RESULTS OF EXPERIMENTS RELATED TO CONTACT OF MINE-SPOILS WATER WITH COAL, WEST DECKER AND BIG SKY MINES, SOUTHEASTERN MONTANA

By Robert E. Davis and Kent A. Dodge

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CONVERSION FACTORS

Inch-pound units used in this report can be converted to the International System (SI) of units by the following conversion factors:

Multiply inch-pound unit	By	To obtain SI unit
inch	25.40	millimeter
foot	0.3048	meter
mile	1.609	kilometer

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by the equation:

$$°F = 9/5\ (°C) + 32$$

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ABSTRACT

Batch-mixing experiments using spoils water and coal from the West Decker and Big Sky Mines were conducted to determine possible chemical changes in water moving from coal-mine spoils through a coal aquifer. The spoils water was combined with air-dried and oven-dried chunks of coal and air-dried and oven-dried crushed coal at a 1:1 weight ratio, mixed for 2 hours, and separated after a total contact time of 24 hours. The dissolved-solids concentration in water used in the experiments decreased an average 210 milligrams per liter, or about 5 to 10 percent. Other chemical changes include general decreases in the concentrations of magnesium, potassium, and bicarbonate, and general increases in the concentrations of barium and boron. In general, the magnitude of the changes increased as the surface area of the coal increased. The quantity of extractable cations and exchangeable cations on the post-mixing coal was larger than on the pre-mixing coal. Equilibrium and mass-transfer relations indicate that adsorption reactions or ion-exchange and precipitation reactions, or both, probably are the major reactions responsible for the chemical changes observed in the experiments.

INTRODUCTION

Coal-mining activities in southeastern Montana continue in response to national energy needs. Near-surface coal beds in the Tongue River Member of the Paleocene Fort Union Formation are the object of the mining activities. These coal beds also are major aquifers in the area and are used primarily for domestic and livestock supplies. Mining of the coal beds eliminates the coal aquifers, but replacement of the disturbed overburden, or mine spoils, creates a new aquifer.

Water in the mine-spoils aquifers characteristically has larger dissolved-solids concentrations than water in the coal aquifers. A previous study (Davis, 1984) demonstrated that the average increase in dissolved solids at the West Decker and Big Sky Mines (fig. 1) was about 1,000 mg/L (milligrams per liter). That study also showed that the dissolved-solids concentration may decrease several hundred milligrams per liter if water from the spoils flows through a coal aquifer. However, detailed analyses to determine the changes in chemical quality were not performed.

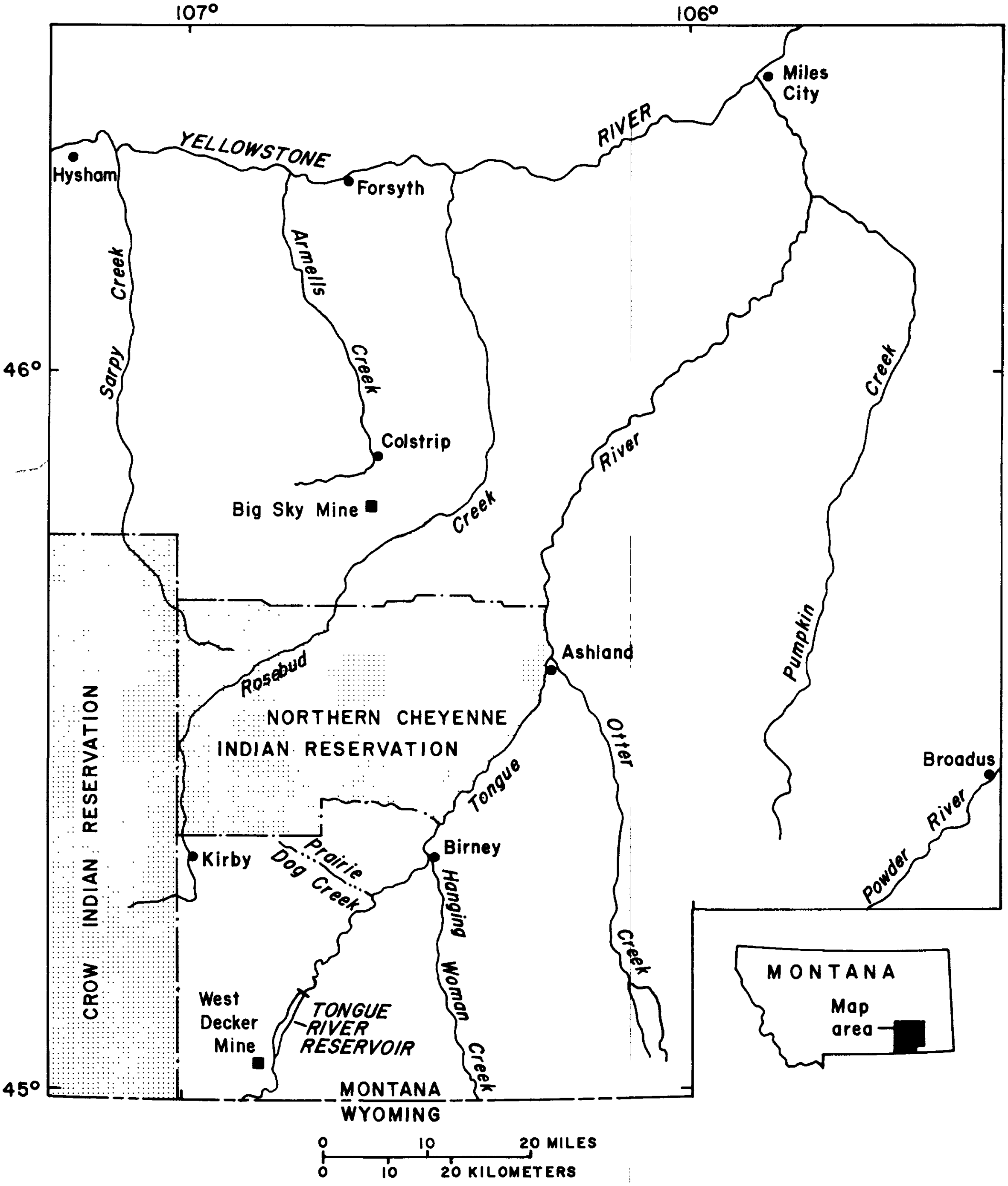

Figure 1.--Location of West Decker and Big Sky Mines.

Purpose and scope

The purpose of this study was to determine possible changes in chemical quality in water moving from coal-mine spoils through a coal aquifer. Spoils water and coal from the West Decker and Big Sky Mines were used in batch-mixing experiments. Both the water and the coal were analyzed for chemical constituents prior to and after the experiments. Equilibrium and mass-transfer relations were used to help determine the reactions possibly responsible for the observed changes in water quality.

Acknowledgments

The authors wish to express appreciation to the Peabody Coal Company, Decker Coal Company, and Peter Kiewit Sons, Inc., for their cooperation in permitting the collection of samples.

SAMPLE DESIGNATION

In this report, letters and numbers are used to designate the source and treatment of the water and coal samples. Pre-mixing water samples are identified by three letters followed by a sequential number. The first letter signifies the sample is water (W) and is followed by two letters signifying the source of the water (WD for West Decker Mine spoils, BS for Big Sky Mine spoils). The letters are followed by a sequential sample number. Thus, sample WWD1 is water from the West Decker Mine spoils and is the first sample analyzed. Post-mixing water samples are identified by six letters. The first letter signifies the sample is water (W); the second letter signifies the source of coal used (A for Anderson-Dietz 1 coal bed, R for Rosebud coal bed); the third and fourth letters signify the source of water used (WD for West Decker Mine spoils, BS for Big Sky Mine spoils); and the fifth and sixth letters signify the treatment the coal received prior to mixing (A for air dried, O for oven dried, B for chunks, C for crushed). Thus, sample WAWDAB is water resulting from mixing Anderson-Dietz 1 coal with water from the West Decker Mine spoils; the coal used was air dried and in chunks prior to mixing.

Pre-mixing coal samples are identified by four letters. The first letter signifies the sample is coal (C); the second letter signifies the source of coal (A for Anderson-Dietz 1 coal bed, R for Rosebud coal bed); and the third and fourth letters signify the treatment the coal received (A for air dried, O for oven dried, C for crushed). Thus, sample CAAC is coal from the Anderson-Dietz 1 coal bed that has been air dried and crushed. Post-mixing coal samples are identified by six letters. The first and second letters signify the sample is coal and indicate the source of coal as above. The third and fourth letters signify the source of water used (WD for West Decker Mine spoils, BS for Big Sky Mine spoils) and the fifth and sixth letters signify the treatment the coal received prior to mixing as above. Thus, sample CAWDAC is coal from the Anderson-Dietz 1 coal bed that has been mixed with water from the West Decker Mine spoils; the coal was air dried and crushed prior to mixing.

METHOD OF STUDY AND EXPERIMENT DESIGN

Water used in the experiments was obtained from a well completed in the spoils aquifer at the West Decker Mine (samples WWD1 and WWD2, tables 1 and 2) and from a well completed in the spoils aquifer at the Big Sky Mine (samples WBS1 and WBS2, tables 1 and 2). Coal was obtained from areas recently mined within each mine.

Batch-mixing experiments were conducted to estimate changes in ground-water quality that may occur when water from a spoils aquifer flows through a coal aquifer. Spoils water and coal were combined at a 1:1 weight ratio and mixed for about 2 hours. Mixing was accomplished by affixing the mixture bottles, which were completely filled to exclude oxygen, to a vertical wheel 3 feet in diameter and rotating at 3 revolutions per minute. The mixtures then were allowed to settle and the water and coal were separated by decanting after a total contact time of about 24 hours.

Both the water and the coal were analyzed prior to and after the mixing experiments. The water was filtered sequentially through 0.45- and 0.10-micrometer (micron) filters, except for samples WAWDAC and WAWDOC (tables 1 and 2), which could only be filtered through a 0.45-micrometer filter. The filtrate was analyzed by the Montana Bureau of Mines and Geology, Butte, Mont. The coal was analyzed for chemical constituents (in ashed coal) by the U.S. Geological Survey laboratory, Denver, Colo.; for extractable cations and exchangeable cations by the Montana Bureau of Mines and Geology using procedures in Sandoval and Power (1977); and for mineralogy by X-ray diffraction analysis of the residue from low-temperature ashing by the U.S. Geological Survey, Reston, Va.

The coal received various treatments prior to the experiments. Initially, the coal was in chunks approximately 1 inch on a side. Some of the chunky coal was air dried at room temperature (about 25° C) and some was oven dried at about 40° C. Drying time was about 24 hours. The dried coal was used to determine the effects on the experiments of the natural moisture content of the coal, which ranges from about 20 to 30 percent (Matson and Blumer, 1973, p. 78). Some of the coal was crushed into pieces about one-fourth inch or less on a side. The crushed coal was used to determine the effects on the experiments of the surface area of the coal. The surface area of the crushed coal was four or more times greater than the surface area of the initial chunks of coal. Some of the crushed coal was air dried and some was oven dried.

Computer program WATEQF (Plummer and others, 1978) was used to determine equilibrium relations in water used in the experiments. The program can determine from a water-quality analysis the degree of saturation of the water with respect to a given mineral species. The degree of saturation is expressed by the saturation index, which is the logarithm of the ratio of the ion activity product to the equilibrium constant. Positive values of the saturation index indicate supersaturation, negative values indicate undersaturation, and values near zero indicate saturation.

Mass-transfer relations were used to help determine which reactions may have occurred as a result of mixing. The number of millimoles per liter of selected constituents added to or subtracted from solution as a result of mixing were calculated.

RESULTS OF EXPERIMENTS

Concentrations of selected constituents in pre-mixing water and post-mixing water for batch-mixing experiments using combinations of chunky, crushed, air-dried, and oven-dried coal are given in tables 1 and 2. For the experiments using materials from the West Decker Mine, the post-mixing water generally decreased in the concentrations of calcium, magnesium, sodium, potassium, bicarbonate, sulfate, dissolved solids, manganese, strontium, and zinc, and increased in the concentrations of barium and boron. For the experiments using materials from the Big Sky Mine, the post-mixing water generally decreased in the concentrations of magnesium, potassium, bicarbonate, and dissolved solids and increased in the concentrations of barium, boron, and strontium.

In general, the water from experiments using crushed coal exhibited greater changes than water from experiments using chunks of coal, indicating that the surface area of coal in contact with the water probably is an important factor. For all experiments using crushed coal, the decrease in dissolved solids ranged from 120 to 340 mg/L and averaged 250 mg/L. For all batch-mixing experiments using chunks of coal, the decrease in dissolved-solids concentration ranged from 50 to 270 mg/L and averaged 180 mg/L. The average decrease in dissolved solids for all experiments was 210 mg/L, or about 5 to 10 percent.

Relations between water from mixtures using air-dried coal and oven-dried coal were varied. Therefore, the effect of the natural moisture content of the coal on the experiment results could not be determined.

The analyses for chemical constituents in the ashed coal were subject to interferences by sulfur in the analytical procedure. Therefore, no results were received from the laboratory, owing to a large degree of inaccuracy or uncertainty.

The results of the analyses for extractable cations and exchangeable cations (table 3) in crushed coal from both the West Decker and Big Sky Mines indicate that the post-mixing coal generally contained greater quantities of extractable and exchangeable cations than the pre-mixing coal. Therefore, if the analysis results are representative of actual conditions, the reactions which occurred in the mixing experiments resulted in deposition, exchange, or adsorption of some constituents onto the coal. This hypothesis also is supported by the larger differences in constituent and dissolved-solids concentrations observed in experiments using crushed coal, which had more surface area exposed to the reaction process.

The results of the X-ray diffraction analyses of ash from pre-mixing and post-mixing, air-dried and oven-dried coal from both mines were similar for all samples. The ash contained quartz, gamma calcium sulfate (a high-temperature polymorph of anhydrite), kaolinite, illite, and possibly a trace of feldspar (Daniel M. Webster, U.S. Geological Survey, written commun., 1984). The similarity of all the samples indicates that any mineral precipitated on the post-mixing coal probably occurred as one of the minerals listed above or that the quantity of any other mineral precipitated was not substantial enough to be detected.

Saturation indices from WATEQF for water used in the batch-mixing experiments are given in table 4. For the experiments using materials from the West Decker Mine, the pre-mixing and post-mixing waters generally were near saturation with respect to quartz, calcite, aragonite, dolomite, magnesite, strontianite, and barite and generally undersaturated with respect to gypsum, anhydrite, celestite, and halite. The post-mixing water generally showed a lesser degree of saturation than the pre-mixing water with respect to the carbonate minerals calcite, aragonite, dolomite, magnesite, and strontianite and a greater degree of saturation with respect to barite. Similarly, the post-mixing water showed a greater degree of undersaturation with respect to the sulfate minerals gypsum, anhydrite, and celestite.

The degree of saturation with respect to quartz and the degree of undersaturation with respect to halite remained essentially unchanged.

For the experiments using materials from the Big Sky Mine, the pre-mixing and post-mixing waters generally were near saturation with respect to quartz, the carbonate minerals, the sulfate minerals, and the feldspar adularia; undersaturated with respect to halite and the feldspars albite and anorthite; and supersaturated with respect to kaolinite. The post-mixing water generally showed a lesser degree of saturation than the pre-mixing water with respect to calcite, aragonite, dolomite, magnesite, strontianite, adularia, and kaolinite and a greater degree of saturation with respect to celestite and barite. Similarly, the post-mixing water showed a greater degree of undersaturation with respect to albite and anorthite. The degree of saturation with respect to quartz and the degree of undersaturation with respect to gypsum, anhydrite, and halite remained essentially unchanged.

Mass-transfer relations for water from the batch-mixing experiments are given in table 5. For the experiments using materials from the West Decker Mine, the observed changes probably result from adsorption reactions or ion-exchange and precipitation reactions, or both. A possible sequence of reactions, particularly for the experiments using crushed coal, could include exchange of sodium ions in solution for calcium ions from the coal. To maintain equilibrium, the increase in calcium ions in solution would be offset by precipitation of calcite, resulting in a relatively large decrease in the concentration of bicarbonate ions in solution and a relatively small net change of calcium ions in solution. Because magnesium carbonate minerals do not readily precipitate from solution, the observed decreases in the concentration of magnesium ions would probably result from exchange in a manner similar to sodium or from adsorption. Barium ions could be involved in a manner similar to calcium ions except that barite would precipitate, resulting in a decrease in the concentration of sulfate ions in solution. The amount of calcite and barite precipitated would be too small to be detected by X-ray diffraction analysis of the post-mixing coal.

For the experiments using materials from the Big Sky Mine, the observed changes also probably result from adsorption reactions or ion-exchange and precipitation reactions, or both. However, the constituents and minerals probably involved are different than for the West Decker Mine. A possible sequence of reactions could include exchange of magnesium ions in solution for calcium ions from the coal. To maintain equilibrium, the increase of calcium ions in solution would be offset by precipitation of calcite and, for some experiments, gypsum. The result would be a relatively large decrease in bicarbonate ions in solution, a decrease for some experiments in sulfate ions, and a relatively small net change of calcium ions in solution. Because magnesium carbonate minerals do not readily precipitate from solution, the observed decreases in the concentration of magnesium ions probably would be due solely to exchange or adsorption reactions. Strontium ions could be involved in a manner similar to calcium ions. The amount of calcite and any strontium minerals precipitated would be too small to be detected by X-ray diffraction analysis of the post-mixing coal.

CONCLUSIONS

Batch-mixing experiments using spoils water and coal from the West Decker and Big Sky Mines demonstrate that water moving from coal-mine spoils through a coal aquifer probably would undergo changes in chemical quality. The dissolved-solids concentration in water used in the experiments decreased an average 210 mg/L, or about 5 to 10 percent. Other chemical changes include general decreases in the concentrations of magnesium, potassium, and bicarbonate and general increases in the concentrations of barium and boron. Changes in concentrations of calcium, sodium, sulfate, manganese, strontium, and zinc were variable. In general, the magnitude of the changes increased as the surface area of the coal increased.

The amounts of extractable cations and exchangeable cations in the post-mixing coal were larger than in the pre-mixing coal. The differences also increased as the surface area of the coal increased, signifying that ion exchange or adsorption probably was an important factor in the observed water-quality changes.

X-ray diffraction analyses of residue from low-temperature ashing of coal indicate the major minerals to be quartz, a polymorph of anhydrite (gamma calcium sulfate), kaolinite, illite, and possibly a trace of feldspar. Water used in the experiments generally was near saturation with respect to quartz, carbonate minerals, and barite. Water from the Big Sky Mine was also near saturation with respect to gypsum, anhydrite, and celestite whereas water from the West Decker Mine was undersaturated with respect to those minerals.

Mass-transfer relationships, coupled with the equilibrium relationships, indicate that adsorption reactions or ion-exchange and precipitation of calcite, or both, probably are the major reactions responsible for the chemical changes observed in the experiments. Precipitation of gypsum is also a possible major reaction for some mixtures using materials from the Big Sky Mine.

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Table 1.--*Common-constituent concentrations in water from batch-mixing experiments using materials from the West Decker and Big Sky Mines*

[Constituents are dissolved and concentrations are reported in milligrams per liter. Samples were filtered through a 0.10-micrometer filter, except as indicated. Analyses by Montana Bureau of Mines and Geology. Source of water: SBS, spoils at Big Sky Mine; SWD, spoils at West Decker Mine. Source of coal: A-Dz1, combined Anderson-Dietz 1 coal bed; R, Rosebud coal bed. Coal treatment: A, air dried; O, oven dried at 40° Celsius; Ch, chunks about 1 inch on a side; Cr, crushed to about one-fourth inch or less on a side. Abbreviations: microsiemens, microsiemens per centimeter at 25° Celsius; °C, degrees Celsius; <, less than]

Sample designation	Date	Source of water	Source of coal	Coal treatment	Mixing ratio by weight (water: coal)	Onsite specific conductance (microsiemens)	Onsite pH (units)	Temperature (°C)	Calcium (Ca)
West Decker Mine									
[1]WWD1	04-03-84	SWD	---	---	---	3,610	7.42	24.9	21
WAWDAB	04-04-84	SWD	A-Dz1	A, Ch	1:1	3,450	7.55	24.5	12
WAWDOB	04-04-84	SWD	A-Dz1	O, Ch	1:1	3,350	7.50	24.5	10
[1]WWD2	04-10-84	SWD	---	---	---	3,610	7.81	24.3	22
[2]WAWDAC	04-10-84	SWD	A-Dz1	A, Cr	1:1	3,050	7.21	24.4	9.2
[2]WAWDOC	04-10-84	SWD	A-Dz1	O, Cr	1:1	3,020	7.33	24.7	9.1
Big Sky Mine									
[1]WBS1	03-15-84	SBS	---	---	---	4,490	7.17	24.5	410
WRBSAB	03-15-84	SBS	R	A, Ch	1:1	4,340	6.82	24.5	410
WRBSOB	03-15-84	SBS	R	O, Ch	1:1	4,360	6.82	24.0	410
[1]WBS2	03-30-84	SBS	---	---	---	4,490	7.52	24.4	390
WRBSAC	03-29-84	SBS	R	A, Cr	1:1	4,160	6.85	24.3	430
WRBSOC	03-30-84	SBS	R	O, Cr	1:1	4,230	6.98	24.7	420

[1] Pre-mixing sample.
[2] Filtered through 0.45-micrometer filter only.

Magnesium (Mg)	Sodium (Na)	Potassium (K)	On-site bicarbonate (HCO_3)	On-site carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Silica (SiO_2)	Dissolved solids, calculated
7.9	830	7	1,600	0	660	9.6	<1	12	2,260
4.6	800	6	1,660	0	480	6.6	<1	12	2,080
3.9	820	7	1,590	0	660	11	<1	12	2,210
8.1	890	8	1,800	0	700	6.0	2.1	12	2,400
3.5	760	6	1,320	0	660	6.3	<1	12	2,060
3.5	760	6	1,290	0	670	6.2	<1	13	2,060
440	210	15	730	0	2,700	14	5.3	12	4,100
400	210	13	560	0	2,600	15	5.5	12	3,900
390	210	13	520	0	2,400	16	7.2	13	3,830
430	200	15	710	0	2,500	16	.3	12	3,950
350	200	12	360	0	2,500	16	.3	14	3,740
370	210	13	350	0	2,600	16	.3	14	3,830

Table 2.--*Trace-element concentrations in water from batch-mixing experiments using materials from the West Decker and Big Sky Mines*

[Constituents are dissolved and concentrations are reported in micrograms per liter. Samples were filtered through a 0.10-micrometer filter, except as indicated. Analyses by Montana Bureau of Mines and Geology. Source of water: SBS, spoils at Big Sky Mine; SWD, spoils at West Decker Mine. Source of coal: A-Dz1, combined Anderson-Dietz 1 coal bed; R, Rosebud coal bed. Coal treatment: A, air dried; O, oven dried at 40° Celsius; Ch, chunks about 1 inch on a side; Cr, crushed to about one-fourth inch or less on a side. Abbreviation: <, less than]

Sample designation	Date	Source of water	Source of coal	Coal treatment	Mixing ratio by weight (water: coal)	Aluminum (Al)	Barium (Ba)	Boron (B)	Cadmium (Cd)	Chromium (Cr)
West Decker Mine										
[1]WWD1	04-03-84	SWD	---	---	---	<30	20	90	2	<2
WAWDAB	04-04-84	SWD	A-Dz1	A, Ch	1:1	<30	290	100	<2	2
WAWDOB	04-04-84	SWD	A-Dz1	O, Ch	1:1	<30	240	160	2	<2
[1]WWD2	04-10-84	SWD	---	---	---	<30	60	110	<2	<2
[2]WAWDAC	04-10-84	SWD	A-Dz1	A, Cr	1:1	<30	150	320	2	<2
[2]WAWDOC	04-10-84	SWD	A-Dz1	O, Cr	1:1	<30	140	320	<2	<2
Big Sky Mine										
[1]WBS1	03-15-84	SBS	---	---	---	100	30	400	4	20
WRBSAB	03-15-84	SBS	R	A, Ch	1:1	90	40	700	<2	20
WRBSOB	03-15-84	SBS	R	O, Ch	1:1	100	50	730	2	20
[1]WBS2	03-30-84	SBS	---	---	---	<30	30	80	2	10
WRBSAC	03-29-84	SBS	R	A, Cr	1:1	100	40	1,200	4	10
WRBSOC	03-30-84	SBS	R	O, Cr	1:1	100	50	1,100	4	20

[1] Pre-mixing sample.
[2] Filtered through 0.45-micrometer filter only.

Copper (Cu)	Iron (Fe)	Lead (Pb)	Lithium (Li)	Manganese (Mn)	Molybdenum (Mo)	Nickel (Ni)	Silver (Ag)	Strontium (Sr)	Titanium (Ti)	Zinc (Zn)	Zirconium (Zr)
<4	<2	<40	200	50	120	<10	<2	1,000	6	30	<4
<2	<2	--	220	3	<20	<10	<2	830	<1	<3	<4
2	3	<40	200	3	<20	<10	<2	680	<1	9	<4
35	6	<40	220	23	<20	<10	<2	1,000	<1	50	<4
<2	20	<40	170	3	<20	<10	<2	590	<1	4	<4
<2	4	<40	170	4	20	<10	<2	580	<1	9	<4
77	20	110	60	320	40	30	13	9,500	40	10	10
66	20	120	60	370	<20	10	6	19,600	40	10	10
71	20	130	60	370	<20	10	12	21,700	40	8	20
52	10	<40	50	3	<20	20	<2	9,800	40	6	<4
58	50	<40	50	420	<20	10	<2	26,600	50	20	<4
62	30	<40	60	360	<20	20	4	26,600	50	10	5

Table 3.--*Results of chemical analyses of coal used in batch-mixing experiments*

[Analyses by Montana Bureau of Mines and Geology. Source of water: SBS, spoils at Big Sky Mine; SWD, spoils at West Decker Mine. Source of coal: A-Dzl, combined Anderson-Dietz 1 coal bed; R, Rosebud coal bed. Coal treatment: A, air dried; O, oven dried at 40° Celsius; Cr, crushed to about one-fourth inch or less on a side. Abbreviation: meq/100 g, milliequivalents per 100 grams]

Sample designation	Source of water	Source of coal	Coal treatment	Mixing ratio by weight (water: coal)	Extractable cations (meq/ 100 g)	Exchangeable cations (meq/ 100 g)
West Decker Mine						
[1]CAAC	---	A-Dzl	A, Cr	---	14.4	26.1
CAWDAC	SWD	A-Dzl	A, Cr	1:1	12.2	30.4
[1]CAOC	---	A-Dzl	O, Cr	---	11.2	22.9
CAWDOC	SWD	A-Dzl	O, Cr	1:1	15.2	33.2
Big Sky Mine						
[1]CRAC	---	R	A, Cr	---	14.4	34.5
CRBSAC	SBS	R	A, Cr	1:1	25.0	41.8
[1]CROC	---	R	O, Cr	---	14.9	43.0
CRBSOC	SBS	R	O, Cr	1:1	17.7	36.4

[1] Pre-mixing sample.

Table 4 begins on next page

Table 4.--*Saturation indices from WATEQF for water from batch-mixing experiments*

[Samples were filtered through a 0.10-micrometer filter, except as indicated. Source of coal: A-Dz1, combined Anderson-Dietz coal bed at West Decker Mine; R, Rosebud coal bed at Big Sky Mine. Coal treatment: A, air dried; O, oven dried at 40° Celsius; Ch, chunks about 1 inch on a side; Cr, crushed to about one-fourth inch or less on a side]

			Saturation index with respect to indicated mineral					
Sample designation	Source of coal	Coal treatment	Quartz (SiO_2)	Calcite ($CaCO_3$)	Aragonite ($CaCO_3$)	Dolomite [$CaMg(CO_3)_2$]	Magnesite ($MgCO_3$)	Strontianite ($SrCO_3$)
West Decker Mine								
[1]WWD1	---	---	0.31	0.14	0.00	0.23	-0.28	-0.80
WAWDAB	A-Dz1	A, Ch	.32	.06	.08	.08	-.35	-.70
WAWDOB	A-Dz1	O, Ch	.32	-.11	-.25	-.26	-.52	-.89
[1]WWD2	---	---	.32	.56	.42	1.06	.13	-.38
[2]WAWDAC	A-Dz1	A, Cr	.32	-.50	-.64	-1.05	-.92	-1.31
[2]WAWDOC	A-Dz1	O, Cr	.35	-.39	-.53	-.83	-.80	-1.21
Big Sky Mine								
[1]WBS1	---	---	.32	.66	.52	1.73	.70	-.63
WRBSAB	R	A, Ch	.32	.21	.07	.79	.21	-.77
WRBSOB	R	O, Cr	.36	.19	.04	.72	.17	-.74
[1]WBS2	---	---	.32	.98	.84	2.38	1.03	-.27
WRBSAC	R	A, Cr	.39	.08	-.06	.45	.00	-.78
WRBSOC	R	O, Cr	.39	.19	.04	.70	.14	-.67

[1] Pre-mixing sample.

[2] Filtered through 0.45-micrometer filter only.

Saturation index with respect to indicated mineral								
Gypsum ($CaSO_4\cdot 2H_2O$)	Anhydrite ($CaSO_4$)	Celestite ($SrSO_4$)	Barite ($BaSO_4$)	Albite ($NaAlSi_3O_8$)	Anorthite ($CaAl_2Si_2O_8$)	Adularia ($KAlSi_3O_8$)	Kaolinite [$Al_2Si_2O_5(OH)_4$]	Halite ($NaCl$)
-1.69	-1.91	-1.44	0.29	---	---	---	---	-6.77
-2.03	-2.25	-1.61	1.35	---	---	---	---	-6.94
-2.00	-2.23	-1.60	1.39	---	---	---	---	-6.71
-1.68	-1.90	-1.44	.78	---	---	---	---	-6.94
-2.01	-2.24	-1.64	1.21	---	---	---	---	-6.98
-2.01	-2.23	-1.64	1.18	---	---	---	---	-6.99
-.13	-.36	-.24	.79	-1.09	-2.42	0.10	3.46	-7.25
-.13	-.35	.08	.91	-2.29	-4.81	-1.16	1.75	-7.21
-.15	-.38	.11	.99	-2.48	-5.35	-1.34	1.23	-7.18
-.17	-.39	-.24	.76	---	---	---	---	-7.21
-.10	-.33	.21	.91	-.84	-2.11	.28	4.37	-7.20
-.11	-.33	.22	1.01	-.72	-1.91	.40	4.30	-7.18

Table 5.--*Mass-transfer relations for water from batch-mixing experiments*

[Source of coal: A-Dz1, combined Anderson-Dietz 1 coal bed; R, Rosebud coal bed. Coal treatment: A, air dried; O, oven dried at 40° Celsius; Ch, chunks about 1 inch on a side; Cr, crushed to about one-fourth inch or less on a side]

Pre-mixing sample designation and source	Post-mixing sample designation	Source of coal	Coal treatment	Millimoles per liter of indicated constituent added to solution (positive) or subtracted from solution (negative) as a result of mixing								
				Calcium	Magnesium	Sodium	Potassium	Bicarbonate	Sulfate	Chloride	Barium	Strontium
West Decker Mine												
WWD1 (spoils)	WAWDAB	A-Dz1	A, Ch	-0.22	-0.14	-1.3	-0.03	0.98	-1.9	-0.08	0.002	-0.002
WWD1 (spoils)	WAWDOB	A-Dz1	O, Ch	-.27	-.16	-.44	.00	-.16	.00	.04	.002	-.004
WWD2 (spoils)	WAWDAC	A-Dz1	A, Cr	-.32	-.19	-5.7	-.05	-7.87	-.42	.01	.001	-.005
WWD2 (spoils)	WAWDOC	A-Dz1	O, Cr	-.32	-.19	-5.7	-.05	-8.36	-.31	.01	.001	-.005
Big Sky Mine												
WBS1 (spoils)	WRBSAB	R	A, Ch	.00	-1.6	.00	-.05	-2.79	-1.0	.03	.000	.115
WBS1 (spoils)	WRBSOB	R	O, Ch	.00	-2.1	.00	-.05	-3.44	-3.1	.06	.000	.139
WBS2 (spoils)	WRBSAC	R	A, Cr	1.0	-3.3	.00	-.08	-5.74	.00	.00	.000	.192
WBS2 (spoils)	WRBSOC	R	O, Cr	.75	-2.5	.44	-.05	-5.90	1.0	.00	.000	.192

*GPO 692-890 (1986)