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

**Quarterly Report
April 1 - June 30, 1996**

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

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SECTION 1

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 (DOE-METC) and Southern Illinois University at Carbondale (SIUC) entered into a cooperative research agreement entitled "Management of Dry Flue Gas Desulfurization By-Products in Underground Mines" (DE-FC21-93MC 30252). Under the agreement Southern Illinois University at Carbondale will develop and demonstrate two technologies for the placement of coal combustion residues in abandoned underground coal mines, and will assess the environmental impact of these technologies for the management of coal combustion by-products. The two technologies for the underground placement that will be developed and demonstrated are: (1) pneumatic placement, using virtually dry materials, and (2) hydraulic placement, using a "paste" mixture of materials with about 70% solids.

Phase II of the overall program began April 1, 1996. The principal objective of Phase II is to develop and fabricate the equipment for placing the coal combustion by-products underground, and to conduct a demonstration of the technologies on the surface. Therefore, this quarter has been largely devoted to developing specifications for equipment components, visiting fabrication plants throughout Southern Illinois to determine their capability for building the equipment components in compliance with the specifications, and delivering the components in a timely manner. At the end of the quarter significant progress had been made.

To assist in the development and fabrication of the necessary equipment for the pneumatic placement, Mr. Eric Powell joined the staff of the SIU Department of Mining Engineering. Mr. Powell formerly was a consultant for the program, working from facilities in Knoxville, Tennessee under a sub-contract. His move to Southern Illinois, and his full-time employment by the Department of Mining Engineering, has greatly facilitated the design and procurement of the components for the pneumatic placement hardware.

Establishing baseline data for water quality and subsidence at the Peabody Mine No. 10 demonstration site continued, with both water samples and subsidence readings being periodically obtained. Also, remaining laboratory analyses of coal combustion by-products and mixtures was conducted throughout the period.

A final technical report on Phase I of the program was completed and furnished to the Department of Energy. The report was a detailed, comprehensive review of the work done under Phase I.

SECTION 2

ENVIRONMENTAL CHARACTERIZATION

**DR. BRADLEY PAUL
CO-PRINCIPAL INVESTIGATOR**

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

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Progress Last Quarter

The basic work to screen and identify hydraulic and pneumatic mixes for final placement at the site has been completed. Laboratory work has focused on filling in any missing information, and more particularly on checking and re-verifying key concentrations for the few elements that may prove critical for this project, and possible subsequent approval of like industrial practices in the future. The leachates most likely to be generated by the materials and mixes for this project are essentially clean with respect to any toxic and heavy metals. However, there are four issues likely to be the key to whether underground placement of SO₂ control byproducts will be permitted on an industrial basis.

1- Most of the components and mixes tested will leach high concentrations of dissolved solids, mostly calcium and alkali metals. This should not be a barrier to placement of materials at the Peabody No. 10 mine site because the water that will be contacted is a brine and naturally high in dissolved solids. The leachate concentrations for total dissolved solids (TDS) is below or about equal to the total dissolved solids baseline naturally in existence at the site. The TDS in the brine is currently high because of sodium and potassium, while the TDS in the mix and component leachate is high because of calcium. In an industrial setting TDS might be a barrier to placement of these materials in contact with very pure water, particularly in cases where the volume and flow rate of the high quality water is small and dilution would be limited.

2- The material and mix leachates are high in leachable sulfate. For a fully oxidized byproduct of SO₂ stack gas scrubbing or a material that is 97 to 98% gypsum as in the case of the scrubber sludge, this result is hardly surprising. Groundwater standards for Illinois specify 400 ppm unless sulfate is higher because of natural or previously disturbed conditions. Most shake test leachates will contain more than 400 ppm sulfate. The brines at the Peabody site show fairly high, but inconsistent sulfate readings, and only a few of the baseline samples actually exceed 400 ppm sulfate. For the Peabody site this should not be an issue, but again for waters receiving heavy human, industrial, or wildlife habitat use the sulfate issue might pose a problem. Most waters with human, industrial, or wildlife use may be in communication with surface waters; however, the waters at the Peabody site cannot contact surface or usable subsurface waters. If mixtures of this type were used in an acid mine drainage remediation plan, there should not be a sulfate problem, because acid mine drainage is usually very high in sulfate.

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3- The materials and mixes proposed for this program will contain oxides of alkali metals. These oxides upon reaction with water and reversion back to lower temperature states will produce high pH values in contacting waters. Surface run-off in Illinois is in the pH 6 to 9 range. The ASTM shake leachates from the venturi scrubber sludge, FBC ash, and PCC fly ash are higher pH, but again can only contact the deep brines at the Peabody site.

4- The materials and mixes contain leachable boron, and based on composition, the boron leaching is sustainable for a long time. The boron concentration in the brine is typical of the rocks surrounding a coal seam. The major problems with boron is that it is an easily migrating salt forming element with toxic effects on plants. Thus there should be no problem with boron leaching into a deep brine.

It is interesting to note that most of the environmental issues that possibly can be raised with these materials and mixes are based not on the leaching of dangerous trace elements, but on the solubility of the major element and mineral composition. Since the elements and minerals are the same as those occurring with natural rock, the materials being tested should pose no special risk of harm to the environment except possibly in cases where the natural groundwater has been in contact with very inert rock formations. The only minor element found to be an issue with the SO₂ control byproduct materials and mixes was boron. In determining total composition boron was analyzed at two wavelengths, with two calibration concentration, and with two methods (ICP and carmine). The boron is surprisingly high and widespread and in some cases raises doubts about whether the small samples needed for digestion were fully representative. It does appear that there is enough boron available to allow boron leaching to go on for a very long time. Total composition of the five study materials is shown in tables 2.1 to 2.5.

Plans for Future Work

Two key questions will determine whether a material producing excess concentrations of an element or anion in the leachate may harm the environment. The first question is whether the material will produce significant quantities of the leachate. If the material or mix is almost impermeable there will be very little leachate available to cause contamination. The second question is whether there are large quantities of water available for dilution. The permeability of the material or mix and its surroundings are key to these questions.

Table 2.1 -- Total Composition -- PCC Fly Ash

PCC Fly Ash	XRF	SEM	Mic	Beaker	Neutron	Infer
Si %	26.19	27.34	0.107	NA	NA	27
Al %	7.75	9.9	1.56	1.2	NA	8.5
Fe %	12.17	7.47	16.53	11.03	NA	12
Ca %	3.28	3.06	7.81	3.25	NA	3.25
Mg %	0.53	0.63	0.58	0.48	NA	0.55
K %	1.54	1.45	1.45	1.6	NA	1.5
Na %	1	1.69	4.25	4.8	NA	1.7
Ti %	0.49	0.34	NA	NA	NA	0.4
P %	0.08	ND	NA	NA	NA	0.08
Mn %	0.034	ND	0.007	0.032	NA	0.033
S %	0.39	1.58	NA	NA	NA	0.4
Ag ppm	ND	ND	<1.75	<3.5	NA	<1.75
As ppm	ND	ND	<12.5	<25	21.1	20
B	ND	Trace	0.38%	3.05%	NA	.4 - 3%
Ba ppm	315	ND	250	315	NA	315
Be ppm	ND	ND	7.5?	5.5?	NA	7
Br ppm	ND	ND	NA	NA	<.8	0.8
Cd ppm	ND	ND	20?	<2	NA	2
Ce ppm	ND	ND	NA	NA	6.2	6.2
Co ppm	ND	ND	20?	<3	17.3	17.3
Cr ppm	ND	ND	160	115	158	160
Cs ppm	ND	ND	NA	NA	630	630
Cu ppm	ND	Scope	42.5	16?	NA	40
Dy ppm	ND	ND	NA	NA	ND	ND
Eu ppm	ND	ND	NA	NA	0.5	0.5
Ga ppm	ND	ND	NA	NA	29.5	29.5
Hg ppm	ND	ND	NA	NA	1.1	1.1
La ppm	ND	ND	NA	NA	64	64
Lu ppm	ND	ND	NA	NA	5.1	5.1
Mo ppm	ND	ND	47.5	<4	127	127
Ni ppm	ND	Scope	97.5	60	244	244
Pb ppm	ND	ND	<10	<20	NA	<10
Rb ppm	ND	ND	NA	NA	8.1	8.1
Sb ppm	ND	ND	<7.5	<15	16.7	17
Sc ppm	ND	ND	NA	NA	4.3	4.3
Se ppm	ND	ND	<12.5	<25	NA	<12.5
Sm ppm	ND	ND	NA	NA	0.83	0.83
Sr ppm	230	ND	NA	NA	NA	230
Ta ppm	ND	ND	NA	NA	2.4	2.4
Tb ppm	ND	ND	NA	NA	19.8	19.8
Th ppm	ND	ND	NA	NA	3.9	3.9
U ppm	ND	ND	NA	NA	ND	ND
V ppm	ND	ND	227.5	195	NA	200
W ppm	ND	ND	NA	NA	<2	<2
Yb ppm	ND	ND	NA	NA	0.64	0.64
Zn ppm	ND	ND	453	360	458	455
Zr ppm	<20	ND	NA	NA	NA	<20

Table 2.2 -- Total Composition -- Synthetic Gypsum

Synthetic Gypsum	XRF	SEM	Mic	Beaker	Neutron	Infer
Si %	0.43	0.37	0.46	NA	NA	0.43
Al %	0.11	0.3	0.34	1.37	NA	0.34
Fe %	0.007	0.37	0.003	0.23	NA	0.37
Ca %	29.32	29.98	30.13	19.8	NA	29.5
Mg %	0.17	ND	<7.5ppm	0.12	NA	0.15
K %	0.008	ND	0.05	0.1	NA	0.02
Na %	0.04	ND	1.35	6.5	NA	0.04
Ti %	0.0006	ND	NA	NA	NA	0.0006
P %	0.017	ND	NA	NA	NA	0.017
Mn %	0.007	ND	0.007	<.5 ppm	NA	0.007
S %	22.34	21.44	NA	NA	NA	22
Ag ppm	ND	ND	<1.75	Det	NA	<1.75
As ppm	ND	ND	Det	<25	0.2	0.2
B	ND	ND	0.20%	2%	NA	.2 - 2%
Ba ppm	<50	ND	65?	<.25	NA	<50
Be ppm	ND	ND	Det	<.15	NA	<.15
Br ppm	ND	ND	NA	NA	4.4	4.4
Cd ppm	ND	ND	Det	<2	NA	<2
Ce ppm	ND	ND	NA	NA	1	1
Co ppm	ND	ND	Det	<3	0.8	0.8
Cr ppm	ND	ND	Det	<2.5	1.4	1.4
Cs ppm	ND	ND	NA	NA	<3	<3
Cu ppm	ND	Scope	20?	<3	NA	<3
Dy ppm	ND	ND	NA	NA	ND	ND
Eu ppm	ND	ND	NA	NA	ND	ND
Ga ppm	ND	ND	NA	NA	0.1	0.1
Hf ppm	ND	ND	NA	NA	<.05	<.05
La ppm	ND	ND	NA	NA	1	1
Lu ppm	ND	ND	NA	NA	ND	ND
Mo ppm	ND	ND	<2	<4	<1	<1
Ni ppm	ND	Scope	<2.5	<5	65	65
Pb ppm	ND	ND	<10	<20	NA	<10
Rb ppm	ND	ND	NA	NA	0.1	0.1
Sb ppm	ND	ND	<7.5	<15	0.1	0.1
Sc ppm	ND	ND	NA	NA	2.9	2.9
Se ppm	ND	ND	Det	<25	NA	<25
Sm ppm	ND	ND	NA	NA	0.02	0.02
Sr ppm	230	ND	NA	NA	NA	230
Ta ppm	ND	ND	NA	NA	<.3	<.3
Tb ppm	ND	ND	NA	NA	0.1	0.1
Th ppm	ND	ND	NA	NA	0.1	0.1
U ppm	ND	ND	NA	NA	ND	ND
V ppm	ND	ND	Det	<2.5	NA	<2.5
W ppm	ND	ND	NA	NA	<3	<3
Yb ppm	ND	ND	NA	NA	0.02	0.02
Zn ppm	ND	ND	20	460	1	20
Zr ppm	<20	ND	NA	NA	NA	<20

Table 2.3 -- Total Composition -- Venturi Scrubber Sludge

Venturi Scrubber	XRF	SEM	Beaker	Neutron	Infer
Si %	1.75	1.35	NA	NA	1.6
Al %	0.74	0.6	0.48	NA	0.6
Fe %	0.62	1.14	0.44	NA	1
Ca %	37.32	36.73	26.2	NA	37
Mg %	0.26	0.38	0.18	NA	0.3
K %	0.16	ND	0.1	NA	0.14
Na %	0.11	ND	0.95	NA	0.11
Ti %	0.042	ND	NA	NA	0.042
P %	0.009	ND	NA	NA	0.009
Mn %	0.004	ND	<.5 ppm	NA	0.004
S %	2.34	3.13	NA	NA	2.8
Ag ppm	ND	ND	Det.	NA	Det.
As ppm	ND	ND	<25	3.8	3.8
B	ND	ND	65 ppm	NA	65 ppm
Ba ppm	<50	ND	<.25	NA	<.25
Be ppm	ND	ND	<.15	NA	<.15
Br ppm	ND	ND	NA	3.2	3.2
Cd ppm	ND	ND	<2	NA	<2
Ce ppm	ND	ND	NA	0.92	0.92
Co ppm	ND	ND	<3	3.2	3.2
Cr ppm	ND	ND	<2.5	21	21
Cs ppm	ND	ND	NA	71	71
Cu ppm	ND	Scope	<3	NA	<3
Dy ppm	ND	ND	NA	ND	ND
Eu ppm	ND	ND	NA	0.1	0.1
Ga ppm	ND	ND	NA	2.3	2.3
Hf ppm	ND	ND	NA	0.1	0.1
La ppm	ND	ND	NA	8.3	8.3
Lu ppm	ND	ND	NA	0.5	0.5
Mo ppm	ND	ND	<4	58	58
Ni ppm	ND	Scope	Det	113	113
Pb ppm	ND	ND	<20	NA	<20
Rb ppm	ND	ND	NA	0.6	0.6
Sb ppm	ND	ND	<15	1.6	1.6
Sc ppm	ND	ND	NA	3.5	3.5
Se ppm	ND	ND	<25	NA	<25
Sm ppm	ND	ND	NA	0.18	0.18
Sr ppm	230	ND	NA	NA	230
Ta ppm	ND	ND	NA	0.3	0.3
Tb ppm	ND	ND	NA	0.3	0.3
Th ppm	ND	ND	NA	2.8	2.8
U ppm	ND	ND	NA	ND	ND
V ppm	ND	ND	Det	NA	Det
W ppm	ND	ND	NA	<3	<3
Yb ppm	ND	ND	NA	0.06	0.06
Zn ppm	ND	ND	0.16%	74	800
Zr ppm	<20	ND	NA	NA	<20

Table 2.4 -- Total Composition -- FBC Fly Ash

FBC Fly Ash	XRF	SEM	Mic	Beaker	Neutron	Infer
Si %	9	9.85	0.33	NA	NA	9.4
Al %	4.16	6.2	2.28	1.38	NA	5.2
Fe %	4.16	4.89	3.29	4.2	NA	4.2
Ca %	29.96	18.46	27.48	28.85	NA	28
Mg %	2.71	0.97	2.53	2.45	NA	2.6
K %	0.75	0.8	0.83	0.5	NA	0.8
Na %	0.36	ND	2.05	3.2	NA	0.4
Ti %	0.19	0.32	NA	NA	NA	0.25
P %	0.06	ND	NA	NA	NA	0.06
Mn %	0.067	0.68	0.032	0.007	NA	0.4
S %	6.1	3.57	NA	NA	NA	5
Ag ppm	ND	ND	<1.75	<3.5	NA	<1.75
As ppm	ND	ND	Det?	<25	6	6
B	ND	ND	0.20%	1.09%	NA	.2 - 1.09%
Ba ppm	330	ND	82.5	300	NA	300
Be ppm	ND	ND	Det?	<.15	NA	<.15
Br ppm	ND	ND	NA	NA	40.8	40.8
Cd ppm	ND	ND	Det	<2	NA	<2
Ce ppm	ND	ND	NA	NA	3.4	3.4
Co ppm	ND	ND	17.5?	<3	20.3	20.3
Cr ppm	ND	ND	35	20	46.5	46.5
Cs ppm	ND	ND	NA	NA	499	499
Cu ppm	ND	Scope	67.5	24.5	NA	65
Dy ppm	ND	ND	NA	NA	ND	ND
Eu ppm	ND	ND	NA	NA	0.4	0.4
Ga ppm	ND	ND	NA	NA	9.9	9.9
Hf ppm	ND	ND	NA	NA	0.36	0.36
La ppm	ND	ND	NA	NA	30.1	30.1
Lu ppm	ND	ND	NA	NA	1.8	1.8
Mo ppm	ND	ND	Det	<4	51	51
Ni ppm	ND	ND	55	25	526	526
Pb ppm	ND	ND	17.5?	<3	NA	<3
Rb ppm	ND	ND	NA	NA	3.5	3.5
Sb ppm	ND	ND	<7.5	<15	6.8	6.8
Sc ppm	ND	ND	NA	NA	6.8	6.8
Se ppm	ND	ND	Det	<25	NA	<25
Sm ppm	ND	ND	NA	NA	0.65	0.65
Sr ppm	535	ND	NA	NA	NA	535
Ta ppm	ND	ND	NA	NA	2.4	2.4
Tb ppm	ND	ND	NA	NA	4.3	4.3
Th ppm	ND	ND	NA	NA	1.4	1.4
U ppm	ND	ND	NA	NA	ND	ND
V ppm	ND	ND	62.5	45	ND	50
W ppm	ND	ND	NA	NA	<8	<8
Yb ppm	ND	ND	NA	NA	0.22	0.22
Zn ppm	ND	ND	0.15%	0.16%	0.13%	0.15%
Zr ppm	<20	ND	NA	NA	NA	<20

Table 2.5 -- Total Composition -- FBC Spent Bed

FBC Spent Bed	XRF	SEM	Mic	Beaker	Neutron	Infer
Si %	3.22	0.65	0.404	NA	NA	3.22
Al %	1.27	ND	1.85	1.39	NA	1.4
Fe %	1.806	1.24	1.63	1.84	NA	1.8
Ca %	41.81	40.46	25.43	26.4	NA	40
Mg %	1.968	0.82	1	1.975	NA	1.9
K %	0.1743	ND	0.3	0.275	NA	0.2
Na %	0.1335	ND	6.1	1.175	NA	0.13
Ti %	0.09	ND	NA	NA	NA	0.09
P %	0.0611	ND	NA	NA	NA	0.0611
Mn %	0.0689	ND	0.04	0.075	NA	0.07
S %	8.744	3.09	NA	NA	NA	8.7
Ag ppm	ND	ND	<1.75	Det	NA	<1.75
As ppm	ND	ND	155	<25	12.1	12.1
B	ND	ND	45 ppm	2%	NA	0 - 2%
Ba ppm	ND	ND	65?	<.5	NA	65
Be ppm	ND	ND	7.5	<.15	NA	<.15
Br ppm	ND	ND	NA	NA	2.6	2.6
Cd ppm	ND	ND	Det	<2	NA	<2
Ce ppm	ND	ND	NA	NA	1.8	1.8
Co ppm	ND	ND	17.5	<3	11	14
Cr ppm	ND	ND	11.25	10	23.8	23.8
Cs ppm	ND	ND	NA	NA	114	114
Cu ppm	ND	Scope	25	<3	NA	25
Dy ppm	ND	ND	NA	NA	ND	ND
Eu ppm	ND	ND	NA	NA	0.2	0.2
Ga ppm	ND	ND	NA	NA	4.3	4.3
Hf ppm	ND	ND	NA	NA	0.17	0.17
La ppm	ND	ND	NA	NA	15.1	15.1
Lu ppm	ND	ND	NA	NA	0.9	0.9
Mo ppm	ND	ND	10	<4	27	27
Ni ppm	ND	ND	25	25	491	491
Pb ppm	ND	ND	<1.5	<3	NA	<1.5
Rb ppm	ND	ND	NA	NA	0.7	0.7
Sb ppm	ND	ND	<7.5	<15	2.8	2.8
Sc ppm	ND	ND	NA	NA	1	1
Se ppm	ND	ND	30?	<25	NA	<25
Sm ppm	ND	ND	NA	NA	0.42	0.42
Sr ppm	660	ND	NA	NA	NA	660
Ta ppm	ND	ND	NA	NA	1.1	1.1
Tb ppm	ND	ND	NA	NA	3.4	3.4
Th ppm	ND	ND	NA	NA	0.7	0.7
U ppm	ND	ND	NA	NA	ND	ND
V ppm	ND	ND	45	10	NA	45
W ppm	ND	ND	NA	NA	<3	<3
Yb ppm	ND	ND	NA	NA	0.11	0.11
Zn ppm	ND	ND	770	955	264	700
Zr ppm	<20	ND	NA	NA	NA	<20

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ENVIRONMENTAL CHARACTERIZATION

Permeability of the surroundings is a site specific condition. It has been found that at the Peabody site there is very little surrounding water, and the rock formations are extremely tight with around 10^{-9} cm/sec hydraulic conductivities. The rapid age tests started in phase I of this program were terminated when it was found that the results are highly sensitive to the way the byproduct mixes are packed. The highest permeability measured for the mixes simply allowing the material to flow into place was about 10^{-7} cm/sec. Under more packed conditions the instrument as designed could not measure the permeability. This could mean that the mix put into the mine workings will be the preferred channel for water flow, although any contamination plume will take centuries to travel very far.

Because hydraulic conductivity will control potential leachate volumes and thus influence dilution and attenuation characteristics, future work will focus on hydraulic conductivity. Information on packing densities that will be achieved in placement are currently speculative. Phase II will involve field placement of material on the surface with the equipment anticipated for underground injection. The coring work planned here should provide key data on packing that will actually be achieved. Only then can the rapid age and hydraulic conductivity tests be truly meaningful. It should be understood that the success of this project does not hinge on the hydraulic conductivity. However, this project should produce data for use in permitting of commercial practices which hopefully will follow a successful demonstration.

SECTION 3

**MATERIALS HANDLING AND SYSTEM
ECONOMICS**

**DR. H. SEVIM
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MANAGEMENT OF DRY FLUE GAS DESULFURIZATION BY-PRODUCTS IN UNDERGROUND MINES

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MATERIAL HANDLING AND SYSTEM ECONOMICS

OBJECTIVES

The objectives of the materials handling research are: 1) To identify the systems that are technically, economically, and environmentally feasible in handling and transporting the coal combustion by-products from the power plant to the injection site, 2) To demonstrate the operation of one or two of the identified systems.

The objectives of the system economics research are: 1) To conduct economic analyses of the selected materials handling and underground residue placement systems, and 2) To develop a generalized "Economic Evaluation" model that can be used in evaluating various types of materials handling and placement systems for different distances and tonnages.

The term "materials handling" in this research project includes loading, transporting, unloading, and temporary storage of the dry coal combustion by-products for the purpose of disposing them into abandoned areas of the underground coal mines in Illinois. Materials handling systems have been analyzed in four consecutive modules: 1) storage, handling and loading of the residues at the plant site, 2) transportation from the plant to the mine site, 3) unloading , handling and storage at the mine site, and 4) transportation from the mine site to the injection site.

In the past, several transportation and handling technologies were evaluated. These technologies can be classified under two categories:

1. Existing Technologies:

- 1.1 Pneumatic Trucks
- 1.2 Pressure differential rail cars
- 1.3 Open Hopper Coal Cars
- 1.4 Tarped Rear-Dump Trucks
- 1.5 Bottom-Dump Container Trucks

2. Adaptable and Futuristic Technologies:

- 2.1 Collapsible Intermodal Containers
- 2.2 Cylindrical Intermodal Tanks
- 2.3 Intermodal Steel Containers
- 2.4 Coal Hopper Cars with Automatic Retractable Tarping
- 2.5 Covered Hopper Cars - Grain Cars

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The first two technologies in each category were found to be environmentally friendly, and, therefore, operating policies for these technologies were developed and engineering and economic analyses were conducted. The results of these analyses were presented in the first phase final report submitted in June 1996.

DURING THE QUARTER

During the last quarter the following activities were undertaken:

1) Development of template for Intermodal Tank technology to be included in the engineering and economic evaluation software.

In the past, templates were developed for Pneumatic Trucks, Pressure Differential Rail Cars, and Collapsible Intermodal Containers technologies as parts of the interactive engineering and economic evaluation software. Recognizing the fact that intermodal containers could be as environmentally friendly as the first three technologies, we decided to develop a template for the intermodal containers too. This template is general enough to accommodate any type of intermodal containers or tanks except Collapsible Intermodal Containers for which a separate template was developed in the past. The spreadsheet leading to the development of the template is shown in Table 3.1.

Table 3.1. Spreadsheet for Cylindrical Tanks leading to the development of template

GENERAL PARAMETERS	
Distance between power plant and mine (miles)	30
Annual amount of by-products to be handled (tons)	50000
Project life	10
Container capacity (tons)	20
Number of containers loaded on a flat-bed car	4
Length of a flat-bed car (yds)	20
Average depth of the mine (feet)	300
CAPITAL COST ITEMS:	
Cost of a container	4000
Cost of a tote trailer	60000
Cost of a flat-bed rail car	25000
Cost of a piggy packer	250000
Cost of storage and staging area (15" concrete) (\$/sq. ft)	4.5
Cost of rail siding (\$/yard)	570

OPERATING COST ITEMS:	
Railroad charge (from chart in user's manual - \$/ton/mile)	0.04
Cost of road construction (\$/sq. yd)	5
Fuel consumption (gal/hour/unit)	2.5
Fuel cost (\$/gallon)	1.1
Hourly wage for equipment operators (including 35 % fringe)	25
Insurance cost (% of capital cost - in decimals)	0.01
Maintenance cost (% of capital cost - in decimals)	0.02
Overhead cost (% of total operating cost - in decimals)	0.1
Average cost of injection holes (\$/foot)	20
Leasing cost of a container (\$/unit/yr)	0
Leasing cost of a tote trailer (\$/unit/yr)	0
Leasing cost of a piggy packer (\$/unit/yr)	0
Leasing cost of a flat-bed rail car (\$/unit/yr)	0
POWER PLANT:	
Do we need silo (1 for yes, 0 for no)?	0
Silo capacity (from prescheduling sheet - tons)	100
Containers required per trip (from prescheduling sheet)	48
Number of container sets	2
Total number of containers required	96
Number of flat-bed cars required	12
Length of rail siding (yds)	300
Number of working weeks per year (from prescheduling sheet)	52
Number of working days per week (from prescheduling sheet)	7
Duration of a shift (from prescheduling sheet - hours)	8
Number of shifts per day	1
Number of tote trailers at the plant (from prescheduling sheet)	1
Number of piggy packers	1
Total number of tote trailer operators	1
Total number of piggy packer operators	1
Area occupied by one container (sq. ft)	200
Storage and staging area (15" concrete) (sq. ft)	19200
PLANT CAPITAL COSTS:	
Silo	0
Storage and staging area	86400
Piggy packer	250000
Tote trailers	60000
Flat-bed rail cars	300000
Rail siding	171000
Containers	384000
Total plant capital cost	1251400
PLANT OPERATING COSTS:	
Leasing cost of containers	0
Leasing cost of tote trailers	0
Leasing cost of piggy packers	0

Leasing cost of flat-bed rail cars	0
Railroad charge	60000
Insurance	12514
Operator wages	145600
Fuel	16016
Maintenance	25028
Subtotal	259158
Overhead cost	25915.8
Total plant operating cost	285073.8
MINE SITE:	
Do we need silo (1 for yes, 0 for no)?	0
Silo capacity (tons)	0
Number of silo operator per shift	0
Area of new road to be constructed (sq. yd)	7000
Storage and staging area (15" concrete - sq. ft)	38400
Length of rail siding (yds)	300
Number of working weeks per year	52
Number of working days per week	6
Duration of a shift (from prescheduling sheet - hours)	8
Number of shifts per day (from prescheduling sheet)	1
Number of tote trailers (from prescheduling sheet)	1
Number of piggy packers	1
Total number of tote trailer operators	1
Total number of piggy packer operators	1
Total number of silo operators	0
Expected amount of by-product injected through one hole (tons)	10000
Number of injection holes to be drilled per year	5
Do we have hydraulic injection system (1 for yes, 0 for no)?	0
Do we have pneumatic injection system (1 for yes, 0 for no)?	1
Injection system capacity (from prescheduling sheet)	30
Operating cost of hydraulic injection system (\$/ton)	0
Operating cost of pneumatic injection system (\$/ton)	2.08
Injection system operating cost (\$/ton)	2.08
MINE CAPITAL COSTS:	
Storage and staging area	172800
Rail siding	171000
Silo	0
Piggy packer	250000
Tote trailers	60000
Hydraulic injection system	0
Pneumatic injection system	113333.0
Total mine capital cost	767133.0
MINE OPERATING COSTS:	
Leasing cost of piggy packer(s)	0
Leasing cost of tote trailer(s)	0

Road construction	35000
Insurance	7671.330
Operators wage	124800
Fuel	13728
Maintenance	15342.66
Cost of injection holes	30000
Injection system operating cost	104168
Subtotal	330709
Overhead cost	33070.9
Total mine operating cost	363779.9
TOTAL CAPITAL COST	2018533.0
TOTAL OPERATING COST	648854
Operating cost per ton	12.98

2) Revision of the interactive software to accommodate pneumatic and hydraulic injection systems into the developed templates.

During this quarter, due to progress in injection system research, capital and operating costs for both pneumatic and hydraulic injection systems were obtained. Although these costs are still not totally reliable, they are quite satisfactory to warrant incorporation of injection modules into the templates of the interactive software. It should be noted that the addition of these modules necessitated substantial restructuring of each template.

3) Development of prescheduling worksheets for transportation and handling technologies.

During the incorporation of injection modules into the templates, it was observed that engineering design computations of the selected technologies were getting more and more voluminous. Therefore, it was decided that these computations be done apart from the templates in order to keep the use of the templates as practical as possible. A spreadsheet was developed for each technology whereby most of the engineering design computations are performed. The results of the computations are then input into the interactive template developed for that technology. To give an example, the spreadsheet developed for the engineering design computations for the Cylindrical Intermodal Tanks technology is shown in Table 3.2. This table exhibits computations for a case where 50,000 tons of FGD by-product is transported to a mine located 30 miles away from the plant.

Table 3.2. Engineering design computations for Cylindrical Intermodal Tanks

PLANT SITE:	
Distance between the plant and the mine (miles)	30
Annual by-product production (tons)	50000
Container capacity (tons)	20
Number of trips per week	1
Existing silo capacity (tons)	100
Average speed of train (mph)	45
Time between delivery of filled cars and pick-up of the empties (hours)	24
Continuous flow rate from plant into silo (tpm)	0.095
Weekly residue production (tons)	962
Required number of containers per trip	48.08
Final number of containers per trip	48
Tonnage transported per trip (tons)	962
Round trip time (hours)	1.333
Total time for train arrival at plant (hours)	25.333
Minimum required silo capacity at plant (tons)	145
Need to adjust the silo capacity?	increase
Number of work weeks per year	52
Number of work days per week	7
Number of shifts per day	1
Duration of a shift (minutes)	480
Cycle time for filling one container (minutes)	30
Total number of containers filled per shift per trailer	16
Number of tote trailers	1
DISPOSAL SITE:	
Number of working weeks per year	52
Working days per week	6
Injection time per shift (minutes)	360
Shifts per day (100 tph inj. rate is max, so $100 \times 6 \times 6 \times 52 = 187200t$)	1
Tote trailer travel time empty (minutes)	10
Tote trailer travel time loaded (minutes)	10
Trailer loading time (minutes)	5
Container unloading time into injection hopper (minutes)	5
Tote trailer cycle time (minutes)	30
Total number of containers transported per shift per trailer	12
Number of tote trailers	1

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4) Completion of a technical paper to be presented at the Fourth International Symposium on Environmental Issues and Waste Management in Energy and Mineral Production, to be held on October 7-11, in Cagliari, Italy.

The title of the paper is "Combustion By-Product Transportation and Underground Disposal." In this paper, the progress made in the last two quarters is reported. The economic evaluation of the three selected technologies includes systems costs with and without injection modules in order to separate transportation and handling cost from the injection cost.

This capability was added to the software during this quarter. A copy of the paper is appendix 1 of this report.

PLANS FOR THE NEXT QUARTER

1. Work with injection system researchers to update the capital and operating costs of the pneumatic and hydraulic injection systems of various capacities,
2. Finalize various sections of the interactive software,
3. Prepare the topical report on "Technologies for Transportation and Handling of FGD By-Products."
4. Prepare User's Manual for the "Economic Evaluation" software.

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Steel Intermodal Container (SIC) Development

In September, 1995, additional research was initiated to develop and demonstrate an alternative technology for handling and transporting CCBs. The Illinois Central Railroad and Wilson Manufacturing Company are cooperating in this research and development project.

The technology involves modifying a standard steel intermodal container (SIC), with dimensions of 20 feet length, 8 feet width, and 8 feet height, so that it can be effectively loaded, unloaded, and transported on flat bed rail cars. The development of the SIC concept requires modifying the container to include: 1) loading mechanism at the top; 2) end dump capability; and 3) ability to vacuum CCBs using available commercial technology. The first two modifications have been engineered and are capable of being implemented at any time; however, the vacuum technology has developed significant problems.

Laboratory simulation studies of different vacuuming approaches, using a physical model built on the scale of 1 inch = 1 foot (20 inches length, 8 inches width, and 8 inches height) were conducted over a period of several months. The best results obtained, after using several configurations, resulted in successfully emptying about 90 percent of the model container.

During this quarter a larger laboratory model, built on the scale of 3 inches = 1 foot (60 inches length, 24 inches width, 24 inches height) was constructed. A number of vacuuming tests were run on the larger model; however, none proved to be successful. The smaller model used about 23 pounds of fly ash and a vacuum pressure of about 8 psi. Scaling this up for the larger model, 132 pounds of fly ash were used, and a vacuum pressure of 25 psi. Apparently the additional weight of material creates a bonding effect in the fly ash, thus making it difficult to move to the emptying vacuum port.

Laboratory studies using the large model continue, with emphasis on the design of the floor to permit easier movement of the CCBs, multiple vacuum ports, and aeration of the CCB material to overcome the apparent bonding effect. It is believed that a combination of these parameters will permit the successful design of a SIC that can efficiently and effectively be utilized in the handling and transporting of CCB material.

SECTION 4

ENVIRONMENTAL ASSESSMENT AND GEOTECHNICAL STABILITY

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

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ENVIRONMENTAL ASSESSMENT AND GEOTECHNICAL STABILITY AND SUBSIDENCE IMPACTS

Accomplishments

Researchers from SIUC and the ISGS involved with the Environmental Assessment portion of the project continued groundwater monitoring during the last quarter. Wells were sampled in February, March, April, May, and June. Tables 4.1 and 4.2 summarize depths to water taken during the study. Tables 4.3-4.5 list data on field parameters taken during sampling. Tables 4.6-4.9 list the cation and anion concentrations as determined by the ISGS Geochemistry Laboratory. Well development by circulating potable water down the well casings just after installation of the monitoring wells likely influenced initial groundwater quality. At this point, too few samples have been collected to completely characterize background water quality. Consistent results collected on successive sampling trips would suggest that the influence of water circulated during well development is no longer a factor and the results reflect background conditions. Preliminary data suggest nonpotable water, possibly a brine, in the formations bounding the target panels.

The researchers also installed automated data loggers and pressure transducers in selected monitoring wells in order to collect head data at regular short intervals (15 minutes). The data loggers are scheduled to be downloaded early next quarter. Table 4.10 lists the information on pressure transducers at the study site.

Plans

Plans for the next quarter include continued monitoring of hydraulic head and groundwater chemistry at the study site.

Table 4.1

Screened interval and depth to water measurement in monitoring wells 2A, 3, and 4.
Deepest wells in each nest are the sampled wells.

Well nest	2A	2A	2A	3	3	4
Screened interval (feet)	75-80	213.25-218.25	340-345	201-206	282.5-287.5	343.5-348.5
9/25/95*	16.87	83.7	237.45	27.5	13.17	257.73
1/8/96	21.22	82.46	NW	42.92	23.67	-
2/6/96	14.48	73.52	NW	-	-	341.43
2/7/96	-	-	-	44.51	274.21	-
3/1/96	-	-	-	-	279.18	341.77
3/2/96	12.9	72.5	NW	-	-	-
3/11/96	15.35	72.27	NW	47.36	282.8	344.16
3/29/96	14.37	71.54	NW	48.25	281.95	343.13
4/9/96	14.16	71.26	NW	48.83	282.81	343.91
5/7/96	14.46	70.33	NW	49.87	281.49	342.48
5/15/96	14.36	70.07	NW	49.97	NW	343.61
6/10/96	-	-	-	50.36	282.14	342.69
6/11/96	14.33	69.36	NW	-	-	-
6/23/96	14.09	69.25	NW	48.81	NW	343.44

Table 4.2

Screened interval and depth to water measurement in monitoring wells 5 and 6. Deepest wells in each nest are the sampled wells.

Well nest	5	5	5	6	6	6
Screened interval (feet)	73-78	215-220	337-342	71-76	216.5-221.5	311-316
9/25/95*	8.1	18.9	66.7	16.18	48.85	260.4
1/8/96	-	-	-	-	-	-
2/6/96	4.12	65.23	N/A	10.84	13.77	NW
2/7/96	4.56	83.94	313.44	13.4	21.47	312.77
3/1/96	-	-	-	-	-	-
3/2/96	3.38	55.13	326.4	11.1	25.8	NW
3/11/96	N/A	N/A	N/A	N/A	N/A	NW
3/29/96	3.34	64.37	NW	10.79	27.67	NW
4/9/96	35.2	64.17	NW	10.28	28.29	NW
5/7/96	N/A	N/A	N/A	N/A	N/A	N/A
5/15/96	2.75	62.89	325.84	10.31	30.16	NW
6/10/96	-	-	-	-	-	-
6/11/96	3.86	64.66	325.24	10.18	31.82	NW
6/23/96	4.19	62.31	325.26	10.03	25.21	NW

N/A Indicates broken tape measure.

NW Indicates no measurable water level.

* Measuring tape not fully labeled so there is a greater, and unknown error with these readings.

- No measurement taken on this date.

Table 4.3

Depth to water measurement, samples collected, and flow-through-cell parameters for deep wells in each well nest, February 6 to March 11, 1996.

Date	Well #	DTW (feet)	Time pumped (min)	Cation sample	Anion, Acidity, Alkalinity sample	Temperature (C)	ORP (mV)	Conductance (mhos)	pH	O2 (ppm)
2/6/96	2A	NW	38	NW	NW					
2/7/96	3	274.21	14	250	500, 250	17.5	27	11.3	12.87	2.3
2/6/96	4	341.43	20	250	IW (125)	13.3	169	2.51	8.21	3.1
2/7/96	4	ND	150	250	500					
2/6/96	5	NW	14	250	500, 250	15.7	56	17.2	12.88	4.3
2/6/96	6	NW	40	NW	NW					
3/2/96	2A	NW	20	NW	NW					
3/1/96	3	279.18	25	NW	IW (150)	11.7	-96	10	7.82	3.7
3/2/96	3	ND	65	IW (75)	NW					
3/1/96	4	341.77	118	NW	IW (25)	9.7	-78	5.03	7.24	2.3
3/2/96	4	ND	105	250	IW (75)					
3/2/96	5	NW	40	NW	NW					
3/2/96	6	NW	45	NW	NW					
3/11/96	2A	NW	18	NW	NW					
3/11/96	3	282.8	110	175	500					
3/11/96	3	ND	71	175	NS					
3/11/96	4	344.16	10	250	500	8.4	19	4.99	8.47	7.1
3/11/96	5	ND	20	IW	IW (25)					
3/11/96	6	NW	15	NW	NW					

Table 4.4

Depth to water measurement, samples collected, and flow-through-cell parameters for deep wells in each well nest, March 29 to May 15, 1996.

Date	Well #	DTW (feet)	Time pumped (min)	Cation sample	Anion Acidity Alkalinity sample	Temperature (C)	ORP (mV)	Conductance (mhos)	pH	O2 (ppm)
3/29/96	2A	NW	13	NW	NW					
3/29/96	3	281.95	57	NS	NS	11.3	-52	12.6	7.24	7.3
3/29/96	4	343.13	82	NS	NS	9.6	-44	7.25	6.96	3.4
3/29/96	5	NW	20	NS	NS					
3/29/96	6	NW								
4/9/96	2A	NW	10	NW	NW					
4/9/96	3	282.81	118	230	500					
4/9/96	4	343.91	26	250	500					
4/9/96	5	NW	18	IW	IW (20)					
4/9/96	6	NW	11	NW	NW					
5/15/96	2A	NW	11	NW	NW					
5/15/96	3	NW	103	IW (50-75)	500					
5/15/96	4	343.61	7	250	500	20.2	40	12.1	8.14	3.3
5/15/96	5	325.84	15	NW	NW					
5/15/96	6	NW	*	*						

Table 4.5

Depth to water measurement, samples collected, and flow-through-cell parameters for deep wells in each well nest, June 23, 1996.

Date	Well #	DTW (feet)	Time pumped (min)	Cation sample	Anion Acidity Alkalinity sample	Temperature (C)	ORP (mV)	Conductance (mhos)	pH	O2 (ppm)
6/23/96	2A	NW	10	NW	NW					
6/23/96	3	NW	112	IW (100)	IW (450)					
6/23/96	4	343.44	10	250	500	23.8	-75	15.8	7.87	3.4
6/23/96	5	325.26	23	250	500					
6/23/96	6	NW	10							

IW Water yielded but insufficient for sample. Amount collected in parentheses.
 ND No depth to water measurement taken.
 NS No water available for sampling.
 NW No measurable water in well.
 * Could not access well with sampling equipment.

Table 4.6

Laboratory analysis of cation constituents, February and March sampling, 1996. All units are mg/L, P unless noted.

Lab #	Date	Well #	Al	As	B	Ba	Be *	Ca	Cd	CO	CR	CU
W01003	2/6/96	4	<0.02	<0.1	0.42	0.14	<2	39.7	<0.01	<0.01	<0.01	<0.01
W01005	2/6/96	5	0.29	<0.1	0.42	1.73	<2	115	<0.01	<0.01	<0.01	<0.01
W01006	2/7/96	3	0.11	<0.1	0.54	0.37	<2	10.1	<0.01	<0.01	<0.01	<0.01
W01004	2/7/96	4	<0.02	<0.1	0.4	0.12	<2	38.8	<0.01	<0.01	<0.01	<0.01
W01007	2/7/96	blank	<0.02	<0.1	<0.02	<0.02	<2	<0.01	<0.01	<0.01	<0.01	<0.01
W01063	3/10/96	3	0.1	<0.1	0.77	0.19	<2	14.8	<0.01	<0.01	<0.01	<0.01
W01064	3/10/96	4	0.03	<0.1	0.51	0.14	<2	67.8	<0.01	<0.01	<0.01	<0.01
W01065	3/10/96	blank	<0.01	<0.1	<0.02	<0.01	<2	<0.01	<0.01	<0.01	<0.01	<0.01
Lab #	Date	Well #	FE	K	LA *	LI	MG	MN	MO	NA	NI	PB
W01003	2/6/96	4	0.02	7	<2	0.03	12	0.09	0.03	377	<0.03	<0.05
W01005	2/6/96	5	0.01	224	<2	1.51	0.01	<0.01	0.12	1605	<0.03	<0.05
W01006	2/7/96	3	0.01	418	<2	1.22	0.02	<0.01	0.13	1027	<0.03	<0.05
W01004	2/7/96	4	0.01	8	<2	0.03	12	0.08	0.02	374	<0.03	<0.05
W01007	2/7/96	blank	<0.01	<1	<2	<0.01	<0.01	<0.01	<0.02	<0.1	<0.03	<0.05
W01063	3/10/96	3	0.01	324	<2	1.02	0.01	<0.01	0.11	1680	<0.03	<0.08
W01064	3/10/96	4	0.04	12	<2	0.05	20.2	<0.01	<0.02	705	<0.03	<0.08
W01065	3/10/96	blank	<0.01	<1	<2	<0.01	<0.01	<0.01	<0.02	0.6	<0.03	<0.08
Lab #	Date	Well #	SB	SC *	SE	SI	SR	TI	TL	V	ZN	ZR
W01003	2/6/96	4	<0.2	<3	<0.1	1.79	0.62	<0.01	<0.6	<0.01	0.01	<0.01
W01005	2/6/96	5	<0.2	<3	<0.1	1.77	8.68	<0.01	<0.6	<0.01	0.3	<0.01
W01006	2/7/96	3	<0.2	<3	<0.1	1.79	1.54	<0.01	<0.6	<0.01	0.01	<0.01
W01004	2/7/96	4	<0.2	<3	<0.1	1.82	0.6	<0.01	<0.6	<0.01	0.02	<0.01
W01007	2/7/96	blank	<0.2	<3	<0.1	<0.01	<0.01	<0.01	<0.6	<0.01	<0.01	<0.01
W01063	3/10/96	3	<0.1	<3	<0.1	2.11	1.86	<0.01	<0.3	<0.01	0.01	<0.01
W01064	3/10/96	4	<0.1	<3	<0.1	2.13	1.31	<0.01	<0.3	<0.01	0.01	<0.01
W01065	3/10/96	blank	<0.1	<3	<0.1	<0.01	<0.01	<0.01	<0.3	<0.01	<0.01	<0.01

Table 4.7

Laboratory analysis of anion constituents, February and March sampling, 1996. . All units are mg/L, P unless noted.

Lab #	Date	Well #	HG *	CL	F	NO3 **	SO4 **	Total K ***	Pal K ***	Acid ***
W01003	2/6/96	4	<0.05	ND	ND	ND	ND	93.5	ND	4
W01005	2/6/96	5	<0.05	1064	ND	0.09	81.9	2532	2418	ND
W01006	2/7/96	3	<0.05	705	ND	0.19	250	901.3	823.1	ND
W01004	2/7/96	4	<0.05	478	ND	0.1	214	127.6	ND	3
W01007	2/7/96	blank	<0.05	ND	ND	ND	ND	ND	ND	ND
W01063	3/10/96	3	<0.05	1668	ND	0.07	549	1033	953	ND
W01064	3/10/96	4	<0.05	1113	ND	0.08	291	150.9	ND	5
W01065	3/10/96	blank	0.07	2.14	ND	<0.01	0.31	1	ND	2

Remarks:

Total K Alkalinity to pH 4.5 as mg CaCO₃/L
 Pal K Alkalinity to pH 8.3 as mg CaCO₃/L
 Acid Acidity to pH 8.3 as mg CaCO₃/L

Analytic Method Codes:

* µg/L, Inductively coupled plasma
 ** mg/L, Ion chromatography
 *** mg/L, Titrimetric
 ND No detection

Table 4.8

Laboratory analysis of cation constituents, April, May, and June sampling, 1996. All units are mg/L, P unless noted.

Lab #	Date	Well #	Al	As	B	Ba	Be *	Ca	Cd	CO	CR	CU
W01122	4/9/96	3	0.1	<0.1	0.77	0.14	<1	20.2	<0.01	<0.01	<0.1	<0.01
W01123	4/9/96	4	0.04	<0.1	0.58	0.14	<1	97.6	<0.01	<0.01	<0.1	<0.01
W01229	5/15/96	3	0.04	<0.1	0.78	0.13	<1	19.4	<0.1	<0.1	<0.1	0.01
W01228	5/15/96	4	<.02	<0.1	0.66	0.15	1	118	<0.1	<0.1	<0.1	0.01
W01230	5/15/96	blank	<.02	<0.1	<0.01	<0.01	<1	0.02	<0.1	<0.1	<0.1	<0.01
W01363	6/23/96	3	0.05	<0.1	0.78	0.13	1	23	<0.1	<0.1	<0.1	<0.01
W01362	6/23/96	4	0.04	<0.1	0.82	0.16	2	168	<0.1	<0.1	<0.1	0.01
W01364	6/23/96	5	0.24	<0.1	0.27	4.78	2	328	<0.1	<0.1	<0.1	<0.01
W01365	6/23/96	blank	<.02	<0.1	<0.02	<0.01	<1	0.06	<0.1	<0.1	<0.1	<0.01
Lab #	Date	Well #	FE	K	LA *	LI	MG	MN	MO	NA	NI	PB
W01122	4/9/96	3	0.03	255	<2	0.88		<0.01	0.12	1780	<0.03	<0.05
W01123	4/9/96	4	0.09	12	<2	0.06	30	0.03	<0.02	1030	<0.03	<0.05
W01229	5/15/96	3	<0.01	229	<2	0.81		<0.01	0.12	1830	<0.3	<0.5
W01228	5/15/96	4	0.07	14	<2	0.07	36.7	0.03	<0.02	1260	<0.3	<0.5
W01230	5/15/96	blank	<0.01	<1	<2	<0.01		<0.01	<0.02	1.1	<0.3	<0.5
W01363	6/23/96	3	0.04	185	<2	0.66		<0.01	0.1	2280	<0.02	<0.08
W01362	6/23/96	4	0.15	19	<2	0.09	52.7	0.04	<0.02	2040	<0.02	<0.08
W01364	6/23/96	5	0.02	159	<2	1.07		<0.01	0.15	4100	<0.2	<0.8
W01365	6/23/96	blank	0.02	<1	<2	<0.01		<0.01	<0.02	0.36	<0.2	<0.8
Lab #	Date	Well #	SB	SC *	SE	SI	SR	TI	TL	V	ZN	ZR
W01122	4/9/96	3	<0.1	<3	<0.1	1.81	1.9	<0.01	<0.3	<0.01	<0.01	<0.01
W01123	4/9/96	4	<0.1	<3	<0.1	2.46	2.1	<0.01	<0.3	<0.01	0.01	<0.01
W01229	5/15/96	3	<0.1	<3	<0.2	1.68	1.97	<0.1	<0.3	<0.1	<0.01	<0.1
W01228	5/15/96	4	<0.1	<3	<0.2	2.7	2.79	<0.1	0.4	<0.1	0.01	<0.1
W01230	5/15/96	blank	<0.1	<3	<0.2	<0.01	<0.01	<0.1	<0.3	<0.1	<0.01	<0.1
W01363	6/23/96	3	<0.2	<3	<0.2	1.59	2.25	<0.1	<0.3	<0.1	<0.01	<0.1
W01362	6/23/96	4	<0.2	<3	<0.2	3.12	4.01	<0.1	<0.3	<0.1	0.02	<0.1
W01364	6/23/96	5	<0.2	<3	<0.2	0.68	12.75	<0.1	<0.3	<0.1	0.02	<0.1
W01365	6/23/96	blank	<0.2	<3	<0.2	<0.01	0.01	<0.1	<0.3	<0.1	0.03	<0.1

Table 4.9

Laboratory analysis of anion constituents, April, May, and June sampling, 1996. All units are mg/L, P unless noted.

Lab #	Date	Well #	HG *	CL	F	NO3 **	SO4 **	Total K ***	Pal K ***	Acid ***
W01122	4/9/96	3	0.31	2059	ND	0.04	684	833.6	789.4	ND
W01123	4/9/96	4	0.34	1527	ND	0.06	383	162.2	ND	7
W01229	5/15/96	3						629.9	597.7	ND
W01228	5/15/96	4						171.3	ND	9
W01230	5/15/96	blank						1.8	ND	ND
W01363	6/23/96	3						382.6	367.5	ND
W01362	6/23/96	4						205.5	ND	13
W01364	6/23/96	5						2804	2760	ND
W01365	6/23/96	blank						0.9	ND	1

Remarks:

Total K Alkalinity to pH 4.5 as mg CaCO₃/L
 Pal K Alkalinity to pH 8.3 as mg CaCO₃/L
 Acid Acidity to pH 8.3 as mg CaCO₃/L

Analytic Method Codes:

* µg/L, Inductively coupled plasma
 ** mg/L, Ion chromatography
 *** mg/L, Titrimetric
 ND No detection

Table 4.10 -- Transducer Data

Installation of Geokon Vibrating Wire Pressure Transducers at Peabody 10

Dates of Installation: June 10 and 11, 1996

Installed by: Steven Esling, Timothy McDonald, Edward Mehnert

Well	Transducer Depth (ft)	Model Number	Pressure Range (psi)	Serial Number	Sensor Number	Swept Frequency
2	30	4500ALV-10	10	34941	no wired	NA
2	218 ^a	4500H-150	150	31797	no wired	NA
2	345 ^a	4500AL-10	10	35407	no wired	NA
3	289 ^a	4500AL-10	10	35408	1	16-22
3	100	4500H-50	50	31799	2	22-28
4	2	4580-1-2.5	2.5	31793	1	13-40
4	348 ^a	4500AL-10	10	35404	2	20-30 ^b
5	78 ^a	4500H-150	150	31794	1	22-30
5	220 ^a	4500H-150	150	31795	2	22-30
5	342 ^a	4500AL-10	10	35406	3	21-26
6	76 ^a	4500H-50	50	31800	1	23-29
6	222 ^a	4500H-150	150	31798	2	23-31
6	316 ^a	4500AL-10	10	35405	3	20-25

a: Transducer was set at the bottom of the well. Depth is approximate.

b: Originally calculated a frequency range of 20-25. This range was adjusted in the field to 20-30 to obtain stable readings.

SECTION 5

GEOTECHNICAL STUDIES

**DR. D. DUTTA
CO-PRINCIPAL INVESTIGATORS**

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

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GEOTECHNICAL STUDIES

Surface Subsidence and Subsurface Strata Movements

Sixty-six (66) surface subsidence monuments have been installed over the two (2) injection panels to monitor the surface movements prior to underground placements. Figure 5.1 shows the grid employed to install the subsidence monuments. The grid consists of subsidence-monument-lines in the transverse and longitudinal directions over the injection panels. In addition, four (4) subsidence-monument-lines were installed at angles to the longitudinal directions of the two panels. This grid provides enough surface movement data to develop contours of vertical surface movements over the panels before and after backfilling.

The surface monuments were spaced at 25-ft intervals in the longitudinal and transverse directions. The subsidence-monument-lines extend at least 100 ft beyond the panel edges.

A subsidence monitoring point consists of a 7/8-inch diameter roof bolt 7 ft. in length. The monitoring point is installed by auguring a 4 inch diameter hole to a depth of three (3) feet, inserting the 7-ft-long roof-bolt (a rebar) through three (3) feet of foam insulation and two-inch-diameter PVC pipe, then hammering the bolt between 3.0 and 3.5 ft into the ground. As the frost heave zone in this area is reported eighteen (18) inches deep from the surface, the subsidence monuments are free from the effects of ground freezing.

The level surveying technique is being used to measure the elevations of the subsidence monuments. An autaset level with an optical micrometer is being used for subsidence measurements. The accuracy of the autaset level is 0.000328 ft. Baseline measurements of surface subsidence monuments were taken in March, 1996. A second set of readings was taken in June, 1996. So far, the readings do not indicate any relative surface movements with respect to the baseline measurements. However, it is expected that some relative movements with respect to the baseline measurements will be noticed after approximately six months from the date the baseline measurements were taken. Measurements of surface monuments will continue during Phases II and III prior to backfilling and after backfilling the panels.

For baseline measurement, the sonic probe was introduced in the two subsurface measurement boreholes. The probe in the boreholes over hydraulic and pneumatic panels could go only 282 ft and 248 ft, respectively. This indicates that the geotechnical boreholes collapsed after the installation of the settlement sensors. No readings could be taken from these two boreholes because the sensors are located at a depth between 290 ft and 340 ft below the collapsed region. However, the elevation of the top of the steel casing of the geotechnical boreholes are being measured by the autaset level

Figure 5.1 Layout of subsidence monuments

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GEOTECHNICAL STUDIES

Surface Subsidence and Subsurface Strata Movements (Continued)

Two (2) geotechnical holes have been drilled (see Figure 5.2 for locations) to install settlement sensors in the boreholes above the coal seam (up to 50 ft above the roof-line). The geotechnical boreholes are six (6) inches in diameter. The settlement probe system consists of the probe with a cable reel, an integral readout device and a corrugated plastic casing with settlement sensors. Fifty (50) feet of corrugated plastic casing with sensors (metal rings) placed every ten (10) feet were installed at the bottom of each geotechnical borehole. Each corrugated casing was attached to the bottom of a four-inch-in-diameter PVC casing installed in the borehole. The casing is built by coupling ten-foot section of PVC pipe. The annulus between the borehole and the PVC casing is filled with silica sand.

The settlement probe detects the position of metal rings (in the corrugated pipe) in the borehole and provides a buzzing signal on the readout device when one is approached. The position of the probe is then slowly adjusted for the maximum signal which is seen on a meter. Once the meter is peaked with the probe, the depth of that particular ring can be directly read off the cable marks and the scale provided on the pipe. The vertical locations of the rings in the corrugated casing will change when vertical movements of the subsurface strata occur. The relative change in the locations of the rings will indicate the amount of vertical subsurface movements. The accuracy of the system is 0.0008 ft.

Figure 5.2 Different Boreholes Over Pneumatic and Hydraulic Injection Panels

SECTION 6

UNDERGROUND PLACEMENT

Yoginder P. Chugh - Co-Principal Investigator
Eric R. Powell - Pneumatic Placement Consultant
Fred Brackebusch - Hydraulic Placement Consultant

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

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UNDERGROUND PLACEMENT

Pneumatic Injection

The first quarter of Phase II of the DOE-SIUC Cooperative Agreement encompassed the detailed design of the pneumatic injection equipment, including shop drawings for the fabrication of the weldments and obtaining quotations for the purchased items. It became apparent that this work for the sake of expediency, would best be undertaken in Carbondale and that the fabrication should be done in shops in the vicinity of Southern Illinois University.

Consequently Eric Powell relocated to Carbondale in mid May and has taken up residence in this area. This arrangement will also be more convenient for supervising the final assembly and shop testing of the pneumatic injection equipment.

The fabricated components and purchased items are being delivered to the Illinois Coal Development Park in Carterville, where the assembly of the pneumatic injection equipment will take place. There is ample facilities at this location, including an overhead crane in the shop area and welding equipment and machine tools to facilitate the assembly. Secure warehouse facilities are available for the storage of those parts not immediately required in the assembly. Office space has also been provided.

At the completion of the shop drawings for each major component assembly, visits have been made to several steel fabrication shops in Southern Illinois to ensure each potential bidder has the capabilities to produce the equipment to acceptable standards and within the given time frame. Three shops were selected for the fabrication and machining work and each have submitted bids. Purchased items, such as air operated valves, air motors, hydraulic pumps, etc., are readily available from any number of suppliers throughout the USA. However, manufacturers with strong representation in this area, especially those representatives with warehouse facilities have been selected. Also, those companies already stocking the needed components and having trained service personnel readily available to assist if necessary in the final assembly and shop testing at ICDP were favored. Bids are in the process of being received prior to placing purchase orders.

The conditioning of the fly ash and subsequent further addition of water requires a paddle mixer. As it is planned to utilize the same equipment arrangements, including the mixer, screw feeder, weigh cells and instrumentation for both the pneumatic injection demonstration and the paste injection demonstration, the availability of mixing equipment suitable for both applications is being investigated. Three manufacturers of mixers, each with throughput of combustion residues have been invited to visit SIUC and to bid for the conditioner/mixer equipment. Sample mixes will be prepared for each manufacturer to ensure they are aware of the mixture consistency required for each application.

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Several possibilities were examined for the location of the surface test, including abandoned rail car load-out facilities, openings from "under the highwall" mining, concrete culverts and any possibility of providing an economically viable alternative sufficiently strong to withstand the pneumatic conveying pressure. It was concluded that Peabody No. 10 mine would be the most economical location for the surface test. The pneumatic injection equipment would only require to be shipped to the one location for both surface and underground demonstrations. Inquiries are in progress to locate construction equipment leasing companies in the general geographical area of Peabody No. 10 with the capability to provide the support equipment required, such as the diesel powered air compressor, front end loader and a crane. Such equipment will be required for both the surface test and underground demonstration. The size and capacity of the equipment required is readily available, providing sufficient notice is given to reserve the particular units required well in advance of the delivery date.

For the surface test it has been decided that the most economical construction for the simulated mine entry will be to dig the trench for the required test length of 300 feet and enclose this with a suitable roof. The roof will overlap the sides of the trench and will be covered to a substantial depth with the material removed in the excavation. The cover will be sufficiently loaded to withstand a pneumatic conveying pressure of 12 psig and the "blast" pressure. The actual blast pressure required is an unknown quantity at this stage and although the air is released from the receiver at 110 psi, the pressure acting on the deposited material will depend on the space volume at the bottom of the borehole into which the blast air will expand. We estimate an air pressure of 30 to 40 psig will act on the material to force a passage through. Therefore the roof over the trench in the immediate area of the injection borehole must be loaded to withstand this upward force.

Other activities involving the pneumatic injection demonstration program have included the provision of estimated capital and operating costs for the economic assessment of the project, coordination with the personnel responsible for the paste backfill in regards to equipment selection common to both systems and assisting with the design of a model to study the effect of the air blast on deposited material in mine entries and cross-cuts.

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UNDERGROUND PLACEMENT

Hydraulic Placement

Hydraulic placement system flowsheets were developed in cooperation with Mr. Fred Brackebusch of Mine Systems Design. In these flowsheets, an attempt was made to develop materials handling and dry mixing facilities than are common to both pneumatic and hydraulic placement systems. A staff visit to the Springfield City Water, Light and Power electric generation power plant and CCB's material handling systems indicated that fly ash and scrubber sludge could be transported dry, but separately, to the demonstration site and stored on ground. Belt conveyors and/or auger systems will feed these materials into a mixing hopper which will in turn feed a mixer. This material handling system can also be used for the pneumatic placement system where the mixer will form the preconditioning unit. An option where dry mixing will be eliminated was also considered. Mixes were made to evaluate the quality and strength characteristics of such a mix.

Available mixer designs were reviewed and new designs were developed. Mixer specifications were identified. Meetings were held with several mixer manufacturers. At this time, the most viable mixer appears to be one fabricated by United Conveyor, Inc. of Waukegan, Illinois and a bid package is being prepared by them for consideration.

Grout pump requirements were established. Pumps fabricated by Schwing Company appear to be most reliable. At the suggestion of the manufacturer, a visit was made to Springfield, Illinois to look at the field performance of one such pump.

The options to rent or to purchase the hydraulic placement system components in were reviewed in depth and the staff is of the opinion the purchase option should be considered. Based on these analyses, discussions were initiated with Mr. Mark Estel and Mr. Scott Renninger of the USDOE to request equipment purchase rather than equipment rental.

The option of electric or diesel power for the placement systems was also considered. Diesel power will provide the flexibility in the field; however, the cost of this equipment will be higher.

Peabody No. 10 mine (demonstration site) has been sold by the company. However, the sales agreement protects the field demonstration activities of the USDOE program. SIUC will maintain a subcontract agreement with the Peabody Coal Company and the new mine owner will be a sub-contractor to the Peabody Coal Company.

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

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UNDERGROUND PLACEMENT

Sites for surface demonstrations were reviewed with Peabody Coal Company. It appears at this time these will be held at Peabody No. 10 mine. Permits for underground demonstrations have been received from the Illinois Environmental Protection Agency.

APPENDIX

Paper to be presented by Dr. Hasan Sevim at the "Fourth International Symposium on Environmental Issues and Waste Management in Energy and Mineral Production", Cagliari, Italy, October 7-11, 1996.

COMBUSTION BY-PRODUCT TRANSPORTATION AND UNDERGROUND DISPOSAL

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SUMMARY: Coal combustion by-product transportation and handling technologies were introduced in conjunction with underground disposal. Operating policies were presented for three most promising technologies. Scenarios applicable to Illinois were developed and engineering designs were performed. These scenarios were then economically evaluated and a comparative analysis was conducted. The favorable operating range in terms of distance and tonnage was determined for each technology.

1. INTRODUCTION AND BACKGROUND

Approximately, 90 million tons of coal combustion by-products (fly ash, bottom ash, scrubber sludge) are generated annually by the U.S. utility industry (ACAA, 1993). This amount is expected to increase significantly after 1995 due to Clean Air Act Amendment of 1990. Disposal of these by-products in an environmentally sound manner has become a major issue for the utility industries. Most of today's by-products are disposed of in surface facilities, or landfills, near power plants. Surface disposal is becoming more and more expensive, especially in and around urban areas, and also bears over time the potential to negatively impact not only land use and land values, but also surface and ground water quality. Disposal of by-products into abandoned sections of underground coal mines is perceived to be a promising alternative whereby most of the disadvantages of surface disposal could be overcome (Sevim et al., 1992). Furthermore, when fluidized gas desulfurization (FGD) by-products from advanced combustion processes are used in backfilling the voids, subsidence and acid mine drainage -- two major problems resulting from underground coal mining -- may be significantly reduced due to the alkalinity and cementitious characteristics of these by-products (Meiers et al., 1995).

Recognizing these potential advantages, the U.S. Department of Energy (DOE) entered into a cooperative research program with the Southern Illinois University to investigate the engineering, environmental, and economic feasibility of disposing by-products into abandoned sections of underground coal mines. Although the investigation focuses on the Illinois coal basin, the findings can easily be projected to other basins. The project is progressing in six (6) branches since September 1993 and is expected to be completed in 1997. The six branches are: 1) By-products and Mix Characterization, 2) Materials Handling and System Economics, 3) Residue Placement Underground, 4) Environmental Monitoring and Assessment, 5) Health and Safety Issues and Permitting, and 6) Field Demonstration.

In this paper, the progress in Materials Handling and System Economics is reported. The objective of the Materials Handling study is to identify the systems that are technically, environmentally, and economically feasible in handling and transporting the by-products from the

power plants to the injection sites. As opposed to surface disposal facilities which are at or near the power plants, most underground mines are far from power plants, requiring long distance hauling of the by-products and thus significantly contributing to the overall disposal cost. Therefore, for underground disposal to be economically viable, transportation and handling cost must be minimized. This requires careful selection of the system and optimal design for efficient operation.

2. TRANSPORTATION AND HANDLING TECHNOLOGIES

To attain the above stated objectives, several technologies were first evaluated from an environmental point of view. They can be classified under two categories:

A. Existing Technologies: 1) Pneumatic Trucks, 2) Pressure Differential Rail Cars, 3) Open Hopper Coal Cars, 4) Tarped Rear-Dump Trucks, 5) Bottom-Dump Container Trucks.

B. Adaptable and Futuristic Technologies: 1) Collapsible Intermodal Containers, 2) Intermodal Steel Containers, 3) Cylindrical Intermodal Tanks, 4) Coal Hopper Cars with Automatic Retractable Tarping, 5) Covered Hopper Cars - Grain Cars.

In coal combustion by-product transportation, the major environmental concern is the fugitive dust due to extremely small size of the particles.

The first two technologies listed above under "A" are currently being utilized in a few operations in the United States. They can be considered as fugitive-dust free technologies if they are operated properly at the loading and unloading stations. These two technologies will be further discussed below.

The third technology (Coal Hopper Cars) has found some application in by-product transportation, but opinions about its effectiveness have been mixed. Chemical sprays have been suggested and applied to the surface of the residue to form a crusted layer to prevent fugitive dust while traveling. The major drawback in this alternative, even if the formation of a crust is successful, is the need of baghouses both at the loading and offloading points to prevent serious fugitive dust problem. Also, penetration of water or moisture through the crust, leading to heating or setting of the by-product, may cause severe problems.

The fourth technology (Tarped Rear-Dump Trucks) has also found application in residue transportation. Currently, at least two fly ash disposal operations in Illinois utilize this technology (Giles, 1995). The major concern in tarped trucks is again the presence of fugitive dust during loading and offloading of the residue. A technology that improves over this method is the Bottom-Dump Container Trucks (fifth technology). These trucks are used to fronthaul coal from the mine to the power plant and backhaul ash from the plant to the mine. They can work very efficiently in surface disposal cases, especially when there is coal fronthauling. However, they will not be very convenient in underground disposal because the by-product has to be offloaded directly from the tank into the injection hopper. With bottom dumping, there has to be a ramp arrangement for the truck to get to the top of the hopper.

Among the futuristic technologies cited above under "B", the first three are similar in concept. They are intermodal, i.e., the containers can be transported by rail, truck, and barge as needed. The first technology, Collapsible Intermodal Containers (CICTM), was developed in cooperation with SEEC Inc. as a part of the reported project. These containers are made of rubber coated aramid and nylon fabric with polyester webbing. They are patented by SEEC Inc. The CICs are collapsible storage bins that are portable and intermodal. Those CICs made to transport fly ash by riding in coal

cars have a height of 3 m, diameter of 2,8 m and a 0,48 m filling port. For ash bulk density of 960 kg/m³, the CIC capacity is about 20 tons. These containers are extremely durable and provide fully encapsulated transport, eliminating fugitive dust problems. However, field demonstration showed difficulties in emptying these containers. SEEC, Inc. is continuing its effort to improve the emptying process.

Intermodal Steel Containers are currently being investigated as a part of the reported project. These are 2,4x2,4x6 m general purpose containers that are used in transporting granular, powdered and various other products. The modifications considered for adaptation to by-product transportation are: 1) a top gate to facilitate filling from ash silos, 2) an end-dump capability through a swing side door, and 3) ability to vacuum by-product using available technology.

Cylindrical Intermodal Tanks have an advantage over the first two intermodal containers due to their shape. This alternative will be elaborated below.

Finally, Grain Cars were also found to be adaptable to residue transportation. They are abundantly available, and they can be loaded pneumatically or by gravity with minimal fugitive dust problem. However, they require an under-track bin to offload at the mine site. Rehandling of the by-product from the under-track bin is not a desired feature. Offloading from these cars into pneumatic trucks is a possibility but retrofitting to a fluidizing system may be costly.

Among the technologies mentioned above, steady operating policies were developed for Pneumatic Trucks, Pressure Differential Rail Cars, and Cylindrical Intermodal Tanks. Scenarios that are applicable to Illinois plants and mines were developed using these technologies. Engineering designs, which encompass selection and sizing of system components as well as operating schedules, were implemented for these scenarios using an interactive software developed specifically for the evaluation of these technologies. Economic analyses were also conducted using the developed software.

3. OPERATING SCENARIOS FOR SELECTED TECHNOLOGIES

3.1 Cylindrical Intermodal Tanks (CIT)

These tanks are made of either steel or aluminum and have a volume of approximately 24 m³. They are used in transporting various products. The capacity of a tank will be approximately 20 to 25 tons assuming an average density of 960 kg/m³ for coal combustion by-product. Since they are cylindrical, the bridging and sticking problems that occur in rectangular containers when handling powdered material like fly ash, or damp material like scrubber sludge, can be eliminated. These tanks may be mounted in steel frames to facilitate handling.

The operating policy for Cylindrical Tank transportation is shown Figure 1. At the plant, an empty tank will be placed on a trailer with the aid of a piggy packer (a specialized crane) and shuttled to by-product silo where it will be filled by gravity. At the rail siding, the piggy packer will lift the filled tank and stage it along the railroad on a concrete pad. When the train arrives, the piggy packer will lift these tanks again one by one and place them on flat-bed rail cars. A flat-bed rail car can accommodate 3-4 of these tanks.

At the mine site, the tanks will be lifted again by a piggy packer and placed on the concrete pad. Following unloading, the same packer will lift the tanks one by one and place them on a trailer to take them to the injection site. The unloading of the residue into the injection hopper will be done by elevating the head of the tank with the aid of a hydraulic jack mounted on the trailer. The gate of the tank will then be opened and the by-product transferred into the injection system hopper. If emptying tanks through a flop gate creates unacceptable levels of fugitive dust, tanks can be emptied

Figure 1. By-product Transportation and Handling in Cylindrical Intermodal Tanks

by pneumatic means. The empty tanks will be staged at the rail siding and will await for a train to return them to the plant. Upon delivery of the empty tanks to the plant a new cycle will start.

3.2 Pressure Differential Rail Cars (PD cars)

These are special type rail cars used to handle powdered materials. They are operated under a pressure differential between car and container to which the product is discharged. Normally, PD cars are complemented with pneumatic trucks at rail terminals to deliver the material to its final destination. When a PD car is pressurized to about 5 psi or more, the outlet valves are opened to form a steady flow of material into the truck until all the material in the compartment is cleared out.

The operating policy for PD car transportation is very similar to CITs. The exception is that there will be a silo at the mine site where the by-product will be stored. In this scenario, one set of cars is filled at the power plant while the other is emptied at the mine. When all the cars at the plant are filled, either a "local train" or a "unit coal train" will take them to the mine. Subsequently, the empty PD cars will be picked from the mine and delivered to the plant to start another cycle. At the mine, the product in the PD cars will be transloaded into a silo with the aid of a stationary blower. Delivery from the silo to the injection site can be done either by pneumatic trucks, or by regular dump trucks if the silo is equipped with a pugmill to wet the residue to prevent fugitive dust.

3.3 Pneumatic Trucks (PT)

Pneumatic trucks, also referred to as bulk tank trucks, are widely used in transporting low density dry flowable powder and granules as well as high density materials such as cement, limestone and fly ash. A pneumatic truck consists of three main components: (i) tractor, (ii) tank trailer, and (iii) blower.

The most common method of loading the material is gravity feeding from a silo by a collapsible spout which engages to the gate on top of the tank. The tank is air tight when the lids of the gates are closed. During offloading, the material flows through the piping below the tank due to pressure differential created by the blower.

The operating policy of PT transportation is simpler than the previous two technologies in that the trucks are loaded from the fly ash bin of the plant and they deliver the material directly to the injection point at the mine site. There, the pressure necessary for offloading the fly ash into the injection hopper is either supplied by the blower mounted on the truck or by a stationary blower. These trucks are approximately 20 tons in capacity and can offload in about 20 minutes.

4. ECONOMIC EVALUATION

The operating policies described above were used in scenarios applicable to southern Illinois. In and around southern Illinois, annual by-product generation of power plants range between 50,000 to 200,000 tons, and typically plants are about 50 to 300 km away from underground mines. Therefore, all evaluations were conducted for distance-tonnage combinations within these ranges. Specifically, nine combinations were formed for each scenario with 50,000, 100,000, and 200,000 tons evaluated at 50, 160, and 320 km.

The economic evaluation model is based on "After-Tax Cost" concept which takes into account depreciation and taxation. All designs were evaluated for a project life of 10 years, a minimum required rate of return of 12%, and an effective tax rate of 40%. Assets were depreciated based on "Modified Accelerated Cost Recovery System, MACRS," and the expected salvage values were credited to the project at the end of the project life.

First, through the engineering design model, system variables such as, number of transport units, silo capacities, loading and unloading rates, injection system capacity, and number of shifts were determined for a scenario. Then, the design is subjected to economic evaluation whereby cost-per-ton of by-product placed in the mine is determined as a final product. Obviously, determination of cost-per-ton requires a wealth of information on operating and capital cost items for each technology. Such information was collected, compiled, and made part of the interactive software.

It is noted that only the pneumatic injection system was considered in all cases since at this time its capital and operating costs could be determined more reliably than the hydraulic injection system. To reveal the contribution of injection cost to overall cost, each scenario was evaluated with and without an injection system. The outcomes are summarized in Figures 2 to 5.

The unit costs (cost-per-ton) for different tonnage-distance combinations using the CIT technology are shown in Figure 2. The gentle slopes of the cost curves indicate that the system is not very sensitive to distance. On the other hand, the significant drop from one curve to the next is indicative of the sensitivity of the system to tonnages transported. Similarly, the significant vertical drop from a cost curve including injection to that of the one with no injection is indicative of high injection cost contribution to the overall cost. For instance, at 100,000 tons -160 km combination, the delivery cost is only \$6.17/ton but the overall cost is \$10.98/ton indicating an injection cost of \$4.81/ton. This high cost of injection is due to the infrastructure preparation, container handling equipment, and labor.

The unit costs for PD rail car technology are shown in Figure 3. The magnitudes and trends of the costs under this technology are very similar to those of CIT technology.

Figure 4 exhibits the costs corresponding to PT technology. The cost curves are distinctively different than those for the CIT and PD technologies. The steep slopes of the curves are indicative of the system's sensitivity to distance, whereas the closeness of the various curves to each other is

Figure 2. Cost-per-ton in Cylindrical Intermodal Tank Transportation

Figure 3. Cost-per-ton in Pressure Differential Rail Car Transportation

Figure 4. Cost-per-ton in Pneumatic Truck Transportation

Figure 5. By-product disposal costs when Pneumatic Trucks or Cylindrical Intermodal Tanks are used in conjunction with Pneumatic Injection System

indicative of the system's insensitivity to tonnages transported. Also, in contrast to CIT and PD technologies, the distinction between the cost curves including the injection operation and those excluding it is not significant. This is an indication of low injection cost when PT technology is used.

The costs of PT technology are compared with those of CIT technology in Figure 5. The curves in this figure are reflective of the delivery and injection combined. Since PD technology has similar costs as CIT, its cost curves are not included in this figure. At 50,000 ton, PT technology provides lower costs up to approximately 200 km. At 100,000 tons, this critical distance fall to 150 km, and at 200,000 to 110 km. This is due to the fact that economies of scale favor CIT and PD technologies over the PT technology.

5. CONCLUSIONS

The economic results presented in this paper are based on hypothetical cases applied to southern Illinois. Although these cases are close to reality, there are a number of critical variables in each technology that may influence the choice of one over the other. Hence, these results have to be interpreted cautiously. However, the interactive software developed for engineering design and economic evaluation can accommodate almost all environmentally acceptable technologies. Sensitivity analyses on critical variables can be conducted within a short period of time. Furthermore, the engineering and economic data compiled for each technology presents valuable information to the user.

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