DEVELOPMENT OF AN ON-LINE COAL WASHABILITY ANALYZER

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Project Title

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DISCLAIMER

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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 Cyprus-Amax Coal Company have joined with the University of Utah and agreed to undertake the development of an **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 will involve development of appropriate software and extensive testing/evaluation of well-characterized coal samples from three 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 used 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 for University of Utah was the development of the software for the size/composition classification of coal particles and preliminary results indicate that the approach can be used to separate coal particles in contact. Further, a meeting was held with Larry Owen from Terra Tek to discuss the design and construct of movable sample chamber. Effort for the subtasks assigned to VPI&SU is now underway to complete the preparation of size and density fractions of Stockton seam coal for use in the development and calibration of the CT-based washability analyzer. In addition, a field meeting was held with technical representatives from Cyprus Amax to discuss potential sites for obtaining the required coal samples and to identify promising commercial applications of the on-line washability analyzer.

RESULTS AND DISCUSSION (by task)

Task 1. Project Management

subtask 1.1 - Project Planning

All activities associated with project planning were successfully completed during the past reporting period. These activities included minor revisions to the project work plan and the preparation of miscellaneous project management reports. At the request of DOE, final revisions were also made to the environmental questionnaires prepared by each of the project participants. These revisions were necessary to clarify uncertainties related to (i) the amounts of waste materials generated by the various project participants during the proposed research program and (ii) the contact persons and landfill locations for waste disposal for each organization. After addressing these concerns, the revised questionnaires were prepared and

submitted to DOE for approval. NEPA approval for the proposed work was received shortly after the submission of the revised environmental questionnaires.

The subcontract with Virginia Polytechnic Institute and State University (VPI&SU) was successfully negotiated and awarded during late 1996. The *Project Authorization Notice* (PAN) authorizing work to begin at VPI&SU was received in the Department of Mining and Minerals Engineering on January 2, 1997.

Subtask 1.2 - Project Management

At present, the proposed work effort is running slightly behind schedule due to administrative delays related to the award of the subcontract. Despite these delays, a variety of activities associated with the project management were undertaken during the past reporting period. Sufficient manpower has been allocated to bring the project back on schedule. Key personnel currently assigned to the project include:

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At the beginning of the summer semester, two graduate research assistant (one each for University of Utah and VPI&SU) will also be assigned to the project to coordinate the plant sampling campaigns, washability tests, software and hardware development and circuit

efficiency studies. The student at the VPI&SU will be expected to spend a significant amount of time in the field at the location selected for the plant efficiency tests.

Task 2. Sample Preparation

Subtask 2.1 - Sample Acquisition

This subtask involves the acquisition of a run-of-mine coal sample to be used in the development, calibration and initial testing of the proposed CT-based washability analyzer. The site selected for the preliminary sampling campaign was the Lady Dunn preparation plant. This newly renovated and recently expanded facility is located in Cannelton, West Virginia, just south of Charleston. The plant is owned and operated by Cyprus Amax Coal Company. The plant is capable of a maximum throughput capacity of approximately 1400 tph. The primary feed coal to the plant is the Stockton seam, although feed coal from the No. 5 Block seam is processed on an as-needed basis. Cyprus Amax has agreed to provide the required coal samples as part of their cost-sharing commitment. A contingency request has also been made should additional coal samples be deemed necessary.

Subtask 2.2 - Gravity/Size Partitioning

The development of the CT-based washability analyzer requires well-characterized test samples for use in calibration and preliminary testing. These samples are presently being prepared by personnel at VPI&SU in cooperation with a commercial coal testing laboratory located in Beckley, West Virginia. The samples will be shipped to the University of Utah when the float-sink tests on the various size fractions are completed. Each of the size and density fractions generated by this procedure will be subjected to coal analysis for the determinations of moisture, volatile matter, ash, fixed carbon and total sulfur content. For review, preliminary washability data for the coal sample from the Stockton seam are provided in Appendix A. Although this subtask is presently running behind schedule, additional manpower has been assigned to bring this effort back on track.

Task 3. Plant Sampling

Subtask 3.1 - Sample Collection

In this subtask, samples of feed coal, clean coal and refuse will be collected from one or more preparation plants (or circuits) over an extended period of 12-18 months. These samples will be used to evaluate the prototype CT washability analyzer under simulated on-line conditions. In addition, coal samples obtained from these sampling campaigns will be subjected to single- and multiple-point float-sink tests so that the circuit organic efficiencies may be calculated. This data will be used to determine the most promising industrial application for the washability analyzer.

During the past month, a site meeting was held at the Lady Dunn preparation plant with technical representatives from Cyprus Amax. This meeting was used to discuss potential

applications of the analyzer and to finalize the selection of the test site for sample collection. Preliminary calculations suggest that the most promising (profitable) near-term application of the analyzer would be for coal blending and yield optimization. Additional calculations are presently being performed to fully evaluate the various applications discussed at this preliminary meeting.

Task 3 Hardware Development

The objective of Task 3 is to setup an appropriate CT system for on-line coal washability analysis. The Philips Tomoscan 60/TX CT scanner located at Terra Tek Inc. will be used for this study. The design and construction of a movable sample chamber was discussed during this reporting period and will be assembled when the coal samples is received from the VPI&SU.

Task 4. Software Development

The x-ray computed tomography equipment being used in this study produces images that are two dimensional slices of the coal particle bed. These slices can be pieced together (stacked) and a three-dimensional data set generated with the assignment of intensity values to small voxels (volume elements) of the object. To illustrate the nature of a packed bed of irregularly shaped coal particles, surface rendering of the three dimensional images obtained from stacking the 2-D slices is shown in Figure 1.

To determine the size and mass density distributions, detection of surface boundaries and classification of the particle population will be critical. As shown in Figure 1, particle contact inside the sample chamber is one of the problems which must be solved for on-line coal washability analysis. The frame work for software development to analyze the packed 3-D coal particles has been prepared during this reporting period. The major data processing steps and the corresponding algorithms for mass-density distribution (coal washability curve) are given in Figure 2. The algorithms include phase segmentation for data reduction, surface extraction (watershed algorithm) to separate contacting particles, labeling for particle classification, and volumetric grade classification for the 3-D CT data set.

Initial results indicate that this approach can be used to separate the particles in contact, as shown in Figure 3. Two consecutive original x-ray CT images (numbers 6 and 7) are shown in the left hand side of Figure 3. The separated particle images are shown in the right hand side of Figure 3.

SUMMARY STATUS ASSESSMENT AND FORECAST

1. A meeting was held with Larry Owen from Terra Tek to discuss the design and construct of movable sample chamber.
2. Effort for the subtasks assigned to VPI&SU is now underway to complete the preparation of size and density fractions of Stockton seam coal for use in the

development and calibration of the CT-based washability analyzer. In addition, a field meeting was held with technical representatives from Cyprus Amax to discuss potential sites for obtaining the required coal samples and to identify promising commercial applications of the on-line washability analyzer.

3. Software has been developed to isolate particles of a 3-D packed bed of coal particles as established from x-ray CT data.

Figure 1. Surface rendering of the three-dimensional image of a packed bed of irregularly shaped coal particles.

Figure 2. Major steps for the determination of the mass-density distribution of a particle population from 3-D image data collected by stacking 2-D slices generated by x-ray computed tomography.

Original Images

After 3-D Watershed Segmentation

Figure 3. Preliminary results for 3-D analysis of packed bed coal particles.

Appendix I
Float-Sink Data
Stockton Coal Seam

Table I-1. Particle size distribution for the Stockton coal sample.

Particle Size		Individual Basis			Cumulative Basis		
Passing	Retain	Mass (%)	Ash (%)	Unit	Mass(%)	unit	Ash(%)
	2"	9.47	46.11	436.7	9.47	436.7	46.11
2"	1"	17.21	34.01	585.3	26.68	1022.0	38.30
1"	1/2"	21.10	31.45	663.6	47.78	1685.6	35.28
1/2"	3/8"	8.80	30.78	270.9	56.58	1956.4	34.58
3/8"	1/4"	8.92	32.45	289.5	65.50	2245.9	34.29
1/4"	14 M	20.89	31.19	651.6	86.39	2897.4	33.54
14 M	28 M	3.83	29.84	114.3	90.22	3011.7	33.38
28 M	60 M	3.08	27.67	85.2	93.30	3097.0	33.19
60 M	100 M	1.15	26.95	31.0	94.45	3127.9	33.12
100 M	325 M	1.51	25.02	37.8	95.96	3165.7	32.99
325 M		4.04	48.57	196.2	100.0	3362.0	33.62
		100.00					

Table I-2. Float-sink analyses for the Stockton coal sample (plus 2 inch).

Specific Gravity		Individual Basis			Cumulative Basis		
Sink	Float	Mass (%)	Ash (%)	Unit	Mass(%)	unit	Ash(%)
	1.30	14.81	3.63	53.8	14.81	53.8	3.63
1.30	1.40	11.71	9.58	112.2	26.52	165.9	6.26
1.40	1.50	12.23	20.71	253.3	38.75	419.2	10.82
1.50	1.60	4.14	27.24	112.8	42.89	532.0	12.40
1.60	1.70	3.27	35.17	115.0	46.16	647.0	14.02
1.70	1.80	3.58	43.08	154.2	49.74	801.2	16.11
1.80	1.90	3.35	51.83	173.6	53.09	974.9	18.36
1.90	2.00	4.44	57.50	255.3	57.53	1230.2	21.38
2.00	2.10	1.13	62.10	70.2	58.66	1330.3	22.17
2.10		41.34	80.10	3311.3	100.0	4611.7	46.12
		100.00					

Table I-3. Float-sink analyses for the Stockton coal sample (2 x 1 inch).

Specific Gravity		Individual Basis			Cumulative Basis		
Sink	Float	Mass (%)	Ash (%)	Unit	Mass(%)	unit	Ash(%)
	1.30	17.81	2.89	51.5	17.81	51.5	2.89
1.30	1.40	19.51	10.73	209.3	37.32	260.8	6.99
1.40	1.50	19.61	21.55	422.6	56.93	683.4	12.00
1.50	1.60	7.77	28.32	220.0	64.70	903.5	13.96
1.60	1.70	2.55	37.71	96.2	67.25	999.6	14.86
1.70	1.80	3.47	43.90	152.3	70.72	1151.9	16.29
1.80	1.90	2.70	51.53	139.1	73.42	1291.1	17.58
1.90	2.00	2.25	56.16	126.4	75.67	1417.4	18.73
2.00	2.10	2.93	62.71	183.7	78.60	1601.2	20.37
2.10		21.40	84.11	1800.0	100.0	3401.1	34.01
		100.00					

Table I-4. Float-sink analyses for the Stockton coal sample (1 x 1/2 inch).

Specific Gravity		Individual Basis			Cumulative Basis		
Sink	Float	Mass (%)	Ash (%)	Unit	Mass(%)	unit	Ash(%)
	1.30	22.72	3.14	71.3	22.72	71.3	3.14
1.30	1.40	20.01	10.10	202.1	42.73	273.4	6.40
1.40	1.50	18.85	23.16	436.6	61.58	710.0	11.53
1.50	1.60	8.19	29.06	238.0	69.77	948.0	13.59
1.60	1.70	3.04	38.29	116.4	72.18	1064.4	14.62
1.70	1.80	2.43	47.36	115.1	75.24	1179.5	15.68
1.80	1.90	2.07	52.61	108.9	77.31	1288.4	16.67
1.90	2.00	1.65	59.87	98.8	78.96	1387.2	17.57
2.00	2.10	2.79	63.43	179.8	81.75	1566.9	19.17
2.10		18.25	86.48	1578.3	100.0	3145.2	31.45
		100.00					

Table I-5. Float-sink analyses for the Stockton coal sample (1/2 x 3/8 inch).

Specific Gravity		Individual Basis			Cumulative Basis		
Sink	Float	Mass (%)	Ash (%)	Unit	Mass(%)	unit	Ash(%)
	1.30	21.30	3.24	69.0	21.30	69.0	3.24
1.30	1.40	20.01	10.87	217.5	41.31	286.5	6.94
1.40	1.50	18.90	21.87	413.3	60.21	699.9	11.62
1.50	1.60	10.74	29.77	319.7	70.95	1019.6	14.37
1.60	1.70	3.36	39.64	133.2	74.31	1152.8	15.51
1.70	1.80	2.58	46.73	120.6	76.89	1273.3	16.56
1.80	1.90	2.14	54.97	117.6	79.03	1391.0	17.60
1.90	2.00	1.79	60.62	108.5	80.82	1499.5	18.55
2.00	2.10	3.24	65.91	213.5	84.06	1713.0	20.38
2.10		15.94	85.67	1365.6	100.0	3078.6	30.79
		100.00					

Table I-6. Float-sink analyses for the Stockton coal sample (3/8 x 1/4 inch).

Specific Gravity		Individual Basis			Cumulative Basis		
Sink	Float	Mass (%)	Ash (%)	Unit	Mass(%)	unit	Ash(%)
	1.30	21.95	2.84	62.3	21.95	62.3	2.84
1.30	1.40	24.14	10.39	250.8	46.09	313.2	6.79
1.40	1.50	13.35	23.10	308.4	59.44	621.5	10.46
1.50	1.60	9.14	30.92	282.6	68.58	904.1	13.18
1.60	1.70	2.77	39.31	108.9	71.35	1013.0	14.20
1.70	1.80	2.21	49.12	108.6	73.56	1121.6	15.25
1.80	1.90	1.73	54.48	94.3	75.29	1215.8	16.15
1.90	2.00	1.27	58.58	74.4	76.56	1290.2	16.85
2.00	2.10	2.41	65.39	157.6	78.97	1447.8	18.33
2.10		21.03	85.39	1795.8	100.0	3243.6	32.44
		100.00					