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The Chemical Enhancement of the Triboelectric Separation of Coal from Pyrite and Ash

A Novel Approach for Electrostatic Separation of Mineral Matter from Coal

Final Report
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Contract
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ABSTRACT

Enhancement of Triboelectric Coal Separation By Chemical Treatment

Arthur D. Little, Inc., under contract to the U.S. DOE Pittsburgh Energy Technology Center, has developed a triboelectric separation device for coal beneficiation, that employs an entrained-flow, rotating-cylinder concept. The described apparatus has been used to test the efficacy of chemical pre-treatment and in-situ treatment of coal on separation efficiency.

Coal particle entrainment is achieved with gaseous carbon dioxide and particle collection is accomplished by an electrostatic plate separator. The triboelectric separation device incorporates instrumentation for the direct measurement of charge in the dilute-phase particle stream.

Some of the pretreatment materials investigated under this project to modify the surface charging characteristics of the coal included oleic acid, sodium oleate, quinoline and dicyclohexylamine. Ammonia and sulfur dioxide at a concentration up to 1000 ppm was used for in-situ treatment of the coal, with carbon dioxide as the carrier/inerting gas. Nitrogen was used earlier in the test program as the carrier/inerting gas for the coal, but a severe arcing problem was encountered in the electrostatic collector with nitrogen as the carrier gas. This problem did not occur when carbon dioxide was used.

The report covers the chemical treatment employed, and summarizes and interprets the results achieved. In addition, an economic analysis of a full scale system based on this concept is presented.

1.0 Introduction

In this section of the report, the program objectives and approaches taken to achieve those objectives are discussed.

1.1 Background

Arthur D. Little undertook this study to determine the effects that chemical conditioning of fine coals would have on contact electrification and subsequent electrostatic separation of pyritic sulfur and ash from coal. This program was undertaken at the Arthur D. Little laboratories in Cambridge, Massachusetts.

1.2 Program Objectives

The program objectives were developed to investigate the enhancement of electrostatic separation techniques using the following techniques:

- Use of novel contact electrification techniques to produce the electric charge;
- Use of chemical conditioning to permit higher efficiency in obtaining a charge;
- Integration of the above concepts with the proposed electrostatic separation unit.

The overall objectives of this program of research was to develop and undertake a program of experimental work on the above concepts for the enhancement of electrostatic separation as a method for advanced col cleaning.

1.3 Program of Work and Approaches Taken

The program of work was divided into six tasks. Each task description is discussed below.

1.3.1 Task 1 Project Planning

The purpose of this task was to develop a final work plan for the program. This work plan was developed to be flexible within the experimental guidelines to ensure that the program objectives were addressed. The work plan was divided into a series of procedural tasks and are listed below:

- Background
- Objectives
- Selection of Test Criteria
- Design Criteria for Apparatus
- Test Procedure
- Sampling Procedure

- Analytical Procedures
- Quality Control
- Data Analysis

This work plan incorporated the objectives of the PETC Chemically Modified Coals Program.

1.3.2 Task 2 Design and Assembly of Test Unit

Literature Search and Review

A comprehensive literature search was conducted to collect information on the electrostatic separation of coal, coal ash and particle electrification by fluidization or tumbling beds. The results of the search were abstracted and were submitted as a separate report presented here as Appendix D.

Design and Specification of Test Unit

In this task, we developed a conceptual design of the laboratory based triboelectric system. Our original intention was to utilize a drum-type electrostatic separator. However, due to some early testing of the separator, and through information we developed in the literature search, it became apparent that a plate-type separator coupled with the fluid-bed would provide for better coal separation. Therefore, we modified the scope and developed this laboratory system design.

A fluidized bed of finely-ground (400 mesh) coal was maintained in a transparent fluidizing column by a flow of CO_2 gas. The bed and its associated piping was isolated from electrical grounding. The repeated friction of the particles on each other and between the rotor and fluid-bed chamber walls as they circulate through the bed lead to triboelectric charge differentials between the pyrite and non-pyrite particles. By transferring particles out of the bed via pneumatic transport, a split was made of the particles between the parallel plates within the electrostatic separator.

Suitable allowance was made in the design of the system to prevent electrical grounding of the particles within the fluidized bed and to the electrostatic separator. This was done by eliminating all metal to metal contact and metal to ground contact within the system. All structural materials were either PVC or plexiglass, with piping of either PVC or ungrounded copper. As humidity can be a factor in such systems, only dried coal and dry gases (sometimes heated in addition) were used. Provisions were made for introducing small flows of "conditioning" gases, chlorine and ammonia, to assess how they affect differential particulate charging within the system.

A four inch PVC fluid bed reactor was built for the program, as was a plate-type electrostatic separator. Our original intention was to use equipment from previous work, but we found that the proposed equipment did not meet the needs of the program.

Assembly and Checkout

The assembly was performed by engineers and technicians who are familiar with this type of equipment. After leak checks were made, the flowmeters, regulators, and the heater were checked to assure the ability to maintain proper gas flows and temperatures. Flowmeters were calibrated for different gases. These preliminary experiments were done with CO_2 and with N_2 as fluidizing gas. It was found that the N_2 was not an acceptable gas due to arcing in the separator, and CO_2 was adopted for the remainder of the program.

1.3.3 Experimental Test Program

This task was divided into the three subtasks described below.

Coal Preparation/Characterization

The three coals used in the test program are listed below:

Coal Type	As Received Condition Run of Mine	 Washed
Upper Freeport	X	X
Pittsburgh Seam	X	
Illinois No. 6	X	

A 55-gallon drum of each of the three coals was obtained from appropriate coal companies. Pittsburgh Seam (PS) coal was selected as the base coal with a large portion of the experiments conducted on Upper Freeport (UF). Illinois was also tested, but to a lesser extent. Triboelectric charging was most effective with coals containing a high percentage of dissimilar material.

Grinding/Sampling/Storages

The coarse coals were initially ground to 10-mesh top size in a sampling mill. A 15% cut was continuously withdrawn in 10 lb. lots. The 85% reject stream was reprocessed through the mill and a second 15% cut removed. This process yielded about ten, 10 lb. samples from each coal. Each 10 lb. lot was blanketed with argon and seal for storage.

When needed, the ten 10 lb. lots were ground to final size (400-mesh) in an impact mill and returned to the storage containers with replacement of inert gas. Prior to grinding the test samples, the 70% reject from the first grind was used to purge the mill of foreign material. For pre-dried coal samples, the drying step was performed prior to fluidization and separation.

Analysis

A sample from each 15% mill cut, or a total of eight (8) samples, was taken for analysis. The samples were analyzed by a local (Resources Engineering) laboratory. The analyses included:

- *Proximate/Ultimate Analysis/Heat Content:* ASTM Standard (D3172) for Proximate Composition of coal sample including moisture, ash, volatile matter, fixed carbon. ASTM Standard (D3176) for Ultimate Composition of coal sample of include carbon, hydrogen, sulfur, nitrogen, ash, oxygen, moisture on and as received and moisture free basis. Heat content of the coal sample reported at Btu/lb determined according to ASTM Standard (D3286) reported on an as received and moisture free basis.

- *Size Consist:* ASTM Standard (D311) for sieve analysis of crushed coal sample down to No. 400 U.S. standard mesh (37 microns). Below 400 mesh, an optical light scattering technique was used to determine particle sizes between 2-37 microns.

Separator Tuning Runs

The first series of runs performed was aimed at fine tuning the charged particle feed system and electrostatic separator. For these runs we began by determining the best rotor speed to effect separation. These tests were run with a grounded rotor.

Charge Optimization

The major area of emphasis in the test program was to determine the optimum conditions of fluidization to obtain effective separation of the mineral matter. Charged optimization was achieved by adjustment of the fluidization variables. The variables that were examined are summarized in the test table provided below.

Variable Range of Investigation

Type of fluidization gas: CO_2, N_2, CO_2+N_2

Gas velocity: Up to entrainment velocity

Conditioning gas: Addition of reactive gas to preferentially effect the conductivity of pyrite material; gas type to include Cl_2, NH_3, HCl; concentration range: 0 to 2000 ppm.

Liquid phase conditioning: Dicyclohexylamine, quinoline, hexane, oleic acid, sodium oleate, Cab-O-Sil.

With regard to addition of conditioning gas and liquid phase conditioning, the goal was to establish the minimum concentration that met the overall objectives of modifying conductivity and reducing charging time.

Separation Experiments

Our original intention was to determine how various chemical conditioning agents affected the coal/sulfur separation efficiency. We therefore developed a factorial matrix of experiments based on the following experimental conditions:

- conditioning gas
- relative humidity of fluidization gas
- coal moisture
- mass velocity of the coal particles within the system

- temperature
- residence time within the system.

Because of our original experiments and problems with the design performance, we were forced to change some of these conditions.

We expanded the methods of coal conditioning to include contacting the coal with liquid conditioning reagents (dicyclohexylamine, oleic acid, etc.). We abandoned the testing with oxygen and nitrogen because of the arc development within the electrostatic separator.

We found that relative humidity and coal moisture content was too difficult to control because of the lack of availability of freshly pulverized coal. Therefore, it was abandoned.

We found during our tuning experiments that maximum mass velocity and an average retention time of less than one second was enough to electrostatically charged the coal. Therefore we abandoned the residence time experiments.

Because of these situations, another experimental matrix for coal separation tests was developed. It expanded the number of chemical conditioning reagents and allowed for finer control of the experimental variables.

1.3.4 Task 4 - Data Analysis

During the experimental test runs (Task 3), a considerable amount of raw data was collected. The data from each test was manually logged during the testing and subsequently loaded into a personal computer data base for future access. The database was developed to be accessible by the spread sheet program, Lotus 1-2-3.

Mass balancing of the separator to determine recovery efficiency was an important aspect of the data analysis. The overall mass balance for the separator is shown by following relationship:

$$F = A+C+L$$

where: F = mass of feed
A = weight of ash fraction
C = weight of combustible fraction
L = weight of loss.

A and C can be obtained by weighing the collected samples. The weight of the feed was easily measured due to the batch type loading of the system. In this manner, we closed the mass balance on the separator. Losses were determined by differences.

In addition, we examined collection efficiency by considering sulfur rejection recovery. A sulfur balance on the separator is given by the following relationship:

$$F \times S_f = A \times S_a + C \times S_c + L \times S_f \text{ where:}$$

S_f = sulfur fraction of feed coal, C = weight fraction sulfur in reject coal sample, S_c =

weight fraction of sulfur in clean coal fraction.

The S_f is known from the feed coal analysis C and C_c was determined by ultimate analysis of the collected samples. A pyritic sulfur balance was performed on a similar manner.

Some of the calculated factors that were developed in the data analysis subtask included:

- total coal recovery efficiency
- total sulfur removal
- pyritic sulfur removal efficiency
- Energy recovery efficiency

Lotus 1-2-3 was used to compute the results. This permitted easy access to the graphics capability of the software package required to present the results.

1.3.5 Task 5 - Engineering Scale-up and Cost Analysis

Scale up Design

Upon completion of the bench scale test program and data analysis, a conceptual design of the system was done. The objective of this design was to establish an engineering basis so that various process parameters could be assessed to determine their impact on process performance and economics.

The conceptual design was based on retro fitting an existing installation that used preconditioned coal for fuel. We developed a series of process flowsheets representing the basic process concept and possible variation of the process. These flowsheets include all major unit operations and auxiliary equipment necessary for the operation. The system includes the following major unit operations:

- micropulverizers for coal grinding
- pulverized coal feeding system
- fluid bed triboelectric generator
- preparation and recovery system for fluidizing medium
- chemical storage and injection system
- conveying and feeding systems for changed particles
- electrostatic separation system
- conveying systems for desulfurized coal and reject material
- pollution control equipment, and
- other auxiliary systems.

In developing our conceptual process design, we prepared a set of process assumptions as the basis for evaluation of the process economics. These included base case estimates and likely ranges of major process variables such as flow rate and type of fluidizing medium, conditioning gas chemistry, charge enhancements conditions, fluidizing velocity, bed expansion ratio, charge potential, etc.

The process flowsheet and assumptions were used in performing material and energy balances which in turn established the basis for estimating the capital and operating cost requirements.

Cost Analysis

Estimates of capital and operating requirements were done to optimize the process variables, assess the overall process economics and identify those areas that could lead to important cost reduction.

In preparing the estimates of capital investment, we generated preliminary specifications of major equipment items. Capital investment estimates were of study grade accuracy in accordance with accepted engineering practice. Costs for equipment items such as compressors, vessels, storage tanks, conveyors and other solids handling equipment were obtained from cost correlations. Vendor quotations were obtained for operating items such as electrostatic separators and pulverizers. Modular factors were used to convert purchased equipment cost into total installed costs. The modular factors, specific to the type of process equipment, incorporate allowances for piping, instrumentation, commodity materials, installation labor and other associated costs. Installed equipment costs were aggregated by process area to facilitate easier comparison with other process alternatives.

Based on the information generated in the energy and materials balances, we estimated operation requirements such as chemical, utilities, as well operating and maintenance. This information along with the capital investment estimates was input into a spreadsheet program for calculating process economics and its sensitivity to key process variables. Taxes, insurances, normal capital changes were included to compute the total processing cost. We compared the calculated total processing cost against that of a conventional flotation process.

1.3.6 Task 6 - Project Management and Reporting

This task was completed based on the program reporting requirements of PETC.

2.0 Summary of Research

2.1 General

The purpose of the research carried out under this contract was to investigate the effect of chemical treatment on the charging and beneficiation of fine ground coal by triboelectric separation. The tribocharging of the coal particles was accomplished in a cylindrical chamber containing a concentric rotor. The coal was entrained through the annular space to an electrostatic plate separator by gaseous carbon dioxide. A variety of pre- and in-situ chemical treatments were tested.

2.2 Test Apparatus

A schematic of the test apparatus is shown in Figure 2-1. The apparatus was operated batch-wise; after charging the ground coal, the rotor was started and fluidizing gas supplied from cylinders. Gas flow was gradually increased to entrain the coal into the plate collector. After leaving the collector, the fluidizing gas passed through a bag filter to catch any fines not captured by the plate collector. A more detailed description of the system is provided in Chapter 3.0.

2.3 Test Program

After an initial shake-down period during which several problems were overcome, a total of 45 test runs was completed. These runs were grouped into two sets as described below.

The first experimental test period occurred between February and June 1989. During this period, 12 tests were performed with various chemical treatments and gases to optimize the system for the final test period. All the testing was performed on Pittsburgh coal. The following treatments and gases were tested:

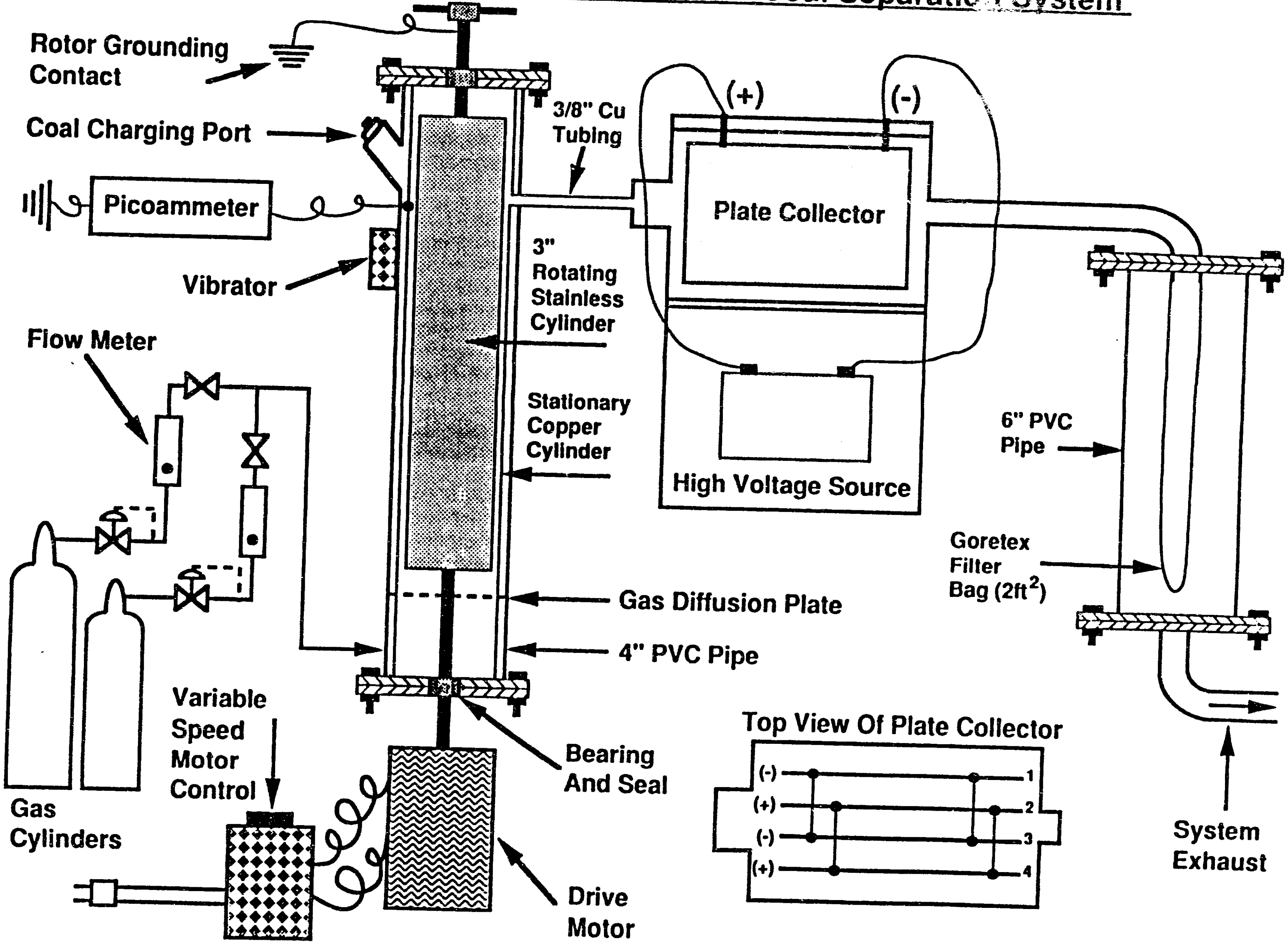
- Oleic Acid
- Quinoline
- Sodium Oleate
- Hexane
- 0.1% Dicyclohexylamine
- 0.5% Dicyclohexylamine
- 200 ppm Sulfur Dioxide
- 200 ppm Ammonia
- 1000 ppm Ammonia

The results from this set of tests determined the test matrix for the final separation runs. The results showed that dicyclohexylamine, ammonia, and possibly quinoline offered the most promise of enhancing the separation of coal and ash.

The final separation runs were conducted between October and December 1989. The test matrix included 33 tests on untreated coal and coal treated with 0.1% Dicyclohexylamine, 0.5% Dicyclohexylamine, 1000 ppm Ammonia and Quinoline. Pittsburgh seam, Upper Freeport, and Illinois #6 were all utilized for this set of runs. The test matrix was as follows:

Figure 2-1

Schematic Of A.D. Little Triboelectric Coal Separation System



COAL	TREATMENT	NUMBER OF RUNS
Pittsburgh (Fine)	None	4
Upper Freeport (Fine)	None	4
Illinois (Fine)	None	4
Pittsburgh (Fine)	0.1% Dicyclohexylamine	3
Pittsburgh (Fine)	0.5% Dicyclohexylamine	3
Pittsburgh (Fine)	1000 ppm Ammonia in CO_2	3
Upper Freeport (Fine)	0.1% Dicyclohexylamine	3
Upper Freeport (Fine)	0.5% Dicyclohexylamine	3
Upper Freeport (Fine)	1000 ppm Ammonia in CO_2	3
Pittsburgh (Fine)	Quinoline	3

2.4 Scale-up Evaluation

An economic analysis was performed to assess the capital and operating costs of a commercial scale coal cleaning system based on this triboelectric separation concept. The capacity basis for the coal cleaning unit is providing sufficient fuel for a 400MW coal fired power plant. An equipment configuration diagram of the commercial process is depicted in Figure 2-2. The scaling parameters (experimental to commercial) used for the sizing of major equipment items are summarized in Table 2-1. The results of the cost evaluation are presented below.

2.5 Results

2.5.1 Experimental

For consistency with other PETC funded developments, the performance parameters utilized to determine effectiveness are Btu recovery, clean coal recovery, and total sulfur rejection. These three parameters were compared to determine if the chemical treatments had a significant effect compared to the untreated coal. Figure 2-3 is a graph of the three parameters for the three untreated coals. Figure 2-4 shows a comparison of the chemical and gas treatments for Pittsburgh coal.

For Pittsburgh coal, each of the chemical and gas treatments produced an increase, over the untreated coal, in the Btu and clean coal fraction recoveries. However, all treatments decreased the total sulfur rejection when compared with the untreated coal results. Although each of the treatments increased the Btu and clean coal recoveries, 0.1% dicyclohexylamine was the only treatment that produced a significant improvement in the two recoveries, 11.4% and 12.8%, respectively. Each of the treatments, however, had a negative effect on the total sulfur rejection. Similar results were obtained with Upper Freeport coal.

There tends to be a correlation between the clean coal recovery and the total sulfur rejection. When the clean coal recovery is increased, the total sulfur rejection for that same run decreases. Likewise, when the total sulfur rejection is increased, the clean coal recovery decreases. This result can be explained. If the treatment increases clean coal recovery, more material (coal) is collecting on the negative plates and along with this material comes more sulfur. If the treatment increases total sulfur rejection, more material (reject) is collecting on the positive plates. This additional reject material brings with it more coal. Therefore, it appears that the chemical treatment does effect

Figure 2-2: Electrostatic Coal Cleaning System - Two Stage

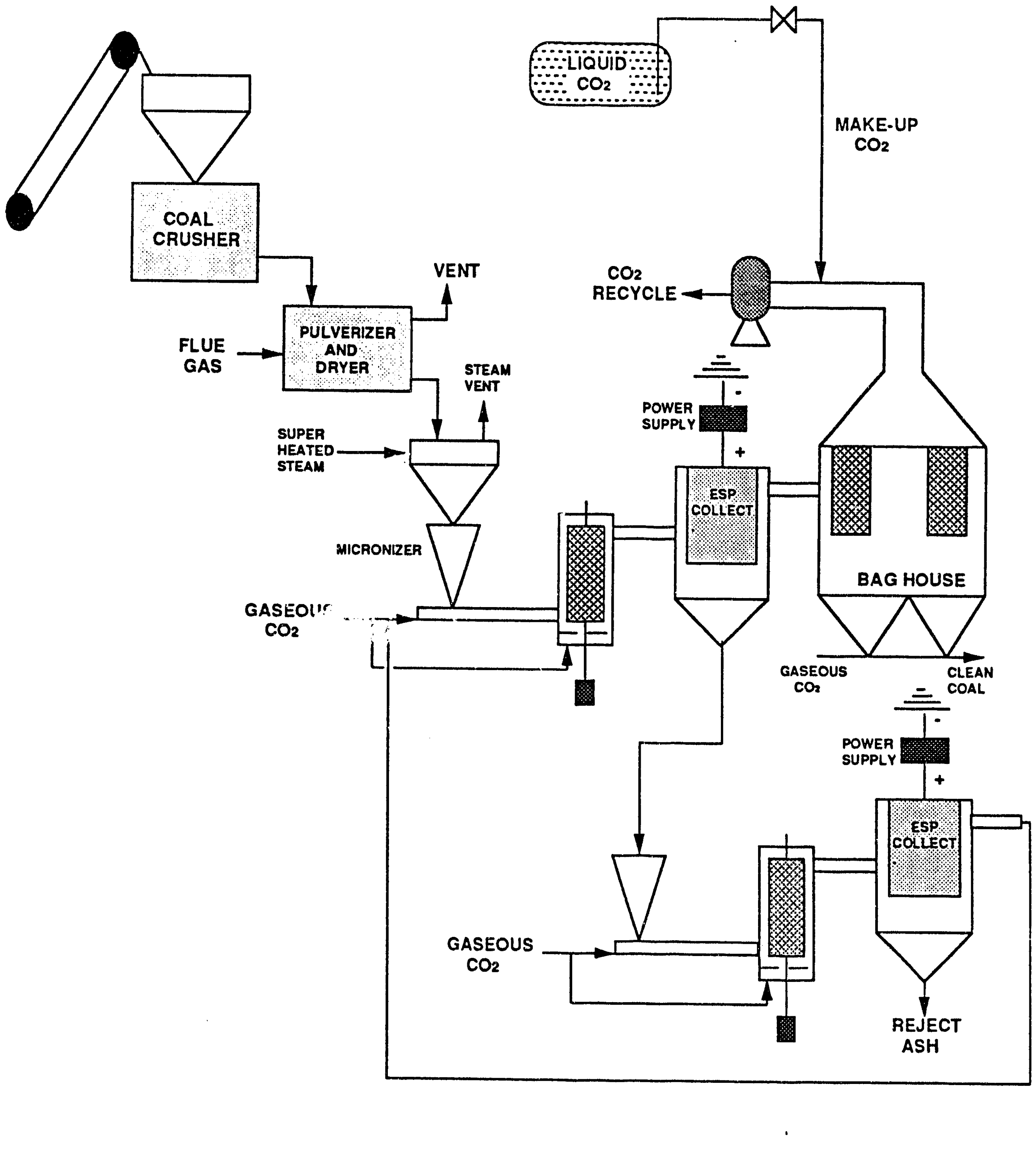


Table 2-1
Key Scaling Parameters

Triboseparator	
coal/gas load ratio	5lb coal/lb CO_2
gas velocity	25 ft/sec.
retention time	0.83 sec.
tip speed	22.6 ft/sec.
inlet temperature	> 250°F
CO_2 inlet pressure	15 psig
rotor speed	108 rpm
gap area	0.5 sq. ft^2
Baghouse	
cloth area	2 ft^3/ft^2-min
modules	4
ESP	
voltage drop	5000v/cm
plate area ratio	0.5 ft^2/ACFM
CO_2 Recycle	
CO_2 loss to combustor	4%
CO_2 loss to system	1%
Chemical Treatment	
dicyclohexylamine addition	0.1 wt %

Figure 2-3

UNTREATED COAL COMPARISON

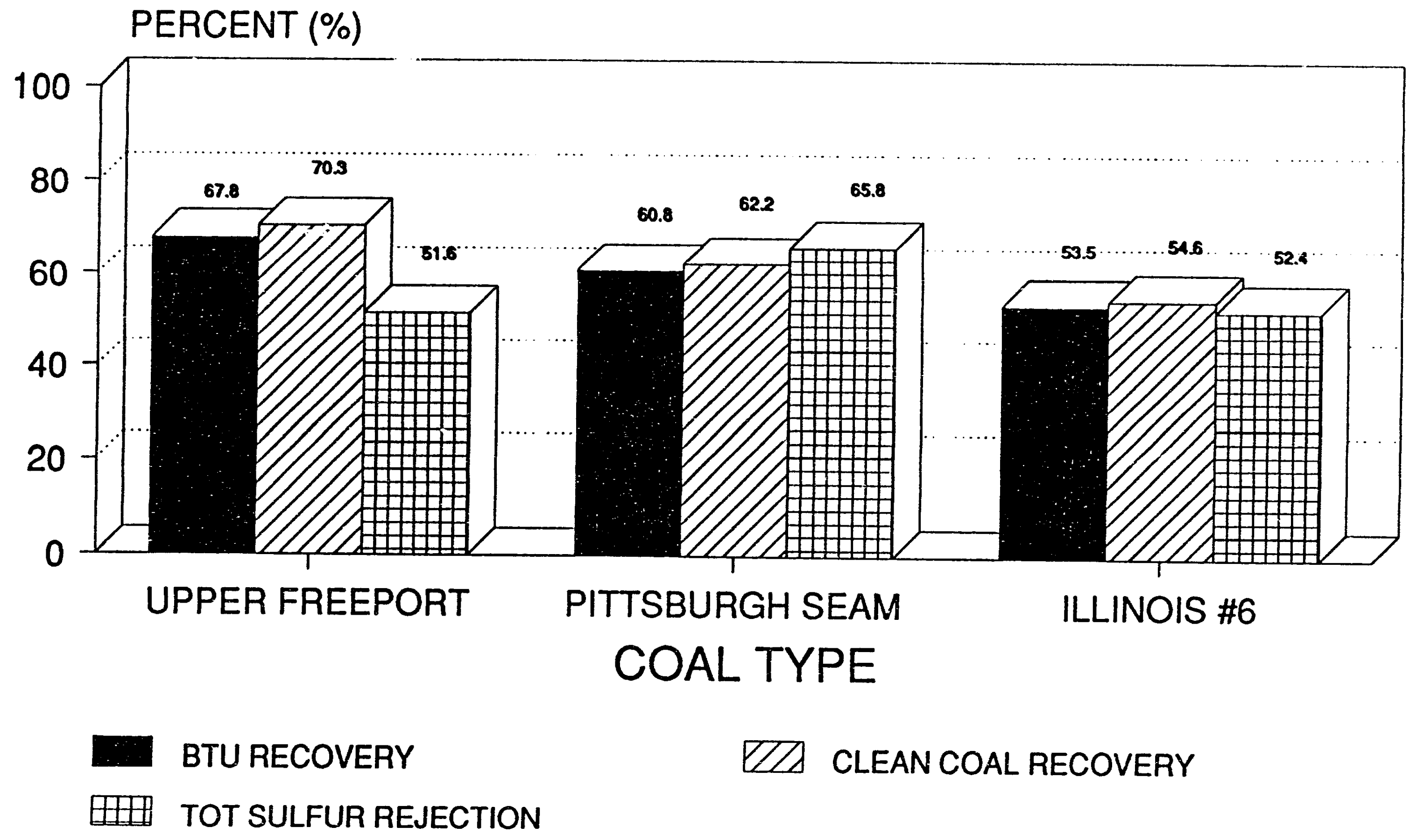
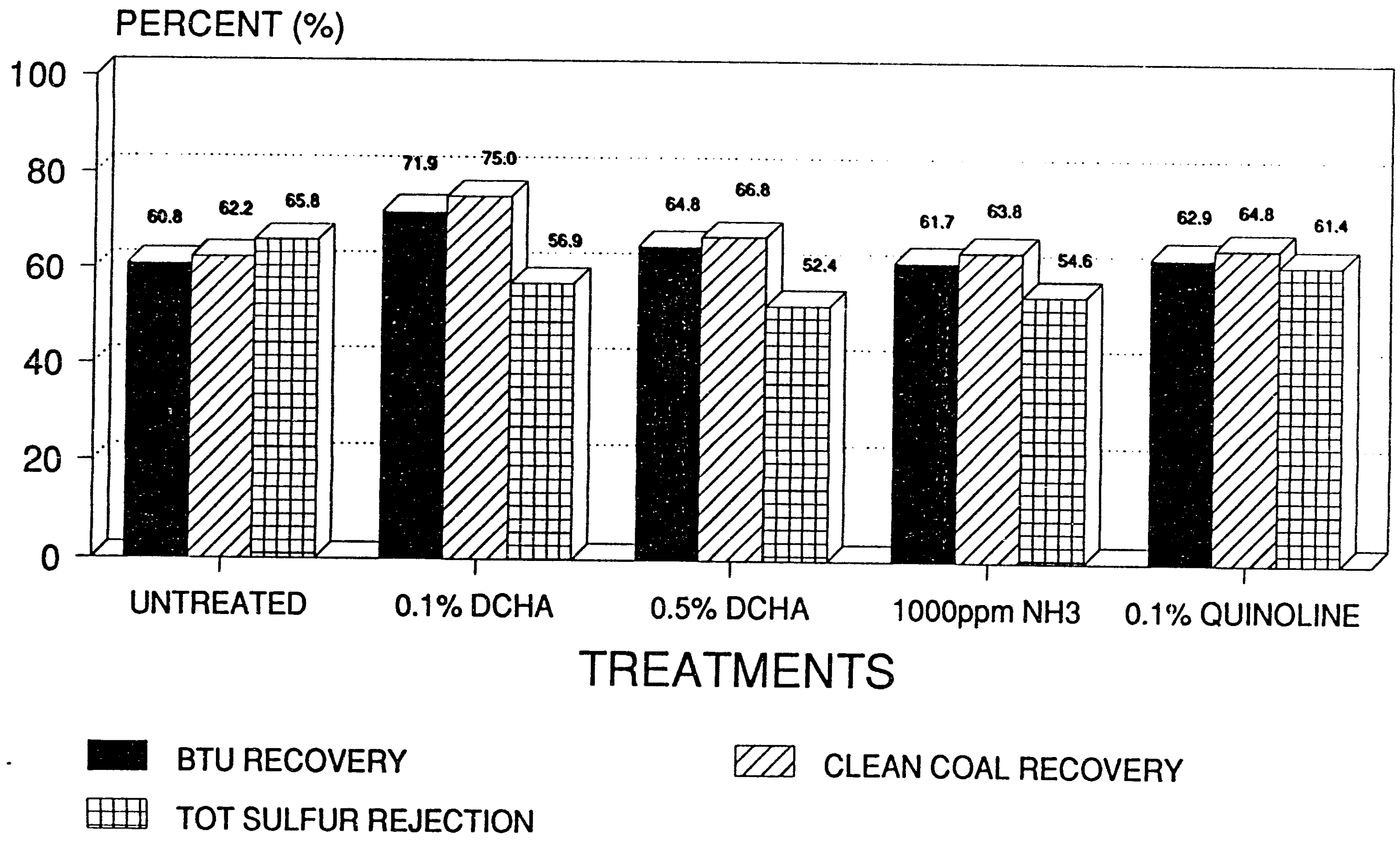


Figure 2-4

PITTSBURGH COAL TREATMENT RESULTS



the collection of particles in aggregate, but is much less effective in segregating sulfur barring particles from non-sulfur barring particles.

2.5.2 Scale-up

Capital cost estimates were developed for four process configurations including:

- Single stage separation without chemical treatment
- Single stage separation with dicyclohexylamine treatment
- Two-stage separation without chemical treatment
- Two-stage separation with dicylohexylamine treatment.

The cost estimate for a the single stage process with chemical treatment is presented in 2-2. The capital investment required for a plant of this size varies between $44,400,000 and $46,000,000. This is an investment of $111/KW and $115/KW. The lower cost is for the basic plant without chemical treatment and the higher cost for the plant with chemical treatment and a recycle stream.

Operating cost estimates for the same plant configurations were also prepared. The operating cost estimate for a two-stage system with chemical treatment is shown in Table 2-3. The incremental operating cost for the two-stage system is 0.94 cents/KWh. The operating costs range up to 1.6 cents/KWh for a single-stage system without chemical treatment.

The cost estimates were based on known chemical costs, utility costs and labor costs. Other variable and fixed costs were based on factors common to the industry such as the cost of maintenance materials, plant overhead, etc. No cost was taken for coal, but a cost penalty for the coal rejected by the process due to the high sulfur and ash was taken. The penalty was $50 per ton for the unburned coal and $15 per ton for waste disposal. Also, the reduced cost of post combustion pollution control of the flue gas and ash disposal were not taken into account.

2.6 Conclusions

Inspection of the results with untreated coals presented earlier in this section indicates that the process performance was the best with untreated Upper Freeport Coal (UFC) in three out of four key parameters. Running the process with UFC produced the highest clean coal recovery (70.3%), the highest ash rejection (79.9%) and the highest BTU recovery (67%). However, the lowest pyritic sulfur rejection was also obtained with this coal. The highest pyritic sulfur rejection sulfur rejection (73.1%) was achieved with Pittsburgh Seam Coal (PSC), however, the energy recovery was lower (60.8%). The results with Illinois No. 6 (INC) were poorer in all respects.

Reviewing the results with respect to feed ash and sulfur characteristics does not reveal any trends. All that can be said is that the coal with the highest pyritic sulfur content produced the highest percentage pyritic sulfur rejection.

A review of the results with Pittsburgh coal (Figure 2-4) indicates that the collectibility of the ash was enhanced by treatment with 0.1% dicyclohexylamine (DCHA) and 0.1%

Tons/Hr Coal	200
Hr/Yr	7884
Tons/Yr Coal	1576800

EQUIPMENT	DESCRIPTION	HP	NO UNITS	UNIT COST	FACTOR	INSTALLED COST
MICRO PULVERIZER	ABB/Raymond impact mill	8000	10	$600,000	2.59	$15,540,000
TRIBO UNIT	25 ft x 4 ft dia.	700	14	$67,000	2.60	$2,438,300
ESP	28.5 tph 2500 volt/cm.	1050	7	$320,000	2.69	$6,025,600
BAGHOUSE	10000 sq ft filter area	50	1	$206,000	2.69	$554,140
CO2 COMPRESSOR	rotary vane	375	1	$57,000	2.60	$148,200
CO2 STORAGE TANK	1,000,000 cu. ft.		10	$450,000	2.00	$9,000,000
CONVEYORS/FEEDE	various	400	10	$40,000	2.69	$1,076,000
CHEMICAL STORAGE	40000 gallon		1	$36,000	2.50	$90,000
METERING PUMP	1 hp	1	2	$2,000	2.40	$9,600
UTILITIES	water and electricity					$700,000
CONTINGENCY	20% TIC					$8,895,585
TOTALS		10575				$44,477,925
						111.19 $/KW

Table 2-2: Capital Investment Cost Estimate for Basic Plant with Chemical Treatment

Table 2-3: Operating Cost Estimate Summary with Chemical Treatment and Recycle

		units/hr		$/unit	$/hr	$/MWh	
Raw Materials	Coal	169	ton	0	0.00	0.000	
	CO2 make up	4523	lb	0.02	90.46	0.226	
	dicyclohexylamine	338	lb	1.70	574.60	1.437	
	by product waste	15	ton	15.00	225.00	0.563	
	heating value loss equivalent	15	ton	50.00	750.00	1.875	
	total raw materials				1640.06	4.100	
Utilities	Electricity	8075	kwh	0.055	444.15	1.110	
	Cooling Water	3000	gal	0.005	15.00	0.038	
	total utilities				459.15	1.148	
Other Variable	Maintenance mat. 3% of TIC				175.00	0.437	
	Operating supplies, 10% OL				5.40	0.014	
	total other variable				180.40	0.451	
Semi-Variable	Operating Labor	3	mh	18.00	54.00	0.135	
	Maintenance Labor	2	mh	18.00	36.00	0.090	
	Supervisors	0.5	mh	23.00	11.50	0.029	
	total semi-variable				101.50	0.254	
VARIABLE AND SEMI-VARIABLE COSTS					2381.11	5.953	
Fixed Costs	General plant overhead, 50% O&M labor				45.00	0.113	
	1% TIC				58.33	0.146	
	Insurance & taxes, 2% TIC				116.67	0.292	
	Depreciation, 20% per annum				1166.65	2.917	
	total fixed				1386.65	3.467	
TOTAL COSTS					3767.76	9.419	
						0.0094	$/kwh

Quinoline. However, this did not always result in an improvement in pyritic sulfur rejection (only for Quinoline).

As previously mentioned in Section 3.1, there was a concern that after enough amine had been added to coat the pyrite surface, additional amine may be ineffective or perhaps detrimental in its effect. This is potentially a problem because of the use of carbon dioxide fluidization gas. Comparison of the results with 0.1% and 0.5% DCHA treatment of PSC seems to support the concept that a carbamate carbonate salt may form where excess amine is available. In all respects, the results were worse with the higher loading of amine on the coal.

The comparison between 0.1% DEHA and 0.1% Quinoline on PSC is also interesting, since Quinoline contains a tertiary nitrogen under normal organic conditions. In this bonding arrangement, the nitrogen should be less susceptible to reaction with CO_2. In fact, the results are comparable to the 0.1% DCHA ratio. The results might have been more revealing had runs been made at 0.5% Quinoline; unfortunately, this was not feasible within the scope of the existing funding.

In conclusion, it appears that surface chemical treatment did have an effect on how the particles partitioned between the positive and negative charged plates relative to untreated coal. However, it is not apparent that this change in partitioning had much effect on the overall coal cleaning performance when compared to untreated coal. If there was a more complete understanding of the chemistry involved, it might be possible to use this phenomenon to improve the benefication further. Recommendations for further development are provided in Section 5.0.

Based on the economic analysis of the full scale system, we determined that the recovery of coal was most economical for a plant using a two stage separation system. The economic benefit of using chemical treatment with this two stage system is also more economical. The operating cost including depreciation for the tow-stage system is approximately $9.42 per megawatt hour of power generated. These cost estimates were based on assumptions that in some cases were not proven experimentally. Therefore, a cost sensitivity analysis is presented in Chapter 4.0

The capital and operating cost of the triboelectric separation process was also compared to that of a froth flotation unit of the same capacity. The results are summarized below.

	Two-Stage Tribo Separation	Froth Flotation Beneficiation
Investment, $MM	$46.00	$32.00
Annual operating cost, $/ton*	24.60	28.60

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* Per net ton to combustor

3.0 Detailed Description of Research

3.1 Triboelectric Separation Applied to Coal

3.1.1 Background

It has been known for a long time that electrostatic charging could be achieved by contact electrification, conductive induction and by ion bombardment. Machines based on conductive induction and ion bombardment have been commercially employed on many mineral separations for some years. Specifically, coal cleaning by electrostatic separation techniques has been the subject of considerable investigations for some years (Literature Survey Refs. 52, 64)

Likewise, the use of contact electrification or the use of "tribo-electric effect" to induce electric charges has been investigated with limited success (Refs. 5,37, 134). The reasons concern the difficulty of obtaining the required amount of charge and the difficulty of maintaining it. Regardless of the method of charging, the amount of charge that can be accumulated on a particle is limited by the maximum achievable charge density and the maximum surface area of the particle. Reference to chemical treatment prior to or during triboelectrification is almost non-existent in the technical literature. Those that exist are for non-coal applications.

In undertaking work on the development of coal/CO_2 slurry technology, Arthur D. Little observed many unusual aspects on the methods of developing triboelectric charge. Specifically, it was found that conventional dry CO_2 gas at pressures of up to 30 psig appears to be unusually effective in inducing electrostatic charges on coal particles. In the work on dense phase pneumatic transport of coal, this actually was a major problem that had to be overcome. In addition to overcoming these problems, this principle was then explored further as the basis for electrostatic separation of the combustible matter from the non-combustible in coal. A working model was constructed that was tested on simulated materials and demonstrated the principle. The system that was tested did not have any electrical equipment for obtaining the charges and the resulting separation.

In conclusion, previous investigations have studied non-enhanced "tribo-separation" of coal. There were a few instances (Refs. 46, 45) of the use of chemical conditioning in non-cal tribo-separator systems. The combining of tribo charging in CO_2 vapor with chemical conditioning of coal to effect a separation, appears to be unique.

3.1.2 Concepts considered for Testing

Based on the prior work of Arthur D. Little and others, we believe that there are a number of materials that could be employed to "condition" the coal and thereby increase the efficacy of electrostatic charging. Details on the possible agents for such use in trace quantities and the methods of conditioning are enhancement features that we believe would further improve the efficiency of electrostatic separation.

3.1.2.1 Concept Development Issues

Particle Charging

When the surfaces of two dissimilar materials are brought into contact, each surface will obtain an exchange charge the moment contact is broken. This phenomenon is known as tribo-electric (contact electrification). In charging by particle-to-particle contact the area of contact is usually quite small and it is necessary to provide some mechanical method for causing repeated contacts in order to build up an appreciable average surface charge on the particles. In the case of granular material, any movement causes repeated particle-to- particle contact.

The theory of contact electrification is complex and the understanding of the electrification properties of solids is not well understood. However, means of alternating (thermally, physically or chemically) the surface of the particles can be employed so that a selective electrification is produced.

To achieve effective separation with rotor-type separators, a ratio of the conductivity of the dissimilar materials of approximately five orders of magnitude is desireable. IN the case of coal, iron pyrites is inherently more conductive than the combustible fraction. The difference in conductivity is typically two or three orders of magnitude. As indicated above, surface chemistry of the particles is an important factor affecting conductivity. Our previous work has shown that fluidization of ground coal with gaseous CO_2 can achieve a reasonable conductivity differential but requires a significant fluidization time. In this case, extended fluidization may erode particle surface enough to produce a conductivity ratio required for effective separation.

Feeding of Charged Particles

Effective separation of fine dissimilarly charged particles in electrostatic separators such as parallel plates or roll separators requires uniform distribution of particles into thin layers. Based on experiences gained in our pilot work and that reported by others practicing in this field, the feeding mechanism of charged particles to an electrostatic separator requires careful consideration.

Particle interactions and fluid dynamics, if not properly addressed in design, can prevent uniform and repeatable feeding of charge particles to the separators. The fact that small particle sizes (minus 200 mesh) is required for physical separation of mineral contents from carbonaceous materials in the coal makes the interaction of the boundary layer adjacent to a rotating surface and the fine particles a significant hindrance to particle feeding. Distribution of uniformly thin layers of charged particle also requires design modification of conventional drum separators employed in electrostatic separation.

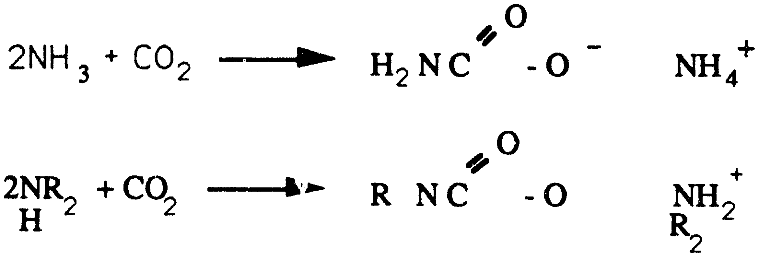
3.1.3 Avenues of Research

Charge Enhancement

One of the main objectives of the research is to reduce the fluidization time required to obtain a sufficient level of contact electrification to achieve efficient separation in the rotor-type separator. The method by which we hope to achieve this goal is preferentially changing the resistivity of the iron pyrite by chemically altering its surface. This will be accomplished by adding to the fluidization gas other reactive gases to chemically alter the surface. For example, it is known that iron chloride has a higher conductivity than iron pyrite. Injection of small quantities of HCl or Cl_2 may produce the desired effect. Other possibilities include hydrogen, oxygen, ammonia, and amine. Heating of the fluidization gas to increase the rate of reaction on the surface of the pyrite may also be beneficial. In selecting the chemical agent, sensitivity to the ultimate use of the coal and the effect of trace elements in it, needs to be considered.

The intention is to preferentially adsorb to the surface of the pyrites organic compounds that will increase the ability of the pyrites to accept and retain an electrostatic charge induced by a triboelectric mechanism. Amines through the pair of unshared electrons on the nitrogen offer an example of a material which we believe will enter into a loose dative bond with iron, sulfur, oxygen .... the elements that we might expect on this surface. The greater the base strength of the amine, the greater the expected affinity to the pyrites.

After enough amine has been added to coat the surface, additional amine may be ineffective or perhaps detrimental in its effect. This is particularly so in the presence of carbon dioxide. Ammonia and amines will form a mixed carbamate carbonate salt where the nitrogenous compound has accumulated. If there is volatile vapor phase amine or an aerosol of amine which has not deposited selectively, carbon dioxide will precipitate it indiscriminately

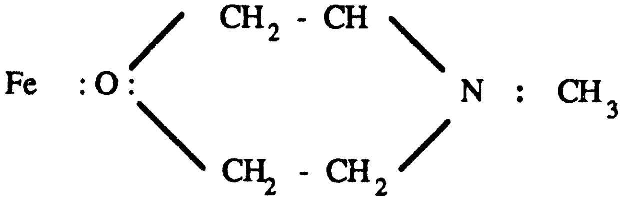


$$2NH_3 + CO_2 \longrightarrow H_2N\overset{O}{C}\ \text{-}O^- \qquad NH_4^+$$

$$2\underset{H}{NR_2} + CO_2 \longrightarrow R\ N\overset{O}{C}\ \text{-}O \qquad \underset{R_2}{NH_2^+}$$

This salt is adherent to metallic surfaces and presumably to pyrites.

If this salt formulation is considered to be a problem, one can reasonably canvass the use of an oxygenated species which might offer the same general mechanism of a formation of a loose bond to the pyrites and incorporation of a tertiary nitrogen as a polar site for charge retention. The tertiary nitrogen cannot react with carbon dioxide, as is indicated below:



N-methyl morpholine

Discharging Coal particles from Fluid-Bed Triboelectric Charger

The discharging of solid particles from a fluid-bed is conventionally accomplished by entrainment in the fluidizing medium followed by cyclonic separation. Due to the difficulty of separating extremely fine particles as encountered in this application in cyclonic separators, the investigation considered the use of a dip leg mechanism which extends to the top of the expanded bed at the center of the fluid bed vessel. Solid particles separated from the fluidizing medium will flow by gravitational force in the electrically insulated dip leg to a hopper accumulator located at a lower elevation with respect to the fluid bed. Another option involved entrainment of the coal particles from the fluid-bed directly to the particle separator. The latter was the approach finally adopted.

3.2.1 Equipment Description

The Triboelectric Coal Separation System is composed of four major systems or pieces of equipment: the gas delivery system, the tribo-charger, the collection chamber and the filter system (See Figure 3-1). Each system or piece of equipment is described in detail below.

Gas Delivery System

The gas delivery system consists of the CO_2 delivery line and the treatment gas delivery line. The CO_2 delivery line is made up of a 150 lb CO_2 cylinder. The system downstream of the cylinder consists of a pressure regulator and gauge, heating tape, temperature regulator and indicator, and flowmeter. We experienced difficulties with the CO_2 regulator freezing in this part of the system. To alleviate this problem the system was run on cylinders of compressed CO_2 gas. The heating tape was installed to prevent the line from frosting and to maintain the gas temperature at approximately 25°C. The CO_2 delivery into the tribo-charger is manually regulated using the CO_2 line pressure. The gas treatment delivery system is made up of individual treatment gas cylinders, manifold and ball valves, flowmeter, and ball valve. The manifold allows all the treatment gases to be connected to the system at the same time. When using a treatment gas, the manifold ball valve for that particular gas line is opened. Opening the second ball valve allows the treatment gas to enter the CO_2 delivery line and be mixed with the CO_2 gas.

Tribo-Charger

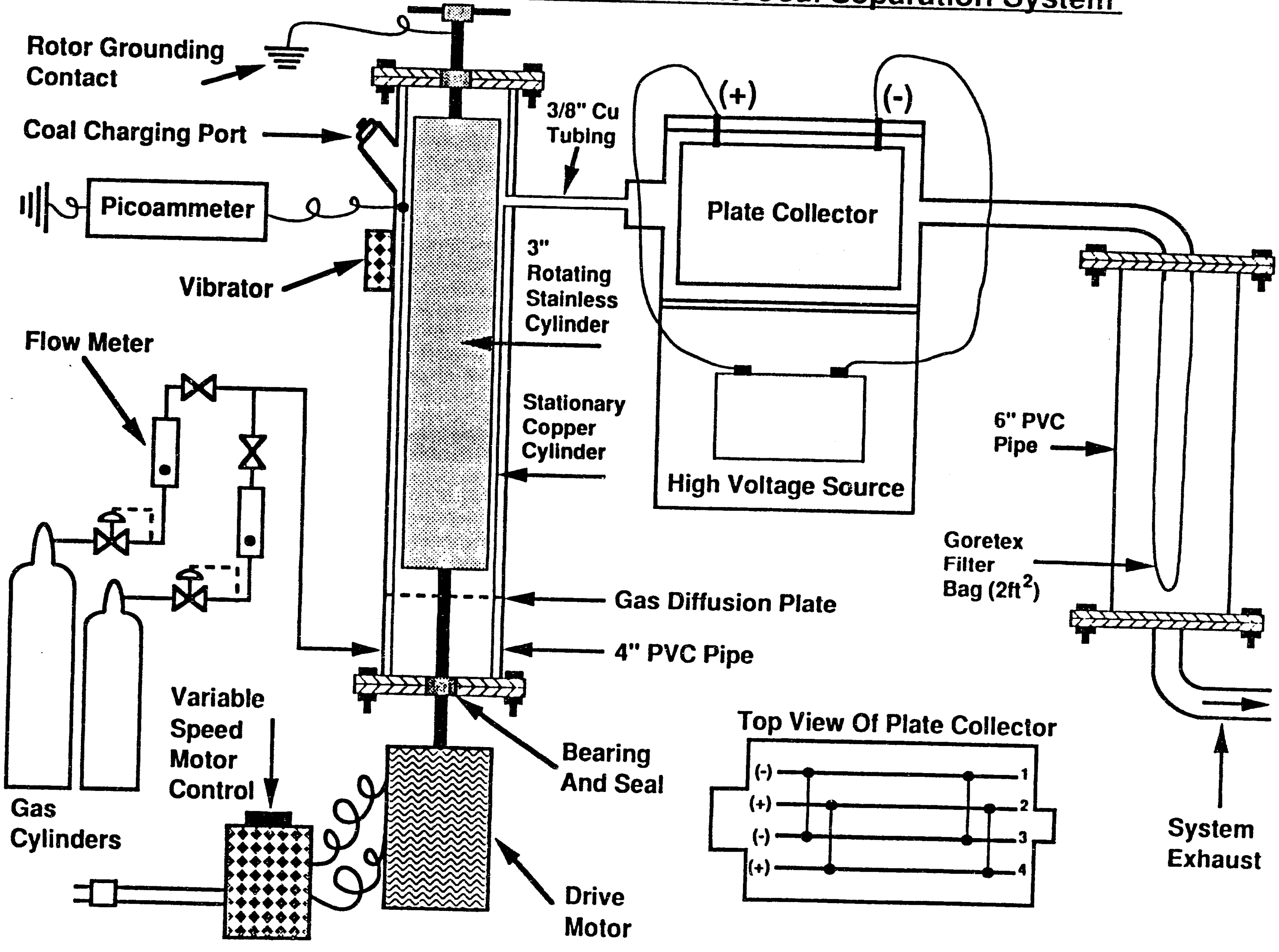
The tribo-charger consists of a 3 inch diameter rotating stainless steel cylinder surrounded by a stationary 4 inch diameter PVC shell. The PVC shell contains a wye piece to serve as the coal charging port and the shell is lined with a copper sleeve, which enhances the frictional charge on the particles. The fluidizing gas (CO_2) enters from the bottom of the charging unit through a gas diffusion plate and exits through a 3/8 inch copper tube located near the top of the unit. The fluidization and the rotating cylinder causes particle-particle interactions as well as particle-wall interactions which in turn imparts a frictional charge to each particle. During these interactions the coal (product) charges positive, while the ash and pyrite (reject) charge negative. A pneumatic vibrator is attached to the outside of the PVC shell to shake off any coal that has accumulated or become attached to the inside copper wall. A picoammeter is connected to the copper wall and the rotating stainless cylinder to detect the leakage current, which is an indication of charge accumulation. The motor drive for the rotating cylinder is rated at 1 HP with a maximum RPM of 1725. The motor is connected to a variable speed motor controller which varies the RPM from 0% to 100%.

Collection Chamber

The collection chamber consists of a plexiglass box (18 1/4" x 12 1/4" x 7") with four stainless steel plates suspended from the top of the box. The plates are alternately charged to (+) 12,000 volts and (-) 12,000 volts with a 2 inch gap between each plate. The CO_2 transports the coal from the tribo charger through a 3/8 inch copper tube and an expansion cone into the collection chamber. The coal is dispersed in the expansion cone and flows between the plates. The coal and mineral matter are separated based on the charge of each particle, the coal is attracted by the negative plates while the ash and

Figure 3-1

Schematic Of A.D. Little Triboelectric Coal Separation System



pyrite are attracted by the positive plates. The CO_2 then passes through the chamber to the filter system.

Filter System

The filter system consists of a 3 ft long Goretex filter bag with a surface area of 2 ft^2. The filter bag is enclosed by a 6 inch diameter PVC pipe. The CO_2 enters from the top of the filter system and passes through the Goretex filter bag, which collects any remaining coal in the gas stream, and exits through the bottom of the unit to the exhaust system.

3.2.2 Operating Procedure

Chemical Pretreatment

- Dissolve the treatment chemical in hexane.
- Mix the loaded solvent with approximately 150 gms of coal.
- Heat the coal to evaporate off the organic solvent using a rotary evaporator under vacuum.
- When the coal is completely dried, remove it from the flask.
- If the coal will not be used immediately, store it under an argon atmosphere.

Experimental Test Procedure

Each experimental test was conducted for an hour and 10 minutes. The test procedure was as follows:

- Charge 100 to 150 gms of coal to the charging chamber.
- Turn on the exhaust system.
- Turn on the power supply system. Set the charge from the positive and negative power supplies to 12 kV. The plates must be charged before the gas is turned on to insure that the micron size particles that tend to be carried over with the gas are collected.
- Turn on the CO_2 gas until the line pressure gauge reads 5.5 psig. Purge the system for 5 minutes.
- After the 5 minutes, turn on the motor controller and set the rotor speed to 100%.
- Record: the CO_2 delivery line pressure, the CO_2 flowrate, the pressure in the charging chamber, the current from the picoammeter, the time and the temperature of the CO_2 delivery line. This data is collected every 5 minutes for 70 minutes.
- After the first 15 minutes, increase the CO_2 line pressure to 8.0 psig. Thereafter, increase the pressure by 2.5 psig every 20 minutes until 13.0 psig is reached.

- After the system has run for 70 minutes, shut off the following equipment in sequence indicated: the CO_2 gas, the motor to the rotor, the power supplies then the exhaust system.

Gas Treatment Procedure

The experimental test procedure is followed for gas treatment tests with some additional steps:

- After turning on the CO_2 gas until the line pressure reads 5.5 psig (approx. 86.4 l/min), open the ball valve on the gas treatment line and the valve on the gas treatment cylinder.

- Adjust the flowrate to 1000 ppm (for ammonia), which is 0.086 l/min at a CO_2 flowrate of 86.4 l/min.

- At maximum CO_2 flow (approx. 161 l/min), the ammonia flowrate will be 0.161 l/min.

- After the system has run for 70 minutes, turn off the ammonia gas and then follow the shutdown procedure under "Experimental Test Procedure".

Product Removal

- To disassemble the system, first remove the cover of the collection chamber (the stainless steel plates will be attached) and suspend it from a frame so as not to knock the coal off of the plates.

- Remove each plate from the cover and brush the collected material off onto a sheet of clean paper.

- Weigh and record the amount of material that was removed from each plate, plates 1 and 3 are charged negative and plates 2 and 4 are charged positive.

- Collect, weigh and record the coal on the bottom of the collection chamber, the coal on the bottom and walls of the charging chamber and the coal attached to the inside of the filter bag.

- To collect the remaining coal from the charging chamber, the chamber must be disassembled. This entails removing the vibrator from the outside wall, disconnecting the picoammeter from the copper shim and rotor, removing the bolts from the top and bottom flanges, and disconnecting the 3/8 inch copper tubing which connects the charging and collection chambers.

- The coal attached to the inside of the filter is very difficult to collect therefore it is only accounted for. Disassemble the filter system by removing the top flange. Weigh the entire filter bag. Remove the coal by rapping or by vacuuming it out. Weigh the filter bag again and record the difference in the measurements.

- Clean out each chamber by vacuuming and wiping it down.

- Reassemble the system and make ready for the next run.

3.2.3 Experimental Difficulties

During the course of the experimental phase, several operation difficulties where encountered and had to be overcome.

- A new Tribo-charging system had to be developed. The existing tribo-charger, consisting of a fluid bed and rotor separator, could not be used because: (1) fine particulates tended to be eluded with the exhausted fluidizing gas due to their low entrainment velocities, (2) uniform feeding of the charged coal to the grounded rotor was a major problem, and (3) the settling velocity of the fine particles leaving the rotor was too low to achieve effective separation.

- The support system for the new Tribo system was changed. When the Tribo-charging system was rebuilt, the charging chamber was attached to a table with the motor for the rotor mounted to the underside and the collection chamber sitting on top. But, this support system was not very stable. The support system was changed to consist of a 2x6 board bolted to a concrete wall with the charging chamber and motor attached to the board by top and bottom mounts. The collection chamber was then set on top of the enclosure for the power supplies.

- Charging wall was added to the inside wall of the charging chamber. As a result of the literature search, a stainless steel charging wall was installed as the inside wall of the charging chamber to enhance the fictional charging of the coal particles. This wall consisted of a series of stainless steel strips tack-welded together. We then experimented with a copper charging wall and found that it was more effective than the stainless steel wall. The stainless steel wall was replaced by a solid copper sheet with a soldered seam along its length and sealed top and bottom with silicone adhesive. This seam eventually broke and the cylinder was replaced with solid 4 inch copper tubing also sealed top and bottom with silicone adhesive.

- Redesigned filter/exhaust system. Originally, the charging chamber was vented through a filter attached to the arm of the wye piece of the chamber. The collection chamber was vented much the same way as the charging chamber, through a filter attached to the outside of the chamber. There were three problems with this system: (1) The vibration from the spinning rotor in the charging chamber caused fractures at the joint between the filter housing and the wye piece; (2) Micron sized particles were passing through the filter on the charging chamber and being sent directly to the exhaust fan, therefore, this coal could not be accounted for; and (3) The filter bag area was undersized and therefore created a back pressure of 10 psig in the system which caused leakages in the collection chamber. The filter system was therefore redesigned. The filter on the charging chamber was removed and the chamber was vented through the collection chamber to collect and account for the micron sized particles. The filter bag on the collection chamber was replaced with a much larger filter bag with a collection area of 300 sq. inches instead of the original 18 sq. inches.

- Bearing seized during experimental test run. During an experimental test run, the bottom rotor shaft bearing seized and the rotor stopped. The bearing was removed and we discovered that coal was making its way into the bearing housing. Aluminum oxide ceramic/carbon face seals plus neoprene sheet/grease seals were added to prevent coal from reaching the bearing housing. A new shaft was also installed at this time because the previous one was bent.

- Experienced a problem with static charge on the rotor. We tried to correct the static charge problem by removing and replacing various items: the neoprene seals in the pillow blocks were removed, the graphite rings in the shaft seals were replaced with Teflon rings, the ceramic rings in the shaft seals were replaced with Teflon rings, all the shaft seals were removed, and the neoprene seals on the bearings were removed. None of these items were the cause of the static charge. We finally discovered that the flexible rubber coupling that replaced the rigid PVC coupling was the cause of the static charge. The rigid PVC coupling was reinstalled. The rigid coupling was originally replaced with the flexible one to reduce vibrations in the charging chamber.

- The gas was channeling through the fluidizing plate in the fluidizing chamber. The fluidizing plate in the fluidizing chamber was originally made up of 2 metal mesh screens and a few pieces of cloth between the screens. These screen were just set into the bottom of the fluidizing chamber. However, this configuration was allowing the fluidizing gas to channel instead of distributing it evenly across the plate. Therefore, a new fluidization plate was made, with a support plate underneath, and rigidly screwed down.

- Reduced coal particle size to less than 36 micron. We were experiencing difficulties in blowing over all the coal to the collection chamber and collecting all the coal that was blown over. The PETC project coordinator felt that the coal particles were too large. When analyzed, the coal particles consisted of 50% greater than 44 microns. The coal was then ground down to 100% less than 36 microns.

- Increased CO_2 flowrate during Final Separation Runs. To aid in entraining over all the coal to the collection chamber, the flowrate of the CO_2 was increased during the test runs. The first separation run was performed at a starting flowrate of approximately 63 L/Min and was increased during the test to a final flowrate of approximately 136 L/Min. However, all the coal was not being blown over to the collection chamber. For the remaining separation tests, the flowrate was increased to a starting flowrate of approximately 86 L/Min and reached a final flowrate of approximately 161 L/Min. This significantly enhanced the carryover rate of the coal. During the preliminary test runs, the flowrate of the fluidizing gas was observed to strongly affect the coal charging. The greater the flowrate the greater the charge on the coal. Therefore, increasing the flowrate during the testing not only enhanced the coal carryover rate, it also increased the charge on the coal.

- Rotor speed found to have an effect on coal charging. Rotor speed was found to have an effect on the coal charging rate. The greater the rotor speed, the greater the charge on the coal. Therefore, the rotor was run at full speed for the subsequent testing. However, this effect, was secondary compared to the effect of the fluidizing gas flowrate.

- Size, location, and material of tube/pipe connecting the charging and collecting chambers. We experimented with the size, location, and material of the transfer tubing/piping between the chambers. This transfer line started as a 1 inch PVC pipe and valve located mid-point on the charging chamber. The PVC pipe and valve was then changed to a 1 inch copper pipe and valve (located mid-way on the chamber) to make this line conductive. We believed the coal and ash were losing charge while being transported through the PVC pipe. The whole line was then relocated to the bottom of the chamber. Next, it was replaced with 3/8 inch copper tubing and valve and relocated to above the rotating cylinder. The 1 inch pipe was replaced with the 3/8 inch tubing to increase the gas velocity through this line. We were having problems with the coal settling out on the bottom of the 1 inch pipe. Lastly, the valve was removed and the line was shortened. This allowed a straight path through to the collection chamber with no obstructions to interfere with the flow of coal.

- Testing of a copper screen on the rotor. We installed a copper screen on the rotor to create a rough surface in hope of enhancing the frictional charging. However, we observed no enhancement of charge and found that the coal collected on the screen and therefore decreased the product yield for the run. The copper screen was removed from the rotor.

- An attempt to increase flowability of the coal. Fumed silica (Cab-O-Sil) was added (0.5%) to the coal in an attempt to increase the flowability of the coal. We found that the fumed silicon increased the grams of coal collected on the plates. However, it also decreased the separation of coal and ash and produced sparking on the collection plates. The mixing of fumed silica with the coal was therefore discontinued.

- Installed vibrator on the outside of the charging chamber. The coal tended to adhere to the inside wall of the charging chamber during fluidization which decreased product yield. To alleviate this problem, a pneumatic vibrator was installed on the outside wall of the chamber to cause enough vibration to prevent the coal from collecting on the inside wall.

- Bonding of PVC fittings to PVC pipe. We were having problems with the PVC fittings bonding to the 4 inch PVC pipe. After consulting a plastics expert at ADL, it was concluded that the pipe we received was not PVC as we had ordered. Therefore, the PVC cement would not bond the fittings to the pipe. The ADL expert recommended using 3-M epoxy cement which produced a strong bond.

- CO_2 delivery line freezing. We experienced problems with the CO_2 regulator and delivery line freezing. We installed heating tape on the regulator delivery line but this did not solve the problem. We finally had to switch from bottled liquid CO_2 to bottled compressed CO_2 gas.

3.3.1 Experimental Runs Performed

There were three distinct test periods during the experimentation phase (Task 3.0) of this project. The three period were as follows: system charge optimization, chemical and gas treatment optimization, and final separation runs. Each period is described below.

The initial test period was conducted from September 1988 to February 1989. This set of tests were performed to optimize the charging capabilities of the system. As a result of these tests, various parts of the tribo-charging system were rebuilt several times.

- The support system was redesigned to allow the rotor to run at a higher RPM with less vibration.

- The size, location, and material of construction for the transfer tube/pipe between the charging and collection chambers were experimented with.

- Various inner charging walls for the charging chamber were tested.
- An improved filter system was built.
- A copper screen to improve the fictional charging of the rotor was tested.
- A pneumatic vibrator was installed on the outside wall of the charging chamber to increase the amount of coal that is transferred to the collection chamber.

Also during this period, some operational changes took place.

- The particle size of the coal was reduced from 50% greater than 44 microns to 100% less than 36 microns.
- Fumed silica was added to the coal in an attempt to improve flowability.

All of the testing during this period was performed on untreated coal. For more detail on each of these design and operational changes see Section 3.2.3 (Operational Difficulties).

The next experimental test period occurred between February 1989 and June 1989. During this period, 12 tests were performed with various chemical treatments and gases to optimize the system for the final test period. All the testing was performed on Pittsburgh coal. The following treatments and gases were tested:

- Oleic Acid
- Quinoline
- Sodium Oleate
- Hexane
- 0.1% Dicyclohexylamine
- 0.5% Dicyclohexylamine
- 200 ppm Sulfur Dioxide
- 200 ppm Ammonia
- 1000 ppm Ammonia

The results from this set of tests determined the test matrix for the final separation runs. The results showed that dicyclohexylamine, ammonia, and possibly quinoline offered the most promise of enhancing the separation of coal and ash.

The final separation runs were conducted between October 1989 and December 1989. The test matrix included 33 tests on untreated coal and coal treated with 0.1% Dicyclohexylamine, 0.5% Dicyclohexylamine, 1000 ppm Ammonia and Quinoline. Pittsburgh seam, Upper Freeport, and Illinois #6 were all utilized for this set of runs. The test matrix was as follows:

COAL	TREATMENT	NUMBER OF RUNS
Pittsburgh (Fine)	None	4
Upper Freeport (Fine)	None	4
Illinois (Fine)	None	4
Pittsburgh (Fine)	0.1% Dicyclohexylamine	3
Pittsburgh (Fine)	0.5% Dicyclohexylamine	3
Pittsburgh (Fine)	1000 ppm Ammonia in CO_2	3

COAL	TREATMENT	NUMBER OF RUNS
Upper Freeport (Fine)	0.1% Dicyclohexylamine	3
Upper Freeport (Fine)	0.5% Dicyclohexylamine	3
Upper Freeport (Fine)	1000 ppm Ammonia in CO_2	3
Pittsburgh (Fine)	Quinoline	3

Each combination of coal and treatment was run several times in order to produce reproducible data within that set of runs. The resulting analytical data from each of these separation runs can be found in Section 3.3.3 (Summary of Raw Data).

An additional test was performed to determine the effect a two stage tribocharger would have on clean coal recovery, sulfur rejection and Btu recovery. The reject streams (positive plate samples) from the 4 untreated Pittsburgh coal runs were combined and run through the system a second time. Feed, positive and negative plate samples were sent to Galbraith for analysis. The analytical lab results are shown in Table 3-3. This test was performed to determine the economics of adding a second tribocharger to the tribo system for the full scale design. The economics for a two stage full scale system are presented in Sections 4.4 and 4.5.

3.3.2 Analytical Measurements

Throughout the entire experimental testing period, we experienced problems with the analytical laboratories. At the beginning of the experimental period, we were sending our samples to Resource Engineering Incorporated (REI) in Waltham, Massachusetts for analysis. However, this lab went out of business in April 1989. This forced us to find a new analytical lab to analyze the coal samples. At the recommendation of an ADL staff member who had dealt with a number of analytical laboratories which do coal analyses, we began sending the samples to Hazen Research of Golden, Colorado. Unfortunately, the sulfur balances performed on the results from Hazen Labs did not close. We, therefore, decided to test another lab, Galbraith Laboratories of Knoxville, Tennessee. We found that the results from Galbraith Labs gave us sulfur balances with a smaller percent error then the Hazen Lab's results. Therefore, we switched to Galbraith Labs for the remainder of the test period.

Samples of the positive and negative plate material from each experimental test run were sent to the analytical lab for analysis. The samples sent to the lab during the separation run testing also included samples of the feed material from each run. The feed samples were sent to act as a reference point and to give more accurate sulfur balances and therefore results. Each sample was analyzed for sulfur type (total, pyritic, sulfate, and organic) and ash content. The test procedure that Galbraith Labs used to analyze sulfur type is ASTM D2492 which measures pyritic and sulfate sulfur. Total sulfur is measured by an independent analysis, ASTM D3177 and organic sulfur is calculated by difference. The Btu value of selected "clean coal" samples (negative plate samples) were also analyzed.

3.3.3 Summary of Raw Data

The raw data collected during the separation test runs are presented in Appendix C: Raw data sheets. Each separation test run can be duplicated using the respective data sheet. The data collected during the test runs includes: CO_2 line pressure, CO_2 flowrate, treatment gas flowrate (gas treatment test runs only), collection chamber pressure, charging chamber pressure, picoammeter current, time, CO_2 line temperature, and coal distribution. The data sheets also include information such as the date, coal type, coal treatment, and amount of coal charged to the system.

The lab results from each run were recorded in spreadsheet form where sulfur balances were performed. The lab results were also used to calculate pyritic sulfur rejection, ash rejection, clean coal recovery, and energy recovery. See Table 3-1 for the analytical data from the tests performed during the system optimization period. Only a select few of the tests performed during this period were sent to the lab for analysis. See Table 3-2 for the analytical data from the 14 tests performed during the chemical and gas treatment optimization period and Table 3-3 for the analytical data from the 33 separation runs.

The first two sections of the spreadsheets contain information describing each run, such as ADL run #, treatment type, coal type, date of run and total amount of coal charged to the system. The data in the next three sections (positive plate, negative plate, and feed) are the actual results from the lab sheets which are presented in Appendix A. The positive and negative plate data also contains the amount of material that was collected on each plate during the run. The data for the feed samples in the charge optimization runs and the chemical and gas treatment optimization runs spreadsheets were taken from base runs of Pittsburgh and Illinois coal. The next five sections show the sulfur and ash balances between the feed and collected plate material. For more detailed information on the sulfur and ash balances see Section 3.4.1 (Sulfur and Ash Balance Closure). The next two sections, entitled Experimental Run Results and Energy Balance, contain information such as ash and pyritic sulfur rejection, clean coal recovery, energy recovery (only in the separation runs spreadsheet), % recovery on plates and % total recovery. The spreadsheet containing the separation runs data is also divided by each coal/treatment combination series. The last section is a material balance for the tribo charging system.

3.4.1 Sulfur and Ash Balance Closure

Sulfur and ash balances were performed on the feed coal and the positive and negative plate material. The results from the analytical lab were used to perform these balances. The five balances performed are as follows:

- Ash
- Total Sulfur
- Pyritic Sulfur
- Organic Sulfur
- Pyritic and Sulfate Sulfur

All the test samples before May 1989 were sent to Resource Engineering Incorporated (REI) in Waltham, Massachusetts for analysis. Unfortunately, this lab went out of business forcing us to find a new analytical lab to do our coal analyses. At the recommendation of an ADL staff member who had dealt with a number of analytical laboratories which do coal analyses, we began sending the samples to Hazen Research of Golden, Colorado. However, the balances performed on the results received from Hazen did not close very well. Because of this problem, we decided to test another lab. We divided the positive plate, negative plate and feed samples from the next two runs in half and sent half to Hazen Research and half to Galbraith Labs of Knoxville, Tennessee. The results from Galbraith Labs gave us sulfur and ash balances with a smaller percent error than the results from Hazen Labs, therefore, we switched to Galbraith Labs for the remainder of the chemical and gas treatment runs.

Table 3-1

RESULTS FROM CHARGE
OPTIMIZATION RUNS
(9/19/88 TO 1/16/89)

EXPERIMENTAL RUN INFORMATION					POSITIVE PLATE						NEGATIVE PLATE					
Run	Treatment	Coal	Date	Total In (gms)	Coal on Plate (gms)	Ash (%)	Total Sulfur (%)	Sulfate Sulfur (%)	Pyritic Sulfur (%)	Organic Sulfur (%)	Coal on Plate (gms)	Ash (%)	Total Sulfur (%)	Sulfate Sulfur (%)	Pyritic Sulfur (%)	Organic Sulfur (%)
I1-R	None	Illinois	9/19		37.8	15.25	3.29	0.50	1.13	1.66	41.6	14.16	3.43	0.56	1.13	1.74
I2-R	None	Illinois	10/25	100.0	12.0	14.05	3.31	0.91	0.72	1.69	11.2	13.38	3.34	0.95	0.67	1.73
P1-R	None	Pittsburgh	11/29	100.0	18.8	9.75	4.11	0.16	2.30	1.65	27.3	8.21	3.71	0.13	2.02	1.56
P2-R	None	Pittsburgh	12/2	100.0	23.7	15.02	5.37	0.24	3.64	1.49	20.2	4.09	3.00	0.07	0.95	1.98
P3-R	None	Pittsburgh	12/8	106.3	20.0	13.93	5.42	0.23	3.50	1.69	26.4	4.49	2.88	0.07	0.95	1.86
P4-R	None	Pittsburgh	12/13	100.0	30.0	12.68	4.90	0.24	2.91	1.75	38.9	6.10	3.42	0.12	1.41	1.89
P5-R	None	Pittsburgh	12/16	99.0	34.2	13.85	5.41	0.24	3.29	1.88	43.6	5.27	3.19	0.09	2.59	0.51
P6-R	None	Pittsburgh	1/5	100.0	9.7	15.02	5.62	0.22	3.84	1.56	14.9	4.67	2.95	0.09	1.14	1.72
P7-R	None	Pittsburgh	1/13	100.0	29.0	10.85	4.18	0.16	2.38	1.64	33.8	9.03	4.15	0.12	2.08	1.95
P8-R	None	Pittsburgh	1/16	101.3	12.2	10.00	3.50	0.14	2.03	1.33	10.4	8.85	3.74	0.12	2.03	1.59

Table 3-1

RESULTS FROM CHARGE
OPTIMIZATION RUNS
(9/19/88 TO 1/16/89)

EXPERIMENTAL RUN INFORMATION				FEED					ASH BALANCE			TOTAL SULFUR BALANCE		
Run	Treatment	Coal	Date	Ash (%)	Total Sulfur (%)	Sulfate Sulfur (%)	Pyritic Sulfur (%)	Organic Sulfur (%)	Feed Ash (gms)	Sample Ash (gms)	Error Ash (%)	Feed T Sulfur (gms)	Sample T Sulfur (gms)	Error T Sulfur (%).
I1-R	None	Illinois	9/19	12.55	3.57	0.28	1.01	2.28	9.96	11.70	17.38%	2.83	2.25	-20.78%
I2-R	None	Illinois	10/25	12.55	3.57	0.28	1.01	2.28	2.91	3.18	9.37%	0.83	0.56	-32.63%
P1-R	None	Pittsburgh	11/29	9.15	4.76	0.20	2.40	2.16	4.22	4.07	-3.41%	2.19	1.72	-21.62%
P2-R	None	Pittsburgh	12/2	9.15	4.76	0.20	2.40	2.16	4.02	4.39	9.19%	2.09	1.81	-13.49%
P3-R	None	Pittsburgh	12/8	9.15	4.76	0.20	2.40	2.16	4.25	3.97	-6.46%	2.21	1.78	-19.41%
P4-R	None	Pittsburgh	12/13	9.15	4.76	0.20	2.40	2.16	6.30	6.18	-2.02%	3.28	2.68	-18.23%
P5-R	None	Pittsburgh	12/16	9.15	4.76	0.20	2.40	2.16	7.12	7.03	-1.18%	3.70	3.12	-15.76%
P6-R	None	Pittsburgh	1/5	9.15	4.76	0.20	2.40	2.16	2.25	2.15	-4.36%	1.17	0.95	-18.88%
P7-R	None	Pittsburgh	1/13	9.15	4.76	0.20	2.40	2.16	5.75	6.20	7.87%	2.99	2.53	-15.43%
P8-R	None	Pittsburgh	1/16	9.15	4.76	0.20	2.40	2.16	2.07	2.14	3.51%	1.08	0.79	-26.90%

Table 3-1

RESULTS FROM CHARGE
OPTIMIZATION RUNS
(9/19/88 TO 1/16/89)

EXPERIMENTAL RUN INFORMATION				PYRITIC SULFUR BALANCE			ORGANIC SULFUR BALANCE			PYRITIC & SULFATE BALANCE		
Run	Treatment	Coal	Date	Feed P Sulfur (gms)	Sample P Sulfur (gms)	Error P Sulfur (%)	Feed O Sulfur (gms)	Sample O Sulfur (gms)	Error O Sulfur (%)	Feed P&S Sulfur (gms)	Sample P&S Sulfur (gms)	Error P&S Sulfur (%)
I1-R	None	Illinois	9/19	0.80	0.90	11.88%	1.81	1.35	-25.52%	1.02	1.32	28.57%
I2-R	None	Illinois	10/25	0.23	0.16	-31.10%	0.53	0.40	-25.03%	0.30	0.38	25.98%
P1-R	None	Pittsburgh	11/29	1.11	0.98	-11.08%	1.00	0.74	-26.08%	1.20	1.05	-12.45%
P2-R	None	Pittsburgh	12/2	1.05	1.05	0.09%	0.95	0.75	-20.58%	1.14	1.13	-1.38%
P3-R	None	Pittsburgh	12/8	1.11	0.95	-14.62%	1.00	0.83	-17.28%	1.21	1.02	-15.84%
P4-R	None	Pittsburgh	12/13	1.65	1.42	-14.04%	1.49	1.25	-15.32%	1.79	1.54	-14.02%
P5-R	None	Pittsburgh	12/16	1.87	2.25	20.74%	1.68	0.87	-48.51%	2.02	2.38	17.45%
P6-R	None	Pittsburgh	1/5	0.59	0.54	-8.14%	0.53	0.41	-23.29%	0.64	0.58	-9.77%
P7-R	None	Pittsburgh	1/13	1.51	1.39	-7.56%	1.36	1.13	-16.35%	1.63	1.48	-9.35%
P8-R	None	Pittsburgh	1/16	0.54	0.46	-15.42%	0.49	0.33	-32.89%	0.59	0.49	-16.89%

Table 3-1

RESULTS FROM CHARGE OPTIMIZATION RUNS (9/19/88 TO 1/16/89)

EXPERIMENTAL RUN INFORMATION				EXPERIMENTAL RUN RESULTS								
Run	Treatment	Coal	Date	P&S Sulfur Rejection	P Sulfur Rejection	Ash Rejection	Clean Coal Feed (gms)	Clean Coal Pos Plate (gms)	Clean Coal Neg Plate (gms)	Overall Clean Coal Recovery	% Recov on Plates	% Total Recovery
I1-R	None	Illinois	9/19	51.5%	52.4%	54.2%		32.5	29.9	47.9%		
I2-R	None	Illinois	10/25	51.9%	53.5%	52.9%	80.3	9.5	9.0	48.5%	23.2%	82.5%
P1-R	None	Pittsburgh	11/29	44.1%	43.9%	45.0%	81.3	15.4	23.0	59.9%	46.1%	91.0%
P2-R	None	Pittsburgh	12/2	81.7%	81.8%	81.2%	81.3	17.6	18.2	50.8%	43.9%	78.8%
P3-R	None	Pittsburgh	12/8	73.5%	73.6%	70.2%	86.5	15.0	23.7	61.2%	43.7%	85.5%
P4-R	None	Pittsburgh	12/13	61.4%	61.4%	61.6%	81.3	23.3	33.9	59.3%	68.9%	81.1%
P5-R	None	Pittsburgh	12/16	50.8%	49.9%	67.3%	80.5	25.8	38.5	59.9%	78.6%	87.2%
P6-R	None	Pittsburgh	1/5	68.2%	68.7%	67.7%	81.3	7.2	13.3	65.1%	24.6%	75.9%
P7-R	None	Pittsburgh	1/13	49.8%	49.5%	50.8%	81.3	23.4	27.9	54.4%	62.8%	90.1%
P8-R	None	Pittsburgh	1/16	54.2%	54.0%	57.0%	82.4	10.1	8.7	46.2%	22.3%	

Table 3-2

RESULTS FROM CHEMICAL AND GAS
TREATMENT OPTIMIZATION RUNS
(2/20/89 TO 6/23/89)

EXPERIMENTAL RUN INFORMATION					POSITIVE PLATE						NEGATIVE PLATE					
Run	Treatment	Coal	Date	Total In (gms)	Coal on Plate (gms)	Ash (%)	Total Sulfur (%)	Sulfate Sulfur (%)	Pyritic Sulfur (%)	Organic Sulfur (%)	Coal on Plate (gms)	Ash (%)	Total Sulfur (%)	Sulfate Sulfur (%)	Pyritic Sulfur (%)	Organic Sulfur (%)
PA1-R	None	Pittsburgh	2/20	100.0	29.0	16.83	5.85	0.32	4.99	0.54	46.7	3.87	2.89	0.07	0.92	1.90
PA2-R	Oleic Acid	Pittsburgh	2/28	94.7	23.9	15.10	5.87	0.27	4.67	0.93	39.5	5.45	3.32	0.10	1.38	1.84
PA3-R	Quinoline	Pittsburgh	3/17	95.3	10.3	9.82	3.98	0.19	2.41	1.38	54.0	8.68	3.93	0.17	2.24	1.52
PA4-R	None	Pittsburgh	4/10	103.4	32.0	11.60	4.07	0.19	2.63	1.25	31.7	5.77	3.88	0.16	2.49	1.23
PA5-R	Sod Oleate	Pittsburgh	4/12	108.1	21.6	14.42	5.21	0.25	2.68	2.28	36.2	4.20	3.73	0.08	2.25	1.40
PA6-R	DCHA	Pittsburgh	4/21	102.6	22.0	15.78	5.31	0.29	3.48	1.54	41.6	4.73	2.88	0.10	1.64	1.14
PA7-H	200-SO2	Pittsburgh	5/8	116.1	33.4	18.14	7.40	0.34	3.33	3.73	37.6	4.30	3.46	0.12	0.65	2.69
PA8-H	Hexane	Pittsburgh	5/12	101.9	21.7	17.71	6.97	0.35	3.76	2.86	38.3	3.44	3.47	0.07	0.59	2.81
PA9-H	None	Pittsburgh	5/19	101.4	29.3	16.41	6.79	0.31	3.82	2.66	42.5	3.62	3.58	0.07	0.48	3.03
FA1-H	None	U Freeport	5/30	112.4	38.1	41.98	2.70	0.14	2.12	0.44	51.3	14.36	1.63	0.06	0.98	0.59
PA10-H	200-NH3	Pittsburgh	6/12	115.8	30.2	17.08	6.49	0.24	3.88	2.37	56.2	3.61	2.88	0.10	0.51	2.27
PA11-H	1000-NH3	Pittsburgh	6/20	103.0	36.2	3.69	3.49	0.14	0.47	2.88	44.4	13.97	5.69	0.47	2.89	2.33
PA12-H	Hex & DCH	Pittsburgh	6/22	103.2	39.5	7.55	3.70	0.15	1.14	2.41	31.6	10.33	5.33	0.23	1.53	3.57
PA13-H	.5% DCHA	Pittsburgh	6/23	104.8	34.6	11.28	4.70	0.15	1.66	2.89	39.0	6.61	4.20	0.20	1.48	2.52
PA12-G	Hex & DCH	Pittsburgh	6/22	103.2	39.5	7.19	3.61	0.14	1.36	2.11	31.6	10.31	5.61	0.27	3.12	2.22
PA13-G	.5% DCHA	Pittsburgh	6/23	104.8	34.6	11.78	5.00	0.16	2.63	2.21	39.0	6.48	4.26	0.20	1.88	2.18

Table 3-2

RESULTS FROM CHEMICAL AND GAS
TREATMENT OPTIMIZATION RUNS
(2/20/89 TO 6/23/89)

EXPERIMENTAL RUN INFORMATION				FEED					ASH BALANCE			TOTAL SULFUR BALANCE		
Run	Treatment	Coal	Date	Ash (%)	Total Sulfur (%)	Sulfate Sulfur (%)	Pyritic Sulfur (%)	Organic Sulfur (%)	Feed Ash (gms)	Sample Ash (gms)	Error Ash (%)	Feed T Sulfur (gms)	Sample T Sulfur (gms)	Error T Sulfur (%)
PA1-R	None	Pittsburgh	2/20	9.15	4.76	0.20	2.40	2.16	6.93	6.69	-3.44%	3.60	2.92	-18.95%
PA2-R	Oleic Acid	Pittsburgh	2/28	9.15	4.76	0.20	2.40	2.16	5.80	5.76	-0.68%	3.02	2.61	-13.50%
PA3-R	Quinoline	Pittsburgh	3/17	9.15	4.76	0.20	2.40	2.16	5.88	5.70	-3.14%	3.06	2.42	-20.91%
PA4-R	None	Pittsburgh	4/10	9.15	4.76	0.20	2.40	2.16	5.83	5.54	-4.93%	3.03	2.42	-20.16%
PA5-R	Sod Oleate	Pittsburgh	4/12	9.15	4.76	0.20	2.40	2.16	5.29	4.64	-12.36%	2.75	2.39	-13.03%
PA6-R	DCHA	Pittsburgh	4/21	9.15	4.76	0.20	2.40	2.16	5.82	5.44	-6.53%	3.03	2.26	-25.32%
PA7-H	200-SO2	Pittsburgh	5/8	9.15	4.76	0.20	2.40	2.16	6.50	7.68	18.15%	3.38	3.61	6.93%
PA8-H	Hexane	Pittsburgh	5/12	9.15	4.76	0.20	2.40	2.16	5.49	5.16	-6.00%	2.86	2.74	-4.11%
PA9-H	None	Pittsburgh	5/19	9.15	4.76	0.20	2.40	2.16	6.57	6.35	-3.40%	3.42	3.39	-0.80%
FA1-H	None	U Freeport	5/30	31.15	2.16	0.06	1.45	0.65	27.85	23.36	-16.11%	1.93	1.78	-7.78%
PA10-H	200-NH3	Pittsburgh	6/12	9.15	4.76	0.20	2.40	2.16	7.91	7.19	-9.09%	4.11	3.45	-16.12%
PA11-H	1000-NH3	Pittsburgh	6/20	9.15	4.76	0.20	2.40	2.16	7.37	7.54	2.22%	3.84	3.53	-7.98%
PA12-H	Hex & DCH	Pittsburgh	6/22	9.15	4.76	0.20	2.40	2.16	6.51	6.25	-3.98%	3.38	3.01	-10.95%
PA13-H	.5% DCHA	Pittsburgh	6/23	9.15	4.76	0.20	2.40	2.16	6.73	6.48	-3.77%	3.50	3.13	-10.53%
PA12-G	Hex & DCH	Pittsburgh	6/22	9.15	4.76	0.20	2.40	2.16	6.51	6.10	-6.27%	3.38	3.06	-9.64%
PA13-G	.5% DCHA	Pittsburgh	6/23	9.15	4.76	0.20	2.40	2.16	6.73	6.60	-1.95%	3.50	3.26	-7.00%

Table 3-2

RESULTS FROM CHEMICAL AND GAS
TREATMENT OPTIMIZATION RUNS
(2/20/89 TO 6/23/89)

EXPERIMENTAL RUN INFORMATION				PYRITIC SULFUR BALANCE			ORGANIC SULFUR BALANCE			PYRITIC & SULFATE BALANCE		
Run	Treatment	Coal	Date	Feed P Sulfur (gms)	Sample P Sulfur (gms)	Error P Sulfur (%)	Feed O Sulfur (gms)	Sample O Sulfur (gms)	Error O Sulfur (%)	Feed P&S Sulfur (gms)	Sample P&S Sulfur (gms)	Error P&S Sulfur (%)
PA1-R	None	Pittsburgh	2/20	1.82	1.88	3.30%	1.64	1.04	-36.16%	1.97	2.00	1.73%
PA2-R	Oleic Acid	Pittsburgh	2/28	1.52	1.66	9.18%	1.37	0.95	-30.70%	1.65	1.77	7.09%
PA3-R	Quinoline	Pittsburgh	3/17	1.54	1.46	-5.53%	1.39	0.96	-30.67%	1.67	1.57	-6.14%
PA4-R	None	Pittsburgh	4/10	1.53	1.63	6.68%	1.38	0.79	-42.59%	1.66	1.74	5.21%
PA5-R	Sod Oleate	Pittsburgh	4/12	1.39	1.39	0.45%	1.25	1.00	-19.96%	1.50	1.48	-1.76%
PA6-R	DCHA	Pittsburgh	4/21	1.53	1.45	-5.15%	1.37	0.81	-40.82%	1.65	1.55	-6.07%
PA7-H	200-SO2	Pittsburgh	5/8	1.70	1.36	-20.39%	1.53	2.26	47.19%	1.85	1.52	-17.91%
PA8-H	Hexane	Pittsburgh	5/12	1.44	1.04	-27.65%	1.30	1.70	30.93%	1.56	1.14	-26.62%
PA9-H	None	Pittsburgh	5/19	1.72	1.32	-23.21%	1.55	2.07	33.29%	1.87	1.44	-22.66%
FA1-H	None	U Freeport	5/30	1.30	1.31	1.09%	0.58	0.47	-19.07%	1.35	1.39	3.31%
PA10-H	200-NH3	Pittsburgh	6/12	2.07	1.46	-29.67%	1.87	1.99	6.71%	2.25	1.59	-29.35%
PA11-H	1000-NH3	Pittsburgh	6/20	1.93	1.45	-24.87%	1.74	2.08	19.31%	2.10	1.71	-18.27%
PA12-H	Hex & DCH	Pittsburgh	6/22	1.71	0.93	-45.28%	1.54	2.08	35.44%	1.85	1.07	-42.35%
PA13-H	.5% DCHA	Pittsburgh	6/23	1.77	1.15	-34.81%	1.59	1.98	24.72%	1.91	1.28	-33.03%
PA12-G	Hex & DCH	Pittsburgh	6/22	1.71	1.52	-10.74%	1.54	1.53	-0.05%	1.85	1.66	-10.00%
PA13-G	.5% DCHA	Pittsburgh	6/23	1.77	1.64	-6.98%	1.59	1.61	1.58%	1.91	1.78	-7.16%

Table 3-2

RESULTS FROM CHEMICAL AND GAS
TREATMENT OPTIMIZATION RUNS
(2/20/89 TO 6/23/89)

EXPERIMENTAL RUN INFORMATION				EXPERIMENTAL RUN RESULTS								
Run	Treatment	Coal	Date	P&S Sulfur Rejection	P Sulfur Rejection	Ash Rejection	Clean Coal Feed (gms)	Clean Coal Pos Plate (gms)	Clean Coal Neg Plate (gms)	Overall Clean Coal Recovery	% Recov on Plates	% Total Recovery
PA1-R	None	Pittsburgh	2/20	76.9%	77.1%	73.0%	81.3	20.7	42.2	67.1%	75.7%	91.8%
PA2-R	Oleic Acid	Pittsburgh	2/28	66.9%	67.2%	62.6%	77.0	17.5	34.7	66.5%	66.9%	86.9%
PA3-R	Quinoline	Pittsburgh	3/17	17.1%	17.0%	17.7%	77.5	8.5	45.1	84.2%	67.5%	93.1%
PA4-R	None	Pittsburgh	4/10	51.8%	51.6%	67.0%	84.1	25.7	27.4	51.6%	61.6%	78.4%
PA5-R	Sod Oleate	Pittsburgh	4/12	42.9%	41.5%	67.2%	87.9	16.2	32.0	66.3%	53.5%	78.7%
PA6-R	DCHA	Pittsburgh	4/21	53.4%	52.9%	63.8%	83.4	16.2	37.2	69.7%	62.0%	95.9%
PA7-H	200-SO2	Pittsburgh	5/8	80.9%	82.0%	78.9%	94.4	22.4	33.4	59.8%	61.2%	92.4%
PA8-H	Hexane	Pittsburgh	5/12	77.9%	78.3%	74.5%	82.9	14.8	34.3	69.8%	58.9%	99.0%
PA9-H	None	Pittsburgh	5/19	83.8%	84.6%	75.8%	82.5	20.5	37.9	64.9%	70.8%	91.7%
FA1-H	None	U Freeport	5/30	61.7%	61.6%	68.5%	72.5	20.0	42.3	67.8%	79.5%	99.5%
PA10-H	200-NH3	Pittsburgh	6/12	78.4%	80.3%	71.8%	94.2	21.1	50.9	70.7%	74.6%	90.3%
PA11-H	1000-NH3	Pittsburgh	6/20	12.9%	11.7%	17.7%	83.8	32.3	33.1	50.6%	78.3%	94.5%
PA12-H	Hex & DCH	Pittsburgh	6/22	47.8%	48.2%	47.7%	83.9	33.6	25.0	42.6%	68.9%	87.0%
PA13-H	.5% DCHA	Pittsburgh	6/23	48.9%	49.9%	60.2%	85.2	27.4	33.1	54.7%	70.2%	86.7%
PA12-G	Hex & DCH	Pittsburgh	6/22	35.6%	35.3%	46.6%	83.9	33.8	24.8	42.3%	68.9%	87.0%
PA13-G	.5% DCHA	Pittsburgh	6/23	54.3%	55.4%	61.7%	85.2	27.1	33.2	55.1%	70.2%	86.7%

Table 3-3

RESULTS FROM FINAL
SEPARATION RUNS
(10/30/89 TO 12/29/89)

EXPERIMENTAL RUN INFORMATION					POSITIVE PLATE						NEGATIVE PLATE					
Run	Treatment	Coal	Date	Total In (gms)	Coal on Plate (gms)	Ash (%)	Total Sulfur (%)	Sulfate Sulfur (%)	Pyritic Sulfur (%)	Organic Sulfur (%)	Coal on Plate (gms)	Ash (%)	Total Sulfur (%)	Sulfate Sulfur (%)	Pyritic Sulfur (%)	Organic Sulfur (%).
PP1-G	None	Pittsburgh	10/30	150.8	24.3	15.82	7.08	0.26	3.96	2.86	31.2	2.81	3.00	0.06	0.43	2.51
PP2-G	None	Pittsburgh	10/31	153.4	38.7	13.70	5.72	0.23	3.27	2.22	49.5	2.97	3.13	0.07	0.50	2.56
PP3-G	None	Pittsburgh	11/2	131.3	45.8	13.62	6.50	0.23	2.97	3.30	64.2	2.86	3.42	0.10	0.46	2.86
PP4-G	None	Pittsburgh	11/6	136.2	47.1	17.73	7.03	0.27	4.89	1.87	64.5	2.85	3.14	0.07	0.43	2.64
UP1-G	None	U.Freeport	11/7	144.1	46.7	49.34	2.90	0.16	2.34	0.40	60.7	11.77	1.71	0.08	0.90	0.73
UP2-G	None	U.Freeport	11/8	150.6	24.5	50.41	2.60	0.17	2.16	0.27	33.5	10.46	1.60	0.13	0.73	0.74
UP3-G	None	U.Freeport	11/9	141.9	26.9	50.92	2.80	0.19	2.06	0.55	34.8	10.96	1.68	0.10	0.66	0.92
UP4-G	None	U.Freeport	11/13	139.9	28.6	47.42	2.98	0.17	2.28	0.53	30.2	12.90	1.84	0.12	0.91	0.81
IP1-G	None	Illinois	11/14	135.9	48.5	16.80	3.69	0.95	0.68	2.06	39.4	8.91	3.46	0.66	0.44	2.36
IP2-G	None	Illinois	11/15	130.8	46.1	17.83	3.79	1.03	0.67	2.09	47.0	7.45	3.46	0.62	0.42	2.42
IP3-G	None	Illinois	11/16	123.6	49.0	18.56	3.79	1.02	0.45	2.32	59.2	6.92	3.11	0.54	0.35	2.22
IP4-G	None	Illinois	11/17	125.1	45.7	18.53	3.89	1.06	0.47	2.36	55.0	7.77	3.35	0.61	0.23	2.51
PD1-G	0.1% DCHA	Pittsburgh	11/21	154.6	39.5	18.95	7.84	0.39	5.36	2.09	82.7	3.20	2.92	0.07	0.54	2.31
PD2-G	0.1% DCHA	Pittsburgh	11/22	136.9	34.3	22.20	8.24	0.37	6.12	1.75	70.4	2.84	2.83	0.06	0.44	2.34
PD3-G	0.1% DCHA	Pittsburgh	11/27	146.5	36.5	22.24	8.18	0.39	4.05	3.74	74.4	2.91	2.92	0.06	0.49	2.37
PD4-G	0.5% DCHA	Pittsburgh	11/28	143.3	30.4	16.40	6.40	0.18	3.02	3.20	49.8	4.41	3.38	0.15	0.82	2.41
PD5-G	0.5% DCHA	Pittsburgh	11/30	138.5	43.5	16.08	6.32	0.16	3.94	2.22	71.7	4.61	3.43	0.14	0.50	2.79
PD6-G	0.5% DCHA	Pittsburgh	12/4	142.5	45.7	15.13	6.35	0.16	4.06	2.13	72.0	4.48	3.42	0.12	0.83	2.47
UD1-G	0.1% DCHA	U.Freeport	12/5	141.7	30.8	49.80	2.89	0.15	2.24	0.50	49.1	10.58	1.65	0.07	0.80	0.78
UD2-G	0.1% DCHA	U.Freeport	12/6	154.4	19.1	53.22	2.69	0.16	1.15	1.38	31.6	10.57	1.60	0.07	0.83	0.70
UD3-G	0.1% DCHA	U.Freeport	12/7	153.2	23.6	50.72	2.90	0.13	2.02	0.75	36.9	11.72	1.71	0.07	0.76	0.88
UD4-G	0.5% DCHA	U.Freeport	12/8	140.3	38.0	49.76	2.68	0.12	2.14	0.43	51.1	9.69	1.68	0.09	0.38	1.21
UD5-G	0.5% DCHA	U.Freeport	12/9	142.4	47.0	46.95	2.85	0.12	2.00	0.73	63.4	11.64	1.78	0.11	0.73	0.94
UD6-G	0.5% DCHA	U.Freeport	12/18	134.5	53.0	47.56	3.01	0.11	2.42	0.48	69.2	11.77	1.82	0.09	0.94	0.80

Table 3-3

RESULTS FROM FINAL
SEPARATION RUNS
(10/30/89 TO 12/29/89)

EXPERIMENTAL RUN INFORMATION					POSITIVE PLATE						NEGATIVE PLATE					
Run	Treatment	Coal	Date	Total In (gms)	Coal on Plate (gms)	Ash (%)	Total Sulfur (%)	Sulfate Sulfur (%)	Pyritic Sulfur (%)	Organic Sulfur (%)	Coal on Plate (gms)	Ash (%)	Total Sulfur (%)	Sulfate Sulfur (%)	Pyritic Sulfur (%)	Organic Sulfur (%)
PN1-G	1000ppm NH3	Pittsburgh	12/14	148.9	57.6	15.28	6.40	0.22	4.18	2.00	74.0	4.04	3.15	0.08	0.68	2.40
PN2-G	1000ppm NH3	Pittsburgh	12/15	133.3	39.7	12.81	5.68	0.20	3.26	2.22	72.5	6.71	3.84	0.11	1.37	2.36
PN3-G	1000ppm NH3	Pittsburgh	12/19	137.8	52.9	16.10	6.75	0.23	4.32	2.20	68.4	3.38	2.96	0.06	0.32	2.58
UN1-G	1000ppm NH3	U.Freeport	12/11	139.3	51.0	44.33	3.00	0.12	1.74	1.14	62.4	11.49	1.81	0.07	0.82	0.92
UN2-G	1000ppm NH3	U.Freeport	12/12	144.4	53.1	42.78	2.86	0.12	2.31	0.43	52.3	12.62	1.92	0.08	0.75	1.09
UN3-G	1000ppm NH3	U.Freeport	12/13	137.3	58.5	46.13	2.78	0.02	2.65	0.02	65.8	11.33	1.80	0.08	0.91	0.81
PQ1-G	0.1% Quinoline	Pittsburgh	12/20	136.5	45.9	18.18	7.33	0.27	4.64	2.42	68.4	2.52	2.82	0.05	0.31	2.46
PQ2-G	0.1% Quinoline	Pittsburgh	12/26	137.6	46.5	17.84	7.31	0.26	4.28	2.77	71.1	2.70	2.63	0.05	0.38	2.20
PQ3-G	0.1% Quinoline	Pittsburgh	12/27	139.6	51.4	15.10	6.46	0.24	3.42	2.80	67.0	2.68	2.91	0.05	0.42	2.44
PV1-G	P-18kV,N-6kV	Pittsburgh	12/29	153.5	55.5	17.29	7.33	0.26	4.30	2.77	78.2	2.90	2.93	0.05	0.41	2.47
ADDITIONAL TESTS																
T1A-G	None	Pittsburgh	1/13	229.7	125.6	8.71	4.64	0.16	2.18	2.30	104.1	9.09	4.67	0.12	2.19	2.36
T1B-G	None	Pittsburgh	1/14	229.7	125.6	8.68	4.05	0.13	2.15	1.77	104.1	8.97	4.76	0.13	2.20	2.43
T2-G	0.1% DCHA	Pittsburgh	1/16	148.4	93.7	8.92	4.65	0.12	2.23	2.30	54.7	8.71	4.78	0.12	2.15	2.51
TEST FOR TWO STAGE TRIBO CHARGER																
TS1-G	None	Pittsburgh	6/8	73.2	25.6	31.90	10.85	0.70	9.70	0.45	39.3	6.76	3.71	0.16	0.38	3.17

Table 3-3

RESULTS FROM FINAL
SEPARATION RUNS
(10/30/89 TO 12/29/89)

EXPERIMENTAL RUN INFORMATION				FEED					ASH BALANCE			TOTAL SULFUR BALANCE		
Run	Treatment	Coal	Date	Ash (%)	Total Sulfur (%)	Sulfate Sulfur (%)	Pyritic Sulfur (%)	Organic Sulfur (%)	Feed Ash (gms)	Plate Ash (gms)	Error Ash (%)	Feed T Sulfur (gms)	Plate T Sulfur (gms)	Error T Sulfur (%)
PP1-G	None	Pittsburgh	10/30	8.73	4.79	0.15	2.16	2.48	4.85	4.72	-2.56%	2.66	2.66	-0.08%
PP2-G	None	Pittsburgh	10/31	8.64	4.40	0.14	1.92	2.34	7.62	6.77	-11.13%	3.88	3.76	-3.04%
PP3-G	None	Pittsburgh	11/2	8.67	4.68	0.15	1.92	2.61	9.54	8.07	-15.34%	5.15	5.17	0.48%
PP4-G	None	Pittsburgh	11/6	8.66	3.54	0.14	1.87	1.53	9.66	10.19	5.43%	3.95	5.34	35.08%
UP1-G	None	U.Freeport	11/7	27.43	2.39	0.12	1.49	0.78	29.46	30.19	2.47%	2.57	2.39	-6.80%
UP2-G	None	U.Freeport	11/8	27.51	2.51	0.12	1.60	0.79	15.96	15.85	-0.63%	1.46	1.17	-19.43%
UP3-G	None	U.Freeport	11/9	27.56	2.44	0.17	1.54	0.73	17.00	17.51	2.98%	1.51	1.34	-11.14%
UP4-G	None	U.Freeport	11/13	27.66	2.42	0.13	1.65	0.64	16.26	17.46	7.34%	1.42	1.41	-1.05%
IP1-G	None	Illinois	11/14	11.87	3.44	0.77	0.45	2.22	10.43	11.66	11.74%	3.02	3.15	4.27%
IP2-G	None	Illinois	11/15	11.90	3.53	0.76	0.35	2.42	11.08	11.72	5.80%	3.29	3.37	2.65%
IP3-G	None	Illinois	11/16	12.17	3.54	0.76	0.51	2.27	13.17	13.19	0.18%	3.83	3.70	-3.45%
IP4-G	None	Illinois	11/17	12.34	3.62	0.77	0.52	2.33	12.43	12.74	2.54%	3.65	3.62	-0.69%
PD1-G	0.1% DCHA	Pittsburgh	11/21	8.69	4.53	0.17	2.48	1.88	10.62	10.13	-4.59%	5.54	5.51	-0.43%
PD2-G	0.1% DCHA	Pittsburgh	11/22	8.74	4.68	0.15	2.35	2.18	9.15	9.61	5.06%	4.90	4.82	-1.66%
PD3-G	0.1% DCHA	Pittsburgh	11/27	8.70	4.71	0.16	2.51	1.32	9.65	10.28	6.57%	5.22	5.16	-1.25%
PD4-G	0.5% DCHA	Pittsburgh	11/28	8.83	4.74	0.15	2.31	2.28	7.08	7.18	1.41%	3.80	3.63	-4.54%
PD5-G	0.5% DCHA	Pittsburgh	11/30	8.89	4.54	0.13	2.13	2.28	10.24	10.30	0.58%	5.23	5.21	-0.41%
PD6-G	0.5% DCHA	Pittsburgh	12/4	8.72	4.62	0.14	2.10	2.38	10.26	10.14	-1.20%	5.44	5.36	-1.35%
UD1-G	0.1% DCHA	U.Freeport	12/5	27.71	2.37	0.09	1.49	0.79	22.14	20.53	-7.26%	1.89	1.70	-10.21%
UD2-G	0.1% DCHA	U.Freeport	12/6	27.79	2.76	0.10	1.52	1.14	14.09	13.51	-4.15%	1.40	1.02	-27.15%
UD3-G	0.1% DCHA	U.Freeport	12/7	27.75	2.40	0.10	1.42	0.88	16.79	16.29	-2.94%	1.45	1.32	-9.41%
UD4-G	0.5% DCHA	U.Freeport	12/8	27.65	2.38	0.10	1.36	0.92	24.64	23.86	-3.15%	2.12	1.88	-11.49%
UD5-G	0.5% DCHA	U.Freeport	12/9	27.44	2.43	0.10	1.49	0.84	30.29	29.45	-2.80%	2.68	2.47	-8.00%
UD6-G	0.5% DCHA	U.Freeport	12/18	27.62	2.42	0.11	1.48	0.84	33.75	33.35	-1.19%	2.96	2.85	-3.47%

Table 3-3
RESULTS FROM FINAL
SEPARATION RUNS
(10/30/89 TO 12/29/89)

EXPERIMENTAL RUN INFORMATION				FEED					ASH BALANCE			TOTAL SULFUR BALANCE		
Run	Treatment	Coal	Date	Ash (%)	Total Sulfur (%)	Sulfate Sulfur (%)	Pyritic Sulfur (%)	Organic Sulfur (%)	Feed Ash (gms)	Plate Ash (gms)	Error Ash (%)	Feed T Sulfur (gms)	Plate T Sulfur (gms)	Error T Sulfur (%)
PN1-G	1000ppm NH3	Pittsburgh	12/14	8.89	4.70	0.14	2.40	2.16	11.70	11.79	0.78%	6.19	6.02	-2.71%
PN2-G	1000ppm NH3	Pittsburgh	12/15	8.62	4.78	0.14	2.34	2.30	9.67	9.95	2.88%	5.36	5.04	-6.04%
PN3-G	1000ppm NH3	Pittsburgh	12/19	8.94	4.74	0.16	1.96	2.62	10.84	10.83	-0.14%	5.75	5.60	-2.68%
UN1-G	1000ppm NH3	U.Freeport	12/11	27.80	2.36	0.10	1.49	0.78	31.53	29.78	-5.54%	2.68	2.66	-0.63%
UN2-G	1000ppm NH3	U.Freeport	12/12	27.69	2.42	0.10	1.49	0.83	29.19	29.32	0.45%	2.55	2.52	-1.09%
UN3-G	1000ppm NH3	U.Freeport	12/13	27.66	2.56	0.15	1.49	0.92	34.38	34.44	0.17%	3.18	2.81	-11.67%
PQ1-G	0.1% Quinoline	Pittsburgh	12/20	8.75	4.73	0.14	2.34	2.25	10.00	10.07	0.67%	5.41	5.29	-2.09%
PQ2-G	0.1% Quinoline	Pittsburgh	12/26	8.65	4.69	0.14	1.21	3.34	10.17	10.22	0.42%	5.52	5.27	-4.47%
PQ3-G	0.1% Quinoline	Pittsburgh	12/27	8.61	4.65	0.12	2.02	2.51	10.19	9.56	-6.25%	5.51	5.27	-4.28%
PV1-G	P-18kV,N-6kV	Pittsburgh	12/29	9.09	4.75	0.14	2.36	2.25	12.15	11.86	-2.38%	6.35	6.36	0.14%
ADDITIONAL TESTS														
T1A-G	None	Pittsburgh	1/13	9.12	4.79	0.14	2.04	2.61	20.95	20.40	-2.61%	11.00	10.69	-2.85%
T1B-G	None	Pittsburgh	1/14	8.76	4.74	0.12	2.23	2.39	20.12	20.24	0.59%	10.89	10.04	-7.77%
T2-G	0.1% DCHA	Pittsburgh	1/16	8.79	4.65	0.13	2.26	2.26	13.04	13.12	0.60%	6.90	6.97	1.03%
TEST FOR TWO STAGE TRIBO CHARGER														
TS1-G	None	Pittsburgh	6/8	17.08	6.97	0.31	2.33	4.33	11.08	10.82	-2.36%	4.52	4.24	-6.36%

Table 3-3

RESULTS FROM FINAL
SEPARATION RUNS
(10/30/89 TO 12/29/89)

EXPERIMENTAL RUN INFORMATION				PYRITIC SULFUR BALANCE			ORGANIC SULFUR BALANCE			PYRITIC & SULFATE BALANCE		
Run	Treatment	Coal	Date	Feed P Sulfur (gms)	Plate P Sulfur (gms)	Error P Sulfur (%)	Feed O Sulfur (gms)	Plate O Sulfur (gms)	Error O Sulfur (%)	Feed P&S Sulfur (gms)	Plate P&S Sulfur (gms)	Error P&S Sulfur (%)
PP1-G	None	Pittsburgh	10/30	1.20	1.10	-8.54%	1.38	1.48	7.39%	1.28	1.18	-8.19%
PP2-G	None	Pittsburgh	10/31	1.69	1.51	-10.66%	2.06	2.13	3.03%	1.82	1.63	-10.03%
PP3-G	None	Pittsburgh	11/2	2.11	1.66	-21.61%	2.87	3.35	16.60%	2.28	1.83	-19.85%
PP4-G	None	Pittsburgh	11/6	2.09	2.58	23.65%	1.71	2.58	51.31%	2.24	2.75	22.66%
UP1-G	None	U.Freeport	11/7	1.60	1.64	2.43%	0.84	0.63	-24.81%	1.73	1.76	2.03%
UP2-G	None	U.Freeport	11/8	0.93	0.77	-16.62%	0.46	0.31	-31.46%	1.00	0.86	-13.90%
UP3-G	None	U.Freeport	11/9	0.95	0.78	-17.51%	0.45	0.47	3.93%	1.06	0.87	-17.57%
UP4-G	None	U.Freeport	11/13	0.97	0.93	-4.46%	0.38	0.40	5.28%	1.05	1.01	-3.33%
IP1-G	None	Illinois	11/14	0.40	0.50	27.21%	1.95	1.93	-1.15%	1.07	1.22	14.13%
IP2-G	None	Illinois	11/15	0.33	0.51	55.37%	2.25	2.10	-6.75%	1.03	1.27	23.14%
IP3-G	None	Illinois	11/16	0.55	0.43	-22.49%	2.46	2.45	-0.21%	1.37	1.25	-9.24%
IP4-G	None	Illinois	11/17	0.52	0.34	-34.82%	2.35	2.46	4.80%	1.30	1.16	-10.61%
PD1-G	0.1% DCHA	Pittsburgh	11/21	3.03	2.56	-15.40%	2.30	2.74	19.09%	3.24	2.78	-14.28%
PD2-G	0.1% DCHA	Pittsburgh	11/22	2.46	2.41	-2.09%	2.28	2.25	-1.53%	2.62	2.57	-1.64%
PD3-G	0.1% DCHA	Pittsburgh	11/27	2.78	1.84	-33.80%	1.46	3.13	113.70%	2.96	2.03	-31.50%
PD4-G	0.5% DCHA	Pittsburgh	11/28	1.85	1.33	-28.40%	1.83	2.17	18.84%	1.97	1.46	-26.21%
PD5-G	0.5% DCHA	Pittsburgh	11/30	2.45	2.07	-15.54%	2.63	2.97	12.93%	2.60	2.24	-13.87%
PD6-G	0.5% DCHA	Pittsburgh	12/4	2.47	2.45	-0.76%	2.80	2.75	-1.77%	2.64	2.61	-0.91%
UD1-G	0.1% DCHA	U.Freeport	12/5	1.19	1.08	-9.05%	0.63	0.54	-14.93%	1.26	1.16	-7.85%
UD2-G	0.1% DCHA	U.Freeport	12/6	0.77	0.48	-37.46%	0.58	0.48	-16.13%	0.82	0.53	-34.91%
UD3-G	0.1% DCHA	U.Freeport	12/7	0.86	0.76		0.53	0.50	-5.76%	0.92	0.81	-11.52%
UD4-G	0.5% DCHA	U.Freeport	12/8	1.21	1.01	-16.74%	0.82	0.78	-4.66%	1.30	1.10	-15.74%
UD5-G	0.5% DCHA	U.Freeport	12/9	1.64	1.40	-14.84%	0.93	0.94	1.07%	1.75	1.53	-12.81%
UD6-G	0.5% DCHA	U.Freeport	12/18	1.81	1.93	6.77%	1.02	0.81	-20.96%	1.94	2.05	5.75%

Table 3-3
RESULTS FROM FINAL
SEPARATION RUNS
(10/30/89 TO 12/29/89)

EXPERIMENTAL RUN INFORMATION				PYRITIC SULFUR BALANCE			ORGANIC SULFUR BALANCE			PYRITIC & SULFATE BALANCE		
Run	Treatment	Coal	Date	Feed P Sulfur (gms)	Plate P Sulfur (gms)	Error P Sulfur (%)	Feed O Sulfur (gms)	Plate O Sulfur (gms)	Error O Sulfur (%)	Feed P&S Sulfur (gms)	Plate P&S Sulfur (gms)	Error P&S Sulfur (%)
PN1-G	1000ppm NH3	Pittsburgh	12/14	3.16	2.91	-7.93%	2.84	2.93	3.01%	3.35	3.09	-7.64%
PN2-G	1000ppm NH3	Pittsburgh	12/15	2.63	2.29	-12.87%	2.58	2.59	0.45%	2.79	2.44	-12.28%
PN3-G	1000ppm NH3	Pittsburgh	12/19	2.38	2.50	5.36%	3.18	2.93	-7.85%	2.57	2.67	3.80%
UN1-G	1000ppm NH3	U.Freeport	12/11	1.69	1.40	-17.20%	0.88	1.16	30.63%	1.80	1.51	-16.19%
UN2-G	1000ppm NH3	U.Freeport	12/12	1.57	1.62	3.08%	0.88	0.80	-9.17%	1.67	1.72	2.97%
UN3-G	1000ppm NH3	U.Freeport	12/13	1.85	2.15	16.03%	1.14	0.55	-52.32%	2.04	2.21	8.48%
PQ1-G	0.1% Quinoline	Pittsburgh	12/20	2.67	2.34	-12.44%	2.57	2.79	8.62%	2.83	2.50	-11.90%
PQ2-G	0.1% Quinoline	Pittsburgh	12/26	1.42	2.26	58.85%	3.93	2.85	-27.38%	1.59	2.42	52.19%
PQ3-G	0.1% Quinoline	Pittsburgh	12/27	2.39	2.04	-14.73%	2.97	3.07	3.44%	2.53	2.20	-13.32%
PV1-G	P-18kV,N-6kV	Pittsburgh	12/29	3.16	2.71	-14.20%	3.01	3.47	15.31%	3.34	2.89	-13.50%
ADDITIONAL TESTS												
T1A-G	None	Pittsburgh	1/13	4.69	5.02	7.08%	6.00	5.35	-10.84%	5.01	5.34	6.72%
T1B-G	None	Pittsburgh	1/14	5.12	4.99	-2.57%	5.49	4.75	-13.43%	5.40	5.29	-2.01%
T2-G	0.1% DCHA	Pittsburgh	1/16	3.35	3.27	-2.63%	3.35	3.53	5.19%	3.55	3.44	-2.91%
TEST FOR TWO STAGE TRIBO CHARGER												
TS1-G	None	Pittsburgh	6/8	1.51	2.63	74.09%	2.81	1.36	-51.57%	1.71	2.87	67.78%

Table 3-3
RESULTS FROM FINAL
SEPARATION RUNS
(10/30/89 TO 12/29/89)

EXPERIMENTAL RUN INFORMATION				EXPERIMENTAL RUN RESULTS									
Run	Treatment	Coal	Date	P&S Sulfur Rejection	P Sulfur Rejection	T Sulfur Rejection	Ash Rejection	Clean Coal Feed (gms)	Clean Coal Pos Plate (gms)	Clean Coal Neg Plate (gms)	Overall Clean Coal Recovery	% Recov on Plates	% Total Recovery
PP1-G	None	Pittsburgh	10/30	80.0%	80.3%	64.7%	79.3%	123.2	17.0	28.5	62.6%	36.8%	77.8%
PP2-G	None	Pittsburgh	10/31	74.5%	74.7%	57.0%	69.6%	126.6	29.0	44.9	60.8%	57.5%	96.2%
PP3-G	None	Pittsburgh	11/2	64.4%	64.4%	57.8%	65.4%	107.6	33.6	58.0	63.3%	83.8%	93.0%
PP4-G	None	Pittsburgh	11/6	108.3%	110.4%	83.8%	86.4%	114.8	32.1	58.6	64.6%	81.9%	97.4%
UP1-G	None	U.Freeport	11/7	67.5%	68.3%	52.8%	78.2%	97.7	20.9	51.5	71.1%	74.5%	95.8%
UP2-G	None	U.Freeport	11/8	57.2%	57.0%	43.8%	77.4%	101.6	10.9	28.9	72.7%	38.5%	96.7%
UP3-G	None	U.Freeport	11/9	57.4%	58.3%	50.0%	80.6%	95.9	11.7	29.8	71.8%	43.5%	61.2%
UP4-G	None	U.Freeport	11/13	66.9%	67.2%	59.9%	83.4%	94.4	13.3	25.2	65.4%	42.0%	88.5%
IP1-G	None	Illinois	11/14	73.7%	83.4%	59.2%	78.1%	110.4	36.8	33.2	47.4%	64.7%	90.6%
IP2-G	None	Illinois	11/15	75.8%	94.8%	53.2%	74.2%	106.0	34.4	40.2	53.9%	71.2%	96.6%
IP3-G	None	Illinois	11/16	52.4%	40.0%	48.5%	69.1%	99.8	36.2	51.4	58.7%	87.5%	97.0%
IP4-G	None	Illinois	11/17	53.8%	41.0%	48.8%	68.1%	100.6	33.7	47.0	58.3%	80.5%	89.1%
PD1-G	0.1% DCHA	Pittsburgh	11/21	70.1%	69.9%	55.9%	70.5%	127.2	25.8	75.2	74.4%	79.0%	94.7%
PD2-G	0.1% DCHA	Pittsburgh	11/22	85.0%	85.3%	57.7%	83.2%	112.1	21.0	64.4	75.4%	76.5%	92.3%
PD3-G	0.1% DCHA	Pittsburgh	11/27	54.7%	53.1%	57.2%	84.1%	121.0	22.4	67.9	75.2%	75.7%	91.3%
PD4-G	0.5% DCHA	Pittsburgh	11/28	49.3%	49.6%	51.2%	70.4%	117.1	21.5	44.2	67.3%	56.0%	93.4%
PD5-G	0.5% DCHA	Pittsburgh	11/30	68.5%	69.8%	52.6%	68.3%	113.6	31.0	63.5	67.2%	83.2%	92.8%
PD6-G	0.5% DCHA	Pittsburgh	12/4	73.1%	75.1%	53.4%	67.4%	116.9	33.0	63.8	65.9%	82.6%	91.8%
UD1-G	0.1% DCHA	U.Freeport	12/5	58.3%	58.0%	47.0%	69.3%	95.7	13.7	42.3	75.6%	56.4%	93.6%
UD2-G	0.1% DCHA	U.Freeport	12/6	30.5%	28.5%	36.7%	72.1%	103.0	7.9	27.2	77.5%	32.8%	92.9%
UD3-G	0.1% DCHA	U.Freeport	12/7	55.2%	55.5%	47.1%	71.3%	103.3	10.3	31.3	75.3%	39.5%	85.9%
UD4-G	0.5% DCHA	U.Freeport	12/8	65.8%	67.1%	48.0%	76.8%	94.8	17.1	44.4	72.3%	63.5%	96.2%
UD5-G	0.5% DCHA	U.Freeport	12/9	56.8%	57.1%	49.9%	72.8%	96.4	22.3	53.8	70.7%	77.5%	95.8%
UD6-G	0.5% DCHA	U.Freeport	12/18	69.2%	70.9%	53.9%	74.7%	90.8	24.6	58.5	70.4%	90.9%	97.6%

Table 3-3

RESULTS FROM FINAL
SEPARATION RUNS
(10/30/89 TO 12/29/89)

EXPERIMENTAL RUN INFORMATION				EXPERIMENTAL RUN RESULTS									
Run	Treatment	Coal	Date	P&S Sulfur Rejection	P Sulfur Rejection	T Sulfur Rejection	Ash Rejection	Clean Coal Feed (gms)	Clean Coal Pos Plate (gms)	Clean Coal Neg Plate (gms)	Overall Clean Coal Recovery	% Recov on Plates	% Total Recovery
PN1-G	1000ppm NH3	Pittsburgh	12/14	75.7%	76.2%	59.6%	75.2%	121.7	41.4	66.3	61.6%	88.4%	95.9%
PN2-G	1000ppm NH3	Pittsburgh	12/15	49.3%	49.3%	42.0%	52.6%	109.1	30.1	62.1	67.3%	84.2%	94.2%
PN3-G	1000ppm NH3	Pittsburgh	12/19	93.6%	96.1%	62.1%	78.5%	112.4	37.2	62.0	62.5%	88.0%	97.2%
UN1-G	1000ppm NH3	U.Freeport	12/11	52.8%	52.5%	57.2%	71.7%	94.0	25.3	53.0	67.6%	81.4%	94.5%
UN2-G	1000ppm NH3	U.Freeport	12/12	77.1%	78.1%	59.5%	77.8%	97.4	27.3	43.7	61.5%	73.0%	96.7%
UN3-G	1000ppm NH3	U.Freeport	12/13	76.6%	83.7%	51.1%	78.5%	92.3	28.3	56.0	66.4%	90.5%	97.0%
PQ1-G	0.1% Quinoline	Pittsburgh	12/20	79.5%	79.6%	62.2%	83.4%	111.6	30.8	62.8	67.1%	83.7%	94.4%
PQ2-G	0.1% Quinoline	Pittsburgh	12/26	133.0%	139.9%	61.6%	81.6%	112.8	31.4	65.4	67.6%	85.5%	96.3%
PQ3-G	0.1% Quinoline	Pittsburgh	12/27	74.2%	73.5%	60.3%	76.1%	114.6	37.0	61.3	62.4%	84.8%	95.0%
PV1-G	P-18kV,N-6kV	Pittsburgh	12/29	75.7%	75.6%	64.1%	79.0%	125.0	37.8	71.3	65.4%	87.1%	94.2%
ADDITIONAL TESTS													
T1A-G	None	Pittsburgh	1/13	58.7%	58.4%	53.0%	52.2%						
T1B-G	None	Pittsburgh	1/14	53.1%	52.7%	46.7%	54.2%						
T2-G	0.1% DCHA	Pittsburgh	1/16	62.1%	62.3%	63.1%	64.1%						
TEST FOR TWO STAGE TRIBO CHARGER													
TS1-G	None	Pittsburgh	6/8	155.4%	164.2%	61.4%	73.7%	50.5	11.9	33.7	74.0%	88.7%	97.1%

Table 3-3
RESULTS FROM FINAL
SEPARATION RUNS
(10/30/89 TO 12/29/89)

EXPERIMENTAL RUN INFORMATION				MATERIAL BALANCE						
Run	Treatment	Coal	Date	Feed gms	Positive Plate gms	Positive Plate %	Negative Plate gms	Negative Plate %	Losses gms	Losses %
PP1-G	None	Pittsburgh	10/30	150.8	24.3	16.1%	31.2	20.7%	95.3	63.2%
PP2-G	None	Pittsburgh	10/31	153.4	38.7	25.2%	49.5	32.3%	65.2	42.5%
PP3-G	None	Pittsburgh	11/2	131.3	45.8	34.9%	64.2	48.9%	21.3	16.2%
PP4-G	None	Pittsburgh	11/6	136.2	47.1	34.6%	64.5	47.4%	24.6	18.1%
UP1-G	None	U.Freeport	11/7	144.1	46.7	32.4%	60.7	42.1%	36.7	25.5%
UP2-G	None	U.Freeport	11/8	150.6	24.5	16.3%	33.5	22.2%	92.6	61.5%
UP3-G	None	U.Freeport	11/9	141.9	26.9	19.0%	34.8	24.5%	80.2	56.5%
UP4-G	None	U.Freeport	11/13	139.9	28.6	20.4%	30.2	21.6%	81.1	58.0%
IP1-G	None	Illinois	11/14	135.9	48.5	35.7%	39.4	29.0%	48.0	35.3%
IP2-G	None	Illinois	11/15	130.8	46.1	35.2%	47.0	35.9%	37.7	28.8%
IP3-G	None	Illinois	11/16	123.6	49.0	39.6%	59.2	47.9%	15.4	12.5%
IP4-G	None	Illinois	11/17	125.1	45.7	36.5%	55.0	44.0%	24.4	19.5%
PD1-G	0.1% DCHA	Pittsburgh	11/21	154.6	39.5	25.5%	82.7	53.5%	32.4	21.0%
PD2-G	0.1% DCHA	Pittsburgh	11/22	136.9	34.3	25.1%	70.4	51.4%	32.2	23.5%
PD3-G	0.1% DCHA	Pittsburgh	11/27	146.5	36.5	24.9%	74.4	50.8%	35.6	24.3%
PD4-G	0.5% DCHA	Pittsburgh	11/28	143.3	30.4	21.2%	49.8	34.8%	63.1	44.0%
PD5-G	0.5% DCHA	Pittsburgh	11/30	138.5	43.5	31.4%	71.7	51.8%	23.3	16.8%
PD6-G	0.5% DCHA	Pittsburgh	12/4	142.5	45.7	32.1%	72.0	50.5%	24.8	17.4%
UD1-G	0.1% DCHA	U.Freeport	12/5	141.7	30.8	21.7%	49.1	34.7%	61.8	43.6%
UD2-G	0.1% DCHA	U.Freeport	12/6	154.4	19.1	12.4%	31.6	20.5%	103.7	67.2%
UD3-G	0.1% DCHA	U.Freeport	12/7	153.2	23.6	15.4%	36.9	24.1%	92.7	60.5%
UD4-G	0.5% DCHA	U.Freeport	12/8	140.3	38.0	27.1%	51.1	36.4%	51.2	36.5%
UD5-G	0.5% DCHA	U.Freeport	12/9	142.4	47.0	33.0%	63.4	44.5%	32.0	22.5%
UD6-G	0.5% DCHA	U.Freeport	12/18	134.5	53.0	39.4%	69.2	51.4%	12.3	9.1%

Table 3-3

RESULTS FROM FINAL
SEPARATION RUNS
(10/30/89 TO 12/29/89)

EXPERIMENTAL RUN INFORMATION				MATERIAL BALANCE						
Run	Treatment	Coal	Date	Feed gms	Positive Plate gms	Positive Plate %	Negative Plate gms	Negative Plate %	Losses gms	Losses %
PN1-G	1000ppm NH3	Pittsburgh	12/14	148.9	57.6	38.7%	74.0	49.7%	17.3	11.6%
PN2-G	1000ppm NH3	Pittsburgh	12/15	133.3	39.7	29.8%	72.5	54.4%	21.1	15.8%
PN3-G	1000ppm NH3	Pittsburgh	12/19	137.8	52.9	38.4%	68.4	49.6%	16.5	12.0%
UN1-G	1000ppm NH3	U.Freeport	12/11	139.3	51.0	36.6%	62.4	44.8%	25.9	18.6%
UN2-G	1000ppm NH3	U.Freeport	12/12	144.4	53.1	36.8%	52.3	36.2%	39.0	27.0%
UN3-G	1000ppm NH3	U.Freeport	12/13	137.3	58.5	42.6%	65.8	47.9%	13.0	9.5%
PQ1-G	0.1% Quinoline	Pittsburgh	12/20	136.5	45.9	33.6%	68.4	50.1%	22.2	16.3%
PQ2-G	0.1% Quinoline	Pittsburgh	12/26	137.6	46.5	33.8%	71.1	51.7%	20.0	14.5%
PQ3-G	0.1% Quinoline	Pittsburgh	12/27	139.6	51.4	36.8%	67.0	48.0%	21.2	15.2%
PV1-G	P-18kV,N-6kV	Pittsburgh	12/29	153.5	55.5	36.2%	78.2	50.9%	19.8	12.9%
ADDITIONAL TESTS										
T1A-G	None	Pittsburgh	1/13							
T1B-G	None	Pittsburgh	1/14							
T2-G	0.1% DCHA	Pittsburgh	1/16							
TEST FOR TWO STAGE TRIBO CHARGER										
TS1-G	None	Pittsburgh	6/8	73.2	25.6	35.0%	39.3	53.7%	8.3	11.3%

Table 3-3

RESULTS FROM FINAL
SEPARATION RUNS
(10/30/89 TO 12/29/89)

EXPERIMENTAL RUN INFORMATION				THEORETICAL BTU CALCULATION					ENERGY RECOVERY		
Run	Treatment	Coal	Date	Base Coal Btu Value	Base Coal Ash	Adjusted Btu Value	MAF Btu Value	Product Btu Value	Feed BTU	Cleaned BTU	BTU Recovery
PP1-G	None	Pittsburgh	10/30	13158	0.0915	13219	14483	14076	1617	968	59.9%
PP2-G	None	Pittsburgh	10/31	13158	0.0915	13232	14483	14053	2573	1534	59.6%
PP3-G	None	Pittsburgh	11/2	13158	0.0915	13228	14483	14069	3208	1991	62.1%
PP4-G	None	Pittsburgh	11/6	13158	0.0915	13229	14483	14070	3255	2001	61.5%
UP1-G	None	U.Freeport	11/7	10224	0.3115	10776	14850	13102	2552	1753	68.7%
UP2-G	None	U.Freeport	11/8	10224	0.3115	10765	14850	13296	1376	982	71.3%
UP3-G	None	U.Freeport	11/9	10224	0.3115	10757	14850	13222	1463	1014	69.3%
UP4-G	None	U.Freeport	11/13	10224	0.3115	10742	14850	12934	1393	861	61.8%
IP1-G	None	Illinois	11/14	12085	0.1255	12179	13819	12588	2360	1093	46.3%
IP2-G	None	Illinois	11/15	12085	0.1255	12175	13819	12790	2499	1325	53.0%
IP3-G	None	Illinois	11/16	12085	0.1255	12138	13819	12674	2895	1654	57.1%
IP4-G	None	Illinois	11/17	12085	0.1255	12114	13819	12746	2689	1545	57.5%
PD1-G	0.1% DCHA	Pittsburgh	11/21	13158	0.0915	13225	14483	14246	3563	2597	72.9%
PD2-G	0.1% DCHA	Pittsburgh	11/22	13158	0.0915	13217	14483	14072	3051	2184	71.6%
PD3-G	0.1% DCHA	Pittsburgh	11/27	13158	0.0915	13223	14483	14062	3233	2306	71.3%
PD4-G	0.5% DCHA	Pittsburgh	11/28	13158	0.0915	13204	14483	13845	2335	1520	65.1%
PD5-G	0.5% DCHA	Pittsburgh	11/30	13158	0.0915	13196	14483	13816	3351	2184	65.2%
PD6-G	0.5% DCHA	Pittsburgh	12/4	13158	0.0915	13220	14483	13834	3430	2196	64.0%
UD1-G	0.1% DCHA	U.Freeport	12/5	10224	0.3115	10735	14850	13279	1891	1437	76.0%
UD2-G	0.1% DCHA	U.Freeport	12/6	10224	0.3115	10723	14850	13280	1199	925	77.2%
UD3-G	0.1% DCHA	U.Freeport	12/7	10224	0.3115	10729	14850	13362	1431	1087	76.0%
UD4-G	0.5% DCHA	U.Freeport	12/8	10224	0.3115	10744	14850	13411	2110	1511	71.6%
UD5-G	0.5% DCHA	U.Freeport	12/9	10224	0.3115	10775	14850	13121	2622	1834	69.9%
UD6-G	0.5% DCHA	U.Freeport	12/18	10224	0.3115	10748	14850	13102	2896	1999	69.0%

Table 3-3

RESULTS FROM FINAL
SEPARATION RUNS
(10/30/89 TO 12/29/89)

EXPERIMENTAL RUN INFORMATION				THEORETICAL BTU CALCULATION					ENERGY RECOVERY		
Run	Treatment	Coal	Date	Base Coal Btu Value	Base Coal Ash	Adjusted Btu Value	MAF Btu Value	Product Btu Value	Feed BTU	Cleaned BTU	BTU Recovery
PN1-G	1000ppm NH3	Pittsburgh	12/14	13158	0.0915	13196	14483	13898	3828	2267	59.2%
PN2-G	1000ppm NH3	Pittsburgh	12/15	13158	0.0915	13235	14483	13511	3274	2160	66.0%
PN3-G	1000ppm NH3	Pittsburgh	12/19	13158	0.0915	13188	14483	13994	3527	2110	59.8%
UN1-G	1000ppm NH3	U.Freeport	12/11	10224	0.3115	10721	14850	13143	2680	1808	67.5%
UN2-G	1000ppm NH3	U.Freeport	12/12	10224	0.3115	10738	14850	12976	2495	1496	60.0%
UN3-G	1000ppm NH3	U.Freeport	12/13	10224	0.3115	10742	14850	13167	2944	1910	64.9%
PQ1-G	0.1% Quinoline	Pittsburgh	12/20	13158	0.0915	13216	14483	14118	3330	2129	63.9%
PQ2-G	0.1% Quinoline	Pittsburgh	12/26	13158	0.0915	13230	14483	14092	3430	2209	64.4%
PQ3-G	0.1% Quinoline	Pittsburgh	12/27	13158	0.0915	13236	14483	14095	3455	2082	60.3%
PV1-G	P-18kV,N-6kV	Pittsburgh	12/29	13158	0.0915	13167	14483	14063	3881	2424	62.5%
ADDITIONAL TESTS											
T1A-G	None	Pittsburgh	1/13								
T1B-G	None	Pittsburgh	1/14								
T2-G	0.1% DCHA	Pittsburgh	1/16								
TEST FOR TWO STAGE TRIBO CHARGER											
TS1-G	None	Pittsburgh	6/8	13158	0.0915	14416	17386	13054	1883	1131	60.1%

Galbraith Labs was also used to analyze the samples obtained from the separation runs. However, upon receiving additional results, we found that we were still unable to close the pyritic sulfur balance. We experienced errors in the range of (-) 37% to (+) 58%. The balances around the total sulfur and the ash, however, were closing within 10%. This confirmed that the samples we were sending were representative and that the problem may lay with the analytical measurement of pyritic sulfur. We called Galbraith Labs to inform them of the discrepancy in the pyritic sulfur results and to determine how they measured pyritic sulfur. The test procedure they use for sulfur type is ASTM D2492 which measures pyritic and sulfate sulfur and calculates organic sulfur by difference. Total sulfur is measured by an independent analysis, ASTM D3177, and may explain why the total sulfur balances have good closure. We also reviewed the results with an in-house chemist who suggested that it may not be an analytical problem. It is possible there is an electrochemical reaction occurring due to the strong electric field of the plates and that the pyritic sulfur is changing its oxidation state to sulfate sulfur. Two additional tests were conducted in order to determine if this reaction is actually occurring. One test was run with untreated Pittsburgh coal and the second test with Pittsburgh coal treated with 0.1% dicyclohexylamine. Coal was distributed evenly on the positive and negative plates. The plates were charged for one hour. The coal was then removed and separated into three samples from the positive plates and three samples from the negative plates. Three samples from the feed were also obtained before the coal was distributed on the plates. The samples were then sent to Galbraith Labs for analysis.

A comparison of pyritic and sulfate sulfur in the feed with the comparable plate sample sulfur levels is shown in Table 3-4. The sulfur species levels in all the samples are relatively close. The data shows a slight increase in the rate of sulfate to pyritic sulfur on the positive plate for samples T1A-G and T1B-G. However, this could be due to analytical variation and round-off, and is not believed to be an indication of any electron transfer phenomenon taking place on the plates.

The data from the October 30, 1989 test run will be used as an example to explain how the sulfur and ash balances were performed.

Table 3-4

Comparison of Pyritic and Sulfate Sulfur in the Feed with Plate Sample Sulfur Levels

Run Number	Feed Coal Sulfur, %			Positive Plate Sulfur, %			Negative Plate Sulfur, %		
	Pyritic	Sulfate	S/P Ratio	Pyritic	Sulfate	S/P Ratio	Pyritic	Sulfate	S/P Ratio
T1A-G	2.04	0.14	.0686	2.18	0.16	.0734	2.19	0.12	.0548
T1B-G	2.23	0.12	.0538	2.15	0.13	.0605	2.20	0.13	.0591
T2-G	2.26	0.13	.0575	2.23	0.12	.0538	2.15	0.12	.0558

Raw Data From Data Sheets

POSITIVE PLATE		NEGATIVE PLATE		FEED
PLATE COAL	PYR SULFUR	PLATE COAL	PYR SULFUR	PYR SULFUR
24.3 gms	3.96 %	31.2 gms	0.43 %	2.16 %

Pyritic Sulfur Balance Calculations

Pyr sulfur(feed)=(coal on pos plate + coal on neg plate) x (% pyr sulfur in feed/100)
= (24.3 gms + 31.2 gms) x (.0216) = 1.20 gms

Pyr sulfur(plates)=(coal on pos plate x % pyr sulfur on pos plate/100)+
(coal on neg plate x % pyr sulfur on neg plate)
= (24.3 gms x .0396)+(31.2 gms x .0043) = 1.10 gms

% Error in balance=(plate pyr sulfur - feed pyr sulfur)/(feed pyr sulfur)
= (1.10 gms - 1.20 gms)/(1.20 gms) = -.0854 = -8.54%

The sulfur and ash balances are contained in the raw data spreadsheets which are presented in Section 3.3.3 (Summary of Raw Data) Tables 3-1, 3-2, and 3-3.

3.4.2 Sulfur and Ash Rejection

Sulfur and ash rejection was calculated using the analytical results from Galbraith Laboratory. Two types of sulfur rejections were calculated: total and pyritic. The sulfur and ash rejection results are contained in the raw data spreadsheets which are presented in Section 3.3.3 (Summary of Raw Data) Tables 3-1, 3-2, and 3-3.

The results presented in the spreadsheet were graphed to evaluate the effectiveness of each chemical treatment on sulfur and ash rejection. Figure 3-2 shows a comparison of the three coals without any chemical treatment. Figure 3-3 shows a comparison of the sulfur and ash rejection for the various chemical and gas treatments with Pittsburgh, while Figure 3-4 show the same for Upper Freeport coal.

As you can see from Figure 3-2, Untreated Coal Comparison, the pyritic and total sulfur rejection is the greatest with Pittsburgh coal while the ash rejection is greatest with Upper Freeport coal. Evaluating the effect that the chemical and gas treatments had on the sulfur and ash rejection of Pittsburgh coal, Figure 3-3, you can see that the pyritic rejection is enhanced with the Quinoline treatment, the ash rejection is enhanced by the Quinoline and Dicyclohexylamine treatments, and the total sulfur rejection was not enhanced by any of the chemical or gas treatments. However, the value of the total sulfur rejection with the Quinoline treatment was very close to the untreated value and accounting for experimental error these values are the same. Therefore, Quinoline enhanced the pyritic and ash rejection but had no effect on the total sulfur rejection. Evaluating Upper Freeport with the chemical and gas treatments, Figure 3-4, it can be said that Ammonia enhances the pyritic and total sulfur rejection, however, it slightly decreases the ash rejection. The ash rejection is greatest with no chemical or gas treatment.

FIGURE 3-2

UNTREATED COAL COMPARISON

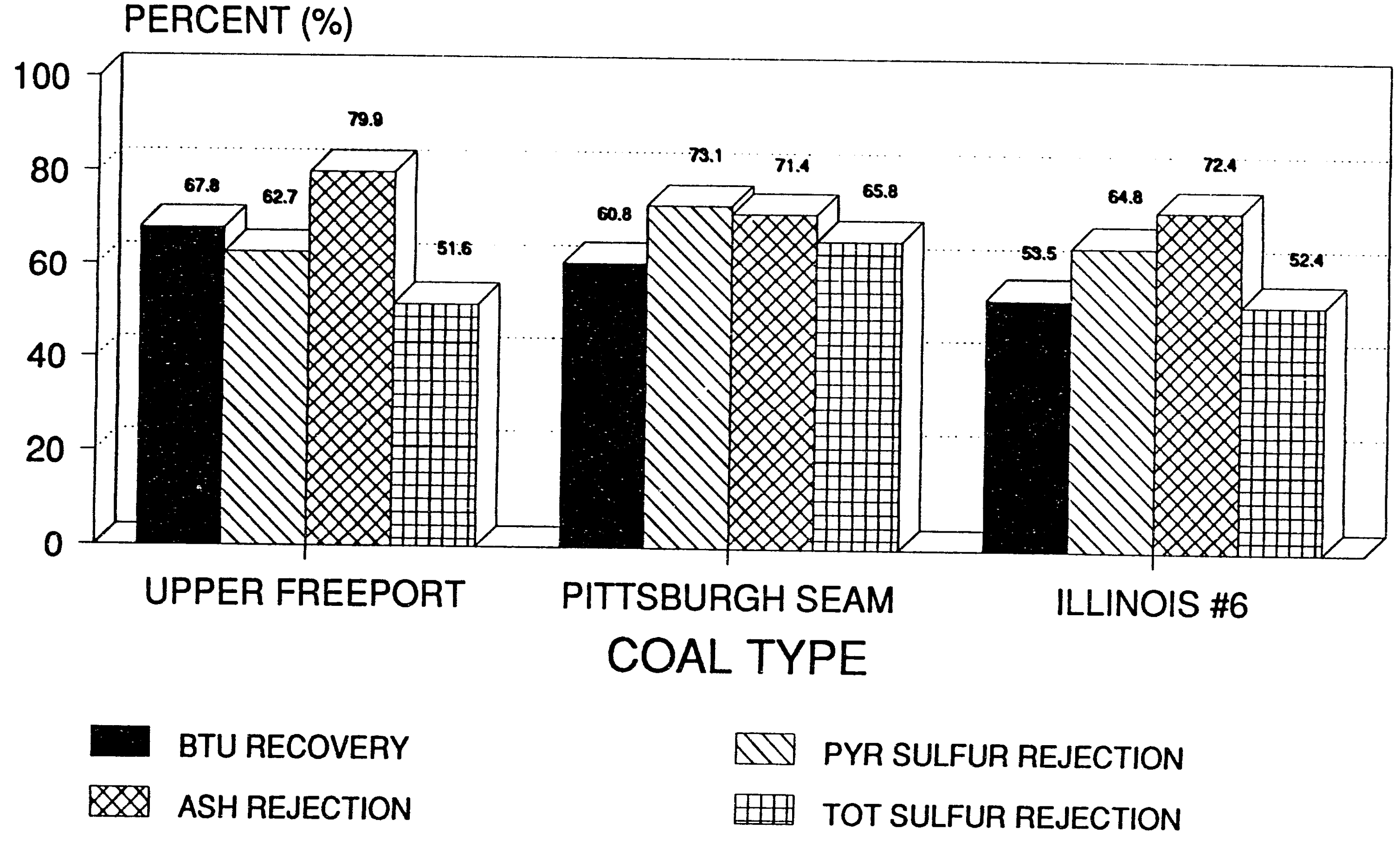


FIGURE 3-3

PITTSBURGH COAL TREATMENT RESULTS

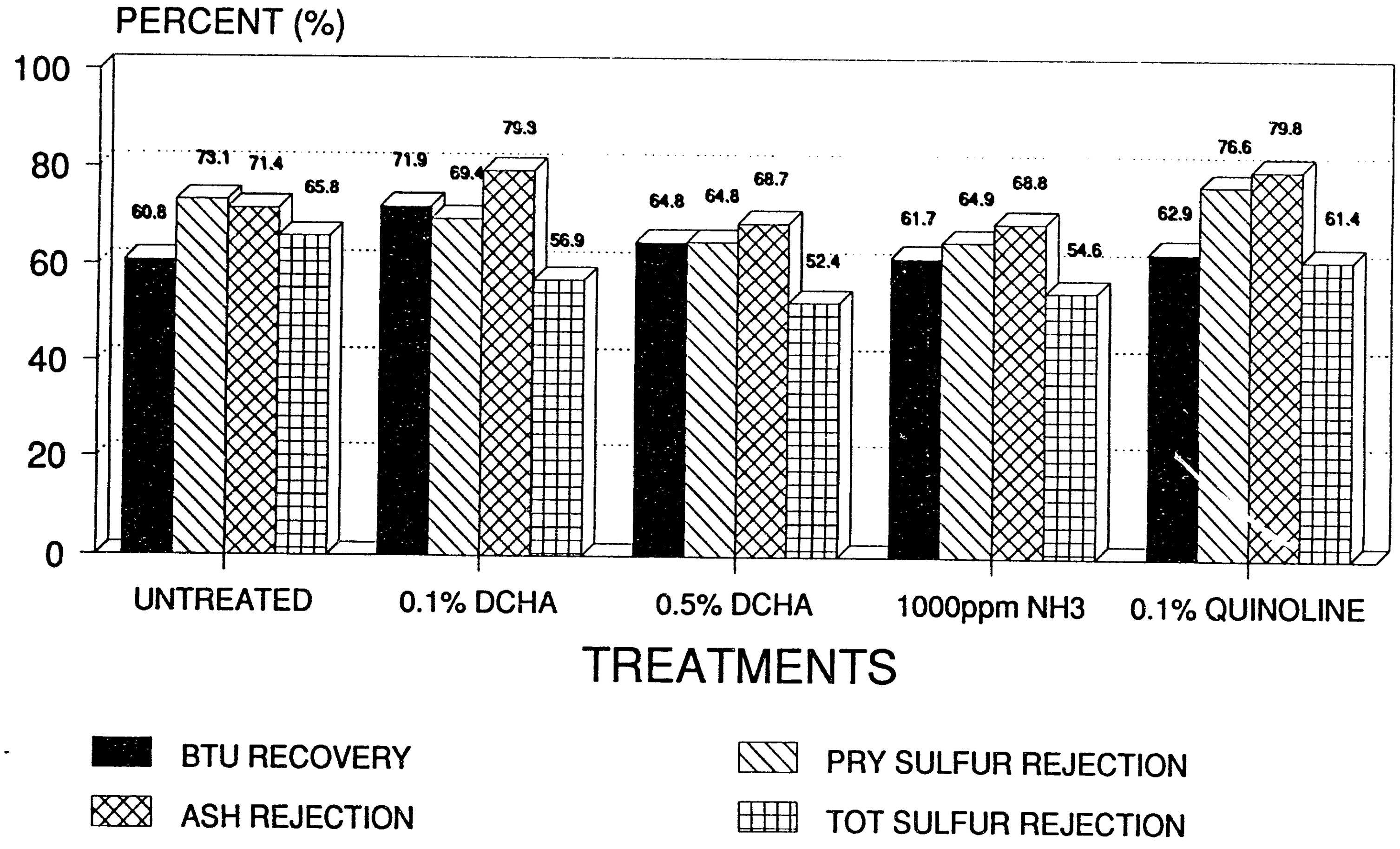
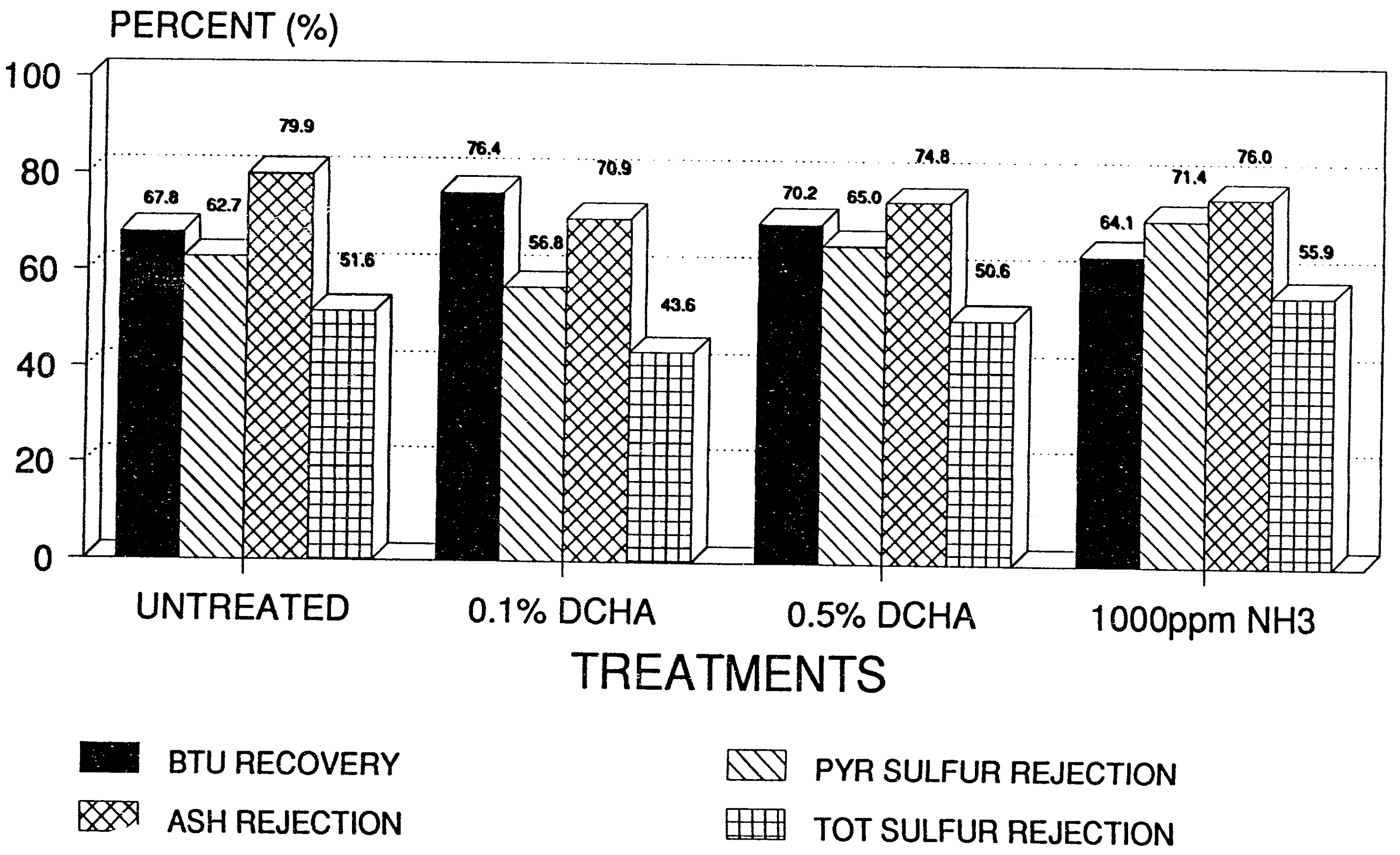


FIGURE 3-4

UPPER FREEPORT TREATMENT RESULTS



The data from the October 30, 1989 test run will be used as an example to explain how the sulfur and ash balances were performed.

Raw Data From Data Sheets

POSITIVE PLATE		NEGATIVE PLATE		FEED
PLATE COAL	PYR SULFUR	PLATE COAL	PYR SULFUR	PYR SULFUR
24.3 gms	3.96 %	31.2 gms	0.43 %	2.16 %

Pyritic Sulfur Rejection Calculations

Pyr sulfur rejection = (coal on pos plate x % pyr sulfur on pos plate/100)/
((coal on neg plate + coal on pos plate) x (% pyr sulfur in feed/100)
= (24.3 gms x .0396)/((24.3 gms + 31.2 gms) x (.0216)) = 80.3 %

The total sulfur rejection and the ash rejection were calculated in the exact same manner as the pyritic sulfur rejection.

3.4.3 Energy Recovery

Energy recovery was calculated from the Btu values received from Galbraith Laboratory and theoretically calculated values. The theoretical values were calculated based on the Btu value that was obtained for a reference sample of each of the three feed coals. The reference Btu value was then adjusted for the difference in ash between the reference coal sample and the run feed sample. The Btu value of the ash in the run feed sample was removed from the adjusted Btu value producing a moisture ash free (MAF) Btu value. The value of the ash in the clean coal sample was then added to the MAF Btu value. This value is the Btu value of the product (clean coal) sample. The calculated results were compared to the few actual sample results from Galbraith and were found to be accurate within 10%. The theoretical Btu calculation is as follows:

Run coal Btu Value = ((1-% run feed ash/100)/(1-% reference ash/100)) x (Reference Btu Value)

Moisture Ash Free (MAF) Btu Value = (Adj Btu Value)/(1-% run feed ash/100)

Clean Coal Btu Value = (MAF Btu Value) x (1-% clean coal ash/100)

Using the data from the October 30, 1989 run, (See Table 3-3):

Adjusted Btu Value = ((1-.9085)/(1-0.9127)) x (13158 Btu/lb) = 13219 Btu/lb

MAF Btu Value = (13097 Btu/lb)/(1-.0873) = 14483 Btu/lb

Clean Coal Btu Value = (14483 Btu/lb) x (1-.0281) = 14076 Btu/lb

Once the Btu values were calculated, the percent energy recovery was calculated for each run. The percent energy recovery was calculated as follows:

Feed Energy = (Run coal Btu/lb) x ((gms on pos plate + gms on neg plate)/ (453.6 gms/lb)

Clean Coal Energy = (Product Btu/lb) x ((gms on neg plate)/(453.6 gms/lb))

% Energy Recovery = (Clean Coal Energy)/(Feed Energy)

Using the data from the same run, October 30, 1989:

Feed Energy Value = (13219 Btu/lb) x ((24.3 gms + 31.2 gms)/(453.6 gms/lb)) = 1617 Btu

Clean Coal Energy Value = (14076 Btu/lb) x ((31.2 gms)/(453.6 gms/lb)) = 968 Btu

% Energy Recovery = (968 Btu)/(1617 Btu) = 59.9%

The percent energy recovery and intermediate Btu and energy values are listed in Table 3-3. These energy recovery results are shown graphically in Section 3.4.2, Figures 3-2 through 3-3. A comparison between the three untreated coals (Figure 3-2) shows Upper Freeport with the highest energy recovery, Pittsburgh with the next highest and Illinois #6 with the lowest. A comparison of the energy recovery for treated and untreated Pittsburgh coal (Figure 3-3) shows all the treated runs with a higher energy recovery than the untreated runs. However, quinoline, ammonia and 0.5% dicyclohexylamine show only a slight improvement over the untreated value while 0.1% dicyclohexylamine shows a significant improvement (11.4%). Figure 3-4 shows a comparison of energy recoveries for treated and untreated Upper Freeport coal. These graphs show ammonia having a negative effect, 0.5% dicyclohexylamine having no effect, and 0.1% dicyclohexylamine having a significant effect (10.7% increase). Therefore, 0.1% dicyclohexylamine was the only treatment that produced a significant increase in the energy recovery for Pittsburgh and Upper Freeport coal.

3.4.4 Effectiveness of Chemical and Gas Treatments

In order to determine the effectiveness of each chemical and gas treatment, an evaluation criteria had to be decided upon. It was decided that the most important performance parameters are Btu recovery, clean coal recovery, and total sulfur rejection. These three parameters were graphed together to determine if any of the treatments had a significant effect compared to the untreated coal. Figure 3-5 is a graph of the three parameters for the three untreated coals. Figure 3-6 shows a comparison of the chemical and gas treatments for Pittsburgh coal, while, Figure 3-7 shows the same comparison for Upper Freeport coal.

For Pittsburgh coal, each of the chemical and gas treatments produced an increase, over the untreated coal, in the Btu and clean coal recoveries. However, they all decreased the total sulfur rejection when compared with the untreated value. Even though each of the

FIGURE 3-5

UNTREATED COAL COMPARISON

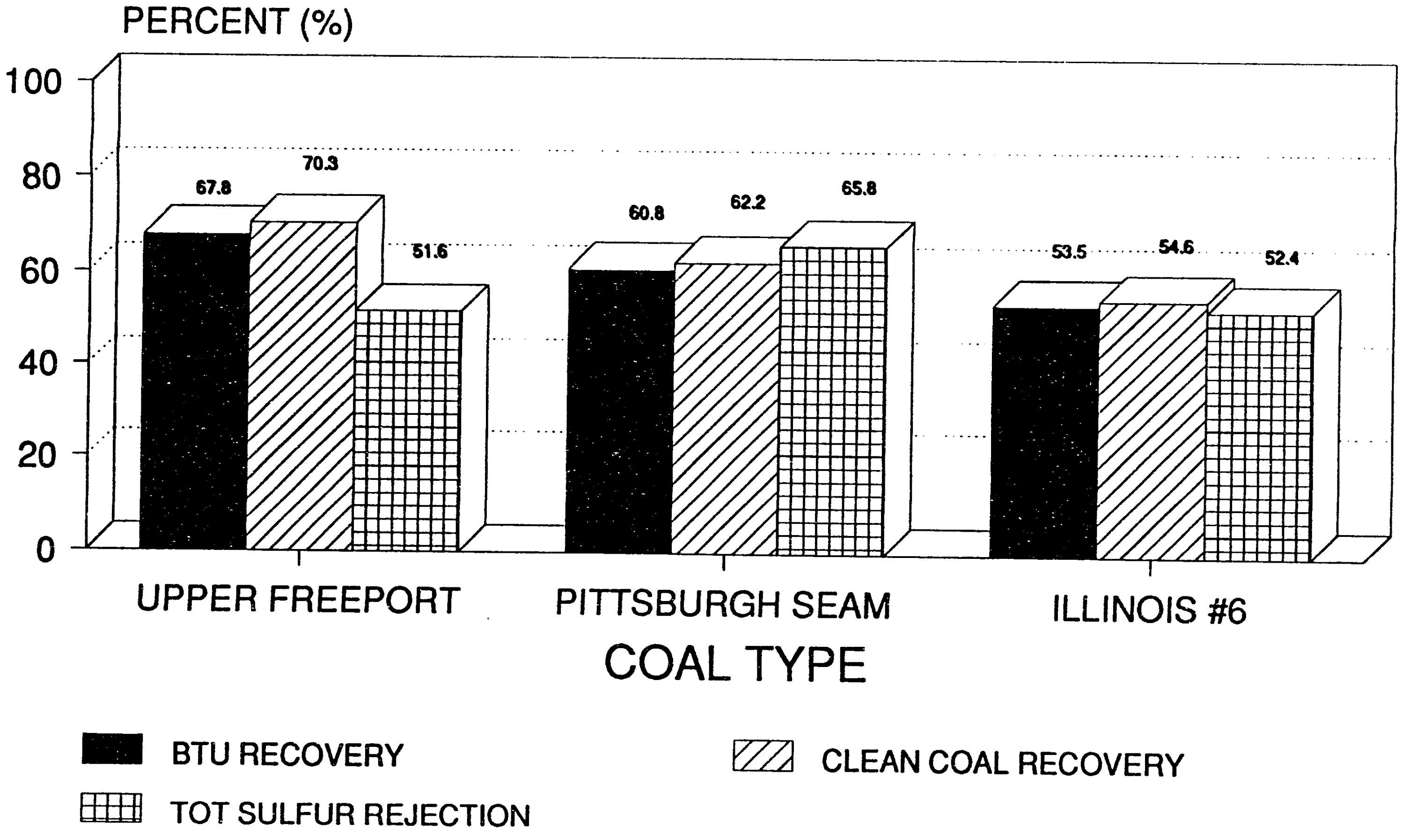


FIGURE 3-6

PITTSBURGH COAL TREATMENT RESULTS

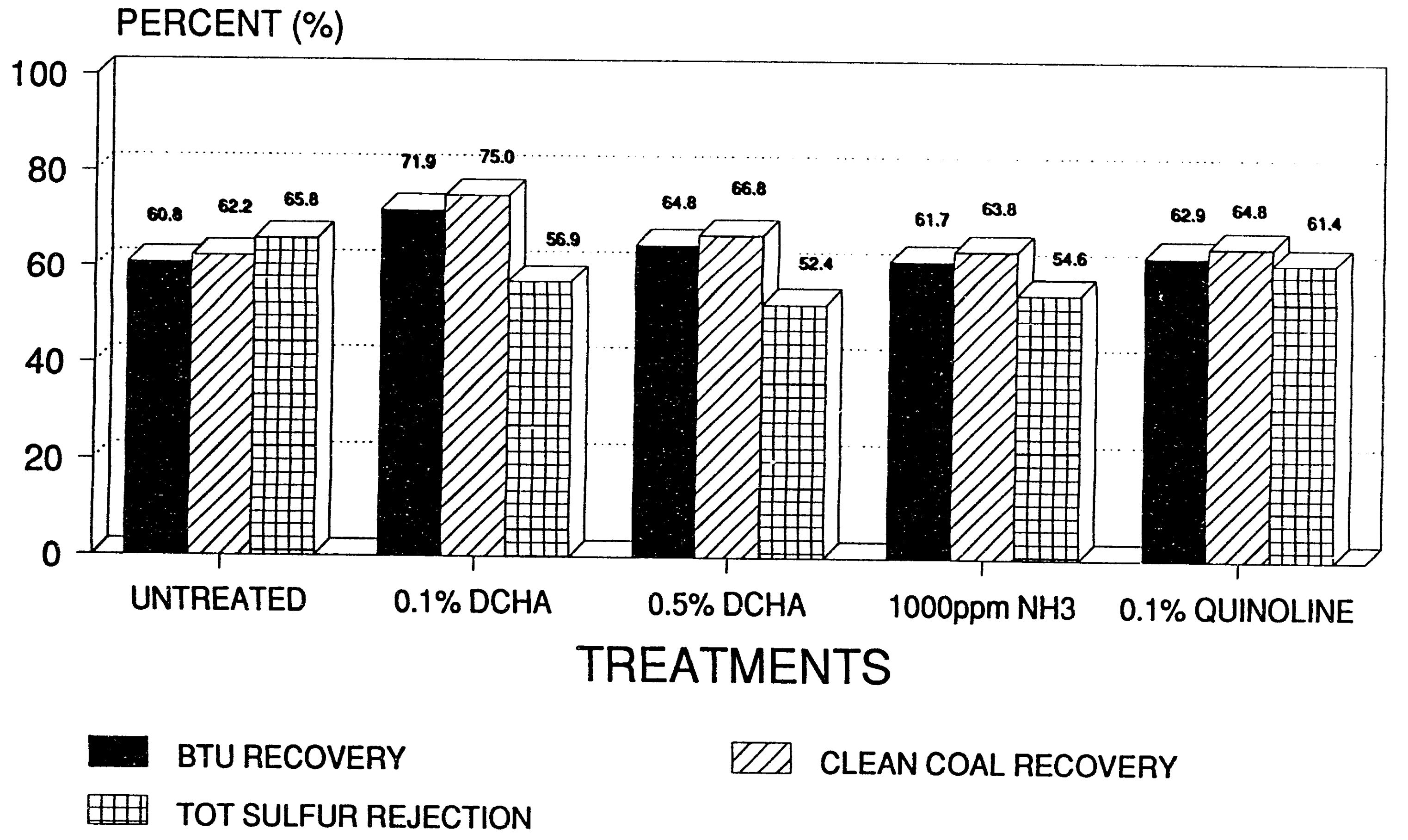
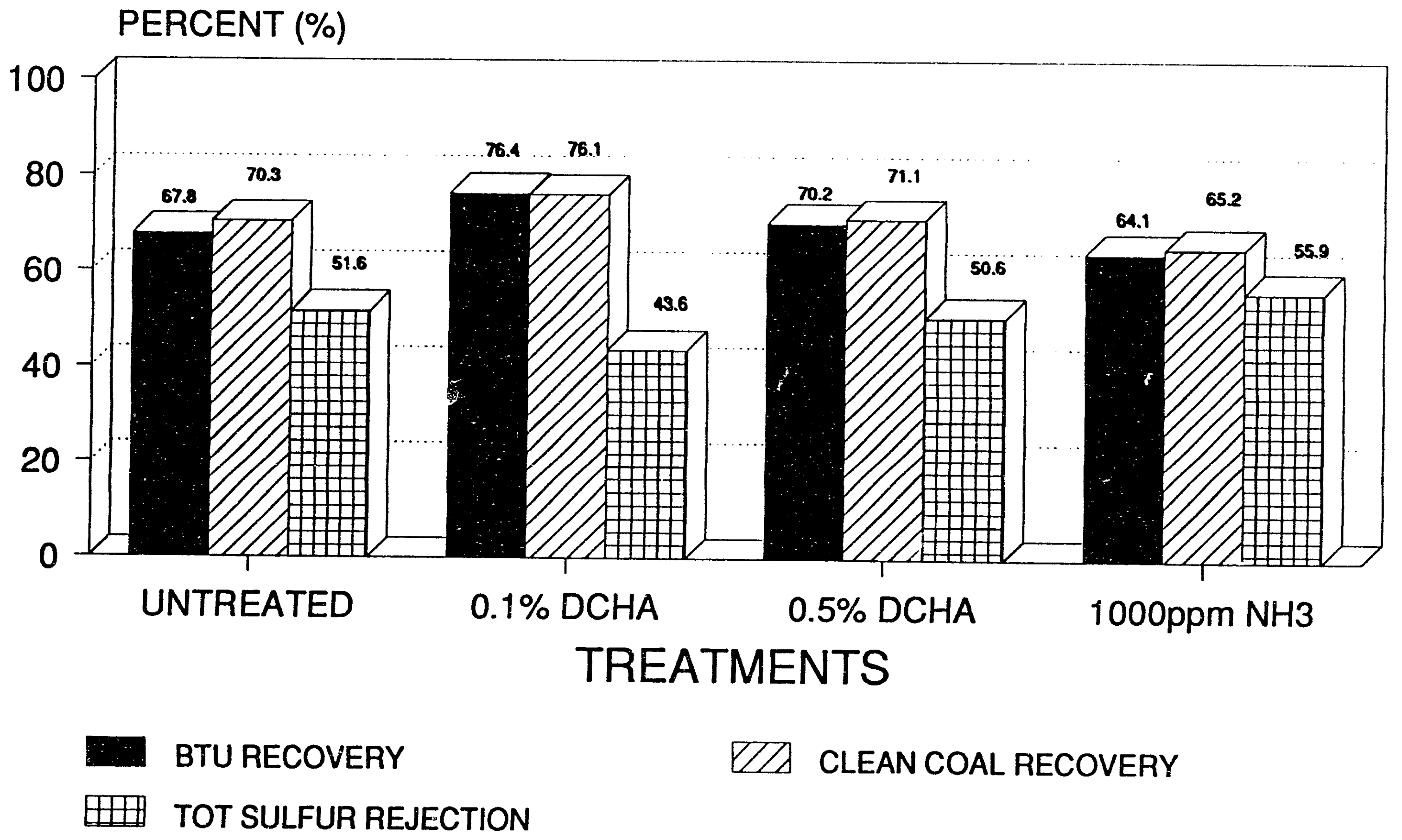


FIGURE 3-7

UPPER FREEPORT TREATMENT RESULTS



treatments increased the Btu and clean coal recoveries, 0.1% dicyclohexylamine was the only treatment that produced a significant improvement in the two recoveries, 11.4% and 12.8%, respectively. Each of the treatments, however, had a negative effect on the total sulfur rejection.

For Upper Freeport coal, only two treatments increase the Btu and clean coal recoveries, 0.1% and 0.5% dicyclohexylamine, with the 0.1% concentration having the greater effect. 0.1% dicyclohexylamine increased the Btu and clean coal recoveries by 10.7% and 5.8%, respectively. Comparing the effect of the treatments on total sulfur rejection, it is seen that ammonia increases the rejection by 4.3% while both dicyclohexylamine treatments decrease the rejection.

There tends to be a correlation between the clean coal recovery and the total sulfur rejection. When the clean coal recovery is increased, the total sulfur rejection for that same run decreases. Likewise, when the total sulfur rejection is increased, the clean coal recovery decreases. This is not unexpected. If the treatment increases clean coal recovery, more material (coal) is collecting on the negative plates and with this material comes more sulfur. If the treatment increases total sulfur rejection, more material (reject) is collecting on the positive plates. This additional reject material brings with it more coal.

3.4.5 Particle Analysis

Because of the ultra fire grinding of the coal, due to the impart mill, we decided to perform particle size analysis of various coal samples. Particle size analysis was conducted on seven coal samples to determine the maximum particle size and the size distribution. Because of the fine coal size, we decided to observe the coal particles in a scanning election microscope.

We felt that we could get a reasonably accurate determination of the size distribution of the coal particles. Scanning Electron Microscope (SEM) photomicrographs were taken and particle diameters were measured for a given field of view.

The particle diameters were measured by photographing the field of view. Enlarging the photograph to an 8X10 photograph and measuring the maximum particle diameter using a Jandel scientific Sigma Scan System. This system digitizes the photographic view and provides for an accurate measurement of the particle diameter. This technique was used for seven coal samples that were magnified 2000X. In each field of view between 200 and 400 particles were measured.

In order to develop a particle size analysis, the particle was assumed to be spherical and a particle volume was calculated. The sum of the particle volumes were calculated and the distribution was determined as shown in Table 3-5. Particle size distribution and cumulative particle size is shown. In all of the fields examined, no particle was found to be larger than 25 m.

Metallographic Interpretation of Sample Coals

Photomicrographs of various coals and coal treatments were taken using an SEM. Magnification of the field of view to 5000X was done. By examining the photomicrographs, it was determined that the coal particles tended to be structured with

Table 3-5
Particle Size Distribution by Weight Percent

Sample		0.5 µm	5-10 µm	10-15 µm	15-20 µm	20-25 µm
Pitts/no treat	Distribution	4.7	20.1	22.3	14.3	38.6
neg	Cumulative Distribution	4.7	24.8	47.1	61.4	100
Ill/no treat	Distribution	4.2	19.1	17.7	10.9	48.1
neg	Cumulative Distribution	4.2	23.3	41.0	51.9	100
Ill/no treat	Distribution	7.4	33.2	59.4	0	0
feed	Cumulative Distribution	7.4	40.6	100	0	0
Pitts/quinoline	Distribution	14.0	30.1	55.9	0	0
feed	Cumulative Distribution	14.0	44.1	100	0	0
Pitts/quinoline	Distribution	8.0	24.3	67.7	0	0
pos	Cumulative Distribution	8.0	32.3	100	0	0
UF/0.1 DCHA	Distribution	20.2	44.2	35.6	0	0
pos	Cumulative Distribution	20.2	64.4	100	0	0
UF/no treat	Distribution	5.4	13.6	27.6	10.6	42.8
neg	Cumulative Distribution	5.4	19.0	46.6	57.2	100

visible fracture surfaces and cleavage planes while the ash and sulfur particles tended to be more rounded in structure. This is evident in Figure 3-8 and 3-9.

Figure 3-10 shows Pittsburgh coal recovered as clean coal and Figure 3-11 shows Illinois coal recovered as clean coal. This Pittsburgh coal is the most cubic, probably the hardest coal and the Illinois #6 has rounded edges, showing that it is softer.

It is difficult to determine how well the sulfur and ash was liberated from the coal, but it appears that the ash was irregularly shaped. The pyritic sulfur should have appeared as cubic structures, but this was not evident from the photomicrographs.

3.4.6 Interpretation of Results

3.4.6.1 Untreated Coals

Inspection of the results with untreated coals presented earlier in this section indicates that the process performance was the best with untreated Upper Freeport Coal (UFC) in three out of four key parameters. Running the process with UFC produced the highest clean coal recovery (70.3%), the highest ash rejection (79.9%) and the highest BTU recovery (67%). However, the lowest pyritic sulfur rejection was also obtained with this coal. The highest pyritic sulfur rejection sulfur rejection (73.1%) was achieved with Pittsburgh Seam Coal (PSC), however, the energy recovery was lower (60.8%). The results with Illinois No. 6 (INC) were poorer in all respects.

The pyritic and total sulfur characteristics of the three coals are summarized below:

	Total Sulfur, %	**Pyritic Sulfur, %**	**P-S/T-S**	**Ash %**
UFC	2.44	1.57	0.64	27.54
PSC	4.35	1.97	0.45	8.68
INC	3.53	0.46	0.13	12.07

Reviewing the results with respect to feed ash and sulfur characteristics does not reveal any trends. All that can be said is that the coal with the highest pyritic sulfur content produced the highest percentage pyritic sulfur rejection.

Although the coal was not analyzed for marcerals, a review of the results relative to marceral distribution might be worthwhile.

3.4.6.2 Treated Coals

A review of the results with Pittsburgh coal (Figure 3-3) indicates that the collectibility of the ash was enhanced by treatment with 0.1% dicyclohexylamine (DCHA) and 0.1% Quinoline. However, this did not always result in an improvement in pyritic sulfur rejection (only for Quinoline).

As previously mentioned in Section 3.1, there was a concern that after enough amine had been added to coat the pyrite surface, additional amine may be ineffective or perhaps detrimental in its effect. This is potentially a problem because of the use of carbon dioxide fluidization gas. Comparison of the results with 0.1% and 0.5% DCHA

Figure 3-8

Upper Freeport Coal Recovered from the Negative Plate (clean coal)

Figure 3-9

Upper Freeport Coal Recovered from the Positive Plate (ash and sulfur)

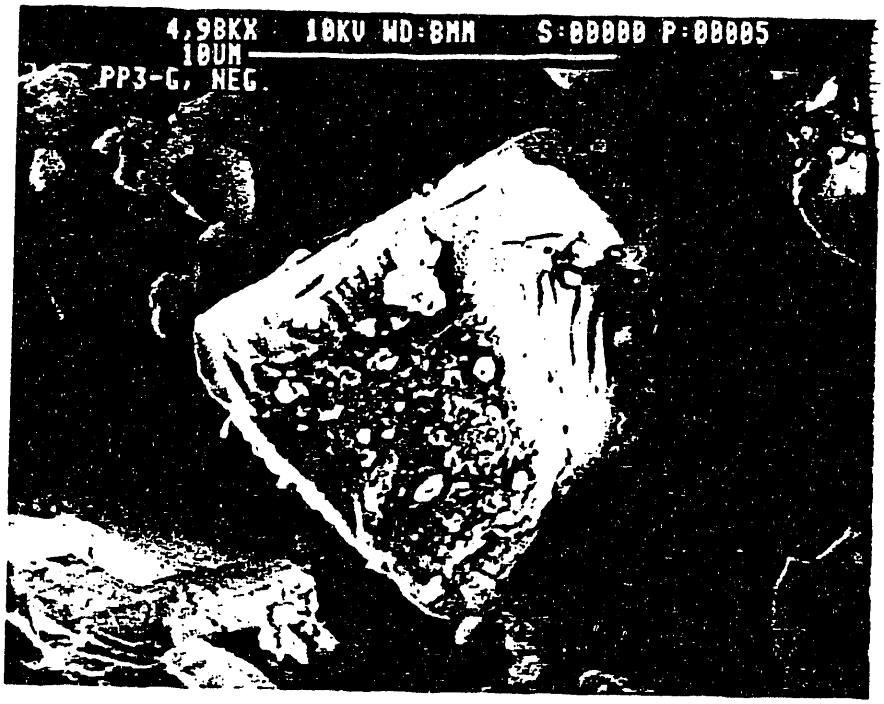


Figure 3-10

Pittsburgh Coal Recovered from the Negative Plate (clean coal)

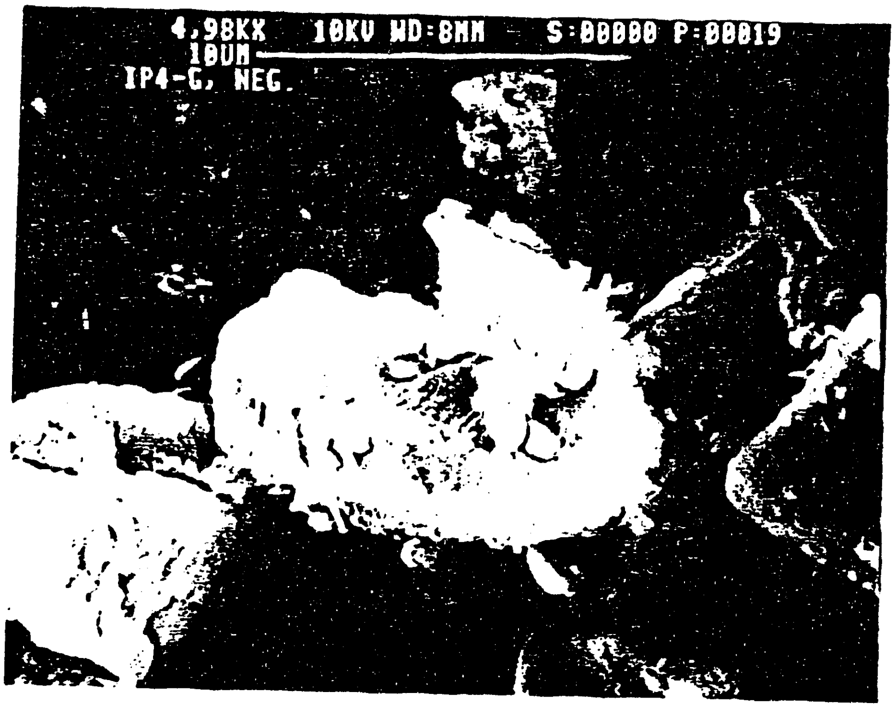


Figure 3-11

Illinois Coal Recovered from the Negative Plate (clean coal) treatment of PSC seems to support the concept that a carbamate carbonate salt may form where excess amine is available.

In all respects, the results were worse with the higher loading of amine on the coal.

The comparison between 0.1% DEHA and 0.1% Quinoline on PSC is also interesting, since Quinoline contains a tertiary nitrogen under normal organic conditions. In this bonding arrangement, the nitrogen should be less susceptible to reaction with CO_2. In fact, the results are comparable to the 0.1% DCHA ratio. The results might have been more revealing had runs been made at 0.5% Quinoline; unfortunately, this was not feasible within the scope of the existing funding.

In conclusion, it appears that surface chemical treatment did have an effect on how the particles partitioned between the positive and negative charged plates relative to untreated coal. However, it is not apparent that this change in partitioning had much effect on the overall coal cleaning performance. If there was a more complete understanding of the chemistry involved, it might be possible to use this phenomenon to improve the benefication further.

4.0 Process Scale-up Evaluation

In this section of the report the basis for scale-up of the triboelectric separator system for sulfur removal from coal is discussed. The methodology used for scale up of the laboratory apparatus to a commercial power plant system, the conceptual process designs and estimates of the process economics are also developed.

4.1 Scale-up design basis

The design of the commercial scale system is based on the use of the triboelectric separator system at a power plant with an output of 400MW. Therefore, based on the material balance developed from the results of the experimental program an shown in table 4-1, a coal feed rate of about 200 tons per hour is required to generate 400MW of electricity. Depending upon the assumptions made and the type of system used, the coal requirements actually range from 169 to 205 tons per hour feed rate. This assumes a heating value of 13700 Btu/lb of coal input and a generation rate of 10500 Btu/KW.

The major design constraint for this system is in the limited available space for this system at a power plant. Since this is designed to be retrofit at a power plant limited space is available between the coal grinding circuit and the combustor. Therefore, limitations on the number of units is required. Limiting the units will hold retrofit costs within a reasonable range.

The basis coal used for evaluating the commercial scale system was Pittsburgh seam. This coal was chosen because of the experience developed with the coal during the experimental program. Run of mine coal was assumed as the input to the existing coal grinding circuit. The output of the existing circuit would be roughly -80 mesh coal. This size would be fed into the coal cleaning circuit. The chemical composition of the coal and the characteristics of the cleaned coal are found in section 3.0.

Transport of the coal within the circuit would be done using a combination of pneumatic transport and screw conveyance. Pneumatic transport would be used within the tribocharging, separation, and collection units within the circuit. The coal would also be transported to the combustor using pneumatic conveyance. The use of screw conveyance would occur within the grinding circuit, for the conveyance of the finely ground coal to the chemical treatment section , and for the removal of the waste material from the circuit.

A dry pulverizer is required for the circuit. This should already be within the existing grinding circuit and should not be purchased for the retrofit. The output of the dry pulverizer should be at about 250 degrees F and no greater than -80 mesh. The micro pulverizer should be able to reduce the coal size to -325 mesh. The ultrafine coal output temperature would again be at least 250 degrees.

The fine ground coal would be pneumatically conveyed through the tribocharger in a carbon dioxide gas stream to prevent arc discharge within the electrostatic precipitator and prevent possible ignition. The tribocharger consists of a vertical system with a spinning rotor such as the arrangement used in the laboratory apparatus. The gap spacing is approximately 0.5 inches and the rotational speed is about 110 rpm.

The electrostatic precipitator is a parallel plate type with only positively charged plates acting as the collector of the pyrite and ash. The ash and pyrite is removed from the

MATERIAL BALANCE (75% CLEAN COAL RECOVERY) NO RECYCLE

EQUIPMENT	COAL (LB/HR) IN	COAL (LB/HR) OUT	CO2 (LB/HR) IN	CO2 (LB/HR) OUT
PULVERIZER	409000	409000	0	0
TRIBO CHARGERS	409000	409000	81800	81391
ESP COLLECTOR	409000	306750	81391	80984
BAG HOUSE	306750	306750	80984	77745
COMBUSTION AREA	306750		3239	
MAKE-UP CO2			4055	
TO WASTE	102250		0	
MW OUTPUT		400		

MATERIAL BALANCE
(75% CLEAN COAL RECOVERY CYCLE 1 60% RECOVERY CYCLE 2)

EQUIPMENT	COAL (LB/HR) IN	COAL (LB/HR) OUT	CO2 (LB/HR) IN	CO2 (LB/HR) OUT
PULVERIZER	347500	347500	0	0
TRIBO CHARGERS 1	408824	408824	81765	81356
ESP COLLECTOR 1	408824	306618	81356	80949
TRIBO CHARGERS 2	102206	102206	20441	20339
ESP COLLECTOR 2	102206	61324	20339	20237
BAG HOUSE	306618	306618	80949	76936
COMBUSTION AREA	306618		3238	
MAKE-UP CO2			4829	
TO RECYCLE	61324		20136	
TO WASTE	40882		0	
MW OUTPUT		400		

MATERIAL BALANCE (80% CLEAN COAL RECOVERY) NO RECYCLE

EQUIPMENT	COAL (LB/HR) IN	COAL (LB/HR) OUT	CO2 (LB/HR) IN	CO2 (LB/HR) OUT
PULVERIZER	383000	383000	0	0
TRIBO CHARGERS	383000	383000	76600	76217
ESP COLLECTOR	383000	306400	76217	75836
BAG HOUSE	306400	306400	75836	72802
COMBUSTION AREA	306400		3033	
MAKE-UP CO2			3798	
TO WASTE	76600		0	
MW OUTPUT		400		

MATERIAL BALANCE
(80% CLEAN COAL RECOVERY CYCLE 1 60% RECOVERY CYCLE 2)

EQUIPMENT	COAL (LB/HR) IN	COAL (LB/HR) OUT	CO2 (LB/HR) IN	CO2 (LB/HR) OUT
PULVERIZER	337000	337000	0	0
TRIBO CHARGERS 1	382955	382955	76591	76208
ESP COLLECTOR 1	382955	306364	76208	75827
TRIBO CHARGERS 2	76591	76591	15318	15242
ESP COLLECTOR 2	76591	45955	15242	15165
BAG HOUSE	306364	306364	75827	72068
COMBUSTION AREA	306364		3033	
MAKE-UP CO2			4523	
TO RECYCLE	45955		15090	
TO WASTE	30636		0	
MW OUTPUT		400		

Table 4-1: Material Balance for Commercial Power Plant

ESP and conveyed to the waste handling system. The clean coal is entrained through a modular baghouse for densifying.

Periodically, the coal will be pulsed from the bags within the baghouse and collected in a hopper at the bottom of the baghouse. The clean coal will then be conveyed using dense phase pneumatic transport with carbon dioxide to the combustor.

The ash and pyrite waste will either be disposed or sent to a second separator circuit to increase the coal recovery. This circuit will recover approximately 60 % of additional coal. The remaining waste will be sent to waste handling.

The majority of the CO_2 used within the circuit will be recycled through a compressor and additional CO_2 will be bleed into the system to maintain a pressure of approximately 15 psi. Loss of CO_2 to the combustor and through system leakage will be made up from the CO_2 storage tank farm.

4.2 Key Scaling Parameters

The key scaling parameters are the coal to gas load ratio, the retention time of the coal within the tribocharger, the mass velocity of the coal through the tribocharger, the system collection and separation efficiency, the heating value of the product and the number of circuits within the system. The key scaling parameters and their values are shown in table 4-2

4.3 Conceptual Process Design

Process flowsheets and material balances were developed. The process flowsheets are shown in figures 4-1 and 4-2 to detail the retrofit coal cleaning systems. Figure 4-1 is for a one pass system and figure 4-2 is for the system with a recycle stream. The run of mine coal is crushed and ground in a conventional size reduction circuit. The fine ground coal is fed into a series of ten impact mills, each operating at 800 horsepower to reduce the coal to 100% passing through a 325 mesh screen.

The coal is then conveyed with a screw to the fluidization chamber. During this conveyance, dicyclohexylamine is added to the system to chemically activate the coal particle surfaces. The coal is introduced into the triboelectric charger through a pneumatic feeding system which fluidizes the coal particles. The coal particles collide with the tribocharger walls and rotor to acquire an electrostatic charge which provides for a means of separation in the ESP. The tribocharger is estimated to be approximately 20 feet long and have a diameter of 4 feet. The rotor is slightly narrower than the wall and rotates at about 100 rpm. The wall of the charger is lined with copper and the rotor is stainless steel. The charger rotor is driven with a fifty horsepower motor. For a circuit processing 200 tph of coal, fourteen chargers are required. The coal that leaves each charger is piped to an ESP through copper pipe to prevent discharge of the coal and ash particles.

The electrostatic separators are parallel type separators with the capacity to treat 28.5 tph. This provides for two tribochargers feeding into one ESP. The ash and pyrites, that have negative charge are attracted to the positively charged plates. The separated coal is removed pneumatically from the system and the ash and sulfur is removed mechanically

Table 4-2
Key Scaling Parameters

Triboseparator	
coal/gas load ratio	5lb coal/lb CO_2
gas velocity	25 ft/sec.
retention time	0.83 sec.
tip speed	22.6 ft/sec.
inlet temperature	> 250°F
CO_2 inlet pressure	15 psig
rotor speed	108 rpm
gap area	0.5 sq. ft^2
Baghouse	
cloth area	2 ft^3/ft^2-min
modules	4
ESP	
voltage drop	5000v/cm
plate area ratio	0.5 ft^2/ACFM
CO_2 Recycle	
CO_2 loss to combustor	4%
CO_2 loss to system	1%
Chemical Treatment	
dicyclohexylamine addition	0.1 wt %

Figure 4-1: ELECTROSTATIC COAL CLEANING SYSTEM

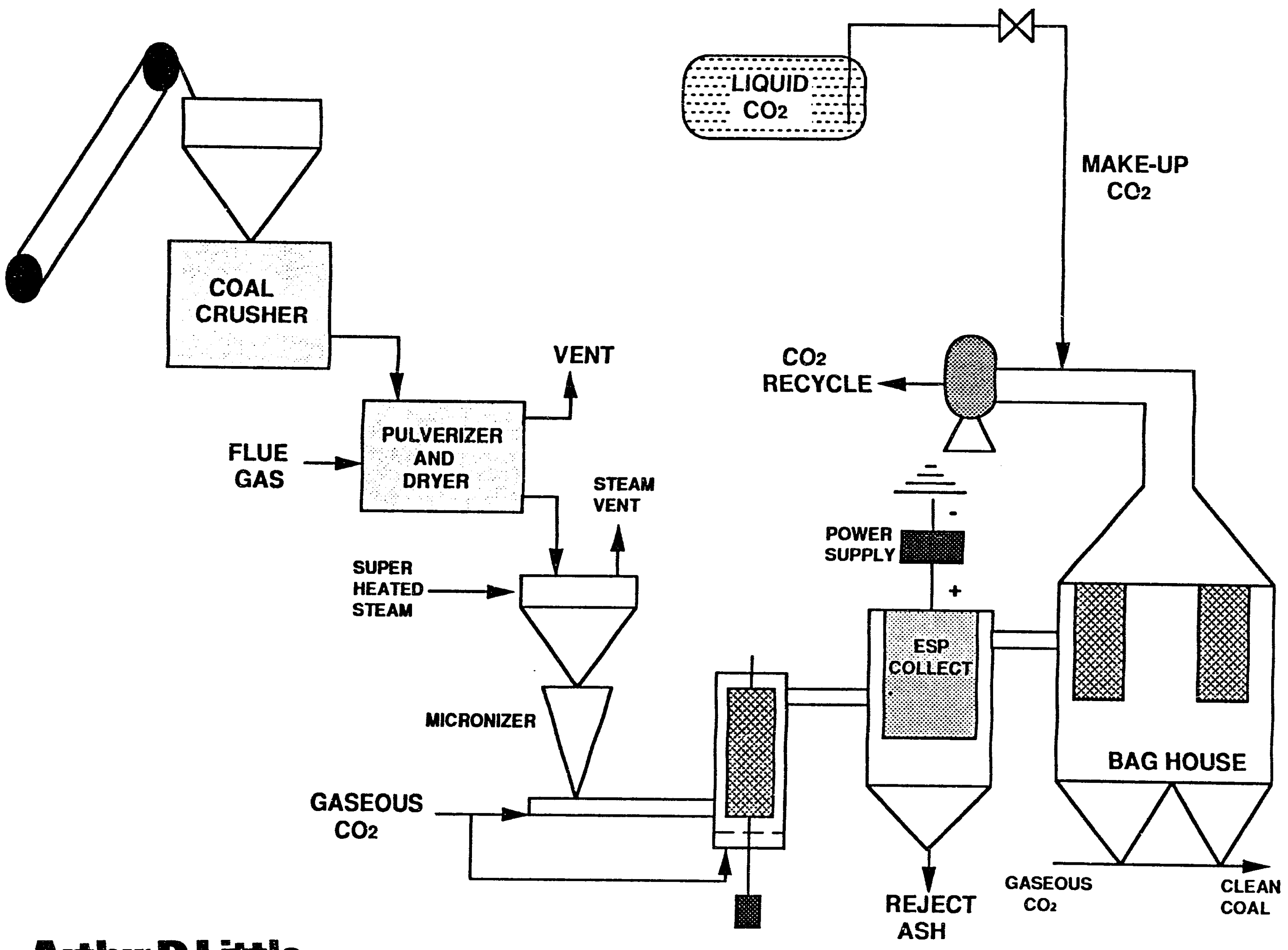
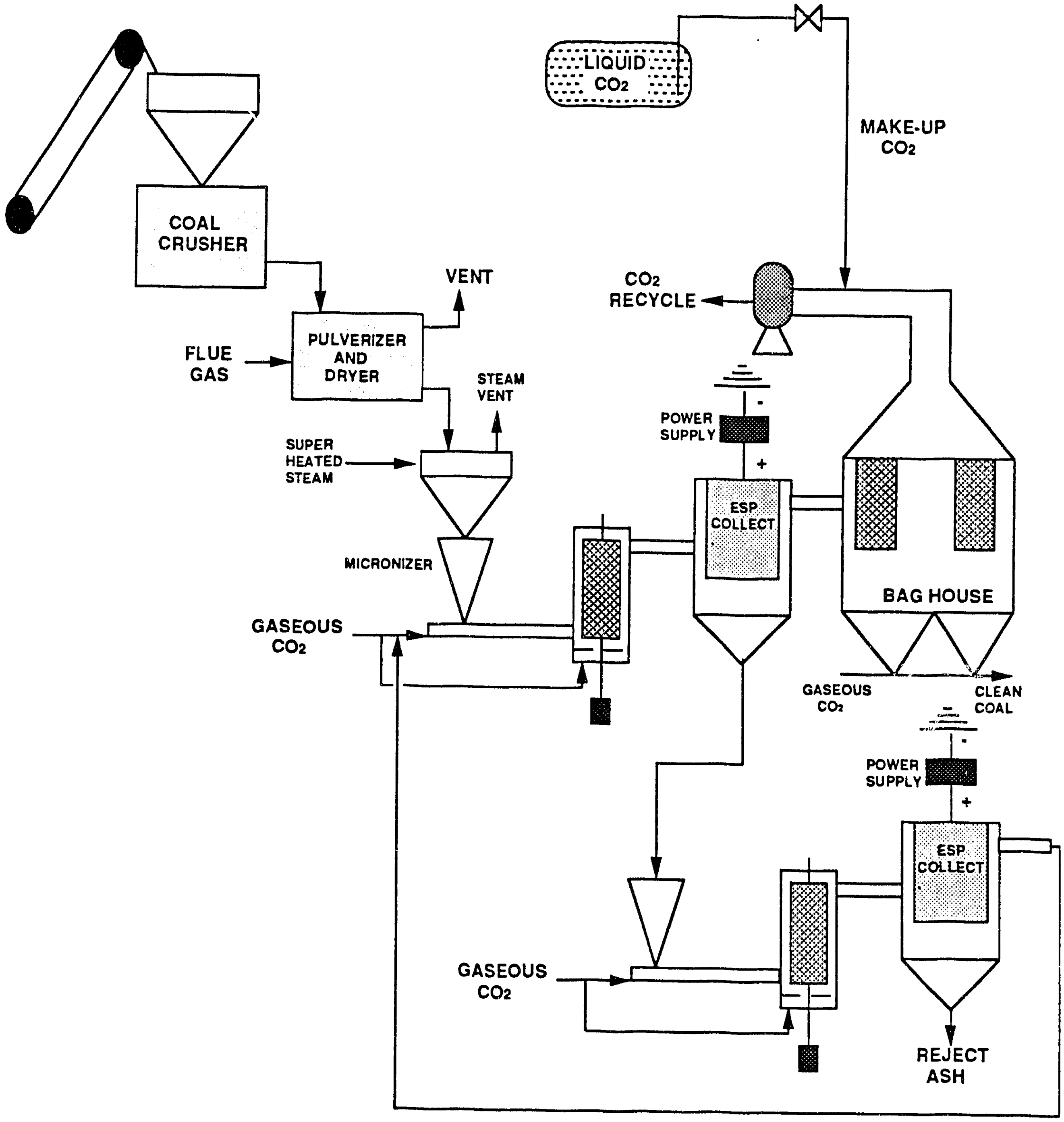


Figure 4-2: ELECTROSTATIC COAL CLEANING SYSTEM - TWO STAGE



or pneumatically to the waste handling system.. The separated streams proceed through the process.

The cleaned coal proceeds pneumatically to the baghouse unit. The coal is collected upon the baghouse filter and is periodically removed by a pulse cleaning. The coal drops to a hopper and it is transferred under a blanket of carbon dioxide to the combustor. The baghouse is a modular design with the ability to shutdown one module at a time to remove the coal while the remaining modules remain operational. The filter efficiency is greater than 99.5% at 2 ft^3/ft^2-min. The baghouse is operated at about 200 degrees F.

The waste ash and pyrite stream is either disposed with the boiler ash and slag or it is sent to another tribocharger and ESP circuit. The waste which is roughly 40% of the recycle feed is sent to the waste storage/disposal section of the plant. The coal recovered by the second circuit is sent back to the feed of the original tribocharger circuit , because it has an ash and pyrite concentration near that of the feed coal.

The carbon dioxide used in the process is recompressed and additional makeup CO_2 is added to maintain the flowrate and the operating pressure. The carbon dioxide is compressed using a 375 horsepower compressor. The outlet gas pressure is required to be about 25 psi and is easily obtainable. The additional CO_2 required for the process is stored in a tankfarm at a pressure of about 175 psi. This bleed stream assists in raising the gas pressure to the required 25 psi.

4.4 Capital Investment Estimate

This section details the methods used to develop the capital investment estimates. We developed capital cost estimates for four process options. One option would be a once through system with the waste being rejected and disposed. Another system would again be a once through system with chemical treatment of the coal with dicyclohexylamine. Another option would be the basic plant with the waste being transported to a second triboelectric circuit. The recovered coal would be returned to the first tribocharger within the circuit for recycle. It cannot be sent through to the combustor because of the higher sulfur and ash content, similar to the feed coal chemical composition. The final circuit would be a recycle circuit with chemical treatment.

Capital investment cost estimates for all the major process units are detailed in tables 4-3, 4-4, 4-5 and 4-6. Each table details one of the process options. Table 4-3 is the cost of the basic plant with dicyclohexylamine treatment of the coal. Table 4-4 is the cost of the basic plant without the chemical treatment. Table 4-5 is the cost of the plant with a recycle stream and chemical treatment and Table 4-6 is the cost of the plant with a recycle stream and no chemical treatment.

The unit costs for each major process unit were developed from vendor quotes, and estimates based on the Richardson system. The installation factors were the module type, taken from the work of Guthrie or estimated when not available. Since this was a study type cost estimate, a contingency of 20% was added to each estimate.

The capital investment required for a plant of this size varies between $44,400,000 and $46,000,000. This is an investment of $111/KW and $115/KW. The lower cost for the basic plant without chemical treatment and the higher cost for the plant with chemical treatment and a recycle stream.

Tons/Hr Coal	200
Hr/Yr	7884
Tons/Yr Coal	1576800

EQUIPMENT	DESCRIPTION	HP	NO UNITS	UNIT COST	FACTOR	INSTALLED COST
MICRO PULVERIZER	ABB/Raymond impact mill	8000	10	$600,000	2.59	$15,540,000
TRIBO UNIT	25 ft x 4 ft dia.	700	14	$67,000	2.60	$2,438,800
ESP	28.5 tph 2500 volt/cm.	1050	7	$320,000	2.69	$6,025,600
BAGHOUSE	10000 sq ft filter area	50	1	$206,000	2.69	$554,140
CO2 COMPRESSOR	rotary vane	375	1	$57,000	2.60	$148,200
CO2 STORAGE TANK	1,000,000 cu. ft.		10	$450,000	2.00	$9,000,000
CONVEYORS/FEEDE	various	400	10	$40,000	2.69	$1,076,000
CHEMICAL STORAGE	40000 gallon		1	$36,000	2.50	$90,000
METERING PUMP	1 hp	1	2	$2,000	2.40	$9,600
UTILITIES	water and electricity					$700,000
CONTINGENCY	20% TIC					$8,895,585
TOTALS		10575				$44,477,925
						111.19 $/KW

Table 4-3: Capital Investment Cost Estimate for Basic Plant with Chemical Treatment

TEST RESULTS:

The Proximate and Ultimate Analysis of the three base coals is complete. Results are:

Analysis Results: Base Coals
(REI)

	Illinois #6	Pittsburgh	ROM Upper Freeport
Moisture	3.16	1.57	0.91
Ash			
as received	12.15	9.01	30.85
dry	12.55	9.15	31.15
Volatiles			
as received	37.86	40.40	24.59
dry	39.10	41.04	24.83
Fixed Carbon			
as received	46.83	49.02	43.61
dry	48.35	49.81	44.02
Sulfur total			
as received	3.46	4.69	2.14
dry	3.57	4.76	2.16
Sulfur as sulfate (dry)	0.28	0.20	0.06
Sulfur as pyrite (dry)	1.01	2.40	1.45
Sulfur as organic (dry)	2.28	2.16	0.65
Carbon			
as received	66.41	71.65	57.56
dry	68.58	72.79	58.11
Elemental hydrogen			
as received	4.63	4.91	3.70
dry	4.78	4.99	3.74
Elemental Nitrogen			
as received	1.22	1.30	0.96
dry	1.26	1.32	0.97
Oxygen			
as received	8.97	6.88	3.83
dry	9.26	6.99	3.87
BTU/lb			
as received	11,703	12,951	10,127
dry	12,085	13,158	10,224

Resource Engineering Incorporated

80 Bacon Street, Waltham, Massachusetts 02154 (617) 894-6720

DATE 11/18/88

ANALYSIS REPORT

YOUR PURCHASE ORDER # 900-957-28

ANALYSIS REPORT: B776-9

SAMPLE RECEIVED: 11/2/88

SAMPLE: Plate 1 (+) 9-19-88

RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Sherrie DiMare

	As Received	Dry Basis
% Moisture	3.04	-
% Ash	14.83	15.30
% Total Sulfur	3.18	3.28
% Sulfate Sulfur	0.55	0.56
% Pyritic Sulfur	1.06	1.10
% Organic Sulfur	1.57	1.62

RESPECTFULLY SUBMITTED BY Daniel R. Wetmore

Daniel R. Wetmore
Laboratory Manager

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DATE 11/18/88

ANALYSIS REPORT

YOUR PURCHASE ORDER #900-957-28 ANALYSIS REPORT: B776-9

SAMPLE RECEIVED: 11/2/88 SAMPLE: Plate 2 (-) 9/19/88

RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Sherrie DiMare

	As Received	Dry Basis
% Moisture	3.49	-
% Ash	13.87	14.38
% Total Sulfur	3.32	3.44
% Sulfate Sulfur	0.49	0.51
% Pyritic Sulfur	1.06	1.10
% Organic Sulfur	1.77	1.83

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Daniel R. Wetmore
Laboratory Manager

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DATE 11/18/88

ANALYSIS REPORT

YOUR PURCHASE ORDER # 900-957-28

ANALYSIS REPORT: B776-9

SAMPLE RECEIVED: 11/2/88

SAMPLE: Plate 3 (+) 9/19/88

RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Sherrie DiMare

	As Received	Dry Basis
% Moisture	3.36	-
% Ash	14.69	15.20
% Total Sulfur	3.18	3.29
% Sulfate Sulfur	0.43	0.44
% Pyritic Sulfur	1.12	1.16
% Organic Sulfur	1.63	1.69

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Daniel R. Wetmore
Laboratory Manager

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DATE 11/18/88

ANALYSIS REPORT

YOUR PURCHASE ORDER # 900-957-28 ANALYSIS REPORT: B776-9

SAMPLE RECEIVED: 11/2/88 SAMPLE: Plate 4 (−) 9/19/88

RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Sherrie DiMare

	As Received	Dry Basis
% Moisture	2.66	-
% Ash	13.57	13.95
% Total Sulfur	3.32	3.41
% Sulfate Sulfur	0.59	0.61
% Pyritic Sulfur	1.13	1.16
% Organic Sulfur	1.60	1.64

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Daniel R. Wetmore
Laboratory Manager

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DATE 11/18/88

ANALYSIS REPORT

YOUR PURCHASE ORDER # 900-957-28
ANALYSIS REPORT: B776-9
SAMPLE RECEIVED: 11/2/88
SAMPLE: Plate 1 (-) 0.9g 10/25
RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Sherrie DiMare

	As Received	Dry Basis
% Moisture	2.21	-
% Ash	12.10	12.38
% Total Sulfur	3.12	3.19
% Sulfate Sulfur	1.03	1.05
% Pyritic Sulfur	0.54	0.55
% Organic Sulfur	1.55	1.59

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DATE 11/18/88

ANALYSIS REPORT

YOUR PURCHASE ORDER # 900-957-28

ANALYSIS REPORT: B776-9

SAMPLE RECEIVED: 11/2/88

SAMPLE: Plate 2 (+) 9.5q 10/25

RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Sherrie DiMare

	As Received	Dry Basis
% Moisture	2.80	-
% Ash	14.55	14.97
% Total Sulfur	3.21	3.30
% Sulfate Sulfur	0.65	0.67
% Pyritic Sulfur	0.84	0.86
% Organic Sulfur	1.72	1.77

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DATE 11/18/88

ANALYSIS REPORT

YOUR PURCHASE ORDER # 900-957-28 ANALYSIS REPORT: B776-9

SAMPLE RECEIVED: 11/2/88 SAMPLE: Plate 3 (-) 10.3g 10/25

RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Sherrie DiMare

	As Received	Dry Basis
% Moisture	2.83	-
% Ash	13.97	14.38
% Total Sulfur	3.39	3.48
% Sulfate Sulfur	0.82	0.84
% Pyritic Sulfur	0.76	0.78
% Organic Sulfur	1.81	1.86

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Daniel R. Wetmore
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DATE 11/18/88

ANALYSIS REPORT

YOUR PURCHASE ORDER # 900-957-28 ANALYSIS REPORT: B776-9

SAMPLE RECEIVED: 11/2/88 SAMPLE: Plate 4 (+) 2.5g 10/25

RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Sherrie DiMare

	As Received	Dry Basis
% Moisture	1.91	-
% Ash	12.87	13.12
% Total Sulfur	3.25	3.32
% Sulfate Sulfur	1.11	1.14
% Pyritic Sulfur	0.56	0.57
% Organic Sulfur	1.58	1.61

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Daniel R. Wetmore
Laboratory Manager

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80 Bacon Street, Waltham, Massachusetts 02154 (617) 894-6720

DATE 11/18/88

ANALYSIS REPORT

YOUR PURCHASE ORDER # 900-957-28 ANALYSIS REPORT: B776-9
SAMPLE RECEIVED: 11/10/88 SAMPLE: Illinois #6
RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Sherrie DiMare

	As Received	Dry Basis
% Moisture	8.83	-
% Volatile Matter	32.41	35.55

RESPECTFULLY SUBMITTED BY Daniel R. Wetmore

Daniel R. Wetmore
Laboratory Manager

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80 Bacon Street, Waltham, Massachusetts 02154 (617) 894-6720

DATE_______________

ANALYSIS REPORT

YOUR PURCHASE ORDER #900-957-28 ANALYSIS REPORT: B781-4

SAMPLE RECEIVED: 12/9/88 SAMPLE: 11/29 "+"

RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Sherrie DiMare

	As Received	Dry Basis
% Moisture	0.88	—
% Ash	9.67	9.75
% Total Sulfur	4.07	4.11
% Sulfate Sulfur	0.16	0.16
% Pyritic Sulfur	2.28	2.30
% Organic Sulfur	1.63	1.65

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Daniel R. Wetmore
Laboratory Manager

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DATE

ANALYSIS REPORT

YOUR PURCHASE ORDER #900-957-28 ANALYSIS REPORT: B781-4

SAMPLE RECEIVED: 12/9/88 SAMPLE: 11/29 " – "

RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Sherrie DiMare

	As Received	Dry Basis
% Moisture	0.97	—
% Ash	8.13	8.24
% Total Sulfur	3.67	3.71
% Sulfate Sulfur	0.13	0.13
% Pyritic Sulfur	2.00	2.02
% Organic Sulfur	1.54	1.56

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Daniel R. Wetmore
Laboratory Manager

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DATE 12/12/88

ANALYSIS REPORT

YOUR PURCHASE ORDER # 900-957-28 ANALYSIS REPORT: B780-2
SAMPLE RECEIVED: 12/5/88 SAMPLE: 12/2 19.4g "+"
RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn. Sherrie DiMare

	As Received	Dry Basis
% Moisture	1.18	-
% Ash	14.85	15.02
% Total Sulfur	5.31	5.37
% Sulfate Sulfur	0.24	0.24
% Pyritic Sulfur	3.59	3.64
% Organic Sulfur	1.48	1.49

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Daniel R. Wetmore
Laboratory Manager

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80 Bacon Street, Waltham, Massachusetts 02154 (617) 894-6720

DATE 12/12/88

ANALYSIS REPORT

YOUR PURCHASE ORDER # 900-957-28 ANALYSIS REPORT: B780-2

SAMPLE RECEIVED: 12/5/88 SAMPLE: 12/2 23.5g "-"

RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Sherrie DiMare

	As Received	Dry Basis
% Moisture	1.15	-
% Ash	4.04	4.09
% Total Sulfur	2.97	3.00
% Sulfate Sulfur	0.07	0.07
% Pyritic Sulfur	0.94	0.95
% Organic Sulfur	1.96	1.98

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Laboratory Manager

Page 3 of 4

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ANALYSIS REPORT

YOUR PURCHASE ORDER # 900-957-28

ANALYSIS REPORT: B781-4

SAMPLE RECEIVED: 12/9/88

SAMPLE: 12/8 "-" 23g

RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Sherrie DiMare

	As Received	Dry Basis
% Moisture	0.97	—
% Ash	4.44	4.49
% Total Sulfur	2.85	2.88
% Sulfate Sulfur	0.07	0.07
% Pyritic Sulfur	0.94	0.95
% Organic Sulfur	1.84	1.86

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Laboratory Manager

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DATE_______

ANALYSIS REPORT

YOUR PURCHASE ORDER #900-957-28 ANALYSIS REPORT: B781-4

SAMPLE RECEIVED: 12/9/88 SAMPLE: 12/8 "±" 19.5g

RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Sherrie DiMare

	As Received	Dry Basis
% Moisture	0.98	—
% Ash	13.80	13.93
% Total Sulfur	5.37	5.42
% Sulfate Sulfur	0.23	0.23
% Pyritic Sulfur	3.47	3.50
% Organic Sulfur	1.67	1.69

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Daniel R. Wetmore
Laboratory Manager

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80 Bacon Street, Waltham, Massachusetts 02154 (617) 894-6720

DATE 1/16/89

ANALYSIS REPORT

YOUR PURCHASE ORDER # ~~900-957-28~~ 566276 ANALYSIS REPORT: B782-2

SAMPLE RECEIVED: 12/14/88 SAMPLE: 12/13/88 30g "Pos."

RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Bill Douglas

	As Received	Dry Basis
% Moisture	1.18	-
% Ash	12.53	12.68
% Total Sulfur	4.85	4.90
% Sulfate Sulfur	0.24	0.24
% Pyritic Sulfur	2.88	2.91
% Organic Sulfur	1.73	1.75

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Daniel R. Wetmore
Laboratory Manager

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DATE 1/16/89

ANALYSIS REPORT

YOUR PURCHASE ORDER # 900-957-28 ANALYSIS REPORT: B782-2

SAMPLE RECEIVED: 12/14/88 SAMPLE: 12/13/88 38g "Neg."

RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Bill Douglas

	As Received	Dry Basis
% Moisture	1.22	-
% Ash	6.03	6.10
% Total Sulfur	3.37	3.42
% Sulfate Sulfur	0.12	0.12
% Pyritic Sulfur	1.39	1.41
% Organic Sulfur	1.86	1.89

RESPECTFULLY SUBMITTED BY Daniel R. Wetmore

Daniel R. Wetmore
Laboratory Manager

RI E

Resource Engineering Incorporated

80 Bacon Street, Waltham, Massachusetts 02154 (617) 894-6720

DATE 1/16/89

ANALYSIS REPORT

YOUR PURCHASE ORDER # ~~900-957-28~~ 566276 ANALYSIS REPORT: B783-2

SAMPLE RECEIVED: 12/19/88 SAMPLE: 12/16/88 "+"

RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Bill Douglas

	As Received	Dry Basis
% Moisture	0.69	-
% Ash	13.75	13.85
% Total Sulfur	5.37	5.41
% Sulfate Sulfur	0.24	0.24
% Pyritic Sulfur	3.27	3.29
% Organic Sulfur	1.86	1.88

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Daniel R. Wetmore
Laboratory Manager

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DATE 1/16/89

ANALYSIS REPORT

YOUR PURCHASE ORDER # 900-957-28 ANALYSIS REPORT: B783-2

SAMPLE RECEIVED: 12/19/88 SAMPLE: 12/16/88 "-"

RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Bill Douglas

	As Received	Dry Basis
% Moisture	0.79	-
% Ash	5.23	5.27
% Total Sulfur	3.16	3.19
% Sulfate Sulfur	0.09	0.09
% Pyritic Sulfur	2.57	2.59
% Organic Sulfur	0.50	0.51

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Daniel R. Wetmore
Laboratory Manager

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DATE 1/16/89

ANALYSIS REPORT

YOUR PURCHASE ORDER # ~~900-957-28~~ 566276 ANALYSIS REPORT: B785-2
SAMPLE RECEIVED: 1/6/89 SAMPLE: 1-5-89 "–"
RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Bill Douglas

	As Received	Dry Basis
% Moisture	0.88	-
% Ash	4.63	4.67
% Total Sulfur	2.92	2.95
% Sulfate Sulfur	0.09	0.09
% Pyritic Sulfur	1.13	1.14
% Organic Sulfur	1.70	1.72

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Laboratory Manager

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DATE 1/16/89

ANALYSIS REPORT

YOUR PURCHASE ORDER # 900-957-28 ANALYSIS REPORT: B785-2

SAMPLE RECEIVED: 1/6/89 SAMPLE: 1-5-89 "+"

RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Bill Douglas

	As Received	Dry Basis
% Moisture	0.94	-
% Ash	14.88	15.02
% Total Sulfur	5.57	5.62
% Sulfate Sulfur	0.22	0.22
% Pyritic Sulfur	3.81	3.84
% Organic Sulfur	1.54	1.56

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Daniel R. Wetmore
Laboratory Manager

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Resource Engineering Incorporated

80 Bacon Street, Waltham, Massachusetts 02154 (617) 894-6720

DATE 2/17/89

ANALYSIS REPORT

YOUR PURCHASE ORDER # 556276 ANALYSIS REPORT: B787-4

SAMPLE RECEIVED: 1/18/89 SAMPLE: 1/13/89 "+"

RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Sherrie DiMare

	As Received	Dry Basis
% Moisture	0.84	-
% Ash	10.76	10.85
% Total Sulfur	4.14	4.18
% Sulfate Sulfur	0.16	0.16
% Pyritic Sulfur	2.36	2.38
% Organic Sulfur	1.62	1.64

RESPECTFULLY SUBMITTED BY

Daniel R. Wetmore
Laboratory Manager

Resource Engineering incorporated

80 Bacon Street, Waltham, Massachusetts 02154 (617) 894-6720

DATE 2/17/89

ANALYSIS REPORT

YOUR PURCHASE ORDER # 556276 ANALYSIS REPORT: B787-4

SAMPLE RECEIVED: 1/18/89 SAMPLE: 1/13/89 "-"

RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Sherrie DiMare

	As Received	Dry Basis
% Moisture	0.71	-
% Ash	8.97	9.03
% Total Sulfur	4.12	4.15
% Sulfate Sulfur	0.12	0.12
% Pyritic Sulfur	2.07	2.08
% Organic Sulfur	1.93	1.95

RESPECTFULLY SUBMITTED BY Daniel R. Wetmore

Daniel R. Wetmore
Laboratory Manager

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80 Bacon Street, Waltham, Massachusetts 02154 (617) 894-6720

DATE 2/17/89

ANALYSIS REPORT

YOUR PURCHASE ORDER # 556276

ANALYSIS REPORT: B787-4

SAMPLE RECEIVED: 1/18/89

SAMPLE: 1/16/89 "+"

RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Sherrie DiMare

	As Received	Dry Basis
% Moisture	0.96	-
% Ash	9.90	10.00
% Total Sulfur	3.47	3.50
% Sulfate Sulfur	0.14	0.14
% Pyritic Sulfur	2.01	2.03
% Organic Sulfur	1.32	1.33

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Daniel R. Wetmore
Laboratory Manager

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80 Bacon Street, Waltham, Massachusetts 02154 (617) 894-6720

DATE 2/17/89

ANALYSIS REPORT

YOUR PURCHASE ORDER # 556276 ANALYSIS REPORT: B787-4
SAMPLE RECEIVED: 1/18/89 SAMPLE: 1/16/89 "-"
RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Sherrie DiMare

	As Received	Dry Basis
% Moisture	0.84	-
% Ash	8.77	8.85
% Total Sulfur	3.71	3.74
% Sulfate Sulfur	0.12	0.12
% Pyritic Sulfur	2.02	2.03
% Organic Sulfur	1.57	1.59

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Daniel R. Wetmore
Laboratory Manager

Resource Engineering Incorporated
80 Bacon Street, Waltham, Massachusetts 02154 (617) 894-6720

DATE 3/6/89

ANALYSIS REPORT

YOUR PURCHASE ORDER # 566276
ANALYSIS REPORT: B794-4
SAMPLE RECEIVED: 3/1/89
SAMPLE: 2/20/89 Positive Plates
RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Sherrie DiMare

	As Received	Dry Basis
% Moisture	1.16	-
% Ash	16.64	16.83
% Total Sulfur	5.78	5.85
% Sulfate Sulfur	0.31	0.32
% Pyritic Sulfur	4.94	4.99
% Organic Sulfur	0.53	0.54
Sample weight as received, grams		31.2

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Daniel R. Wetmore
Laboratory Manager

Resource Engineering Incorporated
80 Bacon Street, Waltham, Massachusetts 02154 (617) 894-6720

DATE 3/6/89

ANALYSIS REPORT

YOUR PURCHASE ORDER # 566276
ANALYSIS REPORT: B794-4
SAMPLE RECEIVED: 3/1/89
SAMPLE: 2/20/89 Negative Plates
RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Sherrie DiMare

	As Received	Dry Basis
% Moisture	1.04	-
% Ash	3.82	3.87
% Total Sulfur	2.86	2.89
% Sulfate Sulfur	0.07	0.07
% Pyritic Sulfur	0.91	0.92
% Organic Sulfur	1.88	1.90
Sample weight as received, grams		48.8

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Daniel R. Wetmore
Laboratory Manager

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DATE 3/6/89

ANALYSIS REPORT

YOUR PURCHASE ORDER # 566276 ANALYSIS REPORT: B794-4
SAMPLE RECEIVED: 3/1/89 SAMPLE: 2/28/89 Positive Plates
RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Sherrie DiMare

	As Received	Dry Basis
% Moisture	1.41	-
% Ash	14.89	15.10
% Total Sulfur	5.79	5.87
% Sulfate Sulfur	0.26	0.27
% Pyritic Sulfur	4.61	4.67
% Organic Sulfur	0.92	0.93
Sample weight as received, grams		25.9

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Daniel R. Wetmore
Laboratory Manager

Resource Engineering Incorporated

80 Bacon Street, Waltham, Massachusetts 02154 (617) 894-6720

DATE 3/6/89

ANALYSIS REPORT

YOUR PURCHASE ORDER # 566276 ANALYSIS REPORT: B794-4

SAMPLE RECEIVED: 3/1/89 SAMPLE: 2/28/89 Negative Plates

RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Sherrie DiMare

	As Received	Dry Basis
% Moisture	1.39	-
% Ash	5.37	5.45
% Total Sulfur	3.27	3.32
% Sulfate Sulfur	0.10	0.10
% Pyritic Sulfur	1.36	1.38
% Organic Sulfur	1.81	1.84

Sample weight as received, grams 40.4

RESPECTFULLY SUBMITTED BY Daniel R. Wetmore

Daniel R. Wetmore
Laboratory Manager

Resource Engineering Incorporated
80 Bacon Street, Waltham, Massachusetts 02154 (617) 894-6720

DATE 4/4/89

ANALYSIS REPORT

YOUR PURCHASE ORDER # 556276 ANALYSIS REPORT: B795-2
SAMPLE RECEIVED: 3/27/89 SAMPLE: 3/17/89 Positive Quinoline
RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Sherrie DiMare

	As Received	Dry Basis
% Moisture	1.46	-
% Ash	9.68	9.82
% Total Sulfur	3.92	3.98
% Sulfate Sulfur	0.19	0.19
% Pyritic Sulfur	2.38	2.41
% Organic Sulfur	1.35	1.38

RESPECTFULLY SUBMITTED BY Daniel R. Wetmore
Daniel R. Wetmore
Laboratory Manager

Resource Engineering Incorporated
80 Bacon Street, Waltham, Massachusetts 02154 (617) 894-6720

DATE 4/4/89

ANALYSIS REPORT

YOUR PURCHASE ORDER # 556276 ANALYSIS REPORT: B795-2
SAMPLE RECEIVED: 3/27/89 SAMPLE: 3/17/89 Negative
RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Sherrie DiMare

	As Received	Dry Basis
% Moisture	1.59	-
% Ash	8.54	8.68
% Total Sulfur	3.87	3.93
% Sulfate Sulfur	0.17	0.17
% Pyritic Sulfur	2.21	2.24
% Organic Sulfur	1.49	1.52

RESPECTFULLY SUBMITTED BY Daniel R. Wetmore

Daniel R. Wetmore
Laboratory Manager

P

Page of

Resource Engineering Incorporated

80 Bacon Street, Waltham, Massachusetts 02154 (617) 894-6720

DATE 4-10-89

ANALYSIS REPORT

YOUR PURCHASE ORDER # 900-957-28 ANALYSIS REPORT: B776-9

SAMPLE RECEIVED: SAMPLE: Plate (-)

RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Sherrie DiMare

	As Received	Dry Basis
% Moisture	0.37	
% Ash	5.75	5.77
% Total Sulfur	3.87	3.88
% Sulfate Sulfur	0.16	0.16
% Pyritic Sulfur	2.48	2.49
% Organic Sulfur	1.23	1.23

33.39

RESPECTFULLY SUBMITTED BY Daniel R. Wetmore

Page of

RESOURCE ENGINEERING INCORPORATED
80 Bacon Street, Waltham, Massachusetts 02154 (617) 894-6720

DATE 4-10-89

ANALYSIS REPORT

YOUR PURCHASE ORDER #900-957-28 ANALYSIS REPORT: B776-9

SAMPLE RECEIVED: SAMPLE: Plate (+)

RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Sherrie DiMare

	As Received	Dry Basis
% Moisture	0.41	
% Ash	11.55	11.60
% Total Sulfur	4.05	4.07
% Sulfate Sulfur	0.19	0.19
% Pyritic Sulfur	2.62	2.63
% Organic Sulfur	1.24	1.25

34.8g

RESPECTFULLY SUBMITTED BY Daniel R. Wetmore

Daniel R. Wetmore

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Page of

Resource Engineering Incorporated
80 Bacon Street, Waltham, Massachusetts 02154 (617) 894-6720

DATE 4-12-89

ANALYSIS REPORT

YOUR PURCHASE ORDER #900-957-28
ANALYSIS REPORT: B776-9
SAMPLE RECEIVED:
SAMPLE: Plate (-)
RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Sherrie DiMare

	As Received	Dry Basis
% Moisture	0.94	
% Ash	4.16	4.20
% Total Sulfur	3.69	3.73
% Sulfate Sulfur	0.08	0.08
% Pyritic Sulfur	2.23	2.25
% Organic Sulfur	1.38	1.40

42.59

RESPECTFULLY SUBMITTED BY Daniel R. Wetmore
Daniel R. Wetmore

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Page of

Resource Engineering Incorporated

80 Bacon Street, Waltham, Massachusetts 02154 (617) 894-6720

DATE 4-12-89

ANALYSIS REPORT

YOUR PURCHASE ORDER #900-957-28 ANALYSIS REPORT: B776-9

SAMPLE RECEIVED: SAMPLE: Plate (+)

RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Sherrie DiMare

	As Received	Dry Basis
% Moisture	0.82	
% Ash	14.30	14.42
% Total Sulfur	5.17	5.21
% Sulfate Sulfur	0.25	0.25
% Pyritic Sulfur	2.66	2.68
% Organic Sulfur	2.26	2.28

24.19

RESPECTFULLY SUBMITTED BY Daniel R. Wetmore

Daniel R. Wetmore

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Page of

REI

Resource Engineering Incorporated

80 Bacon Street, Waltham, Massachusetts 02154 (617) 894-6720

DATE 4-21-89

ANALYSIS REPORT

YOUR PURCHASE ORDER #900-957-28

ANALYSIS REPORT: B776-9

SAMPLE RECEIVED:

SAMPLE: Plate (-)

RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Sherrie DiMare

	As Received	Dry Basis
% Moisture	0.99	
% Ash	4.68	4.73
% Total Sulfur	2.85	2.88
% Sulfate Sulfur	0.10	0.10
% Pyritic Sulfur	1.62	1.64
% Organic Sulfur	1.13	1.14

37.89

RESPECTFULLY SUBMITTED BY Daniel R. Wetmore

Daniel R. Wetmore

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Page of

Resource Engineering Incorporated
80 Bacon Street, Waltham, Massachusetts 02154 (617) 894-6720

DATE 4-21-89

ANALYSIS REPORT

YOUR PURCHASE ORDER #900-957-28

ANALYSIS REPORT: B776-9

SAMPLE RECEIVED:

SAMPLE: Plate (+)

RECEIVED FROM:

Arthur D. Little
20 Acorn Park
Cambridge, MA 02140

Attn: Sherrie DiMare

	As Received	Dry Basis
% Moisture	0.87	
% Ash	15.65	15.78
% Total Sulfur	5.26	5.31
% Sulfate Sulfur	0.28	0.29
% Pyritic Sulfur	3.45	3.48
% Organic Sulfur	1.53	1.54

23.89

RESPECTFULLY SUBMITTED BY Daniel R. Wetmore
Daniel R. Wetmore

HAZEN

Hazen Research, Inc.
4601 Indiana St. • Golden, Colo. 80403
Tel: (303) 279-4501 • Telex 45-860

DATE	June 9, 1989
HRI PROJECT	009-285
HRI SERIES NO.	42485-1
DATE RECD.	5/24/89
CUST P.O.#	567265

Arthur D. Little, Inc.
Nr. Joseph C. Sbatini
20 Acorn Park
Cambridge, Massachusetts 02140-2390

REPORT OF ANALYSIS

SAMPLE NO. 42485-1
SAMPLE IDENTIFICATION: Chamber 5/8/89

Moisture, %	1.95
Ash (As Received), %	3.94
Ash (Dry Basis), %	4.02
Sulfate Sulfur (As Received), %	0.11
Pyritic Sulfur (As Received), %	0.48
Organic Sulfur (As Received), %	2.39
Total Sulfur (As Received), %	2.98
Sulfate Sulfur (Dry Basis), %	0.11
Pyritic Sulfur (Dry Basis), %	0.49
Organic Sulfur (Dry Basis), %	2.44
Total Sulfur (Dry Basis), %	3.04

By:
Coal Laboratory Supervisor

HAZEN

Hazen Research, Inc.
4601 Indiana St. • Golden, Colo 80403
Tel: (303) 279-4501 • Telex 45-860

DATE June 9, 1989
HRI PROJECT 009-285
HRI SERIES NO. 42485-2
DATE RECD. 5/24/89
CUST P.O.# 567265

Arthur D. Little, Inc.
Nr. Joseph C. Sbatini
20 Acorn Park
Cambridge, Massachusetts 02140-2390

REPORT OF ANALYSIS

SAMPLE NO. 42485-2
SAMPLE IDENTIFICATION: Positive Plate 5/8/89

Moisture, %	1.90
Ash (As Received), %	17.80
Ash (Dry Basis), %	18.14
Sulfate Sulfur (As Received), %	0.33
Pyritic Sulfur (As Received), %	3.27
Organic Sulfur (As Received), %	3.66
Total Sulfur (As Received), %	7.26
Sulfate Sulfur (Dry Basis), %	0.34
Pyritic Sulfur (Dry Basis), %	3.33
Organic Sulfur (Dry Basis), %	3.73
Total Sulfur (Dry Basis), %	7.40

By:
Coal Laboratory Supervisor

HAZEN

Hazen Research, Inc.
4601 Indiana St • Golden, Colo 80403
Tel (303) 279-4501 • Telex 45-860

DATE	June 9, 1989
HRI PROJECT	009-285
HRI SERIES NO.	42485-3
DATE RECD.	5/24/89
CUST P.O.#	567265

Arthur D. Little, Inc.
Mr. Joseph C. Sbatini
20 Acorn Park
Cambridge, Massachusetts 02140-2390

REPORT OF ANALYSIS

SAMPLE NO. 42485-3
SAMPLE IDENTIFICATION: Negative Plate 5/8/89

Moisture, %	2.04
Ash (As Received), %	4.21
Ash (Dry Basis), %	4.30
Sulfate Sulfur (As Received), %	0.12
Pyritic Sulfur (As Received), %	0.64
Organic Sulfur (As Received), %	2.63
Total Sulfur (As Received), %	3.39
Sulfate Sulfur (Dry Basis), %	0.12
Pyritic Sulfur (Dry Basis), %	0.65
Organic Sulfur (Dry Basis), %	2.69
Total Sulfur (Dry Basis), %	3.46

Coal Laboratory Supervisor

Hazen Research, Inc.
4601 Indiana St. • Golden. Colo. 80403
Tel: (303) 279-4501 • Telex 45-860

DATE	June 9, 1989
HRI PROJECT	009-285
HRI SERIES NO.	42485-4
DATE RECD.	5/24/89
CUST P.O.#	567265

Arthur D. Little, Inc.
Nr. Joseph C. Sbatini
20 Acorn Park
Cambridge, Massachusetts 02140-2390

REPORT OF ANALYSIS

SAMPLE NO. 42485-4
SAMPLE IDENTIFICATION: Positive Plate 5/12/89

Moisture, %	2.03
Ash (As Received), %	17.35
Ash (Dry Basis), %	17.71
Sulfate Sulfur (As Received), %	0.34
Pyritic Sulfur (As Received), %	3.68
Organic Sulfur (As Received), %	2.81
Total Sulfur (As Received), %	6.83
Sulfate Sulfur (Dry Basis), %	0.35
Pyritic Sulfur (Dry Basis), %	3.76
Organic Sulfur (Dry Basis), %	2.86
Total Sulfur (Dry Basis), %	6.97

By:
Coal Laboratory Supervisor

HAZEN

Hazen Research, Inc.
4601 Indiana St. • Golden Colo 80403
Tel: (303) 279-4501 • Telex 45-860

DATE	June 9, 1989
HRI PROJECT	009-285
HRI SERIES NO.	42485-5
DATE RECD.	5/24/89
CUST P.O.#	567265

Arthur D. Little, Inc.
Mr. Joseph C. Sbatini
20 Acorn Park
Cambridge, Massachusetts 02140-2390

REPORT OF ANALYSIS

SAMPLE NO. 42485-5
SAMPLE IDENTIFICATION: Negative Plate 5/12/89

Moisture, %	2.29
Ash (As Received), %	3.36
Ash (Dry Basis), %	3.44
Sulfate Sulfur (As Received), %	0.07
Pyritic Sulfur (As Received), %	0.58
Organic Sulfur (As Received), %	2.74
Total Sulfur (As Received), %	3.39
Sulfate Sulfur (Dry Basis), %	0.07
Pyritic Sulfur (Dry Basis), %	0.59
Organic Sulfur (Dry Basis), %	2.81
Total Sulfur (Dry Basis), %	3.47

By: Willis Collins
Coal Laboratory Supervisor

HAZEN

Hazen Research, Inc.
4601 Indiana St. • Golden, Colo 80403
Tel: (303) 279-4501 • Telex 45-860

DATE	June 9, 1989
HRI PROJECT	009-285
HRI SERIES NO.	42485-6
DATE RECD.	5/24/89
CUST P.O.#	567265

Arthur D. Little, Inc.
Nr. Joseph C. Sbatini
20 Acorn Park
Cambridge, Massachusetts 02140-2390

REPORT OF ANALYSIS

SAMPLE NO. 42485-6
SAMPLE IDENTIFICATION: Positive Plate 5/19/89

Moisture, %	2.02
Ash (As Received), %	16.08
Ash (Dry Basis), %	16.41
Sulfate Sulfur (As Received), %	0.30
Pyritic Sulfur (As Received), %	3.74
Organic Sulfur (As Received), %	2.61
Total Sulfur (As Received), %	6.65
Sulfate Sulfur (Dry Basis), %	0.31
Pyritic Sulfur (Dry Basis), %	3.82
Organic Sulfur (Dry Basis), %	2.66
Total Sulfur (Dry Basis), %	6.79

By: Collins
Coal Laboratory Supervisor

HAZEN

Hazen Research, Inc.
4601 Indiana St. • Golden. Colo. 80403
Tel: (303) 279-4501 • Telex 45-860

DATE	June 9, 1989
HRI PROJECT	009-285
HRI SERIES NO.	42485-7
DATE RECD.	5/24/89
CUST P.O.#	567265

Arthur D. Little, Inc.
Nr. Joseph C. Sbatini
20 Acorn Park
Cambridge, Massachusetts 02140-2390

REPORT OF ANALYSIS

SAMPLE NO. 42485-7
SAMPLE IDENTIFICATION: Negative Plate 5/19/89

Moisture, %	2.17
Ash (As Received), %	3.54
Ash (Dry Basis), %	3.62
Sulfate Sulfur (As Received), %	0.07
Pyritic Sulfur (As Received), %	0.47
Organic Sulfur (As Received), %	2.96
Total Sulfur (As Received), %	3.50
Sulfate Sulfur (Dry Basis), %	0.07
Pyritic Sulfur (Dry Basis), %	0.48
Organic Sulfur (Dry Basis), %	3.03
Total Sulfur (Dry Basis), %	3.58

By
Coal Laboratory Supervisor

HAZEN

Hazen Research, inc.
4601 Indiana St • Golden, Colo 80403
Tel (303) 279-4501 • Telex 45 860

DATE	June15 1989
HRI PROJECT	009-285
HRI SERIES NO.	42535-B
DATE RECD	5/30/89
CUST P.O.#	567265

REPORT OF ANALYSIS

Arthur D. Little Inc.

20 Acorn Park
Cambridge Massachusetts 02140-2390

SAMPLE IDENTIFICATION:
Negative 5/30/89

-

REPORTING BASIS >	AS RECD	DRY	EQM	AIR DRY
PROXIMATE (%)				
MOISTURE	1.44	0.00		1.44
ASH	14.15	14.36		14.15
VOLATILE				
FIXED C				
	------	------	------	------
TOTAL				
SULFUR	1.61	1.63		1.61
BTU/LB				
MMF BTU/LB				
MAF BTU/LB				
AIR DRY LOSS (%)				
ULTIMATE (%)				
MOISTURE				
CARBON				
HYDROGEN				
NITROGEN				
SULFUR				
ASH				
OXYGEN*				
	------	------	------	------
TOTAL				
CHLORINE**				

FORMS OF SULFUR (AS S,%)		
SULFATE	0.06	0.06
PYRITIC	0.97	0.98
ORGANIC	0.58	0.59
	------	------
TOTAL	1.61	1.63

LB. ASH/MM BTU=
LB. SO2/MM BTU=
HGI= @ % MOISTURE
AS REC'D. SP.GR.=
FREE SWELLING INDEX=

REPORT PREPARED BY:

COAL LABORATORY SUPERVISOR

WATER SOLUBLE ALKALIES (%)

NA2O
K2O

* OXYGEN BY DIFFERENCE.
** NOT USUALLY REPORTED AS PART OF THE ULTIMATE ANALYSIS

Hazen Research, Inc.
4601 Indiana St • Golden, Colo. 80403
Tel (303) 279-4501 • Telex 45-860

DATE June15 1989
HRI PROJECT 009-285
HRI SERIES NO. 42535-A
DATE RECD 5/31/89
CUST P.O.# 567265

REPORT OF ANALYSIS

Arthur D. Little Inc.

20 Acorn Park
Cambridge Massachusetts 02140-2390

SAMPLE IDENTIFICATION:
Positive 5/30/89

-

REPORTING BASIS >	AS RECD	DRY	EQM	AIR DRY
PROXIMATE (%)				
MOISTURE	1.31	0.00		1.31
ASH	41.43	41.98		41.43
VOLATILE				
FIXED C				
	------	------	------	------
TOTAL				
SULFUR	2.66	2.70		2.66
BTU/LB				
MMF BTU/LB		-		
MAF BTU/LB				
AIR DRY LOSS (%)				
ULTIMATE (%)				
MOISTURE				
CARBON				
HYDROGEN				
NITROGEN				
SULFUR				
ASH				
OXYGEN*				
	------	------	------	------
TOTAL				
CHLORINE**				
FORMS OF SULFUR (AS S,%)				
SULFATE	0.14	0.14		
PYRITIC	2.09	2.12		
ORGANIC	0.43	0.44		
	------	------		
TOTAL	2.66	2.70		
WATER SOLUBLE ALKALIES (%)				
NA2O				
K2O				

LB. ASH/MM BTU=
LB. SO2/MM BTU=
HGI= @ % MOISTURE
AS REC'D. SP.GR.=
FREE SWELLING INDEX=

REPORT PREPARED BY:

COAL LABORATORY SUPERVISOR

* OXYGEN BY DIFFERENCE.
** NOT USUALLY REPORTED AS PART OF THE ULTIMATE ANALYSIS

HAZEN

Hazen Research, Inc.
4601 Indiana St • Golden, Colo. 80403
Tel. (303) 279-4501 • Telex 45-860

DATE June 16 1989
HRI PROJECT 009-285
HRI SERIES NO. 42658
DATE RECD 6/13/89
CUST P.O.# 567265

REPORT OF ANALYSIS

Arthur D. Little Inc.

20 Acorn Park
Cambridge Massachusetts 02140-2390

SAMPLE IDENTIFICATION:
Control 6/12/89

-

REPORTING BASIS >	AS RECD	DRY	EQM	AIR DRY
PROXIMATE (%)				
MOISTURE	1.62	0.00		1.62
ASH	9.00	9.15		9.00
VOLATILE				
FIXED C				
	------	------	------	------
TOTAL				
SULFUR	3.69	3.75		3.69
BTU/LB				
MMF BTU/LB				
MAF BTU/LB				
AIR DRY LOSS (%)				
ULTIMATE (%)				
MOISTURE				
CARBON				
HYDROGEN				
NITROGEN				
SULFUR				
ASH				
OXYGEN*				
	------	------	------	------
TOTAL				
CHLORINE**				

FORMS OF SULFUR (AS S,%)		
SULFATE	0.15	0.15
PYRITIC	2.25	2.29
ORGANIC	1.29	1.31
	-------	------
TOTAL	3.69	3.75

WATER SOLUBLE ALKALIES (%)

NA2O
K2O

LB. ASH/MM BTU=
LB. SO2/MM BTU=
HGI= @ % MOISTURE
AS REC'D. SP.GR.=
FREE SWELLING INDEX=

REPORT PREPARED BY:

COAL LABORATORY SUPERVISOR

* OXYGEN BY DIFFERENCE.
** NOT USUALLY REPORTED AS PART OF THE ULTIMATE ANALYSIS

Hazen Research, inc.
4601 Indiana St. • Golden, Colo 80403
Tel: (303) 279-4501 • Telex 45-860

DATE	July 13, 1989
HRI PROJECT	009-285
HRI SERIES NO.	42715-1
DATE RECD.	6/16/89
CUST P.O.#	567265

Arthur D. Little, Inc.
Nr. Joseph C. Sbatini
20 Acorn Park
Cambridge, Massachusetts 02140-2390

REPORT OF ANALYSIS

SAMPLE NO. 42715-1
SAMPLE IDENTIFICATION: Negative 6/12/89

Moisture, %	1.53
Ash (As Received), %	3.55
Ash (Dry Basis), %	3.61
Sulfate Sulfur (As Received), %	0.10
Pyritic Sulfur (As Received), %	0.50
Organic Sulfur (As Received), %	2.24
Total Sulfur (As Received), %	2.84
Sulfate Sulfur (Dry Basis), %	0.10
Pyritic Sulfur (Dry Basis), %	0.51
Organic Sulfur (Dry Basis), %	2.27
Total Sulfur (Dry Basis), %	2.88

By:
Coal Laboratory Supervisor

Hazen Research, Inc.
4601 Indiana St. • Golden, Colo 80403
Tel: (303) 279-4501 • Telex 45-860

DATE	July 13, 1989
HRI PROJECT	009-285
HRI SERIES NO.	42715-2
DATE RECD.	6/16/89
CUST P.O.#	567265

Arthur D. Little, Inc.
Nr. Joseph C. Sbatini
20 Acorn Park
Cambridge, Massachusetts 02140-2390

REPORT OF ANALYSIS

SAMPLE NO. 42715-2
SAMPLE IDENTIFICATION: Positive 6/12/89

Moisture, %	1.44
Ash (As Received), %	16.83
Ash (Dry Basis), %	17.08
Sulfate Sulfur (As Received), %	0.24
Pyritic Sulfur (As Received), %	3.82
Organic Sulfur (As Received), %	2.34
Total Sulfur (As Received), %	6.40
Sulfate Sulfur (Dry Basis), %	0.24
Pyritic Sulfur (Dry Basis), %	3.88
Organic Sulfur (Dry Basis), %	2.37
Total Sulfur (Dry Basis), %	6.49

By
Coal Laboratory Supervisor

HAZEN

Hazen Research, Inc.
4601 Indiana St. • Golden, Colo 80403
Tel: (303) 279-4501 • Telex 45-860

DATE	July 14, 1989
HRI PROJECT	009-285
HRI SERIES NO.	42795-1
DATE RECD.	6/27/89
CUST P.O.#	567265

Arthur D. Little, Inc.
Nr. Joseph C. Sbatini
20 Acorn Park
Cambridge, Massachusetts 02140-2390

REPORT OF ANALYSIS

SAMPLE NO. 42795-1
SAMPLE IDENTIFICATION: Positive 6/19/89

Moisture, %	1.79
Ash (As Received), %	3.62
Ash (Dry Basis), %	3.69
Sulfate Sulfur (As Received), %	0.14
Pyritic Sulfur (As Received), %	0.46
Organic Sulfur (As Received), %	2.83
Total Sulfur (As Received), %	3.43
Sulfate Sulfur (Dry Basis), %	0.14
Pyritic Sulfur (Dry Basis), %	0.47
Organic Sulfur (Dry Basis), %	2.88
Total Sulfur (Dry Basis), %	3.49

By:
Coal Laboratory Supervisor

HAZEN

Hazen Research, Inc.
4601 Indiana St. • Golden, Colo. 80403
Tel: (303) 279-4501 • Telex 45-860

DATE	July 14, 1989
HRI PROJECT	009-285
HRI SERIES NO.	42795-2
DATE RECD.	6/27/89
CUST P.O.#	567265

Arthur D. Little, Inc.
Nr. Joseph C. Sbatini
20 Acorn Park
Cambridge, Massachusetts 02140-2390

REPORT OF ANALYSIS

SAMPLE NO. 42795-2
SAMPLE IDENTIFICATION: Negative 6/19/89

Moisture, %	1.57
Ash (As Received), %	13.75
Ash (Dry Basis), %	13.97
Sulfate Sulfur (As Received), %	0.46
Pyritic Sulfur (As Received), %	2.84
Organic Sulfur (As Received), %	2.30
Total Sulfur (As Received), %	5.60
Sulfate Sulfur (Dry Basis), %	0.47
Pyritic Sulfur (Dry Basis), %	2.89
Organic Sulfur (Dry Basis), %	2.33
Total Sulfur (Dry Basis), %	5.69

By:
Coal Laboratory Supervisor

HAZEN

Hazen Research, Inc.
4601 Indiana St. • Golden, Colo. 80403
Tel: (303) 279-4501 • Telex 45-860

DATE	July 14, 1989
HRI PROJECT	009-285
HRI SERIES NO.	42795-3
DATE RECD.	6/27/89
CUST P.O.#	567265

Arthur D. Little, Inc.
Nr. Joseph C. Sbatini
20 Acorn Park
Cambridge, Massachusetts 02140-2390

REPORT OF ANALYSIS

SAMPLE NO. 42795-3
SAMPLE IDENTIFICATION: Positive 6/22/89

Moisture, %	1.86
Ash (As Received), %	7.41
Ash (Dry Basis), %	7.55
Sulfate Sulfur (As Received), %	0.15
Pyritic Sulfur (As Received), %	1.12
Organic Sulfur (As Received), %	2.36
Total Sulfur (As Received), %	3.63
Sulfate Sulfur (Dry Basis), %	0.15
Pyritic Sulfur (Dry Basis), %	1.14
Organic Sulfur (Dry Basis), %	2.41
Total Sulfur (Dry Basis), %	3.70

By:
Coal Laboratory Supervisor

HAZEN

Hazen Research, Inc.
4601 Indiana St. • Golden, Colo. 80403
Tel: (303) 279-4501 • Telex 45-860

DATE	July 14, 1989
HRI PROJECT	009-285
HRI SERIES NO.	42795-4
DATE RECD.	6/27/89
CUST P.O.#	567265

Arthur D. Little, Inc.
Nr. Joseph C. Sbatini
20 Acorn Park
Cambridge, Massachusetts 02140-2390

REPORT OF ANALYSIS

SAMPLE NO. 42795-4
SAMPLE IDENTIFICATION: Negative 6/22/89

Moisture, %	1.71
Ash (As Received), %	10.15
Ash (Dry Basis), %	10.33
Sulfate Sulfur (As Received), %	0.23
Pyritic Sulfur (As Received), %	1.50
Organic Sulfur (As Received), %	3.51
Total Sulfur (As Received), %	5.24
Sulfate Sulfur (Dry Basis), %	0.23
Pyritic Sulfur (Dry Basis), %	1.53
Organic Sulfur (Dry Basis), %	3.57
Total Sulfur (Dry Basis), %	5.33

By Willis Collins Jr.
Coal Laboratory Supervisor

Hazen Research, Inc.
4601 Indiana St. • Golden, Colo. 80403
Tel: (303) 279-4501 • Telex 45-860

DATE	July 14, 1989
HRI PROJECT	009-285
HRI SERIES NO.	42795-5
DATE RECD.	6/27/89
CUST P.O.#	567265

Arthur D. Little, Inc.
Mr. Joseph C. Sbatini
20 Acorn Park
Cambridge, Massachusetts 02140-2390

REPORT OF ANALYSIS

SAMPLE NO. 42795-5
SAMPLE IDENTIFICATION: Control 6/22/89

Moisture, %	1.69
Ash (As Received), %	8.88
Ash (Dry Basis), %	9.03
Sulfate Sulfur (As Received), %	0.21
Pyritic Sulfur (As Received), %	2.21
Organic Sulfur (As Received), %	2.18
Total Sulfur (As Received), %	4.60
Sulfate Sulfur (Dry Basis), %	0.21
Pyritic Sulfur (Dry Basis), %	2.25
Organic Sulfur (Dry Basis), %	2.22
Total Sulfur (Dry Basis), %	4.68

By:
Coal Laboratory Supervisor

HAZEN

Hazen Research, Inc.
4601 Indiana St. • Golden, Colo. 80403
Tel: (303) 279-4501 • Telex 45-860

DATE	July 14, 1989
HRI PROJECT	009-285
HRI SERIES NO.	42795-6
DATE RECD.	6/27/89
CUST P.O.#	567265

Arthur D. Little, Inc.
Mr. Joseph C. Sbatini
20 Acorn Park
Cambridge, Massachusetts 02140-2390

REPORT OF ANALYSIS

SAMPLE NO. 42795-6
SAMPLE IDENTIFICATION: Positive 6/23/89

Moisture, %	2.03
Ash (As Received), %	11.05
Ash (Dry Basis), %	11.28
Sulfate Sulfur (As Received), %	0.15
Pyritic Sulfur (As Received), %	1.63
Organic Sulfur (As Received), %	2.82
Total Sulfur (As Received), %	4.60
Sulfate Sulfur (Dry Basis), %	0.15
Pyritic Sulfur (Dry Basis), %	1.66
Organic Sulfur (Dry Basis), %	2.89
Total Sulfur (Dry Basis), %	4.70

By: Nellie Collins
Coal Laboratory Supervisor

HAZEN

Hazen Research, Inc.
4601 Indiana St. • Golden, Colo. 80403
Tel: (303) 279-4501 • Telex 45-860

DATE	July 14, 1989
HRI PROJECT	009-285
HRI SERIES NO.	42795-7
DATE RECD.	6/27/89
CUST P.O.#	567265

Arthur D. Little, Inc.
Nr. Joseph C. Sbatini
20 Acorn Park
Cambridge, Massachusetts 02140-2390

REPORT OF ANALYSIS

SAMPLE NO. 42795-7
SAMPLE IDENTIFICATION: Negative 6/23/89

Moisture, %	1.77
Ash (As Received), %	6.49
Ash (Dry Basis), %	6.61
Sulfate Sulfur (As Received), %	0.20
Pyritic Sulfur (As Received), %	1.45
Organic Sulfur (As Received), %	2.48
Total Sulfur (As Received), %	4.13
Sulfate Sulfur (Dry Basis), %	0.20
Pyritic Sulfur (Dry Basis), %	1.48
Organic Sulfur (Dry Basis), %	2.52
Total Sulfur (Dry Basis), %	4.20

By:
Coal Laboratory Supervisor

HAZEN

Hazen Research, Inc.
4601 Indiana St. • Golden, Colo 80403
Tel: (303) 279-4501 • Telex 45-860

DATE	July 14, 1989
HRI PROJECT	009-285
HRI SERIES NO.	42795-8
DATE RECD.	6/27/89
CUST P.O.#	567265

Arthur D. Little, Inc.
Nr. Joseph C. Sbatini
20 Acorn Park
Cambridge, Massachusetts 02140-2390

REPORT OF ANALYSIS

SAMPLE NO. 42795-8
SAMPLE IDENTIFICATION: Control 6/23/89

Moisture, %	1.76
Ash (As Received), %	8.86
Ash (Dry Basis), %	9.02
Sulfate Sulfur (As Received), %	0.17
Pyritic Sulfur (As Received), %	2.05
Organic Sulfur (As Received), %	1.64
Total Sulfur (As Received), %	3.86
Sulfate Sulfur (Dry Basis), %	0.17
Pyritic Sulfur (Dry Basis), %	2.09
Organic Sulfur (Dry Basis), %	1.67
Total Sulfur (Dry Basis), %	3.93

By:
Coal Laboratory Supervisor

HARRY W. GALBRAITH, PH.D
CHAIRMAN OF THE BOARD

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EXECUTIVE VICE-PRESIDENT

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SECRETARY/TREASURER

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QUANTITATIVE MICROANALYSES
ORGANIC – INORGANIC
615/546-1335

P.O. BOX 51610
KNOXVILLE, TN 37950-1610

2323 SYCAMORE DR.
KNOXVILLE, TN 37921-1750

Mr. Lawrence Woodland
ARthur D. Little Inc.
20 Acorn Park
Cambridge, Massachusetts 02140

August 3, 1989

Received: July 20th
PO#: 200-302-28

Dear Mr. Woodland:

Analysis of your compounds gave the following results:

Your #,	Our #,	% Ash,	% Total Sulfur,	% SO4 as Sulfur,	% Pyritic Sulfur,	% Organic Sulfur,
6/22 Pos	G-8014	7.19	3.61	0.14	1.36	2.11
6/22 Neg	G-8015	10.31	5.61	0.27	3.12	2.22
6/23 Pos	G-8016	11.78	5.00	0.16	2.63	2.21
6/23 Neg	G-8017	6.48	4.26	0.20	1.88	2.18

Sincerely yours,

GALBRAITH LABORATORIES, INC.

Gail R Hutchens

Gail R. Hutchens
Exec. Vice-President

GRH:sc

HARRY W GALBRAITH, PH D
CHAIRMAN OF THE BOARD

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2323 SYCAMORE DR.
KNOXVILLE, TN 37921-1750

Ms. Sherrie L. DiMare
Arthur D. Little Inc.
20-428 Acorn Park
Cambridge, Massachusetts 02140

November 27, 1989

Received: November 10th
PO#: 568651

Dear Ms. DiMare:

Analysis of your compounds gave the following results:

Your #,	Our #,	Analyses,	
Positive Plates 11-6-89	I-6637	% Ash	17.73
		% Total Sulfur	7.03
		% SO_4 as Sulfur	0.27
		% Pyritic Sulfur	4.89
		% Organic Sulfur	1.87
Negative Plate 10-30-89	I-6638	% Ash	2.81
		% Total Sulfur	3.00
		% SO_4 as Sulfur	0.056
		% Pyritic Sulfur	0.43
		% Organic Sulfur	2.51
Sample before run 10-30-89	I-6639	% Ash	8.73
		% Total Sulfur	4.79
		% SO_4 as Sulfur	0.15
		% Pyritic Sulfur	2.16
		% Organic Sulfur	2.48
Sample before run 11-2-89	I-6640	% Ash	8.67
		% Total Sulfur	4.68
		% SO_4 as Sulfur	0.15
		% Pyritic Sulfur	1.92
		% Organic Sulfur	2.61
Positive Plates 10-30-89	I-6641	% Ash	15.82
		% Total Sulfur	7.08
		% SO_4 as Sulfur	0.26
		% Pyritic Sulfur	3.96
		% Organic Sulfur	2.86

Your #,	Our #,	Analyses,	
Sample before run 10-31-89	I-6642	% Ash	8.64
		% Total Sulfur	4.40
		% SO_4 as Sulfur	0.14
		% Pyritic Sulfur	1.92
		% Organic Sulfur	2.34
Positive Plates 10-31-89	I-6643	% Ash	13.70
		% Total Sulfur	5.72
		% SO_4 as Sulfur	0.23
		% Pyritic Sulfur	3.27
		% Organic Sulfur	2.22
Sample before run 11-6-89	I-6644	% Ash	8.66
		% Total Sulfur	3.54
		% SO_4 as Sulfur	0.14
		% Pyritic Sulfur	1.87
		% Organic Sulfur	1.53
Negative Plates 11-2-89	I-6645	% Ash	2.86
		% Total Sulfur	3.42
		% SO_4 as Sulfur	0.10
		% Pyritic Sulfur	0.46
		% Organic Sulfur	2.86
Positive Plates 11-2-89	I-6646	% Ash	13.62
		% Total Sulfur	6.50
		% SO_4 as Sulfur	0.23
		% Pyritic Sulfur	2.97
		% Organic Sulfur	3.30
Negative Plates 10-31-89	I-6647	% Ash	2.97
		% Total Sulfur	3.13
		% SO_4 as Sulfur	0.066
		% Pyritic Sulfur	0.50
		% Organic Sulfur	2.56
Negative 11-6-89	I-6648	% Ash	2.85
		% Total Sulfur	3.14
		% SO_4 as Sulfur	0.068
		% Pyritic Sulfur	0.43
		% Organic Sulfur	2.64

Sincerely yours,

GALBRAITH LABORATORIES, INC.

Gail R. Hutchens
Exec. Vice-President

GRH:mck

HARRY W. GALBRAITH, PH.D
CHAIRMAN OF THE BOARD

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P.O. BOX 51610
KNOXVILLE, TN 37950-1610

2323 SYCAMORE DR.
KNOXVILLE, TN 37921-1750

Ms. Sherre L. DiMare
Arthur D. Little Inc.
20-428 Acorn Park
Cambridge, Massachusetts 02140

December 14, 1989

Received: November 15th
PO#: 568651

Dear Ms. DiMare:

Analysis of your compounds gave the following results:

Your #,	Our #,	% Ash,	% Total Sulfur,	% SO_4 as Sulfur,	% Pyritic Sulfur,	% Organic Sulfur,
Positive Plates 11-9-89	I-7373	50.92	2.80	0.19	2.06	0.55
Negative Plates 11-7-89	I-7374	11.77	1.71	0.083	0.90	0.73
Positive Plates 11-7-89	I-7375	49.34	2.90	0.16	2.34	0.40
Sample before run 11-7-89	I-7376	27.43	2.39	0.12	1.49	0.78
Sample before run 11-13-89	I-7377	27.66	2.42	0.13	1.65	0.64
Negative Plates 11-13-89	I-7378	12.90	1.84	0.12	0.91	0.81
Positive Plates 11-13-89	I-7379	47.42	2.98	0.17	2.28	0.53
Positive Plates 11-8-89	I-7380	50.41	2.60	0.17	2.16	0.27
Negative Plates 11-8-89	I-7381	10.46	1.60	0.13	0.73	0.74
Negative Plates 11-9-89	I-7382	10.96	1.68	0.10	0.66	0.92

Your #,	Our #,	% Ash,	% Total Sulfur,	% SO_4 as Sulfur,	% Pyritic Sulfur,	% Organic Sulfur,
Sample before run 11-9-89	I-7383	27.56	2.44	0.17	1.54	0.73
Sample before run 11-8-89	I-7384	27.51	2.51	0.12	1.60	0.79

Sincerely yours,

GALBRAITH LABORATORIES, INC.

Gail R Hutt

Gail R. Hutchens
Exec. Vice-President

GRH:mck

HARRY W. GALBRAITH, PH.D
CHAIRMAN OF THE BOARD

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P.O. BOX 51610
KNOXVILLE, TN 37950-1610

2323 SYCAMORE DR.
KNOXVILLE, TN 37921-1750

Ms. Sherrie L. DiMare
Arthur D. Little Inc.
20-428 Acorn Park
Cambridge, Massachusetts 02140

December 18, 1989

Received: November 22nd
PO#: 568651

Dear Ms. DiMare:

Analysis of your compounds gave the following results:

Your #,	Our #,	% Ash,	% Total Sulfur,	% Sulfate as Sulfur,	% Pyritic Sulfur,	% Organic Sulfur,
Negative Plates 11/14/89	I-8575	8.91	3.46	0.66	0.44	2.36
Sample before run 11/14/89	I-8576	11.87	3.44	0.77	0.45	2.22
Positive Plates 11/14/89	I-8577	16.80	3.69	0.95	0.68	2.06
Negative Plates 11/15/89	I-8578	7.45	3.46	0.62	0.42	2.42
Sample before run 11/15/89	I-8579	11.90	3.53	0.76	0.35	2.42
Positive Plates 11/15/89	I-8580	17.83	3.79	1.03	0.67	2.09
Negative Plates 11/16/89	I-8581	6.92	3.11	0.54	0.35	2.22
Sample before run 11/16/89	I-8582	12.17	3.54	0.76	0.51	2.27
Positive Plates 11/16/89	I-8583	18.56	3.79	1.02	0.45	2.32
Negative Plates 11/17/89	I-8584	7.77	3.35	0.61	0.23	2.51

Your #,	Our #,	% Ash,	% Total Sulfur,	% Sulfate as Sulfur,	% Pyritic Sulfur,	%Organic Sulfur,
Sample before run 11/17/89	I-8585	12.34	3.62	0.77	0.52	2.33
Positive Plates 11/17/89	I-8586	18.53	3.89	1.06	0.47	2.36

Sincerely yours,

GALBRAITH LABORATORIES, INC.

Gail R. Hutchens

Gail R. Hutchens
Exec. Vice-President

GRH:mck

HARRY W. GALBRAITH, PH.D
CHAIRMAN OF THE BOARD

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2323 SYCAMORE DR.
KNOXVILLE, TN 37921-1750

Ms. Sherrie L. DiMare
Arthur D. Little Inc.
20-428 Acorn Park
Cambridge, Massachusetts 02140

December 22, 1989

Received: November 29th
PO#: 568651

Dear Ms. DiMare:

Analysis of your compounds gave the following results:

Your #,	Our #,	% Ash,	% Total Sulfur,	% Sulfate as Sulfur,	% Pyritic Sulfur,	% Organic Sulfur,
Negative Plates 11/21/89	I-9410	3.20	2.92	0.070	0.54	2.31
Positive Plates 11/21/89	I-9411	18.95	7.84	0.39	5.36	2.09
Sample before run 11/21/89	I-9412	8.69	4.53	0.17	2.48	1.88
Negative Plates 11/22/89	I-9413	2.84	2.83	0.055	0.44	2.34
Positive Plates 11/22/89	I-9414	22.20	8.24	0.37	6.12	1.75
Sample before run 11/22/89	I-9415	8.74	4.68	0.15	2.35	2.18
Negative Plates 11/27/89	I-9416	2.91	2.92	0.058	0.49	2.37
Positive Plates 11/27/89	I-9417	22.24	8.18	0.39	4.05	3.74
Sample before run 11/27/89	I-9418	8.70	4.71	0.16	2.51	1.32

Sincerely yours,

Gail R. Hutchens
Executive Vice-President

GRH:mck

HARRY W GALBRAITH, PH.D
CHAIRMAN OF THE BOARD

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PRESIDENT

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P.O. BOX 51610
KNOXVILLE, TN 37950-1610

2323 SYCAMORE DR.
KNOXVILLE, TN 37921-1750

Ms. Sherrie L. DiMare
Arthur D. Little, Inc.
20-428 Acorn Park
Cambridge, Massachusetts 02140

January 2, 1990

Received: December 7th
PO#: 568651

Dear Ms. DiMare:

Analysis of your compounds gave the following results:

Your #,	Our #,	% Ash,	% Total Sulfur,	% Sulfate, as Sulfur,	% Pyritic Sulfur,	% Organic Sulfur,
Positive Plates 11/28/89	J-0646	16.40	6.40	0.18	3.02	3.20
Before Run 11/30/89	J-0647	8.89	4.54	0.13	2.13	2.28
Positive Plates 12/04/89	J-0648	15.13	6.35	0.16	4.06	2.13
Before Run 11/28/89	J-0649	8.83	4.74	0.15	2.31	2.28
Negative Plates 12/04/89	J-0650	4.48	3.42	0.12	0.83	2.47
Before Run 12/04/89	J-0651	8.72	4.62	0.14	2.10	2.38
Negative Plates 11/28/89	J-0652	4.41	3.38	0.15	0.82	2.41
Negative Plates 11/30/89	J-0653	4.61	3.43	0.14	0.50	2.79
Positive Plates 11/30/89	J-0654	16.08	6.32	0.16	3.94	2.22

Sincerely yours,

Gail R. Hutchens, Executive Vice-President

TTER AND SHIPMENTS BY U.S. MAIL · P.O. BOX 51610, KNOXVILLE, TN 37950-1610. OTHER CARRIERS · 2323 SYCAMORE DR, KNOXVILLE, TN 37921-1750

GRH:mck

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EXECUTIVE VICE-PRESIDENT

VELMA M. RUSSELL
SECRETARY-TREASURER

GALBRAITH
Laboratories, Inc.
QUANTITATIVE MICROANALYSES
ORGANIC – INORGANIC
615/546-1335

P.O. BOX 51610
KNOXVILLE, TN 37950-1610

2323 SYCAMORE DR.
KNOXVILLE, TN 37921-1750

Ms. Sherrie L. DiMare
Arthur D. Little Inc.
20-428 Acorn Park
Cambridge, Massachusetts 02140

January 4, 1990

Received: December 11th
PO#: 568651

Dear Ms. DiMare:

Analysis of your compounds gave the following results:

Your #,	Our #,	% Ash,	% Total Sulfur,	% Sulfate as Sulfur,	% Pyritic Sulfur,	% Organic Sulfur,
Sample Before Run 12/6/89	J-1039	27.79	2.76	0.10	1.52	1.14
Negative Plates 12/6/89	J-1040	10.57	1.60	0.07	0.83	0.70
Negative Plates 12/5/89	J-1041	10.58	1.65	0.07	0.80	0.78
Positive Plates 12/5/89	J-1042	49.80	2.89	0.15	2.24	0.50
Sample Before Run 12/5/89	J-1043	27.71	2.37	0.09	1.49	0.79
Positive Plates 12/6/89	J-1044	53.22	2.69	0.16	1.15	1.38
Sample Before Run 12/7/89	J-1045	27.75	2.40	0.10	1.42	0.88
Negative Plates 12/7/89	J-1046	11.72	1.71	0.07	0.76	0.88
Positive Plates 12/7/89	J-1047	50.72	2.90	0.13	2.02	0.75

Sincerely yours,

Gail R. Hutchens
Executive Vice-President

TTER AND SHIPMENTS BY U.S. MAIL · P.O. BOX 51610, KNOXVILLE, TN 37950-1610. OTHER CARRIERS · 2323 SYCAMORE DR. KNOXVILLE, TN 37921-1750

GRH:mck

ESTABLISHED 1950

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PRESIDENT

GAIL R. HUTCHENS
EXECUTIVE VICE-PRESIDENT

VELMA M. RUSSELL
SECRETARY TREASURER

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Laboratories, Inc.

QUANTITATIVE MICROANALYSES
ORGANIC – INORGANIC
615/546-1335

P.O. BOX 51610
KNOXVILLE, TN 37950-1610

2323 SYCAMORE DR.
KNOXVILLE, TN 37921-1750

Ms. Sherrie L. DiMare
Arthur D. Little, Inc.
20-428 Acorn Park
Cambridge, Massachusetts 02140

January 16, 1990

Received: December 21st
PO#: 568651

Dear Ms. DiMare:

Analysis of your compounds gave the following results:

Your #,	Our #,	% Ash,	% Total Sulfur,	% Sulfate As Sulfur,	% Pyritic Sulfur,	% Organic Sulfur,
Positive Plates 12/8/89	J-2829	49.76	2.68	0.115	2.14	0.425
Negative Plates 12/19/89	J-2830	3.38	2.96	0.063	0.321	2.58
Sample Before Run 12/8/89	J-2831	27.65	2.38	0.102	1.36	0.918
Sample Before Run 12/19/89	J-2832	8.94	4.74	0.162	1.96	2.62
Negative Plates 12/14/89	J-2833	4.04	3.15	0.077	0.676	2.40
Negative Plates 12/9/89	J-2834	11.64	1.78	0.113	0.727	0.940
Positive Plates 12/15/89	J-2835	12.81	5.68	0.201	3.26	2.22
Positive Plates 12/14/89	J-2836	15.28	6.40	0.221	4.18	2.00
Sample Before Run 12/14/89	J-2837	8.89	4.70	0.144	2.40	2.16
Positive Plates 12/19/89	J-2838	16.10	6.75	0.234	4.32	2.20
Positive Plates 12/9/89	J-2839	46.95	2.85	0.119	2.00	0.731

Your #,	Our #,	% Ash,	% Total Sulfur,	% Sulfate As Sulfur,	% Pyritic Sulfur,	% Organic Sulfur,
Sample Before Run 12/9/89	J-2840	27.44	2.43	0.098	1.49	0.842
Negative Plates 12/18/89	J-2841	11.77	1.82	0.086	0.937	0.797
Positive Plates 12/18/89	J-2842	47.56	3.01	0.109	2.42	0.481
Sample Before Run 12/15/89	J-2843	8.62	4.78	0.144	2.34	2.30
Sample Before Run 12/18/89	J-2844	27.62	2.42	0.105	1.48	0.835
Negative Plates 12/8/89	J-2845	9.69	1.68	0.088	0.383	1.21
Negative Plates 12/15/89	J-2846	6.71	3.84	0.107	1.37	2.36

Sincerely yours,

GALBRAITH LABORATORIES, INC.

Gail R. Hutchens
Exec. Vice-President

GRH:mck

HARRY W GALBRAITH, PH.D
CHAIRMAN OF THE BOARD

KENNETH S. WOODS
PRESIDENT

GAIL R. HUTCHENS
EXECUTIVE VICE-PRESIDENT

VELMA M. RUSSELL
SECRETARY TREASURER

GALBRAITH
Laboratories, Inc.

QUANTITATIVE MICROANALYSES
ORGANIC – INORGANIC
615/546-1335

P.O. BOX 51610
KNOXVILLE, TN 37950-1610

2323 SYCAMORE DR.
KNOXVILLE, TN 37921-1750

Ms. Sherrie L. DiMare
Arthur D. Little Inc.
20-428 Acorn Park
Cambridge, Massachusetts 02140

January 11, 1990

Received: December 14th
PO#: 568651

Dear Ms. DiMare:

Analysis of your compounds gave the following results:

Your #,	Our #,	% Ash,	% Total Sulfur,	% Sulfate As Sulfur,	% Pyritic Sulfur,	% Organic Sulfur,
Positive Plates 12/13/89	J-1723	46.13	2.78	0.109	2.65	0.021
Negative Plates 12/11/89	J-1724	11.49	1.81	0.074	0.82	0.92
Negative Plates 12/13/89	J-1725	11.33	1.80	0.078	0.91	0.81
Negative Plates 12/12/89	J-1726	12.62	1.92	0.078	0.75	1.09
Sample Before Run 12/12/89	J-1727	27.69	2.42	0.096	0.65	1.67
Positive Plates 12/12/89	J-1728	42.78	2.86	0.116	2.31	0.43
Positive Plates 12/11/89	J-1729	44.33	3.00	0.12	1.74	1.14
Sample Before Run 12/13/89	J-1730	27.66	2.56	0.15	1.09	1.32
Sample Before Run 12/11/89	J-1731	27.80	2.36	0.095	1.49	0.78

Sincerely yours,

Gail R. Hutchens
Executive Vice-President

HARRY W. GALBRAITH, PH D
CHAIRMAN OF THE BOARD

KENNETH S. WOODS
PRESIDENT

GAIL R. HUTCHENS
EXECUTIVE VICE-PRESIDENT

VELMA M. RUSSELL
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P.O. BOX 51610
KNOXVILLE, TN 37950-1610

2323 SYCAMORE DR.
KNOXVILLE, TN 37921-1750

Ms. Sherrie L. DiMare
Arthur D. Little Inc.
20-428 Acorn Park
Cambridge, Massachusetts 02140

February 13, 1990

Received: January 30th
PO#: 569072

Dear Ms. DiMare:

Analysis of your compounds gave the following results:

Your#,	Our#	% Ash,	% Sulfur,	% Pyritic Sulfur,	% Sulfate as Sulfur,	% Organic Sulfur (by difference),
Negative Plates 1/14/90	J-8354	8.97	4.76	2.20	0.13	2.43
Negative Plates 12/29/89	J-8355	2.90	2.93	0.41	0.051	2.47
Negative Plates 1/13/90	J-8356	9.09	4.67	2.19	0.12	2.36
Negative Plates 1/16/90	J-8357	8.71	4.78	2.15	0.12	2.51
Sample Before Run 12/29/89	J-8358	9.09	4.75	2.36	0.14	2.25
Sample Before Run 1/13/90	J-8359	9.12	4.79	2.04	0.14	2.61
Sample Before Run 1/14/90	J-8360	8.76	4.74	2.23	0.12	2.39
Sample Before Run 1/16/90	J-8361	8.79	4.65	2.26	0.13	2.26
Positive Plates 1/13/90	J-8362	8.71	4.64	2.18	0.16	2.30
Positive Plates 1/14/90	J-8363	8.68	4.05	2.15	0.13	1.77
Positive Plates 12/29/89	J-8364	17.29	7.33	4.30	0.26	2.77

Your#,	Our#,	% Ash,	% Sulfur,	% Pyritic Sulfur,	% Sulfate as Sulfur,	% Organic Sulfur (by difference),
Positive Plates 1/16/90	J-8365	8.92	4.65	2.23	0.12	2.30
Polistive Plates 12/27/89	J-8366	15.10	6.46	3.42	0.24	2.80
Positive Plates 12/26/89	J-8367	17.84	7.31	4.28	0.26	2.77
Positive Plates 12/20/89	J-8368	18.18	7.33	4.64	0.27	2.42
Sample Before Run 12/20/89	J-8369	8.75	4.73	2.34	0.14	2.25
Sample Before Run 12/26/89	J-8370	8.65	4.69	1.21	0.14	3.34
Sample Before Run 12/27/89	J-8371	8.61	4.65	2.02	0.12	2.51
Negative Plates 12/20/89	J-8372	2.52	2.82	0.31	0.046	2.46
Negative Plates 12/26/89	J-8373	2.70	2.63	0.38	0.049	2.20
Negative Plates 12/27/89	J-8374	2.68	2.91	0.42	0.050	2.44

Sincerely yours,

GALBRAITH LABORATORIES, INC.

Gail R. Hutchens
Exec. Vice-President

GRH:mck

HARRY W. GALBRAITH, PH.D.
CHAIRMAN OF THE BOARD

KENNETH S. WOODS
PRESIDENT

GAIL R. HUTCHENS
EXECUTIVE VICE-PRESIDENT

VELMA M. RUSSELL
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GALBRAITH
Laboratories, Inc.
QUANTITATIVE MICROANALYSES
ORGANIC – INORGANIC
615/546-1335

P.O. BOX 51610
KNOXVILLE, TN 37950-1610

2323 SYCAMORE DR.
KNOXVILLE, TN 37921-1750

Ms. Sherrie L. DiMare
Arthur D. Little, Inc.
20-431 Acorn Park
Cambridge, Massachusetts 02140

May 17, 1990

Received: May 8th
PO# 570138

Dear Ms. DiMare:

Analysis of your compounds gave the following results:

Your #,	Negative Plates 12-7-89	Negative Plates 11-16-89	Negative Plates 11-21-89
Our #,	L-4947	L-4948	L-4949
Analyses,			
% Moisture	1.08	3.65	1.83
% Carbon	74.98	68.29	77.41
% Hydrogen	3.88	4.45	5.04
% Nitrogen	1.01	1.21	1.36
% Chlorine	0.15	0.065	0.034
% Sulfur	1.61	3.07	2.81
% Ash	11.78	6.98	2.73
BTU/Pound	13218	12211	13985

Sincerely yours,

GALBRAITH LABORATORIES, INC.

Gail R. Hutchens /ew

Gail R. Hutchens
Exec. Vice-President

GRH:ew

HARRY W GALBRAITH. PH.D
CHAIRMAN OF THE BOARD

KENNETH S. WOODS
PRESIDENT

GAIL R. HUTCHENS
EXECUTIVE VICE-PRESIDENT

VELMA M. RUSSELL
SECRETARY TREASURER

GALBRAITH
Laboratories, Inc.

QUANTITATIVE MICROANALYSES
ORGANIC – INORGANIC
615/546-1335

P.O. BOX 51610
KNOXVILLE, TN 37950-1610

2323 SYCAMORE DR.
KNOXVILLE, TN 37921-1750

Ms. Sherrie L. DiMare
Arthur D. Little
20-431 Acorn Park
Cambridge, Massachusetts 02140

June 20, 1990

Received: June 13th
PO#: 570409

Dear Ms. DiMare:

Analysis of your compounds gave the following results:

Your #,	Our #,	Analyses,	
6/8/90 Positive Plate	M-0330	% Sulfur	10.85
		% SO_4 as S	0.70
		% Pyritic Sulfur	9.70
		% Organic Sulfur	0.45
		BTU/Pound	8879
		% Ash	31.90
6/8/90 Negative Plate	M-0331	% Sulfur	3.71
		% SO_4 as S	0.16
		% Pyritic Sulfur	0.38
		% Organic Sulfur	3.17
		BTU/Pound	13054
		% Ash	6.76
6/8/90 Feed	M-0332	% Sulfur	6.97
		% SO_4 as S	0.31
		% Pyritic Sulfur	2.33
		% Organic Sulfur	4.33
		BTU/Pound	11575
		% Ash	17.08

Sincerely yours,

GALBRAITH LABORATORIES, INC.

Gail R. Hutchens/ew

Gail R. Hutchens
Exec. Vice-President

GRH:ew

ETTER AND SHIPMENTS BY U.S. MAIL · P.O. BOX 51610, KNOXVILLE, TN 37950-1610. OTHER CARRIERS · 2323 SYCAMORE DR. KNOXVILLE, TN 37921-1750

ESTABLISHED 1950

Appendix B

Pilot Plant Equipment List

APPENDIX B

EQUIPMENT LIST FOR TRIBO PILOT PLANT

QUANTITY	EQUIPMENT	COMMENTS
1	Dayton SCR Controller	
1	Dayton DC Motor	1/4 HP, 1725 RPM
1	Pressure Gauge	0-30 Psig
2	Pressure Gauges	0-15 Psig
1	Fisher Flowmeter	
1	Cole-Parmer Flowmeter	25-375 ml/min
1	Keithley Picoammeter	Model 485
1	Matheson Mass Flowmeter	Model 8100
1	Atkins Digital Thermometer	Model 49700-k-c
1	Matheson 4 Tube Flowmeter	Model 7411T
1	Dowty Temperature controller	
2	Hipotronics Power Supplies	30 kV, Model 30B
2	Simpson Analog Panel Meters	Model 27, 0-100 kV Scale
2	Stanco Variable Transformers	Type 171
1	Mc Master Carr Pneumatic Vibrator	7700 VPM
1	Corrosion Resistant Gas Regulator	SO2 Gas
1	Corrosion Resistant Gas Regulator	HCl Gas
1	Corrosion Resistant Gas Regulator	NH3 Gas
1	Corrosion Resistant Gas Regulator	Cl2 Gas
1	Brass Two-Stage Gas Regulator	N2 Gas

Appendix C

Test Run
Raw Data Sheets

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE 10/30/89 COAL PITTSBURGH TREATMENT UNTREATED COAL INPUT (GMS) 150.8

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
3.0	62.9	0.0	0.0	100	1:46	27
3.0	62.9	0.0	0.0	50	1:51	26
3.0	61.4	0.0	0.0	100	1:56	27
3.0	62.9	0.0	0.0	170	2:01	27
5.5	91.2	0.0	0.0	197	2:06	26
5.5	89.6	0.0	0.0	185	2:11	26
5.5	91.2	0.0	0.0	177	2:16	26
5.5	92.8	0.0	0.0	175	2:21	26
8.0	113.6	0.0	0.5	175	2:26	26
8.0	115.3	0.0	0.9	183	2:31	26
8.0	115.3	0.0	0.9	191	2:36	27
8.0	115.3	0.0	0.9	197	2:41	27
10.5	135.8	0.0	1.4	209	2:46	27
10.5	135.8	0.0	1.4	213	2:51	28
10.5						

COAL DISTRIBUTION (GMS)		
PLATE 1 (-)	6.9	
PLATE 2 (+)	21.9	
PLATE 3 (-)	24.3	
PLATE 4 (+)	2.4	
FILTER BAG	2.5	
CHARGING CHAMBER		
WALL	37.2	
BOTTOM	20.3	
COLLECTION CHAMBER		
BOTTOM	1.8	
TOTAL RECOVERED		117.3
TOTAL INPUT		150.8
TOTAL LOST		33.5

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE 10/31/89 COAL PITTSBURGH TREATMENT UNTREATED COAL INPUT (GMS) 153.4

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	89.6	0.0	0.0	.003	3:35	44
5.5	89.6	0.0	0.0	.005	3:40	25
5.5	89.6	0.0	0.0	-.001	3:45	25
5.5	89.6	0.0	0.0	-.005	3:50	25
8.0	113.6	0.0	0.5	-.012	3:55	25
8.0	113.6	0.0	0.5	-.040	4:00	26
8.0	113.6	0.0	0.5	.020	4:05	26
8.0	113.6	0.0	0.5	.005	4:10	26
10.5	134.0	0.0	1.2	.030	4:15	26
10.5	134.0	0.0	1.2	.017	4:20	26
10.5	135.8	0.0	1.2	.030	4:25	26
10.5	135.8	0.0	1.2	.025	4:30	26
13.0	155.5	0.0	2.0	.011	4:35	26
13.0	155.5	0.0	2.0	.015	4:40	26
13.0	155.5	0.0	2.0	.020	4:45	26

COAL DISTRIBUTION (GMS)		
PLATE 1 (-)	33.3	
PLATE 2 (+)	35.3	
PLATE 3 (-)	16.2	
PLATE 4 (+)	3.4	
FILTER BAG	0.9	
CHARGING CHAMBER		
WALL	36.5	
BOTTOM	18.5	
COLLECTION CHAMBER		
BOTTOM	2.9	
TOTAL RECOVERED		147.0
TOTAL INPUT		153.4
TOTAL LOST		6.4

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE 11/2/89 COAL PITTSBURGH TREATMENT UNTREATED COAL INPUT (GMS) 131.3

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	89.6	0.0	0.0	63	10:40	30
5.5	91.2	0.0	0.0	64	10:45	25
5.5	92.8	0.0	0.0	93	10:50	25
8.0	115.3	0.0	0.5	115	10:55	24
8.0	115.3	0.0	0.5	120	11:00	25
8.0	117.0	0.0	0.5	122	11:05	25
8.0	115.3	0.0	0.5	97	11:10	25
10.5	135.8	0.0	1.2	97	11:15	25
10.5	137.6	0.0	1.2	119	11:20	26
10.5	137.6	0.0	1.2	132	11:25	26
10.5	135.8	0.0	1.2	135	11:30	26
13.0	157.4	0.0	1.6	133	11:35	26
13.0	157.4	0.0	1.7	139	11:40	26
13.0	157.4	0.0	1.6	136	11:45	26
13.0	157.4	0.0	1.6	137	11:50	26

COAL DISTRIBUTION (GMS)		
PLATE 1 (-)	48.8	
PLATE 2 (+)	42.5	
PLATE 3 (-)	15.4	
PLATE 4 (+)	3.3	
FILTER BAG	2.0	
CHARGING CHAMBER		
WALL	5.5	
BOTTOM	3.0	
COLLECTION CHAMBER		
BOTTOM	1.6	
TOTAL RECOVERED		122.1
TOTAL INPUT		131.3
TOTAL LOST		9.2

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE 11/6/89 COAL PITTSBURGH TREATMENT UNTREATED COAL INPUT (GMS) 136.2

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	89.6	0.0	0.0	218	10:05	26
5.5	91.2	0.0	0.0	223	10:10	25
5.5	91.2	0.0	0.0	230	10:15	25
8.0	118.7	0.0	0.5	221	10:20	24
8.0	117.0	0.0	0.5	210	10:25	24
8.0	117.0	0.0	0.5	188	10:30	25
8.0	118.7	0.0	0.5	167	10:35	25
10.5	139.4	0.0	1.2	155	10:40	25
10.5	137.6	0.0	1.2	148	10:45	25
10.5	136.7	0.0	1.2	144	10:50	26
10.5	138.5	0.0	1.2	134	10:55	26
13.0	157.4	0.0	2.0	116	11:00	26
13.0	157.4	0.0	1.8	126	11:05	26
13.0	159.3	0.0	1.6	141	11:10	26
13.0	159.3	0.0	1.6	135	11:15	27

COAL DISTRIBUTION (GMS)		
PLATE 1 (-)	34.0	
PLATE 2 (+)	43.2	
PLATE 3 (-)	30.5	
PLATE 4 (+)	3.9	
FILTER BAG	2.8	
CHARGING CHAMBER		
WALL	9.8	
BOTTOM	4.1	
COLLECTION CHAMBER		
BOTTOM	4.4	
TOTAL RECOVERED		132.7
TOTAL INPUT		136.2
TOTAL LOST		3.5

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE 11/7/89 COAL U. FREEPORT TREATMENT UNTREATED COAL INPUT (GMS) 144.1

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	91.2	0.0	0.0	126	9:05	45
5.5	91.2	0.0	0.0	153	9:10	24
5.5	92.8	0.0	0.0	158	9:15	24
8.0	115.3	0.0	0.5	148	9:20	24
8.0	119.6	0.0	0.5	138	9:25	24
8.0	117.9	0.0	0.5	142	9:30	25
8.0	117.0	0.0	0.5	132	9:35	25
10.5	148.3	0.0	1.0	148	9:40	25
10.5	139.4	0.0	1.0	144	9:45	25
10.5	138.5	0.0	1.0	153	9:50	25
10.5	137.6	0.0	1.0	163	9:55	26
13.0	157.4	0.0	1.5	164	10:00	26
13.0	159.3	0.0	1.5	158	10:05	26
13.0	159.3	0.0	1.5	163	10:10	26
13.0	159.3	0.0	1.5	185	10:15	26

COAL DISTRIBUTION (GMS)		
PLATE 1 (-)	39.2	
PLATE 2 (+)	44.1	
PLATE 3 (-)	21.5	
PLATE 4 (+)	2.6	
FILTER BAG	1.3	
CHARGING CHAMBER		
WALL	12.0	
BOTTOM	9.1	
COLLECTION CHAMBER		
BOTTOM	8.3	
TOTAL RECOVERED		138.1
TOTAL INPUT		144.1
TOTAL LOST		6.0

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE	11/8/89	COAL	U. FREEPORT	TREATMENT	UNTREATED	COAL INPUT (GMS)	150.6

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	90.4	0.0	0.0	167	9:45	27
5.5	89.6	0.0	0.0	210	9:50	25
5.5	91.2	0.0	0.0	187	10:00	26
8.0	115.3	0.0	0.5	224	10:05	24
8.0	118.7	0.0	0.5	261	10:10	24
8.0	118.7	0.0	0.5	259	10:15	25
8.0	115.3	0.0	0.5	232	10:20	25
10.5	135.8	0.0	1.0	220	10:25	25
10.5	141.2	0.0	1.5	239	10:30	25
10.5	136.7	0.0	1.2	271	10:35	26
10.5	137.6	0.0	1.0	252	10:40	26
13.0	153.6	0.0	1.5	246	10:45	26
13.0	158.3	0.0	1.5	245	10:50	26
13.0	158.3	0.0	1.5	239	10:55	26
13.0						

COAL DISTRIBUTION (GMS)		
PLATE 1 (-)	2.7	
PLATE 2 (+)	10.8	
PLATE 3 (-)	30.8	
PLATE 4 (+)	13.7	
FILTER BAG	1.1	
CHARGING CHAMBER		
WALL	9.5	
BOTTOM	72.7	
COLLECTION CHAMBER		
BOTTOM	5.5	
TOTAL RECOVERED		146.8
TOTAL INPUT		150.6
TOTAL LOST		3.8

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE 11/9/89 COAL U. FREEPORT TREATMENT UNTREATED COAL INPUT (GMS) 141.9

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	94.4	0.0	0.0	364	9:15	39
5.5	92.8	0.0	0.0	354	9:20	25
5.5	92.0	0.0	0.0	312	9:25	24
8.0	117.9	0.0	0.2	274	9:30	23
8.0	120.4	0.0	0.0	271	9:35	24
8.0	117.0	0.0	0.5	251	9:40	25
8.0	118.7	0.0	0.5	230	9:45	25
10.5	139.4	0.0	1.0	248	9:50	25
10.5	141.2	0.0	1.0	240	9:55	25
10.5	139.4	0.0	1.0	205	10:00	25
10.5	139.4	0.0	1.0	211	10:05	26
13.0	159.3	0.0	1.5	214	10:10	26
13.0	157.4	0.0	1.25	214	10:15	26
13.0	160.2	0.0	1.25	216	10:20	26
13.0	160.2	0.0	1.25	210	10:25	26

COAL DISTRIBUTION (GMS)		
PLATE 1 (-)	3.9	
PLATE 2 (+)	8.8	
PLATE 3 (-)	30.9	
PLATE 4 (+)	18.1	
FILTER BAG	1.1	
CHARGING CHAMBER		
WALL	10.3	
BOTTOM	5.8	
COLLECTION CHAMBER		
BOTTOM	7.7	
TOTAL RECOVERED		86.6
TOTAL INPUT		141.9
TOTAL LOST		55.3

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE 11/13/89 COAL U. FREEPORT TREATMENT UNTREATED COAL INPUT (GMS) 139.9

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	94.4	0.0	0.0	126	3:00	26
5.5	92.8	0.0	0.0	141	3:05	25
5.5	92.8	0.0	0.0	177	3:10	24
8.0	117.0	0.0	0.5	130	3:15	25
8.0	116.2	0.0	0.5	73	3:20	25
8.0	116.2	0.0	0.5	70	3:25	25
8.0	117.0	0.0	0.5	88	3:30	26
10.5	137.6	0.0	1.0	122	3:35	26
10.5	137.6	0.0	1.0	155	3:40	26
10.5	139.4	0.0	1.0	186	3:45	26
10.5	137.6	0.0	1.0	164	3:50	26
13.0	157.4	0.0	1.5	156	3:55	27
13.0	159.3	0.0	1.5	128	4:00	27
13.0	158.3	0.0	1.5	128	4:05	26
13.0	158.3	0.0	1.5	135	4:10	26

COAL DISTRIBUTION (GMS)		
PLATE 1 (-)	2.5	
PLATE 2 (+)	8.7	
PLATE 3 (-)	27.7	
PLATE 4 (+)	19.9	
FILTER BAG	1.1	
CHARGING CHAMBER		
WALL	23.0	
BOTTOM	11.6	
COLLECTION CHAMBER		
BOTTOM	29.0	
TOTAL RECOVERED		123.5
TOTAL INPUT		139.9
TOTAL LOST		16.4

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE 11/14/89 COAL ILLINOIS TREATMENT UNTREATED COAL INPUT (GMS) 135.9

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	89.6	0.0	0.0	159	2:25	30
5.5	89.6	0.0	0.0	175	2:30	25
5.5	91.2	0.0	0.0	178	2:35	25
8.0	117.0	0.0	0.5	188	2:40	24
8.0	116.2	0.0	0.5	206	2:45	24
8.0	117.0	0.0	0.5	190	2:50	25
8.0	117.0	0.0	0.5	184	2:55	25
10.5	137.6	0.0	1.0	176	3:00	26
10.5	137.6	0.0	1.0	189	3:05	26
10.5	139.4	0.0	1.0	157	3:10	27
10.5	137.6	0.0	1.0	160	3:15	27
13.0	157.4	0.0	1.5	159	3:20	28
13.0	153.6	0.0	1.5	165	3:25	28
13.0	157.4	0.0	1.5	165	3:30	27
13.0	157.4	0.0	1.5	174	3:35	27

COAL DISTRIBUTION (GMS)		
PLATE 1 (-)	2.9	
PLATE 2 (+)	17.4	
PLATE 3 (-)	36.5	
PLATE 4 (+)	31.1	
FILTER BAG	1.5	
CHARGING CHAMBER		
WALL	1.8	
BOTTOM	0.9	
COLLECTION CHAMBER		
BOTTOM	31.0	
TOTAL RECOVERED		123.1
TOTAL INPUT		135.9
TOTAL LOST		12.8

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE 11/15/89 COAL ILLINOIS TREATMENT UNTREATED COAL INPUT (GMS) 130.8

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	94.4	0.0	0.0	69	1:45	55
5.5	92.8	0.0	0.0	69	1:50	28
5.5	92.8	0.0	0.0	88	1:55	26
8.0	118.7	0.0	0.5	95	2:00	26
8.0	117.0	0.0	0.5	96	2:05	26
8.0	118.7	0.0	0.5	98	2:10	27
8.0	118.7	0.0	0.5	90	2:15	28
10.5	137.6	0.0	1.0	94	2:20	28
10.5	137.6	0.0	1.0	89	2:25	28
10.5	141.2	0.0	1.0	89	2:30	30
10.5	137.6	0.0	1.0	120	2:35	31
13.0	159.3	0.0	1.5	98	2:40	30
13.0	159.3	0.0	1.5	103	2:45	29
13.0	159.3	0.0	1.5	100	2:50	28
13.0	159.3	0.0	1.5	100	2:55	28

COAL DISTRIBUTION (GMS)		
PLATE 1 (-)	3.8	
PLATE 2 (+)	30.0	
PLATE 3 (-)	43.2	
PLATE 4 (+)	16.1	
FILTER BAG	1.0	
CHARGING CHAMBER		
WALL	5.3	
BOTTOM	3.1	
COLLECTION CHAMBER		
BOTTOM	23.9	
TOTAL RECOVERED		126.4
TOTAL INPUT		130.8
TOTAL LOST		4.4

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE	11/16/89	COAL	ILLINOIS	TREATMENT	UNTREATED	COAL INPUT (GMS)	123.6

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	92.8	0.0	0.0	88	11:25	63
5.5	92.8	0.0	0.0	96	11:30	27
5.5	92.8	0.0	0.0	103	11:35	25
8.0	115.3	0.0	0.5	115	11:40	24
8.0	117.0	0.0	0.5	119	11:45	26
8.0	117.0	0.0	0.5	116	11:50	25
8.0	115.3	0.0	0.5	123	11:55	25
10.5	137.6	0.0	1.3	127	12:00	26
10.5	137.6	0.0	1.3	120	12:05	27
10.5	135.8	0.0	1.3	110	12:10	27
10.5	139.4	0.0	1.3	115	12:15	29
13.0	157.4	0.0	1.6	111	12:20	27
13.0	157.4	0.0	1.6	126	12:25	29
13.0	159.3	0.0	1.6	123	12:30	28
13.0	159.3	0.0	1.6	122	12:35	27

COAL DISTRIBUTION (GMS)		
PLATE 1 (-)	3.4	
PLATE 2 (+)	37.5	
PLATE 3 (-)	55.8	
PLATE 4 (+)	11.5	
FILTER BAG	1.9	
CHARGING CHAMBER		
WALL	4.2	
BOTTOM	3.3	
COLLECTION CHAMBER		
BOTTOM	2.3	
TOTAL RECOVERED		119.9
TOTAL INPUT		123.6
TOTAL LOST		3.7

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE	11/17/89	COAL	ILLINOIS	TREATMENT	UNTREATED	COAL INPUT (GMS)	125.1

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	92.0	0.0	0.0	106	9:30	26
5.5	92.8	0.0	0.0	116	9:35	27
5.5	92.0	0.0	0.0	114	9:40	28
8.0	117.0	0.0	0.5	121	9:45	28
8.0	116.2	0.0	0.5	118	9:50	26
8.0	117.0	0.0	0.5	127	9:55	27
8.0	117.0	0.0	0.5	110	10:00	28
10.5	137.6	0.0	1.2	135	10:05	29
10.5	139.4	0.0	1.0	107	10:10	29
10.5	139.4	0.0	1.0	115	10:15	27
10.5	137.6	0.0	1.0	116	10:20	28
13.0	159.3	0.0	1.6	113	10:25	28
13.0	159.3	0.0	1.6	108	10:30	27
13.0	159.3	0.0	1.6	110	10:35	28
13.0	159.3	0.0	1.6	104	10:40	24

COAL DISTRIBUTION (GMS)		
PLATE 1 (-)	24.8	
PLATE 2 (+)	43.0	
PLATE 3 (-)	30.2	
PLATE 4 (+)	2.7	
FILTER BAG	0.4	
CHARGING CHAMBER		
WALL	1.4	
BOTTOM	3.9	
COLLECTION CHAMBER		
BOTTOM	5.1	
TOTAL RECOVERED		111.5
TOTAL INPUT		125.1
TOTAL LOST		13.6

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE 11/21/89 COAL PITTSBURGH TREATMENT 0.1% DICYCLOHEXYLAMINE COAL INPUT (GMS) 154.6

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	91.2	0.0	0.0	183	9:50	26
5.5	92.8	0.0	0.0	162	9:55	27
5.5	92.8	0.0	0.0	176	10:00	27
8.0	115.3	0.0	0.7	148	10:05	26
8.0	115.3	0.0	0.7	150	10:10	26
8.0	117.0	0.0	0.7	153	10:15	27
8.0	117.0	0.0	0.7	171	10:20	27
10.5	137.6	0.0	1.3	161	10:25	26
10.5	138.5	0.0	1.3	146	10:30	26
10.5	138.5	0.0	1.3	155	10:35	27
10.5	137.6	0.0	1.3	153	10:40	28
13.0	157.4	0.0	1.6	167	10:45	28
13.0	159.3	0.0	1.6	130	10:50	28
13.0	159.3	0.0	1.7	104	10:55	28
13.0	159.3	0.0	1.7	105	11:00	28

COAL DISTRIBUTION (GMS)		
PLATE 1 (-)	50.6	
PLATE 2 (+)	37.6	
PLATE 3 (-)	32.1	
PLATE 4 (+)	1.9	
FILTER BAG	2.8	
CHARGING CHAMBER		
WALL	8.1	
BOTTOM	9.7	
COLLECTION CHAMBER		
BOTTOM	3.2	
TOTAL RECOVERED		146.0
TOTAL INPUT		154.6
TOTAL LOST		8.6

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE 11/22/89 COAL PITTSBURGH TREATMENT 0.1% DICYCLOHEXYLAMINE COAL INPUT (GMS) 136.9

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	91.2	0.0	0.0	45	9:50	26
5.5	91.2	0.0	0.0	46	9:55	27
5.5	91.2	0.0	0.0	72	10:00	27
8.0	117.0	0.0	0.6	93	10:05	28
8.0	117.0	0.0	0.6	80	10:10	26
8.0	118.7	0.0	0.6	83	10:15	26
8.0	117.0	0.0	0.6	100	10:20	27
10.5	137.6	0.0	1.4	85	10:25	25
10.5	137.6	0.0	1.3	89	10:30	27
10.5	139.4	0.0	1.3	76	10:35	27
10.5	139.4	0.0	1.3	79	10:40	27
13.0	159.3	0.0	1.8	104	10:45	28
13.0	159.3	0.0	1.8	100	10:50	28
13.0	161.1	0.0	1.8	81	10:55	27
13.0	161.1	0.0	1.8	83	11:00	27

COAL DISTRIBUTION (GMS)		
PLATE 1 (-)	28.8	
PLATE 2 (+)	31.9	
PLATE 3 (-)	41.6	
PLATE 4 (+)	2.4	
FILTER BAG	2.7	
CHARGING CHAMBER		
WALL	9.2	
BOTTOM	6.2	
COLLECTION CHAMBER		
BOTTOM	3.6	
TOTAL RECOVERED		126.4
TOTAL INPUT		136.9
TOTAL LOST		10.5

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE 11/27/89 COAL PITTSBURGH TREATMENT 0.1% DICYCLOHEXYLAMINE COAL INPUT (GMS) 146.5

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	92.8	0.0	0.0	177	1:35	26
5.5	92.8	0.0	0.0	178	1:40	26
5.5	91.2	0.0	0.0	193	1:45	26
8.0	117.0	0.0	0.5	187	1:50	26
8.0	117.0	0.0	0.5	198	1:55	26
8.0	117.0	0.0	0.5	181	2:00	26
8.0	116.2	0.0	0.5	159	2:05	26
10.5	138.5	0.0	1.3	139	2:10	25
10.5	139.4	0.0	1.3	146	2:15	26
10.5	138.5	0.0	1.3	141	2:20	26
10.5	137.6	0.0	1.3	136	2:25	27
13.0	159.3	0.0	1.6	131	2:30	28
13.0	159.3	0.0	1.8	120	2:35	28
13.0	159.3	0.0	1.8	88	2:40	27
13.0	159.3	0.0	1.8	85	2:45	27

COAL DISTRIBUTION (GMS)		
PLATE 1 (-)	30.1	
PLATE 2 (+)	33.6	
PLATE 3 (-)	44.3	
PLATE 4 (+)	2.9	
FILTER BAG	1.6	
CHARGING CHAMBER		
WALL	11.8	
BOTTOM	6.9	
COLLECTION CHAMBER		
BOTTOM	2.6	
TOTAL RECOVERED		133.8
TOTAL INPUT		146.5
TOTAL LOST		12.7

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE 11/28/89 COAL PITTSBURGH TREATMENT 0.5% DICYCLOHEXYLAMINE COAL INPUT (GMS) 143.3

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	89.6	0.0	0.0	183	1:55	27
5.5	89.6	0.0	0.0	190	2:00	27
5.5	89.6	0.0	0.0	170	2:05	26
8.0	113.6	0.0	0.5	176	2:10	25
8.0	113.6	0.0	0.5	175	2:15	25
8.0	115.3	0.0	0.5	160	2:20	26
8.0	115.3	0.0	0.5	148	2:25	26
10.5	135.8	0.0	1.0	150	2:30	27
10.5	135.8	0.0	1.0	142	2:35	26
10.5	135.8	0.0	1.0	160	2:40	27
10.5	135.8	0.0	1.0	170	2:45	27
13.0	157.4	0.0	1.5	180	2:50	28
13.0	157.4	0.0	1.5	146	2:55	27
13.0	157.4	0.0	1.5	154	3:00	26
13.0	157.4	0.0	1.5	165	3:05	27

COAL DISTRIBUTION (GMS)		
PLATE 1 (-)	20.6	
PLATE 2 (+)	27.5	
PLATE 3 (-)	29.2	
PLATE 4 (+)	2.9	
FILTER BAG	3.3	
CHARGING CHAMBER		
WALL	32.8	
BOTTOM	15.1	
COLLECTION CHAMBER		
BOTTOM	2.5	
TOTAL RECOVERED		133.9
TOTAL INPUT		143.3
TOTAL LOST		9.4

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE 11/30/89 COAL PITTSBURGH TREATMENT 0.5% DICYCLOHEXYLAMINE COAL INPUT (GMS) 138.5

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	89.6	0.0	0.0	2	11:35	47
5.5	89.6	0.0	0.0	2	11:40	27
5.5	89.6	0.0	0.0	28	11:45	26
8.0	115.3	0.0	0.9	44	11:50	25
8.0	115.3	0.0	0.9	49	11:55	26
8.0	115.3	0.0	0.9	53	12:00	27
8.0	115.3	0.0	1.0	75	12:05	27
10.5	135.8	0.0	1.4	76	12:10	27
10.5	135.8	0.0	1.4	85	12:15	26
10.5	137.6	0.0	1.4	85	12:20	26
10.5	135.8	0.0	1.4	84	12:25	28
13.0	157.4	0.0	1.6	105	12:30	26
13.0	157.4	0.0	1.6	126	12:35	26
13.0	157.4	0.0	1.6	107	12:40	26
13.0	157.4	0.0	1.7	121	12:45	26

COAL DISTRIBUTION (GMS)		
PLATE 1 (-)	47.4	
PLATE 2 (+)	40.8	
PLATE 3 (-)	24.3	
PLATE 4 (+)	2.7	
FILTER BAG	3.5	
CHARGING CHAMBER		
WALL	4.2	
BOTTOM	1.1	
COLLECTION CHAMBER		
BOTTOM	4.5	
TOTAL RECOVERED		128.5
TOTAL INPUT		138.5
TOTAL LOST		10.0

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE 12/4/89 COAL PITTSBURGH TREATMENT 0.5% DICYCLOHEXYLAMINE COAL INPUT (GMS) 142.5

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	89.6	0.0	0.0	71	11:15	25
5.5	91.2	0.0	0.0	97	11:20	24
5.5	89.6	0.0	0.0	103	11:25	24
8.0	117.0	0.0	0.8	220	11:30	24
8.0	115.3	0.0	0.8	249	11:35	24
8.0	117.0	0.0	0.8	241	11:40	24
8.0	116.5	0.0	0.8	263	11:45	25
10.5	135.8	0.0	1.2	276	11:50	24
10.5	135.8	0.0	1.4	264	11:55	25
10.5	135.8	0.0	1.4	270	12:00	25
10.5	135.8	0.0	1.4	270	12:05	26
13.0	155.5	0.0	1.7	331	12:10	26
13.0	157.4	0.0	1.8	341	12:15	26
13.0	157.4	0.0	1.8	305	12:20	26
13.0	157.4	0.0	1.8	301	12:25	26

COAL DISTRIBUTION (GMS)		
PLATE 1 (-)	11.6	
PLATE 2 (+)	38.2	
PLATE 3 (-)	60.4	
PLATE 4 (+)	7.3	
FILTER BAG	6.3	
CHARGING CHAMBER		
WALL	4.0	
BOTTOM	0.9	
COLLECTION CHAMBER		
BOTTOM	2.1	
TOTAL RECOVERED		130.8
TOTAL INPUT		142.5
TOTAL LOST		11.7

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE 12/5/89 COAL U. FREEPORT TREATMENT 0.1% DICYCLOHEXYLAMINE COAL INPUT (GMS) 141.7

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	89.6	0.0	0.0	248	4:05	24
5.5	89.6	0.0	0.0	294	4:10	23
5.5	89.6	0.0	0.0	308	4:15	23
8.0	113.6	0.0	0.5	302	4:20	23
8.0	115.3	0.0	0.5	320	4:25	23
8.0	117.0	0.0	0.5	367	4:30	23
8.0	115.3	0.0	0.9	354	4:35	24
10.5	135.8	0.0	1.3	335	4:40	24
10.5	139.4	0.0	1.3	331	4:45	24
10.5	137.6	0.0	1.3	337	4:50	24
10.5	138.5	0.0	1.3	306	4:55	25
13.0	158.3	0.0	1.8	310	5:00	24
13.0	159.3	0.0	1.8	320	5:05	25
13.0	159.3	0.0	1.8	316	5:10	25
13.0	159.3	0.0	1.8	326	5:15	25

COAL DISTRIBUTION (GMS)		
PLATE 1 (-)	30.7	
PLATE 2 (+)	28.9	
PLATE 3 (-)	18.4	
PLATE 4 (+)	1.9	
FILTER BAG	1.6	
CHARGING CHAMBER		
WALL	36.0	
BOTTOM	13.7	
COLLECTION CHAMBER		
BOTTOM	1.5	
TOTAL RECOVERED		132.7
TOTAL INPUT		141.7
TOTAL LOST		9.0

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE 12/6/89 COAL U. FREEPORT TREATMENT 0.1% DICYCLOHEXYLAMINE COAL INPUT (GMS) 154.4

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	89.6	0.0	0.0	73	4:05	27
5.5	89.6	0.0	0.0	130	4:10	23
5.5	89.6	0.0	0.0	169	4:15	23
8.0	115.3	0.0	0.9	269	4:20	22
8.0	115.3	0.0	0.9	243	4:25	23
8.0	115.3	0.0	0.9	172	4:30	23
8.0	117.0	0.0	0.9	207	4:35	23
10.5	137.6	0.0	1.3	247	4:40	23
10.5	135.8	0.0	1.3	258	4:45	24
10.5	135.8	0.0	1.3	240	4:50	24
10.5	135.8	0.0	1.3	181	4:55	25
13.0	157.4	0.0	1.9	266	5:00	24
13.0	159.3	0.0	1.9	295	5:05	25
13.0	157.4	0.0	2.0	245	5:10	25
13.0	157.4	0.0	2.0	213	5:15	25

COAL DISTRIBUTION (GMS)		
PLATE 1 (-)	23.3	
PLATE 2 (+)	17.6	
PLATE 3 (-)	8.3	
PLATE 4 (+)	1.5	
FILTER BAG	0.5	
CHARGING CHAMBER		
WALL	40.4	
BOTTOM	50.1	
COLLECTION CHAMBER		
BOTTOM	1.8	
TOTAL RECOVERED		143.5
TOTAL INPUT		154.4
TOTAL LOST		10.9

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE 12/7/89 COAL U. FREEPORT TREATMENT 0.1% DICYCLOHEXYLAMINE COAL INPUT (GMS) 153.2

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	89.6	0.0	0.0	205	3:10	24
5.5	89.6	0.0	0.0	177	3:15	24
5.5	88.0	0.0	0.0	217	3:20	23
8.0	113.6	0.0	0.9	335	3:25	23
8.0	113.6	0.0	0.9	320	3:30	23
8.0	113.6	0.0	0.9	300	3:35	23
8.0	113.6	0.0	0.9	265	3:40	24
10.5	135.8	0.0	1.4	310	3:45	24
10.5	135.8	0.0	1.4	32[illegible]	3:50	24
10.5	135.8	0.0	1.4	302	3:55	24
10.5	135.8	0.0	1.4	308	4:00	25
13.0	157.4	0.0	2.0	305	4:05	24
13.0	157.4	0.0	1.9	236	4:10	25
13.0	157.4	0.0	2.0	289	4:15	25
13.0	157.4	0.0	2.0	318	4:20	25

COAL DISTRIBUTION (GMS)		
PLATE 1 (-)	28.2	
PLATE 2 (+)	22.5	
PLATE 3 (-)	8.7	
PLATE 4 (+)	1.1	
FILTER BAG	0.8	
CHARGING CHAMBER		
WALL	35.9	
BOTTOM	28.9	
COLLECTION CHAMBER		
BOTTOM	5.5	
TOTAL RECOVERED		131.6
TOTAL INPUT		153.2
TOTAL LOST		21.6

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE 12/8/89 COAL U. FREEPORT TREATMENT 0.5% DICYCLOHEXYLAMINE COAL INPUT (GMS) 140.3

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	91.2	0.0	0.0	76	1:45	26
5.5	89.6	0.0	0.0	104	1:50	22
5.5	89.6	0.0	0.0	126	1:55	23
8.0	115.3	0.0	0.9	144	2:00	22
8.0	115.3	0.0	0.9	76	2:05	23
8.0	115.3	0.0	0.9	51	2:10	23
8.0	115.3	0.0	0.9	49	2:15	24
10.5	137.6	0.0	1.3	18	2:20	24
10.5	137.6	0.0	1.3	44	2:25	24
10.5	137.6	0.0	1.4	41	2:30	24
10.5	137.6	0.0	1.4	73	2:35	25
13.0	157.4	0.0	1.9	43	2:40	25
13.0	157.4	0.0	1.9	53	2:45	25
13.0	157.4	0.0	1.9	53	2:50	25
13.0	157.4	0.0	1.9	56	2:55	25

COAL DISTRIBUTION (GMS)		
PLATE 1 (-)	8.3	
PLATE 2 (+)	31.1	
PLATE 3 (-)	42.8	
PLATE 4 (+)	6.9	
FILTER BAG	3.3	
CHARGING CHAMBER		
WALL	20.8	
BOTTOM	18.6	
COLLECTION CHAMBER		
BOTTOM	3.2	
TOTAL RECOVERED		135.0
TOTAL INPUT		140.3
TOTAL LOST		5.3

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE 12/9/89 COAL U. FREEPORT TREATMENT 0.5% DICYCLOHEXYLAMINE COAL INPUT (GMS) 142.4

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	91.2	0.0	0.0	398	10:00	28
5.5	89.6	0.0	0.0	415	10:05	24
5.5	89.6	0.0	0.0	430	10:10	24
8.0	113.6	0.0	0.9	333	10:15	24
8.0	115.3	0.0	0.9	340	10:20	24
8.0	115.3	0.0	0.9	298	10:25	24
8.0	115.3	0.0	0.9	320	10:30	25
10.5	135.8	0.0	1.3	261	10:35	24
10.5	137.6	0.0	1.3	265	10:40	25
10.5	137.6	0.0	1.3	286	10:45	25
10.5	137.6	0.0	1.3	205	10:50	26
13.0	159.3	0.0	1.8	116	11:00	23
13.0	159.3	0.0	1.7	84	11:05	24
13.0	159.3	0.0	1.8	39	11:10	24
13.0						

COAL DISTRIBUTION (GMS)		
PLATE 1 (-)	6.5	
PLATE 2 (+)	18.6	
PLATE 3 (-)	56.9	
PLATE 4 (+)	28.4	
FILTER BAG	1.6	
CHARGING CHAMBER		
WALL	9.4	
BOTTOM	12.0	
COLLECTION CHAMBER		
BOTTOM	3.0	
TOTAL RECOVERED		136.4
TOTAL INPUT		142.4
TOTAL LOST		6.0

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE 12/11/89 COAL U. FREEPORT TREATMENT 1000 PPM AMMONIA COAL INPUT (GMS) 139.3

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	NH3 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	91.2	0.0802	0.0	0.0	127	1:45	24
5.5	89.6	0.0846	0.0	0.0	168	1:50	23
5.5	91.2	0.0780	0.0	0.0	100	1:55	23
8.0	115.3	0.1120	0.0	1.0	152	2:00	23
8.0	115.3	0.1074	0.0	1.0	125	2:05	23
8.0	115.3	0.1146	0.0	1.0	88	2:10	24
8.0	115.3	0.1074	0.0	1.0	78	2:15	24
10.5	135.8	0.1434	0.0	1.4	79	2:20	24
10.5	137.6	0.1461	0.0	1.4	250	2:25	24
10.5	135.8	0.1461	0.0	1.4	189	2:30	25
10.5	137.6	0.1354	0.0	1.4	239	2:35	25
13.0	157.4	0.1623	0.0	1.9	132	2:40	25
13.0	157.4	0.1569	0.0	1.9	206	2:45	25
13.0	157.4	0.1680	0.0	1.9	319	2:50	25
13.0	157.4	0.1623	0.0	1.9	315	2:55	25

COAL DISTRIBUTION (GMS)	
PLATE 1 (-)	10.7
PLATE 2 (+)	26.5
PLATE 3 (-)	51.7
PLATE 4 (+)	24.5
FILTER BAG	2.7
CHARGING CHAMBER	
WALL	3.4
BOTTOM	0.9
COLLECTION CHAMBER	
BOTTOM	12.2
TOTAL RECOVERED	132.6
TOTAL INPUT	139.3
TOTAL LOST	6.7

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE 12/12/89 COAL U. FREEPORT TREATMENT 1000 PPM AMMONIA COAL INPUT (GMS) 144.4

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	NH3 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	89.6	0.0653	0.0	0.0	554	10:20	23
5.5	91.2	0.0619	0.0	0.0	529	10:25	23
5.5	89.6	0.0602	0.0	0.0	263	10:30	23
8.0	113.6	0.0824	0.0	1.0	409	10:35	23
8.0	115.3	0.0824	0.0	1.0	269	10:40	23
8.0	113.6	0.0846	0.0	1.0	115	10:45	23
8.0	115.3	0.0868	0.0	1.0	218	10:50	24
10.5	135.8	0.1172	0.0	1.4	280	10:55	24
10.5	137.6	0.1250	0.0	1.4	198	11:00	24
10.5	137.6	0.1120	0.0	1.4	191	11:05	24
10.5	135.8	0.1172	0.0	1.4	366	11:10	25
13.0	157.4	0.1596	0.0	1.8	309	11:15	25
13.0	157.4	0.1680	0.0	1.8	189	11:20	25
13.0	157.4	0.1596	0.0	1.8	203	11:25	25
13.0	157.4	0.1596	0.0	1.8	277	11:30	25

COAL DISTRIBUTION (GMS)	
PLATE 1 (-)	4.5
PLATE 2 (+)	19.4
PLATE 3 (-)	47.8
PLATE 4 (+)	33.7
FILTER BAG	2.2
CHARGING CHAMBER	
WALL	1.7
BOTTOM	0.9
COLLECTION CHAMBER	
BOTTOM	29.4
TOTAL RECOVERED	139.6
TOTAL INPUT	144.4
TOTAL LOST	4.8

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE 12/13/89 COAL U. FREEPORT TREATMENT 1000 PPM AMMONIA COAL INPUT (GMS) 137.3

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	NH3 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	89.6	0.0890	0.0	0.0	93	10:50	25
5.5	89.6	0.0868	0.0	0.0	86	10:55	25
5.5	89.6	0.0868	0.0	0.0	30	11:00	25
8.0	113.6	0.1120	0.0	1.0	45	11:05	24
8.0	115.3	0.1120	0.0	1.0	18	11:10	25
8.0	113.6	0.1172	0.0	1.0	67	11:15	25
8.0	113.6	0.1250	0.0	1.0	13	11:20	25
10.5	135.8	0.1461	0.0	1.4	80	11:25	25
10.5	135.8	0.1461	0.0	1.4	62	11:30	25
10.5	135.8	0.1434	0.0	1.4	125	11:35	25
10.5	135.8	0.1461	0.0	1.4	-0.019	11:40	25
13.0	157.4	0.1596	0.0	2.0	-0.055	11:45	25
13.0	157.4	0.1596	0.0	2.0	-0.013	11:50	25
13.0							
13.0							

COAL DISTRIBUTION (GMS)		
PLATE 1 (-)	4.4	
PLATE 2 (+)	22.2	
PLATE 3 (-)	61.4	
PLATE 4 (+)	36.3	
FILTER BAG	2.2	
CHARGING CHAMBER		
WALL	1.9	
BOTTOM	0.5	
COLLECTION CHAMBER		
BOTTOM	4.3	
TOTAL RECOVERED		133.2
TOTAL INPUT		137.3
TOTAL LOST		4.1

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE 12/14/89 COAL PITTSBURGH TREATMENT 1000 PPM AMMONIA COAL INPUT (GMS) 148.9

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	NH3 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	91.2	0.0890	0.0	0.0	379	10:10	38
5.5	89.6	0.0868	0.0	0.0	397	10:15	24
5.5	89.6	0.0802	0.0	0.0	231	10:20	24
8.0	115.3	0.1074	0.0	1.0	164	10:25	23
8.0	113.6	0.1120	0.0	1.0	15	10:30	23
8.0	113.6	0.1172	0.0	1.0	291	10:35	24
8.0	115.3	0.1051	0.0	1.0	138	10:40	24
10.5	135.8	0.1488	0.0	1.5	53	10:45	24
10.5	135.8	0.1461	0.0	1.5	126	10:50	24
10.5	135.8	0.1434	0.0	1.5	26	10:55	24
10.5	135.8	0.1434	0.0	1.5	154	11:00	25
13.0	157.4	0.1680	0.0	1.9	119	11:05	25
13.0	157.4	0.1569	0.0	1.9	49	11:10	25
13.0	157.4	0.1710	0.0	1.9	21	11:15	25
13.0	157.4	0.1680	0.0	1.9	20	11:20	25

COAL DISTRIBUTION (GMS)	
PLATE 1 (-)	6.7
PLATE 2 (+)	21.7
PLATE 3 (-)	67.3
PLATE 4 (+)	35.9
FILTER BAG	4.7
CHARGING CHAMBER	
WALL	2.4
BOTTOM	0.2
COLLECTION CHAMBER	
BOTTOM	3.9
TOTAL RECOVERED	142.8
TOTAL INPUT	148.9
TOTAL LOST	6.1

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE 12/15/89 COAL PITTSBURGH TREATMENT 1000 PPM AMMONIA COAL INPUT (GMS) 133.3

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	NH3 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	88.0	-------	0.0	0.0	105	10:20	26
5.5	89.6	0.0868	0.0	0.0	129	10:50	23
5.5	88.0	0.0913	0.0	0.0	194	10:55	23
8.0	113.6	0.1146	0.0	1.0	108	11:00	22
8.0	115.3	0.1146	0.0	1.0	54	11:05	23
8.0	113.6	0.1146	0.0	1.0	23	11:10	23
8.0	113.6	0.1074	0.0	1.0	10	11:15	24
10.5	135.8	0.1434	0.0	1.3	5	11:20	24
10.5	137.6	0.1488	0.0	1.4	9	11:25	24
10.5	135.8	0.1380	0.0	1.4	33	11:30	24
10.5	135.8	0.1380	0.0	1.4	22	11:35	25
13.0	157.4	0.1650	0.0	1.9	24	11:40	25
13.0	155.5	0.1650	0.0	1.9	21	11:45	25
13.0	157.4	0.1623	0.0	1.9	22	11:50	25
13.0	157.4	0.1650	0.0	1.9	25	11:55	25

COAL DISTRIBUTION (GMS)	
PLATE 1 (-)	12.2
PLATE 2 (+)	16.4
PLATE 3 (-)	60.3
PLATE 4 (+)	23.3
FILTER BAG	5.3
CHARGING CHAMBER	
WALL	3.7
BOTTOM	0.1
COLLECTION CHAMBER	
BOTTOM	4.5
TOTAL RECOVERED	125.8
TOTAL INPUT	133.3
TOTAL LOST	7.5

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE 12/18/89 COAL U. FREEPORT TREATMENT 0.5% DICYCLCHEXYLAMINE COAL INPUT (GMS) 134.5

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	89.6	0.0	0.0	170	1:20	26
5.5	89.6	0.0	0.0	68	1:25	25
5.5	89.6	0.0	0.0	27	1:30	25
8.0	113.6	0.0	0.9	48	1:35	24
8.0	113.6	0.0	0.9	131	1:40	24
8.0	113.6	0.0	0.9	62	1:45	25
8.0	115.3	0.0	0.9	46	1:50	25
10.5	135.8	0.0	1.3	55	1:55	24
10.5	135.8	0.0	1.4	53	2:00	25
10.5	135.8	0.0	1.3	234	2:05	25
10.5	135.8	0.0	1.3	228	2:10	25
13.0	157.4	0.0	1.7	50	2:15	25
13,0	157.4	0.0	1.8	129	2:20	25
13.0	157.4	0.0	1.8	54	2:25	25
13.0	157.4	0.0	1.8	240	2:30	25

COAL DISTRIBUTION (GMS)		
PLATE 1 (-)	2.8	
PLATE 2 (+)	20.3	
PLATE 3 (-)	66.4	
PLATE 4 (+)	32.7	
FILTER BAG	2.3	
CHARGING CHAMBER		
WALL	3.3	
BOTTOM	0.4	
COLLECTION CHAMBER		
BOTTOM	3.1	
TOTAL RECOVERED		131.3
TOTAL INPUT		134.5
TOTAL LOST		3.2

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE 12/19/89 COAL PITTSBURGH TREATMENT 1000 PPM AMMONIA COAL INPUT (GMS) 137.8

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	NH3 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	89.6	0.0913	0.0	0.0	105	10:50	24
5.5	89.6	0.0846	0.0	0.0	10	10:55	24
5.5	92.8	0.0619	0.0	0.0	27	11:00	24
8.0	113.6	0.1172	0.0	1.0	15	11:05	23
8.0	113.6	0.1198	0.0	1.0	82	11:10	23
8.0	115.3	0.1097	0.0	1.0	7	11:15	23
8.0	115.3	0.1146	0.0	1.0	20	11:20	24
10.5	137.6	0.1461	0.0	1.5	9	11:25	24
10.5	135.8	0.1407	0.0	1.5	7	11:30	24
10.5	137.6	0.1407	0.0	1.5	2	11:35	24
10.5	135.8	0.1407	0.0	1.5	1	11:40	25
13.0	157.4	0.1650	0.0	1.9	13	11:45	25
13.0	157.4	0.1650	0.0	1.9	43	11:50	25
13.0	157.4	0.1623	0.0	1.9	37	11:55	24
13.0	157.4	0.1650	0.0	1.9	16	12:00	25

COAL DISTRIBUTION (GMS)		
PLATE 1 (-)	3.8	
PLATE 2 (+)	21.7	
PLATE 3 (-)	64.6	
PLATE 4 (+)	31.2	
FILTER BAG	3.3	
CHARGING CHAMBER		
WALL	2.1	
BOTTOM	0.2	
COLLECTION CHAMBER		
BOTTOM	7.0	
TOTAL RECOVERED		133.9
TOTAL INPUT		137.8
TOTAL LOST		3.9

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE 12/20/89 COAL PITTSBURGH TREATMENT 0.1% QUINOLINE COAL INPUT (GMS) 136.5

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	89.6	0.0	0.0	220	1:35	28
5.5	91.2	0.0	0.0	278	1:40	24
5.5	89.6	0.0	0.0	226	1:45	25
8.0	113.6	0.0	0.9	256	1:50	24
8.0	113.6	0.0	1.0	34	1:55	24
8.0	113.6	0.0	1.0	310	2:00	24
8.0	115.3	0.0	1.0	146	2:05	24
10.5	135.8	0.0	1.5	121	2:10	24
10.5	135.8	0.0	1.5	80	2:15	24
10.5	135.8	0.0	1.4	279	2:20	24
10.5	137.6	0.0	1.5	195	2:25	25
13.0	157.4	0.0	2.0	112	2:30	25
13.0	157.4	0.0	2.0	45	2:35	25
13.0	157.4	0.0	2.0	222	2:40	25
13.0	157.4	0.0	2.0	235	2:45	25

COAL DISTRIBUTION (GMS)		
PLATE 1 (-)	3.6	
PLATE 2 (+)	21.2	
PLATE 3 (-)	64.8	
PLATE 4 (+)	24.7	
FILTER BAG	1.6	
CHARGING CHAMBER		
WALL	8.3	
BOTTOM	2.1	
COLLECTION CHAMBER		
BOTTOM	2.5	
TOTAL RECOVERED		128.8
TOTAL INPUT		136.5
TOTAL LOST		7.7

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE 12/26/89 COAL PITTSBURGH TREATMENT 0.1% QUINOLINE COAL INPUT (GMS) 137.6

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	89.6	0.0	0.0	56	1:25	25
5.5	89.6	0.0	0.0	9	1:30	24
5.5	89.6	0.0	0.0	9	1:35	24
8.0	113.6	0.0	0.9	16	1:40	24
8.0	115.3	0.0	0.9	14	1:45	24
8.0	115.3	0.0	1.0	99	1:50	24
8.0	117.0	0.0	1.0	97	1:55	25
10.5	137.6	0.0	1.4	144	2:00	24
10.5	135.8	0.0	1.4	150	2:05	24
10.5	135.8	0.0	1.4	139	2:10	24
10.5	135.8	0.0	1.4	50	2:15	[illegible]
13.0	157.4	0.0	1.9	38	2:20	24
13.0	157.4	0.0	1.9	15	2:25	24
13.0	157.4	0.0	1.9	25	2:30	24
13.0	157.4	0.0	1.9	65	2:35	24

COAL DISTRIBUTION (GMS)		
PLATE 1 (-)	4.5	
PLATE 2 (+)	29.6	
PLATE 3 (-)	66.6	
PLATE 4 (+)	16.9	
FILTER BAG	2.2	
CHARGING CHAMBER		
WALL	7.1	
BOTTOM	2.2	
COLLECTION CHAMBER		
BOTTOM	2.4	
TOTAL RECOVERED		131.5
TOTAL INPUT		137.6
TOTAL LOST		6.1

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE 12/27/89 COAL PITTSBURGH TREATMENT 0.1% QUINOLINE COAL INPUT (GMS) 139.6

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	91.2	0.0	0.0	29	10:30	37
5.5	89.6	0.0	0.0	34	10:35	23
5.5	89.6	0.0	0.0	40	10:40	24
8.0	115.3	0.0	1.0	22	10:45	23
8.0	118.7	0.0	1.0	34	10:50	23
8.0	117.0	0.0	1.0	28	10:55	24
8.0	118.7	0.0	1.0	71	11:00	25
10.5	139.4	0.0	1.5	76	11:05	24
10.5	137.6	0.0	1.4	51	11:10	24
10.5	137.6	0.0	1.4	50	11:15	25
10.5	137.6	0.0	1.4	48	11:20	25
13.0	159.3	0.0	1.9	50	11:25	24
13.0	159.3	0.0	1.9	8	11:30	24
13.0	159.3	0.0	1.9	17	11:35	24
13.0	159.3	0.0	1.9	20	11:40	24

COAL DISTRIBUTION (GMS)		
PLATE 1 (-)	3.1	
PLATE 2 (+)	21.9	
PLATE 3 (-)	63.9	
PLATE 4 (+)	29.5	
FILTER BAG	1.3	
CHARGING CHAMBER		
WALL	7.1	
BOTTOM	2.9	
COLLECTION CHAMBER		
BOTTOM	2.9	
TOTAL RECOVERED		132.6
TOTAL INPUT		139.6
TOTAL LOST		7.0

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE	12/29/89	COAL	PITTSBURGH	TEST	POS-18kV, NEG-6kV	COAL INPUT (GMS)	153.5

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	91.2	0.0	0.0	3	10:20	40
5.5	89.6	0.0	0.0	16	10:25	24
5.5	89.6	0.0	0.0	13	10:30	24
8.0	113.6	0.0	1.0	14	10:35	23
8.0	115.3	0.0	1.0	14	10:40	23
8.0	115.3	0.0	1.0	12	10:45	24
8.0	113.6	0.0	1.0	2	10:50	24
10.5	135.8	0.0	1.5	3	10:55	24
10.5	137.6	0.0	1.5	2	11:00	24
10.5	137.6	0.0	1.5	21	11:05	24
10.5	137.6	0.0	1.5	11	11:10	24
13.0	157.4	0.0	1.9	14	11:15	25
13.0	157.4	0.0	1.9	15	11:20	24
13.0	157.4	0.0	1.9	95	11:25	24
13.0	157.4	0.0	1.9	97	11:30	25

COAL DISTRIBUTION (GMS)		
PLATE 1 (-)	4.4	
PLATE 2 (+)	41.5	
PLATE 3 (-)	73.8	
PLATE 4 (+)	14.0	
FILTER BAG	3.4	
CHARGING CHAMBER		
WALL	3.4	
BOTTOM	1.1	
COLLECTION CHAMBER		
BOTTOM	3.0	
TOTAL RECOVERED		144.6
TOTAL INPUT		153.5
TOTAL LOST		8.9

RAW DATA SHEETS FROM EXPERIMENTAL TEST RUN

DATE 6/8/90 COAL PITTSBURGH TEST TWO STAGE SYSTEM COAL INPUT (GMS) 73.2

CO2 LINE PRESSURE (PSIG)	CO2 FLOWRATE (L/MIN)	COLLECTION CHAMBER PRESSURE (PSIG)	CHARGING CHAMBER PRESSURE (PSIG)	PICO-AMMETER CURRENT (MICRO AMP)	TIME	CO2 LINE TEMP. (DEG C)
5.5	91.2	0.0	0.0	59	10:15	
5.5	91.2	0.0	0.0	90	10:20	
5.5	91.2	0.0	0.0	103	10:25	
8.0	115.3	0.0	1.0	70	10:30	
8.0	115.3	0.0	1.0	55	10:35	
8.0	115.3	0.0	1.0	94	10:40	
8.0	115.3	0.0	1.0	89	10:45	
10.5	135.8	0.0	1.5	125	10:50	
10.5	137.6	0.0	1.5	135	10:55	
10.5	137.6	0.0	1.5	107	11:00	
10.5	137.6	0.0	1.5	92	11:05	
13.0	157.4	0.0	2.0	97	11:10	
13.0	157.4	0.0	2.0	107	11:15	
13.0	157.4	0.0	2.0	127	11:20	
13.0	157.4	0.0	2.0	131	11:25	

COAL DISTRIBUTION (GMS)		
PLATE 1 (-)	13.2	
PLATE 2 (+)	24.5	
PLATE 3 (-)	26.1	
PLATE 4 (+)	1.1	
FILTER BAG	0.0	
CHARGING CHAMBER		
WALL	3.2	
BOTTOM	1.8	
COLLECTION CHAMBER		
BOTTOM	1.2	
TOTAL RECOVERED		71.1
TOTAL INPUT		73.2
TOTAL LOST		2.1

Appendix D

Literature Search

LITERATURE SURVEY

The Chemical Enhancement of the Triboelectric Separation of Coal from Pyrite and Ash

for DOE-PETC project

Novel Approach for
ELectrostatic Separation of Mineral Matter from Coal

Contract DE-AC22-87PC79888

Project Leader: R. Peter Stickles

Principal Investigator: Richard M. Gustafson

ARTHUR D. LITTLE, INC.

July 1988

Reference C-60371-21

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[illegible]

INTRODUCTION

As part of the Chemical Enhancement of Triboelectric Separation (PRDA DE-RA22-86PC91251), a literature review of information pertaining to the task, particularly background information and prior experience, was requested. This report presents the results of that review. The review was based predominately on articles, books, and patents located by searching on-line abstract databases. The discussion first covers dry chemical enchancement and triboelectrification, followed by brief reviews on surface chemistry and aqueous based chemical cleaning processes. Extensive bibliographic citations are given in Appendices A and B. Search strategies used for the database review are given in Appendix C.

SUMMARY:

The literature survey identified several potentially beneficial and reactive chemical treatments for augmenting triboelectrification. The use of negative ion doping agents and glycerides may prove to be a useful and practical aid and has been successfully demonstrated elsewhere. The development of a model to explain a method of identifying appropriate treatments was located. Enough of the tribochargers mentioned in other studies have a similar design to ours (spinning charging rotors, dual plate precipitators) that we can be confident our new design will be a successful research tool. Methods of energizing coal/doping chemicals by plasma development through corona discharge and microwave irradiation have been identified. Finally several reactive treatment chemicals have been identified as possibly being useful in enhancing electrostatic precipitation (Hydrogen, chlorine, or bromine gas, and ammonia comminution or comminution by other saturated gases).

During the search further literature which may be of interest was identified that was not picked up in the abstract review. We are listing these additional references in Appendix B, so the reader may obtain them if so desired.

DRY COAL SEPARATION TECHNIQUES:
CHEMICAL ENHANCEMENT:

Two patents, but no additional references, were found in which chemical treatment was used to enhance coal electrostatic cleaning. However, several dry chemical coal treatment techniques which may be applicable to electrostatic separation enhancement were identified.

In work reported by Pearse (Ref 46), the triboelectrostatic separation of quartz from calcite and apatite was accomplished by the addition of oleate ions to a mixture of the three minerals. The mechanism of this process illustrates an important approach which could be useful in coal processing.

According to triboelectric theory (Refs 5,46), if two materials are to separate, one must possess a higher work function and one must possess a lower work function relative to the the surface they contact during tribocharging. For example (Refs 5,6,47,48), coal will usually exhibit a positive charge, and pyrite and ash a negative charge, upon contact with stainless steel, and separation of the coal from pyrite and ash can be achieved. However, when materials aquire the same charge, such as quartz, calcite, and apatite, they cannot be separated. Non-separation due to like charging is possible in coal-pyrite ash separation; in (Ref 6) tribocharging a Sardinian coal mixture resulted in both a coal and pyrite mixture charging negatively, with the Sardinian ash fraction charging positively. Tribocharging would not have separated the coal and pyrite.

When a chemical additive can modify the surface work function, however, the situation changes. According to triboelectric theory (Ref 43 pg 65), tribocharging moves electrons from one contacted material to another until the Fermi energy levels of the materials are aligned. The Fermi energy is defined by Fermi-Dirac Statistics as the mean value of the energy distribution at which the valence electrons occupy a surface of constant energy (Fermi-surface) above absolute zero and at normal temperatures (Ref 16 pg 63). The work function is the difference in energy between the Fermi energy and the required vacuum level and quantifies the energy to totally liberate one electron into vacuum. The greater the work function, the more energy is required to liberate an electron. This work function can be reduced by the addition of negative ions onto the mineral surface, and can therefore alter the polarity of triboelectric charging relative to a reference surface. If a material preferentially absorbs onto one material over another in a mixture, the charge separation between the two can increase, and separation made easier.

Because oleate ions were known to preferentially absorb onto non-metallic mineral surfaces, Pearce treated mixtures of quartz-calcite and quartz-apatite with a basic aqueous solution of sodium oleate. The ore mixtures were separated and then dried. The results were a decrease in the magnitude of all negative charges. Quartz remained negative, but calcite and apatite became positive, allowing trbioelectric separation. In addition, the charging was less sensitive to humidity after treatment. Although soaking ground coal in aqueous oleate ion would not be possible within a dry system, it might be possible to spray a solution into the fluidized chamber, in which the highly turbulent coal mixture would become coated with the oleate ion. If the oleate ion preferentially absorbed onto the positive coal, an increase in its positive charge might occur. It might also be possible to increase the recovery of coal first drawn off into the ash-laden side, with post-treatment and a second pass through the charger.

An electrostatic coal cleaning process has been patented which makes use of a similar treatment. In a patent assigned to Kali und Salz Aktiengesellschaft (Singewald, Ref 55), the triboelectric separation of coal is enhanced with fatty acid glycerides. The glycerides are added to the coal and the mixture is vigorously mixed for periods of

10 seconds to 30 minutes, at temperatures of 25 ° C to 100 ° C in amounts of 100 - 2000 grams of additive per ton of powdered coal. The treated coal is then separated in a free-fall parallel plate electrostatic precipitator. The additives mentioned in the patent are mono-, di-, and triglyceride esters of searic, palmitic, oleic, linoleic, and linolenic acids. A copy of the patent is provided in Appendix E.

In a patent assigned to Advanced Energy Dynamics, Inc. (Rich, Ref 52), a triboelectric separator is described in which -200 mesh coal is deagglomerated for separation in an electrostatic separator by an AC corona discharge. According to the patent, gas passes through two electrodes, one axial to another. A low current, high voltage AC voltage is applied across the electrodes to generate a corona discharge. The gas and particles are then passed between the electrodes, forming a particle suspension in a gas plasma. This should render the gas highly reactive. In this way, the attack of the coal pyrite surface by various doping gases can be carried out. The patent suggests that the doping gas should be selected in such a way as to raise the conductivity of the pyrite surface. It is not clear as to what effect this will have on the work function and the polarity of the triboelectric charging. According to Carta, Pearse and Moore (Refs 5,46,43 pps 64-67) the work function and Fermi-level are most appropriate for categorizing electrostatic separation success. We believe that the plasma activating method in Advanced Energy Dynamic's (AED) patent is a good one, but should but be rationalized in terms of the Carta, Pearce, and Moore theory. Doping gases suggested by AED included chlorine, hydrogen chloride, and hydrogen. They also suggested ammonia comminution as an appropriate treatment (see below).

Syracuse Research Program developed a patented process, on a bench scale, in which coal fracturing was enhanced by treatment with gas or liquefied gas chemical comminuters (Refs 11,12,50). The comminuter of choice was ammonia, but other materials will comminute coal. The chemical comminuter does not appear to chemically react with the coal; subsequent cleaning can recover virtually all of the chemical. Instead, the chemical, either a saturated liquid or gas near saturation, adsorbs and migrates preferentially along the coal pyrite interstices. The coal then swells and fragments along the interstices, liberating pyrite with particle sizes of coal and pyrite which would be larger than those developed by mechanical crushing. The rate of absorption into the coal controls the rate of solution; thus a small molecular size results in a faster treatment. A treatment with gaseous ammonia at about 75 to 195 psig for 50 minutes optimally comminutes the coal. Treatment at atmospheric pressure with ammonia gas shows no enhancement. The comminuting is carried out on coarse coal; a fine coal may be too small to show the enhanced separation from the coarse particle size. In the Syracuse studies, the coal was -1.5 inch size run of mine. Using gravity separation as the separating method, the overall sulfur content of chemically comminuted coal was about 1.3 % ; For 14 mesh mechanically crushed coal it is about 1.5 %; for the original 1.5 inch it was about 1.6 %. These pyrite reduction values are for coal recovery levels of 95 %.

There are several potential points to chemical comminuting which must be kept in mind if it is used to augment electrostatic cleaning.

1) The chemical comminuting bench tests have only been done with the large size grinds. If the comminuting requires a coarse coal, then the chemical comminuting may have to be performed separately from the tribocharging, adding to the processing costs. One of the ways tribocharging has been attributed to coal is a process called "fracto-charging" (Ref 38) in which the charge generation is accomplished primarily through the creation of fresh surfaces upon particle impact. In addition, the larger particles may not charge and separate effectively because of a smaller surface to volume ratio. However, pre-cleaning with chemical comminution, followed by a finer pulverizing and fracto-charging might successfully combine the two processes together to generate higher yields.

2) The Syracuse ammonia gas experiments required an aqeuous wash and steam strip to remove all of the ammonia. High levels of ammonia present in the combusted coal could cause high NOx emissions. If an additional wash step is required for the coal, the process could be uneconomical. However, because the comminuter behavior is attributed more to physical adsorption rather than chemical reaction, other materials at different temperatures or pressures might be used for treatment. For instance, propane is somewhat more volatile then ammonia. It might work as a comminuter, but due to a large molecular volume, at a slower rate than ammonia. Excess propane carried over with the coal after a depressurization could be easily combusted. Another alternative might be natural gas or LNG at moderate pressures and lower pressures. All of these would be gases or liquids near the saturation point, like the ammonia, but would combust cleanly.

3) In chemical comminution, the chemical additives are concentrated. Significant amounts of the chemicals must be recycled or added to the processed coal.

Another dry chemical treatment process of note is the KVB Research Cottrell process (Refs 2, 26 pps 258-269, 40, 44). In this process, dry, powdered coal is treated with an atmospheric pressure, 100 ^{o}C mixture of O_2 (0.5 to 20 %), NO_2 (0.25 to 10 %), NO (0.25 to 10 %), and N_2. After 1 to 4 hours of contact, the sulfur is partially oxidized to SO_2, SO_3, and $FeSO_4$ (ferric sulfate). The SO_2 and SO_3 come off as gaseous by-products. The ferric sulfate in the original process is washed off in an aqueous wash step. Although this is not possible in our study, the reaction to form SO_2 and SO_3 could be significant in partially reducing sulfur content, as a comminuting chemical (it could weaken the pyrite bonds) or as a creator of surface defects, which can change charging behavior. Note that one problem noted in the Research Cottrell work was the development of nitrated coal. This could potentially raise NO_x levels. The principle KVB reactions are: (Ref 26 pg 259)

$NO + 1/2\ O_2 \rightarrow NO_2$ (gaseous)

$FeS_2 + 6NO_2 \rightarrow FeSO_4 + SO_2 + 6NO$ (gaseous+solid)

$R1\text{-}S\text{-}R2 + NO_2 \rightarrow R1\text{-}S::O\text{-}R2 + NO$ (gaseous + solid)

$R1\text{-}S::O\text{-}R2 + NO_2 \rightarrow R1\text{-}S::O2\text{-}R2 + NO$ (gaseous + solid)

$R1\text{-}S::O2\text{-}R2 + NO_2 \rightarrow R1 + R2 + NO + SO_3 + SO_2$ (gaseous + solid)

Other steps in the process included the leaching of organic sulfur in the R1-S::O-R2 and $FeSO_4$ with NaOH and $CaOH_2$ to form Na_2SO_4 and $CaSO_4$.

Another principle dry process mentioned in the literature is the Hazen Research "Magnex" process(Ref 27, Ref 26 pps 135-147), in which dry coal is reacted with iron pentacarbonyl vapors, generated within a reactor system by a system which vaporizes, then condenses and reclaims iron pentacarbonyl. The iron pentacarbonyl reacts with the pyrite and some ash surfaces to attach iron complexes, increasing the magnetic susceptibiltiy of the pyrite and the ash. The pyrite and the ash can then be separated by conventional magnetic separators. The main disadvantages with the process is the high toxicity of iron pentacarbonyl (similar to handling tetraethyl lead in manufacturing gasoline), and projected high raw material costs (Ref 44). Although the reaction may not be directly applicable to electrostatic precipitation, the illustration of a complexing attachable species having major changes in the pyrite behavior, even though only a small amount attaches, is worth noting. The Magnex process reactions are believed to be (Ref 27):

$Fe(CO)_5 \rightarrow Fe + 5CO$

$FE(CO)_5 + Ash \rightarrow Fe.Ash + 5CO$

$FE(CO)_5 + FeS_2 \rightarrow Fe(1\text{-}x)S + 5CO$

Another gaseous reaction, although carried out in a suspended liquid phase, is the Jet Propulsion Laboratory Chlorinolysis process (Ref 26 pg 232-244). In the Chlorinolysis process, coal is first suspended in a chlorinated hydrocarbon, then reacted with gaseous chlorine dissolved in the suspension. The reaction occurs at one atmosphere and 74 $_o$ C for 1 to 4 hours. Chlorine is used up at a rate of 3 to 3.5 moles/mole of sulfur (250 kg CL_2 per 1000 kg of coal). Moisture is also supplied at a rate of 30-50 % by weight of feed coal. In addition to solvent vapors, large amounts of CL_2 and HCL gas are vented off during the reaction. After treatment, the chlorinated coal is washed with water, filtered, dried, then dechlorinated with superheated steam for about 1 hour. The key points to note about the process are that without much moisture, chlorine will react with FeS_2 to form $FeCl_2$ and S_2Cl_2, but that the reaction is slow, and that the S_2Cl_2 may react with organic comounds to form organo-sulfur compounds. At higher temperatures and with moisture, this does not happen. Instead, the S_2Cl_2 will form HCl and H_2SO_4. The process has also had problems with high levels of chlorinated coal being carried over into the "cleaned" product. (Ref 41)

Thus, although chlorine will react with pyrite and coal, the products of the reaction, even when enhanced by the addition of water, could generate as many problems as the sulfur compounds initially present. Chlorine may not be a good additive chemical. Note also that in the original process HCL was a product. This would indicate that HCL is probably not strongly reactive with the coal or the pyrite.

There are also a number of dry hydrogenation (reduction) processes described with coal, but all require the handling of highly flammable hydrogen, and high processing temperatures (> several hundred degrees centigrade). For example, the Institute of Gas Technology developed a process (Ref 16 pgs 127 to 128) in which pyrite was reduced to Fe and H_2S in the presence of a H_2S scavenger (ground limestone or an alkaline earth oxide). The scavenger shifted the equilibirum in favor of H_2S conditions, but process temperatures were still 800 ° F. At ambient temperatures coal does not normally react with hydrogen, but will readily absorb into it (Ref 66).

DRY COAL SEPARATION TECHNIQUES:
ELECTROSTATIC SEPARATION:

A number of useful references were located which discuss the tribo-electrostatic separation of coal and other non-conductors and electrostatic separations in general. Several people have reported favorable results on non-enhanced triboelectric separation of coal from pyrite and ash. M. Carta of the University of Cagliari in Sardinia has used cyclone tribocharging, and an Electrocyclojet (Cyclone plus corona discharge) to clean several coals (Refs 5, 34). Masuda and others (Ref 37) have reported using a cyclone tribocharger to develop some separation of coal from ash. but their results were not as good as those claimed by Carta. The Masuda system was a recirculating cyclone in which the wall material could be changed. They tested copper, PVC, Teflon, and "acryl" materials (polymethyl methacrylate?). Copper and PVC gave the best separation. The cylone discharged between two vertical charged plates 1 meter apart. The voltage gradient was not given. The coals they separated contained ash of quartz, kaolinite clay and alumina. The observed varying performance, depending upon the wall material, but noted that only the coarsest material moved to the cathode and the anode. With the copper system (most similar to our steel system), the quartz and alumina collected at the anode, and no separation was noted for the kaolinite. With the teflon system, quartz and alumina did not separate, but kaolinite tended to collect at the anode. They also ran tests with a fluidized bed which developed no separation. They concluded the reason was that only particle-particle interactions occurred in the fluidized bed system, and that, therefore, the particle-wall contact is the predominant charging mechanism. One problem which could account for the low recovery for the system is a weak electric field gradient. Very high voltages would be required to charge a one meter gap (about 400,000 volts) to the same gradient as developed in the PETC Tribocharging systems. A weak field would cause a minimum deflection of the charged particles.

In another patent assigned to Advanced Energy Dynamics, (Ref 64), an electrostatic precipitator with a rotating, grounded rotor is described, which uses a corona discharge to charge the material. An extension of the feed hopper scrapes the rotor and cuts away a boundary layer of gas off of the moving rotor before depositing the coal onto it, enhancing rotor contact and separation. An additional conductive barrier, placed axisymmetric and just above the rotor so a gap of constant width is formed, prevents the corona wind (a moving gas stream of ions) from blowing the settling coal dust away from the rotor.

Petrzhik (Ref 48) has also used Tribocharging to charge brown, gas, and anthracite coal. The tribocharging was done between a grounded drum, rotating at 30 rpm, and an inner glass surfaced rotor moving countercurrently at 2940 rpm. Within 1 minute of contact the coal had taken up a positive charge so strong that it all adhered to the drum, and remained adhered for hours. Stainless steel was also used. For a "friction velocity" (relative wall velocity ?) of 4.6 m/sec, and 1 to 5 mm particles, currents of 2.5 to 25 10-10 amps/g were generated, with the smallest particles charged the most. Note that anthracite charged less than gas coal, but positive, and brown coal charged negatively. No attempt to separate pyrite or minerals was made.

Another spinning device, using both tribocharging, and optional corona discharging, is described in a Soviet patent issued to Ilyukhin, V.V. and others (Ref 22). The device, designed to test electrostatic charging of food stuffs and mineral matter, consists of two static concentric cylinders, one inner and one outer, below which a turbine agitator of a dielectric material rotates. The concentric cylinders function as electrodes. A corona discharge electrode and a charge measuring tube are also inserted into the device. The tube is tangent to the outer wall and constructed with a slot in it. The tube is capable of rotation and back and forth movement. By charging the material and then collecting it in the tube, the magnitude of charge can be estimated from the sampled material.

Some interesting references to general triboelectric behavior and theory were also uncovered. In Carta's paper "Triboelectric Phenomena in Mineral Processing" (Ref 5), he claims that his group has developed a general model which will predict the separation performance of different materials based on the Fermi energy and work function of pure crystals of the material relative to a standard reference metal (Carta uses gold). He claims the surface energy properties of the materials can be explained entirely by Fermi-Dirac statistics. If the work function is higher relative to the impacted surface, the material is negatively charged. If it is lower it is postively charged. By using the surface energy information, the model can predict the results of treatment with radiation, ionic bombardment, or temperature change.

In a paper by Fanslow, G.E., "Dielectric Heating of Coals" (Ref 17), work is reported in which temperature sensitive properties of coals and pyrite/ash were altered by the use of bursts of microwaves of coal-pyrite-ash mixtures. In particular, the magnetic separation of pyrite from coal was accomplished by heating the metallic containing pyrite with the bursts of microwaves, raising its magnetic susceptibility. Equations are given which can be used to predict the temperature of irradiated particles. For the magnetic susceptibility study, the 25 g samples were irradiated at 2.45 gigahertz and 2 kw forward and 100 w reflected power. The coal rate of temperature rise was about 1.7 ^{o} K/s, while the pyrite temperature rose at a rate of 2.5 to 4 ^{o} K/s.

Several papers discuss interesting details of triboelectric charging. In a paper by Lowell "Triboelectric Charging of Identical Insulators" (Ref 35), a study was made which indicates that a frictional charge can be developed between two identical materials if they are rubbed against each other in a different manner. The charge sign the samples will take on depends upon the manner in which they are rubbed. For instance, A moving sample of polystyrene rubbed over a nonmoving plate of polystyrene will always take a positive charge. The magnitude of the charge is dependent primarily upon atmospheric conditions such as humidity. Charging orientation and magnitude does not seem to be affected by different frictional heating histories, but instead is based on the orientation of the motion.

In a paper by Lee "Two Step Decay for Triboelectricity of Polymers" (Ref 33) a Xerox ink and toner system were tribocharged. It was noted that steady-state, equilibrium charge values could be developed. Moisture strongly affected both the charging rate and equilibrium value and the decay rate. The first decay was rapid and strongly affected by relative humidity. The second stage was more gradual, and the effect of relative humidity was even stronger. The first decay is attributed to dynamic sources. The slower second step is attributed to static sources.

In two papers, the details on measuring charge are developed in experimental setups:

In Kittaka's paper "New System for Measuring the Charging Tendency of Solid Particles " (Ref 28) a cyclic charging chamber with attached fine metal mesh Faraday cage is described. A charged sample from the chamber is removed by vacuum pump, drawn into the Faraday cage, and the charge measured through the Faraday cage ground by electrometer. Samples could be measured every 10 seconds, with charges measured on the orders of 10^{-10} coulombs/particle. A monitoring probe for charging was made of a 3 mm diameter by 20 mm long tube inside a 5 mm diameter shielding tube. The shielding tube had a slit in it. The monitoring probe was inserted into the swirling chamber about 1/2 the chamber radius away from the wall. The rotating particles pass between the two tubes. A particle passing near the slot causes a voltage pulse if it is charged. The magnitude of the pulse indicated the degree of charge. The velocity of the particles is measured by the period of the induced pulses. An oscilloscope and electronic counter are used to measure the pulses.

In a paper by Kamiensky "Triboelectrification of Aerosol Particles" (Ref 25), a study is described in which charged aerosol particles are impacted against a glass fiber filter. The filter holder acted as a Faraday cage. The current to the ground from the filter, in the nanoamp range, was measured though an electrometer. To avoid signal noise, solid conducter teflon insulated coaxial cables, and teflon insulators were used for electrical hook-up. The sensing element was enclosed inside two solid copper shields and the coaxial cable was placed inside solid copper tubes and rigidly fastened.

Besides a parallel plate type separator, a novel separater with V and flat plates has also been patented. (Inculet et al, Ref 23). In this device a V shaped plate is placed symmetrically parallel to a flat plate, and the two plates used as charging plates. When charged, the plates form a varying gradient which imparts a centrifugal electrical force that separates particles with varying charges. AC voltages are used to generate the electric field.

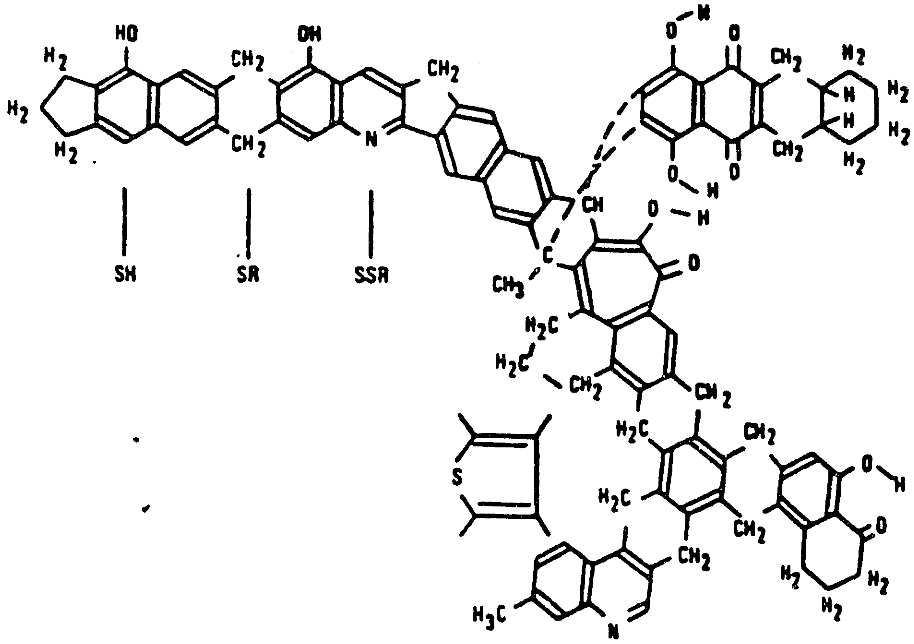
Finally an excellant overall review of the subject of dry beneficiation, particularly electrostatic methods, by Lockhart was located (Ref 34). It contains an excellant bibliography, with 224 references dated from 1949 to 1984. Topics of particular interest to our study include triboelectric separation, with a special section for coal; electrodynamic (corona) separation, particle size effects; electrical separation (general); air fluidized particle beds; and characterization and analysis.

COAL PROPERTIES AND SURFACE CHEMISTRY:

It is helpful in selecting beneficiating chemical mechanisms for triboelectric coal cleaning to have some understanding of the surface reactive groups in coal and a representative structure for a coal

FIGURE 1

Model of Organic Coal Matrix



Source: EPA 600/7-79-098b

from Khoury, D.L., Ed. Coal Cleaning Technology, Noyes Data Corp, N.J., 1981, pg 132

TABLE 1

Minerals Frequently Occurring in Coals, Their Stoichiometric Compositions, Their Modes of Occurrences, and Relative Abundance[a]

Mineral	Composition	Chief occurrences Physical[b]	Chief occurrences Genetic[c]	Relative abundance
Clay minerals				
Illite (sericite, K-mica)	$KAl_2(AlSi_3O_{10})(OH)_2$	D,L	d,s(?)	Common
Smectite (mixed layered)	$Al_2Si_4O_{10}(OH)_2 \cdot xH_2O$	D,L	d,s(?)	Common
Kaolinite group	$Al_4Si_4O_{10}(OH)_2$	L,F	e,d,s(?)	Common
Sulfides				
Pyrite	FeS_2 (isometric)	D,N,F	s,e	Rare–common
Marcasite	FeS_2 (orthorhombic)	D(?)	s(?)	Rare
Sphalerite	ZnS	F	e	Rare
Others: greigite, galena, chalcopyrite, and pyrrhotite are reported as very rare				
Carbonates				
Calcite	$CaCO_3$	N,F	s,e	Common
Dolomite, including ankerite	$Ca(Mg,Fe)(CO_3)_2$	N	s,e	Rare–common
Siderite	$FeCO_3$	N	s,e	Common
Oxides				
Hematite	Fe_2O_3	N	s	Rare
Quartz	SiO_2	D,L,N	d	Rare–common
Others: magnetite and rutile are reported as very rare				
Others				
Limonite-goethite	FeOOH	N	e	Rare
Apatite, including phosphorite	$Ca_5(PO_4)_3(F,Cl,OH)$	D	d,s(?)	Rare
Sulfates, mainly gypsum, barite, and several iron-rich ones				
Feldspars	$K(Na)AlSi_3O_8$	D,L	d	Rare
Zircon	$ZrSiO_4$	D,L	d	Rare
Others: many others reported as very rare[a]				

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[a] After Mackowsky, in: Stach *et al.* (1982); see also Finkelman (1980) for complete listing and discussion of accessory minerals that have been observed in coals.

[b] D = disseminated; L = layers (partings); N = nodules, F = fissures (cleat). Each mineral listed may often occur in rock fragments within coal beds.

[c] d = detrital; e = epigenetic, second stage of coalification (mainly along joints (cleat) in coal beds); s = syngenetic, first stage of coalification (disseminated, intimately intergrown with macerals). The indicated occurrences are the more common ones in U.S. coals; others are reported in some coal fields.

from Cooper B.R. and Ellingson, W.A., the Science and Technology of Coal and Coal Utilization, Plenum Press, N.Y., 1984, pg 23.

TABLE 2

Mean Analytical Values for 114 Whole Coal Samples from the Illinois Basin Coal Field[a]

Element	Arithmetic mean	Geometric mean	Range Minimum	Range Maximum	Standard deviation
Ag	0.03 ppm	0.03 ppm	0.02	0.08	0.02
As	14 ppm	7.4 ppm	1.0	120	20
B	110 ppm	98 ppm	12	230	50
Ba	100 ppm	75 ppm	5.0	750	110
Be	1.7 ppm	1.6 ppm	0.5	4.0	0.82
Br	13 ppm	10 ppm	0.6	52	7.4
Cd	2.2 ppm	0.59 ppm	0.1	65	7.4
Ce	14 ppm	12 ppm	4.4	46	7.5
Co	7.3 ppm	6.0 ppm	2.0	34	5.3
Cr	18 ppm	16 ppm	4.0	60	9.7
Cs	1.4 ppm	1.2 ppm	0.5	3.6	0.73

(Continued)

from Cooper, B.R. and Ellingson, W.A. Ed: Science and Technology of Coal and Coal Utilization Plenum Press, N.Y. 1984, pgs 26, 27

TABLE 2 (continued)

Element	Arithmetic mean	Geometric mean	Range		Standard deviation
			Minimum	Maximum	
Cu	14 ppm	13 ppm	5.0	44	6.6
Dy	1.1 ppm	1.0 ppm	0.5	3.3	0.42
Eu	0.26 ppm	0.25 ppm	0.1	0.87	0.12
F	67 ppm	63 ppm	29	140	26
Ga	3.2 ppm	3.0 ppm	0.8	10	1.2
Ge	[a] 6.9 ppm	4.8 ppm	1.0	43	6.4
Hf	0.54 ppm	0.49 ppm	0.13	1.5	0.25
Hg	0.2 ppm	0.16 ppm	0.03	1.6	0.19
I	1.7 ppm	1.2 ppm	0.24	14	2.0
In	0.16 ppm	0.13 ppm	0.01	0.63	0.11
La	6.8 ppm	6.4 ppm	2.7	20	2.8
Lu	0.09 ppm	0.08 ppm	0.02	0.44	0.06
Mn	53 ppm	40 ppm	6.0	210	41
Mo	8.1 ppm	6.2 ppm	0.3	29	5.4
Ni	21 ppm	19 ppm	7.6	68	10
P	64 ppm	45 ppm	10	340	60
Pb	32 ppm	15 ppm	0.8	220	42
Rb	19 ppm	17 ppm	2.0	46	9.9
Sb	1.3 ppm	0.81 ppm	0.1	8.9	1.4
Sc	2.7 ppm	2.5 ppm	1.2	7.7	1.1
Se	2.2 ppm	2.0 ppm	0.4	7.7	1.0
Sm	1.2 ppm	1.1 ppm	0.4	3.8	0.55
Sn	3.8 ppm	0.94 ppm	0.2	51	8.8
Sr	35 ppm	30 ppm	10	130	23
Ta	0.15 ppm	0.14 ppm	0.07	0.3	0.06
Tb	0.22 ppm	0.18 ppm	0.04	0.65	0.14
Th	2.1 ppm	1.9 ppm	0.71	5.1	0.87
Tl	0.66 ppm	0.59 ppm	0.12	1.3	0.31
U	1.5 ppm	1.3 ppm	0.31	4.6	0.93
V	32 ppm	29 ppm	11	90	13
W	0.82 ppm	0.63 ppm	0.04	4.2	0.69
Yb	0.56 ppm	0.53 ppm	0.27	1.5	0.21
Zn	250 ppm	87 ppm	10	5300	650
Zr	47 ppm	41 ppm	12	130	27
Al	1.2 %	1.2 %	0.43	3.0	0.39
Ca	0.67 %	0.51 %	0.01	2.7	0.48
Cl	0.14 %	0.08 %	0.01	0.54	0.13
Fe	2.0 %	1.9 %	0.45	4.1	0.63
K	0.17 %	0.16 %	0.04	0.56	0.07
Mg	0.05 %	0.05 %	0.01	0.17	0.02
Na	0.05 %	0.03 %		0.2	0.04
Si	2.4 %	2.3 %	0.58	4.7	0.7
Ti	0.06 %	0.06 %	0.02	0.15	0.02

[a] Gluskoter *et al.* (1977).

particle. Khoury (Ref 26 pps 131 - 134), sugests that coal can be considered to be predominately an aromatic and cyclic ring organic structure with active sites including OH, carbonyl and carboxyl groups (see Figure 1). Sulfur occurs predominantly as mercaptans, thiophenes, sulfides, and disulfides. Inorganic material can be dispersed or in inclusions. Inorganic sulfur occurs predominantly as pyrite, but also as sulfate minerals such as melanterite, jarosite, and gypsum.

The inorganic mineral matter in coal can vary widely in incorporated structure and type. Table 1 gives typical compositions. A composition profile of elemental forming ash is given in Table 2. Major elements (>0.5 %) typically are Al, Ca, Fe, and Si. Minor elements(0.02 to 0.05 %) are K, Mg, Na, and Ti. A wide variety of trace elements can be present.

The dielectric constant of coal is given in Cooper (Ref 10 pg 39) as 10^{-14} /Ohm cm at 80 % carbon to 10^{-4} /Ohm cm at 96 % carbon.

In a paper by Clark, "ESCA Applied to Coal Chemistry", (Ref 7), the surface chemistry of Lower Kittanning coal was analyzed. Several other coals were also examined. For the Lower Kittanning coals the principle finding was the presence of a much higher oxygen functionality than expected. Although the authors believe this could be due to a problem in sample preparation, they also believe it could be illustrating the rapid rate at which the surface of coal can become oxidized, even under controlled conditions.

In a study by Marsh of carbonization of oxidized coals (Ref 36), it was pointed out that, at lower temperatures, oxidation of coal has been found to be dominated by single functional carbonyl groups. During carbonization it appeared that crosslinking of molecules by ether or ester groups is responsible for loss of fluidity. Other work suggested that it was due predominantley to reactions with carbonyl groups as opposed to phenolic or carboxylic groups. They also concluded that until that the reactive groups of high temperatures are reached, singly bound CO groups predominate over carboxyl and carbonyl. The identification of these reactive sites could prove useful in identifying reactive sites for binding.

NON-DRY COAL CLEANING PROCESS CHEMISTRY:

The majority of coal cleaning and procesing chemistry is either wet or high temperature. In practice most of these processes have been too costly to be economical, or required costly raw materials. However, it still is worthwhile to briefly discuss some of their chemistry, because it gives us some insight into the type of conditions and reactants that are required to cause coal or pyrite to chemically react. The reactions can be broken down into three general categories; oxidation reactions, reduction reactions, and caustic reactions.

Oxidation Reactions:

In oxidation reactions, pyrite is reacted with oxygen to form ferric sulfate. Since most of the reactions occur in water, the water soluble ferric sulfate leaches out. The process conditions vary somewhat, depending upon the process, but in general run from 1 to several atmospheres in pressure, and from 75 ^{o} C to 200 ^{o} C in temperature. In the Ledgemont process (Ref 26 pps 182-192), oxygen is sparged through the water at 100-130 ^{o} C and 300 psi. In the Bureau of Mines process (Ref 26 pps 197-202), compressed air is used as the oxygen source in a water reactor. Reaction conditions are accordingly harsher. The required pressure is 500 to 1500 psi and the temperature is 150 ^{o} C to 200 ^{o} C. In the TRW-Meyers Ferric Sulfate process (Ref 26 ppps 162-181, Ref 40), ferric sulfate is added to the oxygenated water. The ferric sulfate acts as an oxygen carrier, promoting the reaction and reducing the process temperature and pressure. Typical conditions are 15 to 80 psi pressure and 90 ^{o} C to 130 ^{o} C temperature.

Reduction reactions:

In reduction systems the reduction of pyrite to hydrogen sulfide is accomplished with the addition of hydrogen and a reaction promoter. Besides those already mentioned in the section "Chemical Enhancement", there have been aqueous (steam based processes) in which water reacts with carbon and pyrite to form hydrogen sulfide, carbon monoxide, and carbon dioxide. All of these reactions require high temperatures (600 - 800 C) and high pressures (up to 1500 psi). (See, for example, Ref 16-pg 135 for note on a patent to Schroeder, U.S. Patent 4013426 march 22, 1977).

Basic systems:

Hot sodium hydroxide solutions can be used to leach out sulfur and form sodium sulfur compunds. In the Battelle hydrothermal process (Ref 26 pps 215-230 , Refs 57,58,59) , hot alkali solution is used without the presence of oxygen to form sodium sulfur compunds. These are then reacted with carbon dioxide to form carbonate compounds and hydrogen sulfide. The temperature is typically 200 to 300 C and the pressure is 25 psig. A similar reaction by Rengel and assigned to the U.S Dept of the Interior (U.S Patent 3993455 Nov 23 1976 see Ref 16 pg 174) uses dilute strong acids instead of CO2. Other processes based on caustic treatment all use high processing temperatures; eg, the TRW Gravimelt and Occidental Petroleum processes (Ref 16 pg 175).

One unusual basic process that is worth noting is the GE caustic-microwave process. In this process, coal is wetted with a 20 % sodium hydroxide solution. The coal is then irradiated briefly for 30 seconds, after which both pyritic and organic sulfur has formed sodium sulfides and hydroxide.(Ref 26, pg 203). The microwaves selectively heat and react the pyrite and sulfur compounds, and cause little decomposition of the coal. The coal is then slurried in water to remove the soluble sodium hydroxides. The main point of interest for the triboelectric work is the use of microwaves to locally heat the pyrite and force the reaction. As noted above, many of the coal reactions occur at elevated temperatures. Microwave irradiation might be useful for enhancing doping reactions which might not normally react. Note that one of the difficulties noted in Khoury's report is potential problems in large scale microwave system scale-up.

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Appendix C:

Data Bases Selected and DIALOG Selection Commands Used to Select Abstracts (Based on DIALOG online databases)

I. Chemical Abstracts

1. COAL (3A) SURFACE (W) CHEMISTRY
   4 Selected - 1 Reviewed

II. Claims/US Patents Abstracts

1. COAL(3N)(CLEAN? OR PYRIT?) AND (SEPARATION OR ELECTRIFICATION)
   23 Selected - 5 Reviewed

III. Compendex (Engineering Index)

1. CLEAN? (2N) COAL
   721 Selected - 73 Reviewed

2. COAL AND SURFACE () CHEMISTRY
   20 Selected - 2 Reviewed

3. PYRITE(N) ANALYSIS
   2 Selected - 0 Reviewed

4. TRIBOELECT? AND SEPARATION AND CHARGE?
   15 Selected - 4 Reviewed

5. FRICTION AND (ELECTRIFICATION OR CHARGE?)
   237 Selected - 4 Reviewed

IV. DOE Energy

1. (SEPARATION OR CLEAN?) AND FRICTION? AND (ELECTRIFICATION OR CHARGE?)
   14 Selected - 5 Reviewed

2. COAL AND FRICTION? AND (ELECTRIFICATION OR CHARGE?)
   15 Selected - 2 Reviewed

3. SURFACE()CHEMISTRY(3N)COAL OR SURFACE()CHEMISTRY AND PYRIT?
   21 Selected - 0 Reviewed

4. COAL()CHEMISTRY OR (COAL AND SURFACE(W)CHEMISTRY)
   60 Selected - 9 Reviewed

5. SEPARAT? AND FRICTION? AND (ELECTRIFICATION OR CHARGE?)
   19 Selected - 3 Reviewed

V. Energyline

1. FRICTION? AND (ELECTRIFICATION OR CHARG?)
   2 Selected - 0 Reviewed

VI. Pollution Abstracts

1. FRICTION? AND (ELECTRIFICATION OR CHARG?)
   4 Selected - 1 Reviewed

VII. World Patents Index

1. [FRICTION? AND (ELECTRIFICATION OR CHARGE?)]
   AND SEPARATE?
   56 Selected - 3 Reviewed

2. TRIBOELECT?
   12 Selected - 6 Reviewed

3. TRIOBOELECT?
   87 Selected - 2 Reviewed

4. COAL AND FRICTION? AND (ELECTRIFICATION OR CHARGE?)
   4 Selected - 1 reviewed

United States Patent [19]

Singewald et al.

[11] **3,941,685**

[45] **Mar. 2, 1976**

[54] **PROCESS FOR ELECTROSTATIC SEPARATION OF PYRITE FROM CRUDE COAL**

[75] Inventors: **Arno Singewald**, Kassel-Wilhelmshohe; **Gunther Fricke**, Neuhof, both of Germany

[73] Assignee: **Kali und Salz Aktiengesellschaft**, Kassel, Germany

[22] Filed: **Aug. 15, 1974**

[21] Appl. No.: **497,636**

[52] **U.S. Cl.** .... **209/9; 209/127 R**
[51] **Int. Cl.**^{2} **B03B 1/04**
[58] **Field of Search** .... **209/9, 11, 127 R, 127 A, 209/127 B, 127 C, 2**

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3,225,924	12/1965	Autenrieth	209/9
3,835,996	9/1974	Singewald et al.	209/9

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744,805	11/1943	Germany	209/127 R
870,832	7/1949	Germany	209/127 R
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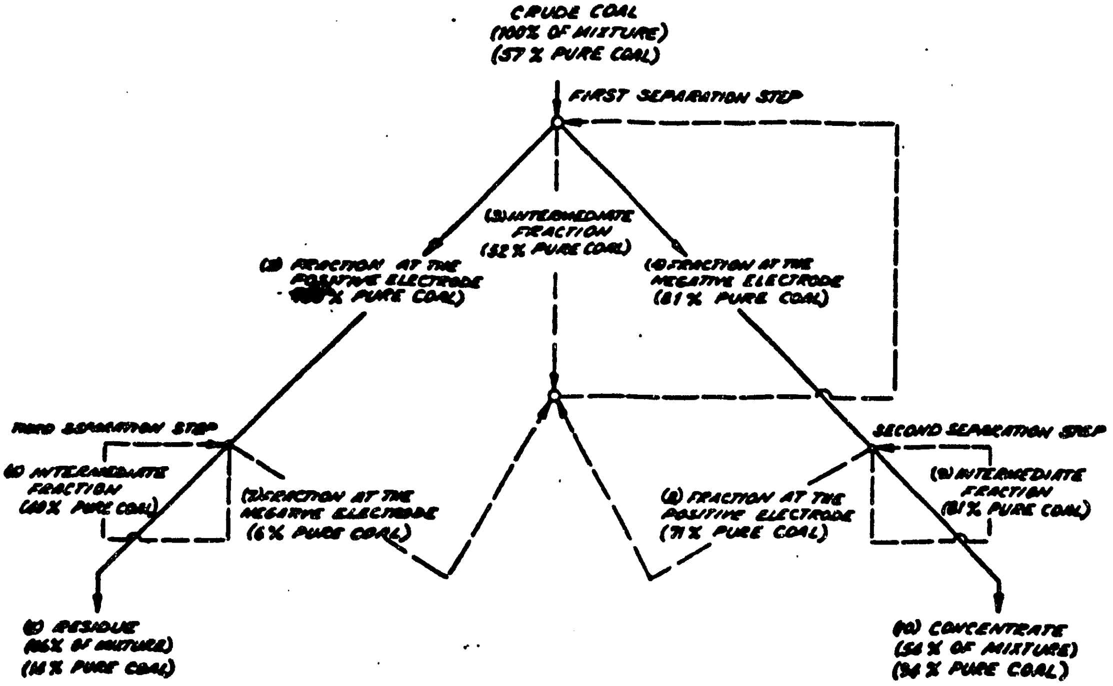
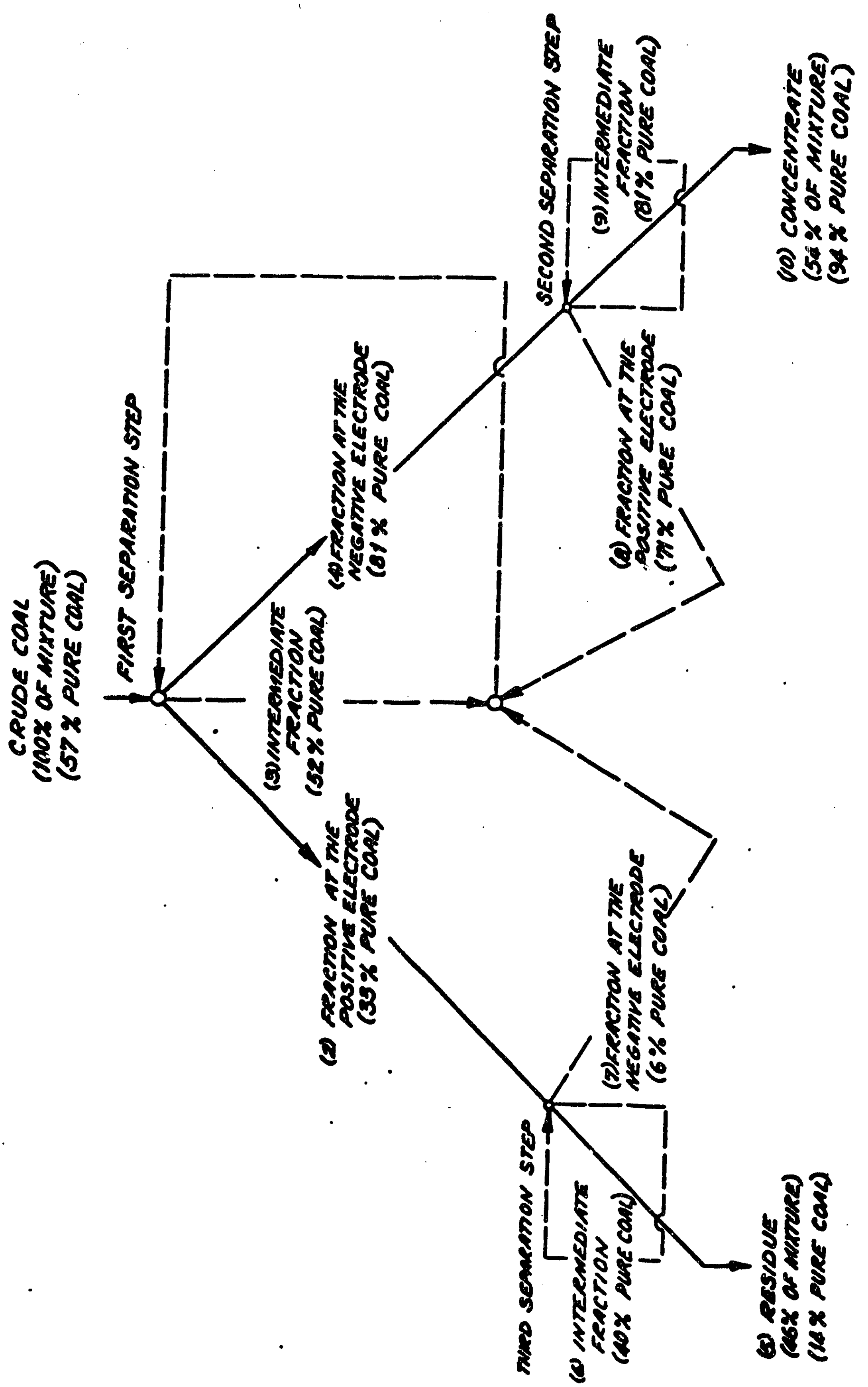
Primary Examiner—Robert Halper
Attorney, Agent, or Firm—Haseltine, Lake & Waters

[57] ABSTRACT

An improved process is disclosed for electrostatic separation of pyrite from powdered crude coal comprising vigorously mixing the powdered crude coal with a selected fatty acid glyceride as a conditioning substance and conducting the electrostatic separation at a relative humidity of 2.5–20% and a temperature between room temperature and 100° C. In a multiple stage process yields of purified coal substantially greater than those of prior art processes can be obtained.

12 Claims, 1 Drawing Figure




CRUDE COAL
(100% OF MIXTURE)
(57% PURE COAL)
FIRST SEPARATION STEP
(2) FRACTION AT THE POSITIVE ELECTRODE (35% PURE COAL)
(3) INTERMEDIATE FRACTION (52% PURE COAL)
(4) FRACTION AT THE NEGATIVE ELECTRODE (81% PURE COAL)
SECOND SEPARATION STEP
(9) INTERMEDIATE FRACTION (81% PURE COAL)
(8) FRACTION AT THE POSITIVE ELECTRODE (71% PURE COAL)
(10) CONCENTRATE (54% OF MIXTURE) (94% PURE COAL)
THIRD SEPARATION STEP
(6) INTERMEDIATE FRACTION (40% PURE COAL)
(7) FRACTION AT THE NEGATIVE ELECTRODE (6% PURE COAL)
(5) RESIDUE (46% OF MIXTURE) (14% PURE COAL)

PROCESS FOR ELECTROSTATIC SEPARATION OF PYRITE FROM CRUDE COAL

BACKGROUND OF THE INVENTION

A current goal of coal technology is to separate pyrite and coal from one another to prepare a coal of the greatest possible purity.

German Patent No. 744,805 discloses a process for electrostatic separation of mixtures of coal and ore by applying an oily wetting agent to increase the surface resistance of at least a portion of the mixture. The wetting agent also has the purpose of increasing the adhesion of the wetted separable material to the wetted electrode. The oil used is not further described as to its chemical composition. The separation of the components relies on the conductivity difference between the components which is produced or enhanced by the wetting agent and not on the contact electric charge of the components as in the process of this invention.

The process of this invention uses a different method of solving the problem which has significant technical advantages.

U.S. Pat. No. 3,073,447 discloses an electrostatic beneficiation of crude potassium salts containing langbeinite into a sylvine concentrate, using known potassium chloride selective reagents, and a langbeinite concentrate using langbeinite-selective reagents at a temperature between 40° and 150°C. Table 1, line 15, shows that sylvine is also recovered by separation using glycerine esters of fatty acids at 60°C., a method which, in comparison to other potassium chloride specific methods, shows a very poor yield of K_2O. According to the process of this invention, no glycerine esters of fatty acids are used but rather selected glycerides of stearic, palmitic, oleic, linoleic, and linolenic acids.

In contrast with the above technology, the process of this invention uses other conditioning substances and produces a surprisingly selective separation. A coal concentrate containing over 80% pure coal is attained with a yield of at least 80%.

Various authors have addressed themselves in "Aufbereitungs-Technik" (No. 4/1970, pages 207–220) to the problem of separation of pyrite from coal dust in electric and magnetic fields.

The separation was undertaken in the electrodynamic field of a cylindrical separator at a temperature between 14° and 34°C. and relative humidity of 20–90%. As conditioning substances for altering the conductivity, HNO_3, H_2SO_4, H_2O_2, and KM_2PO_4 were employed. The report states concerning the separation results:

"From a complete review of all the results, which were obtained in numerous experiments with the electrodynamic cylindrical separator, it was abandoned, since the separation results in all experiments — even in the case of the most favorable assumptions about raw materials — were unsatisfactory."

These investigations did not suggest the conditioning means used in the process of this invention. Rather, the prior technology proceeded in an entirely different direction in which separations were made using differences between conductors and non-conductors and not by means of contact electric charges. These processes have the disadvantage of a low specific output of the cylindrical separator, since the electric field for charging and separation must come in contact with each mineral particle at the charging electrode for the purpose of charging and charge equalization.

SUMMARY OF THE INVENTION

According to the process of this invention which operates with contact electric charges, the electric field serves only for separating components according to their charge. The specific throughput of the process of the invention is greater by a factor of 40 than that of the above scheme according to present technology.

A process for electrostatic separation of pyrite from crude coal at a temperature from room temperature to about 100°C. has now been found in which the powdered crude coal is vigorously mixed with glycerides of the high and middle saturated and unsaturated fatty acids as conditioning substances for between 10 seconds and 30 minutes, and at relative humidity of about 2.5 to 20% is separated by known procedures in one separation step into a first purified coal concentrate containing over 80% purified coal with a yield of at least 80% and a first residue, and a first intermediate fraction is recovered which may be recycled into the starting material.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A process has further been found in which mono-di-, and tri-glyceride esters of stearic, palmitic, oleic, linoleic, and linolenic acids are used as conditioning substances in quantities of about 100–200 grams per ton of crude coal, preferably 200–500 grams per ton, and the separation of the material is carried out at 30°–60°C. at a relative humidity of 5–15%. Furthermore, a process has been discovered in which the first purified coal concentrate, without reconditioning and without heating, is separated in a second separation step into a second purified coal concentrate with over 90% pure coal and with a yield of at least 90%, a second residue which is recycled into the starting material and a second intermediate fraction which is recycled into the first purified coal concentrate. By way of example, crude coal of the following particle size is used for the separation according to the process of this invention:

Particle Size (mm)	%
larger than 1.0	2.0
1.0 – 0.8	2.7
0.8 – 0.5	15.3
0.5 – 0.25	33.0
0.25 – 0.16	22.7
0.16 – 0.1	14.1
smaller than 0.1	10.2

The material for purification contains about 57% pure coal. The pyrite content is about 4.3%, the silica content about 8.3%, and the total sulfur content about 2.8%. This crude coal was separated at a relative humidity of 5% and a temperature of 58°C. in a free falling plate-type separator with a throughput of 5 tons per hour at a field strength of 4 Kilovolts per centimeter. 500 grams of conditioner were used per ton of crude coal.

The results of the separation are shown in the following table for one stage of separation. The intermediate fraction is the difference between the initial material (100%) and the total of concentrate and residue. The time of mixing of the conditioning material with the starting material was about 1 minute.

Example No.	Conditioning Substance	Concentrate (Fraction at the negative electrode Percent of Mixture	Concentrate Concentration of Pure Coal (%)	Residue (Fraction at the positive electrode) Percent of Mixture	Residue Concentration of Pure Coal (%)
1	Vegetable oil	26	81	30	27
2	Bone oil	32	78	32	31
3	Peanut oil	32	84	31	29
4	Olive Oil	35	84	33	27
5	Glycerine and Oleic acid	35	85	34	29
6	Poppy-seed oil	27	86	33	32
7	Sunflower oil	28	84	35	36
8	Castor oil	34	85	32	29
9	Monoolein	31	81	33	33
10	Monostearin	29	78	30	31
11	Tripalmitin	28	84	35	28
12	Tristearin	30	84	34	29

The following examples show the dependence of the degree of separation on the proportion of conditioning material for the same starting material at 43°C. and a relative humidity of 10% using olive oil as the conditioning means.

Example No.	Conditioner grams/ton	Concentrate (Fraction at negative electrode) Fraction of Mixture (%)	Concentrate Pure Coal (%)	S (%)	Residue (Fraction at positive electrode) Fraction of Mixture (%)	Residue Pure Coal (%)	S (%)
13	2,000	36	87	1.3	30	30	4.0
14	1,000	31	87	1.3	32	30	4.0
15	500	27	86	1.4	33	37	3.8
16	250	28	84	1.5	32	30	4.0

These results establish that the separation results are already attained with proportions of 200–500 grams per ton of conditioning material.

The further separation in the second and third separative steps is described in the following examples and illustrated in the flowsheet shown in the drawing.

The material to be beneficiated 1 is separated in the first step into three fractions, of which the first intermediate fraction 3 is recycled in a continuous process. The concentrate separated at the negative electrode and the residue falling at the positive electrode are separated without further conditioning, in a second and a third separation steps in which likewise three fractions are separated. The intermediate fractions in the second and third steps 6 and 9 are likewise recycled in the same separation step while the fractions 7 and 8 together with the intermediate fraction 3 are led back to the first separation step.

Typically, from a crude coal comprising 100% mixture, in a continuous process which comprises recycling of the intermediate fractions, the following products are obtained: 54% of the mixture as concentrate 10 containing 94.7 pure coal, 46% of the mixture as residue 5 containing 14% pure coal. The yield of pure coal amounts to about 88%.

We claim:

1. A process for electrostatic separation of particles of pyrite from powdered crude coal in a mixture thereof at a temperature between room temperature and 100°C, by contact electrification of said particles, comprising

a. vigorously mixing said particles with a conditioning substance comprising glycerides of high and middle saturated and unsaturated fatty acids for a period of between 10 seconds and 30 minutes and in quantities of about 100–2000 grams per ton of powdered crude coal, thereby to form conditioned electrified particles thereof in said field, and

b. separating said conditioned electrified particles in an electric field produced by a free falling plate type separator according to their charge at a relative humidity of about 2.5–20% whereby there is obtained a first purified coal concentrate, a first residue containing the greater portion of the pyrite, and an intermediate fraction.

2. An improved process according to claim 1, wherein said intermediate fraction is recycled into the initial powdered crude coal.

3. An improved process according to claim 1, wherein said glycerides are selected from the group consisting of the mono-, di- and tri-glyceride esters of stearic, palmitic, oleic, linoleic, and linolenic acids.

4. An improved process according to claim 1, wherein said glycerides are used in quantities of 200–500 grams per ton of powdered crude coal.

5. An improved process according to claim 1, wherein the separation is carried out at a temperature of 30°–60°C.

6. An improved process according to claim 1, wherein the separation is carried out at a relative humidity of 5–15%.

7. An improved process accroding to claim 1, wherein the first purified coal concentrate without further conditioning is separated in a second separation step into a second purified coal concentrate, a second residue, and a second intermediate fraction.

8. An improved process according to claim 7, wherein said second intermediate fraction is recycled into said first purified coal concentrate.

9. An improved process according to claim 7 wherein said second residue is recycled into said powdered crude coal.

10. An improved process according to claim 1, wherein said first residue without further conditioning is separated in a third separation step into a third purified coal concentrate, a third intermediate fraction, and a third residue.

11. An improved process according to claim 10 wherein said third intermediate fraction is recycled into said first residue.

12. An improved process according to claim 10 wherein said third purified coal concentrate is recycled into the powdered crude coal.

* * * * *

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