



Project Summary

Water Quality Characterization of an Eastern Coal Slurry

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Current and projected uses of coal have resulted in several proposals for coal slurry pipelines in the eastern part of the United States. While several researchers have reported on the water quality aspects of western coal slurries, less work has been done with respect to eastern coals. An experimental study was conducted at the University of Central Florida from 1982 to 1983 with slurries of 50 percent eastern Kentucky coal and 50 percent water. Experiments were conducted with and without the addition of a corrosion inhibitor. Twenty-nine water quality parameters were measured as a function of pumping time in a 12-meter (40-ft) long, 2.54 cm (1 inch) diameter pipeline constructed for this study. Also, the treatability of the 10-day slurry filtrate was assessed using both lime and alum addition.

By about the fourth day in the pipeline, most parameters had reached equilibrium values. As expected for this high-ash, medium-sulfur coal, sulfates, TDS, and conductivity in the slurry filtrate started high and increased with time. Dissolved oxygen quickly dropped to near zero. Concentrations of several heavy metals were substantial, but organics were generally very low, about 5–10 mg/L. Trihalomethane formation potential was quite low, never exceeding 35 ppb. Although the samples were consistent in any one run, samples from different runs on the "same" coal were significantly different. Addition of the corrosion inhibitor increased the concentrations of sulfates, TDS, and several other parameters. The characterization of this particular coal slurry was compared with

those of several western coal slurries reported in the literature.

This Project Summary was developed by EPA's Hazardous Waste Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The United States is heavily dependent on coal for electricity generation. This reliance on coal is projected to increase even more in the future, as oil and gas decrease in supply and increase in price. The use of coal is expected to increase substantially in Florida and other southeastern and Gulf-coast states, based on their projected population growth and on their previously high percentage use of oil and gas for power generation.

In recent years, the coal slurry pipeline has been promoted as a safe, reliable, and economical alternative to railroad transportation of coal. Basically, coal slurry pipelining is a means of transporting coal that involves mixing pulverized coal with water and pumping it in a steel pipeline as shown schematically in Figure 1. First, the coal is pulverized to a powder consistency, then mixed with an equal weight of water to form a slurry. (A 50 percent coal slurry is a pumpable fluid that is somewhat more dense and substantially more viscous than water.) The slurry is then pumped through a pipeline, using a number of strategically placed pumping stations, from the coal source area to the receiving power

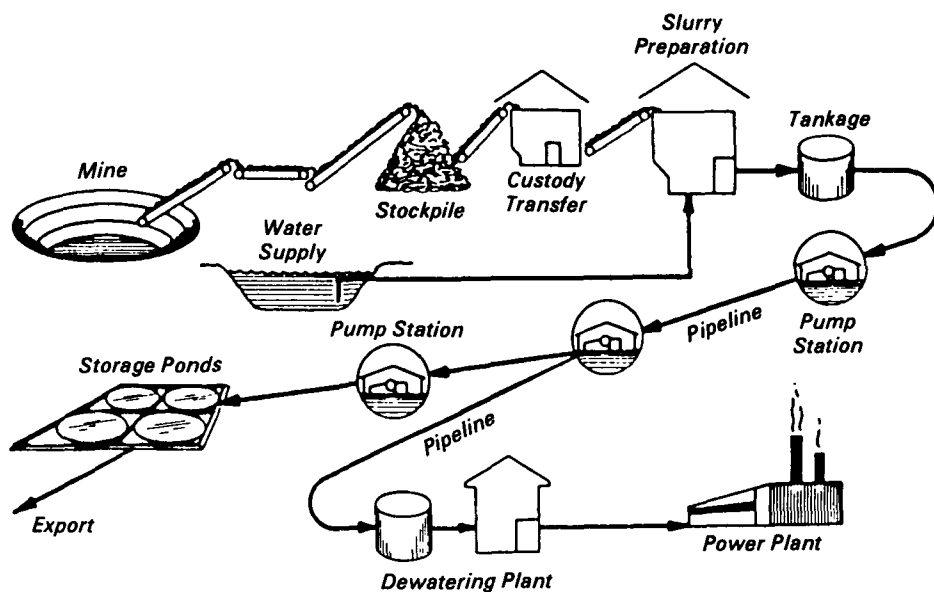


Figure 1. Schematic diagram of a full scale coal slurry pipeline system. Source: A.D. Dorris, 1981. Used by permission.

plants. At the receiving sites, the slurry is dewatered and the coal is burned. The water is treated before re-use or discharge.

One objection to coal slurry pipelines has been the possible pollution of waters at the receiving location by contaminants leached from the coal while in the pipeline. Both inorganic and organic chemicals are solubilized in concentrations that depend on the physical and chemical nature of coal, the water source, and the time in the pipeline. Several researchers have studied various western coals, but less work has been done with respect to eastern coal slurries. Eastern coals typically contain more sulfur than western coals, and they typically have lower percentages of the alkaline metals (Na, K, Ca, Mg) in their ash. Thus, there could be substantial differences between the slurry water resulting from eastern coals and that from western coals.

Purpose and Scope

The primary objective of this work was to characterize the slurry water resulting from an eastern coal. For characterization, 29 water quality parameters were measured on slurry filtrate sampled at various pumping times in a small pipe-loop system built for this study. The parameters included 11 general items (such as pH, dissolved solids, and sulfates); three organic tests (total

organic carbon, trihalomethane formation potential, and phenols); and 15 metals. The characteristics observed in this study were then compared with those of other coal slurries reported previously in the literature.

Another major objective was to assess the effects of the addition of a commercial corrosion inhibitor on water quality. Due to the potential for corrosion of the pipeline by coal slurries, some consideration has been given to adding a chemical corrosion inhibitor. The effects of the addition of a nitrite-based inhibitor on slurry water quality were investigated in this research.

A third objective was to address the question of treatability of the slurry water. Previous researchers have indicated that conventional technology is adequate to treat coal slurry wastewaters. Two of the more common treatment processes were used to treat the 10-day slurry water: high pH lime precipitation and alum coagulation. After treatment, the wastewaters were analyzed for the same parameters as above. In addition, the sludges from the treatment processes were subjected to the EP toxicity (leaching) test and tested for eight toxic metals.

Experimental Procedures

The coal used in this study was obtained with the help of personnel at the McIntosh Power Plant in Lakeland, Flor-

ida. Coal, shipped by unit train from an eastern Kentucky mine, was received at that power plant and processed through the usual sequence of processing steps. A portion of the feed stream of pulverized coal to one of the burners was diverted into a custom designed barrel that caught the coal dust, but allowed the air to exhaust through an attached filter bag. Approximately two days were required to obtain a full drum (125 kg), thus allowing for some "time-averaging" of the coal sample. About 70 percent of the pulverized coal passed a 200 mesh screen.

All slurries were processed in a pilot-scale system constructed specifically for this project. A 50-percent solids slurry was made by adding tap water from the University of Central Florida's potable water system to the pulverized coal in an open top 210-liter steel drum. The final volume of slurry was mixed in about one hour by hand-held steel rods and a small (12 volt, 15 amp) boat trolling motor.

The slurry was transferred by hand into a closed top, nitrogen-inerted, 265-liter steel tank into which was mounted a Hazleton submersible slurry pump. The pump was belt driven with a 1.12 kw motor and had a speed controller. The pump worked very well; because it was submersible, seal leaks were not a problem. A second electric trolling motor installed in the tank kept the slurry well mixed during the run. The slurry was pumped through a 15 meter long, 2.54 cm diameter schedule 80 steel pipe loop that returned to the bottom of the tank. The pump speed was adjusted to achieve a slurry velocity of 1.2 to 1.8 m/s in the pipe. The tank was kept nitrogen-blanketed throughout the 10-day slurry runs. Cooling water flowed through an external concentric pipe to maintain the slurry temperature between 26°C and 32°C for all runs. A schematic diagram of the experimental system is presented in Figure 2.

Samples of the slurry were taken several times throughout each 10-day run, more frequently in the first few days. The sample times were 3 hours, 7 hours, and 1, 2, 4, 7, and 10 days. Whole slurry samples were immediately tested for pH, dissolved oxygen, and redox potential. The remaining samples were then vacuum filtered through a 24-cm diameter Whatman No. 1 filter paper, and then through a 0.45 micron glass filter. Some of the filtrate was then acidified and refrigerated

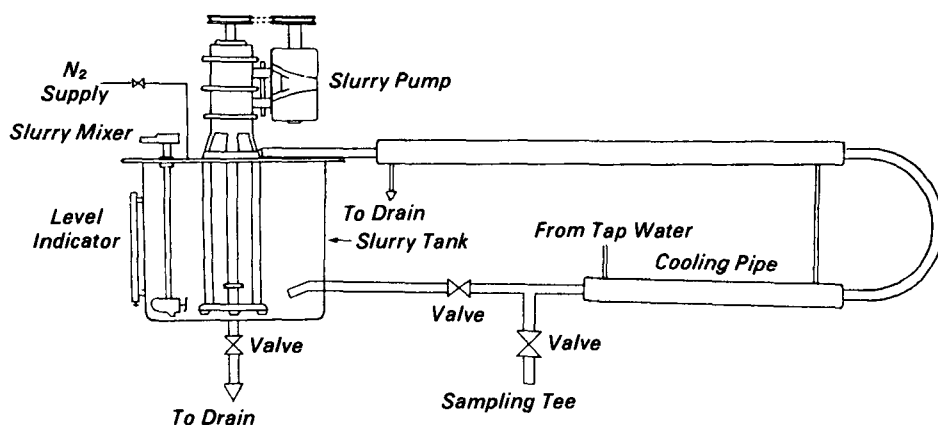


Figure 2. Schematic diagram of pilot-scale pipe loop used for coal slurry experiments.

for later metals analysis; the rest of the filtrate was tested for a variety of water quality parameters.

All analytical tests were conducted according to *Standard Methods for Examination of Water and Wastewater*, 14th edition (1975), or *Methods for the Analysis of Water and Waste*, EPA 600/4-79-020 (1979). Metals were analyzed with a DC arc plasma emissions spectrophotometer in lieu of an atomic absorption unit. In all, the tests included 11 general water quality parameters, 3 measures of organic content including trihalomethane formation potential (THMFP), and 15 metals. All parameters were observed on each sample except for phenols and THMFP due to the lengthy test procedures for these two.

On the tenth day, large volume samples were drawn for treatability testing. A laboratory procedure was used to simulate conventional treatment processes that might be anticipated in practice: coal separation by sedimentation and decantation, chemical addition, coagulation, flocculation, sedimentation, and filtration. The chemicals added were either lime or alum. The optimum dose was defined as that which maximized turbidity removal on small aliquots of the untreated decantate. The remainder of the decantate was then treated at the optimum dose. The final treated effluent was analyzed for all the original parameters (except phenols) to determine removal efficiencies. Finally, the sludges produced by the treatments were later tested according to the EP toxicity test to assess their potential as a hazardous waste.

Results and Discussion

The coal used in this research project came by unit train from eastern Kentucky and can be characterized as a medium sulfur (1.9%), high ash (16%), eastern bituminous coal. Some test data for the coal used in the four experimental runs are presented in Tables 1 and 2. Also, a mineral analysis for the major components in the ignited ash showed approximately 50 percent silica, 25 percent alumina, 17 percent ferric oxide, and about 6 percent basic metal oxides.

The source water was University of Central Florida tap water. The water originated from an underground limestone aquifer and was aerated and chlorinated prior to distribution to the potable water system. Typical source water characteristics are shown along with the slurry filtrate analyses.

Four valid experimental runs were completed, Runs 2 and 3 without a commercial corrosion inhibitor (nitrite based) and Runs 4 and 5 with the inhibitor. (Run 1 was used for equipment and procedures shakedown.) The fact that there were significant variations in the coal quality was reflected in the resulting slurry qualities. In all runs, similar trends in the time behavior of the slurry contaminants were observed. However, in Run 2 the concentrations of all pollutants were significantly higher than in Run 3. A similar situation existed for Runs 4 and 5. The slurry with the corrosion inhibitor had significantly higher concentrations of sulfates, TDS, conductivity, and alkalinity. Differences

in the other parameters were not so pronounced or may have been masked by differences in the coal samples.

Results of all the tests are tabulated in Tables 3 and 4, which present averaged data of the two runs without the corrosion inhibitor and the two with the inhibitor. Generally, most parameters reached equilibrium values in the first few days of the run. For the runs without inhibitor, the slurry pH dropped immediately on mixing but then rose to about 6 by the tenth day for all runs. The initial pH drop was suppressed by the corrosion inhibitor. Dissolved oxygen quickly dropped to near zero as it reacted with the sulfur and other minerals in the coal.

As expected for this coal, sulfates were high and reflected the sulfur content of the coal. Equilibrium concentrations averaged about 1300 mg/L for the two runs without corrosion inhibitor, but surprisingly averaged about 3500 mg/L with the inhibitor. Apparently, the inhibitor enhanced some ion exchange process with the coal minerals because the inhibitor itself did not contain sulfur. This difference in the sulfates' behavior is shown graphically in Figure 3. Figure 4 presents the averaged data for pH, and highlights the differences observed with and without the corrosion inhibitor. Furthermore, for the slurry with the inhibitor, it was observed that coal-water separation was more difficult.

The concentrations of dissolved organics were low for this coal slurry, as indicated by the tests for total organic carbon and phenols. TOC was in the 5-10 mg/L range and phenols were around 1 ppb. Also, for this particular coal slurry, THMFP was quite low, never exceeding 35 ppb. As shown in Tables 3 and 4, the concentrations of several metals increased one to three orders of magnitude over the levels in the mix water, the largest percentage gainers being iron and manganese. Some heavy metals exhibited little or no increase.

Treatability results are not tabulated in this Summary. However, it was shown that both lime and alum additions were effective in removing certain contaminants. Lime treatment removed metals better than alum, but alum removed organics better than lime. It should be obvious that the treatment processing sequence specified at a coal slurry receiving site depends on the characteristics of the particular coal slurry and the degree of treatment de-

Table 1. Coal Proximate Analysis (Dry Basis)*

Parameter	Run 2	Run 3	Run 4	Run 5	Avg.	Composite as received, 2 unit trains (May and June, 1983)**
% Ash	15.28	14.39	15.37	18.50	15.89	14.43
% Volatiles	32.85	36.79	36.49	35.13	35.32	36.10
% Fixed Carbon	51.87	48.82	47.63	46.37	48.67	49.48
Heating Value (Btu/lb)	11,632	12,830	11,922	11,500	11,971	12,688
% Sulfur	2.26	1.69	1.93	1.70	1.90	2.13
% Passing 200 mesh	80	--	68	72	73	--

*SOURCE: McIntosh Power Plant Chem. Lab., Department of Elec. and Water Utilities, Lakeland, Florida

**SOURCE: McIntosh Power Plant files

Table 2. Trace Metals Analysis of Coal

Component	ppm in ignited ash, as the element				
	Run 2	Run 3	Run 4	Run 5	Average
Hg	56	47	63	59	56
Se	92	83	72	63	78
Cd	3.5	4.3	4.2	4.2	4.1
Zn	106	311	228	219	216
As	156	238	379	421	298
Mn	163	541	408	505	404
Cu	221	139	154	110	156
Pb	122	101	109	104	109
Ni	90	136	133	135	124
Cr	231	133	150	123	159
Ba	585	837	797	720	735
Mg	8,490	15,900	8,190	9,610	10,550
Ag	4.0	2.0	7.0	2.5	3.9

sired. However, this and previous studies reported in the literature, indicate that conventional treatment with existing technology should be sufficient.

Conclusions and Recommendations

Eastern coals typically have higher sulfur content and less alkaline ash than western coals. As expected, the slurry filtrate obtained in this study of an eastern coal exhibited higher sulfate concentrations and lower pH values than would be expected from a typical western coal.

For the particular coal used in this study, very few organics were leached into the water. TOC averaged 5–10 mg/L, phenols averaged about 1 ppb and THMFP never exceeded 35 ppb. Also, for this particular coal, very significant concentrations of iron (100–500 mg/L) and manganese (5–25 mg/L) leached into the water. Concentrations of lead, nickel, and aluminum also increased

significantly, but each remained in the 0.1 to 1 mg/L range. It was shown that oxygen reacts readily with sulfur and other minerals in coal slurries, and thus care should be taken to exclude oxygen as much as possible when forming, pumping, or loading coal slurries commercially.

Coal-water interactions require some time to reach equilibrium. For several parameters, at least four or five days must elapse before equilibrium is approached. A corrosion inhibitor significantly increased the concentrations of sulfates, TDS, conductivity, and alkalinity. In addition, coal-water separation became more difficult.

Even though the coal samples used in this study were from the same source and were obtained in a "time-averaged" manner, the properties of the coal samples were apparently different enough to result in significant differences in the slurry filtrate observed in "replicate" runs. While the time-behavior

trends for most parameters were similar, absolute levels in the filtrate were different. Thus, it is recommended that several replications be conducted to be able to characterize the slurry of any particular coal with confidence. In order to reach valid conclusions about the behavior of eastern coal slurries, at least 10 more eastern coals should be studied.

Coal slurry wastewaters likely will require treatment before reuse or discharge. Studies thus far indicate that present treatment technology can provide adequate treatment, but the specific processing scheme will depend on the particular coal slurry characteristics and site specific regulations. The treatment sludges produced in this study did not fail the EP toxicity test.

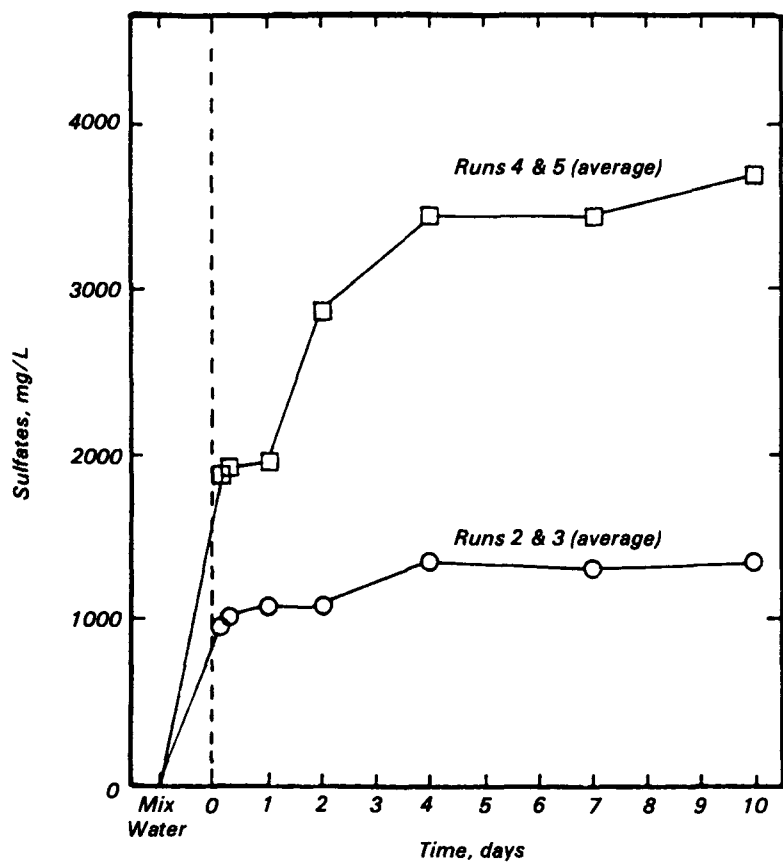


Figure 3. Effect of corrosion inhibitor (CI) on sulfates (Runs 2 and 3 without CI and Runs 4 and 5 with CI).

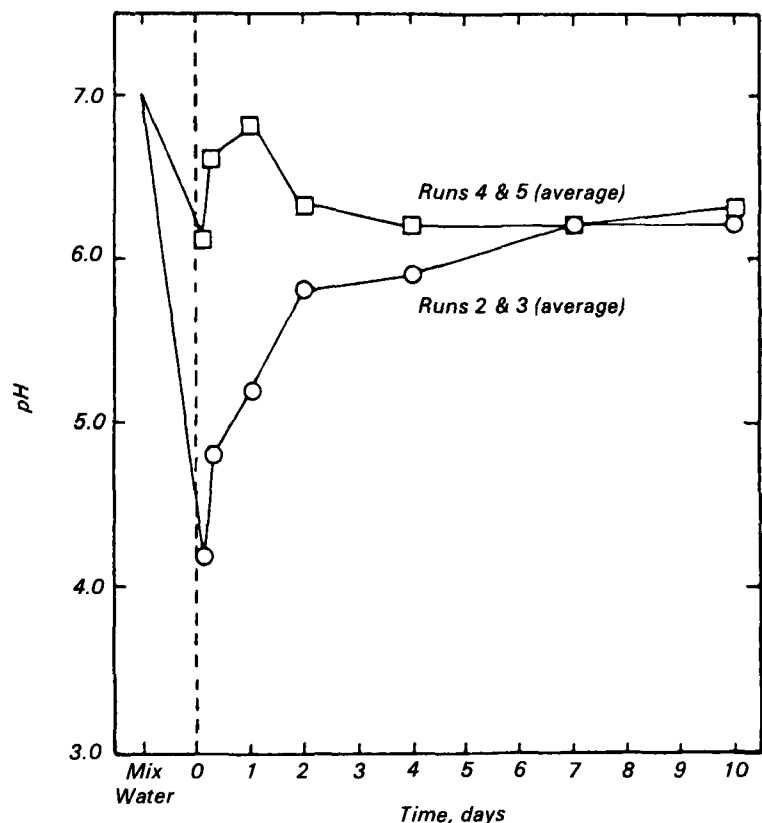


Figure 4. Effect of corrosion inhibitor (CI) on pH (Runs 2 and 3 without CI and Runs 4 and 5 with CI).

Table 3. Data Summary Table—Average of Runs 2 and 3

Parameter, Units	Typical Mix Water	Average Concentrations in Slurry Filtrate by Time after Start of Run						
		3-hours	7-hours	1-day	2-days	4-days	7-days	10-day
General								
Sulfates, mg/L	2	942	1016	1075	1070	1340	1306	1342
Chlorides, mg/L	19	36	43	58	72	86	108	116
TDS, mg/L	207	1612	1596	1740	1966	2400	2636	2695
Conductivity, mho/cm	366	1483	1468	1590	1713	1974	2120	2452
Dissolved Oxygen, mg/L	7.9	2.5	0.3	0.2	0.15	0.05	0.05	0.0
Redox Potential, mv	526	211	158	62	-32	-84	-152	-196
pH	7.0	4.2	4.8	5.2	5.8	5.9	6.2	6.2
Acidity, mg/L as CaCO ₃	-96	470	423	480	530	778	878	852
Alkalinity, mg/L as CaCO ₃	120	12.4	14.3	12.4	22.2	15.2	22.4	13.2
Color, CPU	6	8	7.5	20.5*	94.5*	69*	132*	280*
Turbidity, JTU	5.3	3.8	10.9	18.2*	52.2*	67.2*	65.2*	53.8
Organics								
TOC, ppm	6	7.4	5.1	3.6	5.0	6.1	6.2	5.6
THMFP, ppb	60	--	--	--	--	--	--	23
Phenols, ppb	--	--	1.0	--	1.0	--	1.2	1.4

Table 3. (continued)

Parameter, Units	Typical Mix Water	Average Concentrations in Slurry Filtrate by Time after Start of Run						
		3-hours	7-hours	1-day	2-days	4-days	7-days	10-days
Metals (mg/L)								
Hg	0.076	0.21	0.18	0.24	0.26	0.40	0.42	0.45
Se**	0.242	0.20	0.22	0.21	0.23	0.33	0.38	0.37
Cd	0.006	0.03	0.03	0.02	0.02	0.03	0.04	0.04
Zn	0.071	1.29	0.96	0.46	0.20	0.17	0.17	0.15
As**	0.045	0.35	0.38	0.36	0.50	0.58	0.68	0.63
Mn	0.009	4.06	4.36	4.98	6.44	10.2	10.5	10.9
Cu	0.016	0.21	0.01	0.02	0.02	0.03	0.02	0.03
Al	0.033	10.7	2.89	0.78	0.30	0.52	0.38	0.47
Fe	1.28	58.1	92.4	168	214	313	344	358
Pb	0.029	0.30	0.30	0.30	0.28	0.34	0.36	0.40
Ni	0.002	1.02	0.76	0.30	0.09	0.10	0.08	0.14
Cr	0.004	0.03	0.03	0.03	0.02	0.03	0.03	0.04
Ba	0.015	0.16	0.12	0.09	0.12	0.12	0.12	0.10
Mg	11.0	67	67	68	67	74	76	78
Ag	0.002	0.02	0.02	0.01	0.02	0.02	0.02	0.02

NOTE: * = Precipitate formed, data not meaningful.
 ** = Data suspect—instrument problems, see quality assurance section.

Table 4. Data Summary Table—Average of Runs 4 and 5

Parameter, Units	Typical Mix Water	Average Concentrations in Slurry Filtrate by Time after Start of Run						
		3-hours	7-hours	1-day	2-days	4-days	7-days	10-days
General								
Sulfates, mg/L	2	1865	1920	1955	2860	3425	3430	3680
Chlorides, mg/L	19	66	80	112	134	147	160	178
TDS, mg/L	207	4398	4277	4192	4364	5624	5920	5712
Conductivity, mho/cm	366	4630	4480	4455	4962	5445	5410	5362
Dissolved Oxygen, mg/L	7.9	0.55	0.35	0.10	0.05	0.05	0.05	0.05
Redox Potential, mv	526	141	62	-118	-102	-144	-137	-136
pH	7.0	6.1	6.6	6.8	6.3	6.2	6.2	6.3
Acidity, mg/L as CaCO ₃	-96	402	416	323	568	920	1010	855
Alkalinity, mg/L as CaCO ₃	120	258	208	158	78	40	54	58
Color, CPU	6	8	9	8	7	8	8	6
Turbidity, JTU	5.3	3	4	32*	50*	114*	94*	96*
Organics								
TOC, ppm	6	2.0	3.8	12.6	5.2	7.3	7.6	18.6
THMFP, ppb	60	--	--	--	--	--	--	8
Phenols, ppb	--	--	--	--	--	1.0	1.5	1.0
Metals (mg/L)								
Hg	0.076	0.05	0.05	0.054	0.09	0.14	0.15	0.15
Se**	0.242	0.24	0.23	0.26	0.31	0.31	0.33	0.31
Cd	0.006	0.007	0.006	0.007	0.01	0.008	0.01	0.01
Zn	0.071	0.09	0.09	0.07	0.16	0.15	0.16	0.15
As**	0.045	0.23	0.24	0.23	0.36	0.36	0.40	0.38
Mn	0.009	7.55	4.80	3.11	8.80	11.9	14.7	16.6
Cu	0.016	0.01	0.03	0.03	0.03	0.02	0.07	0.02
Al	0.033	0.28	0.29	0.32	0.29	0.34	0.46	0.45
Fe	1.28	0.52	0.45	11.3	137	259	270	270
Pb	0.029	0.36	0.34	0.32	0.39	0.39	0.40	0.42
Ni	0.002	0.36	0.08	0.06	0.12	0.17	0.22	0.32
Cr	0.004	0.19	0.03	0.03	0.04	0.03	0.03	0.03
Ba	0.015	0.06	0.09	0.08	0.18	0.15	0.09	0.03
Mg	11.0	175	108	104	128	158	162	163
Ag	0.002	0.008	0.002	0.007	0.01	0.015	0.018	0.016

NOTE: * = Precipitate formed, data not meaningful.
 ** = Data suspect—instrument problems, see quality assurance section.

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The complete report, entitled "Water Quality Characterization of an Eastern Coal Slurry," (Order No. PB 87-169 975/AS; Cost: \$18.95, subject to change) will be available only from:

National Technical Information Service

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The EPA Project Officer can be contacted at:

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