Report Title:

DEVELOPMENT OF AN ON-LINE COAL WASHABILITY ANALYZER

Report Type:	SEMI-ANNUAL	Reporting Period Start Date:	04/01/1998	End Date:	09/30/1998
Principal Author(s): Jan D. Miller C. L. Lin G.H. Luttrell G.T. Adel					
Report Issue Date:		03/31/1998	DOE Award No.: DE- FG22 -96PC96215 -04		

Submitting Organization(s)	University of Utah Department of Metallurgical Engineering	(1)
Name & Address	135 S 1460 E Rm 412 Salt Lake City, Utah 84112	
<hr/>		
	Virginia Polytecnic Institute and State University Department of Mining and Mineral Engineering	(2)
	100 Holden Hall, Virginia Tech Blacksburg, Virginia 24061	
<hr/>		
		(3)
<hr/>		
		(4)
<hr/>		
		(5)

Project Title

DEVELOPMENT OF AN ON-LINE COAL WASHABILITY ANALYZER

Semi-Annual Report
(04/01/1998 - 09/30/1998)

DOE award No. : DE-FG22-96PC96215

Principal Investigator:

J. D. Miller, Professor, Department of Metallurgical Engineering, University of Utah.

Co-Principal Investigators:

G. H. Luttrell, Professor, Department of Mining and Minerals Engineering, Virginia Polytechnic Institute and State University.

G. T. Adel, Professor, Department of Mining and Minerals Engineering, Virginia Polytechnic Institute and State University.

C. L. Lin, Research Associate Professor, Department of Metallurgical Engineering, University of Utah.

Barbara Marin, Geologist, Terra Tek. Salt Lake City, Utah.

David Brafford, General Manager, Northland Resources, Mingo County, Delbarton, West Virginia.

September 30, 1998

TABLE OF CONTENTS

DISCLAIMER.....	3
ABSTRACT.....	4
EXECUTIVE SUMMARY.....	5
RESULTS AND DISCUSSION (by tasks).....	5
SUMMARY STATUS ASSESSMENT AND FORECAST.....	8

DISCLAIMER

This report was prepared as an account to 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.

ABSTRACT

Washability analysis is the basis for nearly all coal preparation plant separations. Unfortunately, there are no on-line techniques for determining this most fundamental of all coal cleaning information. In light of recent successes at the University of Utah, it now appears possible to determine coal washability on-line through the use of x-ray computed tomography (CT) analysis. The successful development of such a device is critical to the establishment of process control and automated coal blending systems. In this regard, Virginia Tech, Terra Tek Inc., and several eastern coal companies have joined with the University of Utah and agreed to undertake the development of a **x-ray CT-based on-line coal washability analyzer** with financial assistance from DOE. The three-year project will cost \$594,571, of which 33% (\$194,575) will be cost-shared by the participants. The project involves development of appropriate software and extensive testing/evaluation of well-characterized coal samples from operating coal preparation plants. Each project participant brings special expertise to the project which is expected to create a new dimension in coal cleaning technology. Finally, it should be noted that the analyzer may prove to be a universal analyzer capable of providing not only washability analysis, but also particle size distribution analysis, ash analysis and perhaps pyritic sulfur analysis.

EXECUTIVE SUMMARY

The primary objective of the proposed research program is to develop a CT-based, on-line coal washability analyzer. A secondary objective will be to demonstrate the capabilities of the analyzer by comparing efficiency data from traditional float-sink tests conducted at three preparation plant sites with efficiency data generated by the washability analyzer. The scope of the proposed research program involves several tasks including (i) the acquisition and preparation of test samples for use in testing and calibrating the analyzer, (ii) the development of appropriate hardware and software necessary to adapt a CT analyzer for use in determining coal washability, (iii) the testing and modification of the analyzer using well-characterized coal samples, (iv) the evaluation of the analyzer's performance under simulated plant conditions, and (v) an evaluation of the technical and economic feasibility of implementing the CT-based washability analyzer on a commercial basis.

Researchers from the University of Utah and Terra Tek Inc. will perform tasks related to the development, calibration and testing the analyzer, while technical personnel from Virginia Tech and Cyprus Amax will provide the required coal samples, evaluate the industrial capabilities of the analyzer, and promote system commercialization.

The main effort during this reporting period involved the determination of a transformation kernel to establish the relationship between 2-D x-ray CT data sets and the 3-D washability curve. In addition, statistical analysis was initiated to establish the relations between ash content and specific gravity of coal particles. Based on this relationship, the washability curve as cumulative ash content can be determined. In addition, plant feed samples have been collected and subjected to float-sink analysis to examine variations in coal washability for a typical industrial site. Plant simulations conducted using these data show that large financial gains may be realized through the use of washability-based control system.

RESULTS AND DISCUSSION (by task)

Task 1. Project Management

Two graduate students (Ataullah Mirza-Baig and Altaf Khan) at the University of Utah were assigned to the project to coordinate the CT scanning for washability analysis, and to develop software and hardware. At Virginia Tech, two additional graduate students (David Brafford and Jaisen Kohmuench) have been assigned to work part-time on this project to acquire coal samples, perform characterization tests and collect field data used to evaluate the industrial applications of the proposed technology.

Task 4. Software Development

The response time will be significantly reduced if a large CT sampling interval can still provide accurate information for coal washability analysis. Base on early studies, it is

expected that the 3-dimensional information can be estimated from sectioned 2-dimensional data with a suitable transformation kernel. In this regard, the second approach involves the development of transformation kernel and algorithms for coal washability information based on non-continuous 2-D images in order to reduce the total response time. In contrast to the approach for the 3-D mass density analysis mentioned previously, algorithms such as the polygonal approximation and the classification of concavities based on polygons are implemented to enhance the robustness of the algorithm for the separation of particles in contact.

The transformation kernel provides the link between 2-D x-ray CT data and 3-D reality (washability curve). Experimental determination of this transformation kernel was performed during this reporting period. The complete transformation kernel can be constructed from a family of curves, each curve representing monosize coal particles with a narrow range of specific gravity. A family of such curves for areal analysis is presented in Figure 1 for coal particle size of $\frac{1}{2}$ " x $\frac{1}{4}$ ".

Task 6. Testing/Modification

The experimental test program is in progress to evaluate the CT scanner using coal samples under carefully-controlled laboratory conditions. The test program is subdivided into four separate series of tests, single size/single gravity, single size/multiple gravity, multiple size/single gravity, and multiple size/multiple gravity.

Figure 2 shows the resulting images at different processing steps for the separation of the coal bed particles in contact for samples with single density/multiple size and multiple density/single size using the 2-D mass density analysis algorithm.

Most of the washability curve constructed by x-ray CT was based on the weight of each density fraction only. However, the washability curves can be constructed based on the ash content of each density fraction. In this regard, statistical analysis between ash content and specific gravity for the x-ray CT 2-D data set was initiated. Figure 3 shows the sectional scans of tests for the $\frac{1}{2}$ x $\frac{1}{4}$ inch sample with 8 different densities as indicated on the top of each image. Histograms of specific gravity distribution of 2-D x-ray CT images of coal particle beds with narrow density are shown in Figure 4. It should be noted that four sectional planes were used for these analyses. Very consistent distributions were observed, which means that ash content of coal particles can be established using the values of specific gravity obtained from x-ray CT analysis. Characteristics of the washability based on ash content of the particle population will be determined once the detailed relationship between ash content and specific gravity is established.

Task 7. Plant Sampling for System Evaluation

The feed to a coal preparation plant may be subject to significant variations in terms of size, quality and mineralogical association. Factors responsible for these variations include fluctuations in seam characteristics, modifications in mining practices and changes in the mix

of coal entering the plant from multiple sections and/or mines. These disturbances make it difficult for plant operations to maintain a consistent coal quality and to maximize clean coal production. In order to examine the extent of these variations, samples were collected from the feed stream to an industrial coal preparation plant and subjected to washability (float-sink) analyses. The plant samples were taken daily and then combined to prepare a composite feed sample at the end of each four-week period. This procedure was continued for a period of about 13 months. Each sample was sized at 6.35 mm (1/4 inch) and 1 mm (16 mesh). Due to the large amounts of material involved, a two-point float-sink procedure was used for each size fraction. This allowed three specific gravity fractions (i.e., float 1.35, 1.35 x 1.65 and sink 1.65) to be produced for each of the two coarser size fractions (i.e., plus 6.35 mm and 6.35 x 1 mm). Since the proposed CT unit is currently not capable of analyzing the minus 1 mm fraction, this size class was not evaluated as part of this study. A summary of the statistical analyses of the washability data is provided in Tables 1 and 2.

Figure 5 shows the mass yield and ash content obtained for the plus 6.35 mm size fraction. As shown, the percentage of low-ash float 1.35 SG material in the composite feed samples varied substantially from a maximum of 41.4% to a minimum of 26.2% during the sampling campaign. Likewise, the percentage of high-ash 1.65 SG sink material in the composite samples mirrored the data for the float 1.35 SG fraction. The large variations in washability were surprising since each sample was prepared as a composite of approximately 20-25 individual daily samples taken over each four-week sampling period. As a result, the variations in washability for the individual samples are expected to exceed these average variations. Statistical analyses suggest that standard deviations for the individual daily samples would be in the order of 28.8%, 9.1% and 37.0% for the float 1.35, 1.35 x 1.65 and sink 1.65 SG classes, respectively. It is also interesting to note that the variations in the washability of the 6.35 x 1 mm size fraction were less prominent (Figure 6). The standard deviations for these daily samples were estimated to be 14.9%, 4.0% and 12.5% for the float 1.35, 1.35 x 1.65 and sink 1.65 SG classes, respectively. The smaller variability may be attributed to the improved liberation of the finer material.

In order to evaluate the potential benefits of the proposed analyzer, a series of plant simulations were performed for the processing of the plus 6.35 mm and 6.25 x 1 mm size fractions. A combined plant feed rate of 750 tph was assumed for these two sizes and a clean coal ash content of 5% was targeted. The simulations were performed using “poor” and “good” plant feeds determined from statistical analyses of the plant data. A regression routine developed as part of this project was used to expand the washability data into classes between 1.2 SG and 2.2 SG in increments of 0.10 SG units. As expected, the simulation data showed that it was impossible to maintain a constant product ash content as the plant feed varied between good and poor washabilities. Therefore, simulations were performed to evaluate the effectiveness of a control system that employs a traditional on-line ash analyzer to maintain a constant product ash in all circuits. This control strategy allowed 309.8 tph of blended clean coal to be produced at 5% ash (see Table 3). Simulation runs were also performed to determine the performance that may be achieved using a washability analyzer for plant control. In this case, 314.4 tph of clean coal were produced at 5% ash (see Table 4). The net difference between the “ash-based” and “washability-based” control schemes is about 4.6 tph

of additional clean coal. For a metallurgical coal sold at \$36.50/ton, this represents in excess of \$1 million in revenues annually (i.e., Revenue = 4.6 ton/hr x \$36.50/ton x 6000 hrs/yr = \$1,007,400/yr). Therefore, a large financial incentive exists for the development of the proposed washability-based control system.

SUMMARY STATUS ASSESSMENT AND FORECAST

1. Transformation kernel for the link between 2-D x-ray CT image data and 3-D reality (washability curve) were established to facilitate the separation and classification the density distribution of the coal particle bed.
2. The algorithm for the 2-D mass density distribution analysis has been implemented. Test results for multiple size/single density and single size/multiple density samples show that the algorithm works in a promising way.
3. Excellent progress has been made on the project and it is expected that the cycle time for the CT scanner and the amount of sample required to achieve a given level of accuracy can be established.
4. Characteristics of the washability based on ash content of the particle population has been initiated. Preliminary results indicate that the ash content of coal particles can be estimated once the relationship between ash content and specific gravity is established.
5. Field data have been collected to evaluate the variability in washability that may be expected for a typical feed to a coal preparation plant. These data show that large variations in washability do occur and suggest that large financial benefits may be derived through the application of a washability-based control system.

Table 1 - Statistical analysis of preparation plant feed data (plus 6.35 mm).

Statistical Parameter	Mass (%)			Ash (%)			Particle	Feed
	Flt 1.35	1.35x1.65	Sink 1.60	Flt 1.35	1.35x1.65	Sink 1.60	Size (%)	Ash (%)
Sample Data:								
Maximum	41.43	10.48	69.71	4.63	26.88	89.77	53.34	62.39
Minimum	26.23	3.64	48.09	3.15	17.76	77.72	21.85	41.68
Range	15.20	6.84	21.62	1.48	9.12	12.05	31.49	20.71
Average	33.66	6.30	60.04	3.60	21.94	82.49	37.43	52.31
Median	33.39	6.07	60.11	3.49	21.98	81.04	37.96	51.11
Variance	37.67	3.79	62.09	0.18	4.79	13.14	87.52	55.08
Std. Deviation	6.14	1.95	7.88	0.42	2.19	3.63	9.36	7.42
Polulation Data:								
Average	33.66	6.30	60.04	3.60	21.94	82.49	37.43	52.31
Variance	828.80	83.41	1366.01	3.97	105.30	289.10	1925.37	1211.82
Std. Deviation	28.79	9.13	36.96	1.99	10.26	17.00	43.88	34.81
95% C. Interval	15.65	4.96	20.09	1.08	5.58	9.24	23.85	18.92
Lower Value	18.01	1.34	39.95	2.52	16.36	73.24	13.58	33.39
Upper Value	49.31	11.27	80.13	4.68	27.51	91.73	61.28	71.23
90% C. Interval	13.13	4.17	16.86	0.91	4.68	7.76	20.02	15.88
Lower Value	20.53	2.14	43.18	2.69	17.25	74.73	17.41	36.43
Upper Value	46.79	10.47	76.90	4.51	26.62	90.24	57.45	68.19
80% C. Interval	10.23	3.25	13.14	0.71	3.65	6.04	15.60	12.37
Lower Value	23.43	3.06	46.90	2.89	18.29	76.44	21.84	39.94
Upper Value	43.89	9.55	73.18	4.31	25.58	88.53	53.03	64.68

Table 2 - Statistical analysis of preparation plant feed data (6.35 x 1.00 mm).

Statistical Parameter	Mass (%)			Ash (%)			Particle	Feed
	Flt 1.35	1.35x1.65	Sink 1.60	Flt 1.35	1.35x1.65	Sink 1.60	Size (%)	Ash (%)
Sample Data:								
Maximum	71.86	7.34	32.78	3.46	22.31	83.46	48.43	29.46
Minimum	60.19	4.89	23.25	2.53	16.99	77.79	30.57	21.48
Range	11.67	2.45	9.53	0.93	5.32	5.67	17.86	7.98
Average	63.83	6.29	29.88	2.88	18.82	80.65	39.67	27.12
Median	63.02	6.52	30.94	2.80	18.59	80.93	36.83	28.18
Variance	10.06	0.72	7.15	0.08	2.14	2.63	30.44	5.45
Std. Deviation	3.17	0.85	2.67	0.28	1.46	1.62	5.52	2.33
Polulation Data:								
Average	63.83	6.29	29.88	2.88	18.82	80.65	39.67	27.12
Variance	221.34	15.88	157.19	1.75	47.01	57.96	669.66	119.90
Std. Deviation	14.88	3.99	12.54	1.32	6.86	7.61	25.88	10.95
95% C. Interval	8.09	2.17	6.82	0.72	3.73	4.14	14.07	5.95
Lower Value	55.75	4.12	23.06	2.16	15.10	76.51	25.60	21.17
Upper Value	71.92	8.46	36.69	3.60	22.55	84.79	53.74	33.07
90% C. Interval	6.79	1.82	5.72	0.60	3.13	3.47	11.81	5.00
Lower Value	57.05	4.47	24.16	2.28	15.70	77.18	27.87	22.12
Upper Value	70.62	8.11	35.60	3.48	21.95	84.12	51.48	32.11
80% C. Interval	5.29	1.42	4.46	0.47	2.44	2.71	9.20	3.89
Lower Value	58.55	4.87	25.42	2.41	16.39	77.94	30.47	23.23
Upper Value	69.12	7.71	34.33	3.35	21.26	83.36	48.87	31.01

Table 3 – Simulation of a control system utilizing a traditional ash analyzer.

	Plus 6.25 mm		6.25 mm x 16 M		Overall Product	
Coal Feed	Clean (tph)	Ash (%)	Clean (tph)	Ash (%)	Clean (tph)	Ash (%)
Poor	75.5	5.00	197.2	5.00	272.8	5.00
Good	124.2	5.00	222.6	5.00	346.8	5.00
Blend	99.9	5.00	209.9	5.00	309.8	5.00

Table 4 – Simulation of a control system utilizing a washability analyzer.

	Plus 6.25 mm		6.25 mm x 16 M		Overall Product	
Coal Feed	Clean (tph)	Ash (%)	Clean (tph)	Ash (%)	Clean (tph)	Ash (%)
Poor	74.8	4.82	190.2	3.85	265.1	4.12
Good	137.6	6.29	226.1	5.25	363.7	5.64
Blend	106.2	5.77	208.1	4.61	314.4	5.00

Figure 1. Transformation kernel function based on areal analysis of 2-D x-ray CT images for coal particles of different specific gravity.

Figure 2. Image sequence shows the results for the separation of multiple size/single density and single size/multiple density coal bed particles in contact using the algorithm for 2-D mass density analysis.

1/2" x 1/4" Coal Particles of Different Density

Figure 3. 2-D x-ray CT scans of 1/2x1/4 inch coal particles of different density.

Figure 4. Preliminary results of statistical analysis of ash contents and specific gravity of 2-D x-ray CT images.

Figure 5. Variations in mass and ash for various SG classes (plus 6.35 mm feed).

Figure 6. Variations in mass and ash for various SG classes (6.35 x 1.0 mm feed).