge points. Slug permeability tests will be performed in each well to estimate the hydraulic conductivity of the near-field materials.

Water level monitoring has included: 1) routine monthly or biweekly monitoring of water levels in all wells, and 2) storm-event monitoring. Water levels have been measured manually on a monthly or biweekly basis to enable potentiometric surface maps and potentiometric profile maps to be constructed to determine pre-FGD-emplacment and post-FGD-emplacment conditions as well as dynamic steady-state conditions. Storm-event monitoring has been accomplished using Stevens water level recorders installed on one set of upgradient wells and one set of downgradient wells. The water level data obtained from these records will enable estimates of storm-related changes in the rate of groundwater flow to be made. These will be tied to storm-related changes in surface water flow rates. Water quality samples have also been taken before, during, and following a storm-event to evaluate storm-related water quality changes. Monitoring will continue for an 18-month period. It may be necessary to install additional monitoring wells.

##### Surface Water

Surface water has been collected at approximately 12 locations. The four visible seeps were sampled to provide water quality data for the AMD as it exits the mine. In addition, the small receiving stream was sampled above (at two locations) and below the point where ADM from the main mine seep enters. Drainage from the gob pile downstream of the main mine seep was also sampled to quantify the AMD production from this area. Lastly, the drainage pond outlet to Wills Creek Lake was sampled to provide an overall analysis of AMD water entering the Wills Creek Lake from this tributary.

Additional sampling locations include the beaver pond along the northwest side of the mine and the stream located southwest of the mine which would likely contain

any AMD seepage from the western highwall, if it is occurring. An effort will also be made to find a local reference stream which can be used as a baseline to measure water quality changes attributed to the grouting project.

Approximately 10 sets of samples were collected to establish baseline conditions prior to the injection of FGD grout. Two storm-event samples will be taken during either the spring or summer months. Flow measurements were also taken at various sampling locations to allow for mass balance calculations for specific constituents.

The water quality data derived from the surface and groundwater monitoring program will be modeled with a non-equilibrium thermodynamic computer model. This geochemical model will be used to analyze the formation and dissolution of the principal mineral (ettringite) which composes FGD material. The modeling results will also be supported by controlled laboratory experiments to determine the ANC of the FGD grout. The batch and column laboratory experiments will evaluate the formation of iron oxide/hydroxide coatings and its direct influence on the hydraulic conductivity of FGD material and its respective ability to buffer AMD water.

#### Preliminary Project Results

A comprehensive final report will be issued by the Ohio State University in late 1998 to present detailed findings of all aspects of the project. However, as of late March, 1998, several preliminary results are evident.

A. Water flow out of the mine has been reduced from approximately 120 gallons per minute (gpm) including entry No. 4, to approximately 20 gpm. Most of the remaining flow comes from entry No. 4, i.e., the unmapped area which received little grouting. Of the original three mine openings from the project mine, only No. 3 shows any leakage, this is less than 1 gpm.

B. Static water levels within the mine have risen by about 6 feet to approximately elevation 827. This water level inundates the mine floor in the entire down-dip side of the mine.

Thus it appears that the two main objectives of the project, sealing and inundating the down-dip area of the mine, have been accomplished.

#### Conclusion

The Roberts-Dawson Mine acid mine drainage project is expected to provide a comprehensive examination of the efficacy of using power Plant flue gas desulfurization byproducts to remediate acid mine drainage. Preliminary results appear to show that sealing and inundating the down-dip areas has been successful. The project demonstrated practical construction methods to drill, provide temporary drainage, inject and monitor placement of FGD grouts in the abandoned underground mine environment, and is expected to yield useful information on the technological and economic viability of this approach. The grouting process was carefully monitored and documented and its effects on surface and groundwater conditions will be assessed in detail. The project sponsors hope that successful completion of this demonstration project will lead to large scale beneficial use of power plant FGD materials in remediating acid mine drainage problems at Ohio's abandoned coal mines.

The project began construction in August 1997, and was completed in January, 1998. Monitoring data assessing its effectiveness will begin to be available in 1999.

#### References

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