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**COAL SURFACE CONTROL FOR ADVANCED
PHYSICAL FINE COAL CLEANING TECHNOLOGIES**

QUARTERLY REPORT

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SUMMARY

During this reporting period, research efforts were focused on Task 7. The progress achieved in this task is summarized in the following:

New drums of the three base coals were opened and sampled. The analyses of the pulverized coal samples show that the sulfate sulfur was higher for the new drums than for the first drums opened in 1988. This finding indicates that the coal in the drums was oxidized during storage.

Wet grinding with 7/32" ceramic balls was carried out using pulverized samples of the three base coals. Grinding times ranging from 5 to 60 min were used. The particle size, pyrite size and association were determined for the samples. Illinois # 6 coal samples ground for 5, 20 and 60 min were subjected to agglomeration tests. The experimental results indicated that under the same operating conditions better performance could be obtained for the samples ground for shorter time.

FeCl_3 was utilized as pyrite depressant in agglomeration tests conducted using Pittsburgh # 8 coal. No improvements in the agglomeration performance were observed. Lime (CaO) was also used as pyrite depressant and an optimum dosage was determined (6.6 lb/ton). LAMMA analyses of Pittsburgh # 8 coal product from the agglomeration tests performed at the optimum lime dosage showed lower Fe, Si, and S concentrations on the surface of the particles than those obtained with the product from tests in which no additives were used.

The structure of Pittsburgh # 8 coal agglomerates was examined as a function of the n-heptane to coal ratio. The study showed that the agglomerates became stronger and well formed as the n-heptane to coal ratio was increased.

ESCA analyses of feed, product, and refuse from agglomeration tests showed that for Upper Freeport and Pittsburgh # 8 coals, the surface concentration of O, Si, S, and Fe followed the trend: Refuse > Feed > Product and the surface concentration of C followed the opposite trend. For Illinois # 6 coal, however, the surface concentrations of Si and S were higher in both the product and refuse than in the feed. These results suggested slime coating of the coal particles during the agglomeration process using Illinois # 6 coal.

1.0 INTRODUCTION

This quarterly report covers the technical progress achieved from April 1 through June 30, 1991, on the Coal Surface Control for Advanced Physical Fine Coal Cleaning Technologies project, under PETC/DOE Contract No. DE-AC22-88PC88877.

The overall objective of the project is to develop techniques for coal surface control prior to the advanced physical fine coal cleaning process of selective agglomeration in order to achieve 90 % pyrite sulfur rejection at an energy recovery greater than 90 % based on run-of-mine coal. The surface control is meant to encompass surface modification during grinding and laboratory beneficiation testing. The project includes the following tasks:

- Task 1: Project Planning
- Task 3: Method for Analysis of Samples
- Task 4: Development of Standard Beneficiation Test
- Task 5: Grinding Studies
- Task 6: Modification of Particle Surface
- Task 7: Exploratory R&D and Support

The coal samples to be used in this project include three base coals, Upper Freeport - Indiana County, PA, Pittsburgh # 8 - Belmont County, OH, and Illinois # 6 - Randolph County, IL, and three additional coals, Upper Freeport - Grant County, WV, Kentucky # 9 - Hopkins County, KY, and Wyodak - Campbell County, WY.

The project work plan (Task 1) was submitted to the DOE and was approved on 12/5/1988. Tasks 3 and 4 were completed, and the analytical methods established and tested for the characterization of coal samples and the experimental procedures developed for the agglomeration tests were reported in the first Annual Report⁽¹⁾. Tasks 5 and 6 were completed in 1989 and the results and conclusions of grinding and surface modification studies using the three base coals were also reported in the first and second Annual Reports^(1,2).

During this quarter the research effort was concentrated on Task 7, Exploratory Research & Development and Support. The main goal of Task 7 is to explore new and promising avenues leading to effective surface control for selective agglomeration processes and to provide support services to the DOE's Engineering Development Program. In order to achieve this goal, the specific objectives of Task 7 are:

1. To improve and optimize the coal surface control techniques developed in Tasks 4, 5, and 6 and found to achieve high energy recovery and pyritic sulfur rejection.
2. To explore and develop new and promising avenues leading to effective coal surface control for selective agglomeration processes.
3. To provide support services to the DOE/PETC and other DOE contractors.

The research work conducted in order to attain these objectives is presented in the following:

2.0 ANALYSES OF NEW COAL DRUMS

New drums of Upper Freeport, Pittsburgh # 8, and Illinois # 6 coals were opened and sampled. The drums were opened in the environmental chamber under argon atmosphere and delumped to obtain a size consist of 1/2" x 0. The delumped samples were split into 15-20 lb fractions and stored in sealed bags. The delumped samples were pulverized to 14 mesh x 0 under argon atmosphere and the pulverized coal is to be used for agglomeration studies.

Pulverized coal samples were analyzed to determine their ash and total, sulfate, pyritic, and organic sulfur contents. The total sulfur was measured using the LECO-132 sulfur analyzer. Sulfate sulfur was leached using a hydrochloric acid (HCl) solution according to the ASTM standard method D2492⁽³⁾. The sulfur content (corresponding to pyritic + organic sulfur) of the solid samples was measured using the LECO-132 analyzer. The iron and sulfur contents of the leachates were analyzed using Inductively Coupled Plasma (ICP) at the Pittsburgh Applied Research Corporation (PARC). The inorganic sulfur (sulfate + pyritic) was leached using a nitric acid (HNO₃) solution according to ASTM standard method D2492⁽³⁾. The sulfur content of the coal samples after leaching, corresponding to the organic sulfur, was determined using the LECO-132 analyzer. The iron and sulfur contents of the leachates were determined using ICP. The ash content of all samples was measured according to the ASTM standard method D3174⁽⁴⁾.

The results of the sulfur analyses are summarized in Tables 2.0-1, 2.0-2, and 2.0-3 for Upper Freeport, Pittsburgh # 8, and Illinois # 6 coals, respectively. Table 2.0-4 lists the sulfate and pyritic sulfur contents obtained using ICP.

Figures 2.0-1 and 2.0-2 compare the sulfate and pyritic sulfur contents obtained using the LECO-132 analyzer and ICP. The error bars indicate the 95 % confidence intervals for the LECO-132 measurements (only one analysis of the filtrate was performed and thus no error bars were calculated for the ICP data). The main source of the variation in the data is the inconsistency of the pyrite content of the samples. This may be due to the fact that pyritic sulfur is not uniformly distributed in the coal matrix, and the presence or absence of a few pyrite particles can greatly alter the sulfur content of the sample.

The data depicted in Figure 2.0-1 show a very good agreement between the sulfate sulfur results obtained with both techniques. The pyritic sulfur data show that for Upper Freeport and Pittsburgh # 8 coals, the ICP results fell within the 95 % confidence level of the values determined using the LECO-132 analyzer. For Illinois # 6 coal, the pyritic sulfur contents obtained using ICP were slightly lower than those measured using the LECO-132 analyzer. These differences are probably due to changes in the weight of the solid samples during the leaching steps.

Table 2.0-5 compares the total and sulfate sulfur of the new drums with the values obtained for the first drums sampled in October 1988 (Task 3) and reported in the first Annual Report⁽¹⁾. For the three coals, the sulfate sulfur content in the new drums are significantly higher than in the first drums. The large increase in sulfate sulfur content suggests that the coals in the new drums are oxidized.

The results of the ash analyses for the new drums are listed in Table 2.0-6. The data agree well with those determined for the first drums: 12.4, 11.4, and 17.2 % for Upper Freeport, Pittsburgh # 8, and Illinois # 6 coals, respectively.

3.0 WET GRINDING USING CERAMIC BALLS

Pulverized (14 mesh x 0) samples of the three base coals were wet ground using 7/32" ceramic balls as grinding medium. Samples of 0.25 kg of pulverized coal were ground in the stirred-ball mill with 1 kg of water and 3.5 kg of ceramic balls. Grinding times ranging from 5 to 60 minutes were employed. The Microtrac was utilized to determine the particle size distributions shown in Figures 3.0-1 through 3.0-3. As expected, the particle size decreased as grinding time increased.

3.1 Pyrite Size and Association

Particle size distribution and pyrite size and association were determined for pulverized and wet ground coal samples. The results of these analyses are listed in Tables 3.1-1 through 3.1-13 and summarized in Figures 3.1-1 through 3.1-3.

The data show that for the three base coals, 5 min grinding time greatly increases the amount of free pyrite and decreases the amount of locked pyrite. For longer grinding times, however, the free and locked pyrite fractions do not follow a clear trend. For instance, for Pittsburgh # 8 and Illinois # 6 coals, 20 min grinding time resulted in an increase in the amount of locked pyrite when compared with the sample ground for 5 min. A similar anomalous effect was observed for the samples of Upper Freeport coal ground for 10 and 30 min. This finding can only be explained as an artifact of the analysis, such as poor dispersion of the fine coal particles during the sample preparation. This problem is being corrected for further studies.

3.2 Effect of Grinding Time on the Agglomeration Performance for Illinois # 6 Coal

The effect of grinding time on the agglomeration performance was studied using Illinois # 6 coal. Samples wet ground for 5, 20, and 60 min in the stirred-ball mill with 7/32" ceramic balls as grinding medium were subjected to the standardized agglomeration procedure using a n-heptane to coal ratio of 1.0, a mixing speed of 9000 rpm, and an agglomeration time of 60 seconds. The particle size distributions of the feed, product, and refuse listed in Table 3.2-1 and shown in Figure 3.2-1 were determined using Microtrac. The average diameters

(d_{50} by volume) are listed in Table 3.2-2. These data indicate that for the sample ground for 5 min there was a reduction of about 7 microns in the average particle size of the refuse sample. This could be the result of retaining some large particles (> 125 microns) on the 115-mesh screen used to separate the product from refuse in the agglomeration process. For the samples ground for 20 and 60 min, no significant differences among feed, product, and refuse particle size distributions were observed.

The results of the agglomeration tests are listed in Table 3.2-3 and summarized in Figure 3.2-2. These data show that the yield and the quality of the product (in terms of its ash, sulfur, and inorganic sulfur contents) were greater for shorter grinding time. This resulted in increasing energy recovery, and decreasing ash and inorganic sulfur rejections (the improvement in product quality is not enough to offset the increase in yield) for longer grinding times. The decrease in energy recovery for smaller particle sizes is probably due to insufficient agglomeration time and/or n-heptane to coal ratio. There is evidence that for small particles the agglomeration rates are lower and therefore they require longer agglomeration times and higher agglomerant dosages to achieve the same performance as large particles. Furthermore, oxidation may occur as the coal is ground for a longer period of time, decreasing the hydrophobicity of the sample and thus reducing its potential for agglomeration.

4.0 USE OF PYRITE DEPRESSANTS

During the last quarter, lime (CaO) was used as pyrite depressant in agglomeration tests carried out with Pittsburgh # 8 coal. These experiments showed that an optimum pyritic sulfur rejection could be found for a lime dosage of about 6.6 lb/ton. During this quarter LAMMA analyses of the product samples obtained using lime were carried out. Also, a new pyrite depressant, FeCl_3 , was tested using Pittsburgh # 8 coal.

4.1 LAMMA Analysis of Samples Treated with Lime

LAMMA analyses were conducted on Pittsburgh # 8 coal product obtained from agglomeration tests carried out using lime as pyrite depressant. Table 4.1-1 shows that a lime dosage of 6.6 lb/ton resulted in a significant improvement in pyritic sulfur rejection without detrimental effects on energy recovery. The results of the LAMMA analyses, shown in Table 4.1-2, indicate that the surface elemental concentration of iron, sulfur and silicon were lower in the samples obtained in the presence of lime. The trend for these elements agrees with the bulk analyses of the total sulfur, pyritic sulfur, and ash contents of the products. The surface concentration of calcium, on the other hand, was higher in the coal sample obtained using lime as pyrite depressant which was expected.

4.2 Agglomeration Tests Using FeCl_3 as Pyrite Depressant

Agglomeration tests using FeCl_3 as pyrite depressant were carried out with Pittsburgh # 8 coal. The experiments were conducted using a slurry concentration of 4 % by weight, a mixing speed of 9000 rpm, a n-heptane to coal ratio of 0.5, and an agglomeration time of 60 seconds. Table 4.2-1 shows the agglomeration data for FeCl_3 dosages of 0, 3, and 5 lb/ton. As can be seen, no significant effects on the agglomeration performance are obtained as a result of FeCl_3 addition. Further research may be conducted at different depressant concentrations.

5.0 STUDY OF AGGLOMERATES STRUCTURE

The study of the morphology of agglomerates obtained from tests conducted using n-heptane as agglomerant was continued by using the two techniques for sample preparation described in the last Quarterly Report⁽⁵⁾.

In the first method (quick-freeze method), a sample of coal agglomerates (product) was removed from the screen during agglomeration experiments and dropped into liquid nitrogen. The agglomerates were freeze-dried in order to remove the water without changing their texture. The sample was then examined using a Scanning Electron Microscope (SEM) in the secondary electron imaging mode (SEI) and backscattered electron imaging mode (BSE).

In the second method (dispersion method), the agglomerates were placed in water and dispersed by gentle shaking. Usually the agglomerates float on the surface of the water and, when sufficiently diluted, a sample was picked up on a SEM stub and left to air-dry at room temperature before observation in the SEM.

5.1 Structure of Pittsburgh # 8 Coal Agglomerates

Pittsburgh # 8 coal agglomerates obtained from agglomeration tests carried out using a n-heptane to coal ratio of 0.5 and an agglomeration time of 60 seconds were examined using the quick-freeze and the dispersion method. Figures 5.1-1 and 5.1-2 show agglomerates dispersed in water. They are not well shaped and their size is not as consistent as those of Upper Freeport coal (shown in the last Quarterly Report). They are generally composed (see Figure 5.1-1) of microagglomerates of 100 to 200 μm in size clustered together. The microagglomerates are rougher in surface texture than those of Upper Freeport coal. They tend to break up during drying leading to the formation of a coarse "skin" which cracks and spalls. This is illustrated by the agglomerate shown in Figure 5.1-2 which appears made of several microagglomerates including a larger one about 500 μm in diameter. The increased cracking during drying suggests that the Pittsburgh # 8 coal agglomerates contain more water than those of Upper Freeport coal.

Freeze-dried agglomerates of Pittsburgh # 8 coal are shown in Figures 5.1-3 and 5.1-4 for the same area. The SEI micrograph in Figure 5.1-3 has more relief than the BSE

micrograph. However, the former has more apparent defects due to charging. The texture of the agglomerates shown in Figure 5.1-3 is tight with large voids that probably contained water (ice). Compared with Upper Freeport coal agglomerates, the identity of these microagglomerates is not as clear. They form a fairly continuous mass (see Figures 5.1-3 and 5.1-4), with less cracks than for Upper Freeport coal. These findings are consistent with the observed flexible structure for Pittsburgh # 8 coal agglomerates.

5.2 Effect of Operating Conditions on Agglomerate Structure

The evolution of the morphology of agglomerates was studied for Pittsburgh # 8 coal using the dispersion method for different agglomeration times and n-heptane dosages. The influence of the n-heptane to coal ratio was clearly demonstrated from the characteristics of the agglomerates generated for n-heptane to coal ratios (HCR) of 0.05, 0.1, 0.2, and 0.5, all prepared using an agglomeration time of 60 seconds. Micrographs of these agglomerates are shown in Figures 5.2-1 through 5.2-4. For a HCR of 0.05, loose, weak microagglomerates have started to form (see Figure 5.2-1); many are larger than 100 μm . At the intermediate HCR of 0.1 and 0.2 (Figures 5.2-2 and 5.2-3, respectively), the microagglomerates are fairly well formed with a size of the order of 100 μm and a little larger. These agglomerates tend to form a skin on drying which tends to spall apparently under the drying stresses. A n-heptane to coal ratio of 0.5 results in well formed microagglomerates of about 100 μm in size which tend to join into larger units (see Figure 5.2-4).

The effect of agglomeration time on the agglomerate structure was also studied at a HCR equal to 0.5. For 15 s of agglomeration time, microagglomerates similar to those produced at 60 s of agglomeration time and HCR of 0.05 were obtained. The morphology of agglomerates formed at 120 s of agglomeration time was similar to that produced at 60 s of agglomeration time but these agglomerates tend to be slightly larger and the individual microagglomerates are less clearly distinguishable.

6.0 ESCA ANALYSIS OF AGGLOMERATION TESTS SAMPLES

ESCA analyses of feed, product, and refuse samples from previous agglomeration tests performed using n-pentane as agglomerant were conducted. The results of the analyses for Upper Freeport, Pittsburgh # 8, and Illinois # 6 coals are listed in Table 6.0-1 and plotted in Figures 6.0-1 and 6.0-2.

Figure 6.0-1 shows that there is a strong correlation among the percent atomic abundances for carbon, oxygen, and silicon. The data indicate that an increase in surface carbon concentration always occurs together with decreases in the surface concentration of oxygen and silicon. For Upper Freeport and Pittsburgh # 8 coals, it can also be observed that the product exhibits higher carbon and lower oxygen and silicon concentrations than the feed. As expected, the refuse exhibits the opposite trend.

The changes in surface concentration were more pronounced for Upper Freeport coal. This finding agreed with the results of the agglomeration tests in which the differences between the product and refuse compositions were larger because of the higher yields obtained for Upper Freeport coal, as compared to Pittsburgh # 8 coal.

For Illinois # 6 coal, however, the surface concentration data showed an increase in oxygen and silicon together with a decrease in carbon for both the product and refuse when compared with the feed. The changes in surface concentration were larger for the refuse, as expected, since its mineral matter content was higher. The changes in surface oxygen concentration for the product suggested that this sample was "oxidized". This phenomenon could also be due to slime coating of the coal particles which in turn may explain the relatively poor performance generally obtained with Illinois # 6 coal.

The surface concentrations of iron and sulfur, shown in Figure 6.0-2, follow similar trends as those observed for the silicon and oxygen. The percent atomic abundances for these two elements are in most cases smaller than 1 % (the exception is iron for Upper Freeport coal refuse which reaches 1.13 % atomic abundance).

7.0 EFFECT OF AGGLOMERATION TIME ON SURFACE COMPOSITION

ESCA and LAMMA analyses of Illinois # 6 coal samples obtained from previous agglomeration tests conducted using agglomeration times of 60 and 360 seconds were carried out. The agglomeration tests were performed using a slurry concentration of 4 % by weight, a n-pentane to coal ratio of 0.5, and a mixing speed of 14000 rpm. The agglomeration data for these experiments were reported in the 1990 Annual Report⁽²⁾ and are also included here in Table 7.0-1.

Table 7.0-2 and Figures 7.0-1 and 7.0-2 show the results of the ESCA analyses for the feed, product, and refuse samples. These data illustrate the differences between the bulk and surface compositions of coal samples. While the surface concentration of oxygen follows the expected trends, that is, higher for the refuse and lower for the product, the surface concentration of the other elements analyzed do not always agree with the bulk values.

The main discrepancies between bulk and surface concentrations were observed for sulfur. For both samples the surface sulfur concentration is higher in the product than in the feed. This finding (also reported in Section 6.0) suggests that slime coating may have occurred during the agglomeration process.

The LAMMA results for product samples of Illinois # 6 coal are shown in Table 7.0-3. These data indicate that the surface concentrations of Al and K were lower whereas those of Si and Fe were higher for the sample agglomerated for 360 s. The surface concentration of sulfur, on the other hand, was not affected by the agglomeration time.

8.0 CONCLUSIONS

A summary of the important conclusions obtained in this reporting period is presented in the following:

- The sulfur forms analyses of the three base coals samples from drums recently opened indicate that the coals are oxidized. This resulted in a significant increase in sulfate sulfur.
- The agglomeration tests results obtained using Illinois # 6 coal wet ground using 7/32" ceramic balls for 5, 20, and 60 min showed that for the same operating conditions, the agglomeration performance, in terms of product quality and yield, decreases for longer grinding time.
- SEM analysis of Pittsburgh # 8 coal agglomerates showed that the microagglomerates were not as tight and well shaped as those formed with Upper Freeport coal. It was also found that the Pittsburgh # 8 coal became stronger and better formed as the n-heptane to coal ratio increased. For a n-heptane to coal ratio of 0.5, the agglomerates were composed of clustered 100 μm microagglomerates.
- ESCA analysis of Illinois # 6 coal samples obtained from agglomeration tests showed that the surface concentrations of Si and S were higher for both the product and refuse samples than for the feed. This finding suggested the occurrence slime coating during the agglomeration of this coal, resulting in low energy recoveries.

9.0 WORK SCHEDULE AND PLAN

The work schedule is shown in Table 9.0-1. The darkened bars indicate the completed portions of each task, and the empty bars refer to the scheduled future work. In the coming quarter, the research work on Task 7 will be continued focusing on the following research subtasks:

1. Analysis of trace elements
2. Use of pyrite depressants
3. Study of fine wet grinding

10.0 REFERENCES

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4. Standard Test Method for ASH IN THE ANALYSIS SAMPLE OF COAL AND COKE FROM COAL, Designation D3174-82, *1986 Annual Book of ASTM Standards*, Section 5, Volume 05.05, Gaseous Fuels; Coal and Coke, pp. 406-9.
5. Morsi, et. al., *Coal Surface Control for Advanced Physical Fine Coal Cleaning Technologies*, Quarterly Report, DOE Contract No. DE-AC22-88PC88877, January 1, 1991 - March 31, 1991.

APPENDIX A: TABLES

Table 2.0-1 LECO Sulfur Analyses for Upper Freeport Coal

	Total Sulfur	Organic + Pyritic Sulfur	Organic Sulfur
	%	%	%
	2.31	1.93	0.63
	2.24	1.75	0.64
	2.39	1.80	0.67
	2.36	1.62	
AVERAGE	2.33	1.78	0.65
STD. DEV.	0.07	0.13	0.02
95% CONFIDENCE ± INTERVAL	0.10	0.20	0.05

	Calculated Value	95 % Confidence ± Interval
Sulfate Sulfur, %	0.55	0.20
Pyritic Sulfur, %	1.13	0.21

Table 2.0-2 LECO Sulfur Analyses for Pittsburgh # 8 Coal

	Total Sulfur	Organic + Pyritic Sulfur	Organic Sulfur
	%	%	%
	4.01	3.60	1.49
	4.53	3.99	1.32
	4.30	3.65	1.43
	4.22	3.78	1.46
	4.46		
	4.24		
	4.17		
AVERAGE	4.28	3.76	1.43
STD. DEV.	0.18	0.17	0.07
95% CONFIDENCE ± INTERVAL	0.16	0.28	0.12

	Calculated Value	95 % Confidence ± Interval
Sulfate Sulfur, %	0.52	0.27
Pyritic Sulfur, %	2.33	0.26

Table 2.0-3 LECO Sulfur Analyses for Illinois # 6 Coal

	Total Sulfur	Organic + Pyritic Sulfur	Organic Sulfur
	%	%	%
	5.11	4.85	1.80
	5.77	5.14	1.79
	5.56	4.48	1.75
	5.40	4.38	1.78
	5.76	4.21	
	5.17	4.37	
AVERAGE	5.46	4.57	1.78
STD. DEV.	0.29	0.35	0.02
95% CONFIDENCE ± INTERVAL	0.30	0.37	0.03

	Calculated Value	95 % Confidence ± Interval
Sulfate Sulfur, %	0.89	0.41
Pyritic Sulfur, %	2.79	0.37

Table 2.0-4 ICP Analysis Results

	Coal		
	Upper Freeport	Pittsburgh # 8	Illinois # 6
Sulfate Sulfur Content, %	0.53	0.52	0.80
Pyritic Sulfur Content, %			
From Fe	1.24	2.09	2.08
From S	1.33	2.12	2.31

**Table 2.0-5 Comparison Between the Total and Sulfate Sulfur Analyses
for the First and New Drums of the Three Base Coals**

	%	COAL		
Sulfur Form	DRUM	Upper Freeport	Pittsburgh # 8	Illinois # 6
TOTAL	1988	2.36	4.27	4.77
	1991	2.33	4.28	5.46
SULFATE	1988	0.02	0.12	0.11
	1991	0.53	0.52	0.80

Table 2.0-6 Ash Analysis Results

	Coal		
	Upper Freeport	Pittsburgh # 8	Illinois # 6
	12.71	10.92	17.02
	11.79	12.18	15.75
	11.18	10.55	16.88
	12.91	11.36	17.51
	12.16	11.28	16.27
	12.52	11.14	18.23
	12.05	10.82	17.21
	12.01	10.49	15.59
	12.17	11.71	17.27
	11.77	12.02	15.97
AVERAGE	12.13	11.25	16.77
STD. DEV.	0.50	0.58	0.85
95% CONFIDENCE ± INTERVAL	0.36	0.42	0.61

**Table 3.0-1 Particle Size Distribution for Upper Freeport
Coal Wet Ground Using 7/32" Ceramic Balls**

Particle Diameter, μm	Volume Percent Passing					
	Grinding Time, min					
	5	10	20	30	40	60
125	100.0					
88	98.7					
62	97.8	100.0				
44	91.4	98.2				
31	77.6	90.8				
22	68.0	87.0	100.0	100.0	100.0	100.0
16	52.9	74.6	93.2	95.0	95.9	99.4
11	37.6	58.6	79.2	84.0	86.8	94.8
7.8	27.4	46.1	66.6	72.2	76.3	89.7
5.5	17.2	30.8	48.2	52.4	57.5	74.6
3.9	10.0	19.0	31.0	33.5	38.0	55.8
2.8	7.0	14.0	22.0	24.0	26.8	44.0
1.9	3.4	7.4	11.6	12.8	14.2	25.8
1.4	1.0	2.8	4.4	4.8	5.4	11.2

**Table 3.0-2 Particle Size Distribution for Pittsburgh # 8
Coal Wet Ground Using 7/32" Ceramic Balls**

Particle Diameter, μm	Volume Percent Passing				
	Grinding Time, min				
	5	10	20	40	60
88	100.0				
62	88.9	100.0			
44	78.9	94.8	100.0		
31	61.6	82.5	92.5		
22	51.0	72.6	87.6	100.0	100.0
16	38.8	58.0	75.0	94.2	96.0
11	26.2	41.9	56.5	81.6	90.1
7.8	18.3	29.2	42.2	65.8	79.2
5.5	10.9	17.7	26.0	45.1	57.8
3.9	5.6	10.6	13.6	28.0	36.5
2.8	4.2	6.5	8.8	17.8	24.8
1.9	1.9	2.9	4.0	8.6	12.7
1.4	0.6	0.8	1.1	2.8	4.6

**Table 3.0-3 Particle Size Distribution for Illinois # 6 Coal
Wet Ground Using 7/32" Ceramic Balls**

Particle Diameter, μm	Volume Percent Passing				
	Grinding Time, min				
	5	10	20	40	60
125	100.0				
88	93.4		100.0		
62	85.3	100.0	98.6	100.0	
44	70.3	93.4	95.7	99.0	
31	52.0	77.1	87.5	94.9	
22	41.0	64.2	81.7	93.1	100.0
16	28.4	47.3	64.9	83.7	91.5
11	16.6	30.6	44.4	71.6	78.0
7.8	10.5	19.9	32.1	53.0	66.5
5.5	5.8	13.5	17.9	34.2	48.9
3.9	1.7	6.8	8.6	22.1	30.7
2.8	1.1	1.6	7.5	13.5	22.0
1.9	0.2	0.2	4.0	6.3	11.6
1.4	0.0	0.0	1.5	2.0	4.4

**Table 3.0-4 Mean Particle Size (d_{50}) for the Three Base Coals
Wet Ground Using 7/32" Ceramic Balls**

Grinding Time, min	Upper Freeport	Pittsburgh # 8	Illinois # 6
5	15.1	21.5	29.4
10	8.8	13.5	17.0
20	5.7	9.5	12.4
30	5.3	N. A.	N. A.
40	4.9	6.0	7.4
60	3.4	4.9	5.6

N. A. = Not Available

**Table 3.1-1 Pyrite Size and Association for
Pulverized Upper Freeport Coal**

Pyrite Size, micron	Accumulated Volume Percent			Total Accumulated Volume Percent
	Locked	Semi- Locked	Free	
1	0.18	0.03	0.04	0.25
2	0.34	0.18	0.13	0.65
3	0.52	0.38	0.26	1.16
4	0.83	0.67	0.30	1.80
5	1.00	0.88	0.42	2.30
6	1.21	1.01	0.48	2.70
7	1.52	1.14	0.66	3.32
8	1.70	1.48	0.75	3.93
9	2.16	1.57	0.89	4.62
10	2.57	1.87	1.11	5.55
11	2.69	1.98	1.18	5.85
12	3.15	2.74	1.61	7.50
13	3.47	3.18		8.26
14	3.94	3.88	2.04	9.86
15	4.79	4.49	2.50	11.78
16		4.84		12.13
17			3.21	12.84
18	5.55	5.33	3.53	14.41
19	5.82	5.84		15.19
20			4.51	16.17
21		6.34		16.67
22		6.46		16.79
23		7.97		18.30
24		10.53		20.86
25	8.96		4.70	24.19
26		11.71		25.37
27	10.50	14.35		29.55
29	10.97			30.02
30			6.69	32.01
33	11.65			32.69
35		19.71		38.05
36	16.79			43.19
40	18.78	29.65		55.12
65	25.23			61.57
125		39.73		71.65
210	53.58			100.00

**Table 3.1-2 Pyrite Size and Association for Upper Freeport Coal
Wet Ground for 5 min Using 7/32" Ceramic Balls**

Pyrite Size, micron	Accumulated Volume Percent			Total Accumulated Volume Percent
	Locked	Semi- Locked	Free	
1	0.80	2.78	1.61	5.19
2	1.63	6.29	3.88	11.80
3	1.92	9.35	5.98	17.25
4	2.31	12.61	8.70	23.62
5	3.22	13.82	11.83	28.87
6		15.81	14.21	33.24
7	5.06	19.30	17.64	42.00
8		24.39	21.00	50.45
9		27.16	22.61	54.83
10		28.83	25.65	59.54
11		31.18		61.89
12		34.77	29.17	69.00
13		41.71		75.94
16			33.69	80.46
17		49.57		88.32
20			45.38	100.00

**Table 3.1-3 Pyrite Size and Association for Upper Freeport Coal
Wet Ground for 10 min Using 7/32" Ceramic Balls**

Pyrite Size, micron	Accumulated Volume Percent			Total Accumulated Volume Percent
	Locked	Semi- Locked	Free	
1	0.79	2.73	1.81	5.33
2	1.41	6.18	4.22	11.81
3	1.90	11.96	6.99	20.85
4	2.35	15.58	8.68	26.61
5		18.69	11.22	32.26
6		19.87	15.04	37.26
7		21.23	16.35	39.93
8		26.80	18.70	47.85
9		32.55	20.51	53.06
10		37.31	24.12	63.78
13		39.76		66.23
14		53.02		79.49
15			35.26	90.63
17		62.40		100.00

**Table 3.1-4 Pyrite Size and Association for Upper Freeport Coal
Wet Ground for 30 min Using 7/32" Ceramic Balls**

Pyrite Size, micron	Accumulated Volume Percent			Total Accumulated Volume Percent
	Locked	Semi- Locked	Free	
1	1.59	4.28	0.92	6.79
2	3.95	12.46	3.69	20.10
3	5.66	24.36	6.30	36.32
4	6.75	33.01	7.32	47.08
5		36.81	8.24	51.80
6		38.64		53.63
7		42.24		57.23
8		43.91	9.24	59.90
9		46.60		62.59
10		52.04	12.87	71.66
14		59.38		79.00
15			18.33	84.46
20			34.18	100.00

**Table 3.1-5 Pyrite Size and Association for Upper Freeport Coal
Wet Ground for 60 min Using 7/32" Ceramic Balls**

Pyrite Size, micron	Accumulated Volume Percent			Total Accumulated Volume Percent
	Locked	Semi- Locked	Free	
1	3.50	4.43	0.79	8.72
2	6.55	15.08	2.73	24.36
3	8.73	24.96	4.77	38.46
4	9.50	38.25	6.20	53.95
5		42.87		58.57
6		46.25		61.95
7		52.71	7.29	69.50
8		59.48		76.27
9			11.38	80.36
20		73.68		100.00

**Table 3.1-6 Pyrite Size and Association for
Pulverized Pittsburgh # 8 Coal**

Pyrite Size, micron	Accumulated Volume Percent			Total Accumulated Volume Percent
	Locked	Semi- Locked	Free	
1	0.14	0.04	0.01	0.19
2	0.29	0.14	0.06	0.49
3	0.51	0.27	0.09	0.87
4	0.73	0.35	0.13	1.21
5	1.20	0.51	0.16	1.87
6	1.51	0.71	0.21	2.43
7	2.05	0.85	0.30	3.20
8	2.90	0.93	0.49	4.32
9	3.40	1.07		4.96
10	3.80	1.14		5.43
11	4.04	1.22		5.75
12	4.26	1.32		6.07
13	4.80	1.39		6.68
14	5.53	1.84		7.86
15	5.81	2.13		8.43
16	6.16	2.66		9.31
17	6.63			9.78
18	7.37			10.52
19	7.74			10.89
20	8.35	3.64		12.48
23	8.49			12.62
24	9.39			13.52
25		4.13		14.01
28	9.71			14.33
29	10.31			14.93
30	10.86			15.48
31	10.99			15.61
32	13.86			18.48
33	14.73			19.35
34	14.84			19.46
35	22.96			27.58
37	24.90	5.23		30.62
38		11.11		36.50
40	25.52			37.12
45	34.46		2.44	48.01
50	44.63			58.18
60		15.24		62.31
70	48.43			66.11
85	60.47			78.15
145		37.08		100.00

**Table 3.1-7 Pyrite Size and Association for Pittsburgh # 8 Coal
Wet Ground for 5 min Using 7/32" Ceramic Balls**

Pyrite Size, micron	Accumulated Volume Percent			Total Accumulated Volume Percent
	Locked	Semi- Locked	Free	
1	0.43	1.14	0.51	2.08
2	1.11	3.17	1.41	5.69
3	2.09	5.39	2.08	9.56
4	2.53	7.64	2.44	12.61
5	3.06	9.32	3.26	15.64
6	3.45	10.96	3.34	17.75
7		13.86	4.60	21.91
8	3.70	17.84	5.60	27.14
9	5.06	21.34		32.00
10		22.14		32.80
11		23.35		34.01
12		25.64	7.20	37.90
15		26.21		38.47
16	5.34			38.75
17		28.83		41.37
18	11.20			47.23
20		29.03		47.43
23		40.40		58.80
25		49.93		68.33
28		63.02		81.42
40		81.59		100.00

**Table 3.1-8 Pyrite Size and Association for Pittsburgh # 8 Coal
Wet Ground for 20 min Using 7/32" Ceramic Balls**

Pyrite Size, micron	Accumulated Volume Percent			Total Accumulated Volume Percent
	Locked	Semi- Locked	Free	
1	1.41	2.86	0.86	5.13
2	3.34	7.42	2.38	13.14
3	5.46	13.81	3.38	22.65
4	5.89	19.11	4.13	29.13
5	8.15	22.72	4.81	35.68
6		29.52		42.48
7	9.35	39.48		53.64
8		43.93	5.10	58.38
9		45.85	8.52	63.72
10		55.23		73.10
11		64.32		82.19
12		71.29		89.16
14	9.97			89.78
16	20.20			100.00

**Table 3.1-9 Pyrite Size and Association for Pittsburgh # 8 Coal
Wet Ground for 60 min Using 7/32" Ceramic Balls**

Pyrite Size, micron	Accumulated Volume Percent			Total Accumulated Volume Percent
	Locked	Semi- Locked	Free	
1	5.62	6.27	1.18	13.07
2	11.74	15.17	2.86	29.77
3	19.32	30.49	4.61	54.42
4	24.19	40.29	6.39	70.87
5	30.90	49.39	8.23	88.52
6	33.77	58.00		100.00

Table 3.1-10 Pyrite Size and Association for Pulverized Illinois # 6 Coal

Pyrite Size, micron	Accumulated Volume Percent			Total Accumulated Volume Percent
	Locked	Semi- Locked	Free	
1	0.04	0.02	0.02	0.08
2	0.13	0.12	0.12	0.37
3	0.28	0.26	0.36	0.90
4	0.54	0.50	0.93	1.97
5	0.79	0.84	1.50	3.13
6	1.04	1.13	2.00	4.17
7	1.48	1.40	2.30	5.18
8	1.89	1.79	2.72	6.40
9	2.32	2.11	3.24	7.67
10	3.09	2.50	3.70	9.29
11	3.62	2.72	4.16	10.50
12	3.99	3.00	4.18	11.17
13	4.68	3.84		12.70
14	4.71	4.17	4.39	13.27
15		4.26	4.82	13.79
16	5.09	4.38	4.99	14.46
17			5.29	14.76
18	5.76	4.65		15.70
19			5.56	15.97
20	6.25	4.98		16.79
21	6.81	5.22		17.59
22		5.54	5.90	18.25
23		6.05		18.76
24	7.13			19.08
26		7.94	6.52	21.59
30		8.81		22.46
33	8.29			23.62
37	11.00			26.33
44	12.66			27.99
100	14.96			30.29
130	25.28			40.61
140		18.99		50.79
158		45.33		77.13
180	48.15			100.00

**Table 3.1-11 Pyrite Size and Association for Illinois # 6 Coal Wet
Ground for 5 min Using 7/32" Ceramic Balls**

Pyrite Size, micron	Accumulated Volume Percent			Total Accumulated Volume Percent
	Locked	Semi- Locked	Free	
1	0.11	0.22	0.15	0.48
2	0.41	0.86	1.12	2.39
3	0.66	1.66	2.39	4.71
4	1.09	2.59	4.49	8.17
5	1.49	3.85	7.12	12.46
6	1.77	5.42	9.55	16.74
7	2.01	7.03	10.70	19.74
8	2.53	8.92	11.99	23.44
9		10.37	13.18	26.08
10		10.83	14.58	27.94
11			15.08	28.44
12		11.80	15.38	29.71
13		14.49	18.57	35.59
14		15.50	18.76	37.79
15		16.63	20.53	40.69
16		17.41	23.34	44.28
17		24.11	25.12	52.76
18		25.84	28.23	57.60
19		28.32		60.08
20		32.83	31.32	67.68
24		33.96	35.69	73.18
26		40.75		79.97
40		41.31		80.53
44		60.78		100.00

Table 3.1-12 Pyrite Size and Association for Illinois # 6 Coal Wet Ground for 20 min Using 7/32" Ceramic Balls

Pyrite Size, micron	Accumulated Volume Percent			Total Accumulated Volume Percent
	Locked	Semi-Locked	Free	
1	0.45	0.50	0.40	1.35
2	1.41	2.59	2.14	6.14
3	2.54	5.18	4.82	12.54
4	3.90	10.10	7.65	21.65
5	5.02	13.88	9.66	28.56
6	6.58	16.79	14.05	37.42
7	7.03	19.59	15.53	42.15
8	7.77	22.50	18.44	48.71
9	9.27	27.69	18.46	55.42
10		32.56	21.60	63.43
11			22.86	64.69
12	11.39	35.82	24.73	71.94
13		42.22	28.14	81.75
14		45.99		85.52
15			32.53	89.91
16		49.22		93.14
18		56.08		100.00

Table 3.1-13 Pyrite Size and Association for Illinois # 6 Coal Wet Ground for 60 min Using 7/32" Ceramic Balls

Pyrite Size, micron	Accumulated Volume Percent			Total Accumulated Volume Percent
	Locked	Semi-Locked	Free	
1	1.42	1.82	1.28	4.52
2	4.30	6.74	5.12	16.16
3	6.18	13.92	12.59	32.69
4	8.45	24.25	21.05	53.75
5	10.43	27.56	26.79	64.78
6	11.40	31.17	32.04	74.61
7	13.62	35.23	33.12	81.97
8		38.71	34.89	87.22
9		42.83	38.49	94.94
12			43.55	100.00

Table 3.2-1 Particle Size Distribution for Illinois # 6 Coal

Volume Percent Passing	Grinding Time, min								
	5			20			60		
	Feed	Product	Refuse	Feed	Product	Refuse	Feed	Product	Refuse
Particle Diameter, μm									
125	100.0	100.0	100.0		100.0				
88	93.4	92.4	94.5	100.0	99.4				
62	85.3	83.3	88.7	98.6	99.0	100.0			
44	70.3	69.8	76.9	95.7	96.8	98.1		100.0	100.0
31	52.0	51.6	59.2	87.5	86.3	87.8		97.1	98.3
22	41.0	38.8	49.4	81.7	79.9	81.8	100.0	96.4	97.1
16	28.4	27.0	34.4	64.9	63.8	63.4	91.5	88.1	89.5
11	16.6	16.9	21.1	44.4	44.6	41.6	78.0	74.1	75.7
7.8	10.5	9.9	16.6	32.1	27.6	29.1	66.5	58.6	61.2
5.5	5.8	6.4	9.3	17.9	16.0	17.7	48.9	40.0	44.6
3.9	1.7	3.1	3.4	8.6	9.9	8.8	30.7	25.2	27.2
2.8	1.1	0.0	3.4	7.5	3.7	4.9	22.0	17.2	15.8
1.9	0.2		1.8	4.0	1.0	1.8	11.6	8.7	7.2
1.4	0.0		0.6	1.5	0.0	0.3	4.4	3.1	2.2

Table 3.2-2 Average Particle Size for Illinois # 6 Coal

Grinding Time, min	Sample	d₅₀, μm
5	Feed	29.3
	Product	29.9
	Refuse	22.6
20	Feed	12.4
	Product	12.4
	Refuse	12.9
60	Feed	5.7
	Product	6.7
	Refuse	6.3

**Table 3.2-3 Agglomeration Results as a Function
of Grinding Time for Illinois # 6 Coal**

Feed Ash Content: 17.4 %

Feed Total Sulfur Content: 5.02 %

Feed Inorganic Sulfur Content: 3.23 %

	Grinding Time, min		
	5	20	60
Product Ash Content, %	9.2	10.5	13.5
Product Total Sulfur Content, %	4.26	4.79	5.11
Product Inorganic Sulfur Content, %	2.55	3.09	3.44
Refuse Ash Content, %	29.6	18.8	17.3
Yield, %	70	49	26
Ash Rejection, %	63	70	80
Total Sulfur Rejection, %	41	53	73
Inorganic Sulfur Rejection, %	45	53	72
Energy Recovery, %	78	54	28

**Table 4.1-1 Results of the Optimum Lime Addition
for Pittsburgh # 8 Coal**

Feed Ash: 12.1 %
Feed Total Sulfur: 4.01 %
Feed Pyritic Sulfur: 3.12 %

	Lime Dosage, lb/ton	
	0.0	6.6
Product Ash Content, %	4.2	4.0
Product Total Sulfur Content, %	2.31	2.11
Product Pyritic Sulfur Content, %	1.32	1.08
Yield, %	90	88
Ash Rejection, %	69	71
Total Sulfur Rejection, %	48	54
Pyritic Sulfur Rejection, %	62	70
Energy Recovery, %	99	97

Table 4.1-2 Results of LAMMA Analyses

Percent Total Ionization	Lime Dosage, lb/ton	
Element	0.0	6.6
Lithium	0.4	0.2
Sodium	7.5	6.1
Magnesium	1.8	2.4
Aluminum	43.7	44.8
Silicon	2.7	2.0
Sulfur	2.4	1.2
Potassium	21.6	20.4
Calcium	10.6	13.3
Titanium	2.9	4.1
Iron	6.4	5.5

Table 4.2-1 Use of FeCl₃ as Pyrite Depressant

Pittsburgh # 8 Coal

Feed Ash Content: 12.55 %

Feed Sulfur Content: 4.20 %

	FeCl ₃ Dosage, lb/ton		
	0	3	5
Product Ash Content, %	4.40	4.82	4.97
Product Sulfur Content, %	2.38	2.39	2.43
Yield, %	88.5	87.9	86.6
Ash Rejection, %	69.0	66.3	65.7
Sulfur Rejection, %	49.8	50.0	49.9
Energy Recovery, %	98.0	96.9	95.3

Table 6.0-1 ESCA Results for Agglomeration Tests Samples

Coal	Sample	Percent Atomic Abundance				
		C	O	Si	Fe	S
Upper Freeport	Feed	56.8	36.5	5.2	0.68	0.82
	Product	84.9	13.8	0.9	0.06	0.40
	Refuse	27.5	58.8	11.7	1.13	0.88
Pittsburgh # 8	Feed	71.0	25.3	2.6	0.35	0.75
	Product	76.4	20.8	1.8	0.29	0.63
	Refuse	69.1	26.8	3.0	0.39	0.79
Illinois # 6	Feed	77.2	19.4	2.8	0.29	0.44
	Product	66.3	29.1	3.6	0.47	0.58
	Refuse	52.8	39.4	6.6	0.56	0.57

**Table 7.0-1 Agglomeration Tests Results
for Illinois # 6 Coal**

	Agglomeration Time, s	
	60	360
Feed Ash Content, % (pulverized)	17.5	13.8
Feed Sulfur Content, % (pulverized)	5.14	3.94
Product Ash Content, %	8.9	8.9
Product Sulfur Content, %	3.08	3.21
Refuse Ash Content, %	21.7	22.0
Yield, %	59	66
Ash Rejection, %	70	57
Sulfur Rejection, %	64	46
Energy Recovery, %	67	71

**Table 7.0-2 ESCA Results for Illinois # 6 Coal
(Agglomeration Tests Samples)**

Agglomeration Time, s	Sample	Percent Atomic Abundance				
		C	O	Si	Fe	S
60	Feed	62.6	30.8	5.7	0.38	0.51
	Product	59.0	27.6	3.7	0.47	0.74
	Refuse	67.5	34.4	5.2	0.51	0.82
360	Feed	60.4	33.5	4.8	0.55	0.74
	Product	66.1	29.1	3.6	0.49	0.76
	Refuse	60.0	33.8	5.0	0.55	0.65

**Table 7.0-3 Results of LAMMA Analyses for Illinois # 6 Coal
(Agglomeration Tests Samples)**

Percent Total Ionization	Agglomeration Time, s	
Element	60	360
Lithium	0.2	0.2
Sodium	5.0	6.1
Magnesium	1.0	1.6
Aluminum	39.9	36.6
Silicon	3.3	5.2
Sulfur	2.8	2.9
Potassium	30.4	24.9
Calcium	7.1	8.9
Titanium	1.7	2.8
Iron	8.4	11.0

Table 9.0-1 Work Schedule

APPENDIX B: FIGURES

Figure 2.0-1 Comparison Between LECO and ICP Sulfate Sulfur Analyses

Figure 2.0-2 Comparison Between LECO and ICP Pyritic Sulfur Analyses

Figure 3.0-1 Particle Size Distribution for Upper Freeport Coal Wet Ground Using 7/32" Ceramic Balls

Figure 3.0-2 Particle Size Distribution for Pittsburgh # 8 Coal Wet Ground Using 7/32" Ceramic Balls

Figure 3.0-3 Particle Size Distribution for Illinois # 6 Coal
Wet Ground Using 7/32" Ceramic Balls

Figure 3.1-1 Pyrite Association for Upper Freeport Coal
Wet Ground Using 7/32" Ceramic Balls

Figure 3.1-2 Pyrite Association for Pittsburgh # 8 Coal
Wet Ground Using 7/32" Ceramic Balls

Figure 3.1-1 Pyrite Association for Illinois # 6 Coal
Wet Ground Using 7/32" Ceramic Balls

Figure 3.2-1 Particle Size Distribution of Illinois # 6 Coal Samples

Figure 3.2-2 Effect of Grinding Time on the Agglomeration Performance for Illinois # 6 Coal

└─ 100 microns

Figure 5.1-1 Microagglomerates of Pittsburgh # 8 Coal (Dispersion Method, SEI Mode). The microagglomerates are irregular and tend to agglomerate together.

— 100 microns

Figure 5.1-2 Microagglomerates of Pittsburgh # 8 Coal (Dispersion Method, SEI mode). The agglomerates tend to break up on drying with the formation of a coarse "skin".

— 100 microns

Figure 5.1-3 Freeze-dried Agglomerates of Pittsburgh # 8 Coal. The matrix is tight in texture and fairly continuous with large voids. Same area in SEI (Top) and BSE imaging (Bottom).

100 microns

Figure 5.2-1. Microagglomerates of Pittsburgh # 8 Coal (Dispersion Method) Prepared Using a N-heptane to Coal Ratio of 0.05 and an Agglomeration Time of 60 s.

100 microns

Figure 5.2-2. Microagglomerates of Pittsburgh # 8 Coal (Dispersion Method) Prepared Using a N-heptane to Coal Ratio of 0.10 and an Agglomeration Time of 60 s.

Figure 5.2-3. Microagglomerates of Pittsburgh # 8 Coal (Dispersion Method) Prepared Using a N-heptane to Coal Ratio of 0.20 and an Agglomeration Time of 60 s.

Figure 5.2-4. Microagglomerates of Pittsburgh # 8 Coal (Dispersion Method) Prepared Using a N-heptane to Coal Ratio of 0.50 and an Agglomeration Time of 60 s.

Figure 6.0-1 Carbon, Oxygen, and Silicon Surface Concentrations for Agglomeration Tests Samples (ESCA)

Figure 6.0-2 Iron and Sulfur Surface Concentrations for Agglomeration Tests Samples (ESCA)

Figure 7.0-1 Effect of Agglomeration Time on Carbon, Oxygen, and Silicon Surface Concentrations for Illinois # 6 Coal (ESCA)

Figure 7.0-2 Effect of Agglomeration Time on Iron and Sulfur Surface Concentrations for Illinois # 6 Coal (ESCA)

END

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