PNEUMATIC BACKFILLING OF COAL COMBUSTION RESIDUES IN UNDERGROUND MINES

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Abstract

In late summer of 1994 an investigation into the effectiveness of using fluidized bed combustion (FBC) byproducts to remediate acid mine drainage, and prevent mine subsidence was carried out. The FBC byproducts are highly pozzolonic and when packed to the roof of abandoned mines have enough compressive strength to prevent mine subsidence. In addition, the FBC material is basic and effectively neutralizes acid mine drainage. The FBC material was backfilled into an abandoned mine using a novel supersonic pneumatic stowing technique. The effect of differing airflows and material size was measured. The paper presents the quantitative results of the pneumatic stowing, along with the results of physical and chemical testing designed to investigate the suitability of FBC byproducts for disposal underground. The potential of this approach to remediate abandoned mine problems is discussed and the FBC shipping and handling systems are discussed in detail.

Key words: Fluidized bed combustion, Ash, Pneumatic, Acid mine drainage, Pozzolonic, Subsidence

Introduction

The United States currently has over 480 billion tons of mineable demonstrated reserve base of coal. Two thirds of this reserve is minable by underground methods. Unfortunately coal contains a number of components such as sulfur and nitrogen that form undesirable oxides during combustion. Coal also contains incombustible mineral matter that is converted into ash and leads to suspended particles in air and degradation of downstream components. Several technologies designed to prevent the release of sulfur dioxide and nitrogen oxides have been developed. Most of these techniques produce a large quantity of waste that has a high percentage of free lime or slaked lime with a large portion of fly ash. This material can present a disposal problem, and, due to its high pH, landfill costs can be quite high.

Coal mining areas have been subjected to a series of problems. The legacy of coal mining has been ground collapse due to subsidence, and acid mine drainage due to dissolved pyrite forming sulfuric acid where abandoned mine workings drain underground water pools. The combined subsidence and acid mine drainage problems due to abandoned coal mines prompted the enactment of the Surface Mining and Control and Reclamation act of 1977. This act was passed in order to accomplish the reclamation of abandoned coal mine lands. This reclamation includes the abatement of acid mine drainage, the prevention of mine subsidence, and reclamation of surface mines. The act also places strict regulations on coal companies, requiring them to take responsibility for the lands left behind after mining.

The problem of advanced coal combustion (ACC) byproducts disposal can be solved by stowing the material in abandoned mines. The waste material typically is highly pozzolonic and will achieve a reasonable compressive strength in the humid underground environment without additives. In addition, the neutralizing capability of the material makes it an ideal candidate for acid mine drainage prevention. This solution carries the multiple benefit of creating a market for the ACC byproducts and providing mine closure engineers and abandoned mine authorities a new tool to combat abandoned mine land problems. There are two basic methods used to backfill large amounts of material into existing underground mine voids to prevent subsidence. They are pneumatic and slurry. Slurry techniques are well known and can be used effectively in many cases where the addition of water will not present a problem. There are many cases however where slurry cannot be used due to a variety of problems posed by the introduction of water. An effective pneumatic technique was required that could effectively blind backfill large underground areas from a single borehole.

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Over the past several years, Burnett Associates, Inc. developed the high efficiency ejector[3] that makes pneumatic stowing of large amounts of gravel through boreholes possible and effective. These programs were funded through the U.S. Bureau of Mines and the Office of Surface Mining. In the late summer and fall of 1994, Burnett Associates, Inc. was funded through the National Mine Land Reclamation Center to field test the ejector with Fluidized Bed Combustion ash (FBC).

Ejector operation

The borehole ejector was developed under contract to the U. S. Bureau of Mines with funding available from the Office of Surface Mines Abandoned Mine Land Program. The ejector was designed to stow material horizontally from the base of a borehole using a supersonic velocity air stream to redirect the material away from the borehole and into the mine void. Until the invention of the ejector by Burnett Associates Inc., there was no commercially viable means of pneumatically stowing large amounts of material from boreholes. Competing technologies such as bent pipes at the base of the borehole are limited due to extreme wear in the bent sections caused by the high velocity fill. There are no parts in the ejector system that are subject to wear, since all of the momentum exchange is done by the air stream.

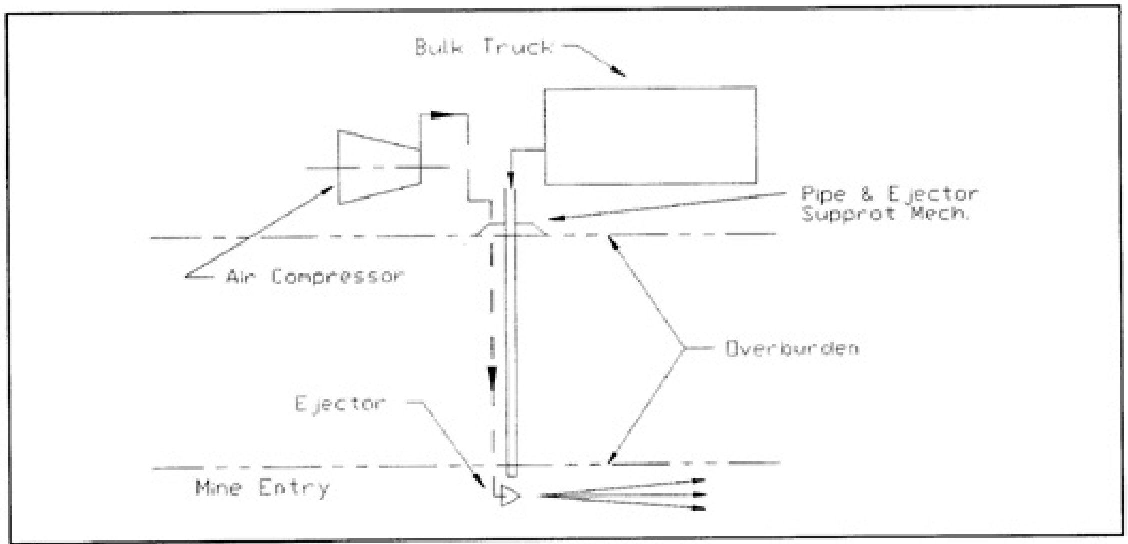

Figure 1. Pneumatic stowing schematic.

3 Development of a High Efficiency Ejector System by Mackenzie Burnett, Burnett Engineering (now Burnett Associates, Inc.) USBM Contract No. J03090 2 April 991

The ejector uses the principle of momentum exchange between air at supersonic velocity and the fill material to accelerate the fill in a horizontal direction as it exits the borehole drop pipe. The system consists of two pipes banded together so that they can be inserted in an 8 in diameter borehole. A schematic of the system is provided in figure 1. One pipe carries dry fill material and the other pipe carries the high pressure air. The air is directed horizontally across the bottom of the material feed pipe at high supersonic velocity to propel the material in a generally horizontal direction. This system operates by the transfer of momentum from the supersonic air stream to the fill material. The momentum transfer results in a horizontal stream of fill material and air at a velocity of about 100 fps. The ejector fits on the bottom end of a 3 in diameter vertical pipe. Fill material is fed into the ejector at a controlled rate through a hopper mounted over the borehole or in the case of fly ash can be connected directly to the bulk tank truck. High pressure air used to operate the ejector is fed through a second 3 in diameter pipe. The ejector system is supported on the surface by a pipe and ejector support mechanism. Once in place the ejector can be rotated to direct the flow in a full 360^0 circle. The ejector has demonstrated that it is capable of moving 3/4 in topsize fill material over 50 ft from the injection point. It is expected that the fly ash material will be transported at least 500 ft. from the base of the borehole due to its small average particle size. Figure 2 is a drawing of the ejector system used for this project. This device is capable of stowing up to 50 tons/hour. The ejector is a truly unique device that has proven itself in AML applications.

Material is fed into the feed pipe at the top of the borehole and it drops by gravity until it exits the feed pipe directly in front of the set of nozzles. The relatively slow moving fill material falls in front of the air jet and is turned 90° and accelerated by the air jet. The mix of air and solids reach a velocity of approximately 100 to 200 ft/s depending on the solids flow rate. This velocity can be calculated by the following simplified

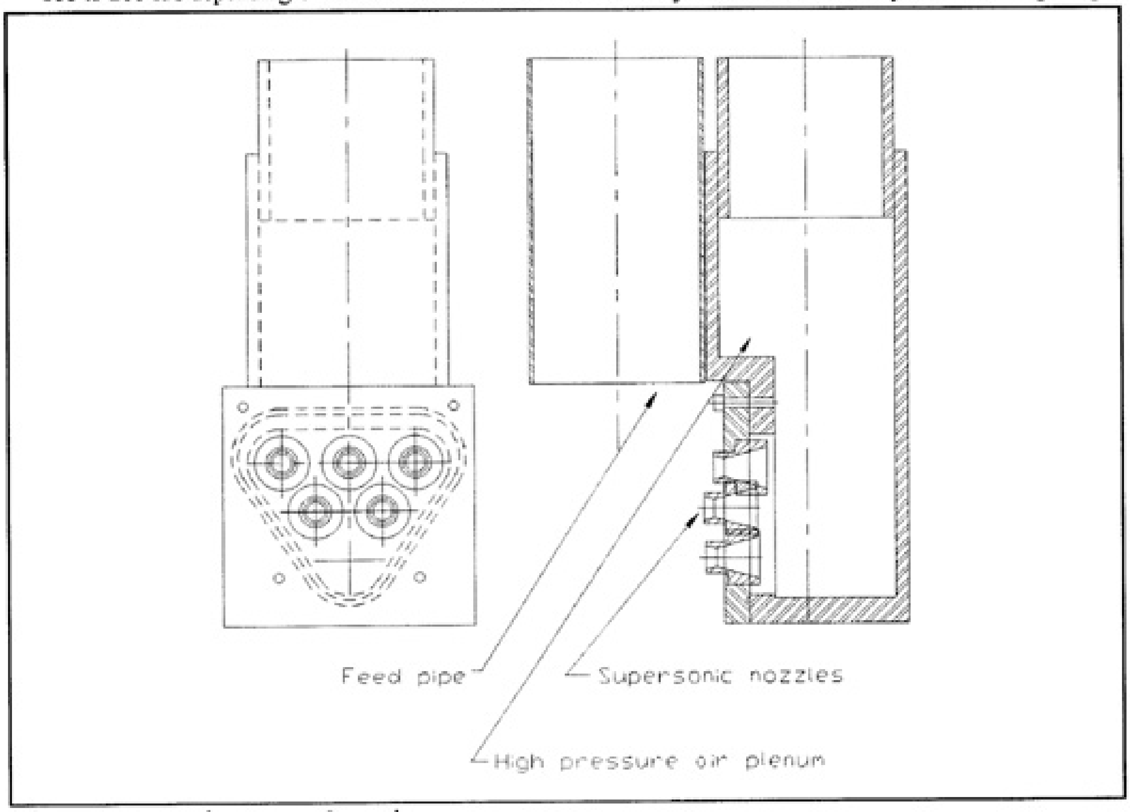

Figure 2. Ejector drawing

Material is fed into the feed pipe at the top of the borehole and it drops by gravity until it exits the feed pipe directly in front of the set of nozzles. The relatively slow moving fill material falls in front of the air jet and is turned 90' and accelerated by the air jet. The mix of air and solids reach a velocity of approximately 100 to 200 ft/s depending on the solids flow rate. This velocity can be calculated by the following simplified momentum exchange equations. In the presentation of the equations, the vertical velocity of the material is ignored and it is assumed to be zero. A slight upward angling of the nozzles can correct for the vertical component of velocity.

$$m_s u_s + m_a u_a = m_s v_s + m_a v_a \tag{1}$$

where: m_s = mass flow rate of solids (lb/s),
m = mass flow rate of air (lb/s),
u_s = initial velocity of solids (ft/s),
u_a = initial velocity of air before mixing (ft/s),
v_s = final velocity of solids after mixing (ft/s)
v_a = final velocity of air after mixing

If we assume 100 pct mixing and momentum transfer then:

$$v_s = v_a \tag{2}$$

where:

m_s. = mass flow rate of solids (lb/s),

m_a = mass flow rate of air (lb/s),

u_s = initial velocity of solids (ft/s),

u_a = initial velocity of air before mixing (ft

v_s = final velocity of solids after mixing (ft

v_a = final velocity of air after mixing

If we assume 100 pct mixing and momentum transfer then:

$v_s = v_a$

However, testing has shown that $v_s = .6v_a$ which partially accounts for the vertical component of the material velocity and for the inefficiency of the momentum transfer of the air to the material. Solving for v_s we get:

$$v_s = \frac{m_a u_a}{m_s + 1.67 \times m_a} \qquad (3)$$

Site Selection and Preparation

The field site for this project needed to pass several criteria. First, the site needed to have easy surface access to allow a pneumatic truck to be within 50 feet of the injection borehole. **The air** compressors also needed to be within similar distances from the injection borehole. Surface access was also needed to allow for the drilling of several observation boreholes in and around the heading or driveway in which the Burnett Ejector was located. Second, the site needed to have an accurate map or access to the mine void so that a map could be derived. Thirdly, the headings needed to be as long as possible, so that the total distance of which the Burnett Ejector would move ash could be observed.

The task of field site selection was completed by Troy Tichnell of Anker Energy and Courtney Black of the NN/fLRC. Mr. Tichnell selected several candidate sites in the Newburgh area of Preston County, WV. Upon investigation of these sites by Mr. Tichnell and Mr. Black, the Sherman Helms Number 2 mine was selected. This mine has excellent surface access and has an average of 50 feet of overburden.

The surface and mine are owned by Patriot Mining Company, Inc. The surface above the mine is a field with easy access from Irish Ridge Road. The low overburden makes drilling costs very affordable.

The mine entry was surveyed by Courtney Black and Paul Ziemkiewicz. A baseline was then laid out on the surface so that the headings could be visualized and borehole locations selected. The Office of Surface Mining aided in the drilling activities by providing a borehole camera. Once the mine void was located the camera was used to locate additional holes. Initially, nine boreholes were drilled into the mine void. The location of these holes can be seen in Figure 3. Holes 1, 2, and 4 were 8 3/4" holes while all other holes were 6 5/8" in diameter. The 8 3/4' holes are considered injection holes while the 6 5/8" holes will be used for observation.

Additionally, the location of the mine pool can be seen in Figure 3. The water feeding this pool permeates through the pavement below the pool. The pool is estimated to be 30,000 gallons and flows from the mine at approximately one gallon per minute (gpm). For additional information see the water quality section that is included in this report.

Additional holes, seen in Figure 4, were added as injection holes. Also all observation hole in Figure 3 were resized from 6 1/4 inch to 8 3/4 inches so they could be used as injection holes if needed.

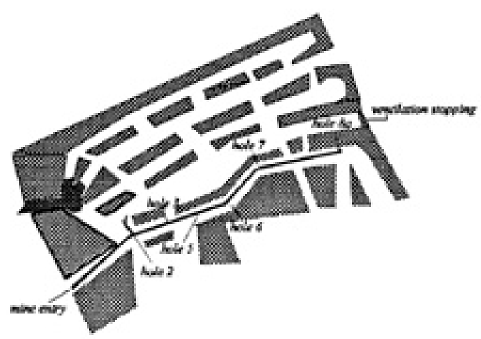

Figure 3. Location of Initial Boreholes Placed in the Sherman Helms No. 2 Mine.

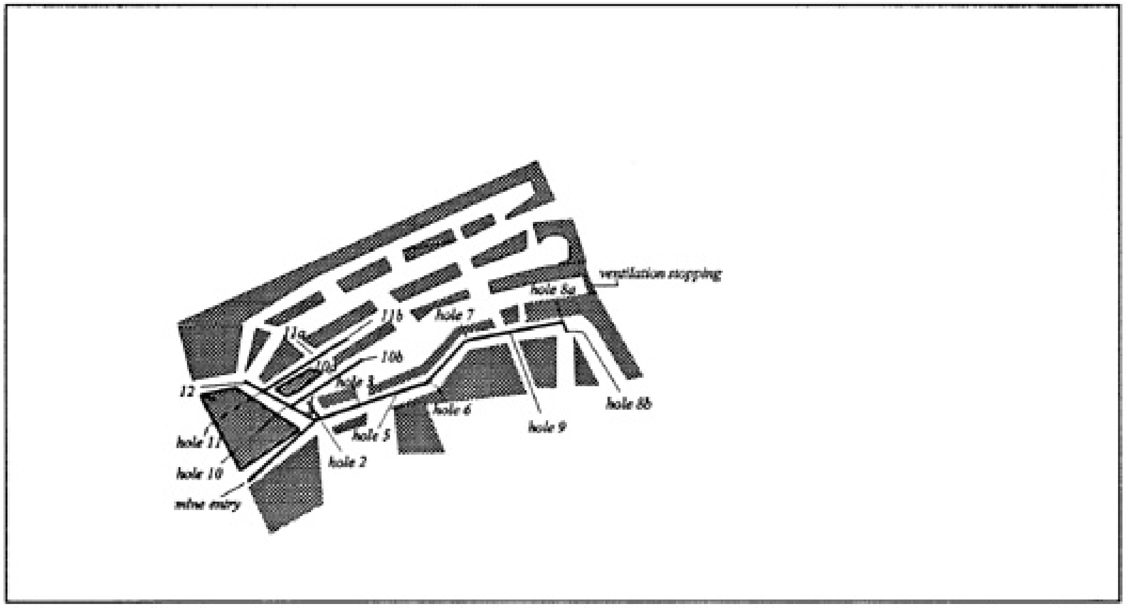

Figure 4. Location of Initial and Additional Boreholes placed in Sherman Helms No. 2 Mine.

Ash Injection

Initially, ash from Morgantown Energy Associates was to be utilized for this project. The ash was to be loaded dry or unquenched into a pneumatic truck and delivered to the site. Problems with loading and transporting the unquenched ash arose and this source was abandoned. The next ash source was the Albright Ash Plant in Albright, West Virginia. The Albright site could not effectively load a pneumatic truck so plans were made to use an open dump trailer with a grain gate and a special tarp. To test this method a tri-axle dumptruck was loaded with ash by the Komatsu loader at Albright. No dust control problems were encountered during transportation since the tarp covered the entire bed. However, problems did arise when the truck unloaded. Once the truck arrived on site, it dumped the ash into a hopper that was fabricated to sit on top of the injection pipe. The system was gravity fed and worked effectively until a large fragment of hardened ash would clog either the butterfly valve on the tailgate of the truck or the 3 inch reducer on the bottom of the hopper. Once the system plugged large volumes of dust would be released into the atmosphere. After approximately 40 tons of material was unloaded in this manner, the method was abandoned.

With the open trailer method failing, the pneumatic truck now looked very favorable for dust control and material handling purposes. A third ash source, American Power's Grant Town Power Station, was located that could load a bulk pneumatic truck. The pneumatic truck is loaded with 25 tons of ash by an "elephant trunk" at the power plant in about 15 minutes. The truck then travels 2 hours to the Sherman Helms site to unload. The unloading process consists of the truck attaching a hose to the truck and to the down-hole delivery pipe, pressurizing the tank and delivering the ash to the pipe. The truck can unload 25 tons of ash in about I hour. The truck will then travel 1.5 hours back to Grant Town to pick up another load. The total round trip time for a pneumatic truck loading out of the Grant Town Power Station is 5 hours.

Performance of System

One hundred forty four tons were injected into borehole number 2 before the hole refused ash. As stated above, the first forty tons of ash were from Patriot's Albright Ash Plant. During the injection of the Albright ash, the air flow through the nozzles was set at 1400 cfm at 100 psi. The air supply was provided by one Ingersoll-Rand 750 cfm compressor and one Ingersoll-Rand 825 cfm compressor. Figure 5a displays a cross section of how this ash was stowed in the mine void. As stated above, several material handling problems were encountered which caused the stowing to take an enormous amount of time. In all only forty tons of ash were stowed during the month of August. At the end of this month the project budget did not allow for the continuation of renting two air compressors. The 750 cfm compressor was returned and nozzles were replaced to yield an air flow of 800 cfm at 100 psi.

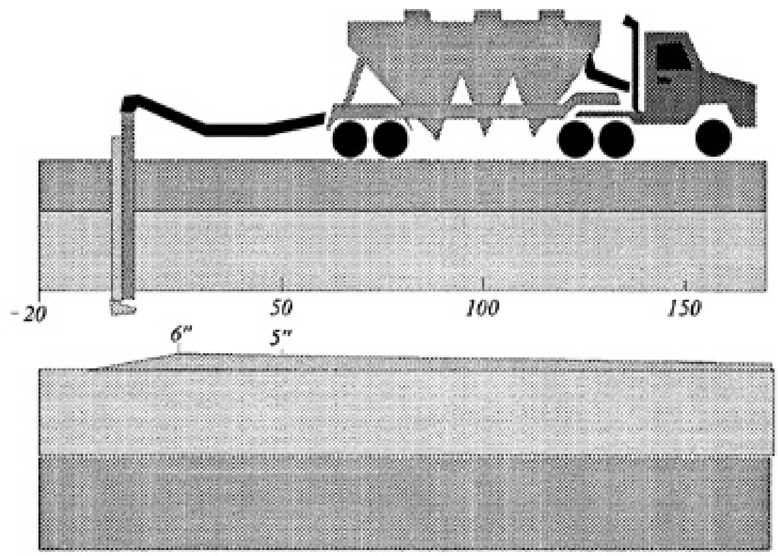

Figure 5a. Location of Albright Ash in Sherman Helms No. 2 Mine. Total ash volume shown equals 44 tons.

The other one hundred tons of ash in Hole 2 was from American Power's Grant Town Power Station. The ash from Albright consisted totally of fly ash particles. The Grant Town material contained both bottom and fly fractions. When stowed, the material was classified at the bottom of the borehole. The bottom ash or sand fraction of the material was stowed within 50 feet of the ejector. The larger particles were near the ejector and finer sand particles out to 50 feet. The fly ash or flour fraction of the ash was dispersed throughout the mine. This can be seen in Figure 5b.

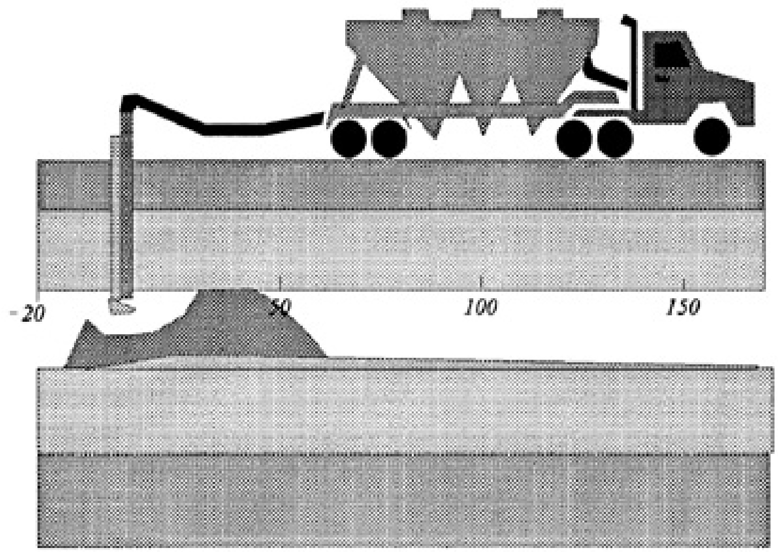

Figure 5b. Location of Grant Town Ash and Albright Ash that was stowed from Borehole no. 2. Total Ash volume shown equals 144 tons.

With this information, it was then believed that the borehole drilling distance for a non-segregated ash stream would be 100 feet. This drilling density is acceptable since current grouting operations have similar drilling densities, but lies far below the project goal of 200+ feet.

Once hole 2 rejected ash, the ejector was moved to hole 10b. Results similar to hole 2 were recorded. Once this hole plugged the ejector was then moved to hole 8b. Again, the hole showed signs of refusal at near 100 tons. When the mine was investigated with the camera, almost all of the sand fraction was within fifty feet of the ejector with the flour fraction being dispersed throughout the mine void.

It should be noted that during operation with the one 825 air compressor, the pressure gage on the compressor never displayed more than 85 psi. After extended use the pressure gauge even displayed pressures as low as 60 psi. The nozzles are designed to deliver 1600 fps air velocities when 100 psi is applied. With these low pressure readings, Mach velocities were never achieved. The pressure readings were reported to Titan Rental, the compressor supplier. A mechanic was sent to the site and it was determined that the 825 cfm compressor was only delivering around 700 cfm. Titan then left a 750 cfm compressor to be coupled with the poorly performing 825 cfm compressor so that we could at least get 800 cfm at 100 psi from both compressors. When air was serviced to the system with both compressors, pressure readings of 115 psi were recorded. This meant that a 1600 fps jet velocity at the ejector was moving material through the mine void. Another 25 tons of ash was stowed with the system operating to specification. The additional tonnage that was placed had been moved out to as far as 100 feet. Depth measurements were taken on the now extended ash pile and are displayed in Figure 6. As the depth measurements were being taken the particle size was examined at various depths. A layering effect of fly and bottom ash was found throughout the 100 foot long pile. This leads us to believe that the supersonic air streams were moving bottom ash that was originally stowed next to the ejector, downstream, and stowing new material on top of it.

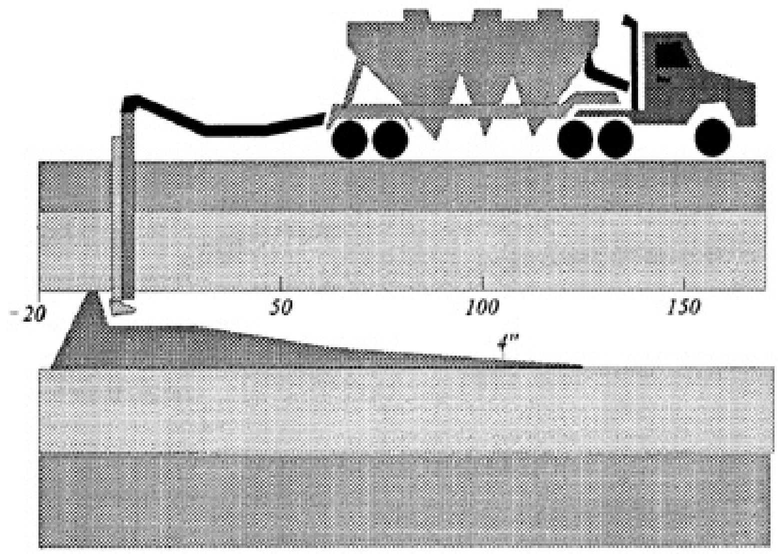

Figure 6. Location of Ash Stowed With Pneumatic System Operating to Specification (800 cfm @ 100 psi).

With the knowledge that the compressors were not performing to specification, additional tests were performed during the week of November 28th to check the performance of ejector at 1700 cfm. Three 750 cfm Ingersoll-Rand compressors were coupled together to achieve 100 psi at 1700 cfm. The test data indicates that achieving the high velocity air jet is crucial to achieving transport distances of 100 feet. The observed performance of the 1700 set up was greater than that of any other configuration tested. The ejector was placed 295 from the mine entrance in hole number 9 (see Figure 3). Due to bad weather only two truck loads of ash were placed in this hole. The ejector blew the ash out of the mine entry (295 feet away). The entry and mine will be surveyed once the winter weather breaks to determine the stowing distance achieved at 1700 cfm.

Water Quality and TCLP Results

The location of the mine pool can be seen in Figure 3. The pool is estimated to be 30,000 gallons and flows from the mine at approximately 1 gpm. The flow peaked in August at 16 gpm. It is to be noted that this area in Preston County received 8 inches of rain in August, 1994.

As the data shows, the water quality in the mine was not affected by the injection of FBC ash. The reason for this is that all of the ash injected into the mine did not come in contact with the source of the mine pool. The water forming the pool permeates through the pavement below the mine pool. However, several small seeps (water coming from the roof) were dried up as a result of the ash injection, but the overall water quality showed no change. Laboratory analyses in past NMLRC projects, suggest that the water quality would have been affected had the mine pool area **been filled with** ash. The research team decided not to fill the pool area unless funds became available to fill that entire area of the mine shown in Figures 3 and 4.

At the request of the West Virginia Division of Environmental Protection, a Toxicity Characteristic Leaching Procedure (TCLP) was performed on the Grant Town ash. The FBC ash from the Morgantown Energy Associates (MEA) power station in Morgantown was also analyzed. The TCLP was performed with three leaching solutions: 1) Standard Method 13 11 solution, pH 4.0 Acetic Acid buffer; 2) Acid Mine Drainage from the Maidsville seep near Morgantown; 3) pH 1.8 H_2SO_4. One hundred grams of ash were leached with two liters of each of the solutions. Samples were ran in duplicate in accordance with Quality Assurance/Quality Control procedures of the National Research Center for Coal and Energy's Analytical Laboratory. All of the analysis that have drinking water limits were within those respective limits.

Conclusions

The tests to date have shown that at least 1400 cfm of air is required to attain acceptable performance. The preliminary data from the 1700 cfm test indicate that the ejector performed even better at the higher flow. The test data also indicates that achieving the high velocity jet is very important in achieving the long transport distances of at least 100 feet. We have learned on this project that the labeled performance of the typical air compressor is almost always optimistic. Actual air flow appears to be as much as 15% below the advertised flow.

The TCLP analysis shows that even when leached with sulfuric acid (pH 1.8 H_2SO_4), the leachate from the ash samples are near the drinking water limits for all analyses.

Remaining Work

A profile of the ash that was stowed during the latter part of November will be generated when the weather allows for observations to be taken. Dr. Robert N. Eli of the Civil and Environmental Engineering department at West Virginia University will be digitizing the Sherman Helms mine. A small Geographic Information System (GIS) will be generated if deemed applicable by the research team.