

Management of Dry Flue Gas Desulfurization By-Products in Underground Mines

**Quarterly Report
October - December 1994**

Y. Chugh
D. Dutta
S. Esling
N. Ghafoori
B. Paul
H. Sevim
E. Thomasson

January 1995

Work Performed Under Contract No.: DE-FC21-93MC30252

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By
Southern Illinois University
at Carbondale
Carbondale, Illinois

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at Carbondale
Department of Mining Engineering
Carbondale, Illinois

January 1995

**MANAGEMENT OF DRY FLUE GAS DESULFURIZATION
BY-PRODUCTS IN UNDERGROUND MINES**

Technical Progress Report -- October 1 - December 31, 1994

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SECTION I

INTRODUCTION AND SUMMARY

MANAGEMENT OF DRY FLUE GAS DESULFURIZATION BY-PRODUCTS IN UNDERGROUND MINES

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INTRODUCTION AND SUMMARY

On September 30, 1993, the U.S. Department of Energy, Morgantown Energy Technology Center and Southern Illinois University at Carbondale (SIUC) entered into a cooperative agreement entitled "Management of Dry Flue Gas Desulfurization By-Products in Underground Mines" (DE-FC21-93MC30252). Under the agreement, Southern Illinois University at Carbondale will develop and demonstrate several technologies for the placement of coal combustion residues in abandoned coal mines, and will assess the environmental impact of such underground residues placement.

Previous quarterly Technical Progress Reports have set forth the specific objectives of the program, as well as the management plan and the test plan for the overall program, and those will not be repeated here. Rather, this report will set forth the technical progress made under the program for the period October 1 - December 31, 1994.

The major event during the quarter was the demonstration of the SEEC, Inc. technology for loading and transporting coal combustion residues in the SEEC developed Collapsible Intermodal Containers (CIC). The demonstration was held on November 17, 1994, at the Illinois Power Company Baldwin power plant, and was attended by about eighty (80) invited guests. A more detailed account of the description is found elsewhere in this report. Also, a complete description of the SEEC technology and the demonstration will be contained in a topical report currently under preparation.

Also during the quarter meetings were held with Peabody Coal Company officials to finalize the area in the Peabody No. 10 mine to be used for the placement of coal combustion residues. After several meetings, the specific underground area for the residues placement was delineated. This area is different and better than had been delineated earlier. A final meeting, to be held in January, 1995, will determine the exact location of the injection wells, and the subsidiary monitoring wells. It is expected that the drilling of the wells will begin in March, 1995.

Mr. Fred Brackebusch, of Mine Systems Design - one of the cooperating organizations - visited the offices here and also accompanied the SIUC investigators to a meeting at the Peabody Number 10 mine. Mr. Brackebusch assisted greatly in defining the mixes to be used in the hydraulic placement of the program.

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INTRODUCTION AND SUMMARY (CONTINUED)

Dr. Nader Ghafoori, of the SIUC Department of Civil Engineering and Mechanics, withdrew from further participation in the program, effective December 31, 1994. Dr. Ghafoori was the Co-Principal Investigator for the Physico-Chemical Characterization of Raw Materials research area. Dr. Deepak Dutta, of the SIUC Department of Mining Engineering, will assume responsibility for the Physico-Chemical Characterization work. It is believed that this change will have no adverse effect on the physico-chemical characterization area or the overall program.

Work under the Materials Handling and Systems Economics area continued, particularly in refining the costs and systems configuration and in economic evaluation of various systems using equipment leasing rather than equipment purchases. Likewise, work progressed on residues characterization, with some preparations being made for long-term testing.

Southern Illinois University at Carbondale was closed for the period December 23, 1994 to January 3, 1995 for the Christmas break.

* * * * *

SECTION II
ENVIRONMENTAL CHARACTERIZATION
DR. BRADLEY PAUL
CO-PRINCIPAL INVESTIGATOR

MANAGEMENT OF DRY FLUE GAS DESULFURIZATION BY-PRODUCTS IN UNDERGROUND MINES

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ENVIRONMENTAL CHARACTERIZATION

OBJECTIVES

Environmental characterization is a service and assurance activity. The purpose is to determine that all mixtures considered for placement underground do not have leaching characteristics that could adversely impact groundwater quality. The mixes to be characterized are to be specified by researchers in the other project areas to assure that funds are expended only for data that is directly relevant to the mixtures being considered.

STATUS

Based on initial discussions with other investigators a broad initial selection of candidate mixtures were developed. The strongest criteria used in this initial mix development were the likely quantities of unmarketable byproduct materials coming from a large scrubbed coal-fired power plant, and handling dynamics at the disposal site. These candidate mixes have now been characterized based on SLP and TCLP shake tests and the data produced has been a topic of previous reports. Based on this data, it was recommended to researchers developing mixtures for strength, elasticity, and flow characteristics that only scrubber sludge and fly ash be used in hydraulic mixes because these mixes were environmentally cleaner than the three component mixes involving bottom ash. This finding illustrates well the degree of interaction between environmental characterization and other areas of the project. From a flow standpoint, an improved gradation of materials made possible by bottom ash addition to the hydraulic mixtures would be an asset. Because of the environmental findings however, individuals in mix development and placement have focused efforts, apparently with success, in developing mixtures that do not depend on gradation with bottom ash.

The next phase of environmental characterization work illustrates well the dependance of this work on the findings of others. None of the candidate mixes developed by those in mix development and hydraulic placement correspond exactly to any of the mixes developed by environmental characterization for the initial battery of TCLP and SLP shake tests. (The mixes do represent intermediate compositions between mixes that were tested during the initial test battery, and it does appear that pneumatic placement workers will accept one of the mixes from the initial test battery on pneumatic mixes). The next phase of environmental characterization is to do a more detailed series of tests on the final candidate mixes including

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ENVIRONMENTAL CHARACTERIZATION (CONTINUED)

ASTM column leaching, acid digestion and accelerated aging tests. Because of cost, these tests must be limited to only a few materials considered final candidates for underground placement at the Peabody site. During this quarter these final candidate tests have not been initiated pending identification of the final mixes. It appears likely that one of the two pneumatic mixes will be identified within a month.

In preparation for the rapid aging tests, researchers on the Environmental Characterization team have met to determine the exact procedure to be used. The proposed procedure is included in the following section and should be regarded as an addendum providing additional detail to the earlier work plan. It should also be noted that the rapid age test now only covers one pneumatic and one hydraulic material, but that multiple test conditions and replicates have been included. Objections or concerns to this work plan addendum should be expressed as early as possible as testing is scheduled to begin during the first quarter of 1995.

Screening of multiple mixes if required is to be accomplished with the ASTM column leaching tests.

PROPOSED ACCELERATED AGING TEST PROCEDURE

The accelerated aging apparatus is structured similar to an ASTM column assembly and is shown in figure 1. The first reservoir contains the leaching medium under gas pressure. The second reservoir contains the material sample. The third reservoir is the leachate recovery vessel. The leaching medium will be forced through the test sample at a specified rate using gas pressure. The couplings between reservoirs allow the material test reservoirs to be removed and exchanged.

In general, the tests are designed to mirror potential field conditions with some provision for extremes in order to accelerate the rate of aging and allow predictions about materials conditions well into the future. Table 1 is a proposed test matrix for the rapid aging test.

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ENVIRONMENTAL CHARACTERIZATION (CONTINUED)

**Table 1
Test Matrix for Rapid Aging Test**

Material Leaching Medium	Pneumatic Mix (80:20 FA:SB ?)	Hydraulic Mix (60:40 SS:FA + 5% Lime)
Neutral 100T	3 Replicates	3 Replicates
Acidic Sulfate	3 Replicates	3 Replicates
Freeze Thaw	4 Replicates	Not Performed
	10 Assemblies	6 Assemblies

Table 1 provides the best currently available guess of the composition of the mixes that will be chosen for placement underground by the placement and mix development teams. The Pneumatic mix will most likely be a 80:20 mixture of FBC fly ash and spent bed with a 30% water addition added as a spray at the underground injection point. Mix development work appears to indicate that a minimum of 30% water will be needed to initiate the hydration reactions that will solidify the mixture. The hydraulic mix will likely consist of 60% scrubber sludge and 40% PCC fly with a 5% addition of lime in a 75% solids paste backfill.

The pneumatic mix will be prepared by placing the dry powdered ingredients in a mixer and then slowly adding 30% moisture. The mix will then be cured on a counter top for about 4 hours. The exact time may be adjusted if the material sets up rigidly in a shorter time and cannot be placed into the column, or a longer time may be used if the material swells so much that it breaks the materials reservoir. The material will be poured into the column in 2 inch lifts and then pressed firmly against the edges to prevent channelling. There will be no other compactive effort.

The hydraulic mix will be prepared by placing the dry ingredients and required water in a mixer and mixing for about 5 minutes. The material will then be poured into place in 2 inch lifts which will be pressed firmly against the edges. No other compactive effort will be used.

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ENVIRONMENTAL CHARACTERIZATION (CONTINUED)

The objective of the test is to determine changes in permeability and leachate characteristics that may occur in the field decades into the future should the backfilled material ever come into contact and communication with groundwater in the area. It should be noted that the proposed fill site is believed to be dry at the present time and not in direct communication with area aquifers except for minor seepage from surface and sandstone aquifers down into the mine. Previous work in SIUC leaching studies on coal mine wastes and combustion residues indicates that a 4 inch column of the size proposed for the rapid aging apparatus already creates a time compression effect that is estimated to be at least 12 to 1, i.e., 1 month of column leaching is equal to 1 year of field leaching. The test procedure here uses additional chemical and physical factors calculated to produce yet more time compression and enable reasonable leaching predictions beyond the lifetimes of those currently making decisions and conducting investigations.

The first leaching medium is the neutral leach medium. In reality the neutral leach medium is a synthetic groundwater with a composition based on the typical brines in southern and central Illinois as determined in earlier studies by the Illinois State Geologic Survey. Based on the rock core logs of the mine site taken earlier by Peabody coal, and by the regional findings of the Illinois State Geologic Survey, the Environmental monitoring team has expressed a belief that the water bearing units near the mine will contain brines. In addition to synthetic leaching medium reflecting area brines, any metals found in the SLP blank will be increased 100 fold were possible. The SLP blank was water collected from the sump at the bottom of the ventilation shaft near the portion of the mine to be filled in the upcoming demonstration. The water in the sump represented seepage into the water collection rings of the shaft from the overlying aquifers. Because the shaft is to be filled with coarse gravel, it is believed that seepage from the overlying aquifers may continue to get into the mine and the fill area in the future. Comparison studies between ASTM and open columns at SIUC have indicated that the duration of the first flush of easily released cations may be a function of pore volumes of water contacting the material. Because of the capacity to force leaching medium through the test material in both the ASTM and proposed accelerated aging test, it is possible to force many more pore volumes of water in a shorter time with the ASTM column test than in an open column test. The result in previous studies has been that a first flush taking about 90 days in an open column takes only 8 days in an ASTM column of the same size. This would indicate about a 10 to 1 time compression, and if the column size effects and the pore volume effect can be combined, could give the test a scale of about 1 month equals 10 years. With about a 1 year duration for the proposed test, it is hoped to simulate the leaching of the fill for 120 years following placement.

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ENVIRONMENTAL CHARACTERIZATION (CONTINUED)

(It is understood that field validation of a 120 year prediction before field placement is impractical). With the neutral leach medium, time compression is to be achieved by forcing larger volumes of water through the material in a shorter time. Previous SIUC studies have found that combustion residues may surface adsorb trace elements out of the contacting groundwater. There are also indications that surface adsorption capacity may be finite and become saturated with time. To deal with these effects, it is proposed to produce a synthetic leaching medium with up to 100 times the concentration of many of the trace elements found in the SLP blank. Concentration boosting will not be practiced for the alkali metals, but may be practiced for the heavy and toxic metals including iron. Because the SLP blank had a near neutral pH and did not have saturation concentrations of the heavy metals, it may not be possible to boost all elements to 100 times concentration. It is desired that none of the toxic or heavy metals added to the solution be at saturation concentrations, since this condition could trigger precipitation with slight pH shifts and such precipitation would not be representative of conditions existing in the field. The pressurizing gas to be used to force this leaching medium through the test sample will be inert. Most likely nitrogen will be chosen, although argon is considered.

The second leaching medium is an acid ferric sulfate solution. There is no acid drainage in the mine today, however surface GOB impoundments have developed acid drainage, and the coal and associated strata do contain pyrite which could be leached to form acid water if enough oxidant reaches the mine site. For a dry mine, 400 feet underground the scenario is extreme, but represents a fairly adverse scenario and harsh leaching conditions. Most tests designed to accelerate aging and time effects use harsh conditions to achieve acceleration. Ferric sulfate leaching has long been used in highway engineering to appraise the durability of aggregates. The second leaching medium will be acidified to pH 2 using sulfuric acid and about 1,000 ppm iron as ferric sulfate. Up to 100 times the concentration of other heavy trace metals found in the SLP blank may also be added to the leaching solution. The gas pressure will be achieved with air or oxygen. Again the pore volume effect discussed above will also be used to try to accelerate aging.

The third leaching medium is a typical brine without the concentration boosting discussed for the first medium. The proposed gas for this test is nitrogen or compressed air. The major accelerator in this test procedure is freeze-thaw cycling. The Peabody 10 mine is 400 feet underground and will probably be slightly warm from slow coal oxidation. Freezing conditions will not exist. The rationale for using a freeze thaw procedure is two fold. First, freeze-thaw cycling has long been used as a durability test procedure for concrete mixes and aggregates in highway engineering. Second, there are indications that

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ENVIRONMENTAL CHARACTERIZATION (CONTINUED)

FBC byproducts and other advanced clean coal combustion process wastes may degrade to Thaumasite, with effects on permeability particularly and leachate composition potentially. There are indications from concrete studies that clean coal combustion process wastes may degrade to Thaumasite, with effects on permeability, and that Thaumasite formation is aggravated and accelerated by freeze-thaw cycling. Thus, freeze thaw cycling will be used in this test to attempt to drive Thaumasite formation, if in fact the pneumatic mixture chosen is prone to such formation. The materials reservoir in the proposed rapid aging apparatus can be decoupled from the assembly. After 6 days of leaching the materials reservoir will be decoupled and placed in a conventional household deep freeze for a period of 6 days. The materials reservoir will then be removed from the deep freeze and will be left out in the open air in the laboratory for 2 days to thaw. The reservoir will then be recoupled to the test assembly and leached for another 6 days, with the cycle repeating there- after.

The leachate volume to be forced through the column will vary between 67% and 10% of materials reservoir volume. The target will be to force the maximum solution through the assembly each day. If the column is either more permeable than anticipated on initial start-up, or if permeability changes during the experiment, it will be permissible to shut a column down for the balance of a day once the maximum flow has been forced through. Similarly, if it is not possible to force the target water volume through with the 60 psi maximum pressure in this test, then a lesser volume of water is acceptable. Unlike the ASTM column test, the rapid aging test will not base water volumes on pore volume, and will allow for variation in the exact water volume forced through the assembly. The reasons for the deviation from the ASTM column procedure include:

- 1- Because of the way material will flow and be thrown underground, the type of compactive effect required by Proctor test will not be available in the field.
- 2- The amount of moisture addition in the field will be based on minimums to trigger cementation or cause the material to flow. This moisture will probably not be the same as the optimum moisture identified by a Proctor test.
- 3- Because the compaction procedure in the rapid aging test does not have the rigid specifications coming out of a Proctor test, it is unlikely that exact pore volumes will be reproducible enough to readily allow the apparatus operator to know with confidence the exact pore volume. This problem will be further aggravated because the FGD byproducts will be going through mineral phase and dissolution changes that will cause the pore volume to vary over the test period.

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ENVIRONMENTAL CHARACTERIZATION (CONTINUED)

4- The proposed rapid age apparatus will be operated at a maximum pressure of no more than 60 psi. FGD materials of the type being tested can potentially become impermeable enough that only minimal flows can be maintained at this pressure. Because the permeability is expected to change with time, and because the test is to run as long as possible within the framework of the cooperative agreement, it is not desired to create a specification that is so rigid that tests may be invalidated early by permeability changes.

Solution will be added to the leaching medium reservoir as required to assure that a constant supply of leaching medium is available. Solution batches will be stored under refrigeration when not in the rapid aging assembly reservoir. Leachate will be collected for analysis on the first day, second day, fourth day, eighth day, sixteenth day, and there after once a month. Records from operation of the rapid aging assembly will include the following, daily leachate volume collected and medium forced through, pressure, and where water is analyzed pH, conductivity, and dissolved cations including trace metals of environmental interest and covering the same set of cations that has been analyzed in other experiments such as the TCLP tests done for this program.

Hydraulic conductivity will be estimated based on leachate volume collected and pressure drop. The hydraulic conductivity will be measured as a function of time. The experiment contains replicate tests to allow for the likelihood that some columns will develop major fractures or channels. Leachate characteristics will also be monitored to indicate potential environmental problems. Medium blanks will be compared to leachate to indicate either cation adsorption or metals release.

At the end of the experiment, the materials reservoir will be weighed with the weight compared to the initial weight of the reservoir. The materials reservoir will then be cut open. The sample will be inspected for structural soundness including an appraisal of the size of the pieces. A sub sample will be dried at 90 degrees celsius until no weight change is observed. The amount of free water stored will be estimated. The leaching medium consumed plus the initial moisture content minus the free water stored minus the leachate volume collected will represent water consumed in reactions or lost to evaporation (this is a closed system). Specimens of the material from the columns may also be sent for mineralogical analysis or subjected to acid digestion and trace element analysis.

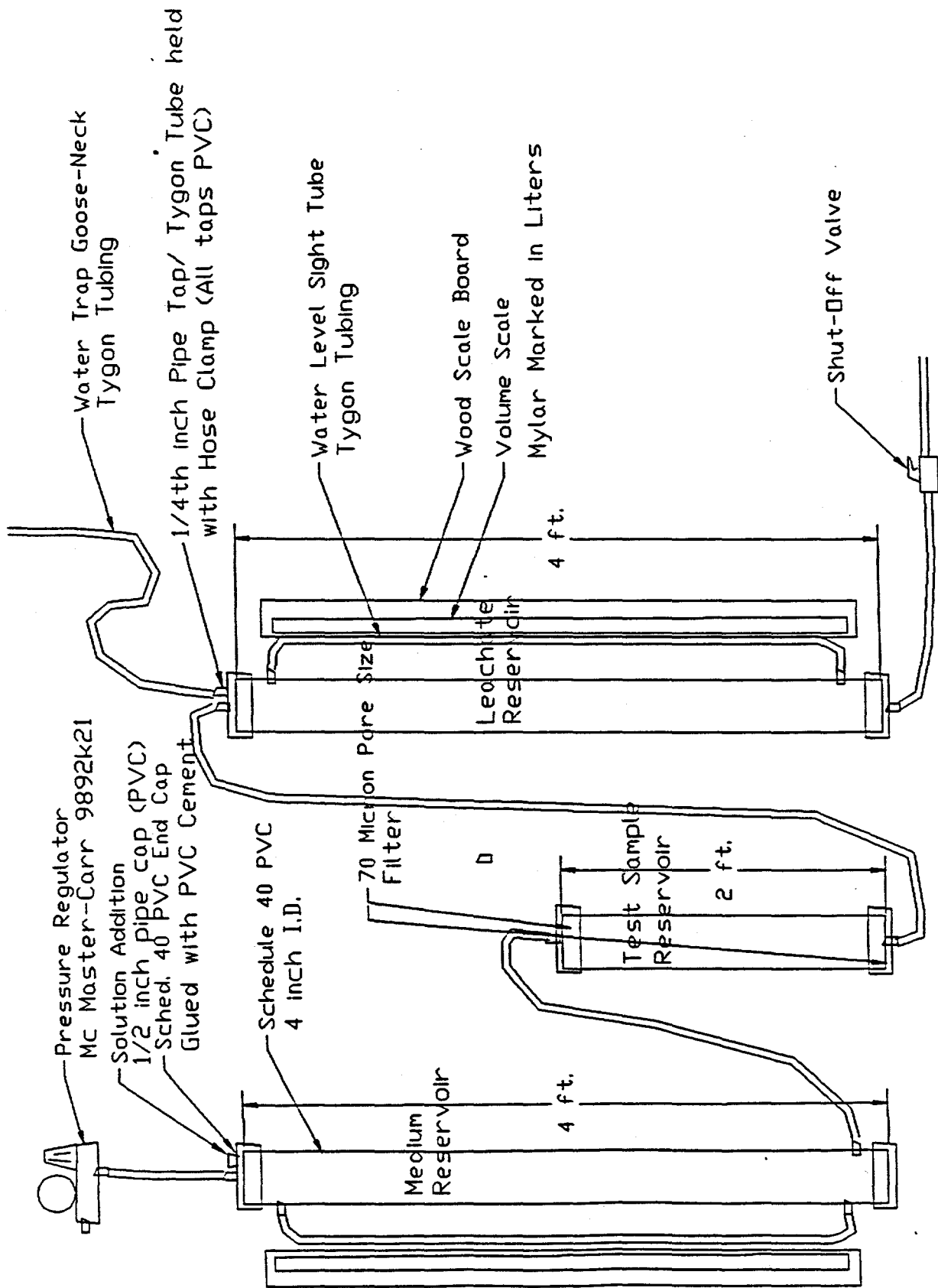


Figure 1 -- Rapid Aging Apparatus

SECTION III
PHYSICO-CHEMICAL CHARACTERIZATION
DR. N. GHAFOORI
CO-PRINCIPAL INVESTIGATOR

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PHYSICO-CHEMICAL CHARACTERIZATION

During this period testing on the bulk properties, unit weight and unconfined compressive strength of the pneumatic and hydraulic mixtures continued. Test results are shown in Figures 1 through 5. At 120 day curing, only marginal strength improvement over that of the 90 day curing was observed.

Dr. Nader Ghafoori withdrew from further participation in the program, effective December 31, 1994. Dr. Deepak Dutta will take over the work formerly conducted by Dr. Ghafoori. Dr. Dutta has been working on other aspects of the program, and has a strong background in mixtures characterization and laboratory and field work. This change in personnel should have no adverse effect on the program.

Figure 1: Bulk Density of FBC Spent Bed-Fly Ash Mixtures Compacted at 25 psi under 30% Moisture

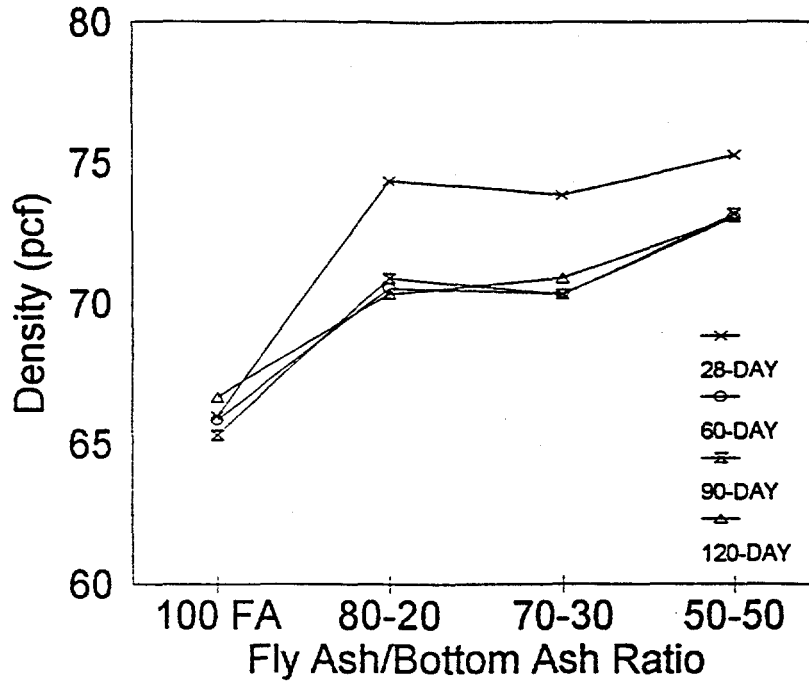


Figure 2: Compressive Strength of FBC Spent Bed-Fly Ash Mixtures Compacted at 25 psi under 30% Moisture

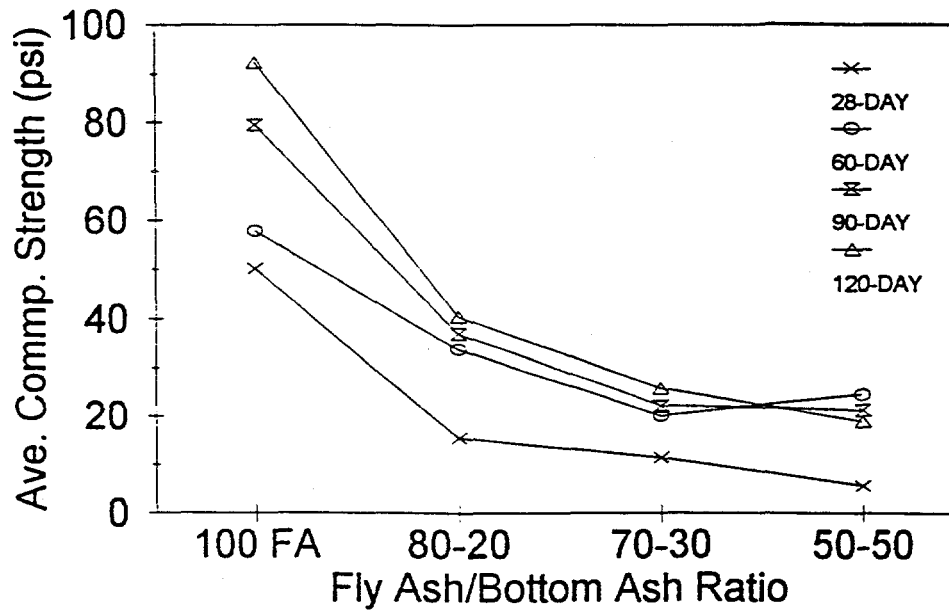


Figure 3: 28-day Compressive Strength of Various Fly Ash/Scrubber Sludge Mixes under Varying Nominal Moisture

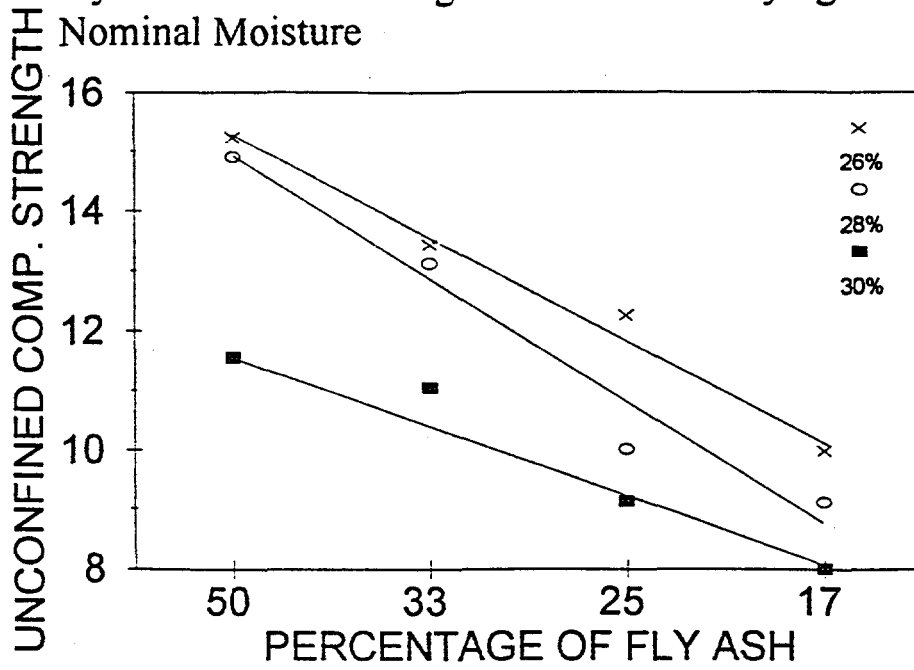


Figure 4: Unit Weight of Various Fly Ash/Scrubber Sludge Mixtures with a Nominal Moisture of 28% of Total Dry Solids

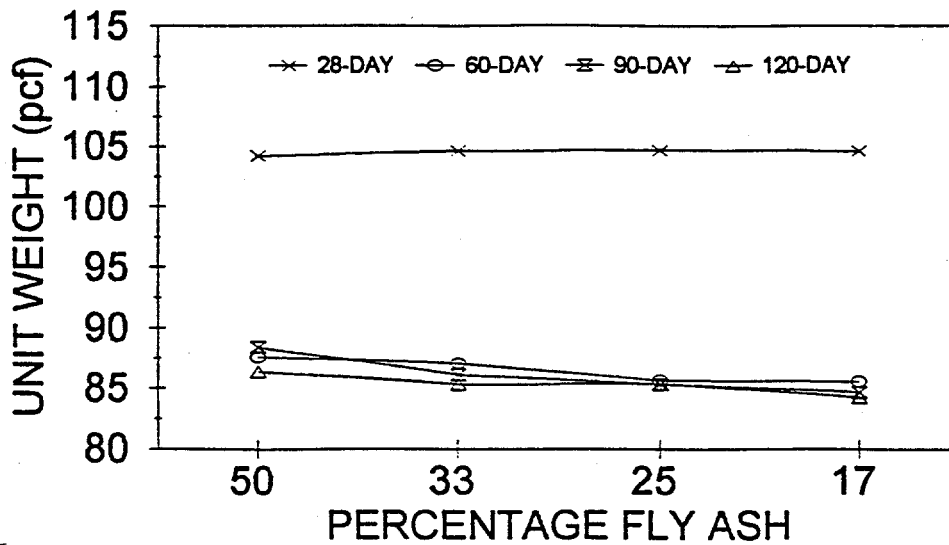
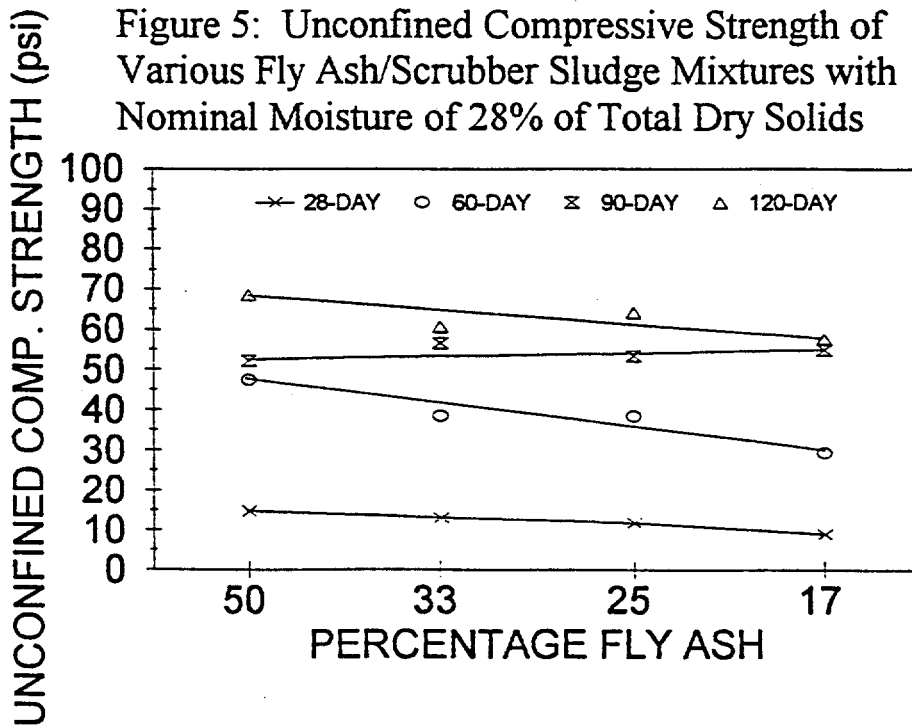


Figure 5: Unconfined Compressive Strength of Various Fly Ash/Scrubber Sludge Mixtures with Nominal Moisture of 28% of Total Dry Solids



SECTION IV
MATERIALS HANDLING & SYSTEM ECONOMICS
DR. H. SEVIM
CO-PRINCIPAL INVESTIGATOR

MANAGEMENT OF DRY FLUE GAS DESULFURIZATION BY-PRODUCTS IN UNDERGROUND MINES

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MATERIALS HANDLING AND SYSTEM ECONOMICS

DEMONSTRATION OF SEEC, INC. TECHNOLOGY

SEEC, Inc., with corporate headquarters in Mendota Heights, Minnesota, is one of the major cooperating parties in the overall project. SEEC has developed the "Collapsible Intermodal Container", or CIC for the handling and transportation of coal combustion residues and, perhaps, other products. The CIC, which is, in effect, a large (10 feet in diameter and 9 feet high), very rugged bag, is designed to hold about 20 tons of residues and to fit into rail coal cars. The concept is that the CICs can be filled with residues at an electric power plant, loaded into rail coal cars, and "back-hauled" to a coal mine for further disposition of the residues. The CIC's can then be collapsed and returned to the power plant for another trip. By using the "back-haul" concept rail rates should be significantly reduced, and by transporting residues in a completely sealed container the problem of fugitive dust should be eliminated.

Earlier SEEC had completed the design of the CIC, had three CIC's manufactured, and had conducted preliminary tests, including an overload test on them. The results of these tests have been reported in previous Technical Progress Reports.

A demonstration of SEEC's CIC technology was held at the Illinois Power Company Baldwin Power Plant on November 17, 1994.

A field demonstration of filling CIC's with coal combustion residue (in this case, fly ash) was conducted at the Illinois Power Company Baldwin Power Plant. The Baldwin plant has an ash silo filled with an ash dispensing spout that moves up and down in an accordion fashion, and is designed to fill pressure differential ash trucks. For the CIC demonstration SEEC constructed a support structure to hold the CIC upright during filling, and provided an interface between the ash spout and the CIC. The support structure had a catwalk to provide physical access to the interface. By using this support on a drop-deck trailer, the CIC's could be moved into position under the ash silo, filled, and then moved to a rail siding quickly and efficiently. No modification to the silo was necessary for the demonstration.

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MATERIALS HANDLING AND SYSTEM ECONOMICS

Once a CIC was placed in position, the ash silo spout was lowered on the CIC interface, and ash flow initiated. Filling the CIC took about five minutes, and there was virtually no fugitive dust generated. The amount of ash placed in each CIC ranged from 17 to 20 tons.

The filled CIC's were immediately transported (using the drop-bed trailer) to the rail siding where a CSX triple hopper coal car was waiting. Each CIC was lifted from the support structure and placed in the hopper car, using a boom crane. One filled CIC was placed in each bay of the hopper car. Care had to be taken to properly position the CIC so that the hooks of the lifting bracket rested on the top chord, and so that each CIC was centered in its hopper. The loading process became more efficient with experience, so that by the time the third CIC was loaded it took only about five minutes to attach the spreader bar, lift the CIC, and place it in position in the hopper car. It is believed that even this time could be significantly reduced in a full-scale operating system where equipment would be optimized for the CIC system.

The three filled CIC's were transported approximately 3,000 miles in a round-trip journey to Norfolk, Virginia and back. In Norfolk the CIC's were taken to a pier that handles ISO intermodal containers. There an overhead gantry crane and an articulating gantry crane (used for ship-to-shore container transfers) were used to move one CIC out of, and then back into the hopper rail-car. The CIC was also transported around the pier yard on a flatbed trailer to test its stability. No problems were encountered in any of these activities, and the container handling experts at the pier stated that they could efficiently handle CIC's in large numbers.

Approximately eighty (80) invited guests witnessed the CIC filling and loading demonstration at the Baldwin Power Plant. The guests represented a wide audience of mining, electric utility, railroad, and State and Federal officials.

During January, 1995, the three CIC's will be returned to the Baldwin plant. There they will be unloaded from the hopper car, transported by flat-bed truck to the Peabody Coal Company Marissa Preparation Plant, and emptied in the plant refuse disposal area. The results of the emptying demonstration will be reported in the Technical Progress Report for the period January 1 - March 31, 1995. Also, a more complete topical report on the SEEC technology and demonstration is being prepared.

MANAGEMENT OF DRY FLUE GAS DESULFURIZATION BY-PRODUCTS IN UNDERGROUND MINES

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SUMMARY OF PAST ACTIVITIES

In the fourth quarter of the project, three transportation alternatives were economically and technically evaluated and the outcomes were presented in the annual report (October, 1994). These alternatives were:

1. Pneumatic trucks (PT)
2. Pressure differential rail cars (PD-car)
3. Collapsible intermodal containers (CIC)

In the economic evaluation of the above alternatives, it is assumed that the company proposing to transport the residues, is buying, and therefore capitalizing, all the necessary equipment. The evaluation of each alternative was conducted for distances ranging from 30 to 200 miles and for production ranging from 100,000 to 300,000 tons, annually that were found to be typical in Illinois. The figure that showed the price per ton of residue, which the proposing company should charge, in each alternative for each combination of distance-tonnage is given again here (Figure 1) to recap the work done during the last quarter and to build a bridge to this quarter's work. The observations from Figure 1 can be summarized as follows:

1. The price to be charged in PT alternative is not sensitive to tonnage, but very sensitive to distance. That is, the longer the distance the higher the price to be charged.
2. The price to be charged in PD-car and CIC alternatives are not sensitive to distance but very sensitive to tonnage. That is, the more the tonnage to be transported the lower the price to be charged.
3. For 100,000-ton annual production, PT alternative provides prices lower than those of the PD-car and CIC alternatives up to a distance of approximately 170 miles. For shorter distances, the difference in the price between the truck and the other two alternatives is very significant.
4. For 200,000-ton annual production, PT alternative provides prices lower than those of the PD-car and CIC alternatives up to a distance of approximately 100 miles. Again the difference is very significant at shorter distances.

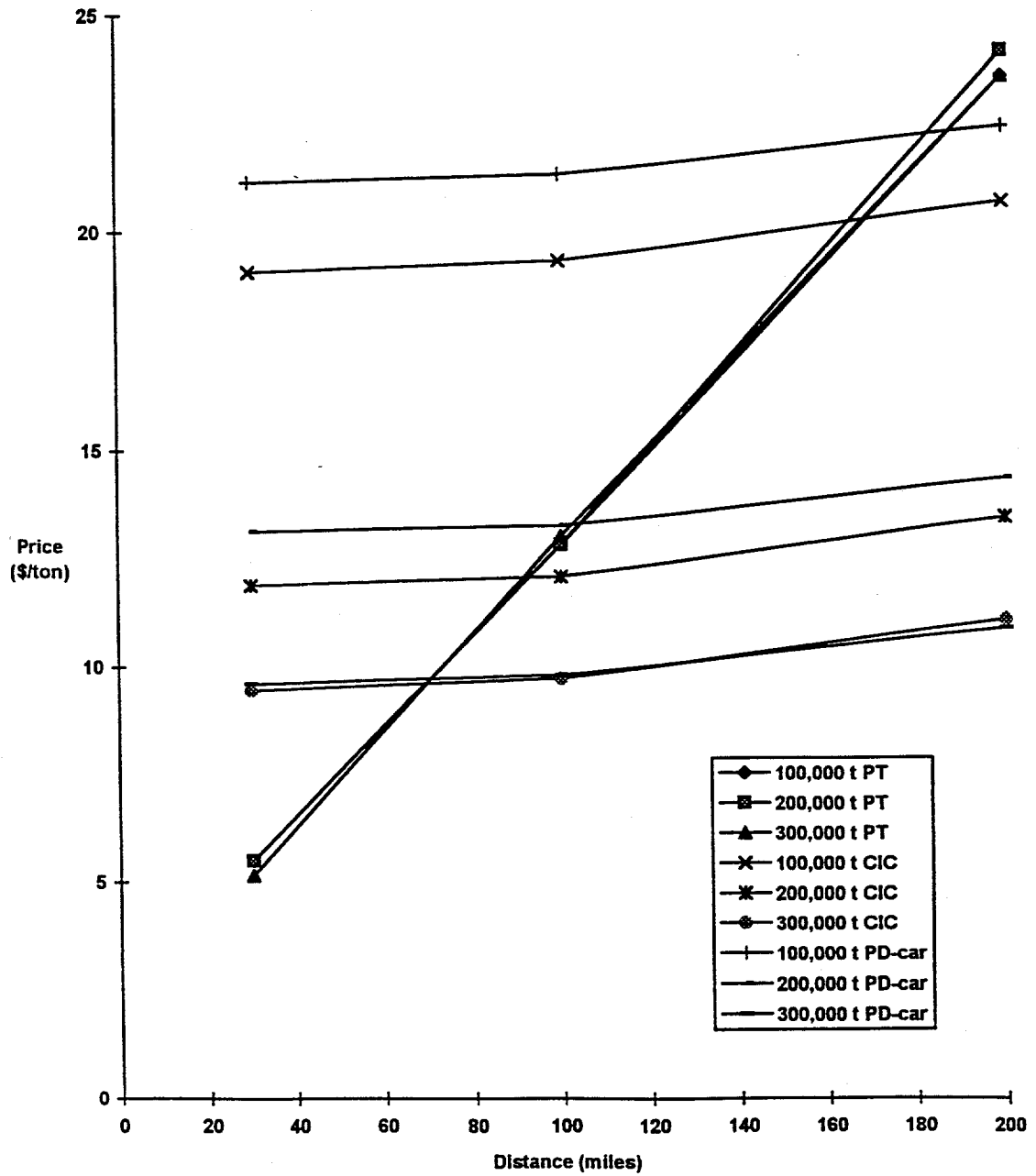


Figure 1. Prices for Transporting Dry FGD Residues by Pneumatic Trucks, PD Cars and CICs Using the Equipment Purchasing Option

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5. For 300,000-ton annual production, PT alternative provides prices lower than those of the PD-car and CIC alternatives up to a distance of
a p p r o x i m a t e l y 7 0 m i l e s .
6. For 100,000-ton annual production, the prices of PD-car and CIC alternatives show the same trend, and the price of CIC alternative runs approximately two dollars less than the PD-car for all distances.
7. For 200,000-ton annual production, the prices of PD-car and CIC alternatives show again the same trend, and the price of CIC runs approximately one dollar less than the PD-car for all distances.
8. For 300,000-ton annual production, the prices of PD car and CIC alternatives overlap for all distances.

ACTIVITIES DURING THE QUARTER OF OCTOBER 1 - DECEMBER 31, 1994

In this quarter, the economic evaluation of the transportation systems were conducted based on the leasing option. In other words, the trucks in the PT alternative, the PD cars in the PD-car alternative, and the CICs in the CIC alternative were assumed to be leased rather than purchased. Consequently, the leasing cost was expended out in the economic analysis. The information obtained for the leasing option and the assumptions made for each alternative are given below.

1. PT Alternative

These trucks cost approximately \$120,000 and have a depreciation life of 5 years. It is assumed that the owner of the trucks could accept a leasing plan that would give him \$24,000 per year per truck ($\$120,000/5$ years) and sell each truck for \$46,732 at the end of the 5th year to obtain a return of 10% on his initial investment of \$120,000. The calculation is shown below:

$$120,000 = 24,000 (A/P, 10\%, 5) + X (P/F, 10\%, 5)$$

- where: - X is the salvage value of the truck at the end of the 5th year (\$46,732).
- (A/P, 10%, 5) is the "uniform payment series present worth factor" for a discount rate of 10% and a life of 5 years.
- (P/F, 10%, 5) is the "single payment present worth factor" for a discount rate of 10% and a life of 5 years.

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Under this scenario, truck maintenance cost is assumed to be the responsibility of the lessee. The input data for the economic evaluation of this alternative is given in Table 1.

2. PD-car alternative

The purchase price of a PD car is approximately \$75,000. Mr. Joseph Lencewicz of Helm Financial Corporation in Chicago, a company specializing in PD car leasing, has indicated that a PD car could be rented for \$900/month on a 5-year contract. The maintenance cost of such cars would be \$0.03 per mile for all miles. The input data for the economic evaluation of this alternative is given in Table 2. It is noted that only the PD cars are considered as the leased items, other equipment and the infrastructure necessary to operate the PD-car system are assumed to be purchased, and therefore, capitalized.

3. CIC Alternative

The SEEC Inc.'s officials indicated that their CICs can be leased out at 65% of its purchase price for a 5-year leasing policy. The purchase price of a CIC is \$15,000. This information has been used to calculate the annual lease cost as:

$$\$15,000 \times 0.65 / 5 \text{ years} = \$4,615 \text{ per year}$$

As in the case of PD-car alternative, all other equipment and infrastructure necessary to operate the CIC system are assumed to be purchased, and therefore, capitalized. The input data for the economic evaluation of this alternative is given in Table 3.

ECONOMIC EVALUATION OF TRANSPORTATION SYSTEMS USING LEASING OPTION

Each transportation alternative was evaluated for nine tonnage-distance combinations and the outcomes are summarized in Tables 4, 5, and 6. In these tables, for an easy comparison of the leasing option with the purchase option, the results of purchase option are given in parenthesis next to the leasing option results. Figure 2 graphically depicts these results, and it is the counterpart of Figure 1. The observations from Figure 2 and Tables 4, 5, and 6 can be summarized as follows:

Table 1. Input Data for the Economic Evaluation of the Pneumatic Truck Alternative
Using the Equipment Leasing Option

Distance between the power plant and the mine (miles)	30	100	200	30	100	200	30	100	200
Annual fly ash production (tons)	100000	100000	100000	200000	200000	200000	300000	300000	300000
Project life	5	5	5	5	5	5	5	5	5
Number of working days per year	300	300	300	300	300	300	300	300	300
Area of new road to be constructed (sq. yd)	14000	14000	14000	28000	28000	28000	42000	42000	42000
Truck capacity (tons)	24	24	24	24	24	24	24	24	24
Availability of trucks	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Truck loading time (minutes)	5	5	5	5	5	5	5	5	5
Truck unloading time (minutes)	30	30	30	30	30	30	30	30	30
Loaded travel speed (miles per hour)	50	50	50	50	50	50	50	50	50
Empty travel speed (miles per hour)	55	55	55	55	55	55	55	55	55
Number of front tires	10	10	10	10	10	10	10	10	10
Number of rear tires	8	8	8	8	8	8	8	8	8
Front tire replacement frequency (miles)	75000	75000	75000	75000	75000	75000	75000	75000	75000
Rear tire replacement frequency (miles)	150000	150000	150000	150000	150000	150000	150000	150000	150000
Fuel consumption (miles per gallon)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Fuel cost per gallon	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Purchase price of the tractor	45000	45000	45000	45000	45000	45000	45000	45000	45000
Purchase price of the tank trailer	70000	70000	70000	70000	70000	70000	70000	70000	70000
Purchase price of the plover	5000	5000	5000	5000	5000	5000	5000	5000	5000
Total purchase price of tractor & trailers	120000	120000	120000	120000	120000	120000	120000	120000	120000
Tire cost (each)	325	325	325	325	325	325	325	325	325
Insurance cost per tractor and trailer	7500	7500	7500	7500	7500	7500	7500	7500	7500
Licence cost per tractor and trailer	2222	2222	2222	2222	2222	2222	2222	2222	2222
Annual highway tax per tractor and trailer	550	550	550	550	550	550	550	550	550
Maintenance cost per mile	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
Hourly wage for truck drivers including fringe benefits	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Hourly charge of contracted labor at the plant	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00
Overhead cost (% of other operating costs)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Cost of road construction (\$/sq. yd)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Truck Cycle time (minutes)	103.73	264.09	493.18	103.73	264.09	493.18	103.73	264.09	493.18
Number of shifts per day	1.00	1.00	1.00	1.00	1.00	1.00	2.00	2.00	2.00
Duration of each shift (hours)	10.00	10.00	10.00	10.00	10.00	10.00	8.00	8.00	8.00
Number of trips per day	13.89	13.89	13.89	27.78	27.78	27.78	41.67	41.67	41.67
Number of trucks required	2.40	6.11	11.42	4.80	12.23	22.83	4.50	11.48	21.41
Number of trucks proposed	3.00	7.00	13.00	6.00	14.00	27.00	6.00	16.00	29.00
Number of drivers required	3.00	7.00	13.00	6.00	14.00	27.00	6.00	32.00	58.00
Minimum # of trucks imposed for system's availability calc.	2.00	6.00	11.00	5.00	12.00	23.00	5.00	14.00	25.00
System's availability	0.97	0.85	0.87	0.89	0.84	0.87	0.89	0.79	0.84
OPERATING COST									
Leasing cost of pneumatic trucks	72000	168000	312000	144000	336000	648000	144000	384000	896000
Insurance	22500	52500	97500	45000	105000	202500	45000	120000	217500
Road construction cost	70000	70000	70000	140000	140000	140000	210000	210000	210000
Licences for tractors and trailers	8866	15554	28888	13332	31108	59994	13332	35552	64438
Highway tax	1650	3850	7150	3300	7700	14850	3300	8800	15950
Tire replacement	15167	50556	101111	30333	101111	202222	45500	151687	303333
Driver wages	192153	432153	792153	384306	884306	1644306	612458	1572458	2820458
Fuel	55000	183333	368667	110000	368667	733333	185000	550000	1100000
Maintenance	35000	116667	233333	70000	233333	466667	105000	350000	700000
Subtotal	470135	1092812	2008800	940271	2185225	4111872	1343590	3382477	6127680
Overhead @10% of the subtotal	47014	109281	200880	94027	218522	411187	134359	338248	612768
Total operating cost	517149	1201874	2209680	1034298	2403747	4523059	1477949	3720725	6740448
Operating cost per ton	5.17	12.02	22.10	5.17	12.02	22.62	4.93	12.40	22.47

Table 2. Input Data for the Economic Evaluation of the Pressure Differential Car Alternative Using the Equipment Leasing Option

Distance between the power plant and the mine (miles)	30	100	200	30	100	200	30	100	200
Annual fly ash production (tons)	100000	100000	100000	200000	200000	200000	300000	300000	300000
Initial distance between rail siding and injection site	1	1	1	1	1	1	1	1	1
Area of new road to be constructed (sq. yd)	14000	14000	14000	28000	28000	28000	42000	42000	42000
Number of working days per year	260	260	260	260	260	260	260	260	260
Number of working days per week	5	5	5	5	5	5	5	5	5
Project life	5	5	5	5	5	5	5	5	5
Pneumatic truck capacity (tons)	25	25	25	25	25	25	25	25	25
Rail car capacity (tons)	100	100	100	100	100	100	100	100	100
Pneumatic truck cycle time (minutes)	60	60	60	60	60	60	60	60	60
Duration of each shift (hours)	8	8	8	8	8	8	8	8	8
Number of rail cars per unit train	20	20	20	20	20	20	20	20	20
Fuel consumption rate (gal/hour)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
PD car maintenance cost (\$0.03/mile/car)	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Trucks maintenance cost rate (% of purchase price - decimal)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Overhead cost (% of operating cost in decimal)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Leasing cost of a PD car (\$/car/month)	900	900	900	900	900	900	900	900	900
Purchase price of pneumatic trucks	120000	120000	120000	120000	120000	120000	120000	120000	120000
Tire cost (\$/truck/mile)	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Contracted labor at the plant site(\$/hr)	35	35	35	35	35	35	35	35	35
Hourly wage for pneumatic truck drivers	27	27	27	27	27	27	27	27	27
Fuel cost per gallon	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Length of rail siding (yard)	440	440	440	440	440	440	440	440	440
Railroad charge (\$/ton/mile)	0.0947	0.03	0.02	0.089	0.0277	0.0189	0.0758	0.0243	0.0172
Insurance cost (% of capital cost in decimal)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Cost of road construction (\$/sq. yd)	5	5	5	5	5	5	5	5	5
Number of shifts per day	1	1	1	1	1	1	2	2	2
Number of unit trains per two weeks	2	2	2	4	4	4	6	6	6
Number of truck trips per shift per truck	8	8	8	8	8	8	8	8	8
Number of pneumatic trucks required per shift	2	2	2	4	4	4	3	3	3
Number of truck trips per shift	16	16	16	31	31	31	24	24	24
Number of pneumatic rail cars required per trip	20	20	20	20	20	20	20	20	20
Total number of PD cars required for the operation	60	60	60	60	60	60	60	60	60
Time to fill a PD car (hours)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Total number of shifts per week	5	5	5	5	5	5	10	10	10
Total number of truck drivers required per shift	2	2	2	4	4	4	3	3	3
CAPITAL INVESTMENT									
Pneumatic trucks	240000	240000	240000	480000	480000	480000	360000	360000	360000
Rail siding (\$570/yard)	250800	250800	250800	250800	250800	250800	250800	250800	250800
Total capital investment	490800	490800	490800	730800	730800	730800	610800	610800	610800
OPERATING COST									
Leasing cost of PD cars	648000	648000	648000	648000	648000	648000	648000	648000	648000
PD cars maintenance cost	5616	18720	37440	11232	37440	74880	16848	56160	112320
Road construction cost.	70000	70000	70000	140000	140000	140000	210000	210000	210000
Rail road charge	284100	300000	400000	534000	554000	756000	682200	729000	1032000
Insurance	4908	4908	4908	7308	7308	7308	6108	6108	6108
Operators wage	121420	121420	121420	242840	242840	242840	364260	364260	364260
Tire cost	499	499	499	998	998	998	748	748	748
Fuel cost	11440	11440	11440	22880	22880	22880	17160	17160	17160
Other maintenance cost	9816	9816	9816	14616	14616	14616	12216	12216	12216
Subtotal	1155799	1184803	1303523	1621874	1668082	1907522	1957540	2043652	2402812
Overhead cost (@10% of subtotal)	115579	118480	130352	162187	166808	190752	195754	204365	240281
Total operating cost	2427177	2488086	2737398	3405935	3502972	4005296	4110834	4291669	5045905
Operating cost per ton	24.27	24.88	27.37	17.03	17.51	20.03	13.70	14.31	16.82

Table 3. Input Data for the Economic Evaluation of the Collapsible Intermodal Container Alternative Using the Equipment Leasing Option

Distance between the power plant and the mine (miles)	30	100	200	30	100	200	30	100	200
Annual fly ash production (tons)	100000	100000	100000	200000	200000	200000	300000	300000	300000
Area of new road to be constructed (sq. yd)	14000	14000	14000	28000	28000	28000	42000	42000	42000
Initial distance between rail and injection site (miles)	1	1	1	1	1	1	1	1	1
Project Life (years)	5	5	5	5	5	5	5	5	5
Number of working days per year	260	260	260	260	260	260	260	260	260
Number of unit trains per two weeks	2	2	2	4	4	4	6	6	6
Railroad charge (\$/ton/mile)	0.0947	0.03	0.02	0.089	0.0277	0.0189	0.0758	0.0243	0.0172
Number of hours per shift	8	8	8	8	8	8	10	10	10
Equipment maintenance cost (percent of capital cost in decimals)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Number of shifts per week	5	5	5	5	5	5	5	5	5
Number of shifts per day	1	1	1	1	1	1	1	1	1
Number of contracted trailers to take back empty CIC's to plant	1	1	1	2	2	2	2	2	2
CIC capacity (tons)	22	22	22	22	22	22	22	22	22
Total trailer capacity (tons)	25	25	25	25	25	25	25	25	25
Cycle time of tote trailer (minutes)	26	26	26	26	26	26	26	26	26
Number of hopper cars	22	22	22	22	22	22	22	22	22
Number of CICs emptied per shift	18	18	18	18	18	18	23	23	23
Number of CIC's required for the operation	105	105	105	105	105	105	105	105	105
Number of tote trailers required	1	1	1	2	2	2	3	3	3
Number of MI-JACK cranes required	1	1	1	1	1	1	1	1	1
Number of boom cranes required	1	1	1	1	1	1	1	1	1
Number of inverters required	1	1	1	1	1	1	1	1	1
Number of tote trailer operators required	1	1	1	2	2	2	3	3	3
Number of boom crane operators required	1	1	1	1	1	1	1	1	1
Number of injection system operators required	1	1	1	1	1	1	1	1	1
Purchase price of CIC	15000	15000	15000	15000	15000	15000	15000	15000	15000
Purchase price of boom crane at plant	200000	200000	200000	200000	200000	200000	200000	200000	200000
Purchase price of tote trailer	60000	60000	60000	60000	60000	60000	60000	60000	60000
Purchase price of inverter	600000	600000	600000	600000	600000	600000	600000	600000	600000
Purchase price of a MI-JACK crane	325000	325000	325000	325000	325000	325000	325000	325000	325000
Purchase price of a Forklift	35000	35000	35000	35000	35000	35000	35000	35000	35000
CAPITAL INVESTMENT									
Construction of a storage site at the plant site (2,000 tons)	400000	400000	400000	400000	400000	400000	400000	400000	400000
Storage and staging area at the mine site (65,000 square feet)	300000	300000	300000	300000	300000	300000	300000	300000	300000
MI-JACK crane	325000	325000	325000	325000	325000	325000	325000	325000	325000
Boom-crane(s)	200000	200000	200000	200000	200000	200000	200000	200000	200000
Tote trailer(s)	60000	60000	60000	120000	120000	120000	180000	180000	180000
Forklift to load empty CIC's at the mine	35000	35000	35000	35000	35000	35000	35000	35000	35000
Inverter	600000	600000	600000	600000	600000	600000	600000	600000	600000
Total capital investment	1920000	1920000	1920000	1980000	1980000	1980000	2040000	2040000	2040000
Cost of road construction (\$/sq. yd)	5	5	5	5	5	5	5	5	5
Fuel consumption (gallons per hour per unit of equipment)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Fuel cost per gallon	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Hourly wage for equipment operators (including 35 % fringe)	27	27	27	27	27	27	27	27	27
Hourly charge of contracted labor at the plant site (4 hrs per train)	35	35	35	35	35	35	35	35	35
Contracting charges for taking back empty CIC's (\$/mile for 36 cars)	5	2	2	5	2	2	5	2	2
Leasing cost of a single CIC (65% of purchase price/project life)	9750	9750	9750	9750	9750	9750	9750	9750	9750
OPERATING COST									
Leasing cost of CICs	204750	204750	204750	204750	204750	204750	204750	204750	204750
Road construction cost	70000	70000	70000	140000	140000	140000	210000	210000	210000
Annual railroad backhaul charge	284100	300000	400000	534000	554000	756000	682200	729000	1032000
Insurance cost @1% of capital cost	19200	19200	19200	19800	19800	19800	20400	20400	20400
Operator wages	231920	231920	231920	295360	295360	295360	443040	443040	443040
Contracting charges for taking back empty CICs	18900	25200	50400	37800	50400	100800	56700	75600	151200
Fuel	22880	22880	22880	28600	28600	28600	42900	42900	42900
Maintenance cost * # of shifts per day	38400	38400	38400	39600	39600	39600	40800	40800	40800
Subtotal	890150	912350	1037550	1299910	1332510	1584910	1700790	1766490	2145090
Overhead @10% of subtotal	89015	91235	103755	129991	133251	158491	170079	176649	214509
Total operating cost	979165	1003585	1141305	1429901	1465761	1743401	1870869	1943139	2359599
Operating cost per ton	9.79	10.04	11.41	7.15	7.33	8.72	6.24	6.48	7.87

**MANAGEMENT OF DRY FLUE GAS DESULFURIZATION
BY-PRODUCTS IN UNDERGROUND MINES**

Technical Progress Report -- October 1 - December 31, 1994

GEOTECHNICAL STUDIES CONTINUED

Table 4. Prices in PT Transportation - Leasing Option (\$/Ton)

Production (tons/year)	Distance (miles)		
	30	100	200
100,000	5.17 (5.52)	12.02 (12.83)	22.10 (23.63)
200,000	5.17 (5.52)	12.02 (12.83)	22.62 (24.17)
300,000	4.93 (5.17)	12.40 (13.02)	22.47 (23.60)

Table 5. Prices in PD-Car Transportation - Leasing Option (\$/Ton)

Production (tons/year)	Distance (miles)		
	30	100	200
100,000	14.21 (21.17)	14.53 (21.35)	15.84 (22.45)
200,000	10.05 (13.15)	10.30 (13.27)	11.62 (14.37)
300,000	7.81 (9.62)	8.12 (9.80)	9.44 (10.90)

Table 6. Prices in CIC Transportation - Leasing Option (\$/Ton)

Production (tons/year)	Distance (miles)		
	30	100	200
100,000	15.86 (19.10)	16.11 (19.35)	17.48 (20.73)
200,000	10.28 (11.90)	10.46 (12.08)	11.85 (13.47)
300,000	8.39 (9.47)	8.63 (9.72)	10.02 (11.10)

Table 7. Average Price Reduction in Residue Transportation Alternatives When Leasing Option is Selected Over Purchasing Option (\$/Ton)

Production (tons/year)	Pneumatic Truck	PD-car	CIC
100,000	0.90	6.80	3.24
200,000	0.90	2.94	1.62
300,000	0.66	1.65	1.08

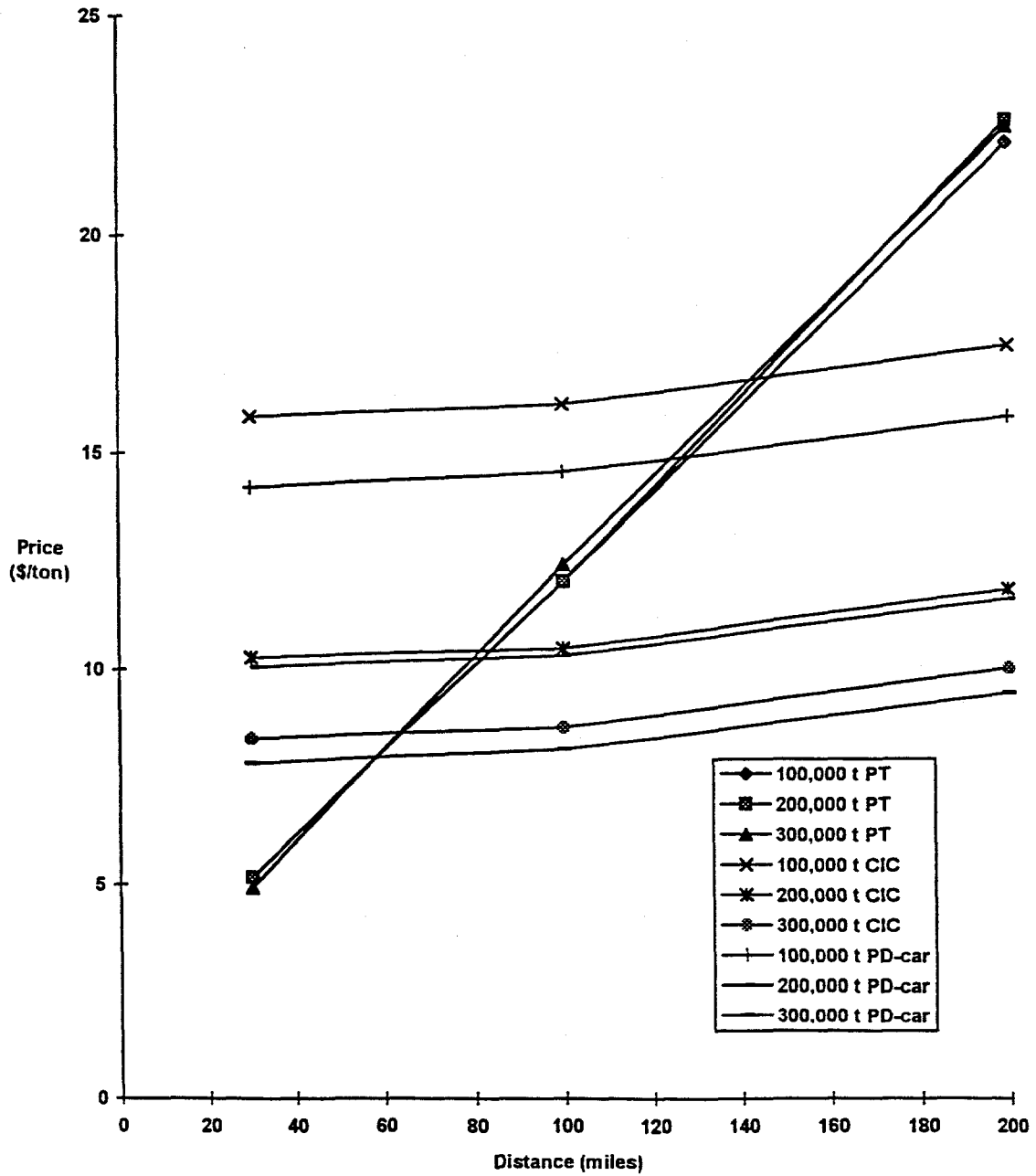


Figure 2. Prices for Transporting Dry FGD Residues by Pneumatic Trucks, PD Cars and CICs Using the Equipment Leasing Option

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MATERIAL HANDLING AND SYSTEM ECONOMICS

1. The price trends remain essentially the same for all three alternatives as in the purchase option. That is, the prices in PT alternative are insensitive to tonnage but very sensitive to distance, whereas those of the PD-car and CIC alternatives are just the opposite.

2. Prices in PT alternative are slightly lower in leasing option when compared with the purchase option, but the difference is insignificant.

3. The prices in PT alternative are lower than those of the PD-car and CIC alternatives for distances up to 150, 80, and 60 miles for annual productions of 100,000, 200,000, and 300,000 tons, respectively.

4. When compared with the purchase option, the prices in PT alternative for the leasing option show a slight decrease. The prices in PD-car and CIC alternatives, however, show significant decrease, especially for 100,000 ton annual production.

5. The average price reductions when switched from purchasing to leasing option for all three transportation alternatives are given in Table 7. The values shown in this table were deduced from the prices listed in Tables 4, 5, and 6. Each value is calculated by averaging the reductions over all three distances. For instance, the \$6.80 average reduction realized in PD-car alternative for 100,000-ton production is calculated by taking the price differences at 30, 100, and 200-mile distances (Table 5, row 1) and dividing the sum of the differences by 3. That is,

$$\{(21.17-14.21) + (21.34-14.53) + (22.45-15.84)\}/3 = \$6.80$$

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MATERIAL HANDLING AND SYSTEM ECONOMICS

It is seen from this table (and from Graph 2) that the average price reduction is significant in PD-car and CIC alternatives, but more so in PD-car alternative. As a matter of fact, for 100,000-ton production rate, the \$6.80 reduction in PD-car alternative was large enough to make PD-car a better alternative than CIC. It is noted that the CIC alternative was better than the PD-car alternative in purchasing option as portrayed in Figure 1. Similarly, for 200,000 and 300,000-ton production rates, the PD-car alternative became slightly better than the CIC for all distances, but the differences are too small to make a statement on the advantage of one system over the other.

It is noted that the above reported outcomes are totally dependent on the input data. These outcomes will be submitted to SEEC Inc. and to Illinois Central Co. to seek their views and comments as previously done with the outcomes presented in the annual report. Both SEEC Inc. and Illinois Central Co. officials have promised to provide written comments about the analyses presented in the annual report, which hopefully will be obtained in the near future.

PLANS FOR THE NEXT QUARTER

It is planned that a topical report will be completed by the end of March 1995. The successful completion of this report will depend on two major factors:

- 1) Obtaining technical and economic information on pneumatic loading and unloading systems. This information was sought earlier from Fuller-Kovako officials had indicated interest and had been optimistic in providing the necessary information. In spite of repeated efforts by us to start the cooperative work with Fuller Kovako, they remained unresponsive for quite some times. This has lead us to the conclusion that they are unwilling to cooperate. New initiatives, therefore, have been made to find another company in the same area.

- 2) Obtaining technical and economic information on pneumatic and hydraulic injection systems.

SECTION V

**ENVIRONMENTAL ASSESSMENT
AND GEOTECHNICAL STABILITY**

DR. S. ESLING

CO-PRINCIPAL INVESTIGATOR

MANAGEMENT OF DRY FLUE GAS DESULFURIZATION BY-PRODUCTS IN UNDERGROUND MINES

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ENVIRONMENTAL ASSESSMENT AND GEOTECHNICAL STABILITY AND SUBSIDENCE IMPACTS

Conceptual Model

Work continued on developing a conceptual model of site geology and hydrology. Timothy McDonald, the graduate assistant working on this project, spent two days at Peabody Coal Company offices working with the computerized well log data base of the Peabody #10 mine. Structure contour and isopach maps were prepared for the major units, including the top of the Herrin (No. 6) Coal, top of bedrock, and thickness of the Anvil Rock Sandstone. The computer system at Peabody has a slow response time and further work on figures summarizing geology at the mine will continue at Southern Illinois University. The SIUC Geology Department has a package (Terra Sciences) for analyzing stratigraphic relationships that should provide a quicker turnaround.

Summary figures prepared thus far indicate errors in the well log files. Work next quarter will concentrate on correcting these problems so that figures summarizing the conceptual model can be prepared.

Drilling Plans

The original test plan submitted to the DOE has to be modified with regard to groundwater sampling. The dry mine and the low permeability of the material above the mine suggest that a groundwater monitoring well screened in the coal would not yield groundwater samples. The nearest horizon that may have sufficient permeability to yield groundwater samples is probably a sandstone located just under 10 feet above the top of the Herrin Coal (Anvil Rock Sandstone). This unit does not contain potable groundwater, but may have sufficient permeability for monitoring hydraulic head.

Drilling is scheduled for the end of the first quarter (March, 1995). Currently six sites are under consideration for injection. These six sites will be reduced to two after preliminary drilling. Activities for the first quarter regarding drilling also include acquiring casing and grout, electronic data logging equipment, and the packer.

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ENVIRONMENTAL ASSESSMENT AND GEOTECHNICAL STABILITY (CONTINUED)

Other Activities

The ISGS team hired a graduate student on an hourly basis to assist with the technical analysis related to this project. Miguel Restrepo, a graduate student in Civil Engineering at the University of Illinois, started work in late September 1994. M. Restrepo works 10 hours per week and plans to work on the project through the Spring semester and possible during the summer.

Ed Mehnert and Miguel Restrepo completed a literature search on the topic of packer testing. M. Restrepo developed a draft document for conducting and analyzing single and double packer tests. Methods discussed include conventional methods discussed in the Bureau of Reclamation's Ground Water Manual (1985) to less common methods such as Dagan (1978). This draft should be finalized by mid-February.

References

Dagan, G., 1978. A note on packer, slug, and recovery tests in unconfined aquifers, Water Resources Research, V. 14, No. 5, pp. 929-934.

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SECTION VI
GEOTECHNICAL STUDIES
DR. D. DUTTA
CO-PRINCIPAL INVESTIGATOR

MANAGEMENT OF DRY FLUE GAS DESULFURIZATION BY-PRODUCTS IN UNDERGROUND MINES

Technical Progress Report -- October 1 - December 31, 1994

GEOTECHNICAL STUDIES

OBJECTIVES

Hydraulic placement of CCR (coal combustion residues) and FGD by-products into abandoned mine workings may negatively impact stability of mine workings and surface subsidence since Illinois coal seams are generally associated with thick 2-4 ft, and weak 300-1000 psi floor strata. Resulting short-term subsidence due to wet backfilling can cause damage to surface structures and impact land use patterns. In addition, underground bulkhead stability may be negatively impacted due to hydraulic and active pressures imposed by hydraulic or pneumatic placement of by-products. The immediate floor strata associated with No. 6 coal seam (Herrin Seam) at Peabody No 10 demonstration mine are known to be weak (Chugh et al., 1989). The objective of these studies are:

1. Analyze the stability of abandoned mine workings prior to and after disposal of combustion by-products,
2. Estimate the surface subsidence movements and their characteristics due to wet disposal of by-products,
3. Assess the stability of isolation structures such as bulkhead to withstand pressures due to the disposal of FGD by-products,
4. Monitor long term surface and sub-surface movements prior to and after backfilling of coal combustion by-products.

The results of the demonstration studies at Peabody No. 10 mine will be generalized for other areas within the Illinois Coal Basin.

TASKS WORKED ON DURING THE LAST QUARTER

In this quarter, strength characteristics of hydraulic fill materials were investigated to find a suitable mix of fly ash, scrubber sludge, lime, and water. Also, time dependent finite element analyses were carried out to simulate the effects of backfilling on floor heave and roof sag.

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GEOTECHNICAL STUDIES (CONTINUED)

Strength Tests of Hydraulic Backfill Materials. Two samples (1) 17% fly ash, 83% scrubber sludge, 28% water, and (2) 50% fly ash, 50% scrubber sludge, 28% water were tested to determine the uniaxial compressive strength and Young's modulus. The sample having 17% fly ash showed an uniaxial compressive strength of 34 psi and Young's modulus of 1600 psi. The sample having 50% fly ash showed an uniaxial compressive strength of 55 psi and Young's modulus of 6700 psi. As there is no material to activate the pozzolanic characteristics of fly ash, the mix of fly ash and scrubber sludge does not develop any significant strength over time. In the last annual report, it was noted that the hydraulic backfill material consisting of fly ash and scrubber sludge disintegrates when it comes in contact with water due to the presence of calcium sulfate in the scrubber sludge. Moreover, the mix consisting of only fly ash and scrubber sludge has very low uniaxial compressive strength and deformation modulus when tested dry. It was decided, therefore, to activate the pozzolanic characteristics of fly ash by adding small amounts of lime to the mix of fly ash and scrubber sludge.

Two sets of samples of backfill mix having 2.5% and 5% lime and different proportions of fly ash and scrubber sludge were prepared for laboratory testing to determine the uniaxial compressive strength and Young's modulus of dry samples and the effects of water on the mix. In the first set of six samples, three samples were made from 25% fly ash, 2.5% lime, 72.5% scrubber sludge, and 30% water. The other three samples were made from 25% fly ash, 5% lime, 70% scrubber sludge, and 30% water. In the second set of two samples, one sample had 5% lime, 25% water, 35% fly ash, and 60% scrubber sludge and the other sample had 40% fly ash, 5% lime, 55% scrubber sludge and 25% water. All the samples were cured for 24 hours before demolding and thereafter cured in the autoclave at 80 psi pressure for 4 hours. Because of high temperature in the auto clave, the gypsum in the scrubber sludge was dehydrated, causing numerous cracks in the samples.

The following laboratory tests were performed on the samples:

1. Determination of free swelling pressures of two samples over a period of three days.
2. Determination of pH of water in contact with the two samples over a period of three days.
3. Determination of temperature rise of water in contact with the two samples over a period of three days.

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GEOTECHNICAL STUDIES (CONTINUED)

4. Determination of moisture content of the two samples after three days the samples were immersed in water for three days.
5. Determination of the ultimate compressive strength and Young's modulus of the two saturated samples (after the samples were immersed in water for three days).
6. Determination of the ultimate compressive strength and Young's modulus of six dry samples.

The laboratory testing procedure was described in the annual report. The results of laboratory tests are as follows:

Temperature Rise: The temperature of water in contact with the samples was never above the room temperature. Most of the time, the water temperature was 0.5 to 1 degree celsius below the room temperature. The temperature of the tap water, which is always 2 to 3 degrees celsius below the room temperature, increased by 1.5 to 2.5 degrees celsius within 1 to 3 hours of pouring water into the water jacket.

Increase in pH: Figure 1 shows the increase in pH of water (in the jacket and in contact with the samples) during the 72 hours of testing. The pH of tap water was 9.0 which increased sharply to 10.2 for the sample having 2.5% lime (25% fly ash) within the first half hour. After the first four hours, the pH was started dropping and eventually came down to 9.3. For the sample having 5% lime (25% fly ash), the pH of water increased to only 9.2 within the first half hour and increased very slowly for the first 48 hours. After three days, the pH increased to 9.8.

Free Swelling Pressure: Figure 1 shows the change in swelling pressure for the two samples. Both the samples show a sharp decrease in the swelling pressure immediately after adding water. This is due to the radial expansion of the samples resulting in axial contraction. In the sample having 5% lime (25% fly ash) the swelling pressure dropped from 15.5 to 11.5 immediately within the first half hour. The sample having 2.5% lime showed a decrease in swelling pressure from 15.5 psi to 9.3 psi within the first half hour. The swelling pressure for this sample decreased for 20 hours before stabilizing at a value of 8.1 psi. This indicates that the sample having 5% lime is more stable in water than the sample having 2.5% lime.

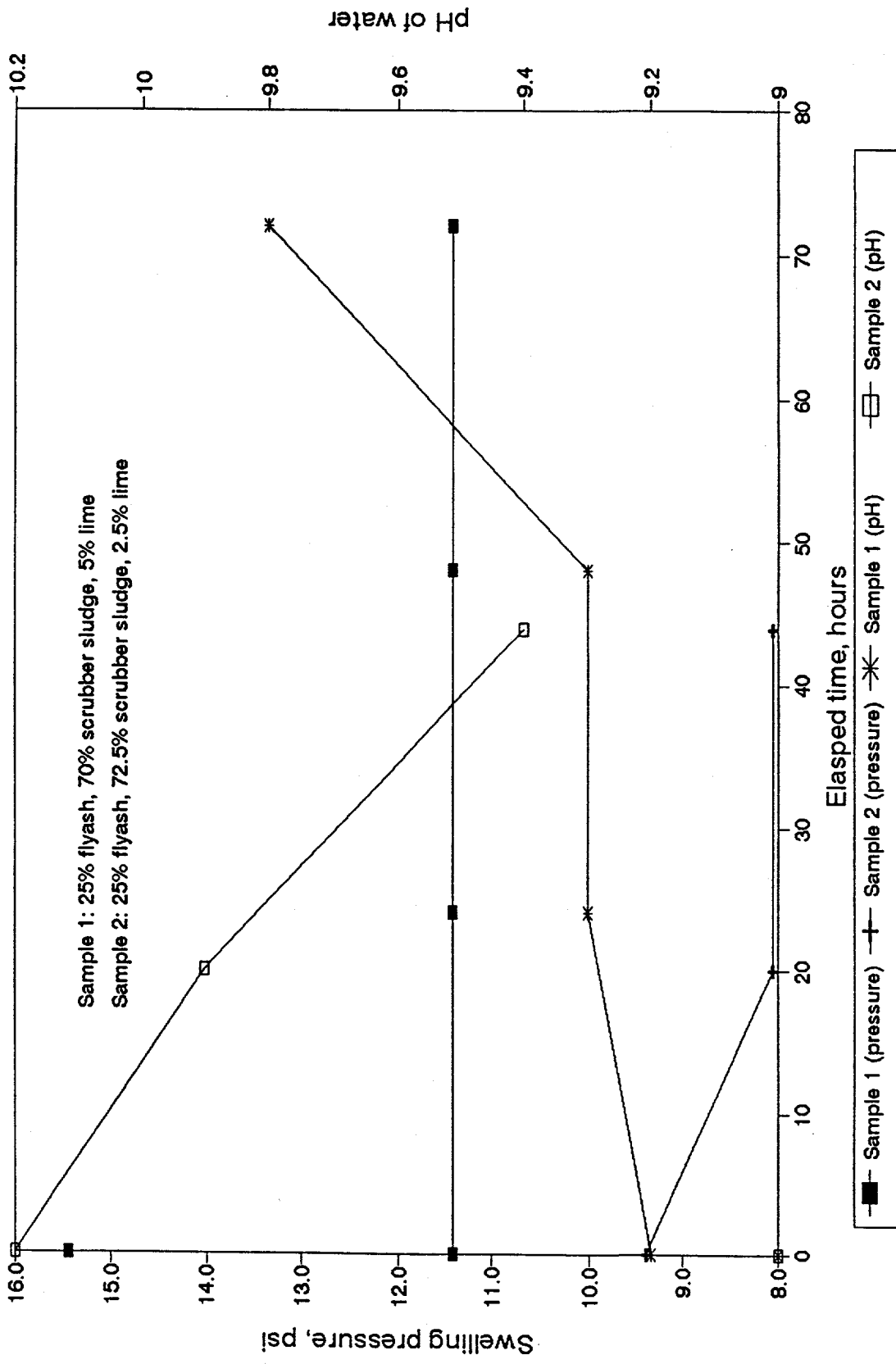


Figure 1 - Swelling Pressures and Water pH for Two Samples

MANAGEMENT OF DRY FLUE GAS DESULFURIZATION BY-PRODUCTS IN UNDERGROUND MINES

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GEOTECHNICAL STUDIES (CONTINUED)

Moisture Content: The post-testing average moisture content of the two samples (25% fly ash, 5% lime and 25% fly ash and 2.5% lime) were 52 and 54 percentages, respectively.

Ultimate Compressive Strength and Young's Modulus: Figures 2 and 3 show the ultimate compressive strength and Young's modulus of six samples--two wet samples (soaked in water for 72 hours) and four dry samples. The wet sample having 5% lime showed an ultimate compressive strength of 90 psi and Young's modulus of 10,290 psi. The wet sample having 2.5% lime showed an ultimate compressive strength of 34 psi and Young's modulus of 3675 psi. Two dry samples having 25% fly ash, 2.5% and 5% lime showed compressive strengths of 147 and 106 psi and Young's moduli of 7375 and 3675 psi, respectively. All these samples had 30% water.

In order to obtain higher compressive strength, two more samples were prepared with 5% lime, 35% and 40% fly ash (60% and 55% scrubber sludge), and 25% water and tested dry. Figure 3 shows the results of the tests. The compressive strengths of two samples were 324 psi (40% fly ash) and 367 psi (35% fly ash) and the Young's moduli were 6900 psi (40% fly ash) and 11,200 psi (35% fly ash). Though the difference between the compressive strengths of the two samples were small, the difference between the Young's moduli were large. This shows that the sample having 40% fly ash had more voids than the sample having 35% fly ash. From these preliminary tests it can be concluded that the mix for backfill material should have 35% to 40% fly ash, 5% lime, and 25% water. The lime in the mix will activate the pozzolanic characters of the fly ash and develop sufficient strength. The mix with lime will also be stable in water for a prolonged period. However, more samples must be tested to fully characterize the mix. This will be done in the next quarter.

Finite Element Modeling

To study the effects of backfill materials on the floor heave and roof sag, time dependent finite element analyses were carried out using 2-D, plane strain models. The finite element mesh is shown in Figure 4. The mesh is a vertical section with parallel entries and the crosscuts are parallel to the plane of the mesh. This implies that the entries are tunnel like openings and are infinitely long. The pillars are also treated as infinitely long in the perpendicular direction.

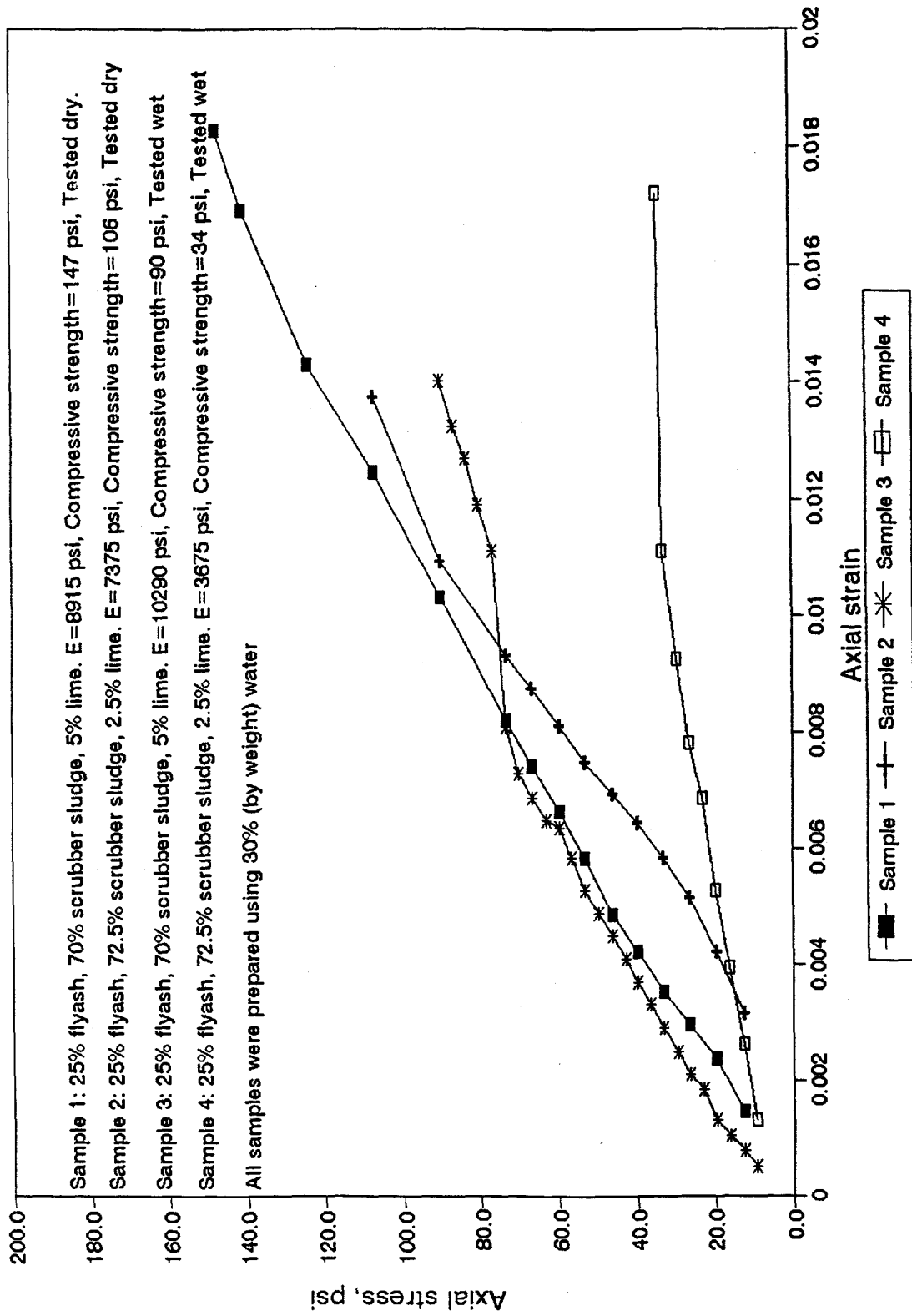


Figure 2 Stress-strain curves for mix having 25% fly ash and 30% water

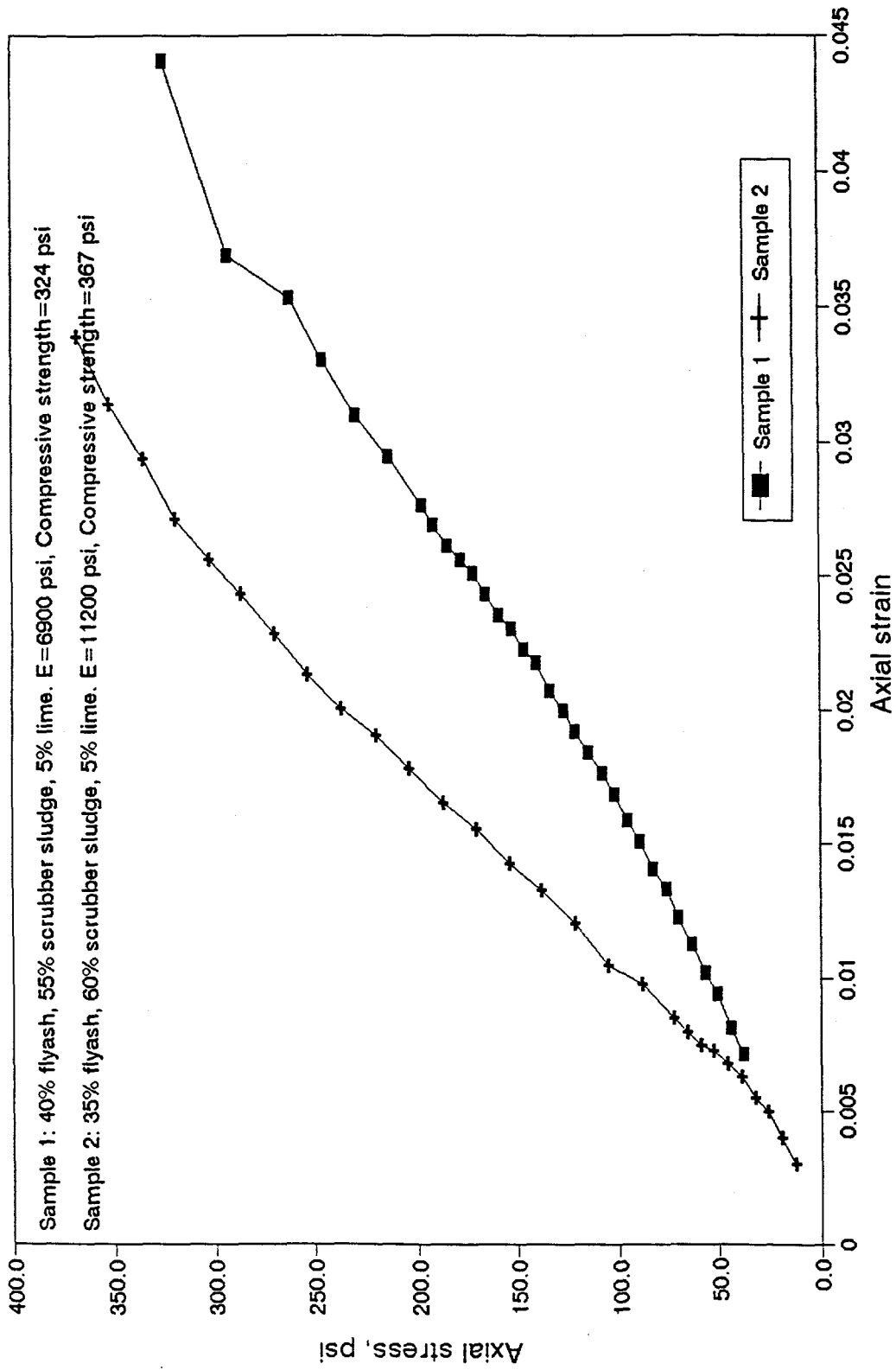


Figure 3 Stress-strain curves for mix having 5% lime and 25% water

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GEOTECHNICAL STUDIES (CONTINUED)

This type of two-dimensional analyses ignore the effects of the crosscuts which result in pillar stresses that are less in analyses than in actuality. To circumvent this problem, Pariseau and Sorenson (1979) have suggested to increase the actual specific weight of overburden strata by the factor $(1 + W_e/W_p)$ where W_e and W_p is the entry and pillar widths. This technique leads to pillar stresses from two-dimensional analyses that are within a few percent of three-dimensional results (Pariseau and Sorenson, 1979). Hence, the specific weight of the overburden strata were increased by the factor described to simulate the three-dimensional effects.

The model is formulated as a large displacement, small strain problem and geometric nonlinearity is incorporated in the model. All the strata in the model are assumed to be linear elastic except the floor and immediate roof strata. The immediate floor and roof strata are assumed to have time dependent behavior. However, instead of using any rheological model, an empirical creep equation is used to simulate the time dependent behavior of immediate floor and roof strata. The empirical creep equation is $\epsilon = a\sigma^b t^c$, where ϵ is the creep strain, σ is the stress, t is the time in days, and a , b , and c are creep constants.

Chugh et al. (1994) have done extensive testing of time dependent floor strata behavior and developed viscoelastic model for time dependent floor behavior. Data from those test results were obtained and the creep constants a , b , and c for floor strata were determined. These constraints are: $a = 2.44 \times 10^{-4}$, $b = 1.1$, and $c = 0.82$. The constant a , b , and c for the roof stratum were also determined from the limited data for time dependent roof properties reported by Chugh et al (1994). The constants a , b , and c for roof stratum are 7.3×10^{-5} , 1.1, and 0.67, respectively.

A typical geologic log as shown in Figure 5 was used for modeling. The extraction height of the coal seam is seven feet and the immediate floor is 10 feet thick claystone (weak floor). The immediate roof is four feet thick grayshale overlain by a eight feet thick limestone stratum. In the model, 68 feet of overburden strata are considered and the rest of the overburden, up to the surface, is modeled by using vertical overburden loads. A floor thickness of 50 feet beneath the coal seam is used for modeling.

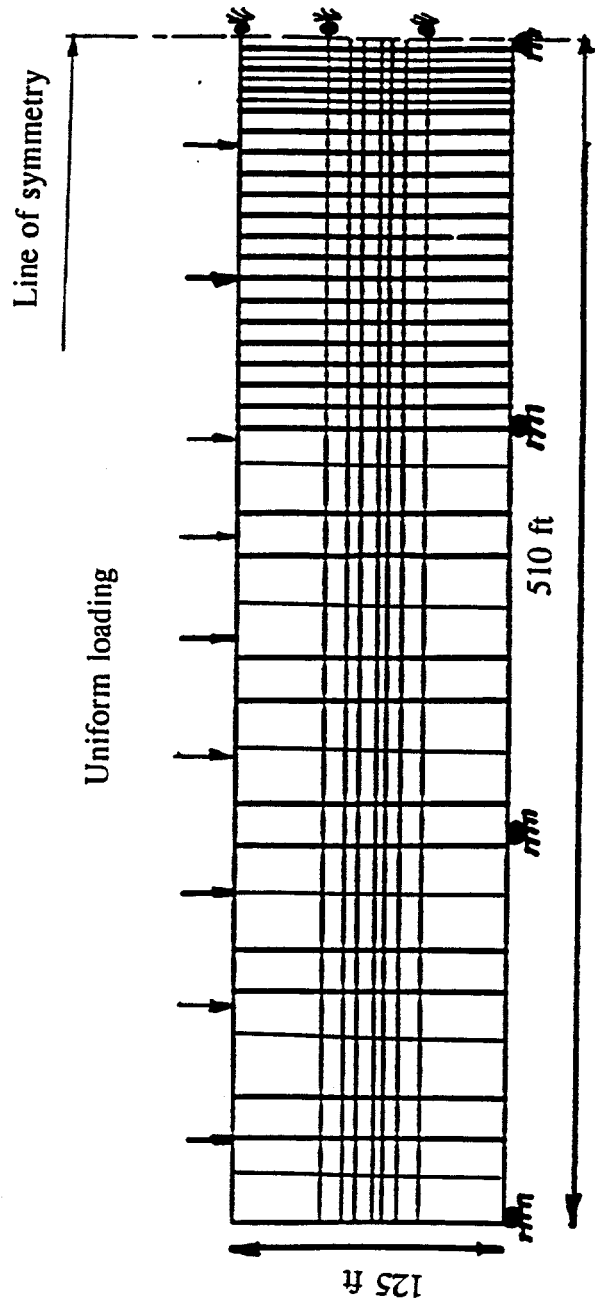


Figure 4 Finite element mesh used in the model

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GEOTECHNICAL STUDIES CONTINUED

Though the model simulates two complete barrier pillars of 80 feet length and two half-barrier pillars (40 feet length) at two extreme ends, only half of the mesh is used because of the symmetry (see Figure 4). A five-entry panel configuration with 20 feet wide entries and 40 feet wide pillars is used in the model. The length of the actual mesh is 510 ft with one half barrier pillar (at the extreme left) and one full barrier pillar. The model is loaded on the top by uniform vertical loads to simulate 282 feet of overburden which corresponds to 350 feet of overburden thickness (282 feet of loading and 68 feet of actual overburden materials). The bottom of the model is constrained in the Y-direction and allowed to move in the X-direction. While the right side of the model is constrained in the X-direction and allowed to move in the Y-direction, a uniform displacement is prescribed in the left side of the model to simulate a horizontal stress of 1000 psi in limestones. The region of interest is one half entry and one half pillar at the extreme right of the mesh (see Figure 4) where the element size is 2 ft by 1 ft.

Table 1 shows material properties used for different strata and backfill materials for modeling purposes. The backfill material is assumed to have linear properties and a Young's modulus of 12000 psi. The program ADINA (Automatic Dynamic Incremental Nonlinear Analysis), a general purpose finite element program, was used for modeling.

Modeling Procedure

The modeling process involves two sets of steps--one without any backfill and one with a backfill material. The first set of steps involve:

1. Apply pre-mining stresses (vertical and horizontal) to the model without any openings.
2. Excavate all the openings within 30 days to simulate coal extraction. Redistribution of stresses occur and vertical displacements in the roof and floor are determined due to the creation of openings.
3. Run the model to simulate nine years at an increment of 30 days. Immediate floor and roof properties change and also the strains in the floor and roof. The time dependent strains induce time dependent floor and roof movements.
4. Floor heaves and roof sags are determined from vertical displacements.

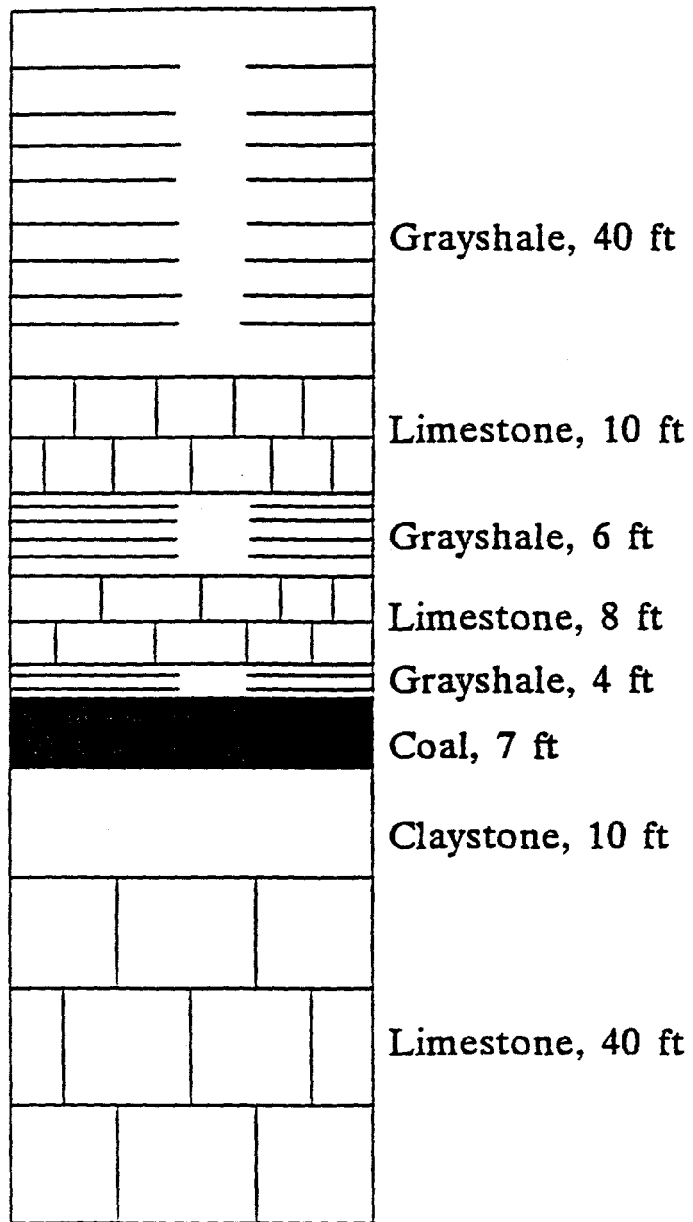


Figure 5 Geologic log used for finite element modeling

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GEOTECHNICAL STUDIES CONTINUED

In the second set of steps, the excavations are created within the 30 days and the openings are backfilled after one year. The model is run to simulate nine years at an increment of 30

days. Floor heaves and roof sags are determined from the vertical displacements.

Table 1 Material properties used for finite element modeling

Materials	Young's Modulus, psi	Poisson's Ratio	Unit Weight, pcf
Limestone	700,000	0.30	180
Grayshale	250,000	0.25	150
Coal	50,000	0.30	75
Claystone	25,000	0.35	160
Backfill materials	12,000	0.35	70

Results and Discussions

Figures 6 and 7 show the maximum floor heave and roof sag at the center of the entry (extreme right in Figure 4) versus time. The maximum floor heave after nine years without any backfilling is 8.3 inches. If back filling is done after one year when the maximum floor heave of 5.2 inches has already occurred, the floor heave increases by an amount 0.7 inches over the next eight years. Without back filling the increase in floor heave will be 3.1 inches over the next eight years. Similarly, the maximum roof sag without backfilling is 3.62 inches over a period of nine years. If backfilling is done after one year when the maximum roof sag of 2.5 inches has already occurred, the roof sag increases by an amount 0.2 inches over a period of eight years. Without backfilling the increase in roof sag will be 1.1 inches over a period of eight years.

Thus, it is shown that due to backfilling the amount of roof sag and floor heave can be considerably reduced. This will also result in less pillar stresses and more stable pillars. Further, as floor heave is related to pillar punching into the floor, less floor heave will result in less pillar punching into the floor, and thus more stable overburden.

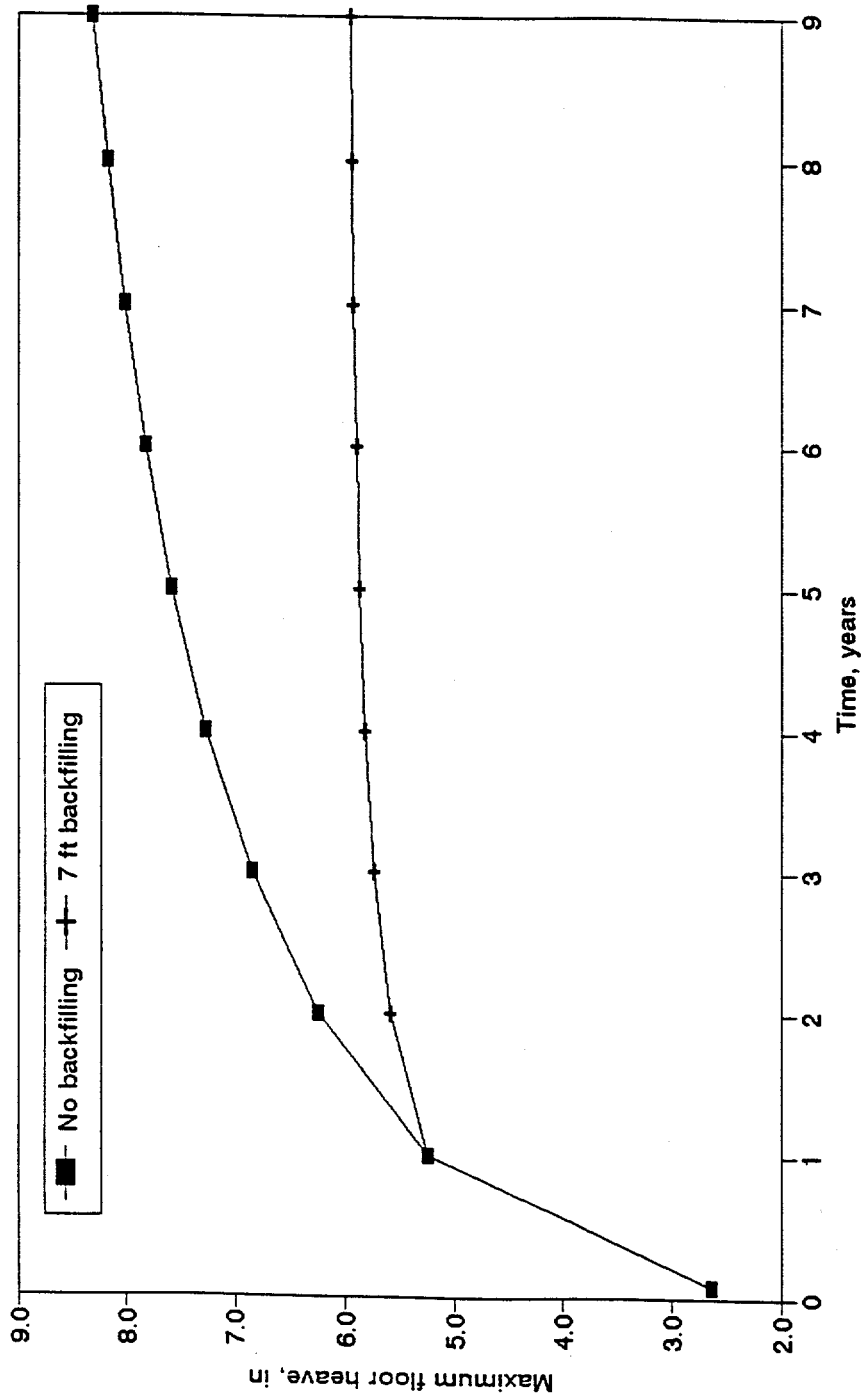


Figure 6 - Maximum Floor Heave at the Center of the Entry

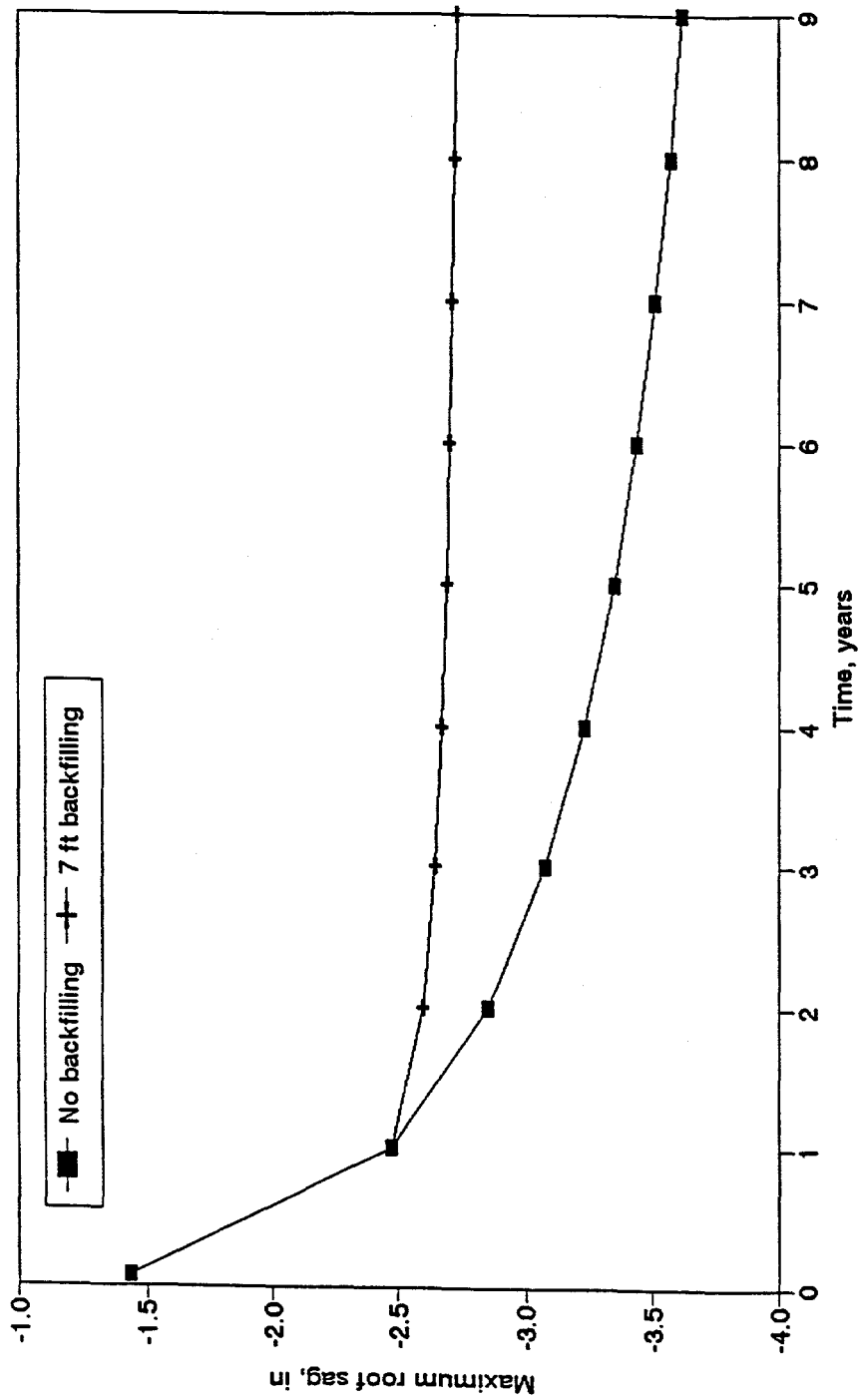


Figure 7 - Maximum Roof Sag at the Center of the Entry

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GEOTECHNICAL STUDIES CONTINUED

PLANS FOR THE NEXT QUARTER

More time dependent finite element models will be run to analyze the effects of backfilling on pillar stability, amount of pillar punching into the floor, and roof-to-floor convergence in the entries. Also slow consolidation of backfill materials will be modelled with voids remaining after backfilling.

More laboratory tests will be carried out to characterize the mix of fly ash, scrubber sludge, and lime. Borehole instrumentation and installation of surface subsidence monuments will start in the next quarter.

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SECTION VII
NEXT QUARTER

**MANAGEMENT OF DRY FLUE GAS DESULFURIZATION
BY-PRODUCTS IN UNDERGROUND MINES**

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NEXT QUARTER

Several major activities will be undertaken during the next quarter (January 1-March 31, 1995). Peabody Coal Company plans to begin drilling the injection wells into the demonstration areas of Peabody Number 10 mine in March. Also, the groundwater monitoring wells will be drilled. Prior to the beginning of drilling, the exact location of the wells will be jointly decided by Peabody and SIUC program personnel. Extensive testing will be conducted when the wells are completed.

Long-term testing of coal combustion residues, including freeze-thaw testing and long-term leaching tests, will be started during the quarter. Some of these tests will continue for one year or more. The tests should yield data enabling predictions of long-term environmental effects of the underground placement of coal combustion residues, if indeed any effects are to be expected.

Also, SEEC, Inc. will complete a topical report on the SEEC technology for handling and transporting coal combustion residues. Much of this report will cover the full-scale demonstration held in November, 1994, as well as the results of the loading and unloading of the Collapsible Intermodal Containers at Norfolk, Virginia. Another topical report, detailing the economic studies in the handling and transport of coal combustion residues, is also expected to be completed during the quarter.

In summary, the first quarter of 1995 promises to be quite productive and quite meaningful.

* * * * *