

QUARTERLY REPORT NO. 5

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For

**ENGINEERING DEVELOPMENT OF
ADVANCED PHYSICAL FINE COAL
CLEANING TECHNOLOGIES –**

FROTH FLOTATION



Prepared for
U.S. DEPARTMENT OF ENERGY
PITTSBURGH ENERGY TECHNOLOGY CENTER
Pittsburgh, Pennsylvania

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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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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 SO₂ per million BTU. This was mainly attributed to the high pyritic sulfur content of the boiler fuel. A significant reduction in SO₂ 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 and Virginia Polytechnic Institute and State University. The organizational chart for this project is presented in Figure 1.1.

This document is the fifth quarterly report prepared in accordance with the project reporting requirements covering the period from October 1, 1989 to December 31, 1989. 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.

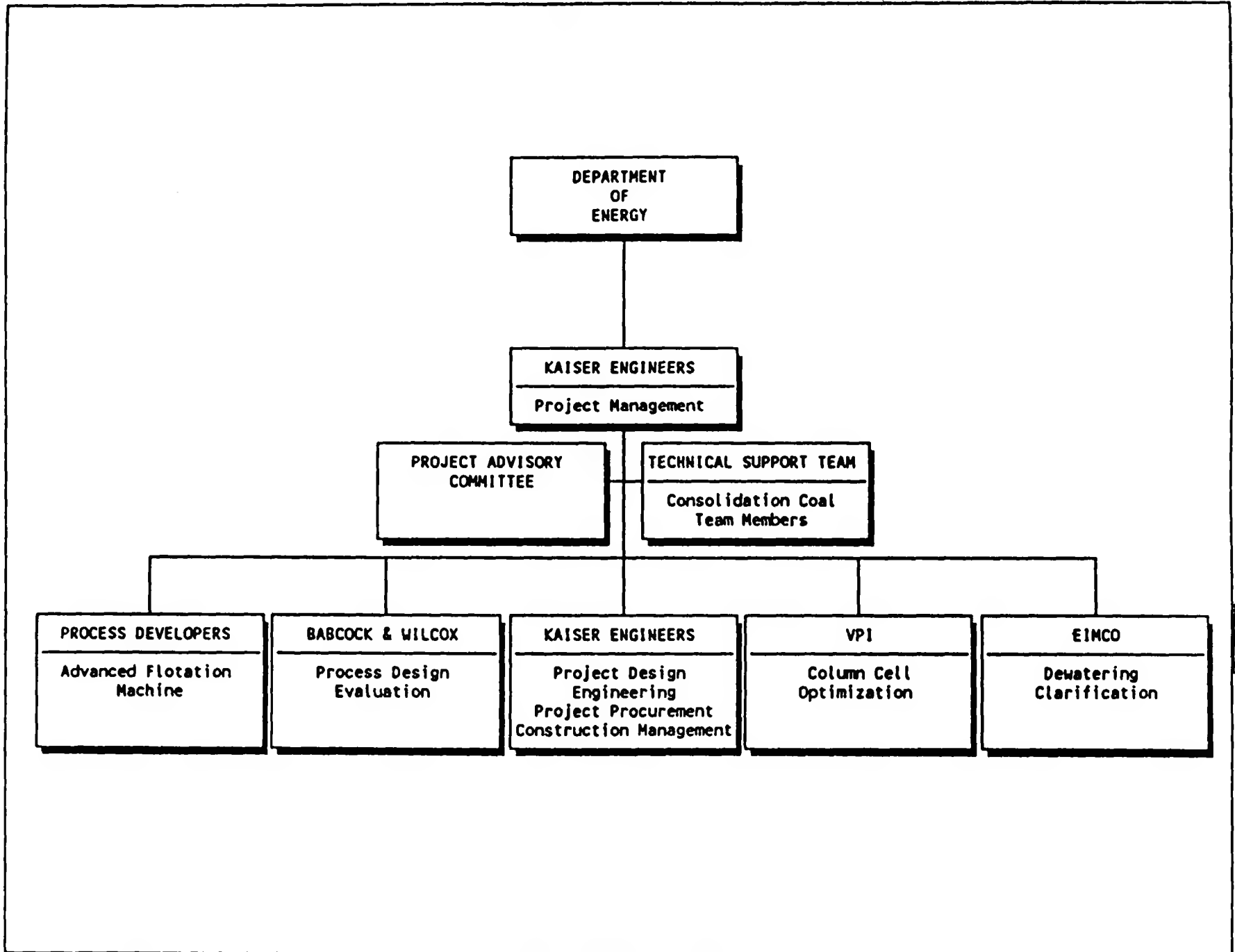


Figure 1-1: Project Organization Chart

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 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 and Virginia Polytechnic Institute and State University 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, 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 Four Quarters

Progress was made in the previous four quarters (October 1, 1988 to September 30, 1989). 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 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 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, 1989.

2.0 TASK 2 PRELIMINARY CONCEPTUAL DESIGN

2.1 Overview and Scope

The 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.

Each sub-task was logically assigned to provide necessary information for the next sub-task, ultimately resulting in completion of the conceptual design. 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, complete with energy and material balances 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 will be 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 are now proceeding with the remainder of the project. No additional work was 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 has identified areas where uncertainties exist in the design of the unit operations for the advanced froth flotation process. Some of these problem

areas cannot 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 their ability to effectively process ultra fine particles.

Each 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 not received approval of the task report. No additional work was completed during this quarter.

4.0 TASK 4 TEST PLAN FORMULATION

4.1 Overview and Scope

This task developed 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 will be 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 will be procured. After agreement with DOE, a selected sample of coal from those previously listed can be secured.

The test plan will be developed in two parts. The first part will list procedures for engineering and computation analysis of those deficiencies previously identified that are amenable to this type of solution. Likewise, the second part will prepare procedures for bench-scale testing and component development for those deficiencies previously identified in Task 3.

The first part, engineering analysis and computation, must provide for means of employing presently known theory from other industries to address deficiencies. This includes 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 the deficiency.

The second part, bench-scale testing and component development, becomes necessary when the part one information is unavailable or the theory has never been commercially applied. Justification for the test work must be provided to show that technical data and process needs can 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 will be based upon non-continuous and/or semi-continuous bench-scale units of general laboratory design and will be only those unit operations identified as deficiencies in Task 3.

The detailed, quantified tests will address obtaining data necessary for solving problems uncovered in the deficiency review. Each identified deficiency will have a plan developed that will address the reason for the testing, the means for the test matrix to obtain results and the expected results. Each test plan must establish procedures, adhering as much as possible, to known and industry acceptable procedures for sampling and data collection. Raw data collection will 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 should contain schedules, manpower requirements, and resources necessary to obtain information to define a commercially available system.

The plan for use of the team members has been 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 should be calculated. A sample of all three of the referenced coals will be obtained, preferably from the same source as the Surface Control contractor. This coal will be stored and handled as outlined in the developed 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 is being developed. The DOE and all team members will be able to 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 has been 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 and have been implemented. The two portions are: "Round Robin Test Plan" and the "Coal Procurement and Storage Plan". Both of these will be discussed further in the Task 5 section.

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 will be examined in a multi-tier program at B&W. Laboratory scale studies will be 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 will then be used to guide small, semi-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 of the process operating costs.

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 and 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 POC module and 20TPH semi-works plant design.

Both the bench-scale and semi-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 advanced flotation technology.

The bench-scale and process testing will consist of eleven major subtasks and be performed over a period of 12 months. The Bench-Scale Process Testing "Flowsheet" shown on Figure 5.1, illustrates 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 - Pittsburgh #8

The raw coal characterization was on the Pittsburgh No. 8 coal seam from the Ohio Valley Coal Co., Alledonia, Ohio. The raw coal sample was procured on September 7, 1989.

TraDet, Inc. of Wheeling, West Virginia completed the pyrite liberation study as shown in Figure 5.2. During the study it became evident the large quantities of material of the minus 200 mesh size fraction had to be separated by organic liquids. This resulted in using centrifugal float/sink, which has the major advantage to gravity separate the colloidal size fraction which is not achievable with static procedures.

Work conducted by DOE, PETC, Coal Preparation Division, developed a procedure for centrifugally separating fine coal. Their procedure greatly improved the results for fine coal gravity separations. However, a problem was indicated when processing the 16 micron top size samples which showed poorer yield/ash relationships, specifically the 1.30 float yield/ash. Intuitively, as topsize is reduced, more and more coal of low specific low ash should be liberated, data from centrifugal work does not confirm this expected result. Therefore, TraDet examined some of the inherent problems associated with fine size centrifugal float/sink work. A topical report will be completed on this work during the next quarter.

The objective of this study was to complete the laboratory performance of an anticipated routine flowsheet paralleling an advanced grinding/flotation pilot plant scheme. Two problems were encountered in the initial implementation of the laboratory work:

- 1) The multi-staged topsize reduction/float-sink sequence, in conjunction with the inherent properties of the Pittsburgh #8 coal (low quantity of mid-gravity material), required very large starting samples which were not conducive to the batch centrifuge float/sink procedure.

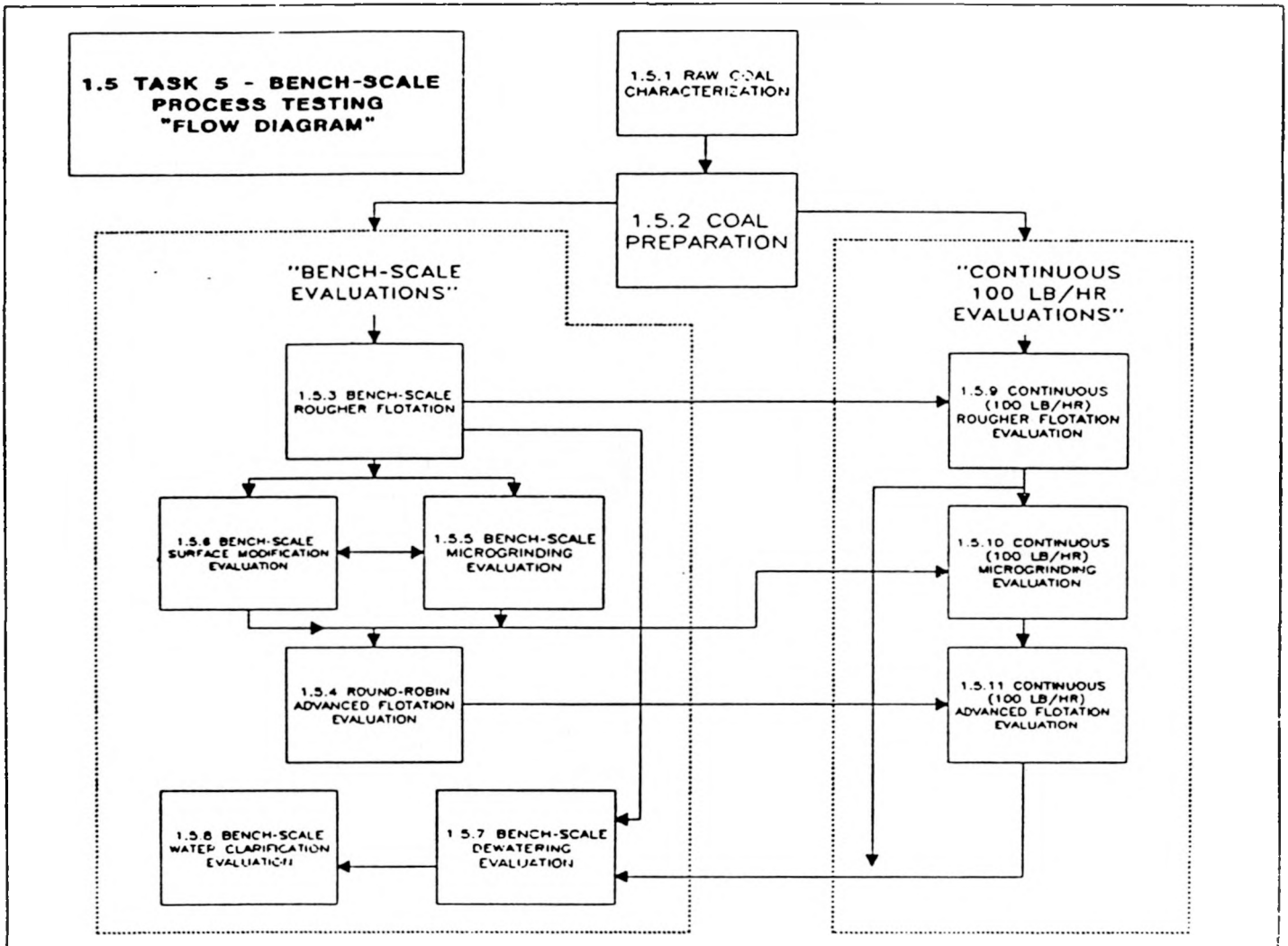
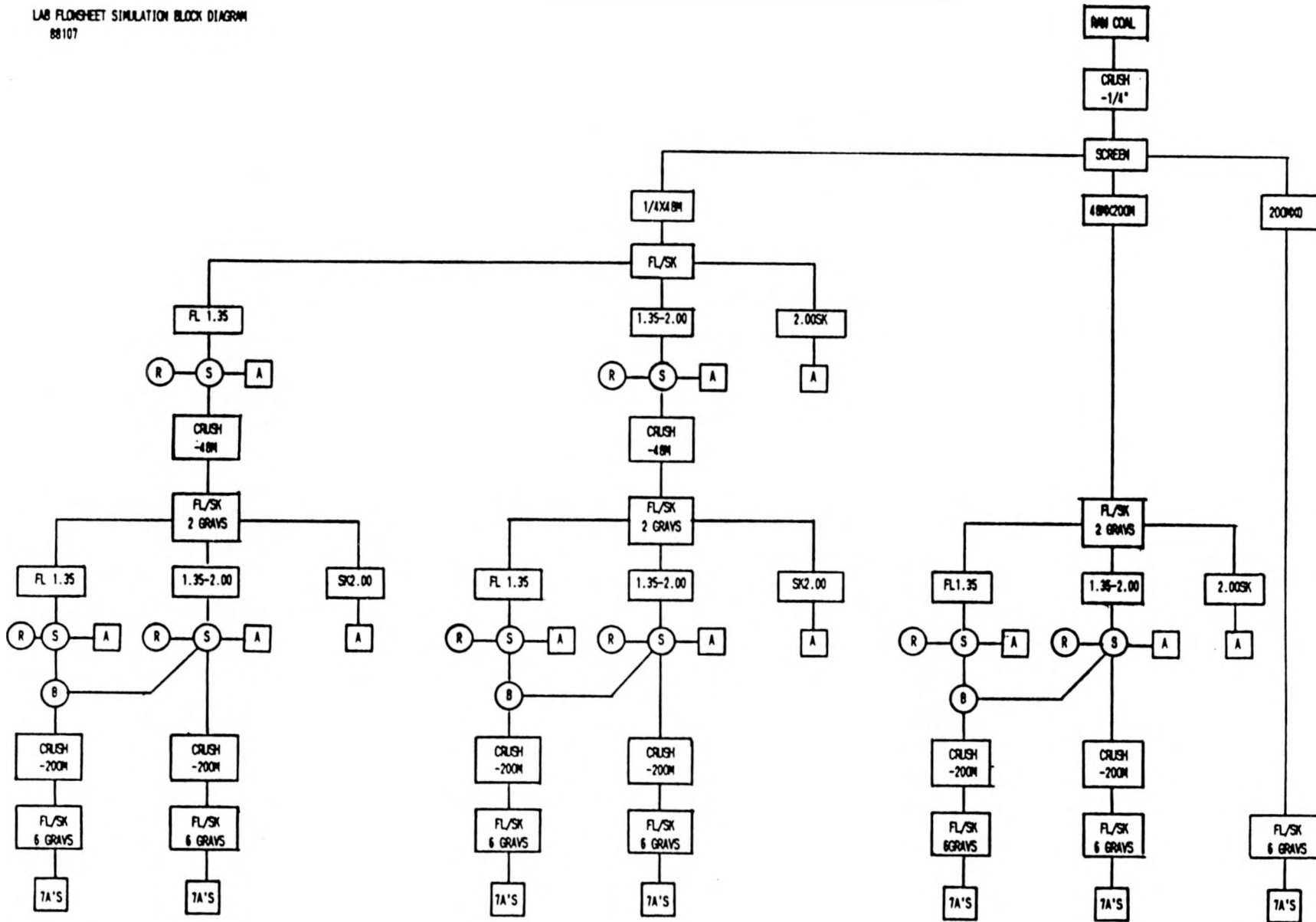


Figure 5.1
Bench Scale Process Testing Flowsheet

FIGURE 5.2 PYRITE LIBERATION TEST

LAB FLOWSHEET SIMULATION BLOCK DIAGRAM
88107



A ANALYSIS(W, A, S, P, DM%, AS%, TOT. SUL. %, PYR. SUL. %, BTU/W)
 B BLEND (AS PER NTV'S)
 S SPLIT 50:50
 6 GRAVITIES = 1.30, 1.35, 1.40, 1.60, 1.80, 2.00
 R RESERVE SPLIT PRIOR TO ANY CRUSHING OR BLENDING STEP

NOTE: ALL FLOAT/SINK ANALYSIS ON MINUS 40 MESH SIZE FRACTIONS BY CENTRIFUGE METHOD

- 2) The sequential removal of the 2.00 sink fractions results in higher than natural occurring proportions of particles with close to a 1.30 specific gravity further exaggerating the previously recognized reproducibility problems with the 1.30 specific gravity separation.

The recognition of the above two problems resulted in the re-evaluation of the process. This re-evaluation resulted in both the development of a higher g-force, semi-continuous flow, float/sink procedure and the theoretical evaluation of the principles controlling the efficient float/sink separation of ultra-fine materials (minus 50-micron).

A procedure utilizing a Sharples continuous flow Super-Centrifuge with organic suspensions of the coal being processed, was developed as a replacement to the batch centrifuge procedure. This approach permitted separating larger sample sizes (limited to 100 to 150 gms. of sink) at lower concentrations (1% w/v), while simultaneously resulting in both a 10 fold increase in separating force (g-force) and the application of the same g-force to each particle. Based on the minus 200-mesh samples, the super-centrifuge had consistently better results when compared to batch centrifuge with the differences becoming less at higher separating gravities. As anticipated, the 48 x 200-mesh results were similar at the 1.35 gravity and essentially identical at the 2.00 gravity. This is implying that the super-centrifuge results in a more efficient separation with minus 200-mesh feed and also a more efficient separation when there is a significant amount of near gravity material (1.30 specific gravity). This would be anticipated performance based on the theoretical interrelationship of particle size and g-force.

TraDet utilized a theoretical approach based on the extrapolation of Stoke's law to a centrifugal force field to develop/optimize the procedure. This approach, and resulting procedure, is in contrast to a multiple variable, statistically developed procedure utilized by other investigators. This approach varied multiple parameters to optimize the Separating Efficiency Index (EI). The two approaches resulted in some differences which will require future resolution. Specific among these differences is the stated lack of dependence of the Separating Efficiency Index on the centrifuge rpm and retention time in the statistically developed procedure. This previous finding contradicts both the actual and theoretical results of this study resulting in TraDet believing that specific properties of the one optimization sample masked the overall relationship. These idiosyncrasies are further compounded by the approach that defines the specific float/sink procedures to be utilized as a function of the topsize of the sample when the actual separating efficiency is dependent upon a combination of the bottom size of the sample and the amount of near gravity material. An additional factor influencing the ability to reproduce results between laboratories is the noted tendency

to utilize centrifuge rpm as an operating parameter as opposed to g-force. With a batch centrifugal procedure there is a wide range of applicable g-forces (sometimes a two-fold difference) depending upon the distance of the particle in the centrifuge flask from the center of rotation (one of the advantages with the continuous flow super-centrifuge). The above noted discrepancies, in conjunction with the utilization of the batch centrifugal float/sink procedure as a reference baseline for the development of Physical Clean Coal Technologies, suggest that an immediate effort should be made to optimize both the batch centrifugal and super-centrifugal procedures. This optimization procedure needs to completely re-evaluate the definitions/parameters utilized to determine which procedure is to be used (coarse static bath, fine float/sink, batch centrifuge, or continuous flow super-centrifuge).

The data for the laboratory analysis of the pyrite liberation study is given in Appendix "A". This data is being evaluated, and as previously stated, and will be incorporated in a topical report to be completed during the next quarter.

5.2.2 Advanced Flotation Round Robin

During this quarter the Round Robin test program was completed through Phase I. This test program was developed to determine the "best available" advanced flotation device. A topical report will be produced during the next quarter to cover the final results in detail.

In subtask 1.5.11, an advanced flotation machine capable of processing 100 pounds per hour is required. This flotation machine will be utilized to verify operating conditions, quality performance, and generating material for filtration, dewatering and clarification equipment testing.

There are several alternative advanced flotation techniques developed to commercial and/or near commercial size unit operations. These alternatives differ primarily in the procedure and chemistry used to generate bubbles and/or treat the coal surfaces during flotation, procedures for injecting fine bubbles into the flotation cell, and the physical design of the flotation cell.

The tests in Subtask 1.5.11 will use the most efficient, cost effective flotation cell available to improve the possibility of attaining the maximum amount of Btu recovery and maximum amount of pyritic sulfur rejection possible for a given coal at a given particle size distribution. Therefore, the objective of this round-robin testing is to select the "best available" advanced flotation technology for installation into the semi-continuous process at Babcock and Wilcox (B&W) Alliance Research Center.

A laboratory scale, round robin advanced flotation test program was conducted to aid in the selection of the advanced flotation cell. The test program was conducted in two phases. Phase one consisted of three flotation tests and used certain specified operating condition. After a review of the results of the three tests ICF Kaiser Engineers (ICF KE) instructed the participant to prepare a sample of coal to the specified top size. The participant determined the reagent dosage rates and the number of stages of flotation that he determined would produce the maximum Btu recovery and maximum pyritic sulfur rejection. The methodology of advanced flotation round-robin test sample preparation is shown in Appendix "B".

Phase one consisted of three tests. Test 1 was conducted on material precleaned and prepared by B&W to minus 325 mesh at the fixed conditions. Test 2 was conducted on material prepared by the participant to simulate the particle size distribution of the B&W material and the same fixed conditions. Test 3 was conducted on material prepared by the participant to 100% minus 100 mesh, 80% minus 200 mesh and 50% minus 400 mesh size distribution and the same fixed conditions as Tests 1 and 2.

The participant performed analytical tests and calculated the separation efficiency. The participant forwarded the analytical test results and calculations to ICF KE. ICF KE submitted these results to the Technical Support Team (TST) composed of a representative of Consolidation Coal, Virginia Polytechnical Institute, and Babcock and Wilcox. The TST determined the best grind size for each participant, based upon the outcome of the review of the data, to perform Test 4.

Test 4 is being conducted on material prepared by the participant to the top size determined by the Technical Support Team and conditions determined by the participant.

The complete results from the two phases of testing will be recorded along with all pertinent flotation cell geometry, operating conditions, reagent type and dosage, laboratory analysis results, an estimated capital cost of a 20 tons per hour feed rate size unit. This information combined with operating costs, will be utilized by ICF KE to determine the most efficient, cost effective advanced flotation round robin test program.

The following participants agreed to participate in the advanced flotation round-robin test program on a cost shared basis.

- Deister Concentrator Company, Inc.
- B. Datta Research
- Michigan Technological University
- All Mineral (Aufbereitungstechnik GmbH & Co. KG)
- Illinois State Geological Survey
- Center for Applied Energy Research

- Virginia Polytechnic Institute and State University

Upon receipt of the information ICF KE prepared all documentation for the round-robin. ICF KE calculated BTU recovery, pyritic sulfur rejection and an efficiency number for each test. The efficiency number was calculated as follows:

$$\text{Separation Efficiency} = \text{BTU Recovery} - (100 - \text{Pyrite Rejection})$$

where

$$\text{Pyrite Rejection} = \frac{(100 - \text{Yield}) \times \% \text{ Pyrite in Refuse}}{100 \times \% \text{ Pyrite in Feed}}$$

and

$$\text{BTU Recovery} = \frac{\text{WT Yield} \times \text{Clean Coal BTU}}{100 \times \text{Raw Coal BTU}}$$

Based on the above separation efficiency, estimated capital cost supplied by participant and operating costs for a full scale, 20 TPH production unit, a successful round robin participant will be selected.

The comparison of Test 1 and 2 for each of the participants indicates that no oxidation occurred to the sample ground at B&W. In fact two participants showed worse results, two showed better results and one remained the same.

The comparison of Tests 1 and 2 to Test 3 indicates that better overall efficiencies occurred with the fine grinding to mean particle size of approximately 12 microns. All participants reporting but one showed better results. For this reason the Technical Support Team requested that all participants grind to the finer size for Test 4.

The results of Test 4 are to be completed by the end of January 1990 along with the economic conditions supplied by the participants. Therefore, during the next quarter the round robin tests will be completed, evaluated and a topical report prepared.

The results from the first three tests are shown on Table 5.1, Flotation Performance Results Phase 1 and Table 5.2, Froth Flotation Process Variables Phase 1. All participants reported results with the exception of B. Datta Research, who experienced difficulty in the operation of his device utilizing the fixed reagent conditions specified for Phase 1 testing. Included in Appendix "C" is additional round-robin data for each participant.

TABLE 5.1

FLOTATION PERFORMANCE RESULTS PHASE 1

| PERFORMANCE PARAMETER | AL MN | | | BDR | | | CAER | | | DCCI | | | ISGS | | | MTU | | | VPI | | |
|--------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| | #1 | #2 | #3 | #1 | #2 | #3 | #1 | #2 | #3 | #1 | #2 | #3 | #1 | #2 | #3 | #1 | #2 | #3 | #1 | #2 | #3 |
| CLEAN COAL | | | | | | | | | | | | | | | | | | | | | |
| WEIGHT % | 58.19 | 69.75 | 62.93 | N/A | N/A | N/A | 8.80 | 9.10 | 94.60 | 86.06 | 85.98 | 91.17 | 82.06 | 40.59 | 81.86 | 88.92 | 87.83 | 90.69 | 60.88 | 58.02 | 62.15 |
| ASH % | 9.20 | 8.30 | 7.80 | N/A | N/A | N/A | 2.47 | 2.10 | 8.48 | 4.72 | 5.70 | 6.73 | 6.60 | 6.40 | 7.80 | 4.45 | 2.90 | 5.19 | 3.35 | 3.09 | 4.90 |
| PYRITIC SULFUR % | 1.69 | 0.91 | 1.13 | N/A | N/A | N/A | 0.50 | 0.39 | 2.00 | 0.95 | 1.39 | 1.88 | 1.53 | 1.19 | 1.82 | 0.69 | 0.41 | 1.05 | 0.65 | 0.57 | 0.74 |
| TOTAL SULFUR % | 3.70 | 2.90 | 3.00 | N/A | N/A | N/A | 1.68 | 1.87 | 3.64 | 2.35 | 2.60 | 2.91 | 2.93 | 2.40 | 3.24 | 2.40 | 1.76 | 2.51 | 2.06 | 2.07 | 2.41 |
| BTU | 12680 | 12949 | 13423 | N/A | N/A | N/A | 14117 | 13870 | 13345 | 14160 | 13916 | 13651 | 13825 | 13883 | 13622 | 13882 | 13795 | 13865 | 14315 | 14176 | 14048 |
| REFUSE | | | | | | | | | | | | | | | | | | | | | |
| WEIGHT % | 41.81 | 30.25 | 37.07 | N/A | N/A | N/A | 91.20 | 90.90 | 5.40 | 13.94 | 14.02 | 8.83 | 17.94 | 59.41 | 18.14 | 11.08 | 12.17 | 9.31 | 39.12 | 41.98 | 37.85 |
| ASH % | 16.20 | 20.70 | 19.40 | N/A | N/A | N/A | 12.54 | 12.31 | 66.74 | 56.48 | 50.20 | 64.97 | 34.80 | 18.70 | 33.30 | 71.44 | 72.61 | 72.49 | 25.09 | 23.81 | 23.63 |
| PYRITIC SULFUR % | 2.97 | 4.55 | 3.61 | N/A | N/A | N/A | 1.90 | 2.80 | 7.35 | 14.25 | 11.63 | 10.90 | 8.33 | 3.77 | 7.31 | 11.15 | 10.26 | 8.63 | 5.43 | 5.41 | 6.34 |
| TOTAL SULFUR % | 4.66 | 6.54 | 5.98 | N/A | N/A | N/A | 3.77 | 4.17 | 9.13 | 11.19 | 12.51 | 11.54 | 9.30 | 5.00 | 8.44 | 16.80 | 18.15 | 15.14 | 6.92 | 6.36 | 6.64 |
| BTU | 11058 | 10231 | 10829 | N/A | N/A | N/A | 11325 | 12572 | 3432 | 5149 | 6471 | 3916 | 8955 | 11810 | 8308 | 2016 | 1960 | 2065 | 10798 | 10135 | 8212 |
| CALCULATED FEED | | | | | | | | | | | | | | | | | | | | | |
| WEIGHT % | 100.0 | 100.0 | 100.0 | N/A | N/A | N/A | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| ASH % | 12.13 | 12.05 | 12.10 | N/A | N/A | N/A | 11.65 | 11.38 | 11.63 | 11.94 | 11.94 | 11.87 | 11.66 | 13.71 | 12.43 | 11.87 | 11.38 | 11.46 | 11.85 | 11.79 | 11.99 |
| PYRITIC SULFUR % | 2.23 | 2.01 | 2.05 | N/A | N/A | N/A | 1.78 | 2.58 | 2.29 | 2.80 | 2.83 | 2.68 | 2.75 | 2.72 | 2.82 | 1.85 | 1.61 | 1.76 | 2.52 | 2.60 | 2.86 |
| TOTAL SULFUR % | 4.10 | 4.00 | 4.10 | N/A | N/A | N/A | 3.59 | 3.96 | 3.94 | 3.58 | 3.99 | 3.67 | 4.07 | 3.94 | 4.18 | 4.00 | 3.75 | 3.69 | 3.96 | 3.87 | 4.01 |
| BTU | 12002 | 12127 | 12461 | N/A | N/A | N/A | 11571 | 12690 | 12810 | 12904 | 12872 | 12792 | 12951 | 12651 | 12839 | 12568 | 12355 | 12766 | 12939 | 12480 | 11839 |
| B&W ANALYZED FEED | | | | | | | | | | | | | | | | | | | | | |
| WEIGHT % | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| ASH % | 11.75 | 11.75 | 11.75 | 12.00 | 12.00 | 12.00 | 11.95 | 11.95 | 11.95 | 12.14 | 12.14 | 12.14 | 12.05 | 12.05 | 12.05 | 11.99 | 11.99 | 11.99 | 12.40 | 12.40 | 12.40 |
| PYRITIC SULFUR % | 2.36 | 2.36 | 2.36 | 2.19 | 2.19 | 2.19 | 2.79 | 2.79 | 2.79 | 2.42 | 2.42 | 2.42 | 2.44 | 2.44 | 2.44 | 2.36 | 2.36 | 2.36 | 2.92 | 2.92 | 2.92 |
| TOTAL SULFUR % | 3.98 | 3.98 | 3.98 | 3.93 | 3.93 | 3.93 | 4.20 | 4.20 | 4.20 | 3.93 | 3.93 | 3.93 | 3.92 | 3.92 | 3.92 | 4.07 | 4.07 | 4.07 | 4.26 | 4.26 | 4.26 |
| BTU | 12350 | 12350 | 12350 | 12412 | 12412 | 12412 | 12506 | 12506 | 12506 | 12335 | 12335 | 12335 | 12389 | 12389 | 12389 | 12420 | 12420 | 12420 | 12506 | 12506 | 12506 |
| BTU RECOVERY | 61.48 | 74.48 | 67.79 | N/A | N/A | N/A | 10.74 | 9.95 | 98.55 | 94.44 | 92.95 | 97.30 | 87.59 | 44.54 | 86.85 | 98.22 | 98.07 | 98.49 | 67.35 | 65.91 | 73.75 |
| PYRITIC SULFUR REJECTION | 55.81 | 68.43 | 65.30 | N/A | N/A | N/A | 97.52 | 98.62 | 17.34 | 70.85 | 57.70 | 35.95 | 54.35 | 82.26 | 47.09 | 66.81 | 77.61 | 45.76 | 84.30 | 87.29 | 83.92 |
| EFFICIENCY | 17.28 | 42.92 | 33.09 | N/A | N/A | N/A | 8.26 | 8.57 | 15.89 | 65.28 | 50.66 | 33.25 | 41.94 | 26.80 | 33.94 | 65.03 | 75.68 | 44.26 | 51.65 | 53.20 | 57.66 |
| MEAN VOLUME | 10.27 | | | 11.36 | | | 11.80 | | | 11.87 | | | 12.53 | 11.62 | 42.40 | 11.14 | | | 11.28 | | |

AL MN = ALL MINERAL, BDR = B. DATTA RESEARCH, CAER = CENTER for APPLIED ENERGY RESEARCH, DCCI = DELISTER CONCENTRATOR COMPANY, INC., ISGS = ILLINOIS STATE GEOLOGICAL SURVEY
 MTU = MICHIGAN TECHNOLOGICAL UNIVERSITY, VPI = VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

TABLE 5.2

FROTH FLOTATION PROCESS VARIABLES PHASE 1

| PERFORMANCE PARAMETER | AL MN | | | BDR | | | CAER | | | DOCI | | | ISGS | | | MTU | | | VPI | | | |
|------------------------|-------|--------|--------|--------|-----|-----|------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| | #1 | #2 | #3 | #1 | #2 | #3 | #1 | #2 | #3 | #1 | #2 | #3 | #1 | #2 | #3 | #1 | #2 | #3 | #1 | #2 | #3 | |
| GEOMETRY | | | | | | | | | | | | | | | | | | | | | | |
| HEIGHT | IN | 12 3/8 | 12 3/8 | 12 3/8 | N/A | N/A | N/A | 236.0 | 236.0 | 236.0 | 122.0 | 122.0 | 122.0 | 7 7/8 | 7 7/8 | 7 7/8 | 96.00 | 96.00 | 96.00 | 60.00 | 60.00 | 60.00 |
| DIAMETER | IN | 3.00 | 3.00 | 3.00 | N/A | N/A | N/A | 2.0 | 2.0 | 2.0 | 3.0 | 3.0 | 3.0 | N/A | N/A | N/A | 1.80 | 1.80 | 1.80 | 2.00 | 2.00 | 2.00 |
| SLURRY FEED POINT | IN | 0.00 | 0.00 | 0.00 | N/A | N/A | N/A | 156.0 | 156.0 | 156.0 | 32.0 | 32.0 | 32.0 | N/A | N/A | N/A | 48.00 | 48.00 | 48.00 | 18.50 | 18.50 | 18.50 |
| WASH WATER ADDITION PT | IN | N/A | N/A | N/A | N/A | N/A | N/A | 12.0 | 12.0 | 12.0 | 1.0 | 1.0 | 1.0 | N/A | N/A | N/A | 2.00 | 2.00 | 2.00 | 3.50 | 3.50 | 3.50 |
| FROTH HEIGHT | IN | 1.00 | 1.00 | 1.00 | N/A | N/A | N/A | 48.0 | 48.0 | 48.0 | 18.0 | 18.0 | 18.0 | 0.75 | 0.75 | 0.75 | N/A | N/A | N/A | 18.50 | 16.50 | 18.00 |
| PULP HEIGHT | IN | 11 3/8 | 11 3/8 | 11 3/8 | | | | 188.0 | 188.0 | 188.0 | 104.0 | 104.0 | 104.0 | 7 1/8 | 7 1/8 | 7 1/8 | N/A | N/A | N/A | 41.50 | 43.50 | 42.00 |
| BAFFLES SPACING | IN | N/A | N/A | N/A | | | | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | NOTE 1 | NOTE 1 | NOTE 1 | N/A | N/A | N/A |
| CONDITIONS | | | | | | | | | | | | | | | | | | | | | | |
| WASH WATER RATE | GPM | N/A | N/A | N/A | N/A | N/A | N/A | 0.100 | 0.100 | 0.100 | 0.330 | 0.330 | 0.330 | N/A | N/A | N/A | 0.048 | 0.036 | 0.048 | 0.132 | 0.132 | 0.132 |
| AIR FLOW RATE | CFM | 0.071 | 0.071 | 0.071 | N/A | N/A | N/A | 0.100 | 0.100 | 0.100 | 0.100 | 0.100 | 0.100 | 0.280 | 0.280 | 0.280 | 0.261 | 0.332 | 0.332 | 0.057 | 0.063 | 0.053 |
| FEED SLURRY RATE | GPM | 0.450 | 0.450 | 0.450 | N/A | N/A | N/A | 0.340 | 0.340 | 0.340 | 0.320 | 0.320 | 0.320 | N/A | N/A | N/A | 0.017 | 0.017 | 0.017 | 0.032 | 0.032 | 0.032 |
| FEED % SOLIDS | WT | 10.00 | 10.00 | 10.00 | N/A | N/A | N/A | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 |
| FEED SLURRY pH | | 7.00 | 7.00 | 7.00 | N/A | N/A | N/A | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 |
| FEED PARTICLE SIZE | MM | | | | | | | | | | | | | | | | | | | | | |
| AIR HOLD-UP | | | | | | | | 9.50 | 9.50 | 9.50 | N/A | N/A | N/A | N/A | N/A | N/A | 30.00 | 31.00 | 31.00 | 8.80 | N/A | N/A |
| RETENTION TIME | MIN | 0.33 | 0.33 | 0.33 | | | | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 |
| REAGENTS | | | | | | | | | | | | | | | | | | | | | | |
| COLLECTOR NAME | | KEROSE | KEROSE | KEROSE | N/A | N/A | N/A | KEROSE | KEROSE | KEROSE | KEROSE | KEROSE | KEROSE | KEROSE | KEROSE | KEROSE | KEROSE | KEROSE | KEROSE | KEROSE | KEROSE | KEROSE |
| COLLECTOR RATE | #/T | 3.00 | 3.00 | 3.00 | N/A | N/A | N/A | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| FROTHER NAME | | M150 | M150 | M150 | N/A | N/A | N/A | M150 | M150 | M150 | M150 | M150 | M150 | M150 | M150 | M150 | M150 | M150 | M150 | M150 | M150 | M150 |
| FROTHER RATE | #/T | 1.00 | 1.00 | 1.00 | | | | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| MODIFIER NAME | | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| MODIFIER RATE | #/T | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

NOTE 1 STACKED CORRUGATED PLATES ARRANGED IN BLOCK POSITION RIGHT ANGLES TO EACH OTHER

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MTU = MICHIGAN TECHNOLOGICAL UNIVERSITY, VPI = VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

5.2.3 Bench Scale Process Testing

During this quarter B&W began bench scale process testing on the Pittsburgh No. 8 raw coal. B&W conducted test work on the first two steps of the precleaning circuit namely the coarse and fine hydrocyclone. The test unit for the hydrocyclone is shown in Figure 5.3.

Fifty-one drums of raw Pittsburgh #8 coal were crushed to 1/4" top size in a Jeffrey hammermill, returned to the drums, and inerted with nitrogen. The Krebs hydrocyclone unit was installed and water tested, and shakedown tests began. Problems were encountered with the performance of the coarse hydrocyclone on Pittsburgh #8 coal. The hydrocyclone performed as a classifying cyclone and did very little cleaning, regardless of feed concentration, apex insert diameter, or feed pressure. The coarser particles, coal and refuse, reported to the underflow, and the finer particles (minus 28M) reported to the overflow. The coarse coal was very evident in the underflow. BTU recovery averaged approximately 35%. Since B&W had no other options in getting the cyclone to operate as required, Krebs Engineers was contacted and arrangements were made for a representative to visit ARC on November 14. Doug Hunt and Bob Antion arrived, and the situation was discussed. Hunt stated that even though the specific gravities of the coal and refuse are different, there is insufficient time for the particles to separate in the 6" cyclone. The masses of the refuse and coal are high enough that both types of particles make their way to the outside of the cyclone and drop out the underflow.

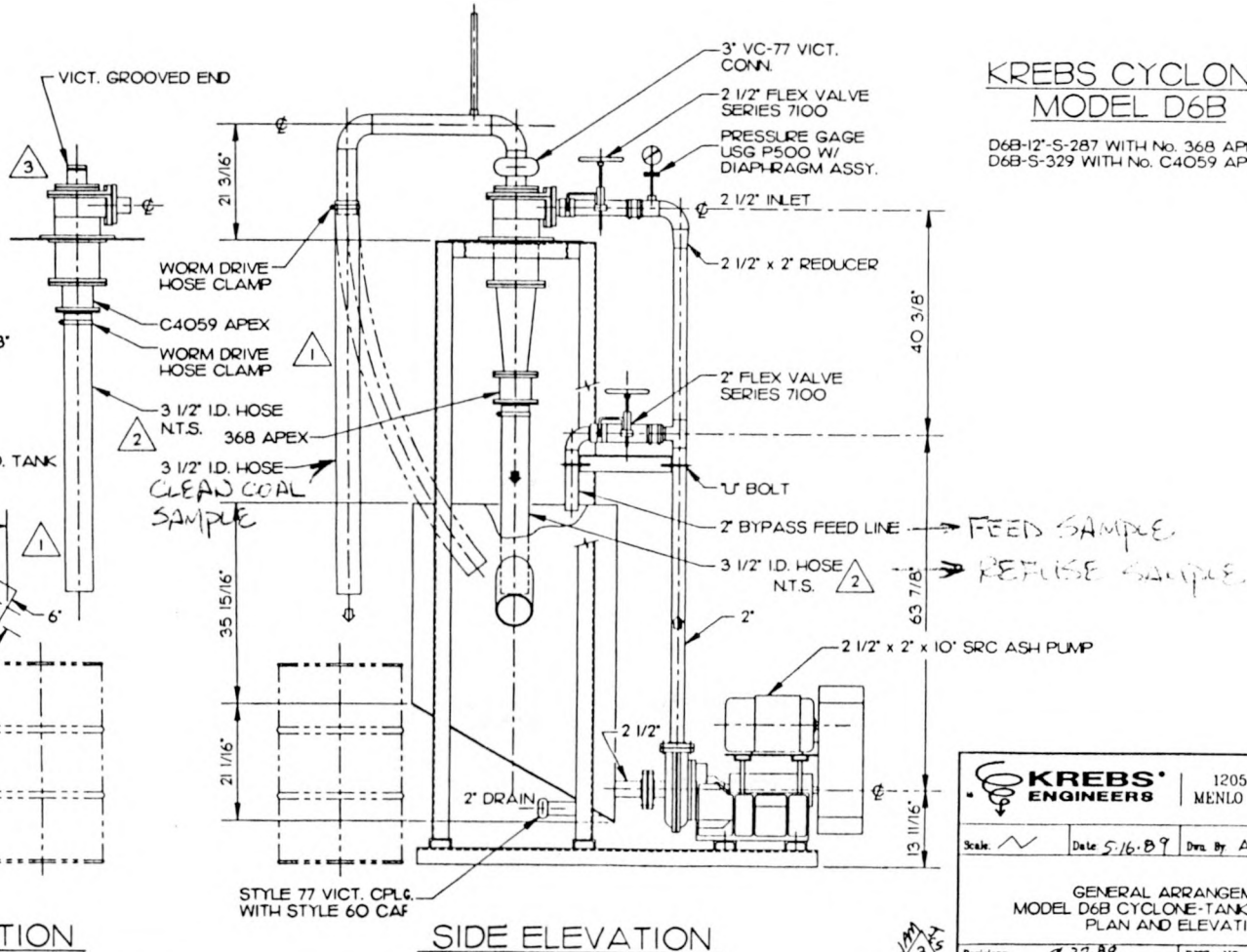
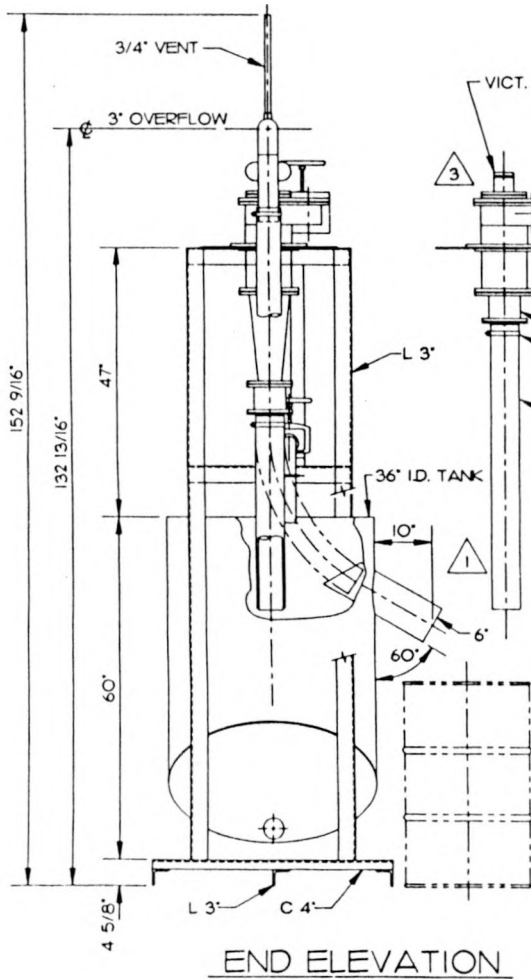
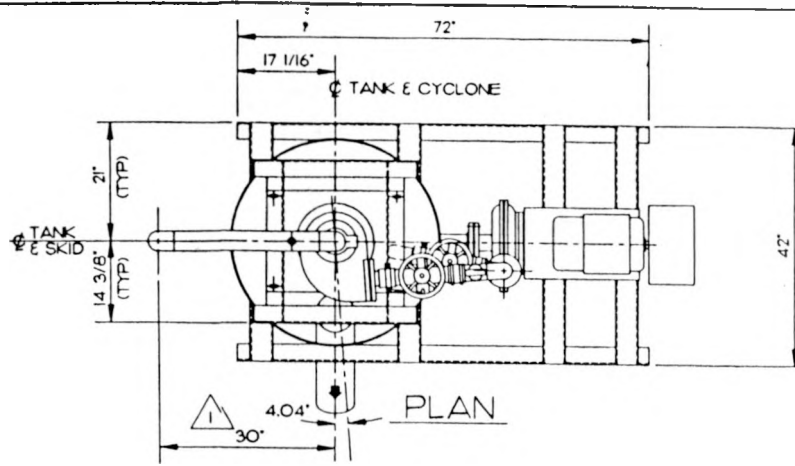
This condition was recognized during the development of the testing procedure for precleaning coal. Because the 6" hydrocyclone is not designed to process 1/4" topsize coal, it was anticipated that results could be obtained by adjusting operating parameters. In actual plant design a 10" or 15" diameter hydrocyclone would be utilized to preclean 1/4" topsize raw coal. The larger cyclone would have required more horsepower, more water, more coal and because of these reasons the 6" diameter cyclone was installed for testing purposes.

Doug Hunt suggested three options to make the 6" cyclone perform as required. These were as follows:

1. Install a longer vortex finder.
2. Increase the feed slurry concentration to make the cyclone perform similar to a "heavy media" cyclone.
3. Remove a cylindrical section of the cyclone to have the apex closer to the vortex finder (this should have a similar effect as installing a longer vortex finder).

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FIGURE 5.3
HYDROCYCLONE
TEST UNIT



KREBS CYCLONE
MODEL D6B

D6B-12"-S-287 WITH No. 368 APEX ASSEMBLY
D6B-S-329 WITH No. C4059 APEX ASSEMBLY

| | | | |
|---|--------------|--|---------------|
| | | 1205 CHRYSLER DR. MENLO PARK, CA. 94025 | |
| Scale | Date 5.16.89 | Des. By ALV | App'd. By JCS |
| GENERAL ARRANGEMENT MODEL D6B CYCLONE-TANK-PUMP UNIT PLAN AND ELEVATION | | | |
| Revised | 9.27.89 | DWG. NO. | SK1080-ARC |
| REV. TO DATE - ALV | | | |

NO. 86070-APP

Since longer vortex finders were not available from Krebs, it was decided to increase feed slurry concentration and check results. The feed percent solids was increased gradually from 10% to 60% with clean coal and refuse samples taken and analyzed at concentrations from 47% to 60%. Samples were also taken at concentrations from 10% to 47%. By visual inspection, it was clear that the coarser coal was not being cleaned, so no analyses were performed on these samples. Apex inserts tested were 1", 3/4", and 5/8", and all were installed in an inverted position to choke the flow of solids out the underflow. The overflow vent was also plugged during all tests to pull more solids out the overflow. Coarse coal could be seen in all of the underflow samples. Samples taken during these tests (47%-60% feed concentration) were inconclusive due to the fact that analyses showed more total clean coal and refuse than feed. The next series of tests were run after removing the cylindrical section of the cyclone. The bottom of the vortex finder was 3-1/4" from the top of the apex insert. Inverted apex inserts of 1/2" and 5/8" were used. Feed was 12% by weight. The clean coal product appeared to be very clean, but coarse coal still reported to the underflow. For this reason, no samples were taken. The overflow vent was plugged during these tests. The next tests were run with longer vortex finders. B&W extended the length of the vortex finders by welding pipe to the vortex finders supplied by Krebs. The cylindrical section of the cyclone was reinstalled. Tests were run at 12%, 20%, and 28.5% feed concentrations. Underflow samples were taken, and BTU recovery for each test was 96-97%. BTU recovery was very high because yield was very high -- over 90%. However, very little cleaning was done. Ash reduction was less than 10%. BTU recovery was calculated by difference since no clean coal samples were taken. Additional tests using vortex finders of several lengths and underflow orifices of various diameters were conducted in an attempt to improve ash removal while maintaining high BTU recovery. However, regardless of vortex finder length or underflow orifice diameter, coarse coal reported to the cyclone underflow. A drum of 1/4" x 0 raw coal was shipped to Krebs in order that tests could be run in their lab to get the 6" hydrocyclone to clean the coarse coal. These tests were unsuccessful. All of these coarse hydrocyclone tests took six weeks to run. Approximately 40 tests were run by varying vortex finder length, vortex finder diameter, apex insert diameter, apex insert position (normal or inverted), feed solids concentration, and feed pressure. Samples were taken on approximately one-half of the tests. Samples were not taken on the tests where it was very evident by visual inspection that the coarser coal was not being cleaned.

The results of all the coarse hydrocyclone tests where samples were taken are shown on Table 5.3, Coarse Hydrocyclone Results. Based upon this data, the best hydrocyclone conditions were determined. The vortex finder selected was 2" diameter - extended 6", the apex insert is 3/4" diameter

TABLE 5.3
COARSE HYDROCYCLONE RESULTS

| SAMPLE NUMBER | F4244 | F4245 | F4246 | F4247 | F4248 | F4249 | F4250 | F4251 | F4252 | F4253 | F4254 | F4255 | F4256 | F4257 | F4260 | F4261 | F4263 | F4264 | F4265 | F4266 | F4267 | F4268 |
|----------------------|--------|--------|--------|--------|--------|--------|--------|-------|-------|-------|-------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| DESCRIPTION | OF 2 | OF 3 | OF 3 | UF2 | UF 3 | UF 4 | FEED | OF | UF | UF | UF | UF | UF | UF | OF | UF | OF | UF | OF | UF | OF | UF |
| FEED PSIG | 16.00 | 16.00 | 16.00 | 16.00 | 16.00 | 16.00 | 14.00 | 14.00 | 14.00 | 15.00 | 15.00 | 15.50 | 15.50 | 14.00 | 14.00 | 14.00 | 15.00 | 15.00 | 15.50 | 15.50 | 15.00 | 15.00 |
| FEED % SOLIDS | 8.00 | 8.00 | 12.00 | 8.00 | 8.00 | 12.00 | 60.00 | 60.00 | 60.00 | 47.00 | 60.00 | 12.00 | 20.00 | 30.00 | 12.00 | 12.00 | 12.00 | 12.00 | 12.00 | 12.00 | 12.00 | 12.00 |
| FEED GPM | 125.0 | 125.0 | 125.0 | 125.0 | 125.0 | 125.0 | 115.0 | 115.0 | 115.0 | 115.0 | 115.0 | 135.0 | 135.0 | 135.0 | 125.0 | 125.0 | 125.0 | 125.0 | 120.0 | 120.0 | 120.0 | 120.0 |
| VORTEX FINDER DIA. | 2 1/2 | 2 1/2 | 2 1/2 | 2 1/2 | 2 1/2 | 2 1/2 | 2 1/2 | 2 1/2 | 2 1/2 | 2 1/2 | 2 1/2 | 2" | 2 1/4" | 2 1/4" | 2" | 2" | 2" | 2" | 2" | 2" | 2" | 2" |
| VORTEX FINDER LEN. | 7 3/4 | 7 3/4 | 7 3/4 | 7 3/4 | 7 3/4 | 7 3/4 | 7 3/4 | 7 3/4 | 7 3/4 | 7 3/4 | 7 3/4 | 8" EXT | 8" EXT | 8" EXT | 6" EXT | 6" EXT | 6" EXT | 6" EXT | 4" EXT | 4" EXT | 4" EXT | 4" EXT |
| APEX DIA. | 1" | 1" | 1" | 1" | 1" | 1" | 1" | 5/8" | 5/8" | 5/8" | 1" | 1/2" | 1/2" | 1/2" | 1/2" | 1/2" | 3/4" | 3/4" | 1/2" | 1/2" | 3/4" | 3/4" |
| APEX POSITION | NORMAL | NORMAL | NORMAL | NORMAL | NORMAL | NORMAL | NORMAL | INVET | INVET | INVET | INVET | INVET | INVET | INVET | INVET | INVET | INVET | INVET | INVET | INVET | INVET | INVET |
| DESCRIPTION % SOLIDS | 1.64 | 1.65 | 1.96 | 23.48 | 24.13 | 43.18 | 56.36 | 61.82 | 61.69 | 63.08 | 70.48 | 16.93 | 31.78 | 40.06 | 16.10 | 31.90 | 17.60 | 29.30 | 14.10 | 41.50 | 17.20 | 20.90 |
| DESCRIPTION GPM | 114.0 | 110.0 | 119.0 | 11.0 | 15.0 | 6.0 | 115.0 | 110.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 121.0 | 4.0 | 120.0 | 5.0 | 117.0 | 3.0 | 112.0 | 8.0 |
| ASH % | 45.73 | 50.91 | 54.55 | 17.69 | 12.80 | 12.41 | 34.66 | 30.93 | 46.46 | 49.66 | 57.50 | 45.00 | 48.53 | 47.18 | 32.25 | 55.57 | 29.27 | 41.80 | 32.84 | 42.33 | 35.23 | 37.88 |
| TOTAL SULFUR % | 2.85 | 2.72 | 2.77 | 4.68 | 4.31 | 4.31 | 4.12 | 3.95 | 6.74 | 7.01 | 8.93 | 8.10 | 6.81 | 7.41 | 4.28 | 9.25 | 3.96 | 7.67 | 4.11 | 8.82 | 4.13 | 8.09 |
| BTU | 6792 | 7010 | 7358 | 11908 | 12680 | 12692 | 9289 | 9619 | 7226 | 6677 | 5439 | 7225 | 6677 | 6875 | 9520 | 5358 | 9962 | 7621 | 9626 | 7698 | 9202 | 8060 |
| BTU RECOVERY | 39.10 | 41.10 | 25.40 | N/A | N/A | N/A | N/A | 84.40 | N/A | N/A | N/A | N/A | N/A | 96.60 | 96.30 | N/A | 94.00 | N/A | 94.20 | N/A | 93.20 | N/A |

OF = OVERFLOW, UF = UNDERFLOW, NORMAL = KREBS STANDARD APEX, INVET = APEX INVERTED, N/A = NOT AVAILABLE

and is inverted, Test Number F4263 and F4264. These conditions result in an ash reduction of 21% at a 94% BTU recovery. Precleaning began on December 14. Two drums of clean coal slurry were screened at 48M on the 2' x 2' vibrating screen to determine the procedure and time requirements for this portion of the testing. Thirty-five 55-gallon drums of 1/4" x 0 clean coal slurry were produced and screened at 48M. The 1/4" x 48M was air dried and crushed to 48M x 0 in a hammermill.

The overall purpose of the coarse hydrocyclone was to eliminate coarse low BTU refuse material. Although the ash reduction was 21% it was anticipated this number would be higher. In addition the BTU recovery of 94% is lower than the anticipated recovery of 97% plus. The primary reason for not obtaining the anticipated results is because of the diameter of the hydrocyclone. It is predicated that in actual plant processing utilizing a larger diameter hydrocyclone improved ash rejection and BTU recovery could be accomplished.

The crushed 48M x 0 was recombined with the correct proportions of the natural 48M x 0 and processed in the same hydrocyclone rig as the coarse material.

Three sets of orifice configurations were tested and samples taken and analyzed. The ash of the coal was not reduced in any of the tests. In order to avoid the major shakedown problems experienced with the coarse hydrocyclone, Krebs was immediately contacted and recommended that the fine hydrocyclone be operated with the vortex finders not extended at all and with the apex inserts installed in the upright position. Bob Moorehead, Krebs Engineers representative, arrived at ARC on January 3 to assist in the fine hydrocyclone shakedown. A 2" diameter vortex finder and 1/2" apex (normal position) were installed and samples taken. By visual inspection, one could see too much coal in the underflow. It was decided to use a 3" diameter vortex finder with various apex inserts at low and high feed pressures. The underflow quality appeared to improve (less coal), so clean coal and refuse samples were taken and analyzed.

All the test results for the fine hydrocyclone are shown on Table 5.4, Fine Hydrocyclone Results. Optimal results were obtained using a 3" diameter vortex finder and 1/2" apex at 11.5 psig feed pressure, Tests Number F4286 and F4287. There was very little ash reduction, but considerable pyrite reduction. This result is what was expected when cleaning the 48M x 0 coal. There was very little ash reduction because 70% of the fine hydrocyclone clean coal was -200M. This 200M x 0 fraction contained the fine clay particles that cannot be removed in the cyclone. This clay will be removed in the rougher flotation test. Thirty-five drums of 48M x 0 clean coal slurry were produced using the fine hydrocyclone. This product will be used as the feed for the Denver continuous flotation unit during flotation testing. The product from

TABLE 5.4
FINE HYDROCYCLONE RESULTS

| SAMPLE NUMBER | F4277 | F4278 | F4279 | F4280 | F4281 | F4282 | F4286 | F4287 | F4288 | F4289 | F4290 | F4291 | F4292 | F4293 | F4294 | F4295 | F4296 | F4297 |
|----------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| DESCRIPTION | OF | UF | OF | UF | OF | UF | OF | UF | OF | UF | OF | UF | OF | UF | OF | UF | OF | UF |
| FEED PSIG | 16.00 | 16.00 | 16.00 | 16.00 | 18.00 | 18.00 | 11.50 | 11.50 | 15.00 | 15.00 | 11.50 | 11.50 | 15.00 | 15.00 | 12.00 | 12.00 | 15.00 | 15.00 |
| FEED % SOLIDS | 10.40 | 10.40 | 10.40 | 10.40 | 10.40 | 10.40 | 10.70 | 10.70 | 10.70 | 10.70 | 10.70 | 10.70 | 10.70 | 10.70 | 10.70 | 10.70 | 10.70 | 10.70 |
| FEED GPM | N/A | N/A | N/A | N/A | N/A | N/A | 125.0 | 125.0 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| VORTEX FINDER DIA. | 2" | 2" | 2" | 2" | 2" | 2" | 3" | 3" | 3" | 3" | 3" | 3" | 3" | 3" | 3" | 3" | 3" | 3" |
| VORTEX FINDER LEN. | 6" EXT | 6" EXT | 6" EXT | 6" EXT | 6" EXT | 6" EXT | 7 3/4" | 7 3/4" | 7 3/4" | 7 3/4" | 7 3/4" | 7 3/4" | 7 3/4" | 7 3/4" | 7 3/4" | 7 3/4" | 7 3/4" | 7 3/4" |
| APEX DIA. | 1/2" | 1/2" | 3/4" | 3/4" | 1" | 1" | 1/2" | 1/2" | 1/2" | 1/2" | 3/4" | 3/4" | 3/4" | 3/4" | 1" | 1" | 1" | 1" |
| APEX POSITION | INVET | INVET | INVET | INVET | INVET | INVET | NORMAL | NORMAL | NORMAL | NORMAL | NORMAL | NORMAL | NORMAL | NORMAL | NORMAL | NORMAL | NORMAL | NORMAL |
| DESCRIPTION % SOLIDS | 11.70 | 19.90 | 11.80 | 23.80 | 11.00 | 31.40 | 10.80 | 66.70 | 10.40 | 58.90 | 10.40 | 48.10 | 10.70 | 46.10 | 10.30 | 38.00 | 10.30 | 39.90 |
| DESCRIPTION GPM | N/A | N/A | N/A | N/A | N/A | N/A | 124.0 | 1.0 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| ASH % | 32.42 | 39.76 | 30.66 | 41.82 | 33.98 | 24.21 | 36.56 | 55.41 | 36.70 | 50.78 | 36.76 | 43.43 | 36.53 | 38.40 | 37.22 | 28.70 | 37.08 | 30.40 |
| TOTAL SULFUR % | 4.38 | 11.12 | 4.17 | 10.57 | 4.02 | 7.22 | 4.10 | 27.25 | 3.92 | 27.46 | 4.04 | 21.66 | 3.98 | 18.04 | 3.92 | 10.90 | 3.96 | 11.92 |
| BTU | 9474 | 7943 | 9798 | 7780 | 9104 | 10791 | 8687 | 5112 | 8687 | 6208 | 8722 | 7376 | 8628 | 8304 | 8692 | 9874 | 8726 | 9586 |
| BTU RECOVERY | N/A | N/A | N/A | N/A | N/A | N/A | 99.50 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

OF = OVERFLOW, UF = UNDERFLOW, NORMAL = KREBS STANDARD APEX, INVET = APEX INVERTED, N/A = NOT AVAILABLE

flotation will be used for VPI test work in Task 6 and preliminary grinding evaluation at B&W.

The overall purpose of the fine hydrocyclone was to eliminate fine liberated pyrite and maintain a high BTU recovery. Both of these purposes were accomplished in this test.

The results of the coarse hydrocyclone - fine hydrocyclone precleaning steps are shown in Figure 5.4 and the mass balance for the numbered streams are shown in Table 5.5. The results were based on calculating ash rejection, total sulfur rejection, pyritic sulfur rejection, BTU recovery and weight recovery for both the coarse and fine hydrocyclone. The pyritic sulfur values were calculated based on calculations of pyritic sulfur (moisture-free basis) for clean coal and refuse from the known value of organic sulfur for raw coal.(3) Based on the above, the coarse and fine hydrocyclone circuits have removed 12% of the material, reduced the ash by 17%, reduced the total sulfur by 38%, reduced the pyritic sulfur by 64% and recovered 91% of the BTU.

Figure 5.4

Coarse and Fine Hydrocyclone Schematic Flowsheet

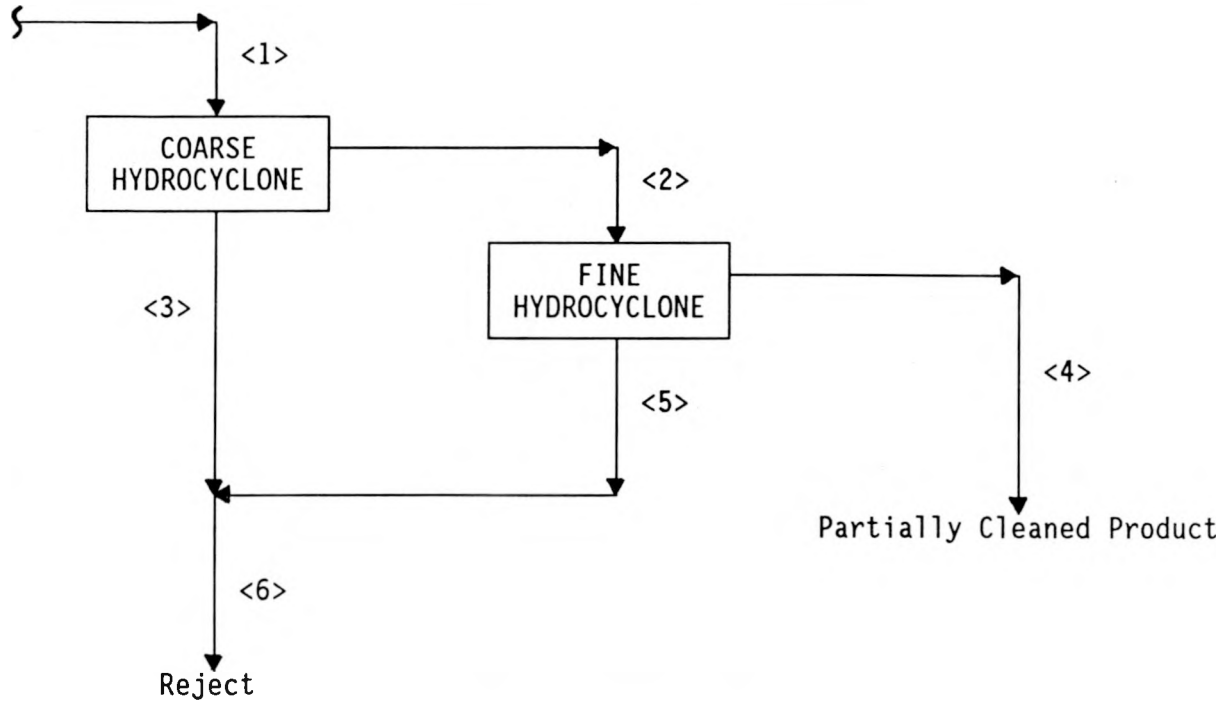


Table 5.5

Stream
Mass Balance for Figure 5.4

| Stream No. | 1 | 2 | 3 | 4 | 5 | 6 |
|------------------|-------|-------|-------|-------|-------|-------|
| Wt% | 100.0 | 93.23 | 6.77 | 87.82 | 5.41 | 12.18 |
| Ash % | 30.12 | 29.27 | 41.80 | 28.44 | 42.75 | 42.23 |
| Total Sulfur % | 4.21 | 3.96 | 7.67 | 2.98 | 19.88 | 13.08 |
| BTU | 9804 | 962 | 7621 | 10206 | 5999 | 6906 |
| Pyritic Sulfur % | 1.45 | 1.20 | 4.91 | 0.60 | 10.94 | 7.58 |

Rejection Calculations

| | Coarse Hydro | Fine Hydro | Total Product |
|--------------------------|-----------------|---------------|------------------|
| Ash Rejection | 9.39 | 8.50 | 17.08 |
| Total Sulfur Rejection | 12.33 | 29.00 | 37.84 |
| BTU Recovery | 94.74 | 96.50 | 91.42 |
| Pyritic Sulfur Rejection | 22.91 | 52.90 | 63.67 |

As indicated the remaining precleaning and advanced froth flotation need only eliminate an additional 26% of the pyritic sulfur while only losing 1% of the BTU. It appears possible that the sulfur rejection can be accomplished. The minimum amount of BTU lose is next to impossible. This is a direct result of the failure of the coarse hydrocyclone to perform at anticipated results. However, the performance of the coarse hydrocyclone can and will be enhanced in the POC where a larger diameter hydrocyclone will be tested.

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

No work was performed on this subtask during the past quarter. Problems at B&W have delayed shipment of the Pittsburgh No. 8 test coal and it is not known when this coal or the other two base coals will arrive. Work will continue on this subtask as soon as a sample arrives.

6.2.2 Optimum Column Cell Circuit Configuration

The status of this subtask is the same as that of Subtask 6.1.

6.2.3 Column Cell Flotation Model Development

Work on the Flotation Circuit Simulator continued to be ahead of schedule during the past quarter due to the temporary suspension of activities related to Subtasks 6.1 and 6.2. The bulk of the work on the simulator is completed and will be finished when the base coals are obtained.

The overall objective of this subtask is the development of a computer simulation program for analysis of multistage flotation circuits. The primary reason for developing such a simulator is to enable study of a variety of circuit configurations in a cost- and time-effective manner.

The unique features of flotation columns have required that many of the operational guidelines and scale-up criteria developed in the past for conventional flotation cells be abandoned or modified. It is believed that the simulator will be useful for the design, control, optimization and scale-up of column flotation cells. The simulator should also be useful for training in column operation and for troubleshooting various operational problems. The simulator, when modified appropriately, will also be useful for conventional flotation circuits.

A further purpose of the simulator will be to provide a mechanism for evaluating and debugging the POC module. Use of the simulator should eliminate the need for extensive trial-and-error testing to determine the best column configuration in the advanced cleaning circuit.

6.2.3.1 Model Development

There are numerous factors which affect the performance of a column flotation cell. These factors can be roughly classified under one or more of the following headings:

- a. flotation rate constant,
- b. particle retention time,
- c. axial mixing,
- d. nonselective entrainment, and
- e. froth transport.

The first three elements in this list can be used to determine the recovery (R) of a given component through the use of Levenspiel's equation Levenspiel, (1) which is given by:

$$R = 1 - \frac{4A \exp\{Pe/2\}}{(1+A)^2 \exp\{(A/2)Pe\} - (1-A)^2 \exp\{(-A/2)Pe\}} \quad [1]$$

$$A = \sqrt{1+4k\tau_p/Pe}, \quad [2]$$

in which k is the rate constant for bubble-particle attachment, τ_p is the particle retention time, and Pe is the Peclet number. This expression, which is plotted in Figure 6.1, shows that an increase in the dimensionless quantities $k\tau_p$ and/or Pe results in an increase in recovery.

Various expressions have been developed which can be used to estimate k, τ_p and Pe for the case of column flotation. Each of these is discussed in further detail in the following sections. The nomenclature used in these expressions and throughout the report can be found in Appendix D.

6.3.2.2 Flotation Rate Constant

A simple theoretical analysis shows that the rate constant for column flotation is given by:

$$k = \frac{3P}{2D_b} V_g, \quad [3]$$

in which D_b is the pulp bubble diameter, P is the probability of bubble-particle attachment, and V_g is the superficial aeration rate. P in turn is a product of the three probabilities, i.e.:

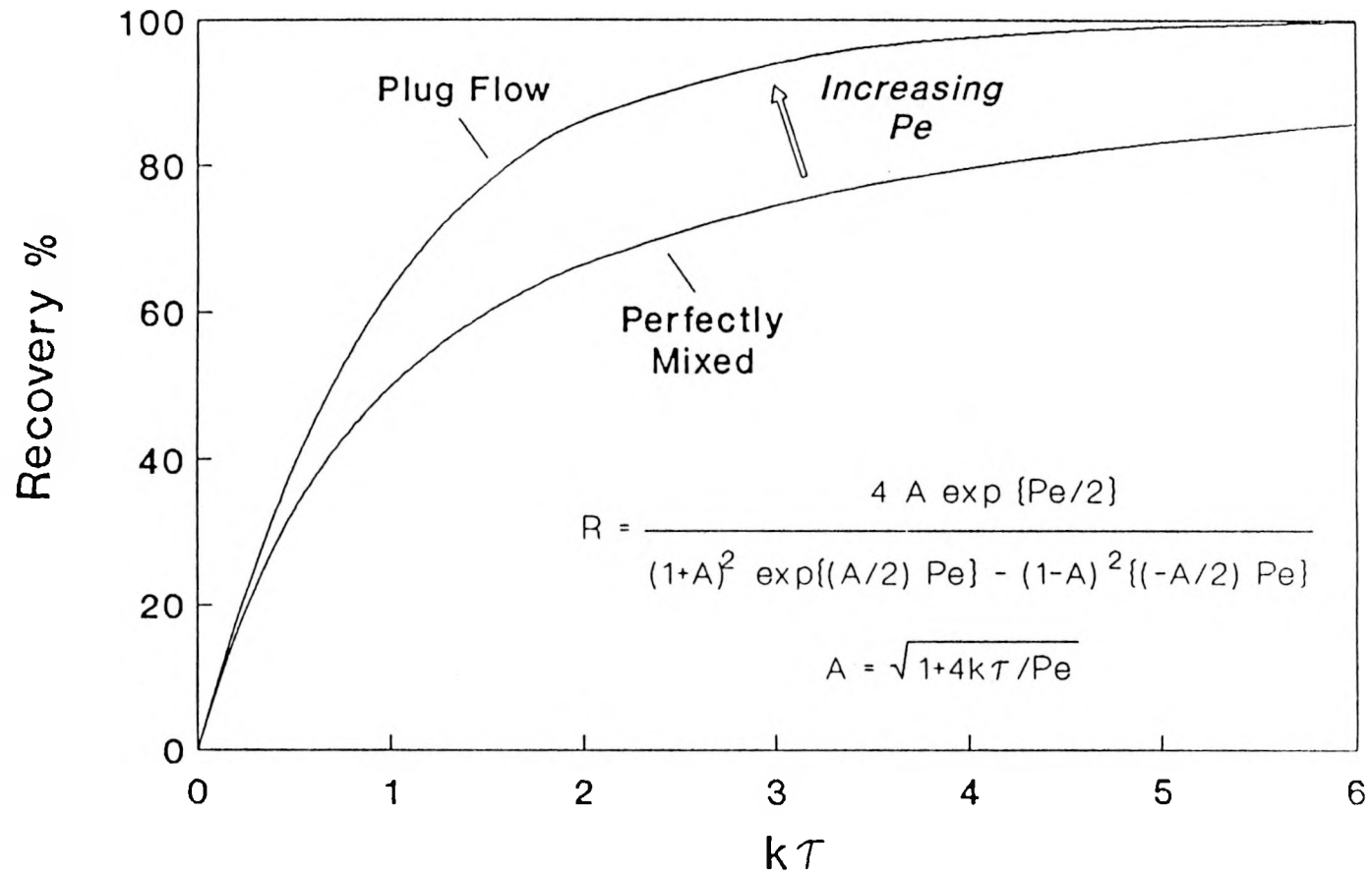
$$P = P_c P_a (1-P_d), \quad [4]$$

In which P_c , P_a and P_d are the probabilities of collision, adhesion and detachment, respectively. P_d for very fine particles is relatively small and has been considered to be zero in the present analysis. The magnitude of P_a is largely determined by the hydrophobicity of the various components in the flotation pulp. Methods for estimating P_a for particulate systems has been presented elsewhere, Yordan and Yoon, (2); Luttrell and Yoon, (3).

In the bubble size range typically employed in flotation, P_c can be estimated from the following expression:

$$P_c = Z (D_p/D_b)^n, \quad [5]$$

FIGURE 6.1



The relationship between rate constant, retention time and Peclet number (Levenspiel, 1972).

in which D_p is the particle diameter. For fine particles, the value of n is approximately 2, and Z is given by:

$$Z = \frac{3}{2} + \frac{4Re^{0.72}}{15} \quad [6]$$

where Re is the Reynolds number of the bubble.

6.3.2.3 Particle Retention Time

The mean residence time of slurry in a column can be determined by dividing the effective cell volume (corrected for air hold-up) by the volumetric flow rate passing down through the column. Thus, the mean retention time (τ) of the slurry within a column can be obtained as follows:

$$\tau = L(1-\epsilon)/V_t, \quad [7]$$

in which L is the length of the column collection zone, V_t is the superficial flow rate of reject, and ϵ is the average gas hold-up. The magnitude of ϵ is primarily determined by the pulp bubble size, the aeration rate, and the volumetric flow rate of the reject stream. A numerical technique for determining ϵ has been reported elsewhere, Mankosa et al., (4).

In most cases, the flow rate of the reject stream is unknown. However, experimental studies indicate that the magnitude of V_t can be estimated from the expression:

$$V_t = V_f + \alpha V_w, \quad [8]$$

in which V_f and V_w are the superficial rates of feed and wash water added to the column and α is the wash water bias factor. The value of α represents the fraction of wash water added to the cell which reports to the reject stream. Typical values for α appear to be in the range between 0.5 and 0.8 for a wide variety of flotation conditions.

Once the residence time of slurry in the column (τ) is known, the particle retention time (τ_p) can be estimated as Dobby and Finch, (5):

$$\tau_p = \frac{V_t}{V_t + U_p} \tau, \quad [9]$$

in which U_p is the terminal settling velocity of the particle.

6.3.2.4 Axial Mixing

The final value which must be known in order to utilize Equation [1] is the Peclet number (Pe). As shown in Figure 6.1, an increase in Pe results in a decrease of axial mixing within the column and improves recovery. Recent studies

Mankosa, (6) indicate that Pe for a flotation column can be approximated by:

$$Pe = B [(L/D)(V_t/V_g)]^m, \quad [10]$$

where L/D is the column length-to-diameter ratio and V_t/V_g is the ratio of the superficial flow rate of the reject stream to the superficial gas rate through the column. This expression has been found to provide reasonable estimates of axial mixing in both laboratory and full-scale columns.

6.3.2.5 Hydraulic Entrainment

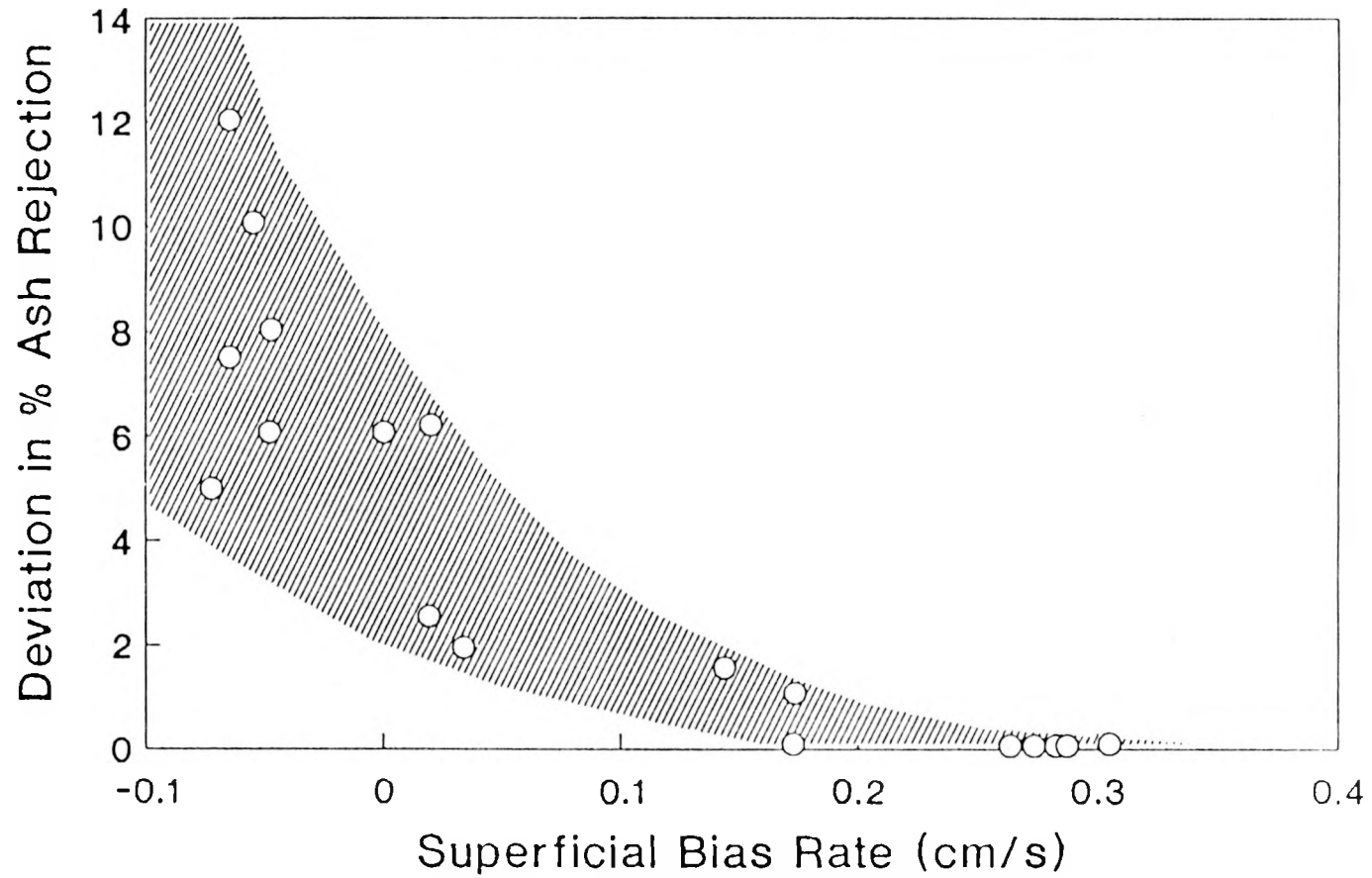
If wash water is properly utilized, only those particles which are attached to bubbles should be collected in the froth product from the column. The effectiveness of the wash water is generally characterized in terms of the "bias" flow rate. The bias rate can be determined experimentally from the difference between the volumetric flow rates of the feed and reject streams.

Experimental studies conducted at Virginia Tech indicate that the entrainment of fine particles is essentially eliminated when a superficial bias rate (V_w) greater than 0.25 cm/s is maintained through the cleaning zone of the column. This phenomenon is illustrated in Figure 6.2 for a fine coal flotation system. As shown, a marked decrease in product grade occurs as the bias rate is decreased below 0.25 cm/s. Below this critical value, the scatter in the experimental data begins to increase as the separation becomes increasingly sensitive to changes in the characteristics of the froth phase. Under these conditions, quantitative predictions become very difficult in the absence of equations which describe the behavior of three-phase froths. Therefore, the effects of bias rates lower than 0.25 cm/s have not been considered in the development of the present simulation package.

6.3.2.6 Froth Transport

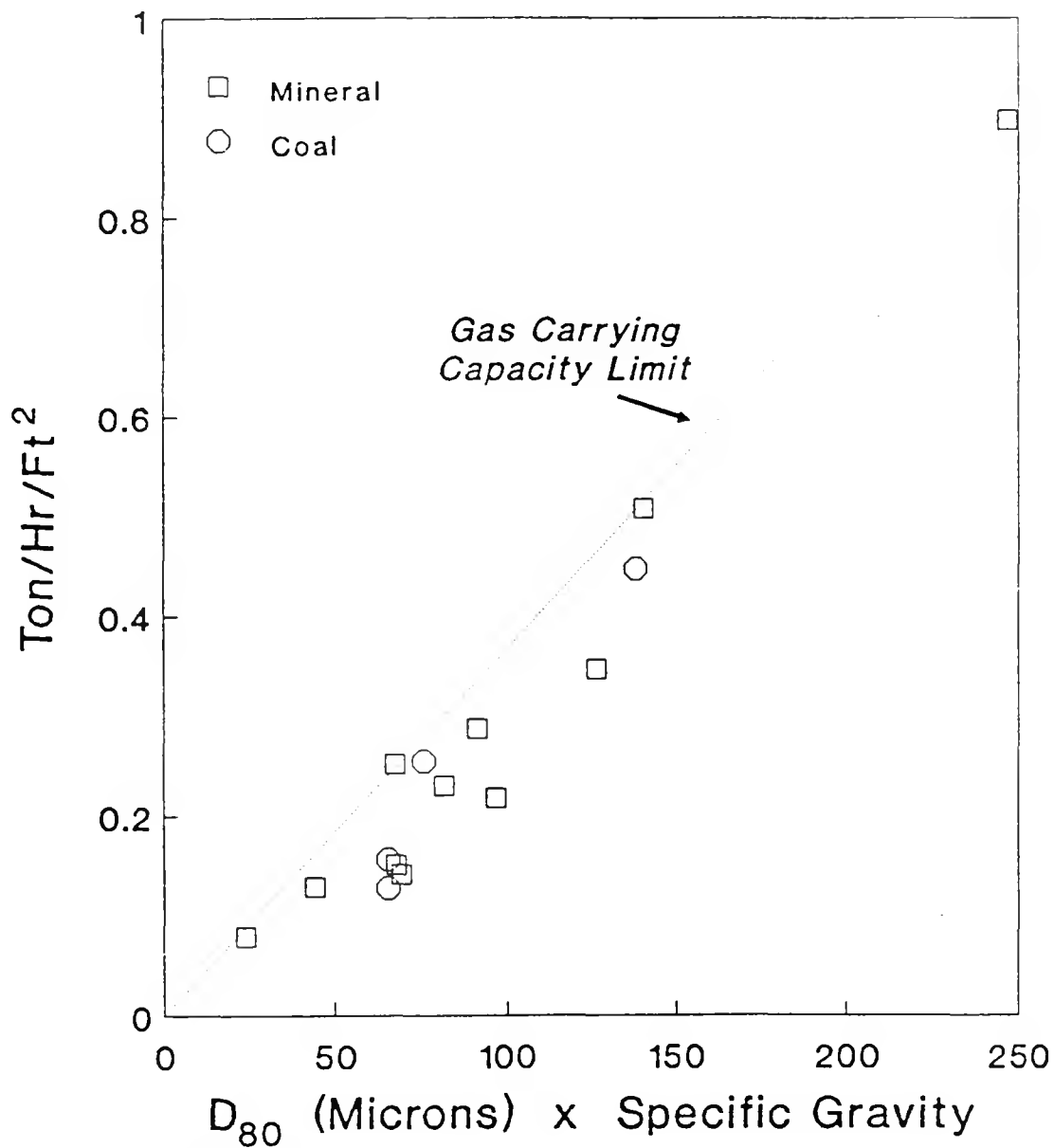
Another key consideration in the design and operation of a column flotation cell is the amount of bubble surface area available to carry particles through the froth phase. Recent data reported by Espinosa-Gomez et al., (7) suggest that the maximum flow rate of product solids per unit of column cross-sectional area is directly proportional to the size and density of the floated particles. These data, which were obtained for mineral systems, are reproduced in Figure 6.3 along with additional experimental data obtained for various coal flotation columns. The data clearly suggest a maximum limit on column capacity, although there is a considerable degree of scatter in the experimental data.

FIGURE 6.2



The effect of superficial bias rate on the reduction in ash rejection for a coal flotation system.

FIGURE 6.3



Experimentally-determined froth carrying capacities for mineral (Espinosa-Gomez et al., 1988) and coal flotation columns.

From a simple theoretical analysis, it can be shown that the flow rate of solids (C) to the product stream is given by:

$$C < \frac{4Q_g D_p \beta}{D_f}, \quad [11]$$

in which Q_g is the volumetric flow rate of air, D_p the particle diameter in the froth phase, the particle density, β a particle packing factor, and D_f the bubble diameter in the froth phase. This expression clearly indicates a linear relationship between the column capacity and particle size and density. However, Equation [11] also suggests that gas flow rate and the size of bubble in the froth may also play a significant role in determining the maximum product flow rate.

6.3.2.7 Column Simulations

Flotation simulations have been carried out by using the above expressions to describe the flows of solids between the pulp and froth phases. A schematic representation of this arrangement is shown in Figure 6.4. In the model, three different components have been considered, i.e., fast-floating, slow-floating and nonfloating.

The recovery rate (X_i) of each component from the pulp phase to the froth phase has been determined using Equations [1] - [9]. Each of these components can be assigned a value for the probability of adhesion (P_a), with the fastest floating particles having the highest P_a . In the present work, it has been assumed that the ratio of the P_a value for the fast-floating component to that of the slow-floating component is constant. The nonfloating component has been assigned $P_a = 0$.

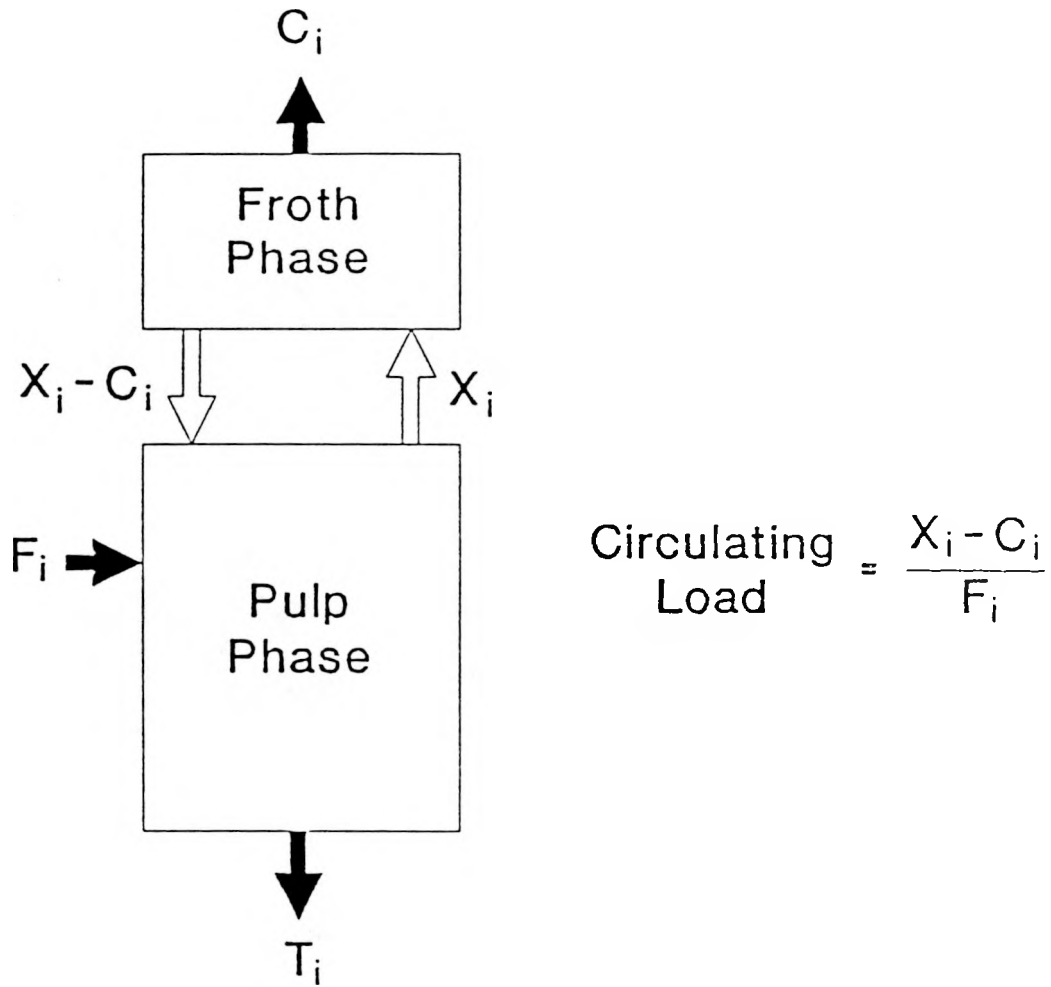
Equation [11] has been used to establish the maximum product rate for each component (C_i) that could be achieved under the assigned conditions. If $X_i > C_i$, then a portion of the particles carried into froth are returned to the pulp phase and given an additional opportunity to be recovered. Therefore, a circulating load (\mathcal{L}) exists between the froth and pulp phases which may be expressed as:

$$\mathcal{L} = \frac{\sum(X_i - C_i)}{\sum F_i}, \quad [12]$$

in which F_i is the solids feed rate of each component to the column. Preliminary tests conducted in various laboratory and pilot-scale columns indicate that \mathcal{L} may be quite large for industrial flotation columns.

In the present work, the return of each component from the froth to the pulp has been assumed to be proportional to the relative amounts of each component contained in the froth phase. This implies that particles are indiscriminately

FIGURE 6.4



Schematic representation of the solid flow rates around the pulp and froth phases of a flotation column.

dropped back to the pulp when bubbles coalesce in the froth. Experimental evidence suggests that this assumption may not be valid for all cases, although further study is needed.

Other factors such as particle agglomeration, bubble loading in the pulp phase, and bubble-particle detachment have not been considered in the development of the simulation package. Nonetheless, preliminary experimental data suggest that the computer simulation package developed in the present work satisfactorily predicts the behavior of column-type cells for many fine particle systems. In the present work, a series of simulations have been performed for a fine coal flotation system. Column response has been measured in terms of the recovery of combustible material to the product stream and product ash content. Each series of simulations has been carried out under conditions representing low (0.08 cm/s), average (0.25 cm/s) and high (0.40 cm/s) superficial feed rates.

A major advantage of the simulator is its ability to independently examine the influence of various operational parameters on flotation column performance. Several of the important operating and design parameters are discussed in the following sections.

6.3.2.8 Effect of Hydrophobicity

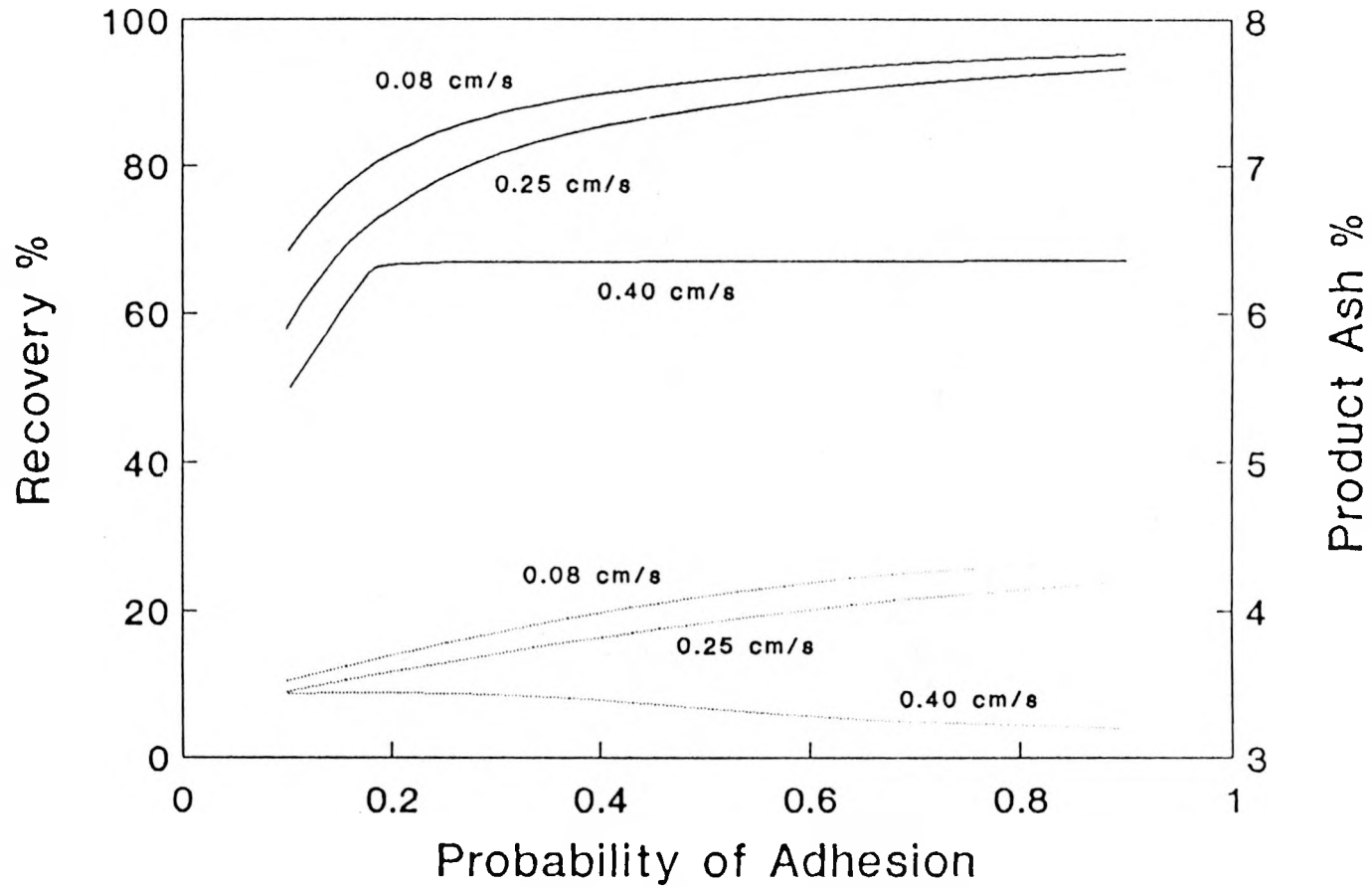
For given bubble and particle sizes, an increase in particle hydrophobicity results in an increase in P_a . The effect of increasing P_a on recovery and product grade is shown in Figure 6.5. For low feed rates, an increase in hydrophobicity produces a corresponding increase in recovery. Since additional middlings particles are recovered under these conditions, an increase in product ash content is also produced.

As the feed rate is increased beyond 0.25 cm/s, the column begins to become carrying-capacity-limited in the froth phase, as indicated by the flattening of the recovery curve. This occurs for P_a values greater than approximately 0.18. As P_a is raised beyond 0.18, the circulating load (\mathcal{L}) between the pulp and froth phases defined by Equation [12] begins to increase. Under these conditions, the fast-floating particles begin to be concentrated in the froth phase. The net effect of this action is to produce an overall improvement in product quality, i.e., a decrease in product ash content, at a relatively fixed level of recovery.

6.3.2.9 Effect of Aeration Rate

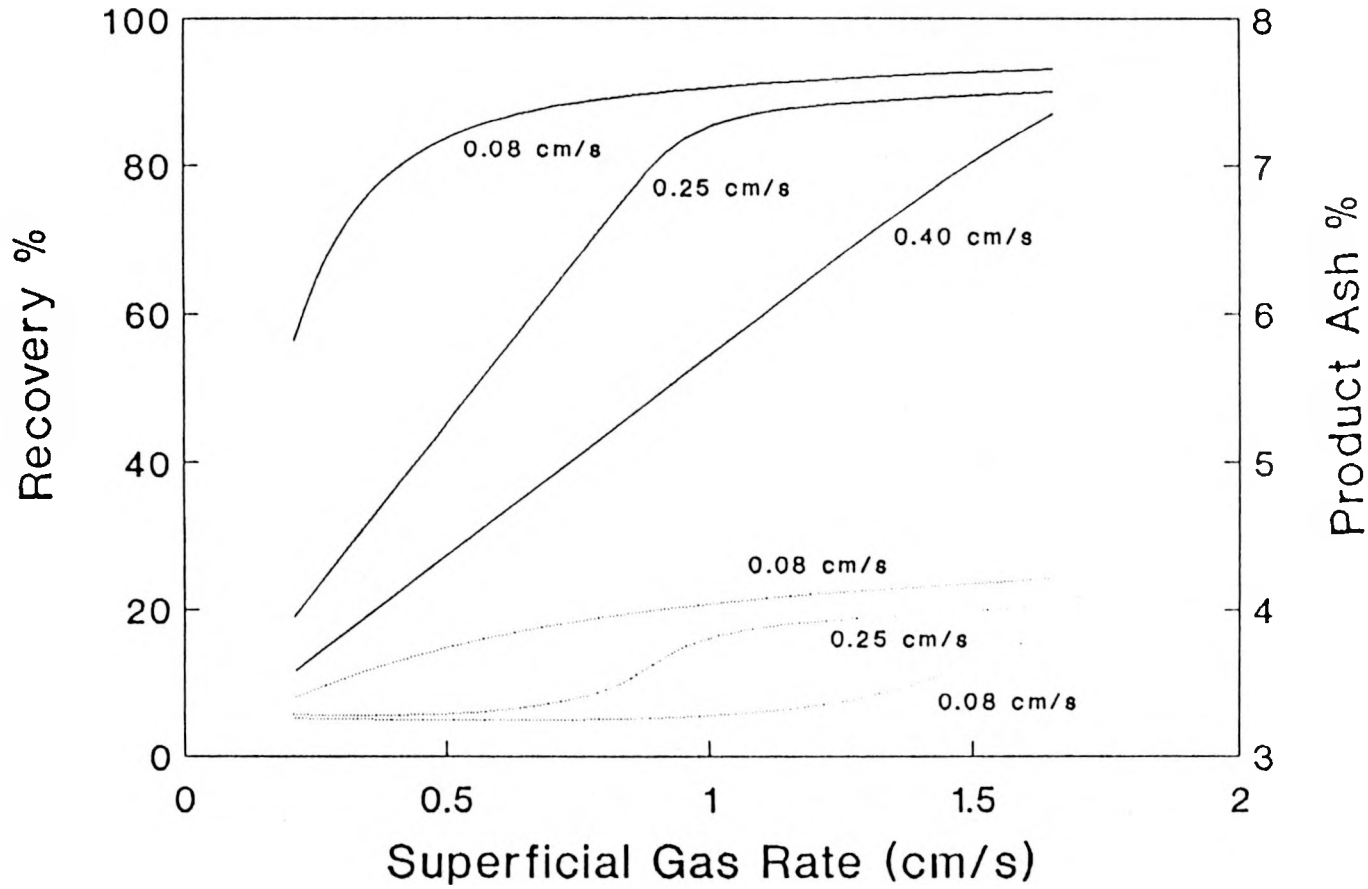
Flotation columns are generally operated at a maximum aeration rate for any given set of conditions in order to maximize flotation recovery and throughput. Figure 6.6 shows the results of simulations in which the air flow rate has been increased while all the other factors were kept constant. For

FIGURE 6.5



The simulated effect of varying hydrophobicity (i.e., P_a) on the recovery and product ash content for a low, medium and high superficial feed rate.

FIGURE 6.6



The simulated effect of aeration rate on the recovery and product ash content for a low, medium and high superficial feed rate.

low feed rates, the improved recovery can be directly related to an increase in the flotation rate constant given by Equation [3]. As before, the higher recoveries result in the collection of additional middlings particles which tend to increase the product ash content.

At high feed rates, the column becomes carrying-capacity-limited. According to Equation [11], the product flow rate should be directly proportional to the aeration rate. This type of behavior is observed in Figure 6.6 for a superficial feed rate of 0.40 cm/s. At intermediate feed rates, both the flotation rate constant and the carrying capacity play a role in determining column performance. As the gas rate is reduced, the available surface area passing through the froth phase for bubble-particle attachment is reduced. Thus, the column becomes carrying-capacity-limited at a lower feed rate when the gas rate is low.

As discussed previously, an improvement in product grade occurs when the column becomes carrying-capacity-limited. For both the intermediate and high feed rate situations, a decrease in gas rate increases the circulating load between the pulp and froth. This, in turn, produces an incremental improvement in product quality which lowers the product ash content.

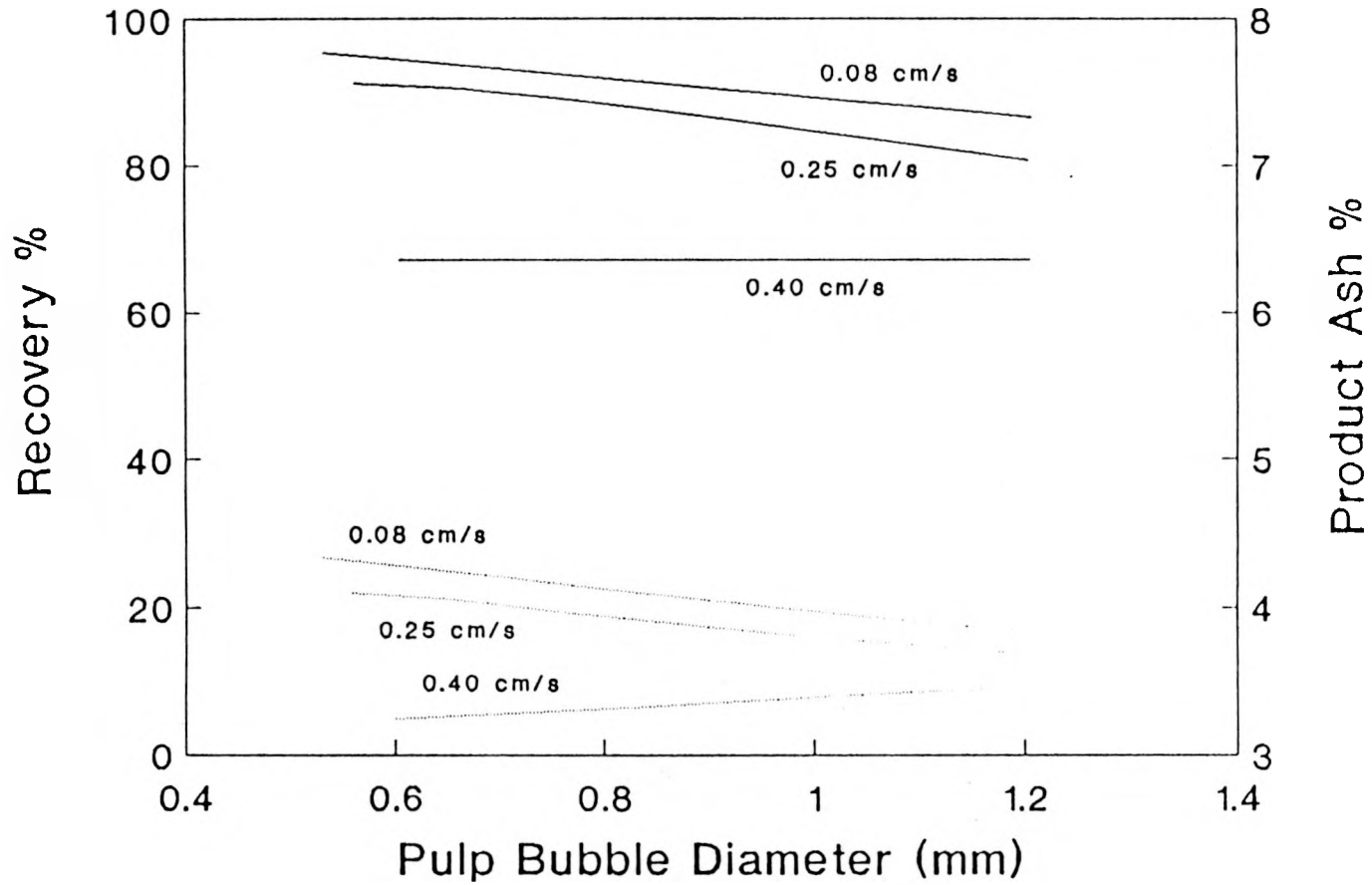
6.3.2.10 Effect of Pulp Bubble Size

A number of studies have been carried out during the past several years which suggest that column performance can be improved by decreasing the size of bubbles in the flotation pulp, Yoon and Luttrell (8). In order to examine this possibility more closely, a series of simulations have been performed as a function of pulp bubble diameter.

Figure 6.7 demonstrates the effect of changing pulp bubble size on recovery and product ash content. As the bubble size is decreased, the flotation rate constant increases in accordance with Equations [3] and [5]. This results in a slight increase in recovery which is somewhat offset by a corresponding increase in air hold-up that reduces the effective retention time of particles within the column (Equation [7]). Since the simulations were conducted while holding all other parameters constant, the pulp bubble size had no influence on recovery under carrying capacity limitations.

In terms of product quality, a decrease in bubble size produces a corresponding increase in product ash content as the operating point moves along the characteristic recovery-grade curve. However, under carrying capacity limitations, the product quality improves as the bubble size is decreased. This improvement is probably due to an increase in the pulp-froth circulating load which becomes more pronounced as the rate constant is increased through the use of smaller bubbles.

FIGURE 6.7



The simulated effect of changes in pulp bubble size on the recovery and product ash content for a low, medium and high superficial feed rate.

6.3.2.11 Effect of Column Height

One of the key design variables in column flotation is the height of the collection zone. The results of simulations conducted as a function of column height are shown in Figure 6.8. The simulation data indicate that the influence of column height on column behavior is similar to that of varying the particle hydrophobicity (i.e., P_a). For low and intermediate feed rates, the retention time of particles increases as the column height is increased (Equations [7] - [9]). As a result, the longer retention time produces a higher recovery. However, once the column becomes carrying-capacity-limited, an increase in column height provides no additional improvement in recovery.

For the low and intermediate feed rates, product ash content increases with recovery as more middlings particles report to the product stream. At higher feed rates, the column once again becomes carrying-capacity-limited. As a result, each incremental increase in column height increases the circulating load between the pulp and froth. The net effect is to concentrate the fast-floating particles and improve the product quality.

6.3.2.12 Effect of Feed Solids Content

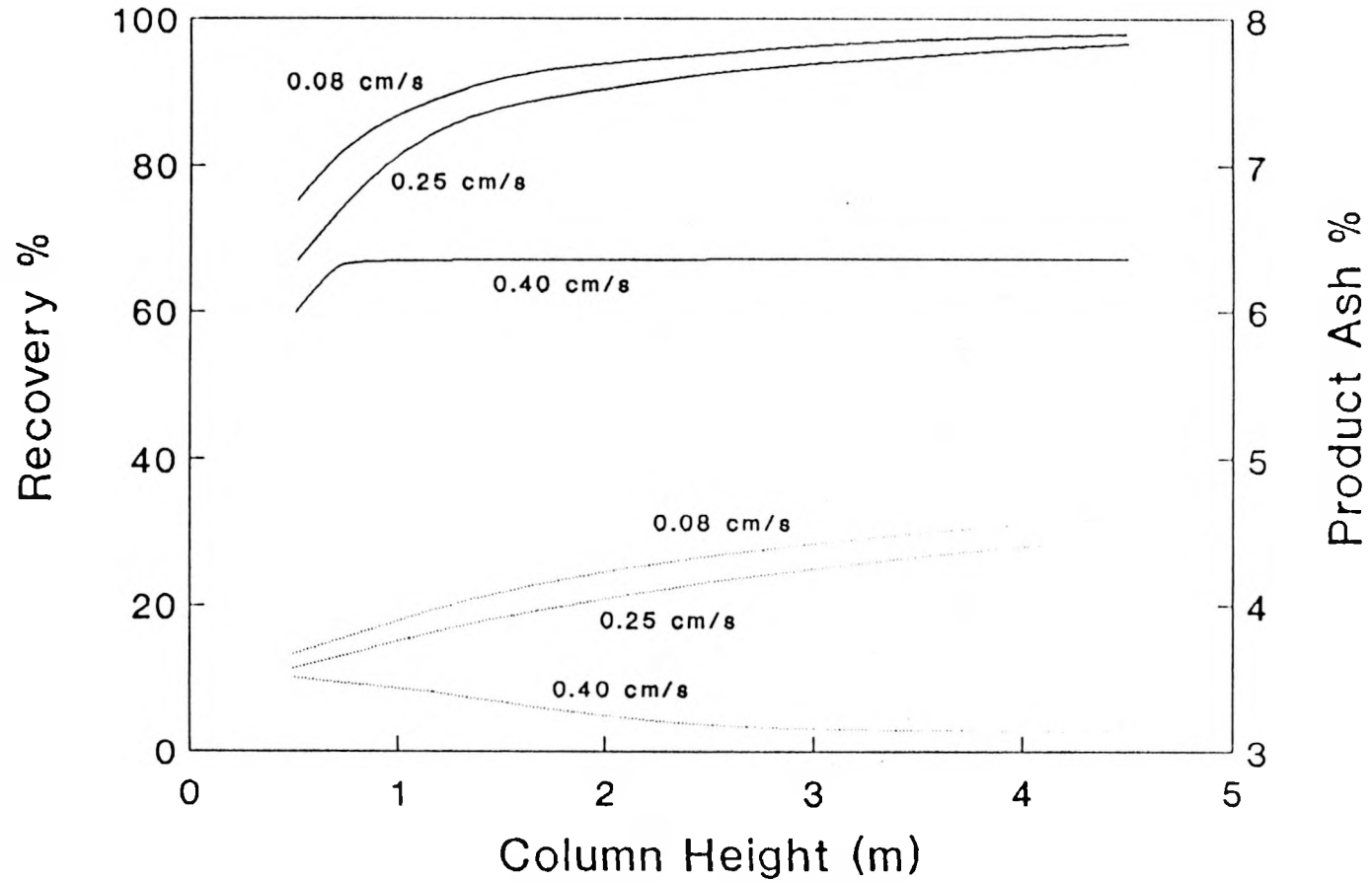
The effect of feed solids content on recovery and product ash is shown in Figure 6.9. In general, the simulation results indicate no change in the recovery of coal or ash rejection when the feed rate to the column is relatively low. However, as the feed rates are increased, the column begins to become very sensitive to the pulp density of the feed. This is due to the fact that the column becomes carrying-capacity-limited at a much faster rate. There is simply an insufficient amount of bubble surface area to carry the additional particles out of the cell.

As expected, the feed solids content has no influence on product grade unless the column becomes carrying-capacity-limited. It should also be noted that the effect of feed solids content on other flotation variables, such as reagent concentrations, have not been considered in the simulator. However, experimental evidence suggests that this phenomenon can have a significant influence on column performance in some cases.

6.3.2.13 Effect of Froth Bubble Diameter

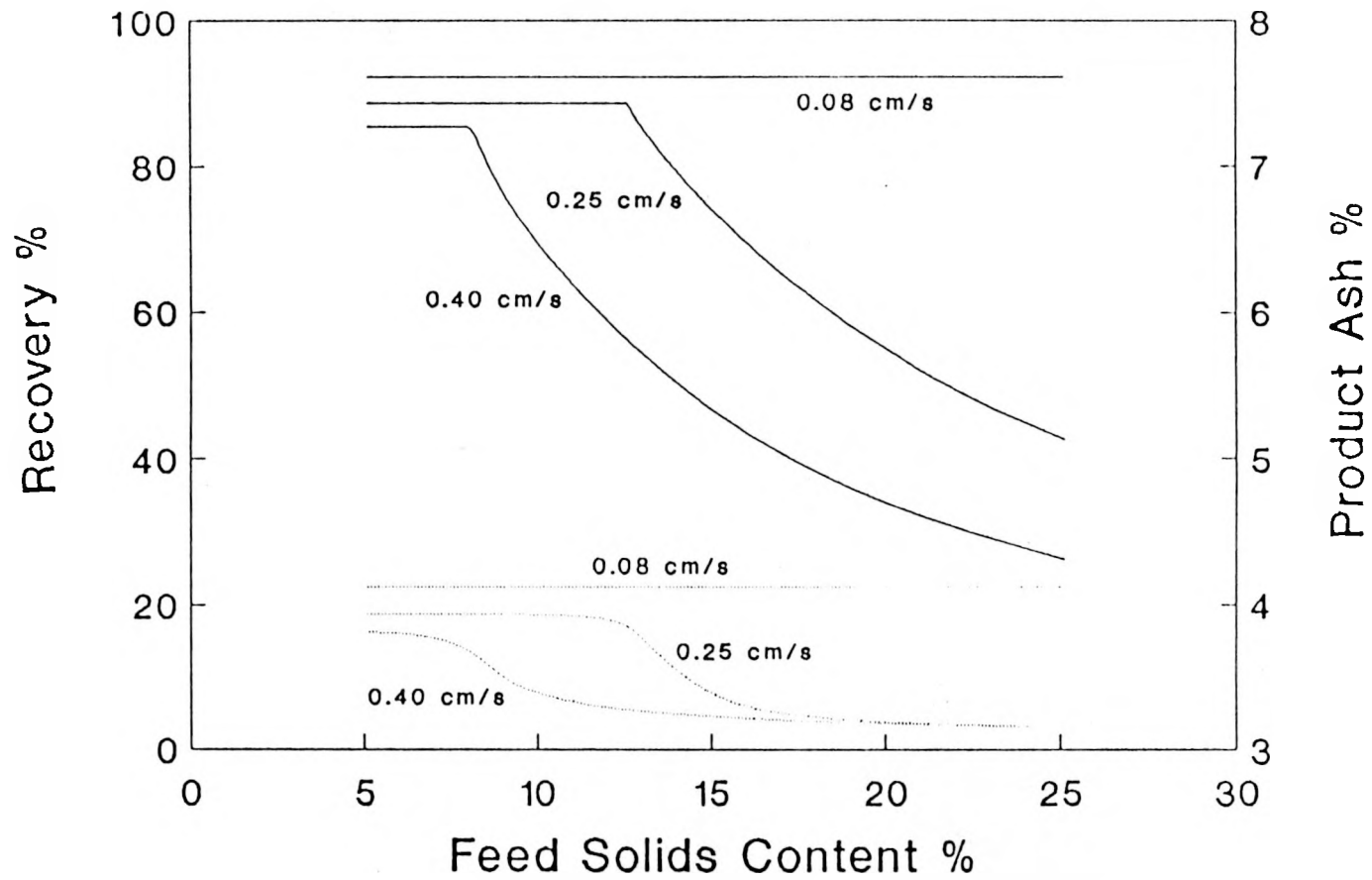
The simulation results shown in Figure 6.10 demonstrate the effect of froth bubble size on column performance. As froth bubble size increases, there is a net loss of available surface area on the bubbles for attached particles. This produces a corresponding reduction in the number of particles recovered in the froth product. As expected, this effect

FIGURE 6.8



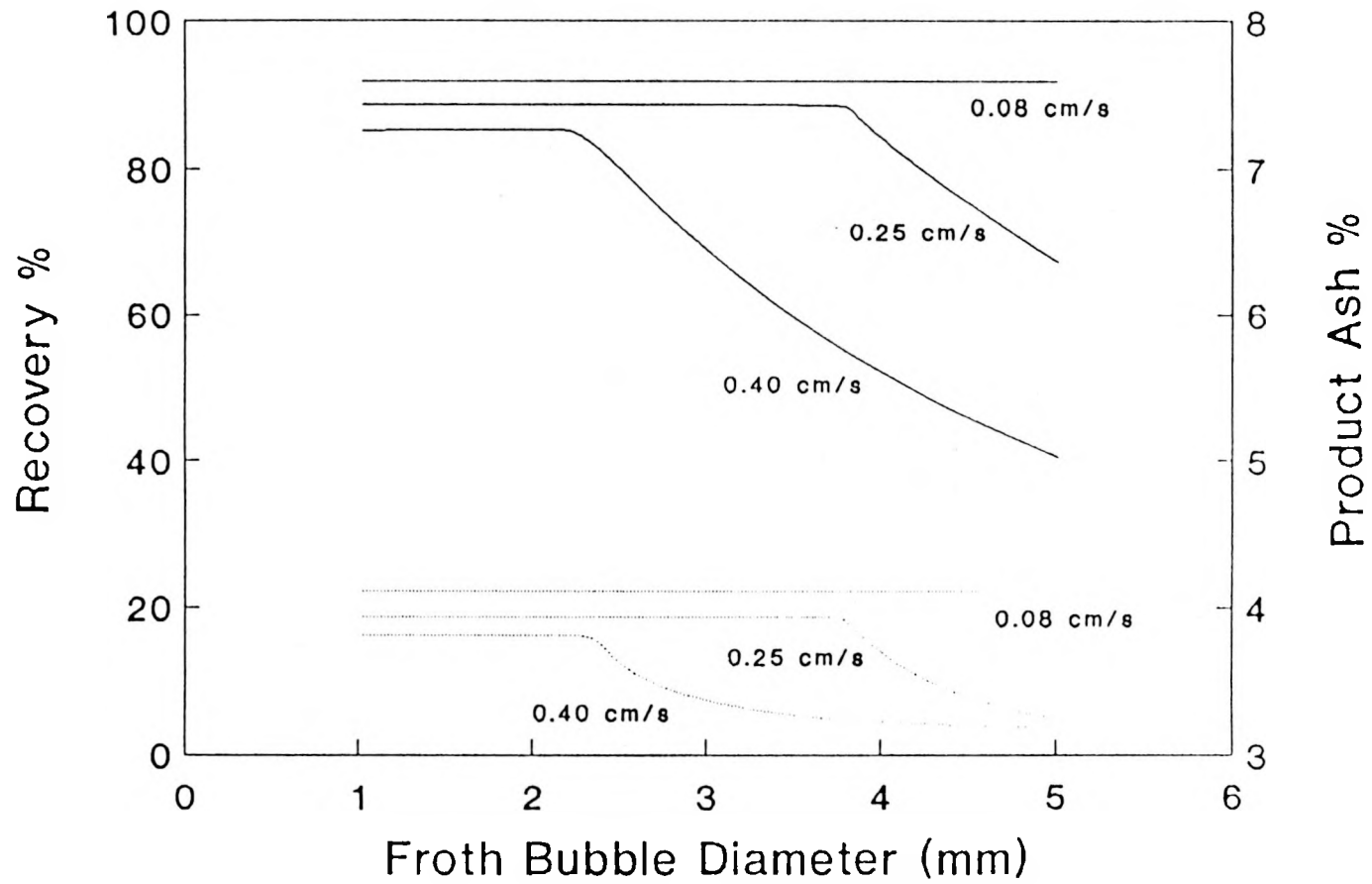
The simulated effect of column height on the recovery and product ash content for a low, medium and high superficial feed rate.

FIGURE 6.9



The simulated effect of feed solids content on the recovery and product ash content for a low, medium and high superficial feed rate.

FIGURE 6.10



The simulated effect of variations in froth bubble size on the recovery and product ash content for a low, medium and high superficial feed rate.

becomes more pronounced as the feed rate to the cell is increased. The product ash content also improves under carrying capacity limitations, which can be explained by the increased circulating load between pulp and froth.

It is also worthwhile to mention that preliminary laboratory data indicate that the pulp and froth bubble sizes may be related. An example of this relationship is shown in Figure 6.11. In general, a smaller bubble size in the pulp corresponds to a smaller bubble size in the froth. As a result, changes in the pulp bubble size may have a more drastic influence on column performance than initially indicated in the foregoing section.

6.3.2.14 Comparisons with Experimental Data

The simulation package was validated using data obtained from a series of laboratory tests conducted using a 5-cm diameter by 150-cm tall column. A Pittsburgh No. 8 coal sample having a feed ash content of 11.8% was used for all tests. In each experiment, all flow rates to the column were measured, as well as the air hold-up.

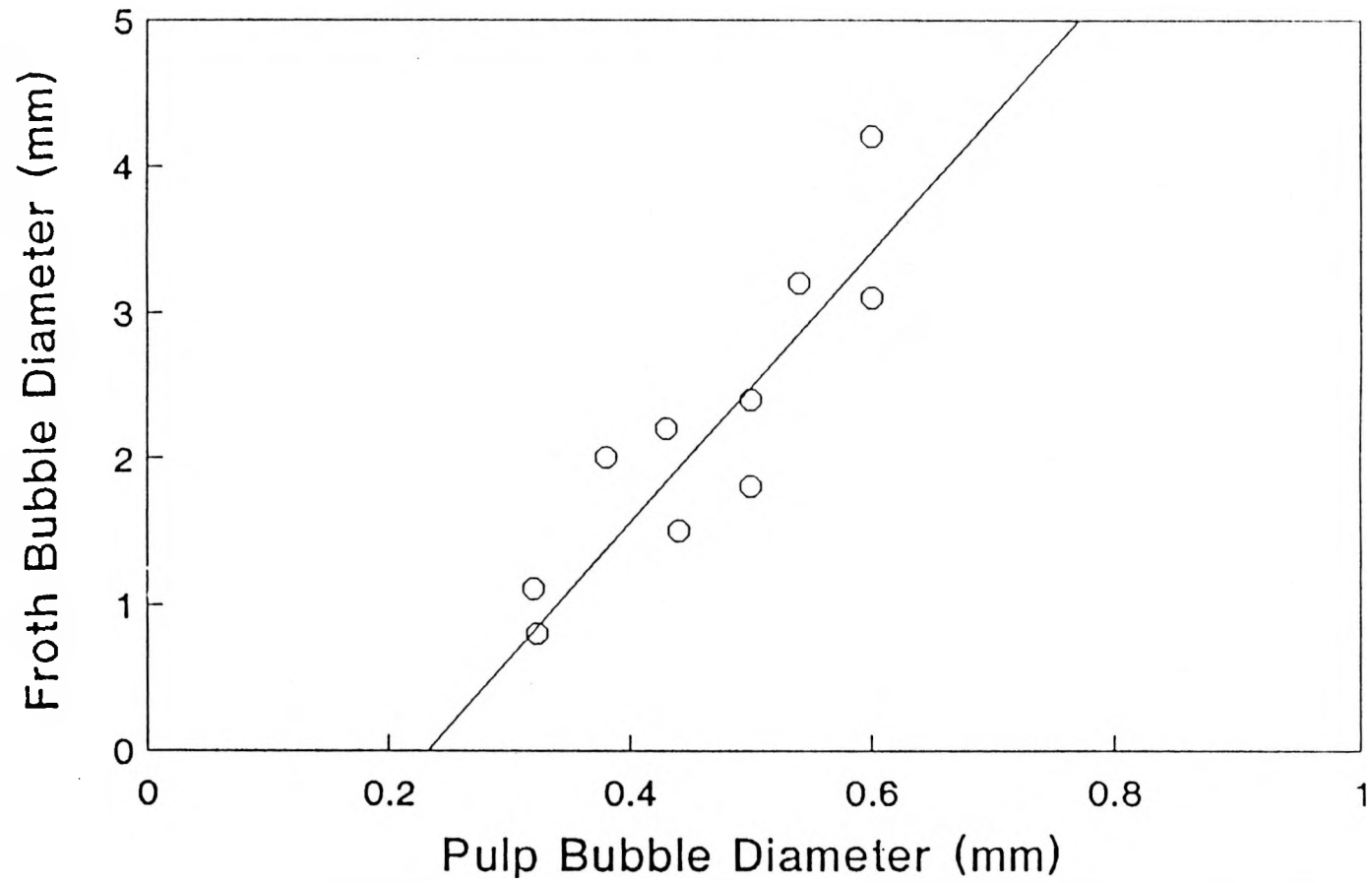
In order to obtain data required by the simulator, the feed coal sample was subjected to release analysis and the results plotted on a modified M-curve, Figure 6.12. The feed coal in this case was an in-house sample of the Pittsburgh No. 8 seam coal. The M-curve data provides information as to the amount and quality of each component present in the flotation feed. The details of this procedure are to be presented in the next quarter for the Pittsburgh No. 8 sample provided by B&W.

After characterizing the feed, the P_a values for the fast- and slow- floating components were determined by back-fitting the experimental data obtained under conditions which were known to be flotation-rate-limited (i.e., low solids contents and low feed rates). The pulp bubble size used in each test was calculated from the air hold-up using the procedure described by Mankosa et al. (6).

Comparisons between the simulated and predicted results are shown in Figures 6.13 and 6.14. As shown, there is a reasonably good agreement between the predicted and measured recovery values for this system. The fit is particularly good in light of the fact that the experimental data were collected over a wide range of bubble sizes, gas flow rates, feed flow rates and wash water addition rates.

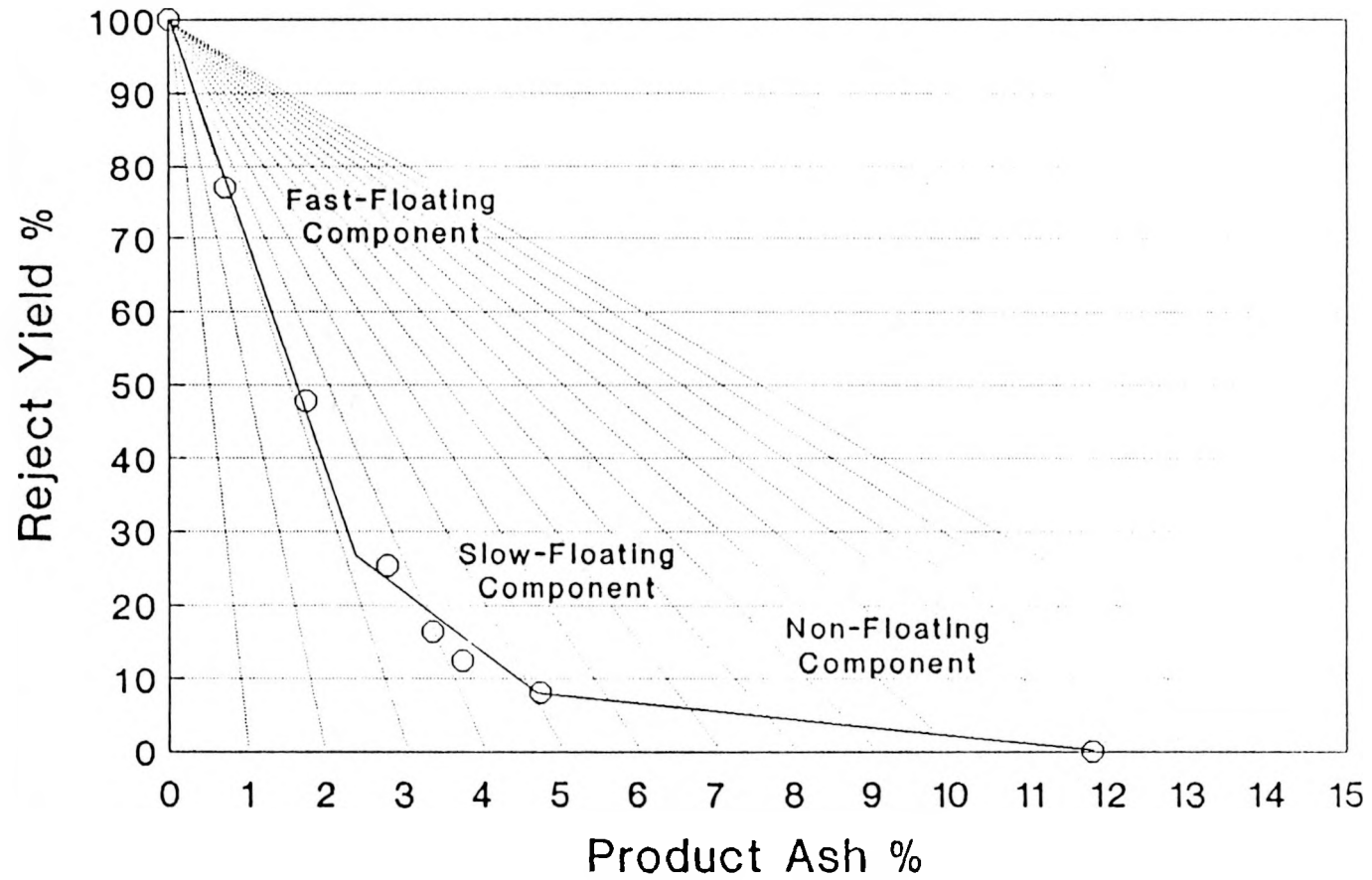
The agreement between the predicted and measured ash contents of the product is much poorer than those obtained for the recoveries. Several reasons may be given for the lack of fit. First, the range of the experimental data values is quite small for this sample, i.e., between 3% and 4.5%. This narrow band makes it difficult to obtain accurate analyses on the product streams. A second reason for the apparent data

FIGURE 6.11



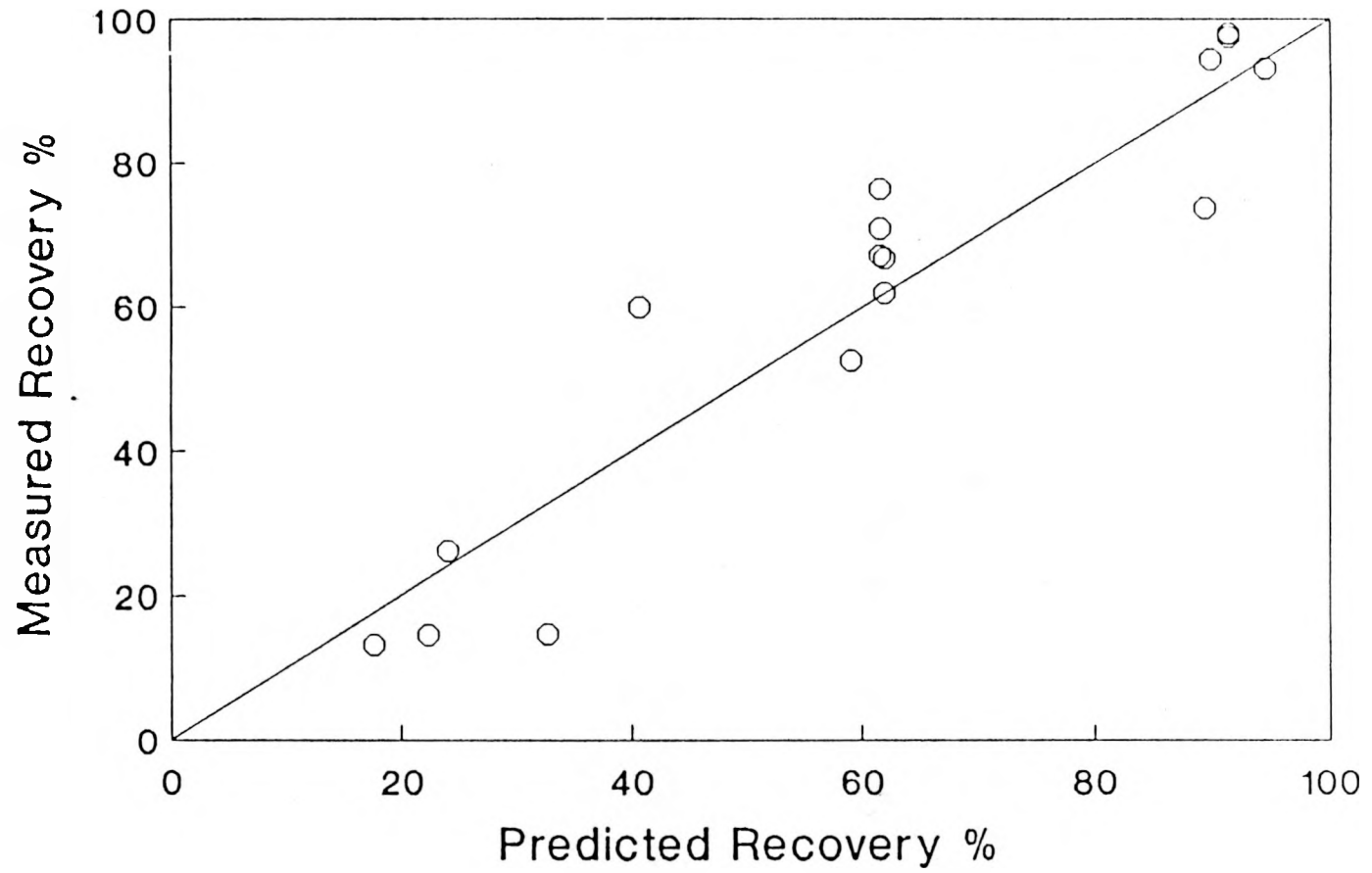
Relationship of pulp bubble size to froth bubble size.

FIGURE 6.12



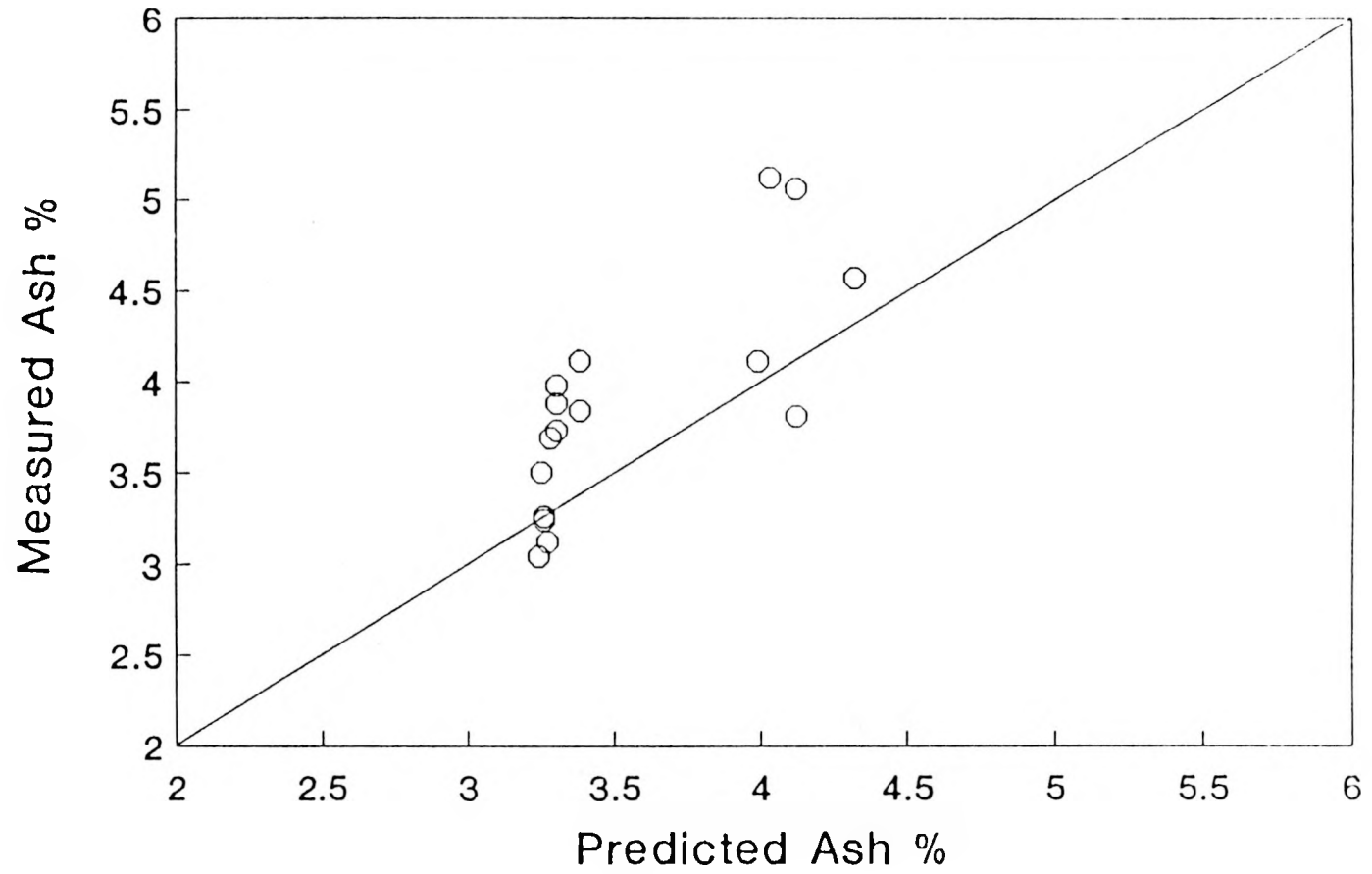
Modified M-curve showing quality and quantity of components in the flotation feed.

FIGURE 6.13



Comparison between measured and predicted recovery values for a fine coal flotation system.

FIGURE 6.14



Comparison between measured and predicted product ash contents for a fine coal flotation system.

scatter is that many of the tests were carried out under positive, but very low, bias flow rates. This allowed some ash-bearing particles to be collected in the product by entrainment. This may explain why many of the measured ash values are higher than the predicted values. Finally, it is possible that slime coatings may be responsible for variations in product quality. Additional studies are needed in order to clarify these problems.

6.3.2.15 Conclusions

Based on the theoretical and experimental work performed to date, the following conclusions can be drawn. It should be kept in mind that the experimental data has been determined from the in-house Pittsburgh No. 8 coal samples and are not directly useful for contractual purposes. However, the data have proved to be useful in testing the simulator prior to validation with the B&W supplied coal samples.

- 1) A computer simulation package for column-type flotation cells has been developed which can be used to predict the performance of fine particle flotation systems.
- 2) Parameters examined by the simulator in the present work include feed rate, gas flow rate, particle hydrophobicity, pulp bubble size, feed solids content, froth bubble size and column height. All of these parameters were found to have a significant impact on column performance.
- 3) The simulation results indicate that limitations arising from the carrying capacity of the froth phase can greatly impact column performance. Although the carrying capacity restricts column throughput, the simulation results suggest that operating under these conditions results in the build-up of a circulating load between the pulp and froth and, hence, improves the product grade.
- 4) The simulation results are in reasonable agreement with experimental data obtained for a fine coal flotation system. However, predictions of product quality were poorer than those for product recovery. This is probably due to other factors, such as slime coatings or particle entrainment/entrapment, which have not been incorporated into the simulator.
- 5) The simulator described here is for a single stage. Simulation of multi-stage circuits is easily accomplished by running the simulator separately for each stage. The results of the initial simulation would be used as the input to the following simulation, and so forth.

- 6) The circuit simulator, although functional, is not completely user friendly. Work will be done in the upcoming quarter to remedy this situation.

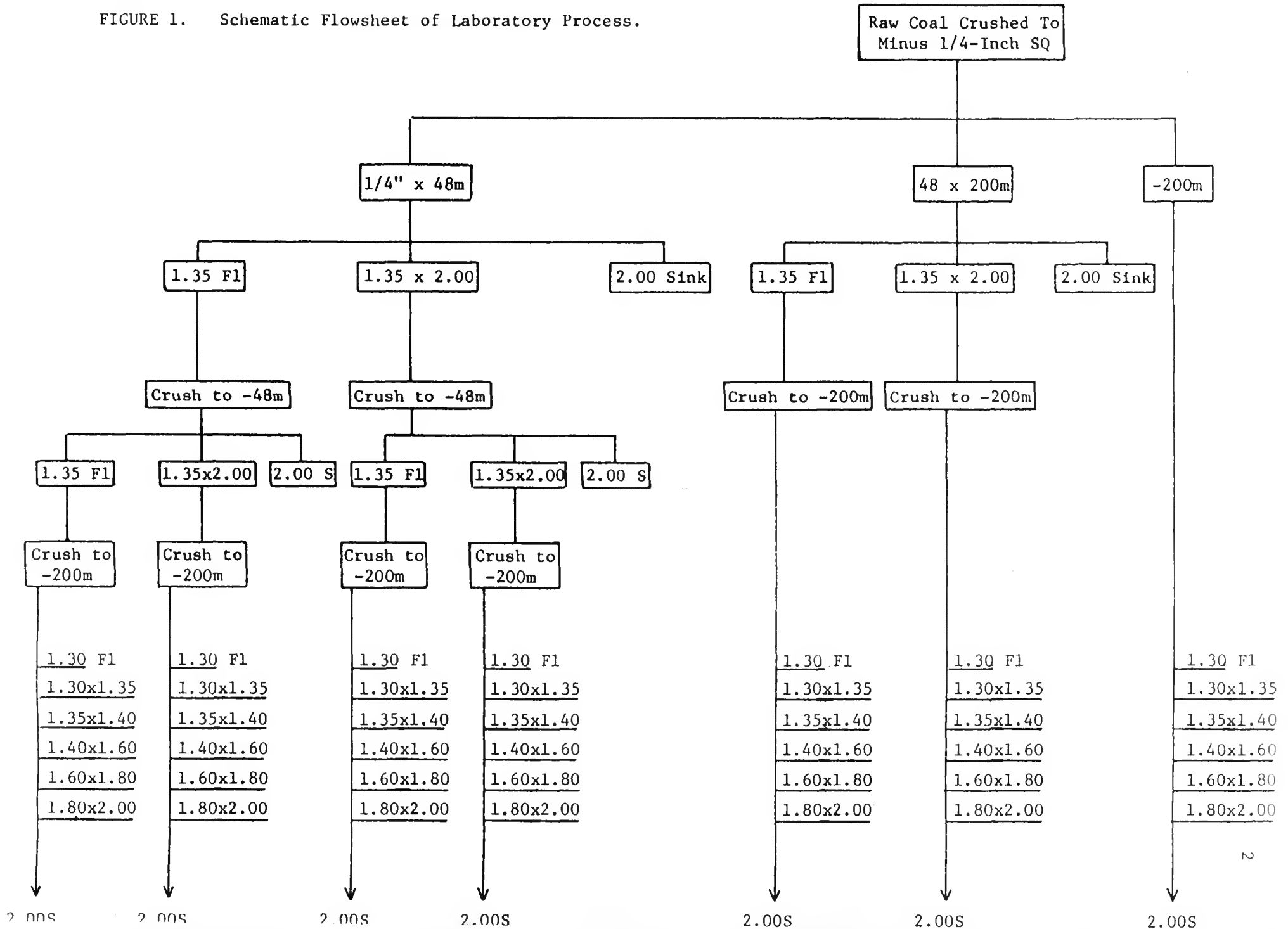
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5. Dobby, G. S. and Finch, J. A., 1988. "Flotation Column Scale-Up and Modeling," Canadian Institute of Mining and Metallurgy Bulletin, Vol. 79, No. 889, pp. 89-96.
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8. Yoon, R. H. and Luttrell, G. H., 1986. "The Effect of Bubble Size on Fine Coal Flotation," Coal Preparation, Vol. 2, No. 3, pp. 179-192.

APPENDIX "A"

Pyrite Liberation Laboratory Data

FIGURE 1. Schematic Flowsheet of Laboratory Process.



KAISER ENGINEERS, INC.
 PYRITE LIBERATION STUDY
 1/4-INCH X 48-MESH FRACTION
 STATIC BATH

| SPECIFIC GRAVITY | | DRY BASIS | | | | | | | | | CUMULATIVE PRODUCT (FLOAT) | | | | | | BTU | PYRSUL | |
|------------------|-------|-----------|-------|---------|----------------|-------------------|------------------|-------------------|--------------------|--------|----------------------------|---------|----------------|-------------------|------------------|-------------------|--------------------|---------------|-------------|
| Sink | Float | % Wt. | % Ash | % Sulf. | BTU per lb. | MAFBTU per lb. | % Pyr. Sulfur | % Sulf. Sulfur | % Organ. Sulfur | % Wt. | % Ash | % Sulf. | BTU per lb. | MAFBTU per lb. | % Pyr. Sulfur | % Sulf. Sulfur | % Organ. Sulfur | RECOVERY % | REJECT % |
| | 1.35 | 53.06 | 5.43 | 3.55 | 13,938 | 14,738 | 0.78 | 0.02 | 2.75 | 53.06 | 5.43 | 3.55 | 13,938 | 14,738 | 0.78 | 0.02 | 2.75 | 74.90 | 84.6 |
| 1.35 | 2.00 | 19.79 | 19.61 | 6.57 | 11,481 | 14,282 | 4.39 | 0.04 | 2.14 | 72.85 | 9.28 | 4.37 | 13,271 | 14,628 | 1.76 | 0.03 | 2.58 | 97.91 | 52.3 |
| 2.00 | | 27.15 | 85.82 | 5.36 | 762 | 5,374 | 5.19 | 0.01 | 0.17 | 100.00 | 30.06 | 4.64 | 9,874 | 14,119 | 2.69 | 0.02 | 1.93 | 100.00 | 0.0 |

KAISER ENGINEERS, INC.
 PYRITE LIBERATION STUDY
 1/4-INCH X 48-MESH, 1.35 FL - CRUSHED TO MINUS 48M
 CRUSHED TO MINUS 48-MESH
 HEAVY LIQUID SUPER CENTRIFUGE

| SPECIFIC GRAVITY | | | DRY BASIS | | | | | | | CUMULATIVE PRODUCT (FLOAT) | | | | | | | BTU RECOVERY | PYRSUL REJECT. | |
|------------------|-------|-------|-----------|---------|-------------|----------------|---------------|----------------|-----------------|----------------------------|-------|---------|-------------|----------------|---------------|----------------|-----------------|----------------|-------|
| Sink | Float | % Wt. | % Ash | % Sulf. | BTU per lb. | MAFBTU per lb. | % Pyr. Sulfur | % Sulf. Sulfur | % Organ. Sulfur | % Wt. | % Ash | % Sulf. | BTU per lb. | MAFBTU per lb. | % Pyr. Sulfur | % Sulf. Sulfur | % Organ. Sulfur | % | % |
| | 1.35 | 88.64 | 3.50 | 2.99 | 14,230 | 14,746 | 0.27 | 0.01 | 2.72 | 88.64 | 3.50 | 2.99 | 14,230 | 14,746 | 0.27 | 0.01 | 2.72 | 90.76 | 70.08 |
| 1.35 | 2.00 | 10.25 | 13.70 | 5.41 | 12,238 | 14,180 | 2.97 | 0.04 | 2.40 | 98.89 | 4.56 | 3.24 | 14,024 | 14,693 | 0.55 | 0.01 | 2.69 | 99.79 | 32.01 |
| 2.00 | | 1.11 | 65.98 | 26.99 | 2,629 | 7,729 | 23.48 | 0.39 | 3.12 | 100.00 | 5.24 | 3.50 | 13,897 | 14,665 | 0.80 | 0.02 | 2.69 | 100.00 | 0.00 |

Physical Head Sample

Head Sample (Raw 1/4" x 48-mesh - 1.35 Float Fraction)

| | | |
|-----------------------|--------|--------|
| % Ash (D/B) | 5.40 | 5.43 |
| % Sulfur (D/B) | 3.57 | 3.55 |
| BTU/lb. (D/B) | 13,672 | 13,938 |
| MAFBTU/lb. | 14,612 | 14,738 |
| % Pyritic Sulf. (D/B) | -- | 0.78 |
| % Sulfate Sulf. (D/B) | -- | 0.02 |
| % Organic Sulf. (D/B) | -- | 2.75 |

KAISER ENGINEERS, INC.
 PYRITE LIBERATION STUDY
 1/4-INCH X 48-MESH, 1.35X2.00 - CRUSHED TO -48M
 CRUSHED TO MINUS 48-MESH
 HEAVY LIQUID SUPER CENTRIFUGE

| SPECIFIC GRAVITY | | DRY BASIS | | | | | | | | | CUMULATIVE PRODUCT (FLOAT) | | | | | | BTU RECOVERY | PYRSUL REJECT. | |
|------------------|-------|-----------|-------|---------|-------------|----------------|---------------|----------------|-----------------|--------|----------------------------|---------|-------------|----------------|---------------|----------------|-----------------|----------------|-------|
| Sink | Float | % Wt. | % Ash | % Sulf. | BTU per lb. | MAFBTU per lb. | % Pyr. Sulfur | % Sulf. Sulfur | % Organ. Sulfur | % Wt. | % Ash | % Sulf. | BTU per lb. | MAFBTU per lb. | % Pyr. Sulfur | % Sulf. Sulfur | % Organ. Sulfur | % | % |
| | 1.35 | 37.09 | 4.22 | 3.17 | 13,977 | 14,593 | 0.59 | 0.01 | 2.56 | 37.09 | 4.22 | 3.17 | 13,977 | 14,593 | 0.59 | 0.01 | 2.56 | 46.09 | 94.50 |
| 1.35 | 2.00 | 51.66 | 21.46 | 5.37 | 10,928 | 13,914 | 3.15 | 0.04 | 2.18 | 88.75 | 14.26 | 4.45 | 12,202 | 14,231 | 2.08 | 0.03 | 2.34 | 96.28 | 54.06 |
| 2.00 | | 11.25 | 61.72 | 21.75 | 3,720 | 9,719 | 19.31 | 0.18 | 2.26 | 100.00 | 19.59 | 6.40 | 11,248 | 13,989 | 4.02 | 0.04 | 2.33 | 100.00 | 0.00 |

Physical Head Sample

Calculated Head Sample (Raw 1/4" x 48-mesh - 1.35 x 2.00 Float Fraction)

| | | |
|-----------------------|--------|--------|
| % Ash (D/B) | 19.81 | 19.61 |
| % Sulfur (D/B) | 6.64 | 6.57 |
| BTU/lb. (D/B) | 11,471 | 11,481 |
| MAFBTU/lb. | 14,306 | 14,282 |
| % Pyritic Sulf. (D/B) | 4.19 | 4.39 |
| % Sulfate Sulf. (D/B) | 0.03 | 0.04 |
| % Organic Sulf. (D/B) | 2.42 | 2.14 |

KAISER ENGINEERS, INC.
 PYRITE LIBERATION STUDY
 1/4" x 48m 1.35 FL - CRUSHED TO -48M, 1.35 FL - CRUSHED TO -200M
 HEAVY LIQUID SUPER CENTRIFUGE

| SPECIFIC GRAVITY | | DRY BASIS | | | | | | | | | CUMULATIVE PRODUCT (FLOAT) | | | | | | | BTU RECOVERY | PYRSUL REJECT. |
|------------------|-------|-----------|-------|---------|-------------|----------------|---------------|----------------|-----------------|--------|----------------------------|---------|-------------|----------------|---------------|----------------|-----------------|--------------|----------------|
| Sink | Float | % Wt. | % Ash | % Sulf. | BTU per lb. | MAFBTU per lb. | % Pyr. Sulfur | % Sulf. Sulfur | % Organ. Sulfur | % Wt. | % Ash | % Sulf. | BTU per lb. | MAFBTU per lb. | % Pyr. Sulfur | % Sulf. Sulfur | % Organ. Sulfur | % | % |
| | 1.30 | 56.98 | 1.42 | 2.65 | 14,187 | 14,392 | 0.02 | 0.01 | 2.63 | 56.98 | 1.42 | 2.65 | 14,187 | 14,391 | 0.02 | 0.01 | 2.63 | 58.70 | 96.83 |
| 1.30 | 1.35 | 33.72 | 3.83 | 2.59 | 13,722 | 14,268 | 0.18 | 0.01 | 2.41 | 90.70 | 2.32 | 2.63 | 14,014 | 14,346 | 0.08 | 0.01 | 2.55 | 92.29 | 79.84 |
| 1.35 | 1.40 | 4.39 | 7.87 | 2.89 | 12,796 | 13,890 | 0.68 | 0.04 | 2.17 | 95.09 | 2.57 | 2.64 | 13,958 | 14,326 | 0.11 | 0.01 | 2.53 | 96.37 | 70.94 |
| 1.40 | 1.60 | 3.12 | 12.90 | 3.90 | 12,177 | 13,981 | 1.65 | 0.04 | 2.21 | 98.21 | 2.90 | 2.68 | 13,901 | 14,317 | 0.16 | 0.01 | 2.52 | 99.13 | 56.35 |
| 1.60 | 1.80 | 0.41 | 26.75 | 8.49 | 9,933 | 13,560 | 6.77 | 0.09 | 1.63 | 98.62 | 3.00 | 2.70 | 13,885 | 14,314 | 0.18 | 0.01 | 2.52 | 99.43 | 50.69 |
| 1.80 | 2.00 | 0.37 | 56.94 | 9.70 | 4,935 | 11,461 | 9.39 | 0.18 | 0.13 | 98.99 | 3.20 | 2.73 | 13,851 | 14,309 | 0.22 | 0.01 | 2.51 | 99.56 | 39.51 |
| 2.00 | | 1.01 | 49.61 | 15.34 | 5,964 | 11,835 | 14.36 | 0.11 | 0.87 | 100.00 | 3.67 | 2.86 | 13,772 | 14,296 | 0.36 | 0.01 | 2.49 | 100.00 | 0.00 |

Physical Head Sample

Head Sample (Raw 1/4"x48m, 1.35 Fl Crushed to Minus 48m, 1.35 Fl)

| | |
|-----------------------|--------|
| % Ash (D/B) | 3.50 |
| % Sulfur (D/B) | 2.99 |
| BTU/lb. (D/B) | 14,230 |
| MAFBTU/lb. | 14,746 |
| % Pyritic Sulf. (D/B) | 0.27 |
| % Sulfate Sulf. (D/B) | 0.01 |
| % Organic Sulf. (D/B) | 2.72 |

KAISER ENGINEERS, INC.
 PYRITE LIBERATION STUDY
 1/4" x 48mm 1.35 FL - CRUSHED TO -48M, 1.35X200 - CRUSHED TO -200M
 HEAVY LIQUID SUPER CENTRIFUGE

| SPECIFIC GRAVITY | | DRY BASIS | | | | | | | | | CUMULATIVE PRODUCT (FLOAT) | | | | | | BTU RECOVERY | PYRSUL REJECT. | |
|------------------|-------|-----------|-------|---------|-------------|----------------|---------------|----------------|-----------------|--------|----------------------------|---------|-------------|----------------|---------------|----------------|-----------------|----------------|-------|
| Sink | Float | % Wt. | % Ash | % Sulf. | BTU per lb. | MAFBTU per lb. | % Pyr. Sulfur | % Sulf. Sulfur | % Organ. Sulfur | % Wt. | % Ash | % Sulf. | BTU per lb. | MAFBTU per lb. | % Pyr. Sulfur | % Sulf. Sulfur | % Organ. Sulfur | % | % |
| | 1.30 | 18.39 | 1.88 | 2.68 | 14,138 | 14,409 | 0.08 | 0.03 | 2.57 | 18.39 | 1.88 | 2.68 | 14,138 | 14,409 | 0.08 | 0.03 | 2.57 | 21.77 | 99.50 |
| 1.30 | 1.35 | 21.91 | 3.56 | 2.65 | 13,697 | 14,203 | 0.26 | 0.15 | 2.24 | 40.30 | 2.79 | 2.66 | 13,898 | 14,298 | 0.18 | 0.10 | 2.39 | 46.89 | 97.77 |
| 1.35 | 1.40 | 11.03 | 6.46 | 2.66 | 12,898 | 13,789 | 0.67 | 0.04 | 1.95 | 51.33 | 3.58 | 2.66 | 13,683 | 14,192 | 0.28 | 0.08 | 2.30 | 58.80 | 95.50 |
| 1.40 | 1.60 | 31.57 | 12.10 | 3.19 | 12,286 | 13,978 | 1.20 | 0.06 | 1.93 | 82.90 | 6.83 | 2.86 | 13,151 | 14,115 | 0.63 | 0.07 | 2.16 | 91.27 | 83.96 |
| 1.60 | 1.80 | 5.90 | 27.33 | 6.43 | 9,825 | 13,521 | 4.77 | 0.05 | 1.61 | 88.80 | 8.19 | 3.10 | 12,930 | 14,083 | 0.91 | 0.07 | 2.12 | 96.12 | 75.21 |
| 1.80 | 2.00 | 2.76 | 44.65 | 10.88 | 6,802 | 12,289 | 9.85 | 0.07 | 0.96 | 91.56 | 9.29 | 3.34 | 12,745 | 14,050 | 1.18 | 0.07 | 2.09 | 97.69 | 66.86 |
| 2.00 | | 8.44 | 62.18 | 27.10 | 3,262 | 8,626 | 25.89 | 0.20 | 1.01 | 100.00 | 13.75 | 5.34 | 11,945 | 13,850 | 3.26 | 0.08 | 1.99 | 100.00 | 0.00 |

Physical Head Sample

Head Sample (Raw 1/4"x48m, 1.35 Fl Crushed to Minus 48m, 1.35x2.00)

| | | |
|-----------------------|--------|--------|
| % Ash (D/B) | 14.49 | 13.70 |
| % Sulfur (D/B) | 5.53 | 5.41 |
| BTU/lb. (D/B) | 12,179 | 12,238 |
| MAFBTU/lb. | 14,244 | 14,180 |
| % Pyritic Sulf. (D/B) | 3.38 | 2.97 |
| % Sulfate Sulf. (D/B) | 0.02 | 0.04 |
| % Organic Sulf. (D/B) | 2.13 | 2.40 |

KAISER ENGINEERS, INC.
 PYRITE LIBERATION STUDY
 1/4" x 48M 1.35X2.00 - CRUSHED TO -48M, 1.35 FL - CRUSHED TO -200M
 HEAVY LIQUID SUPER CENTRIFUGE

| SPECIFIC GRAVITY | | DRY BASIS | | | | | | | | | CUMULATIVE PRODUCT (FLDAT) | | | | | | | BTU RECOVERY | PYRSUL REJECT. |
|------------------|-------|-----------|-------|---------|-------------|----------------|---------------|----------------|-----------------|--------|----------------------------|---------|-------------|----------------|---------------|----------------|-----------------|--------------|----------------|
| Sink | Float | % Wt. | % Ash | % Sulf. | BTU per lb. | MAFBTU per lb. | % Pyr. Sulfur | % Sulf. Sulfur | % Organ. Sulfur | % Wt. | % Ash | % Sulf. | BTU per lb. | MAFBTU per lb. | % Pyr. Sulfur | % Sulf. Sulfur | % Organ. Sulfur | % | % |
| | 1.30 | 46.41 | 1.70 | 2.67 | 14,171 | 14,416 | 0.09 | (0.01 | 2.58 | 46.41 | 1.70 | 2.67 | 14,171 | 14,416 | 0.09 | (0.01 | 2.58 | 48.44 | 93.86 |
| 1.30 | 1.35 | 37.56 | 3.04 | 2.61 | 13,756 | 14,187 | 0.18 | 0.02 | 2.84 | 83.97 | 2.30 | 2.64 | 13,985 | 14,315 | 0.13 | 0.01 | 2.70 | 86.49 | 83.95 |
| 1.35 | 1.40 | 6.19 | 7.05 | 2.93 | 12,711 | 13,675 | 0.77 | 0.05 | 2.11 | 90.16 | 2.63 | 2.66 | 13,898 | 14,273 | 0.17 | 0.02 | 2.66 | 92.29 | 77.46 |
| 1.40 | 1.60 | 6.94 | 11.31 | 3.73 | 12,366 | 13,944 | 1.54 | 0.04 | 2.15 | 97.10 | 3.25 | 2.74 | 13,788 | 14,251 | 0.27 | 0.02 | 2.62 | 98.61 | 61.45 |
| 1.60 | 1.80 | 0.74 | 26.26 | 9.08 | 9,949 | 13,491 | 7.29 | 0.08 | 1.17 | 97.84 | 3.42 | 2.79 | 13,759 | 14,247 | 0.32 | 0.02 | 2.61 | 99.15 | 53.96 |
| 1.80 | 2.00 | 0.55 | 51.41 | 11.00 | 5,930 | 12,203 | 9.66 | 0.16 | 1.14 | 98.39 | 3.69 | 2.83 | 13,716 | 14,241 | 0.38 | 0.02 | 2.60 | 99.40 | 45.02 |
| 2.00 | | 1.61 | 55.14 | 21.02 | 5,103 | 11,377 | 19.27 | 0.18 | 1.57 | 100.00 | 4.52 | 3.13 | 13,577 | 14,219 | 0.68 | 0.02 | 2.58 | 100.00 | 0.00 |

Physical Head Sample

Head Sample (Raw 1/4"x48m - 1.35x2.00, Crushed to Minus 48m, 1.35 Fl)

| | | |
|-----------------------|--------|--------|
| % Ash (D/B) | 4.64 | 4.22 |
| % Sulfur (D/B) | 3.22 | 3.17 |
| BTU/lb. (D/B) | 13,887 | 13,977 |
| MAFBTU/lb. | 14,563 | 14,593 |
| % Pyritic Sulf. (D/B) | 0.68 | 0.59 |
| % Sulfate Sulf. (D/B) | 0.02 | (0.01 |
| % Organic Sulf. (D/B) | 2.52 | 2.56 |

KAISER ENGINEERS, INC.
 PYRITE LIBERATION STUDY
 1/4" x 48M 1.35X2.00 - CRUSHED TO -48M, 1.35X2.00 - CRUSHED TO -200M
 HEAVY LIQUID SUPER CENTRIFUGE

| SPECIFIC GRAVITY | | DRY BASIS | | | | | | | | | CUMULATIVE PRODUCT (FLOAT) | | | | | | BTU RECOVERY | PYRSUL REJECT. | |
|------------------|-------|-----------|-------|---------|-------------|----------------|---------------|----------------|-----------------|--------|----------------------------|---------|-------------|----------------|---------------|----------------|-----------------|----------------|-------|
| Sink | Float | % Wt. | % Ash | % Sulf. | BTU per lb. | MAFBTU per lb. | % Pyr. Sulfur | % Sulf. Sulfur | % Organ. Sulfur | % Wt. | % Ash | % Sulf. | BTU per lb. | MAFBTU per lb. | % Pyr. Sulfur | % Sulf. Sulfur | % Organ. Sulfur | % | % |
| | 1.30 | 5.75 | 6.62 | 2.70 | 13,323 | 14,268 | 0.36 | 0.05 | 2.29 | 5.75 | 6.62 | 2.70 | 13,323 | 14,268 | 0.36 | 0.05 | 2.29 | 7.16 | 99.40 |
| 1.30 | 1.35 | 19.24 | 3.05 | 2.65 | 13,765 | 14,198 | 0.17 | 0.04 | 2.45 | 24.99 | 3.87 | 2.66 | 13,663 | 14,214 | 0.21 | 0.04 | 2.41 | 31.90 | 98.47 |
| 1.35 | 1.40 | 16.91 | 12.49 | 2.85 | 11,854 | 13,546 | 1.03 | 0.07 | 1.75 | 41.90 | 7.35 | 2.74 | 12,933 | 13,959 | 0.54 | 0.05 | 2.15 | 50.63 | 93.42 |
| 1.40 | 1.60 | 27.87 | 13.22 | 2.95 | 12,031 | 13,863 | 1.11 | 0.05 | 1.79 | 69.77 | 9.69 | 2.82 | 12,573 | 13,922 | 0.77 | 0.05 | 2.00 | 81.96 | 84.38 |
| 1.60 | 1.80 | 11.46 | 30.38 | 4.02 | 9,385 | 13,481 | 2.19 | 0.06 | 1.77 | 81.23 | 12.61 | 2.99 | 12,123 | 13,873 | 0.97 | 0.05 | 1.97 | 92.01 | 77.10 |
| 1.80 | 2.00 | 7.04 | 46.74 | 5.95 | 6,724 | 12,624 | 4.73 | 0.07 | 1.15 | 88.27 | 15.33 | 3.23 | 11,692 | 13,810 | 1.27 | 0.05 | 1.91 | 96.43 | 67.41 |
| 2.00 | | 11.73 | 64.11 | 21.15 | 3,255 | 9,069 | 19.77 | 0.16 | 1.22 | 100.00 | 21.06 | 5.33 | 10,703 | 13,557 | 3.44 | 0.07 | 1.82 | 100.00 | 0.00 |

| | Physical Head Sample | Head Sample (Raw 1/4"x48m Crushed to Minus 48m, 1.35x2.00) | D.O.E. Calculated Composite |
|-----------------------|----------------------|--|-----------------------------|
| % Ash (D/B) | 21.89 | 21.46 | 21.37 |
| % Sulfur (D/B) | 5.52 | 5.37 | 5.51 |
| BTU/lb. (D/B) | 10,853 | 10,928 | |
| MAFBTU/lb. | 13,894 | 13,914 | |
| % Pyritic Sulf. (D/B) | 3.57 | 3.15 | 3.48 |
| % Sulfate Sulf. (D/B) | 0.04 | 0.04 | |
| % Organic Sulf. (D/B) | 1.91 | 2.18 | |

KAISER ENGINEERS, INC.
 PYRITE LIBERATION STUDY
 48 X 200-MESH FRACTION
 STATIC CENTRIFUGE - HEAVY LIQUID SUPER CENTRIFUGE COMPARISON

| SPECIFIC GRAVITY | | DRY BASIS | | | | | | | | | CUMULATIVE PRODUCT (FLOAT) | | | | | | BTU RECOVERY | PYRSUL REJECT. | |
|-------------------------------|-------|-----------|-------|---------|-------------|----------------|---------------|----------------|-----------------|--------|----------------------------|---------|-------------|----------------|---------------|----------------|-----------------|----------------|-------|
| Sink | Float | % Wt. | % Ash | % Sulf. | BTU per lb. | MAFBTU per lb. | % Pyr. Sulfur | % Sulf. Sulfur | % Organ. Sulfur | % Wt. | % Ash | % Sulf. | BTU per lb. | MAFBTU per lb. | % Pyr. Sulfur | % Sulf. Sulfur | % Organ. Sulfur | % | % |
| BATCH CENTRIFUGE | | | | | | | | | | | | | | | | | | | |
| | 1.35 | 56.64 | 3.69 | 3.11 | 14,204 | 14,748 | 0.42 | 0.02 | 2.67 | 56.64 | 3.69 | 3.11 | 14,204 | 14,748 | 0.42 | 0.02 | 2.67 | 74.73 | 93.43 |
| 1.35 | 2.00 | 20.76 | 18.56 | 6.09 | 11,694 | 14,358 | 3.67 | 0.14 | 2.28 | 77.40 | 7.68 | 3.91 | 13,531 | 14,656 | 1.29 | 0.05 | 2.57 | 97.28 | 72.42 |
| 2.00 | | 22.60 | 78.44 | 12.33 | 1,297 | 6,018 | 11.59 | 0.14 | 0.60 | 100.00 | 23.67 | 5.81 | 10,766 | 14,105 | 3.62 | 0.07 | 2.12 | 100.00 | 0.00 |
| HEAVY LIQUID SUPER CENTRIFUGE | | | | | | | | | | | | | | | | | | | |
| | 1.35 | 59.40 | 3.82 | 3.09 | 14,138 | 14,699 | 0.45 | 0.01 | 2.63 | 59.40 | 3.82 | 3.09 | 14,138 | 14,700 | 0.45 | 0.01 | 2.63 | 78.50 | 92.32 |
| 1.35 | 2.00 | 18.42 | 21.46 | 6.71 | 10,988 | 13,990 | 4.36 | 0.11 | 2.24 | 77.82 | 8.00 | 3.95 | 13,392 | 14,556 | 1.38 | 0.03 | 2.54 | 97.42 | 69.14 |
| 2.00 | | 22.18 | 78.97 | 11.38 | 1,244 | 5,916 | 10.86 | 0.21 | 0.31 | 100.00 | 23.74 | 5.60 | 10,698 | 14,028 | 3.48 | 0.07 | 2.05 | 100.00 | 0.00 |

KAISER ENGINEERS, INC.
 PYRITE LIBERATION STUDY
 48 X 200-MESH, 1.35 FL - CRUSHED TO MINUS 200-MESH
 HEAVY LIQUID SUPER CENTRIFUGE

| SPECIFIC GRAVITY | | | DRY BASIS | | | | | | | CUMULATIVE PRODUCT (FLOAT) | | | | | | | BTU RECOVERY | PYRSUL REJECT. | |
|------------------|-------|-------|-----------|---------|-------------|----------------|---------------|----------------|-----------------|----------------------------|-------|---------|-------------|----------------|---------------|----------------|-----------------|----------------|-------|
| Sink | Float | % Wt. | % Ash | % Sulf. | BTU per lb. | MAFBTU per lb. | % Pyr. Sulfur | % Sulf. Sulfur | % Organ. Sulfur | % Wt. | % Ash | % Sulf. | BTU per lb. | MAFBTU per lb. | % Pyr. Sulfur | % Sulf. Sulfur | % Organ. Sulfur | % | % |
| | 1.30 | 74.26 | 1.82 | 2.72 | 14,146 | 14,408 | 0.05 | 0.02 | 2.65 | 74.26 | 1.82 | 2.72 | 14,146 | 14,408 | 0.05 | 0.02 | 2.65 | 76.01 | 92.10 |
| 1.30 | 1.35 | 18.24 | 5.02 | 2.80 | 13,667 | 14,389 | 0.52 | 0.02 | 2.26 | 92.50 | 2.45 | 2.74 | 14,052 | 14,405 | 0.14 | 0.02 | 2.57 | 94.05 | 72.45 |
| 1.35 | 1.40 | 3.74 | 9.12 | 3.37 | 12,979 | 14,281 | 0.71 | 0.06 | 2.60 | 96.24 | 2.71 | 2.76 | 14,010 | 14,400 | 0.16 | 0.02 | 2.57 | 97.56 | 67.24 |
| 1.40 | 1.60 | 2.21 | 15.10 | 5.40 | 11,950 | 14,075 | 3.10 * | 0.07 * | 2.23 * | 98.45 | 2.99 | 2.82 | 13,964 | 14,394 | 0.23 | 0.02 | 2.57 | 99.48 | 51.82 |
| 1.60 | 1.80 | 0.31 | 25.30 | 10.83 | 10,112 | 13,537 | 9.21 * | 0.10 * | 1.52 * | 98.76 | 3.06 | 2.84 | 13,952 | 14,392 | 0.26 | 0.02 | 2.56 | 99.70 | 45.37 |
| 1.80 | 2.00 | 0.15 | 32.17 | 14.38 * | 7,826 * | 11,538 | 13.45 * | 0.13 * | 1.25 * | 98.91 | 3.10 | 2.86 | 13,942 | 14,389 | 0.28 | 0.02 | 2.56 | 99.78 | 41.07 |
| 2.00 | | 1.09 | 68.89 | 19.60 | 2,685 | 8,631 | 17.85 | 0.67 | 1.43 | 100.00 | 3.82 | 3.04 | 13,820 | 14,368 | 0.47 | 0.03 | 2.55 | 100.00 | 0.00 |

* VALUES EXTRAPOLATED DUE TO INSUFFICIENT MATERIAL FOR ANALYSES.

| | Physical Head Sample | Head Sample (Raw 48 x 200-mesh - 1.35 Float Fraction) |
|-----------------------|------------------------------------|---|
| % Ash (D/B) | | 3.82 |
| % Sulfur (D/B) | | 3.09 |
| BTU/lb. (D/B) | Insufficient Material for Analyses | 14,138 |
| MAFBTU/lb. | | 14,699 |
| % Pyritic Sulf. (D/B) | | 0.45 |
| % Sulfate Sulf. (D/B) | | 0.01 |
| % Organic Sulf. (D/B) | | 2.63 |

KAISER ENGINEERS, INC.
 PYRITE LIBERATION STUDY
 48 X 200M, 1.35X2.00 - CRUSHED TO -200M
 HEAVY LIQUID SUPER CENTRIFUGE

| SPECIFIC GRAVITY | | DRY BASIS | | | | | | | | | CUMULATIVE PRODUCT (FLOAT) | | | | | | BTU | PYRSUL | |
|------------------|-------|-----------|-------|---------|----------------|-------------------|------------------|-------------------|--------------------|--------|----------------------------|---------|----------------|-------------------|------------------|-------------------|--------------------|--------|-------|
| Sink | Float | % Wt. | % Ash | % Sulf. | BTU per lb. | MAFBTU per lb. | % Pyr. Sulfur | % Sulf. Sulfur | % Organ. Sulfur | % Wt. | % Ash | % Sulf. | BTU per lb. | MAFBTU per lb. | % Pyr. Sulfur | % Sulf. Sulfur | % Organ. Sulfur | % | % |
| | 1.30 | 18.90 | 2.30 | 2.75 | 14,197 | 14,530 | 0.13 | 0.02 | 2.60 | 18.90 | 2.30 | 2.75 | 14,197 | 14,531 | 0.13 | 0.02 | 2.60 | 25.01 | 99.45 |
| 1.30 | 1.35 | 18.34 | 4.30 | 2.54 | 13,737 | 14,354 | 0.27 | 0.04 | 2.23 | 37.24 | 3.28 | 2.65 | 13,970 | 14,445 | 0.20 | 0.03 | 2.42 | 48.49 | 98.44 |
| 1.35 | 1.40 | 9.64 | 7.05 | 2.34 | 13,423 | 14,441 | 0.61 | 0.04 | 1.69 | 46.88 | 4.06 | 2.58 | 13,858 | 14,444 | 0.28 | 0.03 | 2.27 | 60.56 | 97.25 |
| 1.40 | 1.60 | 22.40 | 13.13 | 2.68 | 12,387 | 14,259 | 1.02 | 0.06 | 1.60 | 69.28 | 6.99 | 2.61 | 13,382 | 14,388 | 0.52 | 0.04 | 2.05 | 86.42 | 92.46 |
| 1.60 | 1.80 | 7.73 | 29.59 | 4.10 | 9,744 | 13,839 | 2.22 | 0.09 | 1.79 | 77.01 | 9.26 | 2.76 | 13,017 | 14,346 | 0.69 | 0.05 | 2.03 | 93.44 | 88.85 |
| 1.80 | 2.00 | 4.27 | 49.75 | 6.48 | 6,293 | 12,525 | 3.39 | 0.16 | 0.93 | 81.28 | 11.39 | 2.96 | 12,664 | 14,291 | 0.94 | 0.05 | 1.97 | 95.95 | 84.02 |
| 2.00 | | 18.72 | 68.97 | 22.33 | 2,322 | 7,484 | 21.48 | 0.41 | 0.44 | 100.00 | 22.17 | 6.59 | 10,728 | 13,783 | 4.78 | 0.12 | 1.68 | 100.00 | 0.00 |

Physical Head
Sample

Head Sample (48x200m, 1.35x2.00)

| | | |
|-----------------------|--------|--------|
| % Ash (D/B) | 22.08 | 21.46 |
| % Sulfur (D/B) | 6.56 | 6.71 |
| BTU/lb. (D/B) | 11,031 | 10,988 |
| MAFBTU/lb. | 14,157 | 13,990 |
| % Pyritic Sulf. (D/B) | 4.48 | 4.36 |
| % Sulfate Sulf. (D/B) | 0.04 | 0.11 |
| % Organic Sulf. (D/B) | 2.04 | 2.24 |

KAISER ENGINEERS, INC.
 PYRITE LIBERATION STUDY
 RAW MINUS 200-MESH FRACTION
 BATCH CENTRIFUGE - HEAVY LIQUID SUPER CENTRIFUGE COMPARISON

| SPECIFIC GRAVITY | | DRY BASIS | | | | | | | | | CUMULATIVE PRODUCT (FLOAT) | | | | | | BTU RECOVERY | PYRSUL REJECT. | |
|-------------------------------|-------|-----------|-------|---------|-------------|----------------|---------------|----------------|-----------------|--------|----------------------------|---------|-------------|----------------|---------------|----------------|-----------------|----------------|-------|
| Sink | Float | % Wt. | % Ash | % Sulf. | BTU per lb. | MAFBTU per lb. | % Pyr. Sulfur | % Sulf. Sulfur | % Organ. Sulfur | % Wt. | % Ash | % Sulf. | BTU per lb. | MAFBTU per lb. | % Pyr. Sulfur | % Sulf. Sulfur | % Organ. Sulfur | % | % |
| BATCH CENTRIFUGE | | | | | | | | | | | | | | | | | | | |
| | 1.30 | 2.25 | 4.16 | 2.65 | 13,378 | 13,959 | 0.12 | 0.01 | 2.52 | 2.25 | 4.16 | 2.65 | 13,378 | 13,959 | 0.12 | 0.01 | 2.52 | 5.84 | 99.88 |
| 1.30 | 1.35 | 6.66 | 4.71 | 2.65 | 13,396 | 14,058 | 0.12 | 0.01 | 2.52 | 8.91 | 4.57 | 2.65 | 13,391 | 14,033 | 0.12 | 0.01 | 2.52 | 23.19 | 99.51 |
| 1.35 | 1.40 | 11.34 | 11.48 | 2.45 | 12,029 | 13,589 | 0.28 | 0.02 | 2.15 | 20.25 | 8.44 | 2.54 | 12,628 | 13,793 | 0.21 | 0.02 | 2.31 | 49.69 | 98.07 |
| 1.40 | 1.60 | 5.49 | 27.59 | 2.17 | 10,292 | 14,214 | 0.89 | 0.06 | 1.22 | 25.74 | 12.52 | 2.46 | 12,130 | 13,867 | 0.35 | 0.03 | 2.08 | 60.67 | 95.91 |
| 1.60 | 1.80 | 4.45 | 48.65 | 2.13 | 6,434 | 12,530 | 1.31 | 0.11 | 0.71 | 30.19 | 17.85 | 2.41 | 11,291 | 13,744 | 0.50 | 0.04 | 1.88 | 66.24 | 93.14 |
| 1.80 | 2.00 | 8.31 | 74.38 | 2.60 | 2,756 | 10,757 | 1.57 | 0.17 | 0.86 | 38.50 | 30.05 | 2.45 | 9,448 | 13,508 | 0.73 | 0.07 | 1.66 | 70.69 | 87.23 |
| 2.00 | | 61.50 | 75.65 | 4.01 | 2,452 | 10,070 | 3.12 | 0.18 | 0.71 | 100.00 | 58.09 | 3.41 | 5,146 | 12,279 | 2.20 | 0.14 | 1.08 | 100.00 | 0.00 |
| HEAVY LIQUID SUPER CENTRIFUGE | | | | | | | | | | | | | | | | | | | |
| | 1.30 | 9.13 | 2.88 | 2.69 | 13,870 | 14,281 | 0.06 | 0.02 | 2.62 | 9.13 | 2.88 | 2.69 | 13,870 | 14,281 | 0.06 | 0.02 | 2.62 | 23.61 | 99.75 |
| 1.30 | 1.35 | 8.55 | 6.11 | 2.64 | 13,466 | 14,342 | 0.18 | 0.02 | 2.44 | 17.68 | 4.44 | 2.67 | 13,675 | 14,310 | 0.12 | 0.02 | 2.53 | 45.07 | 99.04 |
| 1.35 | 1.40 | 7.28 | 9.36 | 2.46 | 12,900 | 14,232 | 0.32 | 0.04 | 2.10 | 24.96 | 5.88 | 2.61 | 13,449 | 14,288 | 0.18 | 0.03 | 2.41 | 62.58 | 97.97 |
| 1.40 | 1.60 | 10.31 | 14.22 | 2.05 | 12,288 | 14,325 | 0.62 | 0.04 | 1.39 | 35.27 | 8.32 | 2.44 | 13,109 | 14,298 | 0.31 | 0.03 | 2.11 | 86.20 | 95.05 |
| 1.60 | 1.80 | 2.67 | 23.41 | 2.18 | 10,908 | 14,242 | 1.19 | 0.09 | 0.90 | 37.94 | 9.38 | 2.42 | 12,954 | 14,295 | 0.37 | 0.03 | 2.02 | 91.62 | 93.65 |
| 1.80 | 2.00 | 2.29 | 67.59 | 5.34 | 3,195 | 9,858 | 4.42 | 0.26 | 0.66 | 40.23 | 12.69 | 2.59 | 12,399 | 14,201 | 0.60 | 0.05 | 1.95 | 92.99 | 89.08 |
| 2.00 | | 59.77 | 87.77 | 3.93 | 629 | 5,143 | 3.30 | 0.19 | 0.44 | 100.00 | 57.57 | 3.39 | 5,364 | 12,641 | 2.21 | 0.13 | 1.05 | 100.00 | 0.00 |

APPENDIX "B"

Methodology for Preparation of Advanced
Flotation Round-Robin Test Samples

METHODOLOGY FOR PREPARATION OF ADVANCED
FLOTATION ROUND-ROBIN TEST SAMPLES

Prepared by

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Approximately 120 lbs of fine coal slurry and 120 lbs of dry 1/4" x 0 coal were prepared by Babcock & Wilcox at its Alliance Research Center (ARC) for use by each participant in the Round-Robin Testing of advanced flotation. Figure 1 is a flowsheet outlining the major steps performed in preparing the dry coal sample and the fine slurry. The methodology of grinding, sampling, inerting, and analyzing the samples during preparation is described in detail below.

1. Coal Crushing and Feed Preparation

o Coal Crushing

Five Barrels (approximate 1400 lbs) of Pittsburgh No. 8 coal were shipped from Praxis Engineers, Inc. This coal was obtained from Belmont county, Ohio and was supplied by R&F Coal Company. This sample of coal was set aside from DOE/PETC's "Coal Surface Control for Advanced Fine Coal Flotation" project. The coal had size of 4" x 0 and was stored in plastic liner, inerted with argon, and taped prior to shipment to B&W's ARC.

Upon arrival, the coal was crushed to 1/4" x 0 using a Hammerville Crusher, Model #3296, from Holmes Bros, Inc. in Danville, Illinois. The size analysis of the 1/4" x 0 fraction is shown in Table 1. The crushing was done very quickly and without inerting. The crushed coal was stored in barrels purged with N₂ as it was produced. After all the coal was crushed, the barrels of product coal were dumped on the floor and mixed together before riffing. The sample was riffled down twice. The first time was to produce a sample of approximately 40 lbs. The 40-lb sample was further split into four 10-lb samples and used for coal analysis and flotation analysis to determine signs of oxidation.

The 10 lb samples were stored in separate plastic bags and purged with N₂ for approximately 4 times the volume of the coal. The plastic bags were sealed with a thermal sealer. The samples were then double bagged and again purged with N₂ before the outer bags were sealed. Two of the 10-lb samples were for ASTM coal analysis. The two other 10-lb

samples were shipped to Professor D. W. Fuerstenau at the University of California at Berkeley (UCB) for standard flotation tests to verify the coal did not change. Professor Fuerstenau's group at UCB is the lead of the "Coal Surface Control for Advanced Coal Flotation".

The remaining coal (approximately 1360 lbs) was remixed and riffled again to obtain 40 lb samples for the Round Robin Test participants. Each sample was weighed, bagged, purged with N₂ for approximately 4 times of coal volume, sealed with a thermal sealer, doubled bagged, purged with N₂ again, sealed, and stored in a 5-gallon plastic bucket. Each bucket was purged with N₂ before the lid was tightened. Three 40 lb samples of 1/4" x 0 coal (total of 120 lbs in 9 buckets) were shipped to each participant. The remaining crushed coal (approximately 400 lbs) which was used by B&W to prepare fine coal slurry was stored in a barrel with a plastic liner, purged with N₂, sealed with a tape, double bagged, purged with N₂ again, taped, and the barrel was purged with N₂ before the lid was sealed.

o Pulverized Feed Preparation

Prior to preparation of slurry, the remaining crushed 1/4" x 0 coal was further reduced in size by pulverizing with a hammermill, a Mikro-Pulverizer, Model 1SH. The pulverized coal has a size distribution of 99.5% less than 300 microns (48 mesh) and 74% less than 75 microns (200 mesh). The size analysis of the pulverized coal is shown in Table 2 and Figure 2. The pulverized coal fraction was used as a feed for a stirred ball mill for fine coal slurry preparation.

2. Slurry Preparation

o Mill Preparation

A laboratory batch stirred ball mill, an attritor mill from Union Process, Model 1S, was used to prepare the fine Pittsburgh No. 8 coal slurry. A photograph of the mill is shown in Figure 3. The dimension and the capacity of the mill are shown below:

| | |
|------------------|---|
| Mill diameter: | 9 inches |
| Mill depth: | 8 inches |
| Mill volume: | 2.5 gallons. |
| Grinding medium: | 3/16" 440 stainless steel beads. |
| Medium charge: | 60 lbs (approximately 60% of mill volume) |

The mill was rinsed with a volume of tap water equivalent to three times the mill volume while the grinding shaft was turning at a slow speed (approximately 70 rpm) to remove any rust in the mill. The mill was then rinsed with

distilled water to displace remaining tap water left in the mill. The wash water was drained out while the grinding shaft was rotated at a slow speed.

o Fine Grinding

The amount of coal required for grinding was calculated based on the moisture in the coal and in the mill. Typical weights of water and coal for fine slurry preparation were as follows:

| | |
|------------------------------------|---------|
| "Target" solids content in slurry: | 35.5% |
| Moisture in pulverized coal : | 3.4% |
| Water left in the mill: | 300 gm |
| Weight of additional water: | 2430 gm |
| Weight of pulverized coal: | 1550 gm |

Prior to grinding, the distilled water for making the slurry was poured into the mill. The coal was then slowly fed into the mill while the shaft was rotated at 185 rpm and the timer was started. No dispersants or any other chemicals were used during grinding.

Generally, it took about 15 minutes to load and wet 1550 grams of coal. N₂ purging was not applied during coal feeding because the N₂ flow tended to blow the fine coal out of the mill. After the coal was completely blended into the water, the coal was ground for 5 minutes at 185 rpm while purging with N₂. The temperature of the mill was controlled by circulating cold tap water through the water jacket provided with the mill.

After grinding, the slurry was discharged from the mill into a plastic container by slowly rotating the grinding shaft at approximately 70 rpm. The mill was purged with N₂ while discharging. The time for discharging was approximately 5 minutes. The slurry produced was weighed. The slurry flowed very easily and had a viscosity of approximately 90 centipoise measured at a shear rate of 100-1 sec using a Haake RV-100 rotational viscometer.

o Slurry Handling and Storage

Approximately seventeen, 0.75 gallon batches of slurry were prepared for each Round Robin Test participant. As each batch was ground it was transferred to a 30-gallon plastic container. The container was purged with N₂ after the slurry was transferred and the lid was then sealed. Residual slurry in the mill was cleaned with tap water and rinsed with distilled water, as described above, prior to grinding the next batch.

After all 17 batches of slurry were ground, they were

mixed at approximately 100 rpm for 10 minutes using an air driven stirrer with a 8-inch diameter impeller. Two quart size samples were then taken for solids, particle size distribution (PSD), pH, ash, Btu, total sulfur, and pyritic sulfur determinations. Also, a 2-gallon composite sample of slurry was taken and shipped to EPRI for washability analysis. These samples were placed in a plastic bag, purged with N₂, tapped, put in a 5-gallon plastic bucket, and purged with N₂ before the bucket was sealed for shipping. The remaining slurry was transferred to another 30-gallon plastic container with double plastic liners. The slurry was purged with N₂ and the inside and the outside plastic liners were sealed with tape. Finally, the container was purged with N₂ and the cover was tightly sealed. The slurry sample (approximately 120 lbs) and 9 buckets of dry coal (approximately 120 lbs) were shipped to each Round Robin Test participant.

3. Coal and Slurry Characterization

o Coal Analysis

The as received coal from Praxis Engineers, Inc was analyzed at B&W for proximate analysis, ultimate analysis, and Btu. Comparison of the coal analysis data from B&W (Table 3) with previous analysis obtained from UCB (Table 4) showed that the coal B&W received from Praxis was the same coal used by UCB on "Coal Surface Control for Advanced Fine Coal Flotation" project.

o Flotation Tests

UCB has developed standard grinding and froth flotation procedures for testing coals as part of "Coal Surface Control for Advanced Fine Coal Flotation" project. They performed their standard grinding and flotation tests on the 1/4" x 0 Pittsburgh No. 8 coal samples obtained from B&W. The flotation results were similar to their previous flotation results on Pittsburgh No. 8 coal. This indicated that the batch of Pittsburgh No. 8 coal received by B&W from Praxis Engineers, Inc. did not oxidize during storage.

o pH of dry coal

The pH of the dry coal was measured by suspending one gram of coal in 100 ml of distilled water. The pH for the dry coal are as follows:

| | |
|--------------------|-----|
| As received coal: | 3.1 |
| 1/4" x 0 fraction: | 3.6 |
| Pulverized coal: | 3.8 |

- o Particle Size Distribution (PSD)

The PSD of the 1/4" x 0 samples was determined using standard ASTM screening methods. The PSDs of pulverized coal feed and the slurry product were measured using two Leeds and Northrup Microtrac particle analyzers. Small dry coal and slurry samples were dispersed in dilute surfactant solutions to insure the particles are well dispersed before the PSDs were measured. A standard L&N particle analyzer measured the particle size range of 4.7 microns to 300 microns. A small L&N particle analyzer measured particles from 0.17 micron to 21.1 microns. The percentages of particles larger than 300 microns were determined using a wet screen method. The PSDs from the two analyzers and the oversized particles (greater than 300 microns) were overlapped using a computer program developed at B&W. The PSD of the composite slurry is shown in Table 5 and the histogram is shown in Figure 4.

- o Solids Content

The solids content of the slurry was measured using a Computrac model Max 50 moisture analyzer. The solids content of slurry from each grinding and the composite slurry were measured. In general, the solids content ranged between 35.5 to 36.5%. The actual solids content for the composite slurry is given in Table 6.

- o Btu, Ash, Total Sulfur, Pyritic Sulfur, and pH for Composite Slurry

The composite slurry was analyzed for Btu, ash, total sulfur, and pyritic sulfur at B&W using ASTM methods. The pH of the composite slurry was measured by immersing the pH electrode in the slurry. The results are shown in Table 6.

- o Washability and Pyrite Liberation:

Washability data on the composite slurry will be determined by EPRI. The pyrite liberation tests on previous slurry samples prepared under similar grinding conditions will be measured by Virginia Polytechnic Institute and State University (VPI). The results will be provided later by Kaiser Engineers, Inc.

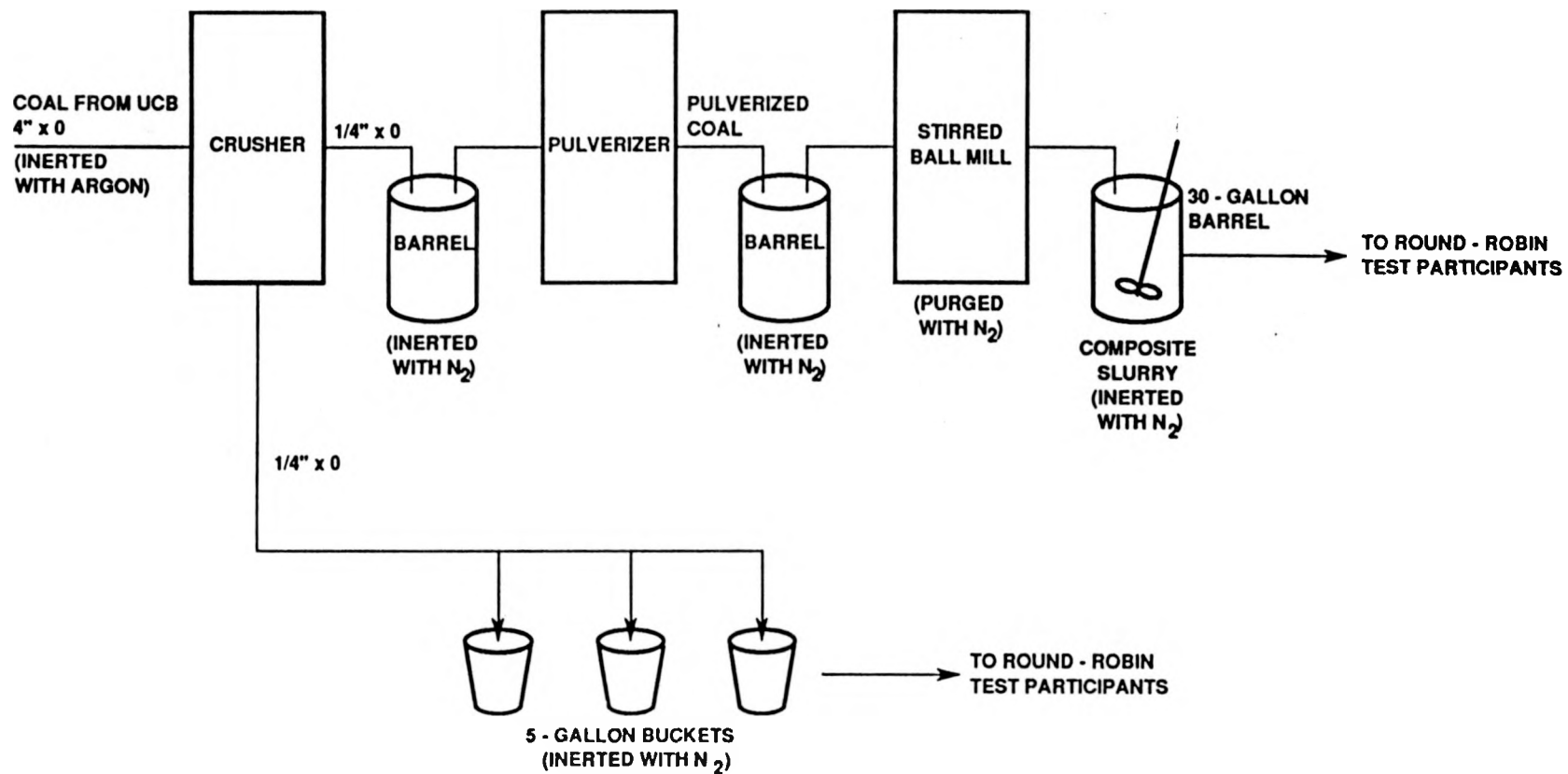


FIGURE 1 FLOWSHEET OF COAL AND SLURRY PREPARATION FOR ROUND - ROBIN TEST PARTICIPANTS

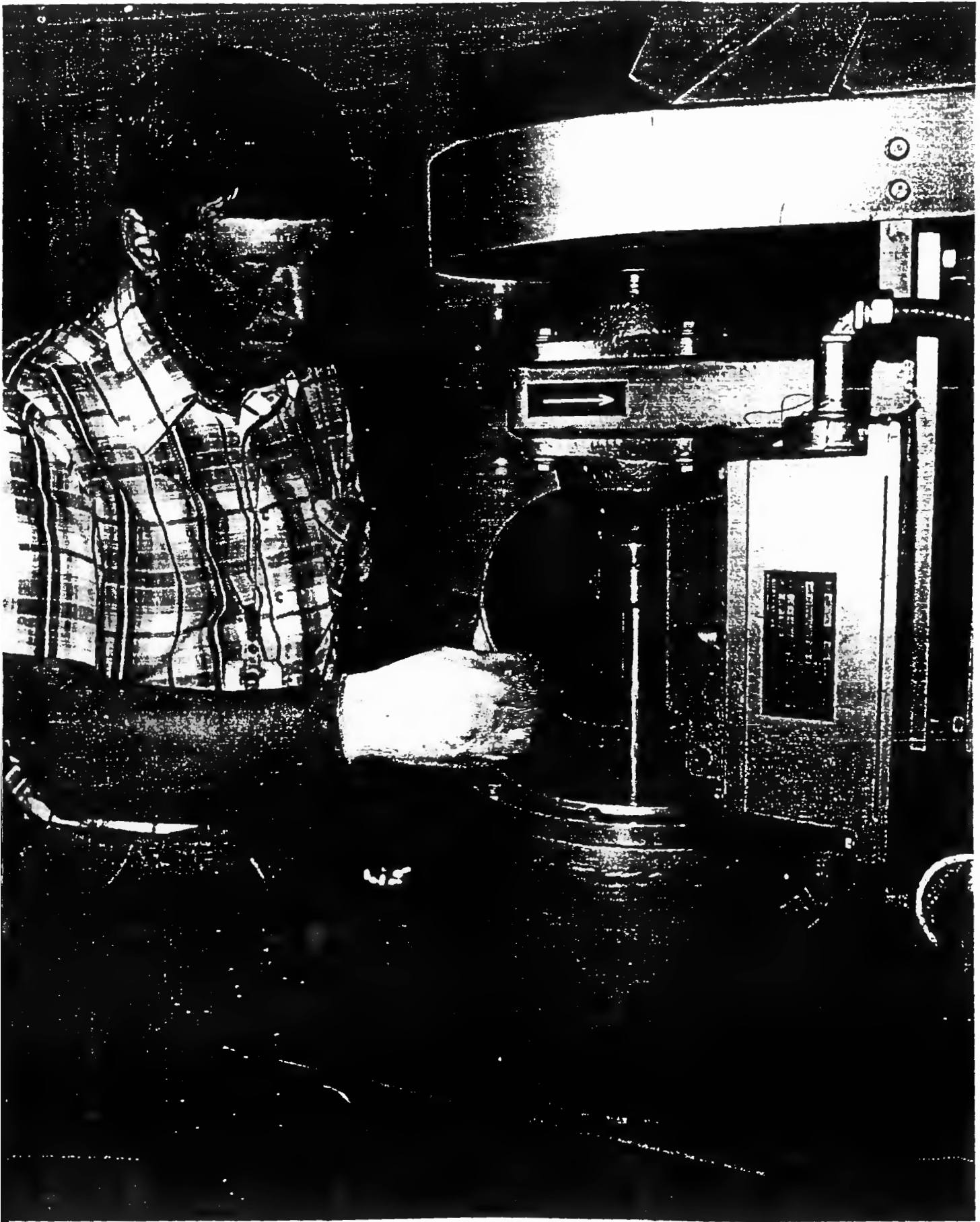


FIGURE 3. Photograph of a 2.5-Gallon Stirred Ball Mill (Attritor Mill)

APPENDIX "C"

Round-Robin Participant's Test Data

MICHIGAN TECHNOLOGICAL UNIVERSITY

Table 6

Characterization of Pittsburgh No. 8 Coal-Water Slurry Product (PBRP0207)
(sent to Michigan Technological University)

| | <u>Slurry</u> | <u>Dry Basis</u> |
|------------------------------|---------------|------------------|
| Gross Heating Value (Btu/lb) | -- | 12,420 |
| Ash % | -- | 11.99 |
| Total Sulfur, % S | -- | 4.07 |
| Pyritic Sulfur, % S | -- | 2.36 |
| pH | 5.3 | |
| Solids Content, % | 35.8 | |

Table 5

Particle Size Distribution of Pittsburgh No. 8 Coal-Water Slurry Product (PBRP0207)
(sent to Michigan Technological University)

F-4212, PITTSBURGH #8 COAL,
 5 MIN. GRINDING @ 185 RPM,
 PH = 5.3, 35.8% SOLIDS, 9-19-89
 PBRP0207, AT 120

| MICRONS | Z LESS | DIFF |
|---------|--------|-------|
| 2400.00 | | |
| 1697.06 | | |
| 1200.00 | | |
| 848.53 | | |
| 600.00 | 100.00 | 0.01 |
| 424.26 | 99.99 | 0.01 |
| 300.00 | 99.98 | 0.00 |
| 212.13 | | |
| 150.00 | | |
| 106.07 | | |
| 75.00 | | |
| 53.03 | | |
| 37.50 | 99.98 | 2.97 |
| 26.52 | 97.01 | 11.86 |
| 18.75 | 85.15 | 16.12 |
| 13.26 | 69.04 | 19.08 |
| 9.38 | 49.96 | 17.79 |
| 6.63 | 32.17 | 12.51 |
| 4.69 | 19.67 | 8.01 |
| 3.31 | 11.66 | 4.75 |
| 2.34 | 6.91 | 2.52 |
| 1.66 | 4.39 | 1.52 |
| 1.17 | 2.87 | 1.21 |
| 0.83 | 1.66 | 0.89 |
| 0.59 | 0.77 | 0.63 |
| 0.41 | 0.14 | 0.14 |
| 0.29 | 0.00 | 0.00 |
| 0.21 | | |
| 0.15 | | |

CS(CAL SURF AREA)=1.07 M²/CM³
 MMD(D43)=11.14 MICRONS
 SMD(D32)=5.59 MICRONS

ROUND ROBIN FEED EVALUATION AND FLOTATION QUANTITY/QUALITY EVALUATION
for MICHIGAN TECHNOLOGY UNIVERSITY

STATISTICAL ANALYSIS
OF FEED

FEED EVALUATION

| SOURCE | ASH % | TOTSUL % | PYRSUL % | BTU | VARIABLE | MEAN | STD DEV | VARIANCE |
|-----------|-------|----------|----------|-------|-----------|-------|---------|----------|
| PRAXIS | 12.04 | 3.90 | 2.78 | 12748 | ASH | 11.96 | 0.36 | 0.13 |
| BMW -1/4 | 12.69 | 4.44 | | 12675 | TOTAL S | 4.14 | 0.22 | 0.05 |
| BMW -325 | 11.99 | 4.07 | 2.36 | 12420 | PYRITIC S | 2.29 | 0.24 | 0.06 |
| EPRI -325 | 11.38 | 3.98 | 2.34 | 12693 | BTU | 12560 | 173.19 | 29996 |
| TEST #1 | 11.96 | 4.43 | 2.12 | 12413 | | | | |
| TEST #2 | 11.91 | 4.31 | 2.24 | 12420 | | | | |
| TEST #3 | 11.84 | 3.93 | 2.13 | 12757 | | | | |
| TEST #4 | 11.84 | 4.04 | 2.06 | 12350 | | | | |

FLOTATION PRODUCT EVALUATION -325 MESH

P8 EPRI (round robin - MICH TECH)

| GRAVITY | SINK | FLOAT | CUM WT (%) | CUM ASH (%) | CUM TOTSUL (%) | CUM PYRSUL (%) | CUM BTU (%) | BTU REC (%) | PYRSUL REJECTION (%) | EFFICIENCY INDEX |
|---------|------|-------|------------|-------------|----------------|----------------|-------------|-------------|----------------------|------------------|
| FLOAT | 1.30 | 1.30 | 11.00 | 1.97 | 1.52 | 0.12 | 14496 | 12.6 | 99.4 | 12.00 |
| | 1.30 | 1.35 | 23.43 | 3.00 | 1.64 | 0.23 | 14298 | 26.4 | 97.7 | 24.09 |
| | 1.35 | 1.40 | 52.25 | 3.86 | 1.75 | 0.32 | 14069 | 57.9 | 92.9 | 50.77 |
| | 1.40 | 1.60 | 88.52 | 5.70 | 2.13 | 0.62 | 13686 | 95.4 | 76.5 | 71.99 |
| | 1.60 | 1.80 | 90.98 | 6.14 | 2.18 | 0.66 | 13609 | 97.5 | 74.3 | 71.88 |
| | 1.80 | 2.00 | 92.26 | 6.58 | 2.24 | 0.71 | 13532 | 98.4 | 72.0 | 70.36 |
| SINK | 2.00 | 2.00 | 100.00 | 11.38 | 3.98 | 2.34 | 12693 | 100.0 | 0.0 | 0.00 |

FLOTATION RESULTS

| TEST NO. | WT (%) | ASH (%) | TOTSUL (%) | PYRSUL (%) | BTU (%) | BTU REC (%) | PYRSUL REJECTION (%) | EFFICIENCY |
|----------|--------|---------|------------|------------|---------|-------------|----------------------|------------|
| #1 | 88.92 | 4.45 | 2.40 | 0.69 | 13882 | 98.22 | 66.81 | 65.03 |
| #2 | 87.83 | 2.90 | 1.76 | 0.41 | 13795 | 98.07 | 77.61 | 75.68 |
| #4 | 84.97 | 2.59 | 1.65 | 0.38 | 13824 | 94.99 | 83.78 | 78.78 |

FLOTATION RESULTS -200 MESH

P8 PRAXIS 7/14/89 200MESHKO

| GRAVITY | SINK | FLOAT | CUM WT (%) | CUM ASH (%) | CUM TOTSUL (%) | CUM PYRSUL (%) | CUM BTU (%) | BTU REC (%) | PYRSUL REJECTION (%) | EFFICIENCY INDEX |
|---------|------|-------|------------|-------------|----------------|----------------|-------------|-------------|----------------------|------------------|
| FLOAT | 1.30 | 1.30 | 53.90 | 2.08 | 1.35 | 0.09 | 14513 | 61.4 | 98.3 | 59.62 |
| | 1.3 | 1.35 | 60.60 | 2.34 | 1.37 | 0.12 | 14469 | 68.8 | 97.4 | 66.17 |
| | 1.35 | 1.40 | 69.20 | 2.65 | 1.38 | 0.15 | 14358 | 77.9 | 96.3 | 74.21 |
| | 1.4 | 1.6 | 86.80 | 4.26 | 1.48 | 0.31 | 14058 | 95.7 | 90.3 | 86.04 |
| | 1.6 | 1.8 | 88.40 | 4.65 | 1.54 | 0.38 | 13993 | 97.0 | 87.9 | 84.95 |
| SINK | 1.8 | 1.8 | 100.00 | 12.04 | 3.90 | 2.78 | 12748 | 100.0 | 0.0 | 0.00 |

FLOTATION RESULTS

| TEST NO. | WT (%) | ASH (%) | TOTSUL (%) | PYRSUL (%) | BTU (%) | BTU REC (%) | PYRSUL REJECTION (%) | EFFICIENCY |
|----------|--------|---------|------------|------------|---------|-------------|----------------------|------------|
| #3 | 90.69 | 5.19 | 2.51 | 1.05 | 13865 | 98.49 | 45.76 | 44.26 |

ROUND ROBIN LABORATORY RESULTS

| PARTICIPANT | TEST | STREAM | YIELD | | ASH | TOTAL | PYRITIC | BTU | BTU | PYRITIC | EFFICIENCY |
|-------------|---------|-----------|--------|----------|-------|--------|---------|-------|----------|---------|------------|
| | | | GRAMS | WEIGHT % | | SULFUR | SULFUR | | RECOVERY | SULFUR | |
| MICH TECH | STD. #1 | FEED | 520.00 | 100.00 | 11.96 | 4.43 | 2.12 | 12413 | 98.22 | 66.81 | 65.03 |
| | | CAL. FEED | | | 11.87 | 4.00 | 1.85 | 12568 | | | |
| | | PRODUCT | 462.40 | 88.92 | 4.45 | 2.40 | 0.69 | 13882 | | | |
| | | REJECT | 57.60 | 11.08 | 71.44 | 16.80 | 11.15 | 2016 | | | |
| | STD. #2 | FEED | 480.00 | 100.00 | 11.91 | 4.31 | 2.24 | 12420 | 98.07 | 77.61 | 75.68 |
| | | CAL. FEED | | | 11.38 | 3.75 | 1.61 | 12355 | | | |
| | | PRODUCT | 421.60 | 87.83 | 2.90 | 1.76 | 0.41 | 13795 | | | |
| | | REJECT | 58.40 | 12.17 | 72.61 | 18.15 | 10.26 | 1960 | | | |
| | STD. #3 | FEED | 644.50 | 100.00 | 11.84 | 3.93 | 2.13 | 12757 | 96.49 | 45.76 | 44.26 |
| | | CAL. FEED | | | 11.46 | 3.69 | 1.76 | 12766 | | | |
| | | PRODUCT | 584.50 | 90.69 | 5.19 | 2.51 | 1.05 | 13865 | | | |
| | | REJECT | 60.00 | 9.31 | 72.49 | 15.14 | 8.63 | 2065 | | | |
| | TEST #4 | FEED | 125.29 | 100.00 | 11.84 | 4.04 | 2.06 | 12350 | 94.99 | 83.78 | 78.78 |
| | | CAL. FEED | | | 11.24 | 3.66 | 1.99 | 12366 | | | |
| | | PRODUCT | 106.46 | 84.97 | 2.59 | 1.65 | 0.38 | 13824 | | | |
| | | REJECT | 18.83 | 15.03 | 60.15 | 15.04 | 11.10 | 4120 | | | |

CENTER FOR APPLIED ENERGY RESEARCH

Table 6

Characterization of Pittsburgh No. 8 Coal-Water Slurry Product (PBRP0190)
(sent to Center for Applied Energy Research)

| | <u>Slurry</u> | <u>Dry Basis</u> |
|------------------------------|---------------|------------------|
| Gross Heating Value (Btu/lb) | -- | 12,506 |
| Ash % | -- | 11.95 |
| Total Sulfur, % S | -- | 4.20 |
| Pyritic Sulfur, % S | -- | 2.79 |
| pH | 5.4 | |
| Solids Content, % | 35.8 | |

Particle Size Distribution of Pittsburgh No. 8 Coal-Water Slurry Product (PBRP0190)
(sent to Center for Applied Energy Research)

F-4200. AT. MITOR. PITTSBURGH #8
 COAL. 6 MIN. GRINDING @ 185 RPM.
 PH = 5.4. 35.8% SOLIDS. 9-15-89.
 SPL. NO. PBRP0190. AT105

| MICRONS | % LESS | DIFF |
|---------|--------|-------|
| 2400.00 | | |
| 1697.06 | | |
| 1200.00 | | |
| 848.53 | | |
| 600.00 | 100.00 | 0.01 |
| 424.26 | 99.99 | 0.01 |
| 300.00 | 99.98 | 0.00 |
| 212.13 | | |
| 150.00 | | |
| 106.07 | | |
| 75.00 | | |
| 53.03 | 99.98 | 0.92 |
| 37.50 | 99.06 | 4.34 |
| 26.62 | 94.72 | 11.17 |
| 18.75 | 83.55 | 17.07 |
| 13.26 | 66.49 | 18.28 |
| 9.38 | 48.21 | 16.89 |
| 6.63 | 31.32 | 12.32 |
| 4.69 | 19.01 | 7.89 |
| 3.31 | 11.12 | 4.42 |
| 2.34 | 6.70 | 2.48 |
| 1.66 | 4.22 | 1.52 |
| 1.17 | 2.70 | 1.15 |
| 0.83 | 1.55 | 0.81 |
| 0.59 | 0.74 | 0.60 |
| 0.41 | 0.14 | 0.14 |
| 0.29 | 0.00 | 0.00 |
| 0.21 | | |
| 0.15 | | |

CS(CAL SURF AREA)=1.04 M²/CM³
 MMD(D43)=11.80 MICRONS
 SMD(D32)=5.78 MICRONS

ILLINOIS STATE GEOLOGICAL SURVEY

ROUND ROBIN FEED EVALUATION AND FLOTATION QUANTITY/QUALITY EVALUATION
for CENTER for APPLIED ENERGY RESEARCH

STATISTICAL ANALYSIS
OF FEED

FEED EVALUATION

| SOURCE | ASH % | TOTSUL % | PYRSUL % | BTU | VARIABLE | MEAN | STD DEV | VARIANCE |
|-----------|-------|----------|----------|-------|-----------|----------|---------|----------|
| PRAXIS | 12.04 | 3.90 | 2.78 | 12748 | ASH | 11.83 | 0.40 | 0.16 |
| BMW -1/4 | 12.69 | 4.44 | | 12675 | TOTAL S | 4.09 | 0.18 | 0.03 |
| BMW -325 | 11.95 | 4.20 | 2.79 | 12506 | PYRITIC S | 3.31 | 0.26 | 0.07 |
| EPRI -325 | 11.64 | 3.91 | 2.36 | 12524 | BTU | 12560.25 | 139.61 | 19492 |
| TEST #1 | 11.65 | 4.12 | 2.20 | 12524 | | | | |
| TEST #2 | 11.38 | 4.12 | 2.20 | 12392 | | | | |
| TEST #3 | 11.65 | 4.12 | 2.20 | 12392 | | | | |
| TEST #4 | 11.65 | 3.92 | 2.39 | 12721 | | | | |

FLOTATION PRODUCT EVALUATION -325 MESH

P8 EPRI (round robin - C FOR AER)

| GRAVITY | SINK | FLOAT | CUM WT (%) | CUM ASH (%) | CUM TOTSUL (%) | CUM PYRSUL (%) | CUM BTU (%) | CUM BTU REC (%) | PYRSUL REJECTION (%) | EFFICIENCY INDEX |
|---------|-------|-------|------------|-------------|----------------|----------------|-------------|-----------------|----------------------|------------------|
| GRAVITY | | | | | | | | | | |
| | FLOAT | 1.30 | 11.05 | 2.09 | 1.54 | 0.13 | 14318 | 12.6 | 99.4 | 12.02 |
| | 1.30 | 1.35 | 26.99 | 2.53 | 1.56 | 0.19 | 14226 | 30.7 | 97.8 | 28.48 |
| | 1.35 | 1.40 | 62.00 | 3.49 | 1.66 | 0.29 | 13963 | 69.1 | 92.4 | 61.51 |
| | 1.40 | 1.60 | 87.75 | 5.11 | 1.89 | 0.47 | 13656 | 95.7 | 82.5 | 78.21 |
| | 1.60 | 1.80 | 89.96 | 5.58 | 2.01 | 0.51 | 13576 | 97.5 | 80.6 | 78.08 |
| | 1.80 | 2.00 | 91.10 | 6.00 | 2.06 | 0.55 | 13505 | 98.2 | 78.8 | 77.00 |
| | SINK | 2.00 | 100.00 | 11.64 | 3.91 | 2.36 | 12524 | 100.0 | 0.0 | 0.00 |

FLOTATION RESULTS

| TEST NO. | WT (%) | ASH (%) | TOTSUL (%) | PYRSUL (%) | BTU (%) | BTU REC (%) | PYRSUL REJECTION (%) | EFFICIENCY |
|----------|--------|---------|------------|------------|---------|-------------|----------------------|------------|
| #1 | 8.80 | 2.47 | 1.68 | 0.50 | 14117 | 10.74 | 97.52 | 8.26 |
| #2 | 9.10 | 2.10 | 1.87 | 0.39 | 13870 | 9.95 | 98.62 | 8.57 |
| #4 | 88.10 | 3.73 | 2.13 | 0.62 | 14110 | 97.72 | 77.15 | 74.87 |

FLOTATION RESULTS -200 MESH

P8 PRAXIS 7/14/89 200MESH00

| GRAVITY | SINK | FLOAT | CUM WT (%) | CUM ASH (%) | CUM TOTSUL (%) | CUM PYRSUL (%) | CUM BTU (%) | CUM BTU REC (%) | PYRSUL REJECTION (%) | EFFICIENCY INDEX |
|---------|-------|-------|------------|-------------|----------------|----------------|-------------|-----------------|----------------------|------------------|
| GRAVITY | | | | | | | | | | |
| | FLOAT | 1.30 | 53.90 | 2.08 | 1.35 | 0.09 | 14513 | 61.4 | 98.3 | 59.62 |
| | 1.3 | 1.35 | 60.60 | 2.34 | 1.37 | 0.12 | 14469 | 68.8 | 97.4 | 66.17 |
| | 1.35 | 1.40 | 69.20 | 2.65 | 1.38 | 0.15 | 14358 | 77.9 | 96.3 | 74.21 |
| | 1.4 | 1.6 | 86.80 | 4.26 | 1.48 | 0.31 | 14058 | 95.7 | 90.3 | 86.04 |
| | 1.6 | 1.8 | 88.40 | 4.65 | 1.54 | 0.38 | 13993 | 97.0 | 87.9 | 84.95 |
| | SINK | 1.8 | 100.00 | 12.04 | 3.90 | 2.78 | 12748 | 100.0 | 0.0 | 0.00 |

FLOTATION RESULTS

| TEST NO. | WT (%) | ASH (%) | TOTSUL (%) | PYRSUL (%) | BTU (%) | BTU REC (%) | PYRSUL REJECTION (%) | EFFICIENCY |
|----------|--------|---------|------------|------------|---------|-------------|----------------------|------------|
| #3 | 94.60 | 8.48 | 3.64 | 2.00 | 13345 | 98.55 | 17.34 | 15.89 |

ROUND ROBIN LABORATORY RESULTS

| PARTICIPANT | TEST | STREAM | YIELD GRAMS | WEIGHT % | ASH | TOTAL SULFUR | PYRITIC SULFUR | BTU | BTU RECOVERY | PYRITIC SULFUR REDUCTION | EFFICIENCY |
|-------------|---------|-----------|----------------|----------|-------|-----------------|-------------------|-------|-----------------|--------------------------------|------------|
| C for AER | STD. #1 | FEED | n/a | 100.00 | 11.65 | 4.12 | 2.20 | 12524 | 10.74 | 97.52 | 8.26 |
| | | CAL. FEED | n/a | | 11.65 | 3.59 | 1.78 | 11571 | | | |
| | | PRODUCT | n/a | 8.80 | 2.47 | 1.68 | 0.50 | 14117 | | | |
| | | REJECT | n/a | 91.20 | 12.54 | 3.77 | 1.90 | 11325 | | | |
| | STD. #2 | FEED | n/a | 100.00 | 11.38 | 4.12 | 2.20 | 12392 | 9.95 | 98.62 | 8.57 |
| | | CAL. FEED | n/a | | 11.38 | 3.96 | 2.58 | 12690 | | | |
| | | PRODUCT | n/a | 9.10 | 2.10 | 1.87 | 0.39 | 13870 | | | |
| | | REJECT | n/a | 90.90 | 12.31 | 4.17 | 2.80 | 12572 | | | |
| | STD. #3 | FEED | n/a | 100.00 | 11.65 | 4.12 | 2.20 | 12392 | 98.55 | 17.34 | 15.89 |
| | | CAL. FEED | n/a | | 11.63 | 3.94 | 2.29 | 12810 | | | |
| | | PRODUCT | n/a | 94.60 | 8.48 | 3.64 | 2.00 | 13345 | | | |
| | | REJECT | n/a | 5.40 | 66.74 | 9.13 | 7.35 | 3432 | | | |
| | TEST #4 | FEED | n/a | 100.00 | 11.65 | 4.12 | 2.20 | 12392 | | | 74.87 |
| | | CAL. FEED | n/a | | 11.65 | 3.92 | 2.39 | 12721 | 97.72 | 77.15 | |
| | | PRODUCT | n/a | 88.10 | 3.73 | 2.13 | 0.62 | 14110 | | | |
| | | REJECT | n/a | 11.90 | 70.27 | 17.20 | 15.50 | 2440 | | | |

TABLE 6

Characterization of Pittsburgh No. 8 Coal-Water Slurry Product (PBRP 0131)
(sent to Illinois State Geological Survey)

| | <u>Slurry</u> | <u>Dry Basis</u> |
|------------------------------|---------------|------------------|
| Gross Heating Value (Btu/lb) | ---- | 12,389 |
| Ash, % | ---- | 12.05 |
| Total Sulfur, % S | ---- | 3.92 |
| Pyritic Sulfur, % S | ---- | 2.44 |
| pH | 5.49 | |
| Solids Content, % | 35.9 | |

TABLE 5

Particle Size Distribution of Pittsburgh No. 8 Coal-Water Slurry Product (PBRP 0131)
(sent to Illinois State Geological Survey)

F-4193. ATTRITOR COMBINED SAMPLE.
 FOR ILL. ST. GEOL. 17 BATCHES
 OF 5 MIN. GRINDING AT 185 RPM.
 95.9% SOLIDS. SPL. NO. PBRP0191. AT 52.

| MICRONS | % LESS | DIFF |
|---------|--------|-------|
| 2400.00 | | |
| 1697.06 | | |
| 1200.00 | | |
| 848.53 | | |
| 600.00 | 100.00 | 0.01 |
| 424.26 | 99.99 | 0.01 |
| 300.00 | 99.98 | 0.00 |
| 212.13 | | |
| 150.00 | | |
| 106.07 | | |
| 76.00 | | |
| 63.03 | 99.98 | 0.83 |
| 37.50 | 99.15 | 4.52 |
| 26.52 | 94.63 | 12.72 |
| 18.75 | 81.91 | 16.03 |
| 13.26 | 65.89 | 17.42 |
| 9.38 | 48.47 | 16.98 |
| 6.63 | 31.51 | 12.20 |
| 4.69 | 19.32 | 7.58 |
| 3.31 | 11.76 | 4.62 |
| 2.34 | 7.14 | 2.81 |
| 1.66 | 4.33 | 1.53 |
| 1.17 | 2.80 | 1.20 |
| 0.83 | 1.60 | 0.83 |
| 0.59 | 0.77 | 0.56 |
| 0.41 | 0.21 | 0.21 |
| 0.29 | 0.00 | 0.00 |
| 0.21 | | |
| 0.15 | | |

CSICAL SURF AREA=1.06 M²/CM³
 MMD(043)=11.91 MICRONS
 SMD(032)=5.67 MICRONS

ROUND ROBIN FEED EVALUATION AND FLOTATION QUANTITY/QUALITY EVALUATION
for ILLINOIS STATE GEOLOGICAL SURVEY

STATISTICAL ANALYSIS
OF FEED

FEED EVALUATION

| SOURCE | ASH % | TOTSUL % | PYRSUL % | BTU | VARIABLE | MEAN | STD DEV | VARIANCE |
|-----------|-------|----------|----------|-------|-----------|-------|---------|----------|
| PRAXIS | 12.04 | 3.90 | 2.78 | 12748 | ASH | 12.18 | 0.76 | 0.58 |
| B&W -1/4 | 12.69 | 4.44 | | 12675 | TOTAL S | 4.01 | 0.21 | 0.05 |
| B&W -325 | 12.05 | 3.92 | 2.44 | 12389 | PYRITIC S | 2.67 | 0.14 | 0.02 |
| EPRI -325 | 11.38 | 3.85 | 2.54 | 12789 | BTU | 12741 | 174.63 | 30494 |
| TEST #1 | 11.70 | 4.07 | 2.75 | 12951 | | | | |
| TEST #2 | 13.70 | 3.94 | 2.72 | 12652 | | | | |
| TEST #3 | 12.40 | 4.18 | 2.81 | 12840 | | | | |
| TEST #4 | 11.45 | 3.79 | 2.67 | 12886 | | | | |

FLOTATION PRODUCT EVALUATION -325 MESH

P8 EPRI (round robin - Illinois State)

| GRAVITY | SINK | FLOAT | CUM WT (%) | CUM ASH (%) | CUM TOTSUL (%) | CUM PYRSUL (%) | CUM BTU (%) | BTU REC (%) | PYRSUL REJECTION (%) | EFFICIENCY INDEX |
|---------|------|--------|------------|-------------|----------------|----------------|-------------|-------------|----------------------|------------------|
| FLOAT | 1.30 | 1.35 | 10.61 | 2.17 | 1.48 | 0.17 | 14536 | 12.1 | 99.3 | 11.34 |
| 1.30 | 1.35 | 28.40 | 2.50 | 1.53 | 0.21 | 14407 | 32.0 | 97.7 | 29.62 | |
| 1.35 | 1.40 | 62.56 | 3.39 | 1.61 | 0.28 | 14207 | 69.4 | 93.1 | 62.55 | |
| 1.40 | 1.60 | 88.85 | 4.83 | 1.78 | 0.44 | 13938 | 96.8 | 84.6 | 81.37 | |
| 1.60 | 1.80 | 90.29 | 5.16 | 1.81 | 0.47 | 13881 | 97.9 | 83.3 | 81.22 | |
| 1.80 | 2.00 | 90.29 | 5.16 | 1.81 | 0.47 | 13881 | 97.9 | 83.3 | 81.22 | |
| SINK | 2.00 | 100.00 | 11.38 | 3.85 | 2.54 | 12798 | 100.0 | 0.0 | 0.00 | |

FLOTATION RESULTS

| TEST NO. | WT (%) | ASH (%) | TOTSUL (%) | PYRSUL (%) | BTU (%) | BTU REC (%) | PYRSUL REJECTION (%) | EFFICIENCY |
|----------|--------|---------|------------|------------|---------|-------------|----------------------|------------|
| #1 | 82.06 | 6.60 | 2.93 | 1.53 | 13825 | 87.59 | 54.35 | 41.94 |
| #2 | 40.59 | 6.40 | 2.40 | 1.19 | 13883 | 44.54 | 82.28 | 26.80 |
| #4 | 86.48 | 3.60 | 1.99 | 0.77 | 14322 | 96.12 | 75.06 | 71.18 |

FLOTATION RESULTS -200 MESH

P8 PRAXIS 7/14/89 200MESHKO

| GRAVITY | SINK | FLOAT | CUM WT (%) | CUM ASH (%) | CUM TOTSUL (%) | CUM PYRSUL (%) | CUM BTU (%) | BTU REC (%) | PYRSUL REJECTION (%) | EFFICIENCY INDEX |
|---------|------|--------|------------|-------------|----------------|----------------|-------------|-------------|----------------------|------------------|
| FLOAT | 1.30 | 1.35 | 53.90 | 2.08 | 1.35 | 0.09 | 14513 | 61.4 | 98.3 | 59.62 |
| 1.3 | 1.35 | 60.60 | 2.34 | 1.37 | 0.12 | 14469 | 68.8 | 97.4 | 66.17 | |
| 1.35 | 1.40 | 69.20 | 2.65 | 1.38 | 0.15 | 14358 | 77.9 | 96.3 | 74.21 | |
| 1.4 | 1.6 | 86.80 | 4.26 | 1.48 | 0.31 | 14058 | 95.7 | 90.3 | 86.04 | |
| 1.6 | 1.8 | 88.40 | 4.65 | 1.54 | 0.38 | 13993 | 97.0 | 87.9 | 84.95 | |
| SINK | 1.8 | 100.00 | 12.04 | 3.90 | 2.78 | 12748 | 100.0 | 0.0 | 0.00 | |

FLOTATION RESULTS

| TEST NO. | WT (%) | ASH (%) | TOTSUL (%) | PYRSUL (%) | BTU (%) | BTU REC (%) | PYRSUL REJECTION (%) | EFFICIENCY |
|----------|--------|---------|------------|------------|---------|-------------|----------------------|------------|
| #3 | 81.86 | 7.80 | 3.24 | 1.82 | 13622 | 86.85 | 47.09 | 33.94 |

ROUND ROBIN LABORATORY RESULTS

| PARTICIPANT | TEST | STREAM | YIELD | | ASH | TOTAL | PYRITIC | BTU | PYRITIC | | EFFICIENCY |
|-------------|-----------|-----------|--------|----------|-------|--------|---------|-------|---------|----------|------------|
| | | | GRAMS | WEIGHT % | | SULFUR | SULFUR | | BTU | RECOVERY | |
| ISGS | STD. #1 | FEED | 488.2 | 100.00 | 11.70 | 4.07 | 2.75 | 12951 | 87.59 | 54.35 | 41.94 |
| | | CAL. FEED | | | 11.66 | 4.07 | 2.75 | 12961 | | | |
| | | PRODUCT | 400.6 | 82.06 | 6.60 | 2.93 | 1.53 | 13825 | | | |
| | | REJECT | 87.6 | 17.94 | 34.80 | 9.30 | 8.33 | 8955 | | | |
| | STD. #2 | FEED | 478.0 | 100.00 | 13.70 | 3.94 | 2.72 | 12852 | 44.54 | 82.26 | 26.80 |
| | | CAL. FEED | | | 13.71 | 3.94 | 2.72 | 12651 | | | |
| | | PRODUCT | 194.0 | 40.59 | 6.40 | 2.40 | 1.19 | 13883 | | | |
| | | REJECT | 284.0 | 59.41 | 18.70 | 5.00 | 3.77 | 11810 | | | |
| | STD. #3 | FEED | 492.3 | 100.00 | 12.40 | 4.18 | 2.81 | 12840 | 86.85 | 47.09 | 33.94 |
| | | CAL. FEED | | | 12.43 | 4.18 | 2.82 | 12839 | | | |
| | | PRODUCT | 403.0 | 81.86 | 7.80 | 3.24 | 1.82 | 13622 | | | |
| | | REJECT | 89.3 | 18.14 | 33.30 | 8.44 | 7.31 | 9308 | | | |
| TEST #4 | FEED | 471.0 | 100.00 | 11.45 | 3.79 | 2.67 | 12886 | 96.12 | 75.07 | 71.19 | |
| | CAL. FEED | | | 11.45 | 3.79 | 2.67 | 12886 | | | | |
| | PRODUCT | 407.3 | 86.48 | 3.60 | 1.99 | 0.77 | 14322 | | | | |
| | REJECT | 63.7 | 13.52 | 61.67 | 15.29 | 14.83 | 3700 | | | | |

DEISTER CONCENTRATOR COMPANY, INC.

TABLE 6

Characterization of Pittsburgh No. 8 Coal-Water Slurry Product (PBRP 0151)
(sent to Deister Concentrator Company)

| | <u>Slurry</u> | <u>Dry Basis</u> |
|------------------------------|---------------|------------------|
| Gross Heating Value (Btu/lb) | ---- | 12,335 |
| Ash, % | ---- | 12.14 |
| Total Sulfur, % S | ---- | 3.93 |
| Pyritic Sulfur, % S | ---- | 2.42 |
| pH | 5.46 | |
| Solids Content, % | 35.7 | |

TABLE 5

Particle Size Distribution of Pittsburgh No. 8 Coal-Water Slurry Product (PBRP 0151)
(sent to Deister Concentrator Company)

F-4194, ATTRITOR COMBINED SAMPLE,
 PITTSBURGH #8 COAL, 186 RPM,
 5 MIN. GRINDING, 35.7% SOLIDS,
 PH = 6.6, SPL. NO. PBRP0151, AT70

| MICRONS | % LESS | DIFF |
|---------|--------|-------|
| 2400.00 | | |
| 1697.06 | | |
| 1200.00 | | |
| 848.63 | | |
| 600.00 | 100.00 | 0.01 |
| 424.26 | 99.99 | 0.01 |
| 300.00 | 99.98 | 0.00 |
| 212.13 | | |
| 150.00 | | |
| 106.07 | | |
| 75.00 | | |
| 53.03 | 99.98 | 1.01 |
| 37.50 | 98.97 | 3.69 |
| 26.62 | 95.28 | 12.62 |
| 18.75 | 82.68 | 18.95 |
| 13.26 | 65.72 | 17.60 |
| 9.38 | 48.12 | 17.05 |
| 6.63 | 31.07 | 12.15 |
| 4.89 | 18.93 | 7.80 |
| 3.31 | 11.33 | 4.60 |
| 2.34 | 6.73 | 2.66 |
| 1.66 | 4.17 | 1.41 |
| 1.17 | 2.76 | 1.15 |
| 0.83 | 1.61 | 0.86 |
| 0.59 | 0.76 | 0.81 |
| 0.41 | 0.14 | 0.14 |
| 0.29 | 0.00 | 0.00 |
| 0.21 | | |
| 0.16 | | |

CS(CAL SURF AREA)=1.04 M²/CM³
 AMD(043)=11.87 MICRONS
 SMD(032)=5.76 MICRONS

ROUND ROBIN FEED EVALUATION AND FLOTATION QUANTITY/QUALITY EVALUATION
for DEISTER CONCENTRATOR CO., INC.

STATISTICAL ANALYSIS
OF FEED

FEED EVALUATION

| SOURCE | ASH % | TOTSUL % | PYRSUL % | BTU | VARIABLE | MEAN | STD DEV | VARIANCE |
|-----------|-------|----------|----------|-------|-----------|-------|---------|----------|
| PRAXIS | 12.04 | 3.90 | 2.78 | 12748 | ASH | 10.70 | 4.02 | 11.01 |
| B&W -1/4 | 12.69 | 4.44 | | 12675 | TOTAL S | 3.99 | 0.22 | 0.05 |
| B&W -325 | 12.14 | 3.93 | 2.42 | 12335 | PYRITIC S | 2.68 | 0.19 | 0.03 |
| EPRI -325 | 11.76 | 3.77 | 2.44 | 12671 | BTU | 12653 | 166.20 | 27623 |
| TEST #1 | 11.94 | 4.11 | 2.81 | 12566 | | | | |
| TEST #2 | 11.94 | 3.80 | 2.80 | 12878 | | | | |
| TEST #3 | 11.87 | 3.88 | 2.81 | 12782 | | | | |
| TEST #4 | 11.94 | 4.11 | 2.81 | 12566 | | | | |

FLOTATION PRODUCT EVALUATION -325 MESH

P8 EPRI (round robin - Deister)

| GRAVITY | SINK | FLOAT | WT (%) | ASH (%) | TOTSUL (%) | PYRSUL (%) | BTU (%) | BTU REC (%) | PYRSUL REJECTION (%) | EFFICIENCY INDEX |
|---------|------|--------|--------|---------|------------|------------|---------|-------------|----------------------|------------------|
| FLOAT | 1.30 | 1.35 | 9.40 | 2.12 | 1.51 | 0.17 | 14570 | 10.8 | 99.3 | 10.15 |
| 1.30 | 1.35 | 30.39 | 2.67 | 1.54 | 0.21 | 14338 | 34.4 | 97.4 | 31.77 | |
| 1.35 | 1.40 | 60.05 | 3.7 | 1.64 | 0.32 | 14105 | 66.8 | 92.1 | 58.97 | |
| 1.40 | 1.60 | 87.79 | 5.18 | 1.85 | 0.51 | 13807 | 95.7 | 81.7 | 77.31 | |
| 1.60 | 1.80 | 90.27 | 5.61 | 1.91 | 0.55 | 13732 | 97.8 | 79.7 | 77.48 | |
| 1.80 | 2.00 | 91.22 | 5.87 | 1.95 | 0.58 | 13670 | 98.4 | 78.3 | 76.73 | |
| SINK | 2.00 | 100.00 | 11.76 | 3.77 | 2.44 | 12671 | 100.0 | 0.0 | 0.00 | |

FLOTATION RESULTS

| TEST NO. | WT (%) | ASH (%) | TOTSUL (%) | PYRSUL (%) | BTU (%) | BTU REC (%) | PYRSUL REJECTION (%) | EFFICIENCY |
|----------|--------|---------|------------|------------|---------|-------------|----------------------|------------|
| #1 | 86.06 | 4.72 | 2.35 | 0.95 | 14160 | 94.44 | 70.85 | 65.28 |
| #2 | 85.98 | 5.70 | 2.60 | 1.39 | 13916 | 92.95 | 57.70 | 50.66 |
| #4 | 86.06 | 4.72 | 2.35 | 0.95 | 14160 | 94.44 | 70.85 | 65.28 |

FLOTATION RESULTS -200 MESH

P8 PRAXIS 7/14/89 200MESHX0

| GRAVITY | SINK | FLOAT | WT (%) | ASH (%) | TOTSUL (%) | PYRSUL (%) | BTU (%) | BTU REC (%) | PYRSUL REJECTION (%) | EFFICIENCY INDEX |
|---------|------|--------|--------|---------|------------|------------|---------|-------------|----------------------|------------------|
| FLOAT | 1.3 | 1.35 | 53.90 | 2.08 | 1.35 | 0.09 | 14513 | 61.4 | 98.3 | 59.62 |
| 1.3 | 1.35 | 60.60 | 2.34 | 1.37 | 0.12 | 14469 | 68.8 | 97.4 | 66.17 | |
| 1.35 | 1.40 | 69.20 | 2.65 | 1.38 | 0.15 | 14358 | 77.9 | 96.3 | 74.21 | |
| 1.4 | 1.6 | 86.80 | 4.26 | 1.48 | 0.31 | 14058 | 95.7 | 90.3 | 86.04 | |
| 1.6 | 1.8 | 88.40 | 4.65 | 1.54 | 0.38 | 13993 | 97.0 | 87.9 | 84.95 | |
| SINK | 1.8 | 100.00 | 12.04 | 3.90 | 2.78 | 12748 | 100.0 | 0.0 | 0.00 | |

FLOTATION RESULTS

| TEST NO. | WT (%) | ASH (%) | TOTSUL (%) | PYRSUL (%) | BTU (%) | BTU REC (%) | PYRSUL REJECTION (%) | EFFICIENCY |
|----------|--------|---------|------------|------------|---------|-------------|----------------------|------------|
| #3 | 91.17 | 6.73 | 2.91 | 1.88 | 13651 | 97.30 | 35.95 | 33.25 |

ROUND ROBIN LABORATORY RESULTS

| PARTICIPANT | TEST | STREAM | YELD | | ASH | TOTAL | PYRITIC | BTU | BTU | PYRITIC | EFFICIENCY |
|-------------|-----------|-----------|--------|----------|-------|--------|---------|-------|----------|-----------|------------|
| | | | GRAMS | WEIGHT % | | SULFUR | SULFUR | | RECOVERY | REDUCTION | |
| DEISTER | STD. #1 | FEED | 487.7 | 100.00 | 11.94 | 4.11 | 2.81 | 12566 | 94.44 | 70.85 | 65.28 |
| | | CAL. FEED | | | 11.94 | 3.58 | 2.80 | 12904 | | | |
| | | PRODUCT | 419.7 | 86.06 | 4.72 | 2.35 | 0.95 | 14160 | | | |
| | | REJECT | 68.0 | 13.94 | 56.48 | 11.19 | 14.25 | 5149 | | | |
| | STD. #2 | FEED | 1077.1 | 100.00 | 11.94 | 3.80 | 2.80 | 12878 | 92.95 | 57.70 | 50.66 |
| | | CAL. FEED | | | 11.94 | 3.99 | 2.83 | 12872 | | | |
| | | PRODUCT | 926.1 | 85.98 | 5.70 | 2.60 | 1.39 | 13916 | | | |
| | | REJECT | 151.0 | 14.02 | 50.20 | 12.51 | 11.63 | 6471 | | | |
| | STD. #3 | FEED | 990.2 | 100.00 | 11.87 | 3.88 | 2.81 | 12782 | 97.30 | 35.95 | 33.25 |
| | | CAL. FEED | | | 11.87 | 3.67 | 2.68 | 12792 | | | |
| | | PRODUCT | 902.8 | 91.17 | 6.73 | 2.91 | 1.88 | 13651 | | | |
| | | REJECT | 87.4 | 8.83 | 64.97 | 11.54 | 10.90 | 3916 | | | |
| TEST #4 | FEED | 487.7 | 100.00 | 11.94 | 4.11 | 2.81 | 12566 | 94.44 | 70.85 | 65.28 | |
| | CAL. FEED | | | 11.94 | 3.58 | 2.80 | 12904 | | | | |
| | PRODUCT | 419.7 | 86.06 | 4.72 | 2.35 | 0.95 | 14160 | | | | |
| | REJECT | 68.0 | 13.94 | 56.48 | 11.19 | 14.25 | 5149 | | | | |

VIRGINIA POLYTECHNIC INSTITUTE & STATE UNIVERSITY

Table 6

Characterization of Pittsburgh No. 8 Coal-Water Slurry Product (PBRP0171)
(sent to Virginia Polytechnical Institute & State University)

| | <u>Slurry</u> | <u>Dry Basis</u> |
|------------------------------|---------------|------------------|
| Gross Heating Value (Btu/lb) | -- | 12,506 |
| Ash % | -- | 12.40 |
| Total Sulfur, % S | -- | 4.26 |
| Pyritic Sulfur, % S | -- | 2.92 |
| pH | 5.3 | |
| Solids Content, % | 35.6 | |

Particle Size Distribution of Pittsburgh No. 8 Coal-Water Slurry Product (PBRP0171)
 (sent to Virginia Polytechnical Institute & State University)

F-4199, ATTRIT R, PITTSBURGH #8
 COAL, 5 MIN. GRINDING @ 185 RPM.
 PH = 5.9, 35.6% SOLIDS,
 SPL. NO. PBRP0171. AT88

| MICRONS | % LESS | DIFF |
|---------|--------|-------|
| 2400.00 | | |
| 1697.06 | | |
| 1200.00 | | |
| 848.53 | | |
| 600.00 | 100.00 | 0.01 |
| 424.26 | 99.99 | 0.01 |
| 300.00 | 99.98 | 0.00 |
| 212.13 | | |
| 150.00 | | |
| 106.07 | | |
| 75.00 | | |
| 53.03 | 99.98 | 0.09 |
| 37.50 | 99.89 | 3.76 |
| 26.52 | 96.13 | 11.08 |
| 18.75 | 85.05 | 16.31 |
| 13.26 | 68.75 | 19.61 |
| 9.38 | 49.14 | 16.77 |
| 6.63 | 32.37 | 12.18 |
| 4.69 | 20.20 | 8.19 |
| 3.31 | 12.01 | 4.71 |
| 2.34 | 7.30 | 2.76 |
| 1.66 | 4.54 | 1.63 |
| 1.17 | 2.91 | 1.26 |
| 0.83 | 1.65 | 0.86 |
| 0.59 | 0.79 | 0.58 |
| 0.41 | 0.21 | 0.21 |
| 0.29 | 0.00 | 0.00 |
| 0.21 | | |
| 0.16 | | |

CS(CAL SURF AREA)=1.08 M²/CM³
 MMD(D43)=11.26 MICRONS
 SMD(D32)=5.53 MICRONS

ROUND ROBIN FEED EVALUATION AND FLOTATION QUANTITY/QUALITY EVALUATION
for VIRGINIA POLYTECHNIC INSTITUTE

STATISTICAL ANALYSIS
OF FEED

FEED EVALUATION

| SOURCE | ASH % | TOTSUL % | PYRSUL % | BTU | VARIABLE | MEAN | STD DEV | VARIANCE |
|-----------|-------|----------|----------|-------|-----------|-------|---------|----------|
| PRAXIS | 12.04 | 3.90 | 2.78 | 12748 | ASH | 12.04 | 0.34 | 0.12 |
| B&W -1/4 | 12.69 | 4.44 | | 12675 | TOTAL S | 4.02 | 0.23 | 0.05 |
| B&W -325 | 12.40 | 4.26 | 2.92 | 12506 | PYRITIC S | 2.53 | 0.47 | 0.22 |
| EPRI -325 | 11.89 | 3.97 | 2.47 | 12548 | BTU | 12714 | 140.01 | 19604 |
| TEST #1 | 11.85 | 3.96 | 2.52 | 12911 | | | | |
| TEST #2 | 11.78 | 3.87 | 2.60 | 12717 | | | | |
| TEST #3 | 11.99 | 4.01 | 2.86 | 12738 | | | | |
| TEST #4 | 11.67 | 3.74 | 1.54 | 12870 | | | | |

FLOTATION PRODUCT EVALUATION -325 MESH

P8 EPRI (round robin - VPI)

| GRAVITY | SINK | FLOAT | CUM WT (%) | CUM ASH (%) | CUM TOTSUL (%) | CUM PYRSUL (%) | CUM BTU (%) | BTU REC (%) | PYRSUL REJECTION (%) | EFFICIENCY INDEX |
|---------|------|-------|------------|-------------|----------------|----------------|-------------|-------------|----------------------|------------------|
| FLOAT | 1.30 | 1.30 | 6.32 | 2.07 | 1.59 | 0.15 | 14481 | 7.3 | 99.6 | 6.91 |
| 1.30 | 1.35 | 1.35 | 26.03 | 2.59 | 1.6 | 0.19 | 14239 | 29.5 | 98.0 | 27.54 |
| 1.35 | 1.40 | 1.40 | 54.18 | 3.59 | 1.73 | 0.31 | 14014 | 60.5 | 93.2 | 53.71 |
| 1.40 | 1.60 | 1.60 | 87.72 | 5.38 | 2.02 | 0.54 | 13676 | 95.6 | 80.8 | 76.43 |
| 1.60 | 1.80 | 1.80 | 90.18 | 5.9 | 2.09 | 0.59 | 13578 | 97.6 | 78.5 | 76.04 |
| 1.80 | 2.00 | 2.00 | 91.22 | 6.29 | 2.14 | 0.64 | 13509 | 98.2 | 76.4 | 74.57 |
| SINK | 2.00 | 2.00 | 100.00 | 11.89 | 3.97 | 2.47 | 12548 | 100.0 | 0.0 | 0.00 |

FLOTATION RESULTS

| TEST NO. | WT (%) | ASH (%) | TOTSUL (%) | PYRSUL (%) | BTU (%) | BTU REC (%) | PYRSUL REJECTION (%) | EFFICIENCY |
|----------|--------|---------|------------|------------|---------|-------------|----------------------|------------|
| #1 | 60.88 | 3.35 | 2.06 | 0.65 | 14315 | 67.35 | 84.30 | 51.65 |
| #2 | 58.02 | 3.09 | 2.07 | 0.57 | 14176 | 65.91 | 87.29 | 53.20 |
| #4 | 72.28 | 2.91 | 1.90 | 0.40 | 14333 | 80.49 | 81.29 | 61.78 |

FLOTATION RESULTS -200 MESH

P8 PRAXIS 7/14/89 200MESHKD

| GRAVITY | SINK | FLOAT | CUM WT (%) | CUM ASH (%) | CUM TOTSUL (%) | CUM PYRSUL (%) | CUM BTU (%) | BTU REC (%) | PYRSUL REJECTION (%) | EFFICIENCY INDEX |
|---------|------|-------|------------|-------------|----------------|----------------|-------------|-------------|----------------------|------------------|
| FLOAT | 1.30 | 1.30 | 53.90 | 2.08 | 1.35 | 0.09 | 14513 | 61.4 | 98.3 | 59.62 |
| 1.3 | 1.35 | 1.35 | 60.60 | 2.34 | 1.37 | 0.12 | 14469 | 68.8 | 97.4 | 66.17 |
| 1.35 | 1.40 | 1.40 | 69.20 | 2.65 | 1.38 | 0.15 | 14358 | 77.9 | 96.3 | 74.21 |
| 1.4 | 1.6 | 1.6 | 86.80 | 4.26 | 1.48 | 0.31 | 14058 | 95.7 | 90.3 | 86.04 |
| 1.6 | 1.8 | 1.8 | 88.40 | 4.65 | 1.54 | 0.38 | 13993 | 97.0 | 87.9 | 84.95 |
| SINK | 1.8 | 1.8 | 100.00 | 12.04 | 3.90 | 2.78 | 12748 | 100.0 | 0.0 | 0.00 |

FLOTATION RESULTS

| TEST NO. | WT (%) | ASH (%) | TOTSUL (%) | PYRSUL (%) | BTU (%) | BTU REC (%) | PYRSUL REJECTION (%) | EFFICIENCY |
|----------|--------|---------|------------|------------|---------|-------------|----------------------|------------|
| #3 | 62.15 | 4.90 | 2.41 | 0.74 | 14048 | 73.75 | 83.92 | 57.66 |

ROUND ROBIN LABORATORY RESULTS

| PARTICIPANT | TEST | STREAM | YIELD | | ASH | TOTAL | PYRITIC | BTU | PYRITIC | | EFFICIENCY |
|-------------|-----------|-----------|--------|----------|-------|--------|---------|-------|---------|--------|------------|
| | | | GRAMS | WEIGHT % | | SULFUR | SULFUR | | BTU | SULFUR | |
| VPI | STD. #1 | FEED | 12.73 | 100.00 | 11.85 | 3.96 | 2.52 | 12911 | 67.35 | 84.30 | 51.65 |
| | | CAL. FEED | | | 11.85 | 3.96 | 2.52 | 12939 | | | |
| | | PRODUCT | 7.75 | 60.88 | 3.35 | 2.06 | 0.65 | 14315 | | | |
| | | REJECT | 4.98 | 39.12 | 25.09 | 6.92 | 5.43 | 10798 | | | |
| | STD. #2 | FEED | 12.22 | 100.00 | 11.78 | 3.87 | 2.6 | 12717 | 65.91 | 87.29 | 53.20 |
| | | CAL. FEED | | | 11.79 | 3.87 | 2.60 | 12480 | | | |
| | | PRODUCT | 7.09 | 58.02 | 3.09 | 2.07 | 0.57 | 14176 | | | |
| | | REJECT | 5.13 | 41.98 | 23.81 | 6.36 | 5.41 | 10135 | | | |
| | STD. #3 | FEED | 12.47 | 100.00 | 11.99 | 4.01 | 2.86 | 12738 | 73.75 | 83.92 | 57.66 |
| | | CAL. FEED | | | 11.99 | 4.01 | 2.86 | 11839 | | | |
| | | PRODUCT | 7.75 | 62.15 | 4.90 | 2.41 | 0.74 | 14048 | | | |
| | | REJECT | 4.72 | 37.85 | 23.63 | 6.64 | 6.34 | 8212 | | | |
| TEST #4 | FEED | 360.59 | 100.00 | 11.85 | 3.60 | 2.12 | 12842 | 80.49 | 81.29 | 61.78 | |
| | CAL. FEED | | | 11.67 | 3.74 | 1.54 | 12870 | | | | |
| | PRODUCT | 260.63 | 72.28 | 2.91 | 1.90 | 0.40 | 14333 | | | | |
| | REJECT | 99.96 | 27.72 | 34.51 | 8.52 | 4.53 | 9057 | | | | |

ALL MINERAL

Table 6

Characterization of Pittsburgh No. 8 Coal-Water Slurry Product (PBRP0226)
(sent to Allmineral Aufbereitungstechnik GMBH)

| | <u>Slurry</u> | <u>Dry Basis</u> |
|------------------------------|---------------|------------------|
| Gross Heating Value (Btu/lb) | -- | 12,350 |
| Ash % | -- | 11.75 |
| Total Sulfur, % S | -- | 3.98 |
| Pyritic Sulfur, % S | -- | 2.36 |
| pH | 5.3 | |
| Solids Content, % | 35.5 | |

Table 5

Particle Size Distribution of Pittsburgh No. 8 Coal-Water Slurry Product (PBRP0226)
(sent to Allmineral Aufbereitungstechnik GMBH)

F-4213, PITTSBURGH #8 COAL.
 5 MIN. GRINDING @ 185 RPM.
 PH = 5.3. 35.5% SOLIDS. 9-22-89
 PBRP0226. AT 137

| MICRONS | % LESS | DIFF |
|---------|--------|-------|
| 2400.00 | | |
| 1697.06 | | |
| 1200.00 | | |
| 848.53 | | |
| 600.00 | 100.00 | 0.01 |
| 424.26 | 99.99 | 0.01 |
| 300.00 | 99.98 | 0.00 |
| 212.13 | | |
| 150.00 | | |
| 106.07 | | |
| 75.00 | | |
| 53.03 | | |
| 37.50 | 99.98 | 3.50 |
| 26.52 | 96.48 | 9.59 |
| 18.75 | 86.89 | 11.75 |
| 13.26 | 75.14 | 18.65 |
| 9.38 | 56.50 | 18.56 |
| 6.63 | 37.94 | 13.56 |
| 4.69 | 24.39 | 9.05 |
| 3.31 | 15.34 | 5.60 |
| 2.34 | 9.74 | 3.63 |
| 1.66 | 6.11 | 1.98 |
| 1.17 | 4.13 | 1.57 |
| 0.83 | 2.56 | 1.21 |
| 0.59 | 1.35 | 1.05 |
| 0.41 | 0.30 | 0.30 |
| 0.29 | 0.00 | 0.00 |
| 0.21 | | |
| 0.15 | | |

CS(CAL SURF AREA)=1.28 M²/CM³
 MMD(D43)=10.27 MICRONS
 SMD(D32)=4.69 MICRONS

ROUND ROBIN FEED EVALUATION AND FLOTATION QUANTITY/QUALITY EVALUATION
for ALL MINERAL.

STATISTICAL ANALYSIS
OF FEED

FEED EVALUATION

| SOURCE | ASH % | TOTSUL % | PYRSUL % | BTU | VARIABLE | MEAN | STD DEV | VARIANCE |
|-----------|-------|----------|----------|-------|-----------|-------|---------|----------|
| PRAXIS | 12.04 | 3.90 | 2.78 | 12748 | ASH | 10.55 | 4.27 | 18.26 |
| B&W -1/4 | 12.69 | 4.44 | | 12675 | TOTAL S | 3.56 | 1.45 | 2.09 |
| B&W -325 | 11.75 | 3.98 | 2.36 | 12350 | PYRITIC S | 1.98 | 0.91 | 0.84 |
| EPRI -325 | 11.65 | 3.93 | 2.51 | 12737 | BTU | 10887 | 4407.84 | 19429035 |
| TEST #1 | 12.10 | 4.10 | 2.08 | 12002 | | | | |
| TEST #2 | 12.05 | 4.00 | 2.08 | 12125 | | | | |
| TEST #3 | 12.10 | 4.10 | 2.08 | 12461 | | | | |
| TEST #4 | 0.00 | 0.00 | 0.00 | 0 | | | | |

FLOTATION PRODUCT EVALUATION -325 MESH

P8 EPRI (round robin - All Mineral)

| GRAVITY | SINK | FLOAT | WT (%) | ASH (%) | TOTSUL (%) | PYRSUL (%) | BTU (%) | BTU REC (%) | PYRSUL REJECTION (%) | EFFICIENCY INDEX |
|---------|------|--------|--------|---------|------------|------------|---------|-------------|----------------------|------------------|
| FLOAT | 1.30 | 1.35 | 9.16 | 2.53 | 1.57 | 0.2 | 14425 | 10.4 | 99.3 | 9.64 |
| 1.30 | 1.35 | 30.66 | 3.07 | 1.63 | 0.26 | 14264 | 34.3 | 96.8 | | 31.16 |
| 1.35 | 1.40 | 62.64 | 3.89 | 1.74 | 0.37 | 14080 | 69.2 | 90.8 | | 60.01 |
| 1.40 | 1.60 | 88.19 | 5.47 | 2.00 | 0.57 | 13795 | 95.5 | 80.0 | | 75.49 |
| 1.80 | 1.80 | 90.56 | 5.95 | 2.05 | 0.62 | 13711 | 97.5 | 77.6 | | 75.12 |
| 1.80 | 2.00 | 100.00 | 11.65 | 3.93 | 2.51 | 12737 | 100.0 | 0.0 | | 0.00 |
| SINK | 2.00 | 100.00 | 11.65 | 3.93 | 2.51 | 12737 | 100.0 | 0.0 | | 0.00 |

FLOTATION RESULTS

| TEST NO. | WT (%) | ASH (%) | TOTSUL (%) | PYRSUL (%) | BTU (%) | BTU REC (%) | PYRSUL REJECTION (%) | EFFICIENCY |
|----------|--------|---------|------------|------------|---------|-------------|----------------------|------------|
| #1 | 58.20 | 9.20 | 3.70 | 1.69 | 12680 | 61.49 | 55.81 | 17.28 |
| #2 | 69.70 | 8.30 | 2.90 | 0.91 | 12949 | 74.43 | 68.43 | 42.92 |

FLOTATION RESULTS -200 MESH

P8 PRAXIS 7/14/89 200MESH80

| GRAVITY | SINK | FLOAT | WT (%) | ASH (%) | TOTSUL (%) | PYRSUL (%) | BTU (%) | BTU REC (%) | PYRSUL REJECTION (%) | EFFICIENCY INDEX |
|---------|------|--------|--------|---------|------------|------------|---------|-------------|----------------------|------------------|
| FLOAT | 1.30 | 1.35 | 53.90 | 2.08 | 1.35 | 0.09 | 14513 | 61.4 | 98.3 | 59.62 |
| 1.3 | 1.35 | 60.60 | 2.34 | 1.37 | 0.12 | 14469 | 68.8 | 97.4 | | 66.17 |
| 1.35 | 1.40 | 69.20 | 2.65 | 1.38 | 0.15 | 14358 | 77.9 | 96.3 | | 74.21 |
| 1.4 | 1.6 | 86.80 | 4.28 | 1.48 | 0.31 | 14058 | 95.7 | 90.3 | | 86.04 |
| 1.6 | 1.8 | 88.40 | 4.65 | 1.54 | 0.38 | 13993 | 97.0 | 87.9 | | 84.95 |
| SINK | 1.8 | 100.00 | 12.04 | 3.90 | 2.78 | 12748 | 100.0 | 0.0 | | 0.00 |

FLOTATION RESULTS

| TEST NO. | WT (%) | ASH (%) | TOTSUL (%) | PYRSUL (%) | BTU (%) | BTU REC (%) | PYRSUL REJECTION (%) | EFFICIENCY |
|----------|--------|---------|------------|------------|---------|-------------|----------------------|------------|
| #3 | 62.90 | 7.80 | 3.00 | 1.13 | 13423 | 67.76 | 65.30 | 33.09 |

ROUND ROBIN LABORATORY RESULTS

| PARTICIPANT | TEST | STREAM | YIELD | | ASH | TOTAL | PYRITIC | BTU | PYRITIC | | EFFICIENCY |
|-------------|---------|-----------|--------|----------|-------|--------|---------|-------|---------|----------|------------|
| | | | GRAMS | WEIGHT % | | SULFUR | SULFUR | | BTU | RECOVERY | |
| ALL MINERAL | STD. #1 | FEED | 1155.4 | 100.00 | 12.10 | 3.70 | 2.08 | 12002 | 61.48 | 55.81 | 17.28 |
| | | CAL. FEED | | | 12.13 | 4.10 | 2.23 | 12002 | | | |
| | | PRODUCT | 672.3 | 58.19 | 9.20 | 3.70 | 1.69 | 12680 | | | |
| | | REJECT | 483.1 | 41.81 | 16.20 | 4.66 | 2.97 | 11058 | | | |
| | STD. #2 | FEED | 947.9 | 100.00 | 12.05 | 4.00 | 2.08 | 12125 | 74.48 | 68.43 | 42.92 |
| | | CAL. FEED | | | 12.05 | 4.00 | 2.01 | 12127 | | | |
| | | PRODUCT | 661.2 | 69.75 | 8.30 | 2.90 | 0.91 | 12949 | | | |
| | | REJECT | 286.7 | 30.25 | 20.70 | 6.54 | 4.55 | 10231 | | | |
| | STD. #3 | FEED | 1055.0 | 100.00 | 12.10 | 4.10 | 2.08 | 12461 | 67.79 | 65.30 | 33.09 |
| | | CAL. FEED | | | 12.10 | 4.10 | 2.05 | 12461 | | | |
| | | PRODUCT | 663.9 | 62.93 | 7.80 | 3.00 | 1.13 | 13423 | | | |
| | | REJECT | 391.1 | 37.07 | 19.40 | 5.98 | 3.61 | 10829 | | | |
| | TEST #4 | FEED | 0.0 | ERR | 0.00 | 0.00 | 0.00 | 0 | ERR | ERR | ERR |
| | | CAL. FEED | | | ERR | ERR | ERR | ERR | | | |
| | | PRODUCT | 0.0 | ERR | 0.00 | 0.00 | 0.00 | 0.00 | | | |
| | | REJECT | 0.0 | ERR | 0.00 | 0.00 | 0.00 | 0.00 | | | |

B. DATTA RESEARCH

Table 6

Characterization of Pittsburgh No. 8 Coal-Water Slurry Product (PBRP0240)
(sent to B. Datta Research)

| | <u>Slurry</u> | <u>Dry Basis</u> |
|------------------------------|---------------|------------------|
| Gross Heating Value (Btu/lb) | -- | 12,412 |
| Ash % | -- | 12.00 |
| Total Sulfur, % S | -- | 3.93 |
| Pyritic Sulfur, % S | -- | 2.19 |
| pH | 5.0 | |
| Solids Content, % | 35.7 | |

Table 5

Particle Size Distribution of Pittsburgh No. 8 Coal-Water Slurry Product (PBRP0240)
(sent to B. Datta Research)

F-4214. PITTSBURGH #8 COAL.
 5 MIN. GRINDING @ 185 RPM.
 PH = 5.0. 35-7% SOLIDS. 9-27-89
 PBRP0240. AT 149

| MICRONS | % LESS | DIFF |
|---------|--------|-------|
| 2400.00 | | |
| 1697.06 | | |
| 1200.00 | | |
| 848.53 | | |
| 600.00 | 100.00 | 0.01 |
| 424.26 | 99.99 | 0.01 |
| 300.00 | 99.98 | 0.00 |
| 212.13 | | |
| 150.00 | | |
| 106.07 | | |
| 75.00 | | |
| 53.03 | | |
| 37.50 | 99.98 | 4.56 |
| 26.52 | 95.42 | 12.09 |
| 18.75 | 83.33 | 14.32 |
| 13.26 | 69.02 | 18.51 |
| 9.38 | 50.51 | 18.04 |
| 6.63 | 32.47 | 12.47 |
| 4.69 | 20.01 | 7.40 |
| 3.31 | 12.61 | 4.88 |
| 2.34 | 7.73 | 3.10 |
| 1.66 | 4.63 | 1.57 |
| 1.17 | 3.06 | 1.23 |
| 0.83 | 1.83 | 0.91 |
| 0.59 | 0.92 | 0.71 |
| 0.41 | 0.21 | 0.21 |
| 0.29 | 0.00 | 0.00 |
| 0.21 | | |
| 0.15 | | |

CS(CAL SURF AREA)=1.11 M²/CM³
 MMD(D43)=11.36 MICRONS
 SMD(D92)=5.43 MICRONS

ROUND ROBIN LABORATORY RESULTS

| PARTICIPANT | TEST | STREAM | YIELD GRAMS | WEIGHT % | ASH | TOTAL SULFUR | PYRITIC SULFUR | BTU | BTU RECOVERY | PYRITIC SULFUR REDUCTION | EFFICIENCY | |
|-------------------|-----------|-----------|----------------|----------|-------|-----------------|-------------------|-------|-----------------|--------------------------------|------------|-----|
| B. DATTA RESEARCH | STD. #1 | FEED | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | |
| | | CAL. FEED | | | N/A | N/A | N/A | N/A | N/A | | | |
| | | PRODUCT | N/A | N/A | N/A | N/A | N/A | N/A | N/A | | | |
| | | REJECT | N/A | N/A | N/A | N/A | N/A | N/A | N/A | | | |
| | STD. #2 | FEED | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| | | CAL. FEED | | | N/A | N/A | N/A | N/A | N/A | | | |
| | | PRODUCT | N/A | N/A | N/A | N/A | N/A | N/A | N/A | | | |
| | | REJECT | N/A | N/A | N/A | N/A | N/A | N/A | N/A | | | |
| | STD. #3 | FEED | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| | | CAL. FEED | | | N/A | N/A | N/A | N/A | N/A | | | |
| | | PRODUCT | N/A | N/A | N/A | N/A | N/A | N/A | N/A | | | |
| | | REJECT | N/A | N/A | N/A | N/A | N/A | N/A | N/A | | | |
| TEST #4 | FEED | | 325.5 | 100.00 | 12.77 | 3.62 | 2.62 | 12700 | 97.58 | 73.09 | 70.67 | |
| | CAL. FEED | | | | 12.78 | 3.62 | 2.62 | 12699 | | | | |
| | PRODUCT | | 286.4 | 88.00 | 3.73 | 1.83 | 0.80 | 14082 | | | | |
| | REJECT | | 39.1 | 12.00 | 79.09 | 16.78 | 15.93 | 2562 | | | | |

APPENDIX "D"

Computer Simulator Nomenclature

Nomenclature

B = constant
C = total product solids flow rate
D = column diameter
 D_b = pulp bubble diameter
 D_f = froth bubble diameter
 D_p = particle diameter
 F_i = feed solids rate for component i
 P = bubble-particle attachment probability
 P_a = probability of adhesion
 P_c = probability of collision
 P_d = probability of detachment
R = component recovery
k = pulp flotation rate constant
L = column length
m = constant
n = constant
 Pe = Peclet number
 Q_g = volumetric gas flow rate
 T_i = reject solids rate for component i
 U_p = terminal particle settling velocity
 V_f = superficial feed rate
 V_g = superficial aeration rate
 V_t = superficial reject rate
 V_w = superficial wash water rate
 X_i = pulp-to-froth solids rate for component i
Z = flow regime correction factor
 α = bias factor
 ϵ = pulp-froth circulating load
 β = particle packing factor
= particle density
 τ = mean slurry retention time
 τ_p = mean particle retention time