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**High Volume -- High Value Usage of Flue Gas
Desulfurization (FGD) By-Products in Underground Mines
Phase 2: Field Investigations**

**Quarterly Report
October 1 - December 31, 1996**

Work Performed Under Contract No.: DE-FC21-93MC30251

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High Volume--High Value Usage of Flue Gas Desulfurization (FGD) By-Products in Underground Mines

Phase II: Field Investigations

Cooperative Agreement No.: DE-FC21-93MC30251

Quarterly Report for the Period October 1, 1996 to December 31, 1996

Summary of Activity for the Quarter

In this quarter, activity focused on the placement of FGD grout into auger holes at the Sunny Ridge Mining Co. site. As discussed in previous reports, the grout was prepared using fluidized bed combustion (FBC) by-product obtained from the Costain Coal Company. The dry FBC material was loaded into concrete mixing trucks at a railway loading facility and transported to the site whereupon a specified amount of water was added. The grout was thoroughly mixed and transferred to a concrete pumping truck. The nozzle on the pumper truck was attached to PVC pipe through which the grout was pumped into the auger holes.

The first field test involved the placement of a very high slump, flowable grout into auger holes using a simple, earthen bulkhead. These tests were conducted to explore the flowability of the grout. The second series of tests was conducted with a lower-slump, higher-viscosity material pumped at high pressure and using sandbags as a bulkhead. The goal of these tests was to examine the feasibility of pressure grouting to completely fill auger holes with a material that will exhibit high long-term strength because of its low initial water content.

Although there were many problems encountered during the field demonstration, these initial tests were, overall, successful. It was shown that a high-slump grout can be pumped the length of the auger holes, and can be successfully placed in holes containing standing water. Furthermore, this can be accomplished using available concrete emplacement equipment. In contrast, the pressure grouting proved more challenging than emplacement of the flowable grout mainly because of pipe-joint failures and difficulties in working the stiff, high-viscosity grout; the amount of water added to the mix is critical when placing this type of material.

Cylinders of grout for compressive strength testing were prepared during the field demonstrations, and cores of the *in-situ* hardened grout will be recovered after a minimum of 30 days. Additional field demonstrations will focus on improving the procedure for placement of the flowable grout.

Task 1. Field Demonstration

Subtask 1.1 Auger Hole Emplacement Demonstration

General Description of Tests

Phase II of the project began on October 4, 1996 with the injection of grout into three auger holes at the Sunny Ridge Mining Company site. A second demonstration was conducted on October 14, 1996, in which three additional holes were at least partially filled. The material used as the grout feedstock was obtained from Costain Coal Company and consists of an FBC by-product that was described in the October-December, 1995 report. The first field test involved the placement of a very high slump, flowable grout using a simple, earthen bulkhead. These tests were conducted to explore the flowability of the grout i.e. its ability to travel and set-up over the length of the holes. The second series of tests was conducted with a lower slump, higher viscosity material pumped at high pressure and using sandbags as a bulkhead. The goal of these tests was to examine the feasibility of pressure grouting to completely fill auger holes with a material that will exhibit high long-term strength because of its low initial water content.

Although the two demonstrations had different goals, in general the methods were similar. Concrete mixing trucks, of 10 yd³ capacity were loaded with a weighed amount of dry FBC fly ash at the Costain Coal Company railway load-out facility (Figure 1) that is located within approximately 5 miles of the demonstration site. The trucks transported the material to the demonstration site whereupon a measured amount of water (and, in some cases, concrete plasticizer) was added. This was accomplished using two portable wheel load scales (PAT Equipment Corp.) of 20,000 pound capacity each to weigh the trucks before and after the water was added. The concrete trucks then thoroughly mixed the grout and transferred it to a concrete pumping truck (Figure 2) manufactured by Morgen Mfg. Co., which has a capacity of 115 yd³/hour and is capable of delivering concrete to a height of 90 feet. The truck remained on the lower access road (described in July-September, 1996 report) with its boom extended up to the auger hole bench to deliver the grout (Figure 3).

Concrete is normally delivered at elevated pressure from the concrete pump through a 5 inch i.d. rubber hose. In order to deliver the FGD grout into the auger holes through 5 inch or 4 inch PVC pipe, a steel connecting flange was machined (Figure 4). A matching PVC flange was connected to the metal flange via threaded bolts, and the entire assembly was connected to the concrete pump rubber hose (Figure 5). The PVC pipe was inserted into the auger holes in 10 foot sections which were connected using PVC couplings and cement. FGD grout was then pumped through the connected sections of pipe into the auger holes.

The remainder of this report describes, in greater detail, the two field demonstrations. Although many problems were encountered during the tests, only those relevant to evaluation of the grouting concept will be discussed.

Figure 1. Concrete mixing trucks immediately after loading with dry FBC fly ash at the Costain Coal Company facility.

Figure 2. FBC grout being transferred from the concrete mixing truck (chute at right) to the pumping truck.

Figure 3. Concrete mixing truck and pumper truck during emplacement of FBC grout into an auger hole.

Figure 4. Flange assembly used to connect PVC pipe to concrete pump hose.

Figure 5. Concrete pump hose attached to PVC pipe via flange assembly.

Field Test: October 4, 1996

As was discussed previously, the objectives of this series of tests focused on the emplacement of a high-slump grout using several methods. The first involves pumping the grout through 4" i.d. PVC pipe, the end of which is placed at the back of the auger hole and is lying on the floor of the hole. Ideally, the grout would be pumped to the back of the hole and the pipe slowly withdrawn as the hole fills. The second test would use 5" PVC, the end of which is placed near the auger hole opening, on top of a natural earthen bulkhead. The grout would be pumped near the hole opening and the hole fills from front to back, with the bulkhead keeping the grout contained. Both of these tests serve to examine the flowability of the grout.

One problem that surfaced just prior to the tests involved the raw material availability. The field demonstration was designed to use FBC "fly ash" instead of bed ash because of the former's lower free lime content and heat generation upon hydration. The bed ash (described in the April-June 1996 report) generates more heat and requires more water than the fly ash. It also is coarser and exhibits delayed hydration in laboratory tests. For these reasons, it was not used in this series of field tests. It was soon discovered that the railcars transporting the ash to the load-out facility were not clearly marked as to their contents i.e. bed ash versus fly ash. This delayed the field tests several days until the material in the railcars could be properly identified.

Costain Coal Company staff were responsible for loading the concrete mixing trucks with FBC fly ash at the load-out facility. A delay in operations occurred almost immediately and was caused by a broken conveyor belt that took several hours to repair. A backhoe was used in the interim to load the trucks, which delayed the first mixing process by approximately 4 hours due to inefficiency of the method. The amount of FBC was determined by weighing the truck before and after loading. Because of the low bulk density of the dry FBC fly ash, the trucks could not be loaded to their rated weight capacity (17,280 pounds) of mixed material; the maximum weight of fly ash that could be loaded dry was 14,000 pounds (approximately 8 yd³).

Two 10 yd³ capacity concrete trucks and one concrete pump were used in placing the FBC grout into the holes. The first truck weighed (empty) 28,440 pounds and the second weighed (empty) 29,100 pounds. As was discussed in the Introduction, the quantity of water added to the FBC fly ash at the mine site was determined by weight using portable truck scales. Unfortunately, the scales were not entirely practical in use because of the rough, uneven terrain at the site (the scales are designed for use on a level, hard surface). Therefore, the added water content was monitored by measuring the slump of the material. This was of some concern because it was observed that the quantity of water required to change the mix from a low-slump, nearly unworkable material to one with good workability is ca. 1-2 weight percent.

The field demonstration began with an experiment in which grout was pumped from the back (towards the front) of one auger hole using 5 inch i.d. PVC pipe, and using 4 inch PVC pipe in another hole. The pumping truck was equipped with a 5 inch diameter hose. Five inch diameter PVC pipe is not considered "standard" and the Schedule 40 pipe used had to be obtained from a

specialty plastics company in Atlanta, GA. For practical purposes, the choices of pipe for this application are the 4 inch and 6 inch diameter PVC. Four inch diameter pipe is preferred based on cost and handling considerations.

The first auger hole (100 feet deep, approximately 26 yd³ capacity) was partially filled (using 5 inch pipe) with approximately 8 yd³ (one truckload) of FBC grout. This material exhibited sufficient flowability but had a rather high water content (40%). In addition, 2 gallons of concrete super-plasticizer were added. This moisture content was felt too be too high for sufficient long-term compressive strength, so this hole was abandoned and another hole selected. The partial filling of the first hole was monitored with the CAER-constructed sled-mounted camera.

The second auger hole was filled with 8 yd³ of grout using 4 inch pipe. A delay in the arrival of the second concrete truck caused material to partially block the pipe with thickened grout, which caused a large pressure increase at the pump nozzle/PVC joint and resultant destruction of the joint. After repairing the joint, a second load of grout (8 yd³) was placed in the hole, which gave a total of approximately 16 yd³ of material placed. The grout apparently covered the entire length of the auger hole but was only 2/3 full vertically. In addition to water, super-plasticizer was added to the grout placed in this hole.

A third hole was selected for emplacement of a low-slump grout. In this experiment, an earthen embankment was constructed at the entrance to the auger hole, and the grout was pumped into the hole at the opening. Although some grout was successfully pumped into the auger hole, and did not leak through the earthen bulkhead, the low-slump material was not very workable and required an additional amount of water to be added; the final water content was probably not low enough for the grout to meet the required strength of 400-500 psi. However, this will not be known until compressive strength testing is completed on the hardened grout.

A significant problem encountered during the field demonstration was the large amount of time required for the concrete trucks to travel to the load-out facility, receive a load of dry FBC fly ash, and return to the field site. The trip required approximately one hour (Table 1) which created a problem since only two concrete trucks were available. During this time period the grout already in the PVC pipe and concrete pump began to thicken. When the next load arrived and was pumped through the system, the stiff grout plugged the pipes and caused a pressure increase that often resulted in rupturing of the PVC pipe joints. Grout in the auger hole also stiffened thus preventing the emplacement of additional grout and necessitating moving to another hole before completely filling the existing one. The next field demonstration will employ additional trucks to circumvent this problem.

The FBC fly ash grout was approximately 5-10°C warmer than concrete, which caused the super-plasticizer to began breaking-down sooner than expected; after 40-50 minutes the benefits of this admixture were lost. For this reason the super-plasticizer will be added only 5-10 minutes before pumping in the next field test.

Table 1.

Task	Duration (min.)
Going downhill to load (empty)	20
weighing empty truck	2
waiting time	10
loading dry FBC	5
weighing loaded truck (containing dry material)	2
add water	4
weigh loaded truck to determine volume of water	2
return (uphill)	25
total	70

Field Test: October 14, 1996

The objective of these experiments was to determine if the FBC grout can be pumped at a lower slump but still maintain sufficient flowability to reach the back of the auger holes. We therefore attempted the tests at a much lower moisture content (approximately 35%) than on 10/4/96, and used sandbags as a bulkhead (Figure 6).

To overcome the problem of the delay in delivery of the grout loads, for these tests three (3) concrete trucks were leased for the day, with a total of four loads used over the course of the experiments. As with the previous demonstration, the trucks were filled with FBC fly ash from the silo and weighed at the facility. Water was then added to the trucks to obtain a specific slump, and the trucks weighed again to determine the quantity of water and the FBC/water ratio. The slump and corresponding FBC/water ratio are provided in Table 2.

Figure 6. Schematic diagram of the pressure-grouting experiment (top) and actual construction of a sandbag bulkhead (bottom).

Table 2.

Truck #	Slump (in)	Water/FBC
1	5	0.350
2	6	0.347
3	4	0.288
4	7	0.360

The 1st auger hole was injected with grout that contained 36% moisture and a slump of 5-6 inches. A black-and-white video camera was placed at the back of the hole to record the flow of grout that came from a 4 inch i.d. PVC pipe placed 60 ft into the hole. It was soon concluded that grout with 5- 6 inches of slump is not a workable material and could not be pumped into the auger holes. Consequently, 5 gallons of concrete super-plasticizer (dispersed in 10 gallons water) was added per 8 yd³ of grout approximately 7 minutes before emplacement. The addition of super-plasticizer improved the slump considerably, to approximately 8 inches. However, the grout still did not exhibit sufficient flow, filling only the very front of the auger hole, and squeezed out of the sandbag bulkhead. A second truck-load of grout was then used (total $\approx$ 16 yd³), but with an increased water content of about 38% by weight. This material behaved similar to the first load in that it forced its way through the bulkhead and only filled the outer portion of the hole.

Another problem was encountered during the grouting operation that involved the composition of the fly ash. Within the second concrete truck was a considerable number of FBC aggregates (Figure 7) and pieces of foam. While the foam pieces posed little problem, the aggregates, which were as large as 6 inches in diameter, proved to be non-pumpable. In fact, the third truck contained so many of them that the entire load had to be rejected as unusable. These aggregates were loaded into the concrete truck from the ash silos and did not form within the trucks. They originated from both the bottom and the top of the railway cars as a crust that was produced from spraying the FBC material with water as it was loaded into the cars. This is done to minimize dust formation and keep the material in place during transit. This crust is essentially cured FBC grout that is hard and very difficult to pulverize. Because they were not destroyed in the concrete trucks or pump, the aggregates lodged in the PVC pipe joints and, when grout was pumped through the system, formed a blockage and caused the pump/PVC reducing joint to rupture. Furthermore, the aggregates probably also significantly reduced the ability of the material to flow (and thus not perform as a grout but rather as a stiff concrete). It is therefore essential, in future tests, to screen these aggregates out of the grout before it enters the pump.

After repairing and replacing the ruptured pipe and joints, the tests were moved to another auger hole. A fourth truck-load of material was used and was prepared with a higher slump than that used in the previous tests of the day. A 5 inch flexible fitting was used to mate the PVC pipe to

Figure 7. Large aggregates of FBC fly ash.

the concrete pump nozzle, and approximately 7yd³ of material was successfully pumped into the hole, thus filling it to approximately 1/3 total capacity. Cylinders of this grout were prepared for unconfined compressive strength testing (Figure 8).

The experiments of October 14th showed that FBC fly ash grout cannot be placed into auger holes at the targeted moisture content of 35 weight percent. Additional testing will therefore likely focus on the use of a higher slump grout, although this will be decided after the compressive strength testing on this type of material is completed. Furthermore, a large screen has been constructed that will be placed between the concrete truck chute and the concrete pump hopper to remove the large aggregates as they emerge from the concrete trucks.

Surveys of the partially filled holes will also be attempted, using the skid-mounted camera system (described in the July-Sept. 1996 report). The goal will be to observe the ends of the holes in order to estimate the slump and the extent of flow of the grout *in situ*.

Figure 8. Cylinders of FBC fly ash grout for compressive strength testing.