QUARTERLY REPORT NO. 7

For

ENGINEERING DEVELOPMENT OF ADVANCED PHYSICAL FINE COAL CLEANING TECHNOLOGIES -

FROTH FLOTATION

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PITTSBURGH ENERGY TECHNOLOGY CENTER
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***ICF KAISER
ENGINEERS***

With

Ohio Coal Development Office

Babcock & Wilcox

Consolidation Coal Company

Center for Research on Sulfur In Coal

EIMCO Process Equipment Company

Illinois State Geologic Survey

Kentucky Energy Cabinet Laboratory

Virginia Polytechnic Institute & State University

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QUARTERLY TECHNICAL PROGRESS REPORT NO. 7

FOR PERIOD

APRIL 1, 1990, THROUGH JUNE 30, 1990

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TABLE OF CONTENTS

	<u>PAGE</u>
1.0 INTRODUCTION	
1.1 Scope of this Document	1
1.2 Overall Project Scope	1
1.3 Work Executed at Different Locations	3
1.4 Work Undertaken During the First Six Quarters	4
2.0 TASK 2 PRELIMINARY CONCEPTUAL DESIGN	
2.1 Overview and Scope	7
2.2 Review of Work Completed This Quarter	8
3.0 TASK 3 CRITICAL AREA DETERMINATION	
3.1 Overview and Scope	8
3.2 Review of Work Completed This Quarter	8
4.0 TASK 4 TEST PLAN FORMULATION	
4.1 Overview and Scope	8
4.2 Review of Work Completed This Quarter	10
5.0 TASK 5 BENCH-SCALE PROCESS TESTING	
5.1 Overview and Scope	10
5.2 Review of Work Completed This Quarter	11
5.2.1 Raw Coal Characterization - Illinois #6	11
5.2.2 Advanced Flotation Round Robin	16
5.2.3 Bench Scale Process Testing	29
6.0 TASK 6 COMPONENT AND UNIT OPERATIONS DEVELOPMENT	
6.1 Overview and Scope	57
6.2 Review of Work Completed This Quarter	57
6.2.1 Optimum Column Cell Development Test Work	57
6.2.2 Optimum Column Cell Circuit Configuration	77
6.2.3 Column Cell Flotation Model Development	78

LIST OF FIGURES

<u>FIGURE</u>	<u>TITLE</u>
1.1	Project Organization Chart
5.1	B&W Bench Scale Process Testing Flowsheet
5.2	PTI Bench Scale Process Testing Flowsheet
5.3	Pyrite Liberation Test
5.4	Carrying Capacity Curve
5.5	Classifying Cyclone Recovery Curve for Lots 2 and 3
5.6	Mass Balance for 48M x 200M Rougher Flotation Lot 2
5.7	Mass Balance for 200M x 0 Rougher Flotation Lot 2
5.8	Mass Balance for 48M x 200M Rougher Flotation Lot 3
5.9	Mass Balance for 200M x 0 Rougher Flotation Lot 2
5.10	Effect of Flow Rate - Stirred Ball Mill, Pittsburgh #8, Lot 1
5.11	Effect of RPM - Stirred Ball Mill, Pittsburgh #8, Lot 1
5.12	Effect of Solids - Stirred Ball Mill, Pittsburgh #8, Lot 1
5.13	Effect of Mill Charge - Stirred Ball Mill, Pittsburgh #8, Lot 1
5.14	Effect of Flow Rate - Stirred Ball Mill, Pittsburgh #8, Lot 2
5.15	Effect of RPM - Stirred Ball Mill, Pittsburgh #8, Lot 2
5.16	Effect of Solids - Stirred Ball Mill, Pittsburgh #8, Lot 2
5.17	Size Analysis of Optimum Stirred Ball Mill Product
5.18	Pittsburgh #8 Mass Balance - 2nd Lot
5.19	Pittsburgh #8 Mass Balance - 3rd Lot
6.1	Yield, Product Ash and Product Sulfur Obtained for Each of the Replicate Tests Conducted Throughout the Parametric Testing Program
6.2	BTU Recovery and Combustible Recovery as a Function of Ash Rejection For All of the Test Conditions Examined in the Parametric Study
6.3	BTU Recovery and Combustible Recovery as a Function of Total Sulfur Rejection For All of the Test Conditions Examined in the Parametric Study
6.4	Combustible Separation Efficiency and Overall Separation Efficiency as a Function of Ash Rejection for All of the Test Conditions Examined in the Parametric Study
6.5	Combustible Separation Efficiency and Overall Separation Efficiency as a Function of Total Sulfur Rejection for All of the Test Conditions Examined in the Parametric Study
6.6	Relationship Between Ash Rejection and Total Sulfur Rejection For Test Results Obtained During the Parametric Study
6.7	Comparison of Experimental Results With Predictions Made by the Empirical Model Developed to Describe Combustible Recovery as a Function of the Various Operating Parameters
6.8	Comparison of Experimental Results With Predictions Made by the Empirical Model Developed to Describe Product Ash Content as a Function of the Various Operating Parameters
6.9	Comparison of Experimental Results With Predictions Made by the Empirical Model Developed to Describe Product Sulfur Content as a Function of the Various Operating Parameters
6.10	Comparison of Experimental Results With Predictions Made by the Empirical Model Developed to Describe the Separation Efficiency of Combustibles from Ash as a Function of the Various Operating Parameters

6.11 Regression Surface Plot Demonstrating the Influence of Air Hold-Up
(a Measure of Bubble Size) and Retention Time (a Measure of
Throughput Capacity) on Combustible Recovery

LIST OF TABLES

<u>TABLE</u>	<u>TITLE</u>
1.1	Task and the Responsible Team Member
5.1	Flotation Performance Results Phase II
5.2	Froth Flotation Process Variable Phase II
5.3	Required Clean Coal and Raw Coal for Economic Evaluation
5.4	Common Equipment and Reagent Costs
5.5	Frother Concentration
5.6	Economic Parameters
5.7	Final Evaluation Ranking
5.8	Coarse Hydrocyclone Analysis of Lots 2 and 3
5.9	Fine Hydrocyclone Analysis of Lots 2 and 3
5.10	200m Classifying Cyclone Analysis for Lot 2
5.11	48M x 200M and 200M x 0 Rougher Flotation Analysis for Lot 2
5.12	Rougher Flotation BTU Recovery for Lot 2
5.13	48M x 200M and 200M x 0 Rougher Flotation Analysis for Lot 3
5.14	Rougher Flotation BTU Recovery for Lot 3
5.15	Shakedown Stirred Ball Mill Test Matrix
5.16	Stirred Mill Test Matrix
6.1	Standard Conditions Used for Parametric Test Program
6.2	Test Levels Utilized in the Parametric Test Program
6.3	Parametric Test Plan Utilized in the Advanced Flotation Optimization Studies
6.4	Summary of Test Results Obtained During the Parametric Testing of the Advanced Flotation Cell
6.5	Estimated Values of Standard Deviation for Various Assays Used in Parametric Test Work

1.0 INTRODUCTION

A study conducted by Pittsburgh Energy Technology Center of sulfur emissions from about 1,300 United States coal-fired utility boilers indicated that half of the emissions were the result of burning coals having greater than 1.2 pounds of SO_2 per million BTU. This was mainly attributed to the high pyritic sulfur content of the boiler fuel. A significant reduction in SO_2 emissions could be accomplished by removing the pyrite from the coals by advanced physical fine coal cleaning.

An engineering development project was prepared to build upon the basic research effort conducted under a solicitation for research into Fine Coal Surface Control. The engineering development project is intended to use general plant design knowledge and conceptualize a plant to utilize advanced froth flotation technology to process coal and produce a product having maximum practical pyritic sulfur reduction consistent with maximum practical BTU recovery.

1.1 Scope of this Document

The Department of Energy (DOE) awarded a contract entitled "Engineering Development of Advanced Physical Fine Coal Cleaning Technology - Froth Flotation", to ICF Kaiser Engineers with the following team members, Ohio Coal Development Office, Babcock and Wilcox, Consolidation Coal Company, Eimco Process Equipment Company, Illinois State Geological Survey, Virginia Polytechnic Institute and State University, Process Technology, Inc. The organizational chart for this project is presented in Figure 1.1.

This document is the seventh quarterly report prepared in accordance with the project reporting requirements covering the period from April 1, 1990 to June 30, 1990. This report provides a summary of the technical work undertaken during this period, highlighting the major results. A brief description of the work done prior to this quarter is also provided in this report.

1.2 Overall Project Scope

The overall project scope of the engineering development project is to conceptually develop a commercial flowsheet to maximize pyritic sulfur reduction at practical energy recovery values. This is being accomplished by utilizing the basic research data on the surface properties of coal, mineral matter and pyrite obtained from the Coal Surface Control for Advanced Fine Coal Flotation Project, to develop this conceptual flowsheet. The conceptual flowsheet must be examined to identify critical areas that need additional design data. This data will then be developed using batch and semi-continuous bench scale testing. In addition to actual bench scale testing, other unit operations from other industries processing fine material will be reviewed for potential application and incorporated into the design if appropriate.

The conceptual flowsheet will be revised based on the results of the bench scale testing and areas will be identified that need further larger scale design data verification, to prove out the design. The

Figure 1-1: Project Organization Chart

proof of concept will be accomplished by designing, constructing, operating and testing a 2-3 ton per hour proof-of-concept plant. This plant will be designed for continuous operation and will include two consecutive 5 days, 24 hour per day runs on each of the three test coals to demonstrate process performance on a commercial basis.

The data from the basic research on coal surfaces, bench scale testing and proof-of-concept scale testing will be utilized to design a final conceptual flowsheet.

The economics of the flowsheet will be determined to enable industry to assess the feasibility of incorporating the advanced fine coal cleaning technology into the production of clean coal for generating electricity. This concept should provide an ability to reduce sulfur oxide emissions more economically than FGD systems when compared on a dollar per ton of sulfur removed basis.

1.3 Work Executed at Different Locations

The project team consists of research and engineering groups at ICF Kaiser Engineers, Babcock and Wilcox, Consolidation Coal Company, Eimco Process Equipment Company, Illinois State Geological Survey, Virginia Polytechnic Institute and State University, Process Technology, Inc. and Michigan Technological University Institute of Materials Processing with ICF Kaiser Engineers as the prime contractor with DOE. The work being conducted by different organizations is based upon their area of expertise and this has been incorporated into the project Work Plan. The work undertaken by the different organizations is identified in Table 1.1. This report is prepared in an integrated manner combining work done by each organization by task. This is considered to be a more effective way of presenting the technical data developed by each organization.

TABLE 1.1
TASKS AND THE RESPONSIBLE TEAM MEMBERS

Task 1	Project Planning	KE
Task 2	Preliminary Conceptual Design	KE, B&W, EIMCO, TSG, TAC
Task 3	Determination of Critical Areas	KE, B&W, EIMCO, TSG, TAC
Task 4	Test Plan Formulation	KE, B&W, EIMCO, TSG
Task 5	Bench Scale Testing	KE, B&W, EIMCO, PTI, TSG, TAC
Task 6	Component Development	VPI, TSG
Task 7	Analysis of Test Results	KE, B&W, EIMCO, VPI, TSG
Task 8	Revised Conceptual Design	KE
Task 9	POC Module Design	KE, B&W, EIMCO, TSG, TAC
Task 10	POC Procurement and Fabrication	KE
Task 11	POC Installation and Startup	KE, B&W, EIMCO, TSG
Task 12	POC Test Plan Formulation	KE, B&W, EIMCO, TSG, TAC
Task 13	POC Testing and Operation	KE, B&W, EIMCO, TSG
Task 14	Analysis of POC Test Results	KE, B&W, EIMCO, TSG
Task 15	Final Conceptual Design	KE, B&W, EIMCO, TSG
Task 16	POC Module Removal	KE

The project progress is being maintained based on verbal authorization from DOE. The project is approximately four months behind schedule. All the DOE reporting requirements of technical, cost, and labor reports, except the technical report for Task 2 were generally met on schedule.

1.4 Work Undertaken During the First Six Quarters

Progress was made in the previous six quarters (October 1, 1988 to March 31, 1990). As presented in the previous quarterly reports, the major accomplishments were:

- Contract award on September 27, 1988.
- ICF KE Team Project Kickoff meeting on October 14, 1988.
- Submittal of Draft Work Plan on November 4, 1988.
- DOE Project Kickoff meeting on November 9, 1988.
- Submittal of Final Work Plan and Draft QA/QC Plan on December 23, 1988.
- Subcontracts awarded to B&W, Consol, Eimco, and VPI.
- ICF KE project review meeting held at PETC on January 30.
- ICF KE team review meeting of February 7, 1989 to review conceptual design.
- Completion of Task 2 and Task 3 reports.
- Surface Control Project review meeting on March 30 attended by ICF KE.
- Submittal of Cost and Labor Plans and three monthly Cost and Labor Reports.
- Completion and submittal of revised reports for Task 2 and Task 3.
- Completion submittal and approval of Round Robin plan and Coal Procurement Plan.
- Choice of Peabody Coal as supplier of Illinois #6 coal.
- Receipt of 1600 pounds of Pittsburgh #8 coal at B&W from Praxis, one of the Surface Control Program subcontractors.
- Completion of fabrication and installation of optimized column cell and three circuit configuration cells at VPI.
- Attended project review meeting at PETC for UCB Surface Control Program.

- Completed revised Task 2 report and submitted to DOE and EOS.
- Compared raw coal sample analysis data with UCB data and verified that no further oxidation occurred since original sample was prepared.
- Continued work on column cell simulator.
- Preliminary grinding work at B&W.
- Testing of sample received from Praxis confirmed that it was Pittsburgh #8 coal and that no further oxidation had occurred which impacted the coal's flotation potential.
- Issued five purchase orders for Round Robin participation.
- Prepared and discussed answers to Task 2 questions. Revised Task 2 report.
- Continued preliminary grinding work at B&W and shipped samples to EPRI for washability analysis and to VPI for pyrite particle size analysis.
- Team members reviewed and critiqued the Task 4 report.
- Dr. S.Y. Shiao of B&W visited UBC to observe testing and to discuss significant results of surface modification work.
- Met with TPO to discuss Task 2 and present final approved version of report. Submitted Task 4 draft report and Task 3 revised report for final approval.
- Received EPRI washability analysis and VPI pyrite particle size analysis for two preliminary samples at different grinding times.
- The base coal sample (Pittsburgh #8) was taken September 7, 1989 at Ohio Valley Coal. The lab homogenized the sample, made a split for analyses, shipped to B&W in inerted drums.
- B&W completed and shipped coal to the round robin participants. Each shipment contained 120 pounds of coal crushed to 1/4" top size and 40 pounds of coal in a 35% solids concentration slurry. Each participant received the sample preparation details and the inerting procedure used by B&W.
- B&W received approximately 12 tons of Ohio Valley's Pittsburgh #8 raw coal from Belmont County, Ohio.
- Detailed sample analyses were sent to Round-Robin participants including PSD, washability, pH, ash, total sulfur, pyritic sulfur and Btu.
- ICF KE process engineers visited all round-robin participants except Deister and Allmineral to witness one round-robin test.

- TraDet, Inc. completed the laboratory work on the Head Sample for the Pittsburgh #8 raw coal.
- B&W received the Krebs portable hydrocyclone rig and the Denver 4-cell flotation machine and installation is completed.
- ICF KE presented a paper at the EPRI workshop on September 25, 1969.
- B&W completed preliminary runs and setup of first and second-stage hydrocyclone.
- B&W performed several lab flotation tests and several preliminary runs on the conventional flotation cells to determine reagent dosage levels.
- A technical Support Group meeting was held on January 10 to discuss budgets and schedules for Task 5 work in progress.
- B&W completed preliminary runs and setup of continuous conventional flotation rig.
- B&W completed a continuous test run on the conventional cells and produced seven drums of material that were shipped to VPI for use in Task 6.
- Data from the fourth round robin test was submitted by participants and was analyzed by ICF KE and other team members.
- B&W and VPI worked on budgeting changes to Task 5 in an attempt to reduce costs and improve schedule.
- B&W completed preliminary runs and setup of 2" diameter advanced flotation rig.
- B&W began the bench-scale microgrinding tests.
- Several runs were made to grind to 325M x 0 and the 2" column was set up and operated at various conditions to zero in on a standard set of operating conditions.
- VPI submitted budgeting estimates for Task 5 in an attempt to reduce costs and improve schedule.
- ICF KE halted B&W work on continuous flotation in conventional cells pending an agreement in work scope modifications.
- ICF KE presented a technical paper entitled "Advanced Froth Flotation - An Effective Tool for Reducing An Acid Rain Precursor?" at the annual AIME meeting.
- ICF KE restarted B&W work on continuous flotation in conventional cells on the Pittsburgh #8 coal. B&W completed the preliminary testing on the grab run, split flotation.

- VPI completed, for B&W, a CCSEM analysis of pyrite particle size distribution in a 4" lump of new Pittsburgh #8 coal.
- ICF KE continued preparation of Topical Reports for the pyrite liberation study and for the round robin program.
- B&W continued work on continuous flotation in conventional cells on the Pittsburgh #8 coal.
- B&W conducted the continuous microgrinding tests.
- Analyses of the final bench-scale microgrinding flotation tests were released.
- ICF KE continued preparation of the Topical Report for the pyrite liberation study and completed the Round Robin Technical Report.
- Negotiations began with Process Technology, Inc. in conjunction with Michigan Tech Institute of Mineral Processing to test Illinois No. 6 and Upper Freeport Coal. This was begun in order to improve the schedule and contain costs.

2.0 TASK 2 PRELIMINARY CONCEPTUAL DESIGN

2.1 Overview and Scope

The previous completion of this task resulted in the preliminary conceptual design of a 20TPH semi-works advanced froth flotation facility. The non-site-specific plant was designed using the best available information and technology to achieve continuous, steady-state process operation with 90% availability. The process plant is a fully instrumented, integrated, stand-alone facility. A greenfield site was assumed for the plant.

Throughout the project, the work was organized along a task/sub-task basis with each sub-task logically assigned to provide necessary information for the next sub-task, ultimately resulting in completion of the conceptual design. For Task 2, the first sub-task determined the design criteria needed to meet or exceed the advanced froth flotation process specifications. At completion, work under this sub-task provided information to design the flowsheet of the process, and provided an energy and material balance of all process streams. A list of all major process equipment was prepared and used as a basis for a factored estimate for the capital, operating and maintenance costs of the semi-works process and plant.

ICF Kaiser Engineers, assisted by the project sub-contractors and Technical Support Group, was responsible for the performance and completion of this task. This conceptual design is the basis for Tasks 3, 4, 5, and 6 and will be revised in Task 8 for use as a basis for the 2-3TPH POC module designs in Task 9.

2.2 Review of Work Completed This Quarter

On August 15, 1989, DOE approved Task 1.2 as submitted. With this as a basis, ICF KE and the team members proceeded with the remainder of the project. No additional work was planned nor completed during this quarter.

3.0 TASK 3 CRITICAL AREA DETERMINATION

3.1 Overview and Scope

Work performed during the conceptual design of Task 2 identified areas where uncertainties exist in the design of the unit operations for the advanced froth flotation process. Some of these problem areas could not be solved based on currently available information or technology. The objective of this task was to determine those critical areas where more information would be necessary and outline the work needed to obtain the design information.

A design deficiency list was generated, and the project team determined the parameters needed for final design of the unit operation - either by further engineering analysis or by experimental data obtained from bench-scale tests. Other solids processing industries, such as phosphate and clay beneficiation, were examined to assess the means by which they effectively process ultra fine particles.

Each identified design deficiency was then ranked according to its relative importance to the successful continuous operation of the advanced froth flotation process. Both a technical and economic analyses of the consequences of not being able to gather the required design information for each deficiency was evaluated.

ICF Kaiser Engineers, Consolidation Coal and the other members of the Technical Support Team (B&W, VPI and EIMCO) have contributed to this task. The process deficiencies identified in this task will be addressed in Tasks 4, 5, and 6 through additional engineering computation and analysis and experimental techniques.

3.2 Review of Work Completed This Quarter

The second draft of this task report has been submitted to DOE for approval. As of the date of this quarterly report ICF KE has received only verbal approval of the task report. No additional work was planned nor completed during this quarter.

4.0 TASK 4 TEST PLAN FORMULATION

4.1 Overview and Scope

Work completed in this task produced the criteria for additional engineering analysis, computation and detailed experimental bench-scale testing for areas of uncertainty identified in Task 3. The engineering analysis, computation, bench-scale testing and component

development was formulated to produce necessary design information to define a commercially operating system.

In order to produce the required information by means of bench-scale testing and component development, a uniform coal sample was procured. After agreement with DOE, a selected sample of coal from those previously listed was secured.

The test plan was developed in two parts. The first part listed procedures for engineering and computational analyses of those deficiencies previously identified that could be solved without bench scale testing. Likewise, the second part prepared procedures for bench-scale testing and component development for those deficiencies previously identified in Task 3.

The first part, engineering analysis and computation, provided for means of employing presently know theory from other industries to address deficiencies. This included examinations of literature and contacting proven experts and operating personnel in fields related to this deficiency. From the information gathered, engineering calculations will be utilized to resolve this type of deficiency.

The second part, bench-scale testing and component development, became necessary when the part one information was unavailable or when the theory had never been commercially applied. Justification for the test work was provided to show that technical data and process needs could only be obtained by test work and that the test work results would produce necessary information to define a commercially operating system.

The test work planned was based upon non-continuous and/or semi-continuous bench-scale units of general laboratory design and would include only those unit operations identified as deficiencies in Task 3.

The detailed, quantified tests addressed obtaining data necessary for solving problems uncovered in the deficiency review. Each identified deficiency had a plan developed to address the reason for the testing, the means for the test matrix to obtain results and the expected results. Each test plan established procedures, adhering as much as possible, to known and industry-acceptable procedures for sampling and data collection. Raw data collection would be reduced to minimize expenses and to better be able to compare results and obtain meaningful information, especially scale-up factors.

The Development Test Plan for both parts one and two contained schedules, manpower requirements, and resources necessary to obtain information to define a commercially available system.

The plan for use of the team members was developed to comply with the results of the DOE uniform coal sample procurement and storage procedures. The quantity of coal necessary for each testing program was calculated. A sample of all three of the referenced coals was to be obtained, preferably from the same source as the Surface Control contractor. This coal would be stored and handled as

outlined in the coal procurement and storage plan. These procedures, when properly followed, should minimize physical and chemical changes to the raw coal.

A common database for all data generated throughout the entire program was to be developed. The DOE and all team members can access the database via modem at any time to view results of the research completed. Special passwords will allow access to individual team members to write data to the file. No other team member will be permitted to alter that input.

ICF Kaiser Engineers is developing the database and determining the logistics of data entry or data viewing. ICF KE will maintain the system throughout the program and provide technical answers to user questions that arise. The QA/QC plan discusses the precautions KE will take to protect the data and the system.

4.2 Review of Work Completed This Quarter

The Task 4 Report was submitted to DOE as a draft which at the time of this quarterly report has been verbally approved. Two portions of the test plan have received written approval but all work has been started.

5.0 TASK 5 BENCH-SCALE PROCESS TESTING

5.1 Overview and Scope

The overall goal of Task 5, "Bench-Scale Process Testing" is to develop the necessary unit operation design and process performance data required to 1) reduce or eliminate the technical and engineering uncertainties of the preliminary 20TPH advanced location semi-works plant and 2) design, build and operate a 2-3 TPH advanced flotation POC module.

The unit operation performance and process design information required to support development of the advanced flotation process is being examined in a multi-tier program at B&W and Process Technology, Inc. Laboratory scale studies are being conducted in several key process areas - conventional precleaning of the raw coal, microgrinding of the pre-cleaned coal, advanced froth flotation of the fine coal and dewatering of the product streams. The results of these studies are then being used to guide small, semi-continuous and continuous testing of the key unit operations at approximately 100 lb/hr.

The bench-scale and semi-continuous process design evaluation test programs will provide detailed information for developing process material and energy balances. The material balance data will be used to correctly design and size the equipment for the POC module. The energy balance information will allow for estimation the cost effectiveness of the design.

The bench-scale test programs will also identify the optimum conditions for microgrinding the coal for maximum pyritic sulfur rejection in advanced flotation and the most promising advanced flotation technique which will then be integrated into the overall processing scheme. The 100 lb/hr test program will provide verification of the laboratory tests results and demonstration that these results can be scaled-up for application in the 20TPH semi-works plant design.

Both the bench-scale, semi-continuous and continuous process design evaluation tests will serve as critical reviews of the preliminary process flowsheet. Process deficiencies and limitations discovered in these programs will require modification of the original conceptual flowsheet. This information will aid in identifying solutions to the successful implementation of advanced flotation technology.

The bench-scale and process testing consists of eleven major subtasks performed over a period of 12 months. The Bench-Scale Process Testing "Flowsheets" shown on Figure 5.1 and 5.2, illustrate the relationships between these subtasks. It should be noted that some subtasks are not sequential and there is some overlap in the timing of these activities.

5 2 Review of Work Completed This Quarter

Two portions of Task 5 have received formal approval and progress has been ongoing during this quarter. The two sub-tasks approved by DOE are: 1) Determination of Raw Coal Characterization and 2) Round Robin Column Cell Evaluation.

5.2.1 Raw Coal Characterization

Topical Report Number 1 was written to present the data for the pyrite liberation study for the Pittsburgh No. 8 coal. This report was completed and submitted to DOE/PETC this quarter.

The purpose of this pyrite liberation study subtask is to measure the pertinent physical and chemical properties of representative samples of the three coals to be used in the program; Pittsburgh No. 8, Upper Freeport, and Illinois No. 6.

Determination of the optimum top size and control of the coal surface properties during coal grinding are essential to achievement of maximum Btu recovery and ash and pyrite rejection in advanced flotation processes. The control of coal size distribution and surfaces depends on coal properties and the particle size distribution of associated minerals, particularly pyrite. Information on the distribution of the pyrite can be obtained from washability data. Standard washability data is also used to predict the expected performance of the proposed raw coal precleaning processes.

Figure 5.1
Bench Scale Process Testing Flowsheet

FIGURE 5.2 Advanced Flotation Process Flowsheet and Sample Locations (Grab & Run Approach)

The raw Illinois No. 6, seam coal was analyzed to determine their properties relevant to the fine grinding and advanced flotation bench-scale and process tests to be performed. The characterization of the coal began with the size and washability analysis.

The washability test was formulated to simulate the Task 2 advanced flotation flowsheet for Illinois No. 6. The washability test will aid designers in predicting the theoretical recoveries of precleaning products at various stage crushing sizes, starting at 1/4" x 0. Within the Task 2 flowsheet there was flexibility built into the flowsheet such that it is feasible to recovery a 1/4" x 200m precleaning product (Case A), or a 48 x 200m precleaning product (Case B), or no precleaning product (Case C). However, in all cases the Task 2 flowsheet will reject high gravity low quality material throughout all stage crushing sizes.

Rather than conduct a conventional washability test on samples crushed to various finer top sizes to evaluate pyrite liberation, it was deemed more appropriate to deviate from the norm and conduct a pyrite liberation washability test to approximate the advanced flotation precleaning circuitry that was developed in the conceptual study of Task 2.

By approximating the advanced flotation conceptual flowsheet design in the pyrite liberation washability study, some of the basic design deficiencies might be resolved. This procedure would also provide a further indication of the possibility of obtaining a product with the desired quality specifications at a coarser size within the gravity separation precleaning circuitry. By extracting an acceptable grade product within the precleaning circuitry one would then avoid directing all the feedstock into the more expensive fine grinding/advanced flotation circuit.

The laboratory process flowsheet used for the pyrite liberation study is presented in - Figure 5.3. The laboratory work in this study was conducted to determine the amount of pyrite liberation occurring at various stage crushing sizes. The philosophy used throughout the flowsheet is to reject high gravity refuse streams containing high quantities of pyritic sulfur and low calorific value (Sink 2.00) while simultaneously collecting a low gravity product stream containing low quantities of pyritic sulfur and high calorific value (Float 1.35). Middling material (1.35 x 2.00 Float Fractions) having neither of the above qualities, would be subjected to further pyrite liberation via stage crushing and additional processing.

The ultimate goal of the study was to determine the weight percentages of high gravity material that could be rejected and of the low gravity material that could be immediately directed to product prior to any of the feedstock reporting to

fine grinding (approximately minus 200 mesh) and advanced flotation circuitry.

As illustrated in Figure 5.3, the feedstock is first crushed to minus 1/4" to achieve some preliminary liberation. The 1/4" x 0 material is then screened at 48 mesh and 200 mesh to produce three size fractions; 1/4" x 48 mesh, 48 x 200 mesh, and 200 mesh x 0. Both the 1/4" x 48 mesh and 48 x 200 mesh size fractions are precleaned at high and low gravities.

As outlined, the middling (1.35 x 2.00) fractions are stage crushed and subjected to additional float sink analysis. In the conceptual flowsheet, the minus 48 mesh crushed middling would be combined with the raw minus 48 mesh and then processed in secondary precleaning equipment. All material flowstreams progress towards a finer size consist until they all reach the 200 mesh size.

It was assumed that there would be an insignificant amount of 2.00 float material liberated by further stage crushing 2.00 sink material to finer sizes. Therefore, no additional stage crushing was performed on sink 2.00 fractions.

Float/sink analysis was performed on all flowstreams below 200 mesh (even though flotation is a surface, not a gravity phenomena), since the float/sink results could be used to predict the ultimate performance of flotation on this fine sized coal. Float/sink analysis was conducted at six gravities, 1.30, 1.35, 1.40, 1.60, 1.80 and 2.00. All float/sink testing below 48 mesh was done using centrifugal techniques. Each fraction was analyzed for wt%, ash%, total sulfur%, pyritic sulfur%, and Btu content using ASTM standard procedures. Analytical work was conducted by TraDet Laboratories of Wheeling, WV.

In the last quarterly report, the results of the Pittsburgh No. 8 coal seams were presented. Topical Report No. 1 resulted from this investigation. The second coal was provided and the investigation of the Illinois No. 6 seam was begun. The same procedure as outlined above will be utilized for the Illinois No. 6 coal seam.

At the time of this report, only preliminary data for Illinois No. 6 was completed. The data that is completed is shown in Appendix I. No conclusion can be drawn at this time. The next quarterly report will contain more detailed results for the Illinois No. 6.

5.2.2 Advanced Flotation Round Robin

During this quarter, the Round Robin Test program was completed by issuing Topical Report 2. This test program was developed to determine the "best available" advanced flotation device. The selection of the "best available" machine resulted from technical and economical selection criteria. In

the last quarterly report, the technical criteria were discussed. This quarter, our work resulted in the economical evaluation.

The economic study of the results from Phase II involved contacting each participant and requesting, based on Test 4 parameters shown on tables 5.1 and 5.2, its best estimate of the capital cost of a nominal 20 tph advanced froth flotation circuit using the circuit configuration of that test. This estimate was to assume that the feed material would be prepared to 10% solids by weight and be ground to minus 325 mesh top size. No downstream dewatering was to be included in the circuit. The participant was to supply all of the utilities and the rates required for their flotation device.

The economic evaluation is to be based upon annual \$/ton of SO_2 removed and \$/ton of clean coal. In order for this comparison to be fair to all participants a series of calculations were made so that each participant produced the same annual Btu to match the demands of a 25 MW electrical power generation station.

The electrical power generation station was assumed to have a net heat rate of 9493 Btu/KWhr. Net heat rate is plant boundary fuel input to busbar electricity. It was further assumed that the plant availability factor would be 75%. The availability factor is the fraction of the year the power generation station is "available" to produce power at some useful output level excluding planned or unplanned shutdowns. Based upon these assumptions the power plant requires 1.5592×10^{12} Btu per year.

The advanced froth flotation coal preparation plant must produce the equivalent amount of Btu as required by the power generation station. The coal preparation plant operates for 16 hours per day, 230 days per year and has a 90% availability factor or operates 3312 hours per year. The coal preparation plant must produce 1.5592×10^{12} Btu in 3312 hours or 4.7078×10^8 Btu per hour.

Based upon each of the participants calculated Btu values from Test #4 and the weight recovery from Test #4, each participant's hourly clean coal and raw coal feed was calculated. ICF KE acknowledges that the "as received" Btu will be lower than the "moisture free" Btu, however, if all participants are assumed to have the same final moisture then the relative differences will be in the same ratio as the "moisture free" Btu. Therefore "moisture free" Btu was used to calculate the clean coal and raw coal tons per hour.

The calculated values of clean coal and raw coal tons per hour for each participant to produce 4.7078×10^8 Btu per hour are shown on Table 5.3.

TABLE 5.1

FLOTATION PERFORMANCE RESULTS PHASE II

PERFORMANCE PARAMETER	AL MN	ELR	CAER	DCI	ISCS	MTU	VP1
	#4	#4	#4	#4	#4	#4	#4
FEED							
WEIGHT %	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BIUMAT REPORTED	100.0	100.0	100.0	100.0	100.0	100.0	100.0
ASH %	11.75	12.00	11.95	12.14	12.05	11.99	12.40
BIUMAT REPORTED	11.80	12.77	11.65	11.94	11.45	11.67	11.67
PYRITIC SULFUR %	2.36	2.19	2.79	2.42	2.44	2.36	2.92
BIUMAT REPORTED	2.08	2.62	2.39	3.58	2.67	1.99	1.54
TOTAL SULFUR %	3.98	3.93	4.20	3.93	3.92	4.07	4.26
BIUMAT REPORTED	4.11	3.62	3.92	2.80	3.79	3.66	3.74
BTU	12378	12339	12347	12317	12331	12340	12277
BIUMAT REPORTED	12350	12412	12506	12335	12389	12420	12506
CLEAN COAL							
WEIGHT %	89.50	89.00	87.50	85.60	85.40	83.70	70.00
BIUMAT REPORTED	89.49	88.00	86.10	86.06	86.48	84.97	72.28
ASH %	6.64	3.73	3.72	4.72	3.60	2.59	2.91
BIUMAT REPORTED	6.65	3.73	3.73	4.72	3.60	2.59	2.91
PYRITIC SULFUR %	0.92	0.76	0.65	0.88	0.73	0.39	0.47
BIUMAT REPORTED	0.84	0.80	0.62	0.85	0.77	0.38	0.40
TOTAL SULFUR %	2.92	1.83	2.13	2.35	1.99	1.65	1.90
BIUMAT REPORTED	2.92	1.83	2.13	2.35	1.99	1.65	1.90
BTU	13268	13786	13788	13614	13809	14216	14088
BIUMAT REPORTED	13424	14082	14110	14160	14322	13824	14333
REFUSE							
WEIGHT %	10.50	11.00	12.50	14.40	14.60	16.30	30.00
BIUMAT REPORTED	10.51	12.00	11.90	13.94	13.52	15.03	27.72
ASH %	55.64	78.99	69.97	56.42	61.58	60.15	34.51
BIUMAT REPORTED	55.70	79.09	70.27	56.48	61.67	60.15	34.51
PYRITIC SULFUR %	13.04	13.77	17.78	11.50	12.42	12.46	9.02
BIUMAT REPORTED	12.67	15.93	15.50	14.25	14.83	11.10	4.53
TOTAL SULFUR %	14.70	20.89	18.66	13.33	15.19	16.47	9.76
BIUMAT REPORTED	14.20	16.78	17.20	11.19	15.29	15.04	8.52
BTU	6895	2562	2440	5149	3700	4120	9057
INTU RECOVERY	95.94	99.14	97.71	94.61	95.64	96.56	80.33
PYRITIC SULFUR REJECTION	50.02	69.16	70.66	68.91	71.32	30.06	101.54
EFFICIENCY	53.95	60.40	77.37	63.52	69.95	32.62	68.89

AL MN = ALL MINERAL, ELR = B. DATTA RESEARCH, CAER = CENTER FOR APPLIED ENERGY RESEARCH, DCI = DEISTER CONCENTRATOR COMPANY, INC., ISCS = ILLINOIS STATE GEOLOGICAL SURVEY
 MTU = MICHIGAN TECHNOLOGICAL UNIVERSITY, VP1 = VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

TABLE 5.2

FROTH FLUTATION PROCESS VARIABLES PHASE II

PERFORMANCE PARAMETER	AL MN	ELR	CAER	DCI	ISCS	MTU	VP1
	#4	#4	#4	#4	#4	#4	#4
GEOMETRY							
HEIGHT	23.00	182.0	236.0	122.0	8.00	96.00	60.0
DIAMETER	3.00	3.00	2.0	3.0	N/A	1.80	2.0
SLURRY FEED POINT	0.00	60.00	156.0	32.0	N/A	46.00	18.5
WASH WATER ADDITION PT	N/A	21.00	12.0	1.0	N/A	2.00	3.5
FROTH HEIGHT	1.00	48.00	48.0	18.0	1.00	N/A	20.0
PULP HEIGHT	22.00	120.0	188.0	104.0	7.00	N/A	48.0
BAPLES SPACING	N/A	N/A	N/A	N/A	N/A	NOTE 1	N/A
CONDITIONS							
WASH WATER RATE	N/A	0.159	0.10	0.330	N/A	0.0356	0.132
AIR FLOW RATE	0.071	0.120	0.070	0.100	0.280	0.2120	0.014
FEED SLURRY RATE	0.450	3.500	0.130	0.320	N/A	0.0180	0.017
FEED % SOLIDS	5.00	10.00	10.00	12.00	9.80	10.00	8.89
FEED SLURRY PH	7.00	7.00	7.00	7.00	7.00	7.00	9.20
FEED PARTICLE SIZE	6.72	12.10	12.22	N/A	10.57	11.98	N/A
AIR HOLD-UP	N/A	10.80	9.50	N/A	N/A	30.00	26.12
RETENTION TIME	0.99	5.00	13.50	4.90	18.00	28.30	5.20
REAGENTS							
COLLECTOR NAME	NOTE 2	NOTE 4	NOTE 4	NOTE 4	NOTE 4	NOTE 5	NOTE 4
COLLECTOR RATE	1.10	3.00	2.00	3.00	6.40	2.56	1.00
FROTHER NAME	N/A	MIBC	MIBC	MISO	MISO	NOTE 6	MISO
FROTHER RATE	N/A	2.00	1.00	1.00	2.99	1.43	3.94
MODIFIER NAME	NOTE 3	N/A	N/A	N/A	N/A	N/A	N/A
MODIFIER RATE	0.22	N/A	N/A	N/A	N/A	N/A	N/A

NOTE 1 STACKED CORRUGATED PLATES ARRANGED IN BLOCK POSITION AT
 NOTE 2 MINTAM 551 P2 THIS IS FROTHER AND COLLECTOR COMBINATION
 NOTE 3 VARIOUS RPTS
 NOTE 4 KROCKEN
 NOTE 5 NO. 2 FUEL OIL
 NOTE 6 PINE OIL
 RIGHT ANGLES TO EACH OTHER

Table 5.3

Required Clean Coal and Raw Coal
for Economical Evaluation

<u>Participant</u>	<u>Test #4 Btu/#</u>	<u>Test #4 Yield</u>	<u>Clean Coal TPH</u>	<u>Raw Coal TPH</u>
ALMN	13268	89.5	17.74	19.82
CAER	13788	87.5	17.07	19.51
DCCI	13614	85.6	17.29	20.20
ISGS	13809	85.4	17.05	19.96
MTU	14236	83.7	16.53	19.75
VPI	14088	70.0	16.71	23.87

ICF KE, in the interest of fairness to all of the participants, contacted known suppliers of froth flotation reagents, and known suppliers for equipment utilized in common by all of the participants, such as reagent feeders, air compressors, and feed pumps. The above information was utilized in all of the participants' calculated capital cost. See Table 5.4 Common Equipment and Reagent Costs.

The participant's capital cost for the flotation device was incorporated with the cost of the other equipment and multiplied by 3 to determine the total installed cost of the flotation plant.

The operating and maintenance cost estimates were based upon the participant's flowsheet, the equipment list, the capital cost estimate and calculated values based upon known and/or estimated costs for expendables, power, and manpower. The assumed criteria was that the plant operates at 90% availability. Based upon two shifts per day, eight hours per shift and 230 operating days per year, the total annual operating hours, total annual raw coal and clean coal tonnages were calculated.

Values from literature, estimates, or material suppliers were established as costs per unit for all operating expendables. The hourly and supervisory manpower for operation was established on an annual basis. The expendables for power, flotation reagents, water, and manpower costs were then estimated. Reagent dosages were based on participant's Test #4 results.

The maintenance material costs were estimated as 10% of the equipment costs. The maintenance manpower was established on an annual basis. From the above values, maintenance materials and manpower costs were estimated.

The total operating and maintenance costs are expressed as total annual cost, dollars per ton of raw coal and dollars per ton of clean coal.

Table 5.4

Common Equipment and Reagent Costs

Reagent Costs

<u>Reagent Name</u>	<u>\$/Pound*</u>	<u>Source</u>
MIBC	0.61	PB&S Chemical
Pine Oil	0.63	Hercules Chemical
M150	0.85	Betz Chemical
No. 2 Fuel Oil	0.088	Orris Fuel Company
Kerosene	0.106	Orris Fuel Company

* Based on 3,000 gallon bulk shipments.

Equipment

<u>Name</u>	<u>Cost - \$/HP</u>	<u>Source</u>
Feed Pump	13,200/40	Gould (Goyne)+
Air Compressor	-	Airtech, Inc.++
150-300 cfm @ 40 psi	48,530/40	
500 cfm @ 50 psi	69,890/50	
1,000 cfm @ 50 psi	89,730/150	
Reagent Pumps	-	Pulsa Feeder+++
Collector	2,476/0.17	
Frother	2,462/0.17	

+ Hi chrome construction all wetted parts, variable speed drive, motor, guards and OH mount.

++ Joy reciprocating, oil free with motor, drive and regenerative drying.

+++ 316 SS construction with 4-20 ma controls, back pressure valves, motor and drive.

The total capital cost and the operating costs per ton of raw coal were used as input to an economic model. This model takes into consideration the plant life, three months of working capital, 100% debt financing, 11% annual debt interest rate, and debt loan period.

Coal cleaning results in some loss of BTU that were contained in the raw coal. For this reason ICF KE penalized each participant for the extra raw coal needed to provide the BTU required to fire the 25 MW power plant. This was accomplished by first calculating the raw coal tons required to fire the boiler based upon Test #4 feed BTU. Second the raw coal that was required to fire the boiler based upon Test #4 clean coal weight yield and clean coal BTU values was calculated. The difference of these two numbers was multiplied by \$20.00 per ton and added as an additional cost of cleaning the coal.

The output of this model is a first year estimate of dollars per clean coal ton, dollars per million BTU, annual dollars per year and annual dollars per ton of sulfur dioxide removed.

The economic analysis maintains all of the common equipment prices and manpower prices constant for each participant, therefore any variation in capital and operating and maintenance is based upon the participant's capital estimate and utilities for the scaled up version of their laboratory device.

The test work for Test #4 was performed on coal ground to pass 44 micron. Furthermore, all participants are operating column type flotation devices, except ISGS who used conventional flotation. Several papers have been recently published that state the scale up and performance of a column flotation device is limited by the rate of concentrate removal. There is a maximum rate at which solids can be removed related to individual bubble loading and the bubble surface area rate. Another name for this is "carrying capacity" and is expressed as mass of solids to overflow per unit time per unit of column cross sectional area. This value calculates to be 0.092 tph/ft² for Test #4 conditions.

The carrying capacity is the product of the D80 particle size in microns and the specific gravity of the particle. A graph shown in Figure 5.4 indicates the tons per hour per square foot carrying capacity required to size the column flotation. In order for all participants to meet the carrying capacity criteria it is necessary for Allmineral, Center for Applied Energy Research, Deister and VPI to provide four of their respective column flotation cells. Michigan Tech requires two of their column flotation cells. ISGS, because it is conventional flotation exceeds the carrying capacity criteria as proposed.

The Technical Support Team examined the reagent dosages used by the participants in Test #4. The TST determined that the collector could be scaled up based upon pounds per ton of solids in the feed. However, the frother should be scaled up based upon concentration in the cell. In order to scale up the frother addition, the concentration of the frother was calculated for each participant's Test #4 results. The same concentration was used to calculate the pounds per ton of frother at the required feed rate corrected for the required number of columns to meet the carrying capacity criteria discussed previously. The results of the frother concentration calculations are shown in Table 5.5. The calculated frother concentration was used to back-calculate the required pounds per ton of frother used in the economic model. The concentration was not calculated for Allmineral due to insufficient Test #4 data and ISGS due to the system being conventional flotation. The frother rate used for both of these participants are the same as reported by each for the required tph scale up.

Figure 5.4
CARRYING CAPACITY CURVE

TABLE 5.5

FROTHER CONCENTRATION

FACTOR	VPI		MTU		DOCI		CAER	
	TEST 4	20 TPH	TEST 4	20 TPH	TEST 4	20 TPH	TEST 4	20 TPH
SOLID SPECIFIC GRAVITY	1.400	1.400	1.400	1.400	1.400	1.400	1.400	1.400
LIQUID SPECIFIC GRAVITY	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
COLUMN DIAMETER	6.080	243.840	4.570	344.000	7.620	243.840	6.080	243.840
COLUMN LENGTH	152.400	670.560	243.840	1219.200	308.880	731.520	588.440	701.040
NUMBER OF COLUMNS	1	4	1	2	1	4	1	4
FEED PER CENT SOLIDS	8.900	10.000	10.000	10.000	10.000	10.000	6.000	10.000
FEED FLOWRATE	68	880883	68	1457688	1211	745456	492	719692
WASH WATER FLOWRATE	500	934836	135	598138	1249	1249060	379	908400
BUBBLE GENERATION WATER	0	0	0	0	946	189250	0	0
TAILINGS FLOWRATE	475	1640027	141	1780308	2484	1241972	717	1258582
BIAS FACTOR	0.812	0.812	0.541	0.541	0.248	0.248	0.594	0.594
FEED SOLIDS MASS RATE	6.301	90680.111	7.000	150067.157	222.065	76736.082	24.959	74116.840
FROTHER DOSAGE	3.900	0.907	1.430	0.821	1.000	1.253	1.000	0.581
LIQUID FLOWRATE	470	1575256	136	1673025	2306	997909	699	1206641
FROTHER CONCENTRATION	26.116	26.116	36.801	36.801	48.162	48.162	17.849	17.849
FROTHER MASS RATE	0.012	41.139	0.005	81.569	6.111	48.081	0.012	21.537
RETENTION TIME	6.50	19.08	28.35	63.62	6.73	32.43	16.94	25.98

NOTES

1. BILMAT VALUES USED FOR VOLUME AND MASS FLOW RATES FOR TEST #4
2. 20 TPH TAILINGS FLOWRATE SCALED-UP BASED ON CONSTANT BIAS FACTOR FROM TEST #4
3. FROTHER CONCENTRATION CONSTANT FROM TEST #4 TO 20 TPH SCALE-UP
4. FEED FLOWRATE BASED ON FEED RATE REQUIRED FOR CONSTANT BTU PRODUCTION
5. BIAS FACTOR EQUALS (TAILINGS FLOWRATE - FEED FLOWRATE) / WASH WATER FLOWRATE

B. Datta Research was not included in the economic evaluation because the machine has not yet been patented and any disclosure of the equipment may have an adverse impact on the patent application. Because of this, the participant did not provide economic information for his device thus preventing developing the economic model.

Table 5.6, Economic Parameters, shows the major numbers generated in the economic evaluation, with and without additional raw coal added to the final costs. The results are based upon Test #4 results with the proper material balances by the BILMAT program. The costs per ton of clean coal on a first year basis for the required tph circuit range from \$16.71 to \$21.29 without additional raw coal added. This dollar figure is a result of all costs divided by the annual clean coal produced.

The annual dollars per ton of sulfur dioxide removed range from \$237.00 to \$677.00 without additional raw coal added.

The costs per ton of clean coal on a first year basis for the required tph circuit including additional raw coal required range from \$17.23 to \$25.50. Likewise, the annual dollars per ton of sulfur dioxide removed including additional raw coal required range from \$305.00 to \$707.00.

TABLE 5.6

ECONOMIC PARAMETERS

DESCRIPTION OF PARAMETER	UNIT	AL MN	HER	CAER	DOCI	ISGS	MTU	VPI
PLANT FEED RATE	TPH	19.82	N/A	19.51	20.20	19.96	19.75	23.87
PLANT RECOVERY RATE	PER CENT	89.50%	N/A	87.50%	85.60%	84.50%	83.70%	70.00%
CLEAN COAL	TONS/YEAR	58751	N/A	56540	57238	55881	54750	55340
OPERATING HOURS	PER YEAR	3312	N/A	3312	3312	3312	3312	3312
FLOTATION REAGENT COSTS	\$/YEAR	\$248,341	N/A	\$34,274	\$95,528	\$204,685	\$48,569	\$69,329
OPERATING COSTS PER YEAR	PER OC TON	13.535	N/A	9.953	11.050	13.586	11.216	11.839
MAINTENANCE COSTS PER YEAR	PER OC TON	3.703	N/A	3.748	3.736	3.647	4.434	4.009
TOTAL O&M COSTS PER YEAR	PER OC TON	17.238	N/A	13.701	14.785	17.242	15.650	15.848
PLANT ESTIMATE CAPITAL COST	DOLLARS	\$1,153,812	N/A	\$985,362	\$1,045,362	\$738,333	\$1,909,308	\$1,238,882
ADDITIONAL RAW COAL REQUIRED	TONS	2660	N/A	1470	3606	2885	2236	15356
COSTS PER YEAR W/O PENALTY	PER OC TON	\$20.69	N/A	\$16.71	\$17.95	\$19.75	\$21.29	\$19.88
\$/TON OF SO ₂ REMOVED W/O PENALTY	DOLLARS	\$677	N/A	\$313	\$401	\$373	\$331	\$237
COSTS PER YEAR W/PENALTY	PER OC TON	\$21.60	N/A	\$17.23	\$19.21	\$20.78	\$22.10	\$25.50
\$/TON OF SO ₂ REMOVED W/PENALTY	DOLLARS	\$707	N/A	\$323	\$429	\$382	\$344	\$306

ALMN - ALLMINERAL, HER - B. DATTA RESEARCH, CAER - CENTER FOR APPLIED ENERGY RESEARCH, DOCI - DEISTER CONCENTRATING COMPANY INC.,

ISGS - ILLINOIS GEOLOGICAL SURVEY, MTU - MICHIGAN TECHNOLOGY UNIVERSITY, VPI - VIRGINIA POLYTECHNIC INSTITUTE

The overall objective of the round robin was to select the most efficient, as determined by the efficiency index, cost effective, as determined by the annual cost per ton of SO₂ removed, advanced flotation device available. This machine was to process ultra fine coal, maximize Btu recovery and maximize pyritic sulfur rejection.

To validate the participant's results, the device will first be installed as a one hundred pound per hour continuous capacity unit and, subject to the outcome of Task 6 of the Engineering Development Contract, increased to a 3 ton per hour capacity unit for installation into a proof-of-concept preparation plant.

It is very difficult to select one winner from all the participants. Any advanced technology being tested can and will at a given time produce values better and worse than have been reported. Therefore, a means was determined to select a device based upon the results of the round robin report.

All of the technical and economic results were submitted to the Technical Support Team (TST) for consideration. The TST members evaluated the data and determined to rank each of the participants 50% on technical merit and 50% on economic merit. The technical merit ranking was to be the efficiency index. The economical merit ranking was to be the annual dollars per ton of clean coal corrected for carrying capacity and frother concentration and the results of Test #4. This factor does not penalize a particular technology for not meeting a 90% pyritic sulfur rejection and therefore leaves something to be desired as the only economic basis for decision.

For the above reason ICF KE determined a second economic evaluation criteria was required that considered the \$/ton of sulfur dioxide removed. This value was calculated and also presented.

The technical and economic factors were calculated and added together for the final evaluation ranking. The technical factor was calculated by multiplying the efficiency index for each participant by 0.5. The two economic factors were calculated by dividing 1,000 by the \$/ton of clean coal and multiplying by 0.5 and by dividing 10,000 by the \$/ton of sulfur dioxide removed and multiply by 0.5. The 1,000 and 10,000 are numbers selected such that when divided by their economic factors, respective numbers resulted in a two digit number. The results of these calculations are shown in Table 5.7.

ICF KE recommends that both economic factors be utilized to select an advanced flotation device to be tested at the 100#/hr feed rate. Therefore, ICF KE recommends testing the Michigan Tech and Center for Applied Energy Research columns.

TABLE 5.7

FINAL EVALUATION RANKING

PARTICIPANT	TECHNICAL PARAMETER		ECONOMIC PARAMETER				FINAL RANKING	
	EFFICIENCY INDEX	TECHNICAL FACTOR	\$/TON OF SO ₂ REMOVED	ECONOMIC FACTOR 1	\$/TON OF CLEAN COAL	ECONOMIC FACTOR 2	COMBINED RANKING 1	COMBINED RANKING 2
ALLMINERAL	53.95	26.975	707.00	7.072	21.80	23.148	34.047	50.123
CENTER FOR APPLIED ENERGY RES.	77.37	38.685	323.00	15.480	17.23	29.019	54.165	67.704
DEISTER CONCENTRATING CO. INC.	63.52	31.780	429.00	11.655	19.21	26.028	43.415	57.788
ILLINOIS ST. GEOLOGICAL SURVEY	69.95	34.975	382.00	12.755	20.78	24.062	47.730	59.037
MICHIGAN TECH UNIVERSITY	82.62	41.310	344.00	14.535	22.10	22.624	55.845	63.934
VIRGINIA POLYTECHNIC INSTITUTE	68.88	34.445	305.00	16.383	25.50	19.608	50.838	54.053

The reasons for testing both of these units are based on the Round Robin Test Results. Michigan Tech reported values that were better than the release analysis curve. The opinion is that results better than the release curve are not possible on a continuous steady-stated basis. Therefore larger scale continuous testing is recommended to verify this technology. Additionally, a problem was discovered with the Center for Applied Energy Research scale-up results involving the amount of air volume required. In order to determine whether or not this is incorrect, larger scale testing is recommended.

5.2.3 Bench Scale Process Testing

During this quarter, B&W continued bench scale process testing on the Pittsburgh No. 8 raw coal, conducting test work on the precleaning circuit. B&W completed coarse and fine hydrocyclone cleaning, 48M x 200M and 200M x 0 rougher flotation, shakedown of pilot Netzsch horizontal stirred ball mill, classifying cyclone at 325 mesh and completed grinding of 48M x 325M to 325M top size for continuous microgrinding evaluation.

The work conducted previously resulted in establishing operating parameters for the coarse hydrocyclone, fine hydrocyclones and 200M classifying cyclone on the first lot of coal. In order to obtain data for a complete flowsheet, Lots 2 and 3 were operated at the determined operating conditions for each of the unit operations.

5.2.3.1 Coal Preparation and Primary Cleaning

The second and third lots (1800 pounds each) of Pittsburgh #8 coal were washed in the coarse hydrocyclone, fine hydrocyclone and classified at 200 mesh. The optimal operating conditions for removing ash, sulfur, and 200 mesh classification were determined during equipment shakedown with the first lot of coal. Consequently, the second and third lots were run at these conditions to produce feed slurry for the rougher flotation tests. For each lot, the feed sump was charged fifteen times for the cyclone runs. A feed sample was taken each time the sump was charged with a batch of slurry. Overflow and underflow samples were taken from each batch while the coal was being processed. All fifteen samples of each were saved and compiled into one bulk sample. Analyses were done on samples pulled from these bulk samples. Also, one additional overflow and underflow sample was taken during processing of the entire lot and analyzed. Flow samples of the overflow and underflow were also taken from each batch for 20 seconds. The overflow was collected in a 55-gallon drum, and the underflow was collected in a 5-gallon bucket. These flow samples were used to determine the mass

TABLE 5.8 COARSE HYDROCYCLONE ANALYSIS OF LOTS # 2 AND # 3

LOT NO. SAMPLE NO. DESCRIPTION	2 FEED	2 F-4429 OFLO 1	2 F-4430 UFLO 1	2 F-4431 OFLO 2	2 F-4432 UFLO 2	3 F-4400 FEED	3 F-4481 OFLO 1	3 F-4482 UFLO 1	3 F-4483 FEED	3 F-4484 UFLO 2	3 F-4485 OFLO 2
ASH %	20.29	25.74	47.98	31.15	33.42	19.95	33.67	31.87	18.85	40.33	28.10
TOTAL SULFUR %	3.97	4.26	10.37	4.04	5.33	4.36	3.66	6.00	4.25	8.51	3.84
BTU	11286	10452	6764	9723	9245	11486	9116	9486	11686	8164	10077
PYRITIC SULFUR %	1.72	2.36	8.75	2.07	3.42	2.16	1.94	4.10	2.12	6.66	1.91

TABLE 5.9 FINE HYDROCYCLONE ANALYSIS OF LOTS # 2 AND # 3

LOT NO. SAMPLE NO. DESCRIPTION	2 FEED	2 F-4447 OFLO 1	2 F-4448 UFLO 1	2 F-4449 FEED	2 F-4450 OFLO 2	2 F-4451 UFLO 2	3 F-4493 FEED	3 F-4494 OFLO 1	3 F-4495 UFLO 1	3 F-4496 FEED	3 F-4497 OFLO 2	3 F-4498 UFLO 2
ASH %	25.72	24.61	37.73	22.90	24.18	37.04	22.14	20.97	30.18	22.70	21.34	26.05
TOTAL SULFUR %	4.03	3.37	15.07	4.10	3.47	15.82	4.24	3.41	11.62	3.99	3.88	8.72
BTU	10388	10658	8360	10684	10764	8459	11022	11247	9764	11064	11151	10422
PYRITIC SULFUR %	2.29	1.49	12.60	2.22	1.52	13.82	2.15	1.43	10.51	2.07	1.89	6.80

balances. Coarse hydrocyclone analyses are shown in Table 5.8 and fine hydrocyclone analyses are shown in Table 5.9. The 200 mesh classifying cyclone results are shown on Table 5.10 and the Recovery Curve on Figure 5.5.

5.3.2.2 Continuous Rougher Flotation

The shakedown of the conventional froth cell was conducted on the first lot of Pittsburgh #8 using the split feed grab-and-run method. There was little or no quality improvement with the grab and run method. However, split feed improved the clean coal quality. Consequently, the continuous rougher flotation on the second and third lots was conducted with the split feed (48M x 200M and 200M x 0) but not grab-and-run. During the shakedown, it was difficult to maintain a constant flow to the cells with the centrifugal pump and throttling valves. It was decided to modify the circuit to feed the cell with two Moyno positive displacement pumps. These pump much less volume (less than 10 GPM total), so the feed rate to the cell would be easier to control and more constant. This resulted in a constant level in the cells which meant more efficient operation.

During the continuous rougher flotation tests on the second lot of Pittsburgh #8 coal, two sets of feed, clean coal froth, and tailings samples were analyzed for both the 48M x 200M and 200M x 0 size fractions. Overall, the 48M x 200M test ran for 1½ hours, and six sets of samples were taken. Samples were taken every 15 minutes. Flow rates were also taken every 15 minutes. The 200M x 0 test ran for 6 hours 45 minutes, and thirteen sets of samples were taken. Samples and flow rates were taken every ½ hour. Analyses are shown on Table 5.11. The BTU recovery and mass balance for each fraction were calculated using Sample #4 from each test. The BTU recovery for the 48M x 200M was 98.8%, and the BTU recovery for the 200M x 0 was 98.2%. The calculations and mass balances are included on Table 5.12 and Figures 5.6 & 5.7. The kerosene dosage for both tests was 2.5 #/T added in the mix tank prior to pumping to the froth cell. The MIBC for both tests was 2#/T, with 1#/T added in the feed box and 1#/T added in the third cell. The feed concentration for the 48M x 200M was 8%, retention time was 4.1 minutes, and the air volume was 12 CFM total (3 CFM/cell). The feed concentration for the 200M x 0 was 5%, retention time was 4.0 minutes, and the air volume was 12 CFM total (3 CFM/cell).

TABLE 5. 10 200 M CLASSIFYING CYCLONE ANALYSIS OF LOTS # 2 AND # 3

LOT NO.	SAMPLE NO.	DESCRIPTION	2		2		2		3		3		3	
			M 46143	FEED	M 46144	OFFLO	M 46145	OFFLO	M 46125	FEED	M 46126	OFFLO	M 46127	OFFLO
SIZE			CUM WT %		CUM WT %		CUM WT %		CUM WT %		CUM WT %		CUM WT %	
MICRONS			LESS		LESS		LESS		LESS		LESS		LESS	
2400.00							100.00						100.00	
1687.02							99.98						99.98	
1200.00			100.00				99.93		100.00				99.97	
848.53			99.98				99.51		99.97				99.29	
600.00			99.96				99.18		99.94				98.78	
424.26			99.20				91.98		99.25				91.83	
300.00			98.66				86.88		98.77				86.92	
212.13			93.65		100.00		66.98		93.20		100.00		66.67	
150.00			86.72		99.37		40.06		86.60		99.28		40.59	
106.07			79.43		91.13		24.33		77.66		96.25		8.87	
75.00			67.40		80.26		13.03		68.24		85.85		5.04	
63.03			57.47		69.48		5.99		57.09		74.12		3.30	
37.50			50.82		60.79		4.96		48.68		64.10		1.13	
26.52			44.53		54.36		3.21		43.66		58.28		0.26	
18.75			37.23		47.21		3.04		37.99		49.95		0.00	
13.26			33.68		40.33		1.65		31.96		42.25		0.00	
9.38			27.49		34.08		0.00		26.66		35.18		0.00	
6.63			20.20		26.02		0.00		20.35		26.67		0.00	
4.69			15.42		18.99		0.00		14.53		19.74		0.00	
3.31			11.07		13.67		0.00		10.31		13.80		0.00	
2.34			7.64		9.41		0.00		7.02		9.45		0.00	
1.66			5.16		6.54		0.00		4.71		6.40		0.00	
1.17			3.50		4.43		0.00		3.19		4.38		0.00	
0.83			2.19		2.73		0.00		1.98		2.75		0.00	
0.69			1.20		1.48		0.00		1.07		1.48		0.00	
0.41			0.38		0.51		0.00		0.33		0.41		0.00	
0.29			0.00		0.00		0.00		0.00		0.00		0.00	
0.21			0.00		0.00		0.00		0.00		0.00		0.00	
0.15			0.00		0.00		0.00		0.00		0.00		0.00	

FIGURE 5.5

Table 5.12

Rougher Flotation BTU Recovery

I. Coarse (48M x 200M)

$$\begin{aligned} \text{Froth} &- 13.87 \text{ \#/min} \times .3997 (\% \text{ solids}) = 5.54 \text{ \# solids/min} (95.85\%) \\ \text{Tails} &- 43.31 \text{ \#/min} \times .0055 (\% \text{ solids}) = \underline{.24 \text{ \#}} \text{ solids/min} (4.15\%) \\ &5.78 \text{ \#} \end{aligned}$$

$$\text{Feed Btu} - (.9585)(13,033) + (.0415)(3743) = 12,647 \text{ Btu/\#}$$

$$\text{Btu Recovery} = \frac{(95.85)(13,033)}{(100)(12,647)} = 98.8\%$$

II. Fine (200M x 0)

$$\begin{aligned} \text{Froth} &- 7.17 \text{ \#/min} \times .2591 = 1.86 \text{ \# solids/min} (74.10\%) \\ \text{Tails} &- 43.94 \text{ \#/min} \times .0148 = \underline{.65 \text{ \#}} \text{ solids/min} (25.90\%) \\ &2.51 \text{ \#} \end{aligned}$$

$$\text{Feed Btu} - (.741)(13,396) + (.259)(685) = 10,104$$

$$\text{Btu Recovery} = \frac{(74.10)(13,396)}{(100)(10,104)} = 98.2\%$$

MASS BALANCE FOR 48M X 200M ROUGHER FLOTATION

**ICF KAISER
ENGINEERS**

DRAWN BY J. J. M.

CHECKED BY

DATE

SCALE

ALL ANALYSES DRY BASIS

JOB NO. 88107-160

DWG. NO. FIG. 5.6

MASS BALANCE FOR 200M X 0 ROUGHER FLOTATION

**ICF KAISER
ENGINEERS**

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CHECKED BY:

DATE:

SCALE:

ALL ANALYSES DRY BASIS

JOB NO. 88107-160

DWG. NO. FIG. 5.7

During the tests on the third lot of coal, two sets of feed, clean coal froth, and tailings samples were analyzed for both the 48M x 200M and 200M x 0 size fractions. Overall, the 48M x 200M test ran for 1-1/4 hours, and five sets of samples were taken. Samples and flow rates were taken every 15 minutes. The 200M x 0 test ran for 5-1/4 hours, and ten sets of samples were taken. Samples and flow rates were taken every 1/2 hour. Analyses are included on Table 5.13. The BTU recovery and mass balance for each fraction were calculated using Sample #3 for the 48M x 200M and Sample #8 for the 200M x 0. BTU recovery for the 48M x 200M was 98.4%, and the BTU recovery for the 200M x 0 was 98.0%. The calculations and mass balances are included on Table 5.14 and Figures 5.8 and 5.9. Kerosene and MIBC dosages and addition were identical to the Lot #2 tests. Feed concentrations, retention times, and air volumes were also identical to the Lot #2 tests for both size fractions.

For Lot #2, ash reduction was 21.2% on the coarse, 81.6% on the fine. Pyritic sulfur reduction was 18.1% on the coarse, 37.0% on the fine. For Lot #3, ash reduction was 21.4% on the coarse, 78.7% on the fine. Pyritic sulfur reduction was 15.4% on the coarse, 38.7% on the fine.

Table 5.14

Rougher Flotation BTU Recovery

I. Coarse (48M x 200M)

$$\begin{aligned} \text{Froth} &- 14.57 \text{ \#/min} \times .4405 (\% \text{ solids}) = 6.42 \text{ \# solids/min (95.82\%)} \\ \text{Tails} &- 40.31 \text{ \#/min} \times .0055 (\% \text{ solids}) = \underline{.24 \text{ \#}} \text{ solids/min (4.15\%)} \\ &5.78 \text{ \#} \end{aligned}$$

$$\text{Feed Btu} - (.9582)(13,184) + (.0418)(4848) = 12,836 \text{ BTU/\#}$$

$$\text{Btu Recovery} = \frac{(95.82)(13,184)}{(100)(12,836)} = 98.4\%$$

II. Fine (200M x 0)

$$\begin{aligned} \text{Froth} &- 8.71 \text{ \#/min} \times .2621 (\% \text{ solids}) + 2.28 \text{ \# solids/min (72.80\%)} \\ \text{Tails} &- 40.62 \text{ \#/min} \times .0182 (\% \text{ solids}) = \underline{.73 \text{ \#}} \text{ solids/min (24.20\%)} \\ &3.01 \text{ \#} \end{aligned}$$

$$\text{Feed Btu} - (.758)(13,405) + (.242)(877) = 10,373 \text{ BTU/\#}$$

$$\text{Btu Recovery} = \frac{(75.8)(13,405)}{(100)(10,373)} = 98.0\%$$

MASS BALANCE FOR 48M X 200M ROUGHER FLOTATION

**ICF KAISER
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DWG. NO. FIG. 5.8

MASS BALANCE FOR 200M X 0 ROUGHER FLOTATION

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DWG. NO. FIG. 5.9

5.2.3.3 Continuous Microgrinding

The shakedown of the Netzsch stirred ball mill was conducted. The mill is horizontal with an agitator shaft with a speed range of 700 to 1600 RPM. The original charge in the mill was 52 pounds of 1/8" stainless steel balls (60% volume). Feed concentration was 45% solids. Tests were run at (1) 800 RPM mill speed at .49 GPM feed, (2) 1000 RPM mill speed at .49 GPM and (3) 1000 RPM mill speed at .39 GPM. Results of the third test showed 5-10% +325 mesh material in the product. This did not meet the size specification of 100% minus 325 mesh, so the mill charge was increased by 10 pounds to 62 pounds total (70% volume). The next test was run at 1000 RPM mill speed and .39 GPM feed. Particle size was 100% minus 325 mesh. To gather additional engineering data, additional tests at 43.5% and 42.0% feed concentrations at various mill speeds and feed rates were performed. The entire shakedown test matrix is shown on Table 5.15. Also included are graphs showing the effects of mill flow rate (Figure 5.10), mill RPM (Figure 5.11), feed percent solids (Figure 5.12), and mill charge (Figure 5.13) on the mass mean diameter of the stirred ball mill product. During all tests, power consumption, slurry temperature, and mill cooling water temperature were monitored. This power consumption data will be used to calculate the grinding energy (KW/ton) required. The following general comments can be made based on the shakedown tests:

- Effect of Flow Rate - Increasing flow rate results in increasing average particle size, regardless of mill charge or mill RPM.
- Effect of RPM - Increasing RPM results in finer average particle size. This effect is greater at higher feed rates and percent solids.
- Effect of Solids - Within the range of the test, increased solids resulted in a slightly finer average particle size.
- Effect of Mill Charge - Increasing mill charge volume results in a finer average particle size.

Fifteen additional tests were run on the second lot of Pittsburgh #8 coal to gather additional engineering data. The test matrix is shown on Table 5.16. Also included are graphs showing effects of mill flow rate (Figure 5.14) RPM (Figure

Table 5.15

Shakedown Stirred Ball Mill Test Matrix

<u>Test</u>	<u>Mill Charge (lb)</u>	<u>% Solids</u>	<u>Mill RPM</u>	<u>Feed Rate (GPM)</u>
1	52	45	800	.49
2	52	45	1000	.49
3	52	45	1000	.39
4	62	45	1000	.39
5	62	43.5	1000	.39
6	62	43.5	800	.39
7	62	42	800	.39
8	62	42	1200	.39
9	62	42	1200	.61
10	62	42	1200	.95

FIGURE 5.10

FIGURE 5.11

FIGURE 5.12

FIGURE 5.13

Table 5.16

Stirred Ball Mill Test Matrix

<u>Test</u>	<u>Mill Charge (%)</u>	<u>% Solids</u>	<u>Mill RPM</u>	<u>Feed Rate (GPM)</u>
1	70	45	1000	.39
2	70	45	1000	.49
3	70	45	1000	.61
4	70	45	800	.39
5	70	45	800	.49
6	70	45	800	.61
7	70	43.5	1000	.39
8	70	43.5	1000	.49
9	70	43.5	1000	.61
10	70	43.5	800	.95
11	70	43.5	800	.39
12	70	43.5	1200	.49
13	70	42	1000	.39
14	70	42	1000	.61
15	70	42	1000	.95

FIGURE 5.14

5.15) and feed solids (Figure 5.16) on the mass mean diameter of the stirred ball mill product. The overall trend for this set of tests is identical to the first set of shakedown tests. After evaluation of these shakedown tests, the mill conditions to prepare the optimum product size to be used as feed to the advanced flotation cell were selected. These conditions were as follows:

- .49 GPM feed slurry
- 1000 RPM
- 48% solids concentration
- 70% mill charge
- 1/8" stainless steel balls

Optimum product is 325 mesh top size and has a mass mean diameter between 11 and 12 microns. The entire 325 mesh classifying cyclone underflow of the Microtrac analyses of this run are shown graphically on Figure 5.17.

For the second and third lots of coal, the mass balances for the process up to the 325 mesh thickening/classifying cyclone feeds have been calculated. These feed qualities are also the qualities to the pilot column flotation cell. The balances are shown on Figure 5.18 and 5.19. The balances for the two lots of coal are very close. Due to the poor performance of the 6" coarse hydrocyclone, overall BTU recovery averages 82.1%. The 6" coarse hydrocyclone poor results resulted from attempting to operate the small diameter hydrocyclone to process too coarse a feed size. As shown previously in Topical Report No. 1, there is no reason to doubt that the recovery of the primary coarse hydrocyclone will be improved by utilizing the correct diameter hydrocyclone for the 1/4" feed. BTU recoveries in excess of 95% will be accomplished.

The mass balance was calculated as follows:

1. The froth and tailings analyses of the rougher flotation fractions were used to calculate the feed to each fraction.
2. These flotation feeds were used to calculate the feed to the 200 mesh classifying cyclone.
3. The feed to the classifying cyclone (also the fine hydrocyclone overflow) calculated very closely to the actual fine hydrocyclone overflow analysis. Consequently, the corresponding underflow sample, was used as the fine hydrocyclone underflow, and the feed to the fine hydrocyclone (coarse hydrocyclone overflow) was calculated.
4. It was difficult to match this coarse hydrocyclone overflow with either of the two overflow analyses -- one collected over the entire processing and a one-time flow sample. The flow analysis was closer on total and pyritic sulfur. For this reason, it was decided to use the average underflow quality of the two as the coarse hydrocyclone refuse. The coarse hydrocyclone feed quality was then calculated.

FIGURE 5.15

EFFECT OF SOLIDS

(1000 RPM, .39 GPM)

(1000 RPM, .49 GPM)

MASS MEAN DIAMETER (MICRONS)

90 SOLIDS

54

53

52

51

50

49

48

47

46

45

44

43

2

3

4

5

6

7

8

9

10

11

12

13

14

15

16

17

FIGURE 5.17

PITTSBURGH #8 MASS BALANCE - 2ND LOT

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PITTSBURGH #8 MASS BALANCE - 3RD LOT

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DWG. NO. FIG. 5.19

The quality (dry basis) of the feed to the pilot flotation cell from Lot #2 is:

- 8.18% ash
- 3.81% total sulfur
- 1.37% pyritic sulfur
- 13,256 BTU/#

Based on the calculated feed to the coarse hydrocyclone, overall ash reduction was 80.0%, total sulfur reduction was 48.1%, and pyritic sulfur reduction was 67.5%.

The quality (dry basis) of the feed to the pilot flotation cell from Lot #3 is:

- 8.14% ash
- 3.75% total sulfur
- 1.41% pyritic sulfur
- 13,323 BTU/#

Based on the calculated feed to the coarse hydrocyclone, overall ash reduction was 78.9%, total sulfur reduction was 47.4%, and pyritic sulfur reduction was 66.7%.

6.0 TASK 6 COMPONENT AND UNIT OPERATIONS DEVELOPMENT

6.1 Overview and Scope

The Task 6 effort involves three main elements including column cell development (Subtask 1.6.1), flotation circuit testing (Subtask 1.6.2) and flotation cell modeling (Subtask 1.6.3). The work outlined in Subtask 1.6.1 is to research column designs and operation parameters in developing an optimized column flotation cell (OCFC) to meet the overall program objectives. The test results obtained through this effort will be evaluated against the results obtained from the round-robin test program in Task 5. Any design parameters of operating conditions that are unique with the round-robin test winner that were not evaluated as part of the optimized column development work will be reviewed and tested so as to incorporate all possible scenarios in presenting DOE with the best available flotation process for use in the 2 to 3 ton per hour POC.

Following development of the OCFC, various flotation circuit configurations will be evaluated (Subtask 1.6.2) to determine the "best" circuit design for the 2 to 3 ton per hour POC. Single and multiple stage flotation, grab and run, rougher/scavenger/cleaner, etc., test circuits will be tested as part of this effort. Upon completion of this test work, the "best" possible flotation cell will have been tested in a number of possible flotation circuit designs to possibly provide the "best" flotation approach in meeting the design criteria.

In conjunction with the flotation test effort, model development work will be conducted to provide a tool in evaluating the various flotation circuit configurations and in predicting flotation performance (Subtask 1.6.3). The model will be useful in selecting operating conditions in the POC and in evaluating the performance of the POC.

6.2 Review of Work Completed This Quarter

Several functions have been completed as described in the next paragraphs.

6.2.1 Optimum Column Cell Development Test Work

The parametric test program submitted to ICF Kaiser Engineers on July 28, 1989, was completed during the past quarter for the precleaned Pittsburgh No. 8 coal sample supplied by B&W. Flotation samples were prepared by grinding representative samples of the as-received slurry for 4 minutes in a laboratory-scale stirred ball mill. This procedure produced a mean particle size of approximately 10 microns. The samples were diluted to the desired solids content using fresh water and reagents were added at the level specified by the experimental design. After conditioning, a variable-speed pump was used to feed the slurry into the flotation column at a distance of approximately 12 inches below the product

overflow lip. A countercurrent flow of wash water was added just below the product overflow lip. Pulp level in the cell was maintained through the use of a simple overflow weir connected to the reject line. A by-pass sand gate was used to prevent a build-up of the coarse or high specific gravity particles (such as pyrite) in the reject stream. Air sparging was accomplished by means of an in-line microbubble generator (i.e., static mixer). Other standard test conditions are summarized in Table 6.1.

Six key operating parameters that can be manipulated during column operation were selected for study in the experimental design. These included collector dosage, frother dosage, feed solids content, aeration rate, wash water flow rate and feed slurry flow rate. The test levels selected for each of these parameters are specified in Table 6.2. These values were selected on the basis of exploratory test work conducted when the sample first arrived. Using these levels, a statistical test program was developed using a composite Box-and-Behnken experimental design. This type of design is well suited for the study of flotation test work since it provides a measure of the contribution of each parameter to the given response as well as allows the influence of joint interactions between the various test parameters to be estimated. The specific tests required by the Box-and-Behnken design are summarized in Table 6.3. The design requires that 54 individual flotation tests be conducted in order to qualify the effects of the six specified test parameters. All tests were conducted in random order to minimize experimental bias.

Parametric Test Overview

The results obtained from the parametric test work are summarized in Table 6.4. In order to obtain a consistent set of experimental data, all test values were analyzed and adjusted using a single-node material balance program originally published by Will (1988). In general, only minor adjustments to the experimental data were noted. The fact that major data manipulation was not required suggests that the measured assay values were reliable. Unfortunately, the assay values for pyritic sulfur were not completed at the time of reporting. After these assays are made available, they will also be incorporated into the statistical design analysis and submitted to ICF Kaiser Engineers for review.

As indicated in Tables 6.3 and 6.4, six replicate "baseline" tests were performed at various times throughout the test program so that the amount of pure experimental error could be assessed. This provided a check on the consistency of both the test procedure and assay determinations. The yield, product ash and product sulfur data obtained from these replicate tests are plotted in Figure 6.1. As shown, a very reproducible set of data was obtained in each test. This finding suggests that the characteristics of the coal sample did not change during the test program and that the sampling

TABLE 6.1 Standard Conditions Used for Parametric Test Program

<u>Parameter</u>	<u>Setting</u>
Column Diameter	2 inches
Column Length	60 inches
Grind Time	4 minutes
Grind Size	-325 mesh
Wash Water Addition Point	15 cm above pulp
Generator Length	30 cm
Generator Diameter	1.3 cm
Frother Type	Dowfroth M-1012
Collector Type	Kerosene
Baffles	None

TABLE 6.2 Test Levels Utilized in the Parametric Test Program

<u>Parameter</u>	<u>Low</u>	<u>Normal</u>	<u>High</u>
Feed Solids (%)	5	10	15
Frother Dosage (lb/ton)	0.5	1.5	2.5
Collector Dosage (lb/ton)	0.5	1.0	1.5
Feed Rate (ml/min)	50	150	250
Aeration Rate (cm ³ /min)	500	1000	1500
Wash Water Rate (ml/min)	200	400	600

TABLE 6.3 Parametric Test Plan Utilized in the Advanced Flotation Optimization Studies

Test No.	Collector Dosage	Frother Dosage	Aeration Rate	Feed Solids	Feed Rate	Wash Water Rate
1	1	1	0	1	0	0
2	-1	1	0	1	0	0
3	1	-1	0	1	0	0
4	1	1	0	-1	0	0
5	-1	-1	0	1	0	0
6	1	-1	0	-1	0	0
7	-1	1	0	-1	0	0
8	-1	-1	0	-1	0	0
9	0	1	1	0	1	0
10	0	-1	1	0	1	0
11	0	1	-1	0	1	0
12	0	1	1	0	-1	0
13	0	-1	-1	0	1	0
14	0	1	-1	0	-1	0
15	0	-1	1	0	-1	0
16	0	-1	-1	0	-1	0
17	0	0	1	1	0	1
18	0	0	-1	1	0	1
19	0	0	1	-1	0	1
20	0	0	1	1	0	-1
21	0	0	-1	-1	0	1
22	0	0	1	-1	0	-1
23	0	0	-1	1	0	-1
24	0	0	-1	-1	0	-1
25	1	0	0	1	1	0
26	-1	0	0	1	1	0
27	1	0	0	-1	1	0
28	1	0	0	1	-1	0
29	-1	0	0	-1	1	0
30	1	0	0	-1	-1	0
31	-1	0	0	1	-1	0
32	-1	0	0	-1	-1	0
33	0	1	0	0	1	1
34	0	-1	0	0	1	1
35	0	1	0	0	-1	1
36	0	1	0	0	1	-1
37	0	-1	0	0	-1	1
38	0	1	0	0	-1	-1
39	0	-1	0	0	1	-1
40	0	-1	0	0	-1	-1

TABLE 6.3 Continued

Test No.	Collector Dosage	Frother Dosage	Aeration Rate	Feed Solids	Feed Rate	Wash Water Rate
-----	-----	-----	-----	-----	-----	-----
41	1	0	1	0	0	1
42	-1	0	1	0	0	1
43	1	0	-1	0	0	1
44	1	0	1	0	0	-1
45	-1	0	-1	0	0	1
46	1	0	-1	0	0	-1
47	-1	0	1	0	0	-1
48	-1	0	-1	0	0	-1
49	0	0	0	0	0	0
50	0	0	0	0	0	0
51	0	0	0	0	0	0
52	0	0	0	0	0	0
53	0	0	0	0	0	0
54	0	0	0	0	0	0

TABLE 6.4 Continued

ID	Meas Yield	Feed Ash	Prod Ash	Tail Ash	Feed Sulfur	Prod Sulfur	Tail Sulfur	Feed BTU	Prod BTU	Reject BTU	Prod Yield	Reject Yield	Ash Rej	Sulfur Rej	Ash Rec	Sulfur Rec
1	92.7	9.63	4.36	78.13	3.56	3.36	6.17	13205	14055	2147	92.86	7.14	57.96	12.38	42.04	87.64
53	90.28	9.73	3.89	61.54	3.55	3.24	6.26	12882	14033	2675	89.87	10.13	64.07	17.86	35.93	82.02
9	68.35	9.55	3.76	20.97	3.37	2.98	4.15	13175	14098	11355	66.36	33.64	73.87	41.43	26.13	58.68
4	92.17	9.6	4.18	70	3.4	3.13	6.36	13240	13365	11847	91.77	8.23	60.04	15.40	39.96	84.48
41	91.51	9.75	4.42	68.9	3.51	3.24	6.52	13129	14005	3416	91.73	8.27	58.41	15.35	41.59	84.68
24	90.58	9.29	3.59	49.06	3.71	3.37	6.05	13159	14103	6573	87.46	12.54	66.20	20.44	33.80	79.45
25	93.54	9.62	3.98	69.83	3.38	3.14	5.96	13205	14144	3172	91.44	8.56	62.17	15.10	37.83	84.94
12	99.99	9.68	7.12	87.66	3.49	3.38	6.82	13159	13590	23	96.82	3.18	28.78	6.21	71.22	93.77
6	76.29	9.6	3.72	28.49	3.46	3.02	4.86	13240	14162	10280	76.26	23.74	70.45	33.34	29.55	66.56
3	85.86	9.61	3.94	44.11	3.46	3.19	5.11	13205	14100	7760	85.88	14.12	64.79	20.85	35.21	79.18
48	85.44	9.69	3.72	42.56	3.27	2.89	5.37	13184	14172	7748	84.63	15.37	67.51	25.24	32.49	74.79
43	72.84	9.74	3.43	28.38	3.49	3.01	4.9	13129	14131	10172	74.71	25.29	73.69	35.51	26.31	64.43
19	93.51	9.28	5.63	63.69	3.8	3.61	6.69	13159	13754	4293	93.71	6.29	43.15	11.07	56.85	89.03
22	98.32	9.29	6.9	74.88	3.78	3.73	5.09	13159	13622	439	96.48	3.52	28.34	4.73	71.66	95.21
8	61.46	9.36	3.15	18.4	3.62	3.2	4.23	13130	14170	11614	59.28	40.72	80.05	47.58	19.95	52.40
51	90.26	9.73	3.98	61.88	3.54	3.21	6.53	12882	14119	1669	90.07	9.93	63.16	18.32	36.84	81.67
18	84.94	9.77	3.68	43.23	3.64	3.32	5.37	13202	14140	8051	84.60	15.40	68.13	22.72	31.87	77.16
40	93.7	10.53	3.89	64.59	3.36	3.03	6.03	13056	14091	4635	89.06	10.94	67.10	19.63	32.90	80.31
37	87.94	10.55	3.87	42.84	3.34	2.92	5.34	13056	14140	7819	82.86	17.14	69.61	27.41	30.39	72.44
29	86.01	9.36	3.6	41.38	3.59	3.18	5.84	13130	14099	7744	84.75	15.25	67.40	24.80	32.60	75.07
7	92.55	9.36	4.31	69.14	3.67	3.46	6.2	13130	13983	3037	92.21	7.79	57.54	13.16	42.46	86.93
34	80.02	10.52	3.79	33.92	3.47	3.03	4.99	13056	14138	9294	77.66	22.34	72.02	32.12	27.98	57.82
33	50.59	9.55	3.46	15.09	3.4	2.92	3.83	13175	14173	12266	47.64	52.36	82.74	58.99	17.26	40.91

FIGURE 6.1 Yield, product ash and product sulfur obtained for each of the replicate tests conducted throughout the parametric testing program.

and storage procedures used to maintain a representative sample were acceptable. The estimated standard deviations for each of the assays determined in the present work are tabulated in Table 6.5. The relatively low values of standard deviation also indicate that the test data acquired from the parametric testing program are reliable and reproducible. It should also be noted that in general the product assays appear to be the most reliable, while the reject assays are the least dependable. This result is not unexpected given the comparatively smaller weight of the reject samples and the very high concentration of very fine particles, e.g., clays, in this stream.

The effects of the various operating conditions on the recovery and ash rejection for this particular sample of coal are shown in Figure 6.2. Both the energy (i.e., Btu) recovery and combustible recovery values are included in this figure. Despite the fact that a wide range of test conditions was examined, most of the experimental values fall along a single grade-recovery curve. A similar set of test results was obtained for sulfur rejection. (Figure 6.3). Although not shown, nearly all of the test results fall very near to or on the release analysis curve obtained for this sample of coal. These findings suggest that a flotation column produces nearly the same metallurgical performance, i.e., grade-recovery curve, if wash water is properly utilized to prevent the nonselective entrainment of fine mineral matter. A change in the operating parameters does impact the capacity and/or shift the column to a new point of the grade-recovery curve, but these changes do not generally shift the performance of the column to a higher or lower curve. When a separation is made over a reasonable range of operating conditions, only those parameters that can alter the hydraulic carry-over of feed water into the product launder appear to be capable of altering the grade-recovery curve for a given coal sample. Therefore, the grade-recovery relationship appears to be primarily determined by the characteristic nature of the coal sample, i.e., degree of liberation and component hydrophobicity. It must be stressed, however, that this general conclusion holds true only if the wash water that is added to the column is effective in preventing entrainment. Changes in any of the operational parameters that would produce a change in the bias flow rate (i.e., flow rate of wash water downward through the stabilized froth phase) could produce a change in the metallurgical performance. In fact, those points which deviate most from the overall grade-recovery curve were obtained under conditions in which the bias flow was the lowest, i.e., wash water was least effective.

Table 6.5 Estimated Values of Standard Deviation for Various Assays Used in the Parametric Test Work

<u>Component</u>	<u>Estimated Standard Deviation</u>
Mass Yield (%)	0.85
Product Ash (%)	0.05
Reject Ash (%)	2.63
Feed Ash (%)	0.41
Product Sulfur (%)	0.07
Reject Sulfur (%)	0.16
Feed Sulfur (%)	0.21
Product Btu	135
Feed Btu	106

FIGURE 6.2 Btu recovery and combustible recovery as a function of ash rejection for all of the test conditions examined in the parametric study.

FIGURE 6.3 Btu recovery and combustible recovery as a function of total sulfur rejection for all of the test conditions examined in the parametric study.

The effect of the operating parameters on separation efficiency are demonstrated in Figures 6.4 and 6.5. Two different separation efficiencies have been calculated, one based on the separation of combustibles from ash and the other based on the overall separation of energy and sulfur. Combustible separations efficiency ($SE_{\text{combustible}}$) has been calculated using the expression:

$$SE_{\text{combustible}} = 100Y \left[\frac{100-A_p}{100-A_f} - \frac{A_r}{A_f} \right] \quad [1]$$

in which Y is the product yield and A_p , A_r and A_f are the ash contents of the product, reject and feed streams, respectively. The energy-sulfur separation efficiency (SE_{overall}) was calculated from:

$$SE_{\text{overall}} = Y \frac{BTU_p}{BTU_f} + (100-Y) \frac{S_r}{S_f} - 100 \quad [2]$$

in which BTU_p and BTU_f are the respective calorific (Btu) values for the product and reject streams and S_r and S_f are the respective sulfur contents of the reject and feed streams. A more appropriate form of this expression would utilize pyritic sulfur in place of total sulfur, but these assay values were not available at the time the calculations were performed.

The results shown in Figure 6.4 show that most of the separation efficiency values fall along two distinct parabolic curves. In both cases, however, a maximum separation efficiency could be obtained at a ash rejection of approximately 65%. This value appears to be independent of whether the separation efficiency was calculated on a combustible basis or overall basis. This level of ash rejection corresponds to the "bend" or "knee" in the grade-recovery curve shown in Figure 6.2. Therefore, it can be concluded that the maximum separation efficiency for a given coal occurs at the point just before the large deterioration in yield. In the present work, the maximum separation efficiency-ash rejection relationship appears to be a function of the coal characteristics. As a result, various combinations of operating conditions can be utilized to obtain the same maximum separation efficiency.

Figure 6.5 shows the separation efficiency values calculated for the various tests as a function of sulfur rejection. As before, most of the points fall along two separate parabolic curves, with the maximum separation efficiency for each curve occurring at a sulfur rejection of approximately 20%. This value also corresponds to the abrupt bend in the grade-recovery curve shown in Figure 6.3. This finding indicates that sulfur is more difficult to reject than ash for this particular sample. This phenomenon is demonstrated more

FIGURE 6.4 Combustible separation efficiency and overall separation efficiency as a function of ash rejection for all of the test conditions examined in the parametric study.

FIGURE 6.5 Combustible separation efficiency and overall separation efficiency as a function of total sulfur rejection for all of the test conditions examined in the parametric study.

clearly in Figure 6.6 in which sulfur rejection has been plotted as a function of ash rejection. As shown, there is a distinct relationship between ash rejection and sulfur rejection. If both sulfur and ash were rejected equally, the points should fall along the dashed line shown in the figure; however, this is clearly not the case. The data plotted in Figure 6.6 suggest that the best separation point for this particular coal would be at an ash rejection of 65% and a sulfur rejection of 20%.

Statistical Data Analysis and Response Surface Development

After all of the flotation test data were collected and mass-balanced, the assay values were analyzed using a statistical data analysis program (DESIGN-EXPERT) developed by Stat-Ease of Minneapolis, Minnesota. DESIGN-EXPERT was used to set up the experimental design and perform all required statistical computations and regression analyses. The overall objective of this effort was to develop an empirical relationship between the various operating parameters (i.e., air rate, frother dosage, etc.) and a variety of response variables (i.e., recovery, product ash, separation efficiency, etc.). This goal was accomplished via the following steps:

- 1) Data Collection - The first stage of the experimental design required the set up and collection of the experimental data. The test matrix utilized is provided in Table 6.3. The tests were performed in random order and the results were mass balanced to obtain a consistent set of results prior to proceeding to the next step.
- 2) Data Analysis - After collecting the specified experimental data, the response data were entered into the DESIGN-EXPERT software package. The data analysis procedure was an iterative process since, in most cases, several analyses were required in order to obtain a suitable response surface. When deemed necessary, data transformations were conducted in order to obtain the best possible response surface that described the experimental data. In the present work, either no transformation or log transformations were found to provide the best fits for the experimental data. After selecting an appropriate transformation and response surface, the initial model fitting was performed by the DESIGN-EXPERT software. The available models included standard linear, quadratic and cubic models. Although cubic models tended to provide the best fit to the experimental data, quadratic or standard linear models were generally selected since they were capable of providing good correlations while minimizing the complexity of the model. After selecting an appropriate model, a variety of statistical routines were executed to identify the goodness-of-fit. For all runs, the values of regression coefficients, standard errors, variances, t-tests, etc., were determined as a means of

FIGURE 6.6 Relationship between ash rejection and total sulfur rejection for test results obtained during the parametric study.

quantifying the statistical significance of each of the coefficients in the model.

- 3) Response Surface Plotting - After a reasonable mathematical model of the desired response was analyzed in light of the various operational parameters, the resultant response surface was plotted using a surface contour program. When combined with the modeling expressions, these plots provide the final product from the parametric test work. The influence of key operating parameters and the joint interactions of the various operating parameters on the process performance can be visualized from the response surface plots.

To date, the following performance indicators have been analyzed using the aforementioned procedures:

- a) recovery
- b) product ash
- c) product sulfur, and
- d) separation efficiency.

Comparisons between the results predicted by the modeling exercise and the results obtained from the experimental measurements are shown in Figures 6.7 - 6.10. In general, very good correlations were obtained between the model predictions and experimental results.

Because of the relatively large amount of information contained in work, it is not practical, within the context of this report, to elaborate on the results obtained with each of the performance indicators. However, several general conclusions can be addressed at this time. First, the modeling exercise confirms the theoretical analyses by demonstrating the importance of flotation rate and retention time in determining flotation recovery. As shown in Figure 6.11, recovery is strongly dependent on both retention time and air hold-up (a measure of bubble size). Most of the data points fall on or near the fitted response surface. Since retention time is a measure of capacity, this plot clearly demonstrates that for a given level of recovery the capacity can be maximized by decreasing the bubble size.

The trade-off between grade and recovery is best observed by examining the response surfaces constructed for separation efficiency. Because of the importance of separation efficiency in establishing the appropriate operating point on the grade-recovery curve, a detailed examination of these response surfaces should provide information as to the appropriate level for each of the operating parameters (i.e., gas rate, frother dosage, feed rate, etc.). Several significant trends can be observed. First, the solids content of the feed stream

FIGURE 6.7 Comparison of experimental results with predictions made by the empirical model developed to describe combustile recovery as a function of the various operating parameters.

FIGURE 6.8 Comparison of experimental results with predictions made by the empirical model developed to describe product ash content as a function of the various operating parameters.

FIGURE 6.9 Comparison of experimental results with predictions made by the empirical model developed to describe product sulfur content as a function of the various operating parameters.

FIGURE 6.10 Comparison of experimental results with predictions made by the empirical model developed to describe the separation efficiency of combustibles from ash as a function of the various operating parameters.

Regression Surface Plot

FIGURE 6.11 Regression surface plot demonstrating the influence of air hold-up (a measure of bubble size) and retention time (an measure of throughput capacity) on combustible recovery.

appears to have only a limited impact on the separation efficiency, except under conditions of low gas flow rates and low wash water rates. Under low gas rates, the column becomes limited by the gas-carrying capacity sooner because of the lower amount of surface area available to carry particles. Under this condition, the separation efficiency drops due to a decrease in recovery. Under low wash water rates, the column becomes less effective in preventing the hydraulic carryover of feed water into the froth product. Since a higher feed solids introduces a higher concentration of mineral fines into the feed water, the product grade is decreased as the feed solids content increases.

Higher gas flow rates appear to have a beneficial effect on separation efficiency for all cases. However, the response surface plots appear to suggest that higher frother dosages may be required when using the high gas rates in order to obtain the best separation efficiency. This result can properly be attributed to the fact that a large amount of bubble surface area is present at the higher gas rates. Higher frother dosages could then be required to maintain a small bubble size. Higher gas rates also seem to dictate the use of large wash water flow rates. At the higher gas rates, more water is carried into the froth launder by the increased flow of air bubbles. In order to maintain the desired bias flow rate for removing entrained particles, additional wash water must be added to compensate for water lost at the higher gas rates.

An optimum frother dosage was identified for nearly all of the test conditions examined. In general, too low a frother dosage resulted in the production of large bubbles and a loss of recovery (which reduced the separation efficiency). Low dosages also contributed to a decrease in froth stability which also adversely affected the flotation recovery. On the other hand, too much frother produced too stable a froth and resulted in an excessive flow of water into the product stream. Unless wash water was increased to compensate for the loss of water to the product, a decrease in the bias flow rate was noted and the separation became less effective. In a similar fashion, an optimum dosage for collector was also found to exist for each of the test conditions examined.

A more detailed analysis of the response surface data is currently under way. The results of these analysis will be reported in the future.

6.2.2 Optimum Column Cell Circuit Configuration

Test work is continuing on evaluation of different circuits for upgrading the Pittsburgh No. 8 seam coal supplied by B&W.

Additional data analysis using the BILMAT material balances are being performed for each circuit. The determination of pyritic sulfur values for earlier tests are also being conducted. As reported in the previous technical progress report, several different circuit arrangements are being or have been examined. These include single-stage (SS), rougher-scavenger-cleaner (RSC), rougher-cleaner-recleaner (RCRC) and rougher-scavenger-scavenger cleaner (RSSC) circuits. The test work continues to show that each of the circuits under consideration produce results that fall along the same grade-recovery curve (provided that wash water is properly added during the test run). The very slight improvement in ash and sulfur rejections obtained from the multiple column circuits appears to be due to the release of entrapped particles of fine mineral matter. These particles are entrapped between coagulated coal particles and between coal particles attached to air bubbles during the first stage of flotation. After repulping the flotation concentrate prior to feeding the second stage of flotation, the entrapped particles of fine mineral matter are released and subsequently rejected. However, the slight improvement in metallurgical performance does not presently appear to justify the additional circuitry. Additional test work will be conducted using coal samples from other sources to determine if the results obtained with the Pittsburgh No. 8 sample can be translated to other coal seams. This test work will be initiated after the samples of Upper Freeport and Illinois No. 6 coal are prepared by PTI.

If improvements in metallurgical performance with columns are not possible, other factors will be considered to determine whether multiple-column circuits have desirable features. For example, it may be possible to develop circuit arrangements which minimize frother consumption while maximizing throughput. Identifying circuits with these characteristics will be the major focus of Subtask 6.2 through the remainder of the project.

6.2.3 Column Cell Flotation Model Development

The rate constant data derived from the various circuit tests are continuing to be analyzed and simulations using multiple-column circuit arrangements are being made. The data obtained from the circuit simulations are being compared with the actual test results obtained with the various circuits. Flotation experiments are continuing in an attempt to better understand the phenomena which occur in the froth phase. Laboratory test results continue to suggest that in most cases, the performance of a coal flotation column is limited by the characteristics of the froth. Two such constraints have been identified: gas-carrying capacity and froth overloading. The carrying capacity limitation occurs when there is insufficient bubble surface area available for particles to attach. Froth overloading occurs when the froth phase above the wash water inlet drains to a point to which it is too heavily loaded with solids and, therefore, collapses.

A series of expressions are being developed in an attempt to quantify these phenomena so their impact can be incorporated into the simulation program.

APPENDIX I

**ILLINOIS #6 SEAM
PYRITE LIBERATION STUDY
ICF KAISER ENGINEERS**

By

**TraDet, Inc.
P. O. Box 2019
Wheeling, West Virginia 26003
(304) 547-9084
July, 1990**

[Faint handwritten notes]

APPENDIX I

RAW COAL - CRUSHING TO MINUS 1/4-INCH SQ

**ILLINOIS #6 SEAM
PYRITE LIBERATION STUDY
ICF KAISER ENGINEERS**

RAW COAL CRUSHED TO MINUS 1/4-INCH SQ

SIZE DISTRIBUTION

Size Fraction	Distribution %
<hr/>	<hr/>
Plus 1/4-Inch SQ	51.86
Minus 1/4-Inch SQ	48.14
Cumulative	100.00

ILLINOIS #6 SEAM
PYRITE LIBERATION STUDY
ICF KAISER ENGINEERS

RAW COAL - MINUS 1/4-INCH SQ

SIZE DISTRIBUTION

Size Fraction	Distribution %
Plus 1/4-inch SQ	0.00
1/4-inch SQ x 48-mesh	77.74
48 x 200-mesh	6.36
Minus 1/4-inch SQ	15.90
Cumulative	100.00

MINUS 200-M?

Doesn't look right

1/4" X 48-mesh Fraction of 1/4" Topsize Raw Coal

1/4-INCH X 48-RECH, 1.35 X 2.00 - CRUSHED TO MINUS 40M
(Heavy Liquid Super Centrifuge)

Illinois #6 Sand
Pyrite Liberation Study
ICF Kaiser Engineers

SPECIFIC GRAVITY	NET BASIS				CUMULATIVE PRODUCT (Pctage)				NO. REJECT
	% Wt.	% Ash	% Sulf.	Wt. % Sulf. per lb. per lb.	% Wt.	% Ash	% Sulf.	Wt. % Sulf. per lb. per lb.	

1.35	6.82				6.82				
1.35	2.80	71.84	25.98	2.95	9,955	13,450			
2.00		21.34	69.28	9.99	2,857	9,300			

Physical Feed Sample
Head Sample (Run 1/4" X 48m - 1.35 Float Fraction)

% Ash (D/B)	0.00	0.00
% Sulfur (D/B)	0.00	0.00
Wt./lb. (D/B)	0	0
Wt./lb.	0	0
% Pyritic Sulf. (D/B)	0.00	0.00
% Sulfate Sulf. (D/B)	0.00	0.00
% Organic Sulf. (D/B)	0.00	0.00

1/4-INCH X 48-MESH, 1.35 X 2.00 - CRUSHED TO MINUS 400
(Heavy Liquid Super Centrifuge)

Illinois #6 Seam
Pyrite Liberation Study
ICE Engineer Engineers

SPECIFIC GRAVITY	NEW BASIS					CUMULATIVE PRODUCT (Pilot)					RECOVER.	PYRITIC RECOVER
	Wt.	ash	Sulf.	pyr.	pyr.	Wt.	ash	Sulf.	pyr.	pyr.		
Sink Float				per lb.	per lb.				per lb.	per lb.		
1.35	6.82	3.36	2.47	13,116	13,573	6.82	3.36	2.47	13,116	13,572	10.33	
1.35	71.84	25.98	2.93	9,935	13,450	78.66	24.02	2.91	10,229	13,463	92.96	
2.00	21.34	69.28	9.99	2,857	9,300	100.00	33.68	4.42	8,656	13,051	100.00	

Physical Feed Sample Feed Sample (Run 1/4" X 400 -
1.35 Float Fraction)

ash (D/B)

Sulfur (D/B)

pyr/lb. (D/B)

pyr/lb.

pyritic Sulf. (D/B)

Sulfate Sulf. (D/B)

Organic Sulf. (D/B)

48 x 200-mesh Fraction of 1/4" Topsize Raw Coal

48 X 200-MESH FRACTION OF 1/4-INCH AND TOPSIZE COAL
(Static Bath Float/Sink)

Illinois #6 Seam
Pyrite Liberation Study
ICP Kaiser Engineers

SPECIFIC GRAVITY	ICF Kaiser Engineers													
	NET WEIGHTS				CUMULATIVE PRODUCT (FLOAT)				BTU RECON.	PYRUL RECON.				
Sink Float	t wt.	t Ash	t Sulf.	BTU RECONU per lb. per lb.	t Pyr. Sulfur	t Sulf. Sulfur	t Oxy. Sulfur	t wt.	t Ash	t Sulf.	BTU RECONU per lb. per lb.	t Pyr. Sulfur	t Sulf. Sulfur	t Oxy. Sulfur
1.35	42.13	2.38	2.52	13,391	0.22	0.03	2.27	42.13	2.38	2.52	13,391	0.22	0.03	2.27
1.35	35.83	17.43	3.24	10,971	2.70	0.09	0.45	77.96	9.30	2.85	12,279	1.36	0.06	1.43
2.00	22.84	71.00	18.56	1,768	6,097			100.00						100.00

48 X 3000, 1.35 PL - CHANGED TO -2000
(Heavy Liquid Super Centrifuge)

Illinois #6 Sand
Pyrite Liberation Study
ICF Malone Engineers

SPECIFIC GRAVITY	DRY BASIS					CUMULATIVE PRODUCT (FLOAT)					PYRITE RECOVERY	PYRITE RECOVERY
	Wt.	ash	Sulf.	Pyr.	Wt. per lb.	Wt.	ash	Sulf.	Pyr.	Wt. per lb.	Wt. per lb.	Wt. per lb.
Sink Float	1.30	35.86	1.20	2.22	12,897	13,853	35.86	1.20	2.22	12,897	13,854	36.44
	1.35	45.55	1.47	2.27	12,786	12,977	41.41	1.35	2.25	12,835	13,011	82.33
	1.40	14.85	3.88	2.52	12,533	13,839	96.26	1.74	2.29	12,768	13,015	97.00
	1.40	1.80	13.04	3.82	11,381	13,887	98.06	1.95	2.32	12,762	13,016	98.61
	1.60	9.98	14.11	4.63	11,295	13,150	98.64	2.02	2.33	12,754	13,017	99.13
	2.00	0.44	18.77	5.14	10,725	13,283	99.08	2.09	2.34	12,745	13,018	99.50
	2.00	0.98	45.29	9.36	6,788	12,485	99.98	2.48	2.41	12,681	13,014	99.98

Physical Read
Sample
Read Sample (Run 48 x 2000 -
1.35 Float Fraction)

ash (D/B)	2.45
Sulfur (D/B)	2.56
Wt./lb. (D/B)	13,513
Wt./lb.	13,851
Pyritic Sulf. (D/B)	0.24
Sulfate Sulf. (D/B)	0.04
Organic Sulf. (D/B)	2.28

48 X 200M, 1.35X2.00 - CHANGED TO -200M
(Heavy Liquid Super Centrifuge)

Illinois #6 Seam
Pyrite Liberation Study
ICP Kaiser Engineers

SPECIFIC GRAVITY	DRY BASES					CUMULATIVE PRODUCT (FLOAT)					STU RECON.	PYRITIC RECON.	
	% WT.	% Ash & Sulf.	STU per lb.	WAFSTU per lb.	% Pyr. Sulfur	% Sulf. Sulfur	% Org. Sulfur	% Ash & Sulf.	STU per lb.	WAFSTU per lb.	% Pyr. Sulfur	% Sulf. Sulfur	% Org. Sulfur
Sink Float	1.30	12.30	2.46	2.32	12,731	13,052	12.30	2.46	2.32	12,731	13,052	14.61	
1.30 1.35	12.30	2.69	2.36	12,673	13,024	24.76	2.58	2.34	12,702	13,038	29.14		
1.35 1.40	25.50	5.67	2.30	12,369	13,112	50.26	4.15	2.32	12,533	13,075	58.37		
1.40 1.60	28.46	13.99	2.19	11,525	13,400	78.72	7.70	2.27	12,169	13,104	88.77		
1.60 1.80	7.04	32.82	2.50	8,000	13,231	86.56	9.98	2.29	11,871	13,187	95.23		
1.80 2.00	4.56	47.92	3.48	6,633	12,736	91.12	11.88	2.35	11,609	13,174	98.03		
2.00	8.08	71.77	11.65	2,395	8,483	100.00	17.20	3.10	10,791	13,032	100.00		

Head Sample (Run 48 x 200m -
1.35x2.00 Float Fraction)

Physical Head
Sample

% Ash (D/B)	17.37
% Sulfur (D/B)	3.31
STU/lb. (D/B)	11,216
WAFSTU/lb.	13,574
% Pyritic Sulf. (D/B)	1.33
% Sulfate Sulf. (D/B)	0.09
% Organic Sulf. (D/B)	1.89

Minus 200-mesh Fraction of 1/4" Topsize Raw Coal

Minus 200m

1.30 Fl

1.30x1.35

1.35x1.40

1.40x1.60

1.60x1.80

1.80x2.00

2.00
Sink

END

DATE FILMED

12 / 20 / 90