Coolside Waste Management Research

Quarterly Report October - December 1994

February 1995

Work Performed Under Contract No.: DE-AC21-91MC28162

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

By
University of Kentucky
Waste Management Center for Applied Energy Research
Lexington, Kentucky 40511

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Morgantown Energy Technology Center
P.O. Box 880
Morgantown, West Virginia 26507-0880

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COOLSIDE WASTE MANAGEMENT RESEARCH

Technical Progress Report

Contract No: DE-AC21-91MC28162

Report Period: October 1, 1994 to October 31, 1994

Statement of Project Objectives

Investigate chemical, mineralogical and physical changes in Coolside waste materials to determine suitability for environmentally safe disposal.

Summary of Progress

A compilation of the field lysimeter leachate data from the lowest leachate transport tubes indicates a major shift in the solution mineral equilibria regime. The pH of the L3 lysimeter (~12.2) and elemental concentrations in the leachates is grossly different from L2 and L1 (e.g., pH ~10.5). Sulfate averaged to date ~10,000 to 12,000 ppm in L1 and L2 compared to ~1,700 ppm in L3. As the materials have the same composition, the preconditioning regime of the materials appears to have a major influence on the leachate chemistry.

Soil gas measurements have now been completed for most of a growing season. CO₂ concentrations as high as >26,000 pm were found in the soil gas. The distribution of the gas in the soil indicates that the FGD material is a major sink for the gas and that carbonation reactions are a major force in the geochemical regime for these materials.

Introduction

Three field lysimeters were filled with by-products from the Coolside technology during the period of August to October of 1992. One lysimeter cell was filled with commercially available Class F fly ash (Lysimeter No. 4). The Coolside material was

emplaced at differing densities and corresponding moistures. Lysimeter No. 1, was loose filled, with a moisture content of 37%; Lysimeter No. 2 was compacted slightly and had a moisture content of about 40%; Lysimeter No. 3 was compacted to optimum density, with approximately 37% water added. A one foot thick layer of Ottawa sand was placed at the bottom of each lysimeter. Each lysimeter was capped with a two foot layer of soil. The first two lysimeters were covered during the filling of the final lysimeter. The covering was removed and all of the lysimeters were allowed to weather naturally.

Since that time the lysimeters have provided samples almost continuously. Leachate collection vessels are normally sampled weekly and semiweekly during wet periods. The most consistent flow has been, not unexpectedly, from the lowermost transport tubes, which have provided the bulk of the samples.

During the spring of 1994 gas monitoring wells were installed in each of the lysimeters at 8, 18 and 30 inch depths. The wells have been monitored continuously since then. This data will be used, in conjunction with the mineral equilibrium model currently under development, to help interpret the mineralogical changes taking place in the materials.

Comparison of Leachate Chemistry

The lysimeters to date have provided a large number of samples. To facilitate the comparison of the gross chemistry of the leachate, the data for the two leachate transport tubes which provided the largest number of samples have been compiled (Tables 1 and 2). The compilations are as ranges and simple mathematical means, not weighted by volume. For large numbers of samples, volume weighted means and simple means are approximately the same. Certain elements have not been found in any measurable quantities in the leachates and have not been included in the tables. These include Ag, Be, Cd and Hg. Elements such

Lysimter/Tube		L1 L1-4	L1-5	L2 L2-3	L2-4	L3 L3-3	L3-4	L4 L4-3	L4-4
Samples (N)		57	61	70	61	88	103	78	29
pH	Mean	10.59	10.53	10.90	10.53	12.19	12.19	9.43	9.21
	Max	11.33	11.44	12.24	11.44	12.42	12.48	9.78	9.74
	Min	8.26	8.37	8.38	8.37	11.9	11.9	8.92	8.71
Anions and Oxy-Anio									
Alk (8.3)	Mean	107	130	198	130	1515	1443	384	199
	Max	170	270	348	270	4985	4710	1006	474
	Min	5	14	9	14	645	275	66	74
Alk(4.5)	Mean	184	241	341	241	2613	2576	ns	61
	Max	299	455	550	455	7810	7735	ns	320
	Min	130	142	143	142	1165	1133	ns	1
Cl	Mean	9127	16239	13617	16239	5466	5104	112	61
	Max	35540	45870	46230	45870	8685	13200	570	320
	Min	212	316	178	316	2660	dl	dl	1
Sulphate	Mean	10284	12867	10636	12867	1763	1786	2632	1951
	Max	22600	19270	21410	19270	3755	3460	4238	4173
	Min	3258	6502	2450	6502	950	dl	dl	1496
Br	Mean	nd	nd	nd	nd	917	807	nd	9
	Max	nd	nd	nd	nd	1760	1960	nd	10
	Min	nd	nd	nd	nd	194	0	nd	9
Mo	Mean	22.03	35.30	28.60	35.30	15.07	13.95	27.18	11.80
	Max	103.00	124.00	138.00	124.00	42.00	41.00	85.00	75.00
	Min	0.78	1.46	1.00	1.46	4.25	3.15	0.30	0.33
B	Mean	1.23	1.32	1.18	1.32	0.84	0.77	63.74	51.55
	Max	3.20	2.30	2.60	2.30	4.80	2.80	115.00	104.00
	Min	0.50	0.50	0.30	0.50	0.30	0.20	15.50	19.00
Se	Mean	2.00	1.95	1.68	1.95	0.86	0.80	0.10	0.08
	Max	4.20	3.80	3.55	3.80	2.30	2.00	0.33	0.31
	Min	0.04	dl	dl	dl	0.20	0.20	dl	0.02
As	Mean	0.43	1.02	1.34	1.02	3.96	3.71	0.50	0.42
	Max	1.10	1.80	2.30	1.80	11.00	11.20	1.00	0.80
	Min	0.07	0.28	0.28	0.28	1.25	0.80	0.30	0.30
V	Mean	0.49	0.86	1.00	0.86	1.28	1.27	0.36	0.31
	Max	0.74	1.50	1.80	1.50	3.53	3.47	0.64	0.68
	Min	0.11	0.21	0.07	0.21	0.67	0.68	0.13	0.19
Cations									
Na	Mean	8050	10871	10165	10871	4522	4228	305	115
	Max	30000	26100	33000	26100	8000	9100	830	710
	Min	1080	1950	1500	1950	2300	1500	4	9
Ca	Mean	473	566	418	566	44	40	548	584
	Max	1380	1400	1340	1400	112	90	730	660
	Min	160	150	100	150	18	18	240	467
K	Mean	2690	3387	3128	3387	1565	1469	677	326
	Max	8100	7500	8000	7500	2600	3300	1690	1700
	Min	540	858	625	858	930	624	25	42
Si	Mean	16.0	17.4	22.0	17.4	70.6	40.2	0.9	0.9
	Max	24.5	32.0	39.0	32.0	2638.0	58.0	2.9	1.5
	Min	4.5	3.5	4.2	3.5	27.0	23.0	0.5	0.3
Mg	Mean	0.73	1.02	0.64	1.02	0.02	0.02	13.69	16.43
	Max	5.95	5.45	4.00	5.45	0.15	0.15	35.00	37.00
	Min	dl	dl	dl	dl	dl	dl	dl	dl

Table 1. Summary of Chemical Data for Field Lysimeter Leachate. Data is for from 10-Foot Leachate Transport Tubes. The 2 Tubes With the Greatest Number of Samples Were Used In the Table. Data is as ppm with the Exception of pH (ns= not significant, dl=below detection, nd=not determined).

Lysimeter/Tube		L1 L1-4	L1-5	L2 L2-3	L2-4	L3 L3-3	L3-4	L4 L4-3	L4-4
Samples (N)		57	61	70	61	88	103	78	29
Minor Ions									
Fe	Mean	0.54	0.80	0.48	0.80	0.05	ns	ns	ns
	Max	15.40	16.70	24.35	16.70	1.95	0.62	0.32	0.20
	Min	dl	dl	dl	dl	dl	dl	dl	dl
Al	Mean	0.23	0.31	0.64	0.31	12.27	12.82	0.37	0.16
	Max	0.62	1.18	1.96	1.18	28.00	29.00	1.70	1.74
	Min	dl	dl	dl	dl	dl	dl	dl	dl
Ti	Mean	0.05	0.06	0.05	0.06	ns	ns	ns	ns
	Max	0.11	0.12	0.13	0.12	0.02	0.02	0.53	0.05
	Min	0.02	0.03	0.02	0.03	dl	dl	dl	dl
Ba	Mean	ns	ns	ns	ns	ns	ns	ns	ns
	Max	0.08	0.12	0.10	0.12	0.03	0.03	0.22	0.23
	Min	dl	dl	dl	dl	dl	dl	dl	dl
Mn	Mean	ns	ns	ns	ns	ns	ns	ns	ns
	Max	0.12	2.42	4.72	2.42	0.07	0.62	dl	dl
	Min	dl	dl	dl	dl	dl	dl	dl	dl
Ni	Mean	ns	ns	ns	ns	ns	ns	ns	ns
	Max	0.18	12.65	20.10	12.65	0.29	0.21	dl	dl
	Min	dl	dl	dl	dl	dl	dl	dl	dl
Cr	Mean	ns	ns	ns	ns	ns	ns	ns	ns
	Max	0.27	3.98	6.30	3.98	0.52	0.18	0.76	0.80
	Min	dl	dl	dl	dl	dl	dl	0.04	dl
Cond.	Mean	33.7	49.3	42.3	49.3	23.4	22.5	5.0	3.3
	Max	100.1	109.0	108.3	109.0	37.7	48.5	9.0	9.1
	Min	6.5	11.4	8.3	11.4	13.3	11.1	2.0	2.1
Volumn	Mean	29	35	41	35	41	32	59	32
	Max	60	100	100	100	80	80	315	65
	Min	10	4	10	4	5	5	2	5
Dis Solids	Mean	30755	45222	37463	45222	15399	14386	4949	3720
	Max	88377	116448	107676	116448	25532	31122	8504	7884
	Min	5376	9680	7216	9680	8368	6140	921	2617

Table 2. Summary of Chemical Data for Minor Ionic Species and Other Parameters.
Data is for Leachates as Used in Table 1.

as Ba, Mn, Ti and Cr have been measured in a few samples early in the collections, but rapidly declined in concentration to levels below the detection limits.

Compared to the fly ash control sample, the leachates from the Coolside material are much more alkaline and are much higher in dissolved ions. For example, total dissolved solids in the leachates in the Class C fly ash of lysimeter L4 is only 10 to 30% of that of the other leachates. Most of the measured ions and elements are lower in the L4 materials with the notable exception of B and Mg.

The major differences among the sample sets, excluding the Class F fly ash, were observed for the leachates from lysimeters L1 and L2, and L3. The L1 and L2 samples were found to have significantly lower pH (10.5 vs 12.2), and significantly higher concentrations of chloride and sulfate by a factor of 2 (~10,000-16,000 ppm vs 5,200 ppm). The L1 and L2 leachates also had significantly higher concentrations of Mo, B, Na, Ca, and K. The L3 leachates had higher concentrations of V, As, Al and alkalinity. The later differences are a function of the higher pH regime of the L3 lysimeter.

Considering that the chemistry of the materials in each cell are the same, the differences in the chemistry of the leachates is amazing. The chemistry of lysimeter L3 indicates a totally different mineral equilibria regime than that of L2 and L3. This difference can only be attributed to the moisturizing and preconditioning regime which the individual cells have been subjected to. The mineralogy along with the thermodynamics of each cell will be investigated and discussed further.

Soil Gas CO₂

The monitoring of the soil gas has been completed for a growing season. Carbon dioxide concentrations of >26,000 ppm were measured several times during the summer. This

may be compared to normal atmospheric CO₂ of 360-400 ppm. The CO₂ was found to follow an unusual distribution pattern. Typically, because it is heavier than O₂ or N₂, it diffuses downward, reaching the highest concentration at the soil rock interface. In the lysimeters L1-L3 the CO₂ essentially disappeared in the gas tube located below the soil horizon (Table 3). In L4 however CO₂ was found in the highest concentration in the fly ash.

The high concentration of CO₂ along with its distribution pattern indicates that carbonation reactions are of major importance in the geochemical evolution of the material.

Gas Tube	N	Mean	Max	Min	
Lysimeter					
20	L1	15	0.66	1.9	0.15
46	L1	15	0.17	0.4	0.4
76	L1	15	0.01	0.20	0.00
20	L2	15	0.57	1.4	0.1
46	L2	15	0.09	0.18	0
76	L2	15	0.02	0.15	0.00
20	L3	15	0.96	2.6	0.3
46	L3	15	1.29	2.6	0.3
76	L3	15	0.04	0.20	0.00
20	L4	15	0.18	0.75	0
46	L4	15	0.07	0.30	0.00
76	L4	15	0.21	0.80	0.00

Table 3. Compilation of CO₂ data from the field lysimeter. CO₂ concentrations is as atmospheric percent.

COOLSIDE WASTE MANAGEMENT RESEARCH
Technical Progress Report
Contract No: DE-AC21-91MC28162
Report Period: November 1, 1994 to November 30, 1994

Statement of Project Objectives

Produce sufficient information on the physical and chemical nature of Coolside waste to design and construct physically stable and environmentally safe landfills.

Summary of Progress for Period.

Construction and packing of an array of laboratory leaching columns was initiated during the last quarter of 1994. Eighteen columns were packed with Coolside-waste materials including samples from all four pilot-plant tests and from two of the four Edgewater plant demonstration runs. In addition, two columns were loaded with pelletized wastes from two different sources, three columns were packed with solid wastes (both bottom and fly ash) from an Archer-Daniel-Midland utility boiler located near Decatur, Illinois, and one column was packed with a locally-marketed lightweight natural aggregate. Data from these latter six columns will be used as a basis for comparison to the columns packed with Coolside wastes.

The laboratory columns are physically similar to those described in previous reports in that they are one meter in height and constructed of clear-acrylic tubing (2" i.d.). However, the current

study will differ in that experience gained in the initial tests was used to modify both the column-packing procedures and manner in which water is added and collected. One of the more significant modifications is that in the current series, nearly all columns are packed at a relatively low density (loose/static packing) of 49 lb/ft³. Three of the columns are packed at a more moderate density (proctor-65 lb/ft³) and none of the columns are packed at the high density level (modified-69 lb/ft³) included in the preliminary study. Low density packing is being emphasized in this test series because of the problems encountered with low porosity and resulting low flow rates in the columns packed at higher density. That is, the low percolation rates in the higher density packings often precluded the collection of sufficient leachate for analysis.

A second significant modification is that, with the exception of the rain-simulation and pelletized-waste columns, the majority of the columns will receive a fixed amount of water each week (46.5 mL) as opposed to maintaining fully saturated conditions with a standing column of water. This amount of water corresponds to the average weekly rainfall (annual rainfall divided by 52) for the region in which the field lysimeters are sited. In this approach, water will make a single pass through the packed bed then collect in a reservoir at the bottom of the column from where it will be drained weekly. Two implications of this approach are that water samples will not be available for analysis until breakthrough occurs several weeks into the study and this setup will permit the wetting and partial drying of the waste materials during the study, both of which are more similar to what occurs in the field lysimeters. In addition, in an effort to evaluate the impact of high levels of dissolved CO₂ in groundwaters, a higher proportion of these columns will be blanketed with enriched CO₂ atmospheres (2.5 and 5.8 vol%). The packing and leaching

procedures along with the test matrix are detailed in the following sections.

LYSIMETER DESCRIPTION.

A schematic of the laboratory leaching columns fabricated for this study is shown in Figure 1. These columns are essentially the same as used in prior studies. They are constructed from clear-acrylic cylinders that are 39" (1 m) in length, 2" inner diameter, and ~1/4" wall thickness. A plexiglass frit was sealed in the bottom of each column inside of a PVC sleeve using PVC cement. The sleeve was in turn connected to a PVC reducing connector and plastic valve. The valve will be maintained in the closed position except during sample collection. The plexiglas frit was overlain with one inch of glass wool followed by one inch of Ottawa sand to prevent blockage of the drain holes in the fritted disk. The void volume of the column from the top of the valve to the top of the sand layer was approximately 100 mL which is an adequate capacity to retain the volume of leachate water passing through the columns each week. Thus, leachate waters pass through the column and collect in the void space at the bottom until they are drained and weighed. This flow regime is believed to more closely simulate landfill conditions.

SAMPLES.

A total of 11 waste samples were selected for placement into 24 columns. Table 1 shows the

Figure 1. Schematic of a laboratory leaching column.

samples to be investigated and the lysimeter number in which they are loaded, the dry weight of sample in each lysimeter, the amount of water added to the sample prior to packing (prehydration water), packing height, and dry-sample densities.

The samples identified as Coolside Run #1 and #3 (lysimeters #1-8) represent FGD wastes from the

Edgewater plant demonstration runs 1 and 3, respectively. These materials are comprised of Class F fly ash mixed with CaSO_4 , CaSO_3 , $\text{Ca}(\text{OH})_2$, and NaOH . The samples used in this study were composited from several barrels early in this project and were retained in sealed 5-gallon plastic buckets. Samples identified as Pilot Plant #1-4 (lysimeters #9-16, 25-26) represent FGD wastes from the four Coolside pilot-plant tests. These samples were taken from 5-gallon plastic buckets that were sealed early in the project following earlier testing.

Samples labeled as ADM-fly ash and ADM-bottom ash (lysimeters #22-24) represent FBC-ash samples that were collected on-site from an Archer-Daniels-Midland utility boiler located near Decatur, Illinois. These wastes were placed into plastic bags then sealed in 55-gallon drums to

SAMPLE	Lysimeter #	Dry wt (lb)	% prehydration water (dry basis)	Column height (in)	Dry Density (lb/cu ft)
Coolside Run#3	1	2.138	40.4	24.0	49.0
Coolside Run#3	2	2.138	40.4	24.0	49.0
Coolside Run#3	3	2.138	40.4	24.0	49.0
Coolside Run#3	4	2.138	40.4	24.0	49.0
Coolside Run#3	5	2.138	40.4	18.0	65.0
Coolside Run#3	6	2.138	40.4	18.0	65.0
Coolside Run#1	7	1.473	40.4	16.5	49.1
Coolside Run#1	8	1.473	40.4	16.5	49.1
Pilot Plant #1	9	2.138	41.1	24.0	
Pilot Plant #2	10	2.138	40.4	24.0	49.0
Pilot Plant #2	11	2.138	40.4	24.0	49.0
Pilot Plant #2	12	2.138	40.4	24.0	49.0
Pilot Plant #2	25	2.138	0.0	23.5	50.0
Pilot Plant #2	26	2.138	50.0	14.5	81.1
Pilot Plant #3	13	2.138	40.6	24.0	49.0
Pilot Plant #3	14	2.138	40.6	24.0	49.0
Pilot Plant #3	15	2.138	40.6	18.0	65.0
Pilot Plant #4	16	2.138	40.4	24.0	49.0
ADM-fly ash	22	2.138	40.4	24.0	49.0
ADM-fly ash	23	2.138	40.4	24.0	49.0
ADM-bottom ash	24	3.136	22.1	24.0	71.9
Pellets-1	27	2.296	0.0	24.0	52.6
Pellets-2	29	2.660	0.0	24.0	61.0
Natural Aggregate	28	2.856	0.0	24.0	65.4

Table 1. Samples, sample weights, and packing characteristics for materials to be examined in the laboratory leaching studies.

suppress hydration until being sub-sampled at the CAER for leaching investigations.

The sample identified as *Pellets-1* (lysimeter #27) represents pellets prepared in a disk pelletizer at the CAER using a blend of wet-scrubber waste (from a Mid-Western power plant), class F fly ash (from another Mid-Western power plant), and a commercial lime blended at 5:3:2. The pellets ranged from $\sim 1/8$ to 1" in diameter and averaged $\sim 3/8$ -1/2". The *Pellets-2* sample was prepared by a Florida-based utility for return shipment to the coal producer and disposal. These pellets also ranged from $\sim 1/8$ "-1" but averaged a slightly greater 1/2-5/8" diameter.

The reference sample identified as natural aggregate (lysimeter #28) represents a sample of shale (Jefferson County, KY) that is being marketed as a lightweight aggregate. This material ranged from $\sim 1/16$ -1/2" in diameter.

LYSIMETER PACKING PROCEDURES.

For the Coolside and ADM samples, packing the laboratory lysimeters entailed weighing approximately 2.1 lb (~ 1 -kg) of dry sample to a 2-L stainless-steel mixing bowl to which was added a targeted amount of distilled water (prehydration water). The sample and water were then blended with a Kitchen-Aide *Classic*TM mixer at low speed for approximately five minutes (or until the prehydrated sample had a homogeneous granular appearance). The bowl with prehydrated sample was then placed onto a top-loading balance from where the targeted weight

of sample was transferred with a plastic scoop to a preassembled lysimeter. The lysimeter was then held vertically and tamped until the targeted column height was attained.

For samples that were loaded to more than one lysimeter, a series of mixtures were prepared as described above with each mixture being split equally among the lysimeters being loaded with that particular sample. The number of such mixtures prepared corresponded to the number of lysimeters being loaded. This approach helped to ensure sample homogeneity between different lysimeters containing the same sample.

The exceptions to the packing procedure as described above were for lysimeters #7-8 (Coolside Run#1), lysimeters 25 and 26 (Pilot Plant #2), and lysimeters 27-29 (pellets and natural aggregate). For #7 and 8, there was an insufficient amount of sample to pack two columns to a height of 24" at loose density. Instead, the available sample was split between two columns and will serve as a measure of method reproducibility (duplicate conditions). The packing of columns #25 and 26 varied from the normal procedure because the degree of prehydration was chosen as a test variable for these two. For column #25, the targeted amount of dry sample was loaded to the column without prehydrating. For #26, an excess of prehydration water was blended with the sample before loading. The 'mudlike' consistency of this high-water-content sample precluded adjusting packing height, i.e. dry density (the procedure used for columns 25 and 26 is further discussed in the section on *No prehydration vs. excess water*). For columns #27-29, column loading entailed simply weighing the amount of pellets or aggregate required to fill a column to a height of 24" since adjusting column height (i.e., packing density) was

prevented by the rigidity (low compressibility) of these materials.

All columns are capped with rubber stoppers. With the exception of the rain-simulated columns and columns exposed to CO_2 , these stoppers are solid, which helps to suppress evaporation by completely sealing the top of the columns. The rain-simulated columns are capped with two-hole stoppers, which permit evaporation. Those samples exposed to elevated levels of CO_2 are also capped with two-hole stoppers. For these columns, CO_2 -containing gases are delivered through one of the holes and exit through the other. The use of rubber plugs as well as the manner in which CO_2 is added is described more fully in the next section.

TEST MATRIX.

The conditions to which each lysimeter will be subjected during the leaching investigation are shown in Table 2. The same weight of material was targeted for each column for all Coolside samples with the exception of the two columns (#'s 7-8) packed with Coolside waste from demonstration run #1. As previously described for these two columns, the available sample was split and the packing height was adjusted to attain the targeted packing density (see Table 1). Sample weight and packing density tended to vary for the bottom ash, pelletized, and aggregate samples (#'s 24, 27-29). For these columns, a constant packing height of 24 inches was targeted.

The column headings in Table 2 that may need explaining are defined as follows:

SAMPLE	Lysimeter #	Compaction	Fixed Water feed	Rain Simulation	Saturated	% CO2	COMMENT (prior flow rate)
Coolside Run#3	1	static	X			0	REPEAT (free flow ~70mL/wk)
Coolside Run#3	2	static	X			5.6	
Coolside Run#3	3	static		X		0	REPEAT (slow ~35mL/wk)
Coolside Run#3	4	static		X		2.5	REPEAT (very slow ~20 mL/wk)
Coolside Run#3	5	proctor	x			0	
Coolside Run#3	6	proctor	x			2.5	
Coolside Run#1	7	static	x			2.5	DUPLICATE
Coolside Run#1	8	static	x			2.5	DUPLICATE
Pilot Plant #1	9	static	x			2.5	
Pilot Plant #2	10	static	x			0	REPEAT (extremely slow ~10mL/wk)
Pilot Plant #2	11	static	x			2.5	
Pilot Plant #2	12	static	x			5.6	
Pilot Plant #2	25	static	x			0	no prehydration
Pilot Plant #2	26	static	x			0	excess water
Pilot Plant #3	13	static		x		0	REPEAT (slow ~35mL/wk)
Pilot Plant #3	14	static		x		2.5	
Pilot Plant #3	15	proctor		x		0	
Pilot Plant #4	16	static	x			2.5	
ADM-fly ash	22	static	x			0	
ADM-fly ash	23	static	x			2.5	
ADM-bottom ash	24	static	x			0	
Pellets-1	27	static			x	0	
Pellets-2	29	static			x	0	
Natural Aggregate	28				x	0	

Table 2. Test matrix for the samples to be investigated in the laboratory leaching study.

Compaction.

Refers to the density of the study samples after packing into the columns and is expressed on a dry basis. All columns were loaded at a low-energy-compaction density (static) of 49 lb/ft³ with the exception of three columns that were packed at a density of 65 lb/ft³ (proctor). These are the packing densities previously determined for Coolside waste samples from demonstration

runs 1 and 3.¹ They correspond to a low-energy compaction (static) and to that which would result from the pressure applied by the tracks of a Caterpillar D9L track-type tractor.

Fixed water feed, rain simulation, and saturated water feed.

Distilled water will be added to each column in one of two manners. For the rain-simulated columns, water additions will be made once each week which match the cumulative inches of rainfall measured weekly at a weather station located approximately 15 miles from the field lysimeters (Farmers-Stanton station). The starting date for these rainfall measurements is the week of November 19, 1991, the same as used in the initial laboratory-simulation study. This interval was selected since 1) the 12 month cumulative rainfall measured from this date (46.94 in) matches within one inch the average annual rainfall for this site (46.1) and 2) the field lysimeters were uncovered and exposed to the elements during November of 1992 so that seasonal wet and dry periods for the laboratory vs. field lysimeters will roughly correspond.

The annual rainfall (46.94) measured from November 19, 1991 through November 18, 1992 equates to 46.5 mL of water/week in a 2" diameter column. This is the value selected for the *fixed water feed* columns. That is, 46.5 mL of distilled water will be added to each of the fixed-feed columns each week. Therefore, after 12 months, both the rain-simulated and fixed-feed columns will have received the same amounts of water.

The rain-simulated and fixed-feed columns also differ in that water added to the rain-simulated columns will be permitted to evaporate and exit the column through either a two-hole rubber

stopper or carried out in the gas stream flowing ($10-15 \text{ cm}^3/\text{min}$) through the top of those columns exposed to elevated levels of CO_2 . Thus, it is anticipated that some drying of the upper portions of the packed solids will occur during the study, particularly during dry periods. This will also be the case for the fixed-feed columns which are blanketed with a mixture of N_2 and CO_2 . The remaining fixed feed columns will be capped with solid rubber stoppers for the duration of the study. It is anticipated that careful measurement of the flow of water through each column may help to explain differences in leachate concentrations that stem from evaporative losses between the capped and exposed columns.

Columns 27-29, which are packed with larger particles ($\sim 1/4-1$ " diameter), will be maintained under fully saturated conditions, i.e., a standing column of water. This is necessitated by the fact that water added to these columns will pass through to the collection reservoir in a matter of minutes providing an inadequate contact time for dissolution of anions/cations as well as complete drying of the solids between water additions. Results from these latter columns should make for useful comparisons to results from the preliminary column leaching studies which were conducted under similar conditions of water saturation.

% CO_2 .

All columns will be maintained under an atmosphere containing elevated levels of CO_2 at either ≤ 0.03 (atmospheric abundance), 2.5, or 5.6 vol% as indicated in Table 2. The effect of CO_2 concentration was selected for study since groundwaters typically contain CO_2 levels well in excess of that in the atmosphere and it is believed that the anions formed from dissolution of

CO₂ in such waters may have a significant impact on both the mechanism and kinetics of leachate chemistry.²

The CO₂ containing gas streams are routed in parallel to the appropriate columns via a common manifold at a rate of 10-15 cm³/min/column. These gases are delivered from compressed gas cylinders via 1/8-i.d. x 1/4"-o.d. tygon tubes which are routed through a two-hole rubber stopper used to cap the CO₂-purged columns. The ends of the delivery tubes are positioned approximately 12" down into the void space at the top of each column. The 1/4" exit holes of each of the rubber stoppers were constricted with 1/8" x 1/16"-o.d. plastic reducing unions which served to suppress exchange of void-space gases with room air as well as to provide a more uniform distribution of the CO₂-containing gas stream among the columns.

Comments.

Repeat. This refers to a duplication of the conditions used in the preliminary round of laboratory-leaching studies. Repeat tests were conducted for three reasons. First, some of the original tests exhibited inadequate flows to conduct a full suite of analyses on a weekly basis (approximate flow rates in the previous tests are shown in parenthesis). This problem will hopefully be avoided in this second round by what are believed to be better packing techniques. It was found that both time and shear rate of the blender used to mix the dry solids with the prehydration water was critical in determining the physical consistency of waste samples loaded to the columns. Care was therefore taken to enhance particle agglomeration (which impacts porosity) of the prehydrated samples in an effort to improve flow characteristics. Time will

determine if this effort was fruitful. In the event that flow rates are not enhanced over the previous tests, it is assumed that low flow rates will not interfere with the planned analysis in the current study. This is based on the fact that the concentrations of the leachates in the waters that first pass through the columns are sufficiently high to permit dilution prior to analysis and thus permit the full range of analyses to be conducted. Later during the study as leachate concentrations decline to a more constant level, weekly analyses will not be as critical, thus permitting the combining of two or more weeks flow into a single sample for analysis. The second reason for including repeat tests is that such tests should provide a means of determining reproducibility of the laboratory method. Third, by repeating several of the initial test conditions, we hope to determine if the time elapsed between the initial and the current study has had an impact on leaching characteristics of the solid wastes.

Duplicate. This refers to a single sample which was split evenly between two lysimeters (#7 & 8) and will be treated under identical conditions. This too should provide an indication of method reproducibility without the potential complications of sample aging as with the repeat tests described above.

No prehydration vs. excess water. Due to swelling problems encountered in the preliminary column study, all samples in this study were prehydrated prior to loading with the exception of columns #25 and #26 (Pilot Plant #2) and #27-29 (pellets and aggregate). The latter, pellets and aggregate samples, were not amenable to prehydration. As for columns 25 and 26, it was noted that the amount of water added during the prehydration step had a substantial

impact on packing characteristics of the Coolside wastes. Accordingly, two columns will be tested under similar conditions with the exception that one column was dry packed whereas the second was prehydrated with an excess amount of water. Treatment with excess water resulted in a sample with a 'mudlike' consistency and precluded adjusting packing density. Immediately after loading, the dry-packed column could only be tamped to a height of 26" without risk of breaking the column. However, this column continued to settle slowly for several days to a final height of 23.5" following the first water addition. The height of this column will continue to be monitored.

Dry weight (Table 1).

The weight of dry sample in each column.

% Prehydration water (Table 1).

After encountering problems with excessive heating, cracking of the lysimeters due to sample swell, and loss of porosity in the initial series of leaching studies, a decision was made to prehydrate all Coolside waste and bottom- and fly-ash samples prior to loading. The values for prehydration water listed in this column represents the amount of water that was mixed with a given sample prior to loading and is expressed as a percentage of the dry sample weight. For the Coolside wastes, 42% was targeted (~1.5% inherent moisture, 40.5% added) since this level of water was previously reported as the optimum moisture content for packing and also provided acceptable packing characteristics (granular consistency).

Dry density (Table 1).

The weight of dry sample divided by the volume of column occupied.

ANALYSIS.

Analysis of and the analytical protocols used for the leachate waters will be the same as conducted in the initial column-lysimeter test series.² Briefly, leachate waters will be analyzed for pH, alkalinity, conductivity, anions (including but not limited to SO₄, SO₃, Cl, NO₃, and Br), and cations/metals (Ag, Al, As, B, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, Se, Si, Ti, V, and Zn). All analyses will be conducted as soon as practical following collection, particularly for alkalinity and anion concentration (usually same day). Portions of each water will be treated with acid to stabilize the sample prior to metals (cation) analysis. Time permitting, this latter test will also be conducted on the day of collection.

As of this writing, only one set of leachate waters have been collected (only the pellets and aggregate generated samples in the first week). It is anticipated that the column leaching studies will continue for a minimum of one year and as long thereafter as potentially useful data is being generated.

1. Coolside Waste Management Research *Annual Techn. Progress Report for Period October 1991 through September 1992*. Prepared for the USDoE under Contract No. DE-AC21-91MC28162 by the University of Kentucky-Center for Applied Energy Research and Kentucky Transportation Center; October, 1992; 61 p.

2. **Coolside Waste Management Research *Annual Techn. Progress Report for Period October 1992 through September 1993.*** Prepared for the USDoE under Contract No. DE-AC21-91MC28162 by the University of Kentucky-Center for Applied Energy Research and Kentucky Transportation Center; October, 1993.

COOLSIDE WASTE MANAGEMENT RESEARCH
Technical Progress Report
Contract No: DE-AC21-91MC28162
Report Period: December 1, 1994 to December 31, 1994

Phase 1
Task 2
Subtask 2.2

Swell Tests

Monitoring of swell continued on the hydrated and non hydrated FBC ash samples. Both types are still in the primary swell phase. Swell of the hydrated ash has been monitored for more than two years while swell of the non-hydrated material has been monitored for 654 days. All samples were remolded near 95% of standard maximum dry density and optimum moisture content. The samples were remolded in CBR molds (6" diameter, 4.584" height) and swell was monitored under the following conditions:

- approximately 12.5 lb. surcharge, no age time
- approximately 2.5 lb. surcharge, no age time
- approximately 12.5 lb. surcharge, 7 days age time
- approximately 2.5 lb. surcharge, 7 days age time

Time of aging represents the amount of time before the samples were placed in water. Aged specimens were sealed at room temperature to prevent moisture loss before placement into the water tank. Swell data is summarized in Figures 1 and 2.

Unconfined Compressive Strength

Unconfined compressive strength tests were performed on remolded Coolside specimens. The specimens were aged for approximately 730 days in sealed containers. No excess moisture was present during the aging process. Samples tested were remolded near; 1) one hundred percent of standard and modified dry density; 2) ninety five percent of standard, modified, and low energy dry density; and, 3) ninety percent of standard dry density. Unconfined compressive strength of specimens sealed and aged at room temperature begin to increase after about 14 days age time as seen in Figures 3, 4, and 5 with data obtained previously.

Permeability

Permeability tests were performed on remolded Coolside specimens. The specimens were aged for approximately 730 days in sealed containers. Samples tested were remolded near; 1) one hundred percent of standard and modified dry density; 2) ninety five percent of standard, modified, and low energy dry density; and, 3) ninety percent of standard dry density. Results of permeability tests are presented in Figures 6, 7, and 8 with previous data. Unconfined compressive strength tests were performed on some specimens after permeability tests were completed. The tests were performed to determine the unconfined compressive strength of the

Coolside material on a saturated condition. The aged Coolside material has high compressive strengths even if saturated after aging as seen in Figures 9, 10, and 11.

Phase 1

Task 4

Subtask 4.1

Natural Clay Liner Tests

Natural clay liner tests have been initiated with three clays and two FGD by-products. The soils being used are naturally occurring clays which meet most states criteria for a landfill liner, that is, they have permeabilities less than 10^{-7} cm/sec when compacted. The FGD by-products are a FBC from an electrical generating station in Pennsylvania and Coolside material from CONSOL'S pilot plant, run #2. The tests are being performed by compacting the soils and FGD by-products in 3-inch diameter by 12-inch length PVC cylinders near 95% of standard maximum density and optimum moisture content. Soil #1 is a residual clay collected in Fayette County, Kentucky; Soil #2 is a glacial till collected at the Franklin County Landfill just south of Columbus, Ohio. Soil #3 is a residual clay collected from a landfill in Kentucky. Three tests consists of water moving through the compacted 12 inch soil specimens. Six tests have water leaching through six inches of compacted FBC and Coolside and six inches of compacted clay. The tests are configured so each clay will be subjected to leachate from each FGD material (Figure 12). Permeabilities of the clays in these six tests will be determined at the end of the leaching period (approximately 1.5 years) and compared to values obtained before leaching. Hopefully, this will indicate any effects of water leaching through the FGD materials into compacted clay soils has on the permeability of the compacted soils. Two tests have 12 inch FBC and Coolside pilot plant #2 specimens.

Water is supplied from a reservoir, mounted above the specimens, through 1/4 inch OD nylon tubing connected to the samples. Silica sand was used to fill the annular space in the end cap between the tubing connection and the sample. Three way valves are located in-line between the reservoir and samples. The valves allow the water supply to be cutoff and the water remaining in the nylon tubing to be vented to atmospheric pressure. Falling head permeability tests can be performed by measuring the water elevation change with time. Permeability tests will be performed at various intervals to determine changes, if any, of the compacted materials. Details of the leachate testing setup are shown in Figure 12 and 13. Initial permeabilities of the clay soils are:

Soil #1	6.10×10^{-8} cm/sec
Soil #2	8.32×10^{-8} cm/sec
Soil #3	6.77×10^{-8} cm/sec

Leachate will be collected from the tests periodically. The leachate samples will be available for analysis by other project participants.

FBC ASH

Hydrated

Figure 1. Swell versus Time, Hydrated FBC Ash.

Figure 2. Swell versus Time, Non hydrated FBC Ash.

UNCONFINED COMPRESSIVE STRENGTH

90% Compaction

Figure 3. Unconfined Compressive Strength versus Time, 90% Compaction.

UNCONFINED COMPRESSIVE STRENGTH

95% Compaction

Figure 4. Unconfined Compressive Strength versus Time, 95% Compaction.

UNCONFINED COMPRESSIVE STRENGTH

100% Compaction

Figure 5. Unconfined Compressive Strength versus Time, 100% Compaction.

PERMEABILITY

90% Compaction

Figure 6. Permeability versus Time, 90% Compaction.

PERMEABILITY

95% Compaction

Figure 7. Permeability versus Time, 95% Compaction.

PERMEABILITY

100% Compaction

Figure 8. Permeability versus Time, 100% Compaction

UNCONFINED STRENGTH AFTER PERMEABILITY

90% Compaction

Figure 9. Unconfined Compressive Strength, after Permeability Test.

UNCONFINED STRENGTH AFTER PERMEABILITY

95% Compaction

Figure 10. Unconfined Compressive Strength, after Permeability Test.

UNCONFINED STRENGTH AFTER PERMEABILITY

100% Compaction

Figure 11. Unconfined Compressive Strength versus Time, after Permeability Test.

Figure 12. Schematic of Clay Liner Leaching Tests

Figure 13. Schematic of water tubing in Clay Liner Leachate Tests.