

DOE/PC/72007-T12

ULTRA-FINE COAL CHARACTERIZATION
12TH PROGRESS REPORT

F. J. Smit

February 29, 1988

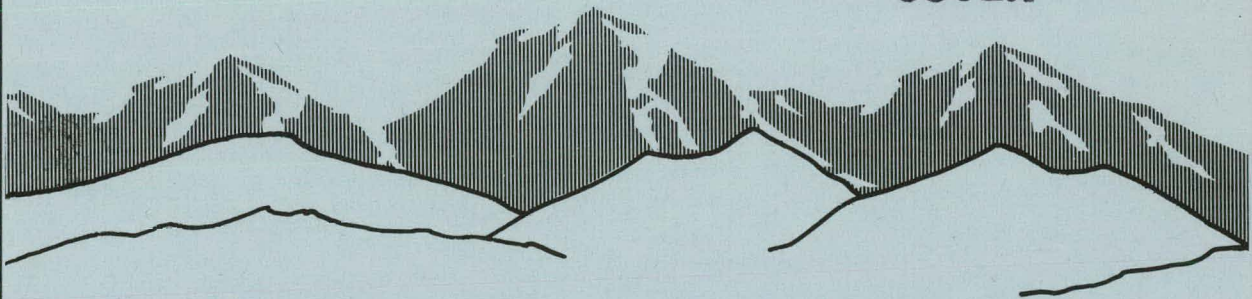
AMAX Research & Development Center
5950 McIntyre Street
Golden, Colorado 80403

Prepared for

The United States Department of Energy
Pittsburgh Energy Technology Center
Pittsburgh, Pennsylvania

Under Contract DE-AC22-84PC72007

DO NOT MICROFILM
COVER



AMAX Research & Development Center

5950 McIntyre Street • Golden, Colorado 80403-7499



Received by USM

APR 09 1990

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

LEGAL NOTICE

THIS REPORT WAS PREPARED BY AMAX RESEARCH & DEVELOPMENT CENTER AS AN ACCOUNT OF WORK SPONSORED BY THE U.S. DEPARTMENT OF ENERGY. NEITHER AMAX RESEARCH & DEVELOPMENT CENTER NOR ANY PERSON ACTING ON ITS BEHALF:

(A) MAKES ANY WARRANTY, EXPRESSED OR IMPLIED, WITH RESPECT TO THE USE OF ANY INFORMATION, APPARATUS, METHOD, OR PROCESS DISCLOSED IN THIS REPORT OR THAT SUCH USE MAY NOT INFRINGE PRIVATELY OWNED RIGHTS; OR

(B) ASSUMES ANY LIABILITIES WITH RESPECT TO THE USE OF, OR FOR THE DAMAGES RESULTING FROM THE USE OF ANY INFORMATION, APPARATUS, METHOD, OR PROCESS DISCLOSED IN THIS REPORT.

NOTICE

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for any third party's use or the results of such use of any information, apparatus, product, or process disclosed in this report, or represents that its use by such third party would not infringe privately owned rights.

AMAX RESEARCH & DEVELOPMENT CENTER

DOE/PC/72007--T12

DE90 009052

ULTRA-FINE COAL CHARACTERIZATION
12TH PROGRESS REPORT

F. J. Smit

February 29, 1988

AMAX Research & Development Center
5950 McIntyre Street
Golden, Colorado 80403

Prepared for

The United States Department of Energy
Pittsburgh Energy Technology Center
Pittsburgh, Pennsylvania

Under Contract DE-AC22-84PC72007

MASTER

ABSTRACT

Research continued on this program to relate beneficiation characteristics of ultra-fine coals to the mineral-matter liberation and bulk properties of the coals. Washability tests are reported here which quantify mineral-matter liberation during ultra-fine grinding of Pittsburgh, Pocahontas No. 3, Sunnyside, Anderson and Beulah-Zap coals. The first three are bituminous coals from Pennsylvania, West Virginia and Utah respectively, and the last two are a subbituminous coal from the Powder River area of Wyoming and a lignite coal from North Dakota. The following results for the 1.90 specific-gravity float products summarized the liberations which which can be achieved by grinding to passing 44-micrometers:

	<u>Fully Dried Basis</u>			
	<u>Ash %</u>	<u>S(t) %</u>	<u>S(Py) %</u>	<u>Btu/lb</u>
Pittsburgh	3.70	0.92	0.11	14,250
Pocahontas No. 3	3.03	0.59	0.03	15,100
Sunnyside	2.37	0.57	0.01	14,367
Anderson	4.50	0.50	0.02	11,599
Beulah-Zap	6.64	0.86	0.01	10,525

These liberation results complete the data set begun with presentation of similar test results for Illinois No. 5, Illinois No. 6, Indiana III, and Upper Freeport bituminous coals in previous Quarterly Reports.

TABLE OF CONTENTS

	<u>Page</u>
INTRODUCTION.....	1
MINERAL-MATTER LIBERATION IN ULTRA-FINE COAL.....	1
REFERENCES.....	3
APPENDIX A Stirred Ball Mill Grinding Data.....	9
APPENDIX B Washability Test Mass Balances.....	15

LIST OF TABLES

	<u>Page</u>
Table 1. Comparison of 1.30, 1.40 and 1.90 Specific-Gravity Float Products From Pittsburgh Coal...	4
Table 2. Comparison of 1.30, 1.40 and 1.90 Specific-Gravity Float Products From Pocahontas No. 3 Coal.....	5
Table 3. Comparison of 1.30, 1.40 and 1.90 Specific-Gravity Float Products From Sunnyside Coal....	6
Table 4. Comparison of 1.30, 1.40 and 1.90 Specific-Gravity Float Products From Andersen Subbituminous Coal.....	7
Table 5. Comparison of 1.30, 1.40 and 1.90 Specific-Gravity Float Products from Beulah-Zap Lignite Coal.....	8

LIST OF TABLES (Continued)

		<u>Page</u>
Table A-1.	Stirred Ball Mill Grinding Data for Pittsburgh Washed Coal.....	10
Table A-2.	Stirred Ball Mill Grinding Data for Pocahontas No. 3 Washed Coal.....	11
Table A-3.	Stirred Ball Mill Grinding Data for Sunnyside Washed Coal.....	12
Table A-4.	Stirred Ball Mill Grinding Data for Anderson Whole-Seam Subbituminous Coal.....	13
Table A-5.	Stirred Ball Mill Grinding Data for Beulah-Zap Whole-Seam Lignite Coal.....	14
Table B-1.	Washability of 44-Micrometer x 0 Pittsburgh Washed Coal.....	16
Table B-2.	Washability of 10-Micrometer x 0 Pittsburgh Washed Coal.....	17
Table B-3.	Washability of 44-Micrometer x 0 Pocahontas No. 3 Washed Coal.....	17
Table B-4.	Washability of 10-Micrometer x 0 Pocahontas No. 3 Washed Coal.....	18
Table B-5.	Washability of 44-Micrometer x 0 Sunnyside Washed Coal.....	18
Table B-6.	Washability of 10-Micrometer x 0 Sunnyside Washed Coal.....	19
Table B-7.	Washability of 44-Micrometer x 0 Anderson Whole-Seam Coal.....	19
Table B-8.	Washability of Beulah-Zap 44-Micrometer x 0 Whole-Seam Coal.....	20

INTRODUCTION

Research continued relating beneficiation characteristics of ultra-fine coals to the mineral-matter liberation and bulk properties of the coals. Washability tests are reported here which quantify mineral-matter liberation during ultra-fine grinding of Pittsburgh, Pocahontas No. 3, Sunnyside, Anderson and Beulah-Zap coals. The first three are bituminous coals from Pennsylvania, West Virginia and Utah, respectively, and the last two are subbituminous and lignite coals, from the Powder River area of Wyoming and from North Dakota, respectively. These washability test results complete the data set begun with presentation of test results for Illinois No. 5, Illinois No. 6, Indiana III, and Upper Freeport bituminous coals in previous Quarterly Reports.

MINERAL-MATTER LIBERATION IN ULTRA-FINE COAL

The amount of ash-mineral and pyrite liberated during ultra-fine grinding of Pittsburgh, Pocahontas No. 3, and Sunnyside washed coals and Anderson and Beulah-Zap whole-seam coals were determined by heavy-liquid washability tests. The bulk properties of these coals and the washability test results at 1/2-inch, 14-mesh, and 65-mesh top-sizes were presented in previous Quarterly Reports (1,2,3).

The heavy-liquid separation procedure developed for the ultra-fine Illinois No. 6 base-case coal and described in the 2nd Quarterly Report (4) was followed for these washability tests. Certigrav solutions were used for the density separations and the Certigrav/coal suspensions were ultrasonically conditioned with 500 ppm Aerosol OT-S surfactant before centrifuging to make the particle separations.

The ultra-fine coals were prepared by grinding samples in a stirred ball mill containing 3/16-inch diameter chromium steel media (4). The grinding times were determined from particle-size determinations on small aliquots taken at specified intervals during preliminary grinding tests. The grindability test data for each coal, and the correlation equations for prediction of grinding times, are given in Appendix A. The grinding times required to produce 44-micrometer and 10-micrometer nominal top-size coals for the washability tests were as follows:

	<u>Grinding Time, Minutes</u>	
	<u>44 μm</u>	<u>10 μm</u>
Pittsburgh Washed Coal	5.2	43.1
Pocahontas No. 3 Washed Coal	4.4	36.0
Sunnyside Washed Coal	5.3	41.7
Anderson Whole-Seam Coal	3.4	
Beulah-Zap Whole-Seam Coal	9.1	

Complete mass balances for the separations on the 44-micrometer x 0 and the 10-micrometer x 0 Pittsburgh, Pocahontas No. 3, and Sunnyside washed coals are given in Tables B-1 through B-6 in Appendix B. Separations were made only on the 44-micrometer x 0 low-rank coals as given in Tables B-7 and B-8, also in Appendix B.

Tables 1 through 5 compare the liberation results on the ultra-fine coals to the separation results reported previously for the coarser whole-seam and washed coals (1, 2, 3). As expected, further comminution liberated additional mineral matter. For example, the combined 1.90 specific-gravity float products from minus 44-micrometer Pittsburgh coal contained only 3.70 percent ash and 0.92 percent sulfur compared to 8.08 percent ash and 1.66 percent sulfur in the comparable float product from minus 1/2-inch Pittsburgh coal.

The changing weight distribution pattern observed when grinding midwestern coals also seemed to be true of these coals, that is, the amount of 1.30 specific-gravity float material virtually disappeared as the coal was ground finer. This was to be expected since none of these coals contained any significant amount of exinite, the only maceral with a density of less than 1.3 grams per cubic centimeter. The large amount of 1.30 specific-gravity float fraction in the coarser coal can be explained by the presence of closed pores which do not soak up the heavy-liquid.

Pittsburgh Coal. The washability results summarized in Table 1 show that 14-mesh and 1/2-inch Pittsburgh coal contains unliberated mineral matter equivalent to between 6.50 and 8.08 percent ash and 0.50 to 0.72 percent sulfur as unliberated pyrite. Ultra-fine grinding, to less than 44 micrometers, improved liberation so that the 1.90 specific-gravity float fraction contained approximately half as much ash and eighty percent less pyritic sulfur than in the coarser coal. There was some additional ash mineral liberation when grinding to 10 micrometers rather than 44 micrometers. The data for separations at 1.40 specific gravity shows that a significant component of the ultra-fine Pittsburgh coal contains even less ash and pyrite.

Despite the good rejection of pyrite, the clean Pittsburgh coal still contained about one percent sulfur in organic forms not amenable to physical separation.

Pocahontas No. 3 Coal. The Pocahontas No. 3 coal contained very little pyrite when received and only about half as much organic sulfur as the Pittsburgh coal. Consequently, ultra-fine grinding had little impact upon sulfur liberation and rejection. As shown in Table 2, about half the ash mineral in washed Pocahontas No. 3 coal was liberated during grinding to 44 micrometers and could be rejected by separation at 1.90 specific gravity. Liberation was practically unchanged by further grinding to passing 10 micrometers.

Sunnyside Coal. The washability results for Sunnyside coal are given in Table 3. Like Pocahontas No. 3 coal, the Sunnyside coal was low in pyritic and total sulfur. A substantial component of the Sunnyside coal contained less than two percent ash, even before ultra-fine grinding, and the 1.90 specific-gravity float fraction from the minus 44-micrometer coal contained 2.37 percent ash. Grinding further to passing 10 micrometers appeared to liberate an additional amount of mineral-matter.

Anderson and Beulah-Zap Coals. As shown in Tables 4 and 5, the two low-rank coals responded similarly to ultra-fine grinding. Very little mineral-matter was liberated from either coal by grinding. In fact, the minus 44-micrometer, 1.90 specific-gravity float fractions from these coals contained more ash than the comparable products from any of the other coals except for the Upper Freeport coal. The two low-rank coals also differed from the bituminous coals by containing very little 1.30 specific-gravity float material before fine grinding.

REFERENCES

1. Smit, F. J., "Ultra-Fine Coal Characterization," 7th Quarterly Report, Contract No. DE-AC22-84PC72007, December 31, 1985
2. Smit, F. J., "Ultra-Fine Coal Characterization," 8th Quarterly Report, Contract No. DE-AC22-84PC72007, April 10, 1986.
3. Smit, F. J., and Baltich, L. K., "Ultra-Fine Coal Characterization," 10th Quarterly Report, Contract No. DE-AC22-84PC72007, March 12, 1987.
4. Smit, F. J., and Odekirk, J. R., "Ultra-Fine Coal Characterization," 2nd Quarterly Report, Contract No. DE-AC22-84PC72007, September 10, 1984.

Table 1. Comparison of 1.30, 1.40 and 1.90 Specific-Gravity
Float Products From Pittsburgh Coal

	Dry Basis				
	<u>Wt %</u>	<u>Ash %</u>	<u>S(t) %</u>	<u>S(Py) %</u>	<u>Btu/lb</u>
<u>1.30-Specific Gravity Float:</u>					
1/2 inch x 0 whole seam	46.3	3.39	1.13	0.26	14,554
14 mesh x 0 whole seam	44.0	2.94	1.04	0.17	14,614
14 mesh x 0 washed	61.6	2.69	1.03	0.16	14,634
65 mesh x 0 washed	54.0	2.03	0.92	0.06	14,796
44 micrometer x 0 washed	35.1	0.94	0.82	0.01	14,769
10 micrometer x 0 washed	2.6	2.16	1.28	0.07	14,733
<u>Cumulative 1.40-Specific Gravity Float:</u>					
1/2 inch x 0 whole seam	69.6	5.44	1.44	0.50	14,221
14 mesh x 0 whole seam	69.5	5.12	1.26	0.65	14,241
14 mesh x 0 washed	90.9	4.82	1.22	0.34	14,283
65 mesh x 0 washed	89.3	4.08	1.05	0.17	14,449
44 micrometer x 0 washed	86.1	2.17	0.88	0.05	14,507
10 micrometer x 0 washed	39.8	1.47	1.12	0.03	14,722
<u>Cumulative 1.90-Specific Gravity Float:</u>					
1/2 inch x 0 whole seam	79.2	8.08	1.66	0.72	13,776
14 mesh x 0 whole seam	78.0	7.41	1.43	0.82	13,856
14 mesh x 0 washed	99.1	6.50	1.37	0.50	14,004
65 mesh x 0 washed	97.8	5.82	1.15	0.29	14,152
44 micrometer x 0 washed	95.7	3.70	0.92	0.11	14,250
10 micrometer x 0 washed	94.7	3.23	1.19	0.12	14,350
<u>Average Separation Feed:</u>					
Whole Seam Coal	100.0	23.92	1.92	1.23	11,121
Washed Coal	100.0	7.07	1.53	0.61	13,807

Table 2. Comparison of 1.30, 1.40 and 1.90 Specific-Gravity
Float Products from Pocahontas No. 3 Coal

	Dry Basis				
	Wt %	Ash %	S(t) %	S(Py) %	Btu/lb
<u>1.30-Specific Gravity Float:</u>					
1/2 inch x 0 whole seam	46.9	2.99	0.58	0.05	15,342
14 mesh x 0 whole seam	50.9	2.28	0.68	0.05	15,463
14 mesh x 0 washed	66.3	2.16	0.62	0.05	14,492
65 mesh x 0 washed	57.4	1.59	0.69	0.03	15,486
44 micrometer x 0 washed	tr				
10 micrometer x 0 washed	tr				
<u>Cumulative 1.40-Specific Gravity Float:</u>					
1/2 inch x 0 whole seam	66.6	4.25	0.58	0.05	15,100
14 mesh x 0 whole seam	72.4	3.62	0.66	0.06	15,206
14 mesh x 0 washed	86.9	3.31	0.61	0.05	15,259
65 mesh x 0 washed	84.9	2.40	0.67	0.04	15,323
44 micrometer x 0 washed	80.7	1.63	0.61	0.02	15,361
10 micrometer x 0 washed	69.8	1.59	0.57	0.02	15,938
<u>Cumulative 1.90-Specific Gravity Float:</u>					
1/2 inch x 0 whole seam	78.5	7.53	0.55	0.06	14,482
14 mesh x 0 whole seam	83.1	6.24	0.63	0.06	14,707
14 mesh x 0 washed	97.7	5.66	0.58	0.06	14,814
65 mesh x 0 washed	96.5	4.29	0.65	0.05	14,964
44 micrometer x 0 washed	96.3	3.03	0.59	0.03	15,100
10 micrometer x 0 washed	94.5	3.01	0.55	0.03	15,562
<u>Average Separation Feed:</u>					
Whole Seam Coal	100.0	22.29	0.52	0.08	11,935
Washed Coal	100.0	6.56	0.59	0.06	14,635

Table 3. Comparison of 1.30, 1.40 and 1.90 Specific-Gravity
Float Products From Sunnyside Coal

	Dry Basis				
	<u>Wt %</u>	<u>Ash %</u>	<u>S(t) %</u>	<u>S(Py) %</u>	<u>Btu/lb</u>
<u>1.30-Specific Gravity Float:</u>					
1/2 inch x 0 whole seam	53.9	2.27	0.56	0.02	14,562
14 mesh x 0 whole seam	66.3	1.96	0.57	0.01	14,478
14 mesh x 0 washed	76.6	1.56	0.53	0.01	14,584
65 mesh x 0 washed	73.6	1.00	0.52	0.01	14,579
44 micrometer x 0 washed	23.6	0.57	0.57	0.01	14,810
10 micrometer x 0 washed	6.0	1.95	0.81	0.01	15,040
<u>Cumulative 1.40-Specific Gravity Float:</u>					
1/2 inch x 0 whole seam	78.4	4.26	0.56	0.04	14,223
14 mesh x 0 whole seam	77.8	3.24	0.57	0.02	14,258
14 mesh x 0 washed	91.9	2.89	0.53	0.02	14,369
65 mesh x 0 washed	89.9	1.97	0.53	0.01	14,425
44 micrometer x 0 washed	90.7	1.38	0.57	0.01	14,533
10 micrometer x 0 washed	82.1	1.40	0.68	0.01	15,259
<u>Cumulative 1.90-Specific Gravity Float:</u>					
1/2 inch x 0 whole seam	86.4	6.96	0.57	0.06	13,773
14 mesh x 0 whole seam	85.9	5.85	0.57	0.04	13,821
14 mesh x 0 washed	98.9	4.64	0.54	0.03	14,079
65 mesh x 0 washed	97.5	3.81	0.52	0.02	14,118
44 micrometer x 0 washed	96.9	2.37	0.57	0.01	14,367
10 micrometer x 0 washed	95.7	2.15	0.67	0.01	15,020
<u>Average Separation Feed:</u>					
Whole Seam Coal	100.0	16.98	0.59	0.13	12,142
Washed Coal	100.0	5.36	0.58	0.04	14,039

Table 4. Comparison of 1.30, 1.40 and 1.90 Specific-Gravity
Float Products from Anderson Subbituminous Coal

	Dry Basis				
	<u>Wt %</u>	<u>Ash %</u>	<u>S(t) %</u>	<u>S(Py) %</u>	<u>Btu/lb</u>
<u>1.30-Specific Gravity Float:</u>					
1/2 inch x 0 whole seam	18.9	4.60	0.51	tr	12,013
14 mesh x 0 whole seam	1.8	5.82	0.43	0.01	12,607
65 mesh x 0 whole seam	0.8	4.25	0.27	tr	13,029
44 micrometer x 0 whole seam	tr				
<u>Cumulative 1.40-Specific Gravity Float:</u>					
1/2 inch x 0 whole seam	79.3	5.01	0.45	0.01	11,760
14 mesh x 0 whole seam	65.3	4.47	0.36	0.01	11,850
65 mesh x 0 whole seam	32.9	3.99	0.33	0.01	11,929
44 micrometer x 0 whole seam	54.9	3.79	0.50	0.01	11,956
<u>Cumulative 1.90-Specific Gravity Float:</u>					
1/2 inch x 0 whole seam	99.1	6.01	0.47	0.04	11,588
14 mesh x 0 whole seam	99.2	5.77	0.37	0.04	11,636
65 mesh x 0 whole seam	99.7	5.76	0.40	0.07	11,525
44 micrometer x 0 whole seam	98.3	4.50	0.50	0.02	11,599
<u>Average Whole Seam Coal</u>	100.0	6.43	0.49	0.09	11,504

Table 5. Comparison of 1.30, 1.40 and 1.90 Specific-Gravity
Float Products From Beulah-Zap Lignite Coal

	Dry Basis				
	<u>Wt %</u>	<u>Ash %</u>	<u>S(t) %</u>	<u>S(Py) %</u>	<u>Btu/lb</u>
<u>1.30-Specific Gravity Float:</u>					
1/2 inch x 0 whole seam	2.2	3.87	0.57	0.01	11,109
14 mesh x 0 whole seam	0.3	3.30	0.55		
65 mesh x 0 whole seam	1.2	3.22	0.75	0.01	11,638
44 micrometer x 0 whole seam	tr				
<u>Cumulative 1.40-Specific Gravity Float:</u>					
1/2 inch x 0 whole seam	52.0	5.78	0.62	0.01	10,975
14 mesh x 0 whole seam	32.3	4.76	0.58	0.01	10,950
65 mesh x 0 whole seam	14.6	3.81	0.62	0.01	10,943
44 micrometer x 0 whole seam	64.7	5.51	0.87	tr	10,759
<u>Cumulative 1.90-Specific Gravity Float:</u>					
1/2 inch x 0 whole seam	98.5	7.43	0.63	0.06	10,658
14 mesh x 0 whole seam	97.9	6.73	0.54	0.04	10,588
65 mesh x 0 whole seam	98.6	5.91	0.49	0.02	10,501
44 micrometer x 0 whole seam	98.0	6.64	0.86	0.01	10,525
<u>Average Whole Seam Coal</u>	100.0	7.80	0.86	0.24	10,426

APPENDIX A
STIRRED BALL MILL GRINDING DATA

Table A-1. Stirred Ball Mill Grinding Data
for Pittsburgh Washed Coal

Particle Size, Micrometers	Weight Passing, Percent						
	2' Grind	4' Grind	8' Grind	16' Grind	32' Grind	64' Grind	128' Grind
44.0	81.3						
38.0	78.4	94.1					
30.0	63.5	82.1	98.2				
20.0	50.9	72.8	90.8				
15.0	41.5	58.1	81.5	93.3			
10.0	27.7	39.5	64.5	84.3	93.5		
8.0	21.1	31.3	52.6	74.9	89.0		
6.0	14.5	21.8	38.4	59.2	78.5	86.4	
5.0	11.8	17.3	30.6	50.6	70.3	81.0	
4.0		12.9	23.1	39.8	59.1	72.3	
3.0			15.7	28.1	45.2	58.8	89.4
2.0				16.4	27.3	39.6	68.0
1.5					16.6	26.8	49.7
1.3					13.9	21.5	42.7
1.0						15.1	29.8

Regression equation for predicting grinding time:

$$\ln t = 6.199 + 1.187 \ln \ln(1/(1-P)) - 1.965 \ln x + 0.0888 (\ln x)^2$$

where "t" is the grinding time in minutes and "P" is the weight fraction passing particle size "x".

<u>Predictor</u>	<u>Value</u>	<u>t-ratio</u>
Constant	6.199	111.26
$\ln \ln(1/(1-P))$	1.187	55.76
$\ln x$	-1.965	-34.59
$(\ln x)^2$	0.0888	6.10

Standard error = 0.121, $R^2 = 99.2\%$, 56 degrees of freedom.

Table A-2. Stirred Ball Mill Grinding Data
for Pocahontas No. 3 Washed Coal

<u>Particle Size, Micrometers</u>	<u>Weight Passing, Percent</u>						
	<u>2'</u> <u>Grind</u>	<u>4'</u> <u>Grind</u>	<u>8'</u> <u>Grind</u>	<u>16'</u> <u>Grind</u>	<u>32'</u> <u>Grind</u>	<u>64'</u> <u>Grind</u>	<u>128'</u> <u>Grind</u>
38.0	90.0	97.8	99.2				
30.0	77.0	92.9	97.4				
20.0	63.7	81.7	88.0				
15.0	52.0	74.7	79.1	98.9			
10.0	40.8	55.8	67.3	92.4	99.5		
8.0	28.4	47.1	59.1	87.8	96.4		
6.0	25.3	37.0	48.0	77.2	89.1		
5.0	21.1	31.7	41.8	68.8	83.4	84.0	
4.0	15.7	24.7	33.7	58.7	74.9	78.9	85.3
3.0	11.6	17.1	24.2	44.6	59.9	66.9	78.2
2.0			13.8	28.1	41.1	47.9	62.0
1.5				19.2	29.0	35.7	49.7
1.3				15.1	23.5	29.4	44.2
1.0					17.1	20.6	33.1

Regression equation for prediction of grinding time:

$$\ln t = 6.078 + 1.416 \ln \ln(1/(1-P)) - 2.234 \ln x + 0.1353 (\ln x)^2$$

where "t" is the grinding time in minutes and "P" is the weight fraction passing particle size "x".

<u>Predictor</u>	<u>Value</u>	<u>t-ratio</u>
Constant	6.078	59.14
$\ln \ln(1/(1-P))$	1.416	32.24
$\ln x$	-2.234	-20.52
$(\ln x)^2$	0.1353	4.78

Standard error = 0.246, $R^2 = 96.5$, 63 degrees of freedom.

Table A-3. Stirred Ball Mill Grinding Data
for Sunnyside Washed Coal

Particle Size, Micrometers	Weight Passing, Percent						
	2'	4'	8'	16'	32'	64'	128'
	<u>Grind</u>	<u>Grind</u>	<u>Grind</u>	<u>Grind</u>	<u>Grind</u>	<u>Grind</u>	<u>Grind</u>
45.0	78.8						
38.0	75.0	95.4					
30.0	61.1	87.7					
20.0	50.6	73.2					
15.0	38.4	61.1	83.8				
10.0	24.0	41.9	62.9	84.9	92.8		
8.0	18.3	30.6	52.4	75.4	88.7		
6.0	12.6	20.8	36.7	59.6	76.1	93.3	
5.0	10.3	16.6	30.0	51.0	66.2	88.1	
4.0		12.4	21.8	39.3	54.1	81.0	93.8
3.0			15.0	27.2	39.6	52.4	82.4
2.0				15.6	22.6	38.4	61.2
1.5				10.2	14.1	25.3	44.8
1.3					11.3	20.1	37.1
1.0						13.7	25.9

Regression equation for prediction of grinding times:

$$\ln t = 6.347 + 1.154 \ln \ln(1/(1-P)) - 2.079 \ln x + 0.1126 (\ln x)^2$$

where "t" is the grinding time in minutes and "P" is the weight fraction passing particle size "x".

<u>Predictor</u>	<u>Value</u>	<u>t-ratio</u>
Constant	6.347	132.66
$\ln \ln(1/(1-P))$	1.154	69.91
$\ln x$	-2.079	-42.68
$(\ln x)^2$	0.1126	9.03

Standard error = 0.103, $R^2 = 99.4\%$, 56 degrees of freedom.

Table A-4. Stirred Ball Mill Grinding Data
for Anderson Whole-Seam Subbituminous Coal

Particle Size, Micrometers	Weight Passing, Percent						
	2' Grind	4' Grind	8' Grind	16' Grind	32' Grind	64' Grind	128' Grind
44.0	93.5						
38.0	92.1						
30.0	77.7						
20.0	59.9	76.0	84.6	89.4			
15.0	46.4	60.5	73.5	80.5	93.1		
10.0	29.3	41.4	55.6	64.2	83.9	89.8	98.1
8.0	22.5	33.2	44.1	54.4	75.9	82.2	96.8
6.0	16.3	24.3	31.8	42.0	63.6	71.2	88.7
5.0	13.3	20.4	26.3	33.9	54.8	64.3	83.9
4.0		15.4	19.8	26.2	45.3	53.5	74.8
3.0		10.8	13.4	18.7	34.6	42.9	61.7
2.0				10.3	19.6	25.9	40.9
1.5					10.8	14.9	25.0
1.3						10.6	18.2

Regression equation for prediction of grinding time:

$$\ln t = 7.778 + 1.655 \ln \ln(1/(1-P)) - 2.298 \ln x$$

where "t" is the grinding time in minutes and "P" is the weight fraction passing particle size "x".

<u>Predictor</u>	<u>Value</u>	<u>t-ratio</u>
Constant	7.778	74.26
$\ln \ln(1/(1-P))$	1.655	41.62
$\ln x$	2.298	-48.24
$(\ln x)^2$		<1.00

Standard error = 0.218, $R^2 = 97.6\%$, 60 degrees of freedom.

Table A-5. Stirred Ball Mill Grinding Data
for Beulah-Zap Whole-Seam Lignite Coal

Particle Size, Micrometers	Weight Passing, Percent						
	2' Grind	4' Grind	8' Grind	16' Grind	32' Grind	64' Grind	128' Grind
45.0	81.3	89.1	98.5				
38.0	76.9	87.8	97.1				
30.0	70.9	74.9	95.2	99.2			
20.0	56.4	60.3	82.5	91.3	97.3		
15.0	44.9	48.6	72.7	80.1	90.6		
10.0	31.0	33.9	51.4	66.1	79.4	82.4	
8.0	25.6	27.2	40.7	55.8	72.4	76.6	83.7
6.0	19.1	20.9	30.5	44.2	61.5	68.5	78.6
5.0	16.5	17.4	25.0	37.9	53.5	62.1	73.8
4.0	13.3	13.5	18.9	30.0	44.6	53.5	67.9
3.0			13.2	21.2	33.3	42.8	57.8
2.0				11.8	19.2	26.9	42.0
1.5					10.9	16.1	28.4
1.3						11.8	21.6

Regression equation for prediction of grinding time:

$$\ln t = 8.008 + 1.763 \ln \ln(1/(1-P)) - 2.529 \ln x + 0.0895 (\ln x)^2$$

where "t" is the grinding time in minutes and "P" is the weight fraction passing particle size "x".

<u>Predictor</u>	<u>Value</u>	<u>t-ratio</u>
Constant	8.008	51.43
$\ln \ln(1/(1-P))$	1.763	36.60
$\ln x$	-2.529	-18.91
$(\ln x)^2$	0.0895	2.99

Standard error = 0.248, $R^2 = 96.7\%$, 67 degrees of freedom.

APPENDIX B

WASHABILITY TEST MASS BALANCES

Table B-1. Washability of 44-Micrometer x 0 Pittsburgh Washed Coal

<u>Specific Gravity</u>		<u>Direct (Dry Basis)</u>							<u>Cumulative Float (Dry Basis)</u>						
<u>Sink</u>	<u>Float</u>	<u>Wt. %</u>	<u>Ash, %</u>	<u>Vol, %</u>	<u>S(T), %</u>	<u>S(SO₄), %</u>	<u>S(Py), %</u>	<u>Btu/lb</u>	<u>Wt, %</u>	<u>Ash, %</u>	<u>Vol, %</u>	<u>S(T), %</u>	<u>S(SO₄), %</u>	<u>S(Py), %</u>	<u>Btu/lb</u>
<u>44-Micrometer x 10-Micrometer, 56.9 Wt %:</u>															
	1.30	55.6	0.99	37.42	0.82	0.004	0.01	14777	55.6	0.99	37.42	0.82	0.013	0.01	14777
1.30	1.40	33.5	4.83	36.94	0.92	0.010	0.12	14204	89.1	2.43	37.24	0.86	0.055	0.06	14561
1.40	1.60	6.5	17.44	32.99	1.31	0.033	0.64	12116	95.6	3.45	36.95	0.89	0.094	0.09	14396
1.60	1.90	1.7	38.25	25.17	2.41	0.056	1.98	8590	97.3	4.06	36.75	0.91	0.127	0.13	14294
1.90		2.7	76.27	15.96	13.80	0.163	11.89	2232	100.0	6.02	36.18	1.27	0.447	0.45	13966
<u>10-Micrometer x 0, 43.1 Wt %:</u>															
	1.30	8.1	0.53	38.06	0.83	0.009	0.02	14697	8.1	0.53	38.06	0.83	0.009	0.02	14697
1.30	1.40	74.1	1.93	36.94	0.92	0.021	0.05	14400	82.2	1.79	37.05	0.91	0.020	0.04	14429
1.40	1.60	9.9	10.01	31.42	1.05	0.051	0.30	12983	92.1	2.68	36.44	0.93	0.023	0.07	14273
1.60	1.90	1.5	35.12	26.73	1.67	0.066	1.29	8880	93.6	3.19	36.29	0.94	0.024	0.09	14188
1.90		6.4	77.41	16.38	10.53	0.231	9.55	1843	100.0	7.94	35.02	1.55	0.037	0.70	13399
<u>44-Micrometer x 0 Composite, 100.0 Wt %:</u>															
	1.30	35.1	0.94	37.43	0.82	0.004	0.01	14769	35.1	0.94	37.48	0.82	0.004	0.01	14769
1.30	1.40	51.0	3.02	36.94	0.92	0.017	0.08	14327	86.1	2.17	37.16	0.88	0.012	0.05	14507
1.40	1.60	8.0	13.44	32.14	1.17	0.043	0.46	12584	94.1	3.13	36.74	0.90	0.014	0.08	14344
1.60	1.90	1.6	37.20	25.78	2.12	0.060	1.71	8704	95.7	3.70	36.55	0.92	0.015	0.11	14250
1.90		4.3	77.20	16.23	11.71	0.207	10.39	1983	100.0	6.85	35.68	1.39	0.023	0.55	13722

Table B-2. Washability of 10-Micrometer x 0 Pittsburgh Washed Coal

Specific Gravity		Direct (Dry Basis)							Cumulative Float (Dry Basis)						
Sink	Float	Wt.,%	Ash,%	Vol.,%	S(T),%	S(SO ₄),%	S(Py),%	Btu/lb	Wt.,%	Ash,%	Vol.,%	S(T),%	S(SO ₄),%	S(Py),%	Btu/lb
	1.30	2.6	2.16	42.32	1.28	0.033	0.07	14733	2.6	2.16	42.32	1.28	0.033	0.07	14733
1.30	1.40	37.2	1.42	38.64	1.11	0.015	0.03	14721	39.8	1.47	38.88	1.12	0.016	0.03	14722
1.40	1.60	53.0	3.72	37.15	1.22	0.028	0.15	14216	92.8	2.75	37.89	1.18	0.023	0.10	14433
1.60	1.90	1.9	26.47	29.95	2.05	0.109	1.11	10252	94.7	3.23	37.73	1.19	0.025	0.12	14350
1.90		5.3	77.07	16.47	10.45	0.245	8.92	1736	100.0	7.11	36.62	1.68	0.036	0.58	13686

Table B-3. Washability of 44-Micrometer x 0 Pocahontas No. 3 Washed Coal

Specific Gravity		Direct (Dry Basis)							Cumulative Float (Dry Basis)						
Sink	Float	Wt.,%	Ash,%	Vol.,%	S(T),%	S(SO ₄),%	S(Py),%	Btu/lb	Wt.,%	Ash,%	Vol.,%	S(T),%	S(SO ₄),%	S(Py),%	Btu/lb
	1.30	tr							tr						
1.30	1.40	80.7	1.63	24.87	0.61	0.002	0.02	15361	80.7	1.63	24.87	0.61	0.002	0.02	15361
1.40	1.60	14.3	8.33	20.98	0.49	0.006	0.05	14057	95.0	2.64	24.28	0.59	0.003	0.03	15165
1.60	1.90	1.3	32.08	21.28	0.37	0.025	0.33	--	96.3	3.03	24.24	0.59	0.003	0.03	15100(a)
1.90		3.7	71.10	26.19	0.47	0.028	0.44	--	100.0	5.57	24.32	0.58	0.004	0.05	14615(a)

(a) Estimated

Table B-4. Washability of 10-Micrometer x 0 Pocahontas No. 3 Washed Coal

<u>Specific Gravity</u>		<u>Direct (Dry Basis)</u>							<u>Cumulative Float (Dry Basis)</u>						
<u>Sink</u>	<u>Float</u>	<u>Wt.,%</u>	<u>Ash.,%</u>	<u>Vol.,%</u>	<u>S(T),%</u>	<u>S(SO4),%</u>	<u>S(Py),%</u>	<u>Btu/lb</u>	<u>Wt.,%</u>	<u>Ash.,%</u>	<u>Vol.,%</u>	<u>S(T),%</u>	<u>S(SO4),%</u>	<u>S(Py),%</u>	<u>Btu/lb</u>
	1.30	tr							tr						
1.30	1.40	69.8	1.59	24.64	0.57	0.002	0.02	15938	69.8	1.59	24.64	0.57	0.002	0.02	15938
1.40	1.60	23.5	5.62	23.09	0.51	0.007	0.04	14729	93.3	2.61	24.25	0.55	0.003	0.03	15633
1.60	1.90	1.2	33.38	24.67	0.42	0.014	0.16	--	94.5	3.01	24.25	0.55	0.003	0.03	15562(a)
1.90		5.5	72.13	22.90	0.52	0.024	0.50	1991	100.0	6.79	24.18	0.55	0.005	0.06	14920(a)

(a) Estimated

18

Table B-5. Washability of 44-Micrometer x 0 Sunnyside Washed Coal

<u>Specific Gravity</u>		<u>Direct (Dry Basis)</u>							<u>Cumulative Float (Dry Basis)</u>						
<u>Sink</u>	<u>Float</u>	<u>Wt.,%</u>	<u>Ash.,%</u>	<u>Vol.,%</u>	<u>S(T),%</u>	<u>S(SO4),%</u>	<u>S(Py),%</u>	<u>Btu/lb</u>	<u>Wt.,%</u>	<u>Ash.,%</u>	<u>Vol.,%</u>	<u>S(T),%</u>	<u>S(SO4),%</u>	<u>S(Py),%</u>	<u>Btu/lb</u>
	1.30	23.6	0.57	40.68	0.57	0.004	0.01	14810	23.6	0.57	40.68	0.57	0.004	0.01	14810
1.30	1.40	67.1	1.66	38.69	0.57	0.007	0.01	14436	90.7	1.38	39.21	0.57	0.006	0.01	14533
1.40	1.60	5.4	13.82	31.14	0.54	0.015	0.04	12436	96.1	2.07	38.76	0.57	0.012	0.01	14417
1.60	1.90	0.8	38.26	25.10	0.48	0.053	0.16	8413	96.9	2.37	38.65	0.57	0.013	0.01	14367
1.90		3.1	81.10	14.94	0.67	0.057	0.61	1399	100.0	4.85	37.90	0.57	0.032	0.03	13958

Table B-6. Washability of 10-Micrometer x 0 Sunnyside Washed Coal

<u>Specific Gravity</u>		<u>Direct (Dry Basis)</u>							<u>Cumulative Float (Dry Basis)</u>						
<u>Sink</u>	<u>Float</u>	<u>Wt.,%</u>	<u>Ash.,%</u>	<u>Vol.,%</u>	<u>S(T),%</u>	<u>S(SO₄),%</u>	<u>S(Py),%</u>	<u>Btu/lb</u>	<u>Wt.,%</u>	<u>Ash.,%</u>	<u>Vol.,%</u>	<u>S(T),%</u>	<u>S(SO₄),%</u>	<u>S(Py),%</u>	<u>Btu/lb</u>
	1.30	6.0	1.95	45.28	0.81	0.008	0.01	15040	6.0	1.95	45.28	0.81	0.008	0.01	15040
1.30	1.40	76.1	1.36	40.38	0.67	0.009	0.01	15276	82.1	1.40	40.74	0.68	0.009	0.01	15259
1.40	1.60	12.8	5.56	35.86	0.59	0.011	0.01	13768	94.9	1.97	40.08	0.67	0.009	0.01	15057
1.60	1.90	0.8	25.54	29.18	0.57	--	--	10361	95.7	2.15	39.99	0.67	0.009(a)	0.01(a)	15020
1.90		4.3	79.40	16.15	0.75	0.064	0.65	1763	100.0	5.50	38.96	0.67	0.012(a)	0.04(a)	14446

(a) Estimated

Table B-7. Washability of 44-Micrometer x 0 Anderson Whole-Seam Coal

<u>Specific Gravity</u>		<u>Direct (Dry Basis)</u>							<u>Cumulative Float (Dry Basis)</u>						
<u>Sink</u>	<u>Float</u>	<u>Wt.,%</u>	<u>Ash.,%</u>	<u>Vol.,%</u>	<u>S(T),%</u>	<u>S(SO₄),%</u>	<u>S(Py),%</u>	<u>Btu/lb</u>	<u>Wt.,%</u>	<u>Ash.,%</u>	<u>Vol.,%</u>	<u>S(T),%</u>	<u>S(SO₄),%</u>	<u>S(Py),%</u>	<u>Btu/lb</u>
	1.30	tr							tr						
1.30	1.40	54.9	3.79	50.43	0.50	0.017	0.01	11956	54.9	3.79	50.43	0.50	0.017	0.01	11956
1.40	1.60	41.8	4.65	44.91	0.48	0.030	0.01	11261	96.7	4.16	48.05	0.49	0.023	0.01	11656
1.60	1.90	1.6	25.92	37.61	0.85	0.265	0.33	8053	98.3	4.50	47.88	0.50	0.026	0.02	11599
1.90		1.7	77.15	17.25	4.80	0.706	3.75	1868	100.0	5.77	47.35	0.57	0.038	0.08	11430

Table B-8. Washability of Beulah-Zap 44-Micrometer x 0 Whole-Seam Coal

<u>Specific Gravity</u>		<u>Direct (Dry Basis)</u>							<u>Cumulative Float (Dry Basis)</u>						
<u>Sink</u>	<u>Float</u>	<u>Wt.,%</u>	<u>Ash,%</u>	<u>Vol,%</u>	<u>S(T),%</u>	<u>S(SO₄),%</u>	<u>S(Py),%</u>	<u>Btu/lb</u>	<u>Wt.,%</u>	<u>Ash,%</u>	<u>Vol,%</u>	<u>S(T),%</u>	<u>S(SO₄),%</u>	<u>S(Py),%</u>	<u>Btu/lb</u>
	1.30	tr							tr						
1.30	1.40	64.7	5.51	49.84	0.87	0.054	tr	10759	64.7	5.51	49.84	0.87	0.054	tr	10759
1.40	1.60	30.4	7.78	43.31	0.80	0.090	0.01	10237	95.1	6.24	47.75	0.85	0.066	0.01	10592
1.60	1.90	2.9	19.79	38.94	1.12	0.332	0.27	8349	98.0	6.64	47.49	0.86	0.073	0.01	10525
1.90		2.0	72.81	29.51	11.99	2.550	8.50	1695	100.0	7.94	47.14	1.07	0.122	0.18	10352