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FOR PERIOD

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ICF KAISER ENGINEERS JOB NO. 88107

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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 SO_2 per million BTU. This was mainly attributed to the high pyritic sulfur content of the boiler fuel. A significant reduction in SO_2 emissions could be accomplished by removing the pyrite from the coals by advanced physical fine coal cleaning.

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

1.1 Scope of this Document

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

This document a quarterly report prepared in accordance with the project reporting requirements covering the period from July 1, 1992 to September 30, 1992. 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 provided in this report under the task headings.

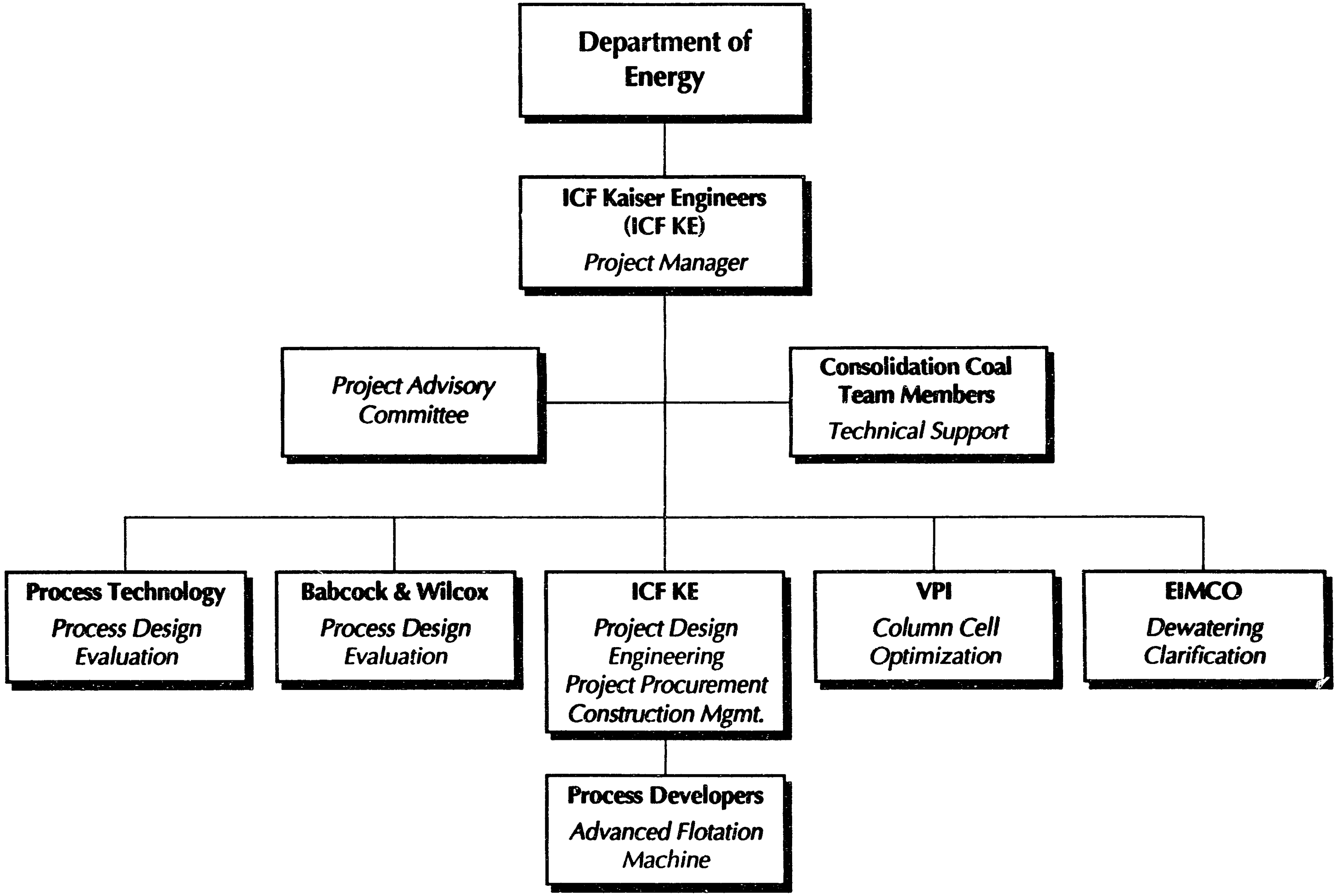
1.2 Overall Project Scope

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

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

Figure 1-1

Project Organization Chart



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

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

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

1.3 Work Executed at Different Locations

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

Table 1.1
Task and the Responsible Team Member

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

2.0 TASK 2 PRELIMINARY CONCEPTUAL DESIGN

2.1 Overview and Scope

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

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

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

2.2 Review of Work Completed This Quarter

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

3.0 TASK 3 CRITICAL AREA DETERMINATION

3.1 Overview and Scope

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

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

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

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

3.2 Review of Work Completed This Quarter

The final report of this task has been submitted to DOE. No additional work was planned nor completed during this quarter.

4.0 TASK 4 TEST PLAN FORMULATION

4.1 Overview and Scope

Work completed in this task produced the criteria for additional engineering analysis, computation and detailed experimental bench-scale testing for areas of uncertainty identified in Task 3. The engineering analysis, computation, bench-scale testing and component development was formulated to produce necessary design information to define a commercially operating system.

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

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

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

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

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

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

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

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

4.2 Review of Work Completed This Quarter

The Task 4 Report was submitted to DOE as a final report. No additional work was planned nor completed during this quarter.

5.0 TASK 5 BENCH-SCALE PROCESS TESTING

5.1 Overview and Scope

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

The unit operation performance and process design information required to support development of the advanced flotation process is being examined in a multi-tier program at B&W and Process Technology, Inc. Laboratory scale studies are being conducted in several key process areas - conventional precleaning of the raw coal, microgrinding of the pre-cleaned coal, advanced froth flotation of the fine coal and dewatering of the product streams.

The results of these studies are then being used to guide small, semi-continuous and continuous testing of the key unit operations at approximately 100 lb/hr.

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

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

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

The bench-scale and process testing consists of eleven major subtasks performed over a period of 12 months.

5.2 Review of Work Completed This Quarter

5.2.1 Raw Coal Characterization

The Illinois No. 6 and Upper Freeport coal seams were completed and Topical Reports No. 3 and No. 4 were submitted to DOE during this quarter. The results of both of the tests were reported in Quarterly Report No. 8 for Illinois No. 6 and Quarterly Report No. 10 for Upper Freeport. This subtask is now complete

5.2.2 Bench Scale Testing

The Task 5 report was submitted to ICF KE by B&W and is under review and will be incorporated into the Task 7 final report.

5.2.3 Dewatering

In addition to detailed dewatering tests conducted by Eimco on the vacuum disc filter, the belt press and the pressure filter, two other dewatering devices were laboratory tested on 325 M x 0 Pittsburgh seam clean coal samples. These were a second pressure filter and the hyperbaric filter, for which the results are presented below.

The second pressure filter can be distinguished from other high pressure filters primarily by its cake discharge system in which a continuous cloth belt automatically advances to empty all chambers fully and simultaneously. Final pressure (up to 235 psi) is applied by a diaphragm that directly contacts and presses the coal slurry/forming cake against the filter cloth belt, which is backed by a rigid polypropylene grid. This membrane squeeze was tested as an option on Eimco's filter press but is the sole means for high pressure (>150 psi) filtration on this second unit. An air blow cycle was also used on this unit.

Eleven tests were conducted on a sample of advanced column flotation concentrate supplied by B&W. A laboratory model filter, which simulates the filtration, pressing, washing and air drying operations available on commercial units, was used for the tests. Pump time, press time and air dry time were varied.

Results for tests indicating maximum capacity and minimum product moisture are presented in Table 5.1.

Test results indicate that cake moisture increase with projected unit capacity and that both moisture and specific capacities vary over a wide range. The 18% moisture achieved in testing this unit was significantly lower than that achieved by any other dewatering method on 325 M x 0 coal samples.

The hyperbaric filter is a rotary filter (disc or drum type) enclosed in a pressure vessel which combines continuous feed and cake discharge capabilities with much higher dewatering-pressure differentials than that available with vacuum-type rotary filters. In applications that require higher capacities without cake washing,a disc filter version is usually employed.

TABLE 5.1
FILTER PRESS (WITH DIAPHRAGM) DEWATERING RESULTS
ON 325 M x 0 PITTSBURGH SEAM CLEAN COAL

PARAMETER	MAXIMUM CAPACITY	MINIMUM PRODUCT MOISTURE
Feed % Solids	26.5	26.5
Cake Moisture (%)	26	18
Capacity (lb/ft^2/hr)	51	28
Chemical Addition	None	None
Pressures (PSI)		
Chamber Fill	80	80
Press Water	230	230
Drying Air	90	90

Pump Time (min)	1.0	1.0
Press Time (min)	1.0	1.0
Air Blow Time (min)	1.0	7.0
Discharge Time (min)	4.0	4.0
Total Cycle Time (min)	7.0	13.0

Two sets of dewatering results (maximum capacity and minimum product moisture) from testing the hyperbaric filter on 325 M x 0 Pittsburgh seam coal are presented in Table 5.2. These results indicate potential cake moistures ranging from 24% to 26% at a fairly wide range of specific capacities. While the recommended operating pressure range is 45-75 psi, only 60 psi was used due to limited sample quantity available for testing. Improved performance may be possible from that indicated.

TABLE 5.2
HYPERBARIC FILTER DEWATERING RESULTS
ON 325 M x 0 PITTSBURGH SEAM CLEAN COAL

PARAMETER	MAXIMUM CAPACITY	MINIMUM PRODUCT MOISTURE
Feed % Solids	21.4	21.4
Cake Moisture (%)	26	24
Capacity (lb/ft^2/hr)	120	80
Chemical Addition	None	None
Pressures (PSI)	60	60
Specific Energy Consumpt. (KWH/ton)	4	10

6.0 COMPONENT AND UNIT OPERATIONS DEVELOPMENT

6.1 Overview and Scope

The Task 6 effort involves three main elements including column cell development, flotation circuit testing and flotation cell modeling. The work outlined 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 or 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 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. 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

The assignment for this task was VPI & SU. VPI & SU has completed their revision to the Task 6 report and submitted the same to ICF KE for review. The total results of this task will be included in the Task 7 report.

Task 6 was divided into three subtasks which are 1) Optimum Column Cell Development Test Work; 2) Optimum Column Cell Configuration, and 3) Column Cell Flotation Model Development. The following descriptions outline a brief determination of results for the three subtasks.

6.2.1 Optimum Column Cell Development Test Work

The objective of this subtask was to utilize parametric testing to determine the effects of various operating parameters on the performance of a column flotation cell. The results of this work were to be used in establishing an optimum column cell configuration which could be incorporated into the POC flowsheet.

The sample used in this investigation was a precleaned Pittsburgh Seam coal obtained from Babcock & Wilcox. The precleaned coal sample was received in slurry form and arrived at Virginia Tech in several 55-gallon drums. The solids content of the froth product in each drum was approximately 15-30%. Grab samples indicated that the quality of the material in each drum was highly variable and that blending was required before the samples could be used in the test work.

Flotation samples (-325 mesh) were prepared by grinding representative samples of the as-received slurry for 4 minutes in a laboratory-scale stirred ball mill. This procedure produced a mean particle size of approximately 10 microns. The samples were diluted to the desired solids content using fresh water and reagents were added at the level specified by the experimental design. After conditioning, a variable-speed pump was used to feed the slurry into the flotation column at a distance of approximately 12 inches below the product overflow lip. A countercurrent flow of wash water was added just below the product overflow lip. Pulp level in the cell was maintained through the use of a simple overflow weir connected to the reject line. A by-pass sand gate was used to prevent a build-up of the coarse or high specific gravity particles (such as pyrite) in the reject stream. Air sparging was accomplished by means of a in-line microbubble generator (i.e., static mixer). A schematic of the column apparatus used in this investigation is shown in Figure 6.1, while the standard test conditions are summarized in Table 6.1.

TABLE 6.1
STANDARD CONDITIONS USED FOR PARAMETRIC TEST PROGRAM

PARAMETER	SETTING
COLUMN DIAMETER	2 INCHES
COLUMN LENGTH	60 INCHES
GRIND TIME	4 MINUTES
GRIND SIZE	-325 MESH
WASH WATER ADDITION POINT	15 CM ABOVE PULP
GENERATOR LENGTH	30 CM
GENERATOR DIAMETER	1.3 CM
FROTHER TYPE	DOWFROTH M-1012
COLLECTOR TYPE	KEROSENE
BAFFLES	NONE

Six key operating parameters that can be manipulated during column operation were selected for study in the experimental design. These included collector dosage, frother dosage, feed solids content, aeration rate, wash water flow rate and feed slurry flow rate. The test levels selected for each of these parameters are specified in Table 6.2. These values were selected on the basis of exploratory test work conducted when the sample first arrived.

TABLE 6.2
TEST LEVELS UTILIZED IN THE PARAMETRIC TEST PROGRAM

PARAMETER	LOW	NORMAL	HIGH
FEED SOLIDS (%)	5	10	15
FROTHER DOSAGE (LB/TON)	0.5	1.5	2.5
COLLECTOR DOSAGE (LB/TON)	0.5	1.0	1.5
FEED RATE (ML/MIN)	50	150	250
AERATION RATE (CM^3/MIN)	500	1000	1500
WASH WATER RATE (ML/MIN)	200	400	600

Using these levels, a statistical test program was developed using a composite Box-and-Behnken experimental design. This type of design is well suited for the study of flotation test work since it provides a measure of the contribution of each parameter to the given response. In addition, it allows the influence of joint interactions between the various test parameters to be estimated. The specific tests required by the Box-and-Behnken design are summarized in Table 6.3. The design requires a total of 54 individual flotation tests in order to quantify the effects of the 6 specified test parameters. All tests were conducted in random order to minimize experimental bias.

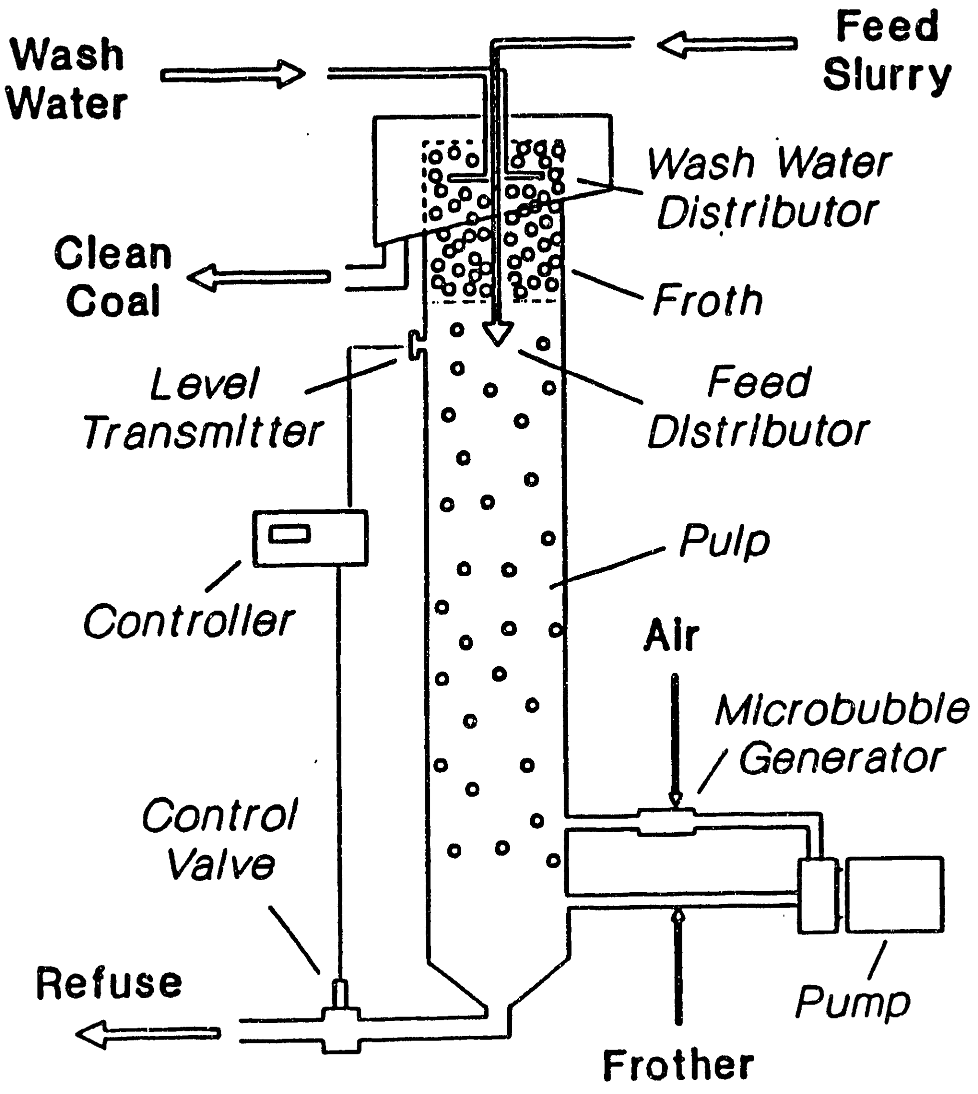


FIGURE 6.1 **Schematic representation of the column and associated components.**

Parametric Test Overview

The results obtained from the parametric test work are summarized in Table 6.4. In order to obtain a consistent set of experimental data, all test values were analyzed and adjusted using a single-node material balance program published by Wills (1988). In general, only minor adjustments to the experimental data were noted. The fact that major data manipulation was not required suggests that the measured values were reliable.

As indicated in Tables 6.3 and 6.4, six replicate "baseline" tests were performed at various times throughout the test program so that the amount of pure experimental error could be assessed. This provided a check on the consistency of both the test procedure and assay determinations. The yield, product ash and product sulfur data obtained from these replicate tests are plotted in Figure 6.2. As shown, a very reproducible set of data was obtained in each test. This finding suggests that the characteristics of the coal sample did not change during the test program and that the sampling and storage procedures used to maintain a representative sample were acceptable. The estimated standard deviations for each of the assays determined in the present work are tabulated in Table 6.5. The relatively low values of standard deviation also indicate that the test data acquired from the parametric testing program are reliable and reproducible. It should also be noted that in general the product assays appear to be the most reliable, while the reject assays are the least dependable. This result is not unexpected given the comparatively smaller weight of the reject samples and the high concentration of very fine particles, e.g., clays, in this stream.

Figures 6.3 through 6.5 provide a summary of the product recoveries obtained as functions of ash, total sulfur and pyritic sulfur rejection rates for the parametric test program. For sake of comparison, both the energy (i.e., Btu) recoveries and combustible recoveries are shown. The test data indicate that at a 90% energy recovery, the following results can be obtained for this coal at the given grind size:

Ash Rejection = 70%
Total Sulfur Rejection = 30%
Pyritic Sulfur Rejection = 60%

Although the test matrix covered a wide range of operating conditions, most of the experimental results are grouped along single grade-recovery curves. All of the data points were found to fall just below the release analysis curve (which is not shown for the sake of clarity). In addition, it was discovered that the experimental data points which deviated the most from the release analysis curve were obtained at high gas flow rates and low wash water addition rates. Under these conditions, a smaller fraction of the wash water which enters the column makes its way down through the froth bed.

Table 6.3
PARAMETRIC TEST PLAN FOR THE OPTIMIZATION STUDIES
PERFORMED USING THE PITTSBURGH NO. 8 SEAM COAL.

TEST NO.	COLLECTOR DOSAGE (LB/TON)	FROTHER DOSAGE (LB/TON	AERATION RATE (CC/MIN)	FEED SOLIDS (%)	FEED RATE (ML/MIN)	WASH WATER RATE (ML/MIN)
	X1	X2	X3	X4	X5	X6
1	1.5	2.5	1000	15	150	400
2	0.5	2.5	1000	15	150	400
3	1.5	0.5	1000	15	150	400
4	1.5	2.5	1000	5	150	400
5	0.5	0.5	1000	15	150	400
6	1.5	0.5	1000	5	150	400
7	0.5	2.5	1000	5	150	400
8	0.5	0.5	1000	5	150	400
9	1.0	2.5	1500	10	250	400
10	1.0	0.5	1500	10	250	400
11	1.0	2.5	500	10	250	400
12	1.0	2.5	1500	10	50	400
13	1.0	0.5	500	10	250	400
14	1.0	2.5	500	10	50	400
15	1.0	0.5	1500	10	50	400
16	1.0	0.5	500	10	50	400
17	1.0	1.5	1500	15	150	600
18	1.0	1.5	500	15	150	600
19	1.0	1.5	1500	5	150	600
20	1.0	1.5	1500	15	150	200
21	1.0	1.5	500	5	150	600
22	1.0	1.5	1500	5	150	200
23	1.0	1.5	500	15	150	200
24	1.0	1.5	500	5	150	200
25	1.5	1.5	1000	15	250	400
26	0.5	1.5	1000	15	250	400
27	1.5	1.5	1000	5	250	400
28	1.5	1.5	1000	15	50	400
29	0.5	1.5	1000	5	250	400
30	1.5	1.5	1000	5	50	400
31	0.5	1.5	1000	15	50	400
32	0.5	1.5	1000	5	50	400
33	1.0	2.5	1000	10	250	600
34	1.0	0.5	1000	10	250	600
35	1.0	2.5	1000	10	50	600
36	1.0	2.5	1000	10	250	200
37	1.0	0.5	1000	10	50	600
38	1.0	2.5	1000	10	50	200
39	1.0	0.5	1000	10	250	200
40	1.0	0.5	1000	10	50	200
41	1.5	1.5	1500	10	150	600
12	0.5	1.5	1500	10	150	600
43	1.5	1.5	500	10	150	600
44	1.5	1.5	1500	10	150	200
45	0.5	1.5	500	10	150	600
46	1.5	1.5	500	10	150	200
47	0.5	1.5	1500	10	150	200
48	0.5	1.5	500	10	150	200
49	1.0	1.5	1000	10	150	400
50	1.0	1.5	1000	10	150	400
51	1.0	1.5	1000	10	150	400
52	1.0	1.5	1000	10	150	400
53	1.0	1.5	1000	10	150	400
54	1.0	1.5	1000	10	150	400

TABLE 6.4
SUMMARY OF TEST RESULTS OBTAINED DURING THE PARAMETRIC TESTING OF THE ADVANCED FLOTATION CELL

	ASH VALUES			TOTAL SULFUR VALUES			BTU VALUES			PROD	ASH	SULFUR	COMB	BTU	COMB	TOTAL
ID	FEED	PROD	TAILS	FEED	PROD	TAILS	FEED	PROD	TAILS	YIELD	REJ	REJ	REC	REC	SE	SE
46	9.73	3.83	45.17	3.45	3.07	5.77	13129	14063	7517	85.73	66.26	23.71	91.33	91.83	57.59	15.54
38	9.64	4.93	79.86	3.41	3.29	5.26	13158	13853	2786	93.71	52.07	9.58	98.60	98.66	50.67	8.25
28	9.68	4.55	57.13	3.73	3.50	5.90	13205	14060	5298	90.24	57.58	15.32	95.37	96.09	52.95	11.41
13	10.57	3.45	16.05	3.59	2.92	4.10	13056	14204	12173	43.49	85.80	64.62	46.95	47.32	32.76	11.94
15	10.52	6.10	79.63	3.67	3.15	11.80	13056	13775	1814	93.99	45.50	19.33	98.63	99.16	44.13	18.49
50	9.60	3.86	71.06	3.42	3.15	6.21	12882	14072	141	91.46	63.23	15.76	97.27	99.91	60.49	15.67
44	9.64	6.16	94.53	3.48	3.35	6.66	13129	13580	2118	96.06	38.62	7.53	99.76	99.36	38.38	6.89
32	9.38	4.45	58.68	3.68	3.30	7.43	13130	13945	4974	90.91	56.87	18.48	95.85	96.55	52.73	15.03
54	9.66	3.93	72.34	3.40	3.13	6.35	12882	13870	2070	91.62	62.72	15.65	97.44	98.65	60.16	14.30
23	9.70	4.13	65.74	3.57	3.36	5.72	13202	13672	8475	90.96	61.27	14.39	96.57	94.20	57.84	8.59
45	9.70	3.41	27.57	3.30	2.80	4.70	13184	14238	10187	73.97	74.00	37.24	79.12	79.88	53.12	17.12
16	11.09	3.41	32.08	3.55	2.99	5.09	13056	14243	9810	73.21	77.49	38.34	79.54	79.87	57.02	18.21
11	9.54	3.16	11.98	3.38	2.95	3.54	13175	14223	12776	27.66	90.84	75.86	29.62	29.86	20.45	5.72
35	9.70	4.01	56.94	3.37	3.17	5.03	13158	14056	5706	89.25	63.10	16.05	94.87	95.34	57.98	11.39
49	9.72	3.92	59.66	3.47	3.10	6.65	12882	14100	2391	89.59	63.87	19.96	95.35	98.07	59.22	18.02
21	9.28	3.43	33.56	3.71	3.27	5.51	13159	14154	9033	80.58	70.22	28.97	85.78	86.68	56.00	15.65
47	9.67	6.32	87.21	3.31	3.19	6.04	13184	13700	1207	95.86	37.35	7.62	99.41	99.61	36.76	7.23
5	8.85	3.80	29.54	3.38	3.14	4.37	13265	14074	9948	80.38	65.49	25.33	84.83	85.28	50.32	10.61
30	9.60	4.23	68.31	3.50	3.09	8.00	13240	14302	1625	91.62	59.63	19.11	97.06	98.97	56.69	18.08
42	9.73	4.33	59.96	3.27	2.94	6.29	13184	14048	5145	90.29	59.82	18.82	95.69	96.21	55.51	15.03
27	9.63	3.80	55.17	3.48	3.12	6.24	13240	14206	5691	88.65	65.02	20.52	94.37	95.12	59.39	15.64
26	8.88	4.05	53.27	3.42	3.16	5.82	13265	14088	5702	90.19	58.87	16.67	94.97	95.78	53.83	12.45
14	9.66	3.52	61.29	3.33	3.04	5.78	13158	14085	5370	89.37	67.43	18.41	95.45	95.67	62.88	14.08
20	9.77	7.07	86.74	3.59	3.51	5.93	13202	13592	2104	96.61	30.09	5.54	99.50	99.47	29.59	5.01
36	9.55	3.71	15.96	3.31	2.98	3.68	13175	14145	12110	52.33	79.67	52.89	55.71	56.18	35.38	9.07
10	9.67	3.89	53.81	3.44	3.17	5.50	13158	13279	12233	88.42	64.43	18.52	94.08	89.23	58.51	7.75
52	9.69	3.84	66.34	3.48	3.19	6.36	12882	13790	4089	90.64	64.08	16.91	96.51	97.03	60.59	13.94

TABLE 6.4 (CONTINUED)
SUMMARY OF TEST RESULTS OBTAINED DURING THE PARAMETRIC TESTING OF THE ADVANCED FLOTATION CELL

ID	ASH VALUES			TOTAL SULFUR VALUES			BTU VALUES			PROD YIELD	ASH REJ	SULFUR REJ	COMB REC	BTU REC	COMB SE	TOTAL SE
	FEED	PROD	TAILS	FEED	PROD	TAILS	FEED	PROD	TAILS							
2	8.88	4.27	73.17	3.45	3.22	6.58	13265	14060	2170	93.31	55.13	12.91	98.03	98.90	53.16	11.81
31	9.85	3.89	57.75	3.35	3.06	6.18	13265	14161	4434	88.93	64.88	18.76	94.81	94.94	59.69	13.71
39	10.53	4.14	54.97	3.39	3.06	5.70	13056	14063	6053	87.43	65.63	21.08	93.67	94.17	59.30	15.25
17	9.78	4.47	73.28	3.48	3.24	6.32	13202	14053	3026	92.28	57.82	14.08	97.71	98.23	55.54	12.31
1	9.63	4.36	78.13	3.56	3.36	6.17	13205	14055	2147	92.86	57.96	12.36	98.27	98.83	56.23	11.19
53	9.73	3.89	61.54	3.55	3.24	6.26	12882	14033	2675	89.87	64.07	17.98	95.68	97.90	59.75	15.88
9	9.55	3.76	20.97	3.37	2.98	4.15	13175	14098	11355	66.36	73.87	41.32	70.60	71.01	44.48	12.33
4	9.60	4.18	70.00	3.40	3.13	6.36	13240	13365	11847	91.77	60.04	15.52	97.27	92.63	57.31	8.15
41	9.75	4.42	68.90	3.51	3.24	6.52	13129	14005	3416	91.73	58.41	15.32	97.15	97.85	55.57	13.18
24	9.29	3.59	49.06	3.71	3.37	6.05	13159	14103	6573	87.46	66.20	20.55	92.96	93.74	59.16	14.29
25	9.62	3.98	69.83	3.38	3.14	5.96	13205	14144	3172	91.44	62.17	15.06	97.14	97.94	59.31	12.99
12	9.68	7.12	87.66	3.49	3.38	6.82	13159	13590	23	96.82	28.78	6.23	99.57	99.99	28.35	6.22
6	9.60	3.72	28.49	3.46	3.02	4.86	13240	14162	10280	76.26	70.45	33.44	81.22	81.57	51.67	15.01
3	9.61	3.94	44.11	3.46	3.19	5.11	13205	14100	7760	85.88	64.79	20.82	91.27	91.71	56.06	12.52
48	9.69	3.72	42.56	3.27	2.89	5.37	13184	14172	7748	84.63	67.51	25.21	90.22	90.97	57.73	16.18
43	9.74	3.43	28.38	3.49	3.01	4.90	13129	14131	10172	74.71	73.69	35.57	79.93	80.41	53.62	15.98
19	9.28	5.63	63.69	3.80	3.61	6.69	13159	13754	4293	93.71	43.15	10.97	97.48	97.95	40.63	8.92
22	9.29	6.90	74.88	3.78	3.73	5.09	13159	13622	439	96.48	28.34	4.79	99.03	99.88	27.36	4.67
8	9.36	3.15	18.40	3.62	3.20	4.23	13130	14170	11614	59.28	80.05	47.60	63.34	63.97	43.39	11.57
51	9.73	3.98	61.88	3.54	3.21	6.53	12882	14119	1669	90.07	63.16	18.33	95.81	98.72	58.96	17.05
18	9.77	3.68	43.23	3.64	3.32	5.37	13202	14140	8051	84.60	68.13	22.84	90.31	90.61	58.45	13.45
40	10.53	3.89	64.59	3.36	3.03	6.03	13056	14091	4635	89.06	67.10	19.69	95.67	96.12	62.77	15.81
37	10.55	3.87	42.84	3.34	2.92	5.34	13056	14140	7819	82.86	69.61	27.56	89.05	89.74	58.65	17.30
29	9.36	3.60	41.38	3.59	3.18	5.84	13130	14099	7744	84.75	67.40	24.93	90.14	91.01	57.54	15.93
7	9.36	4.31	69.14	3.67	3.46	6.20	13130	13983	3037	92.21	57.54	13.07	97.35	98.20	54.89	11.27
34	10.52	3.79	33.92	3.47	3.03	4.99	13056	14138	9294	77.66	72.02	32.18	83.50	84.10	55.53	16.28
33	9.55	3.46	15.09	3.40	2.92	3.83	13175	14173	12266	47.64	82.74	59.09	50.84	51.24	33.58	10.33

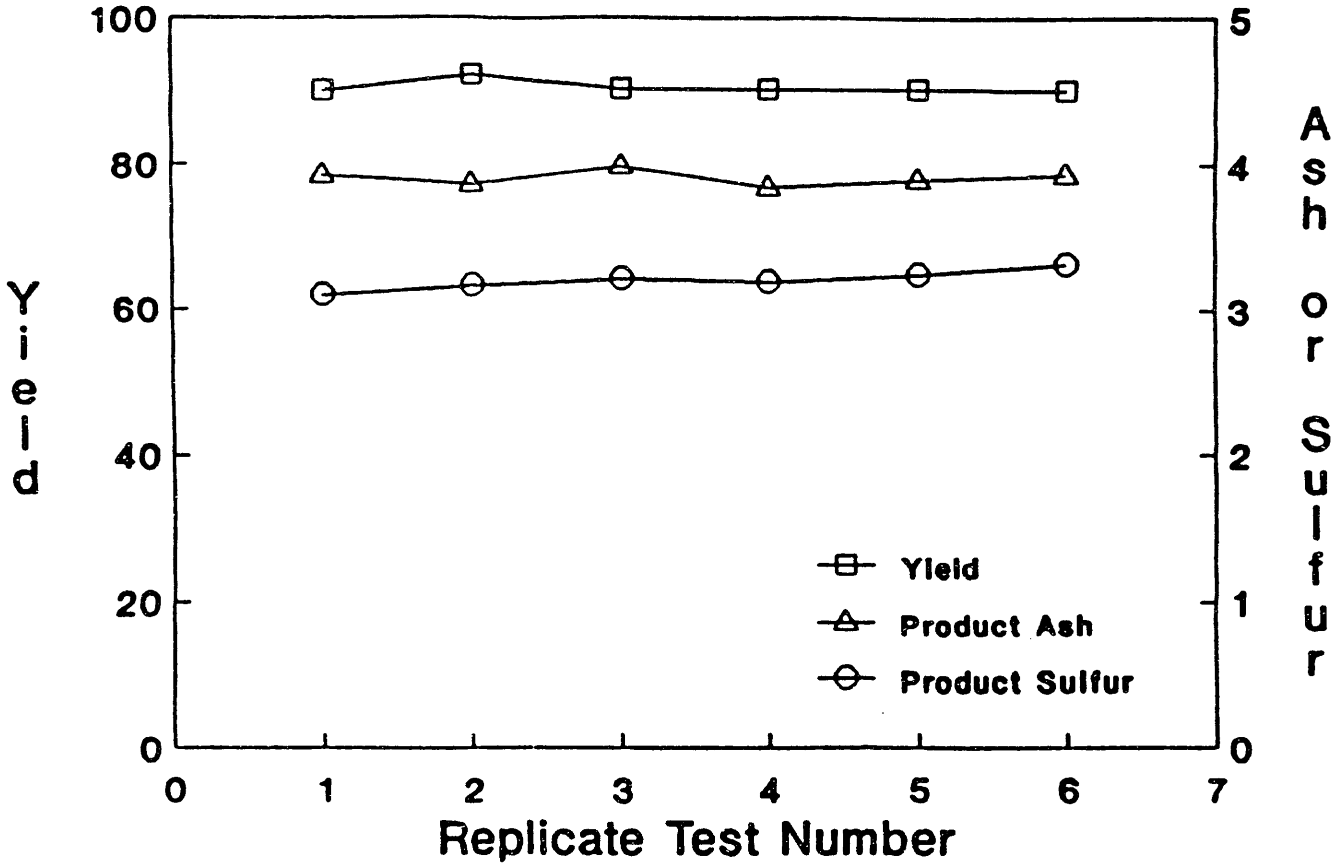


FIGURE 6.2 Yield, product ash and product sulfur obtained for each of the replicate tests conducted throughout the parametric testing program.

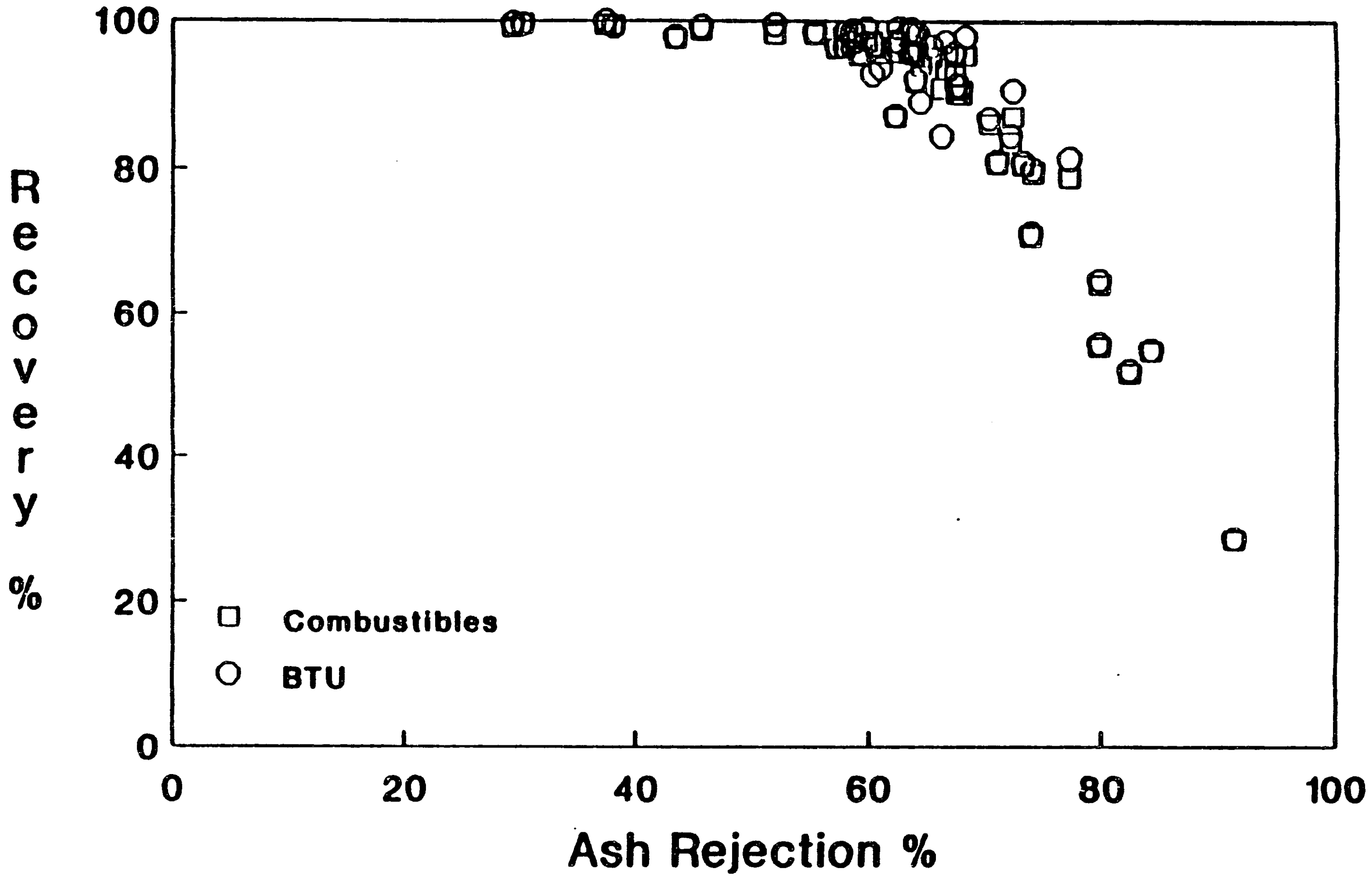


FIGURE 6.3 **Btu (energy) recovery and combustible recovery as a funcion of ash rejection for all tests performed in the parametric study.**

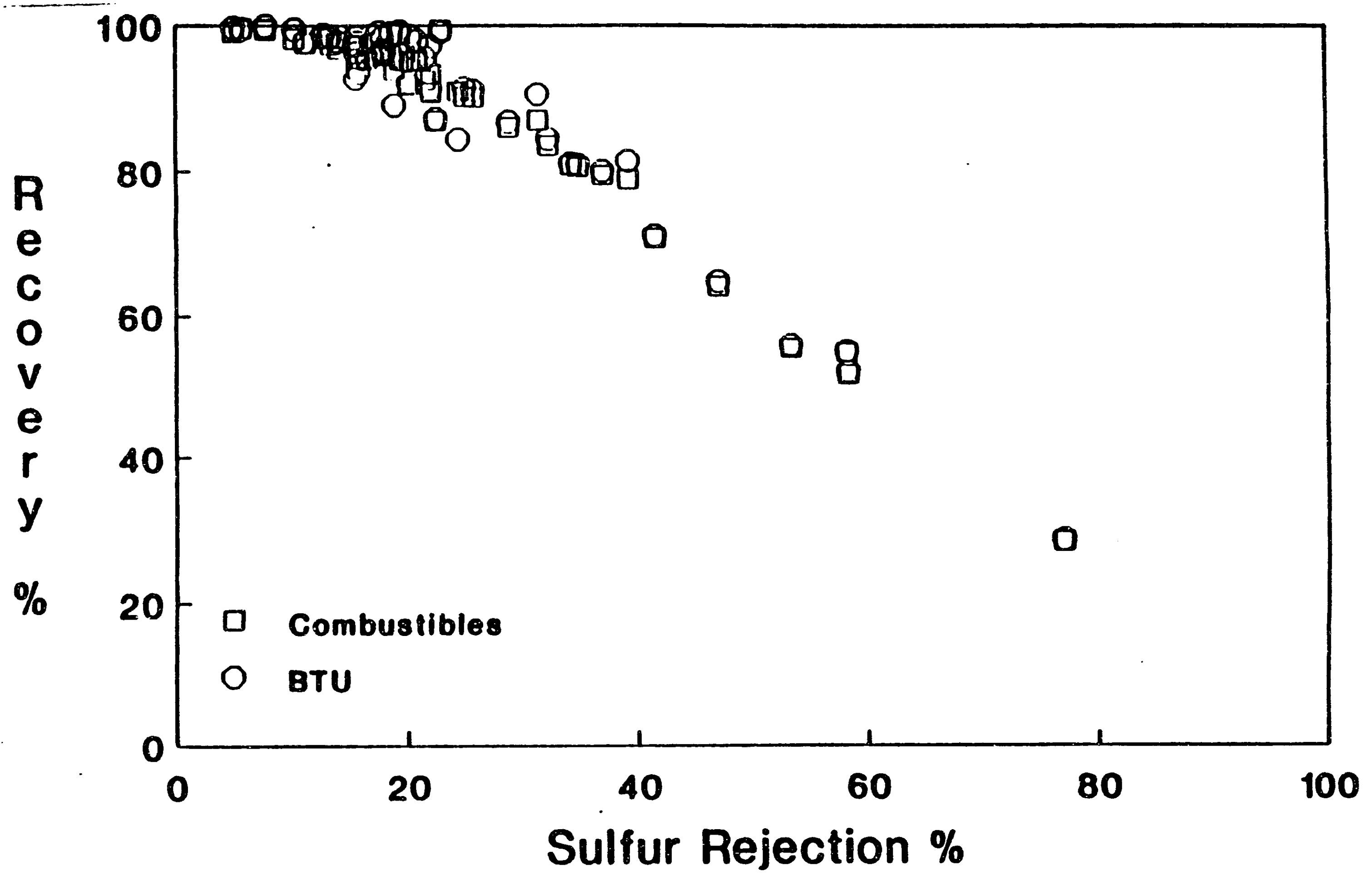


FIGURE 6.4 Btu (energy) recovery and combustible recovery as a function of total sulfur rejection for all tests performed in the parametric study.

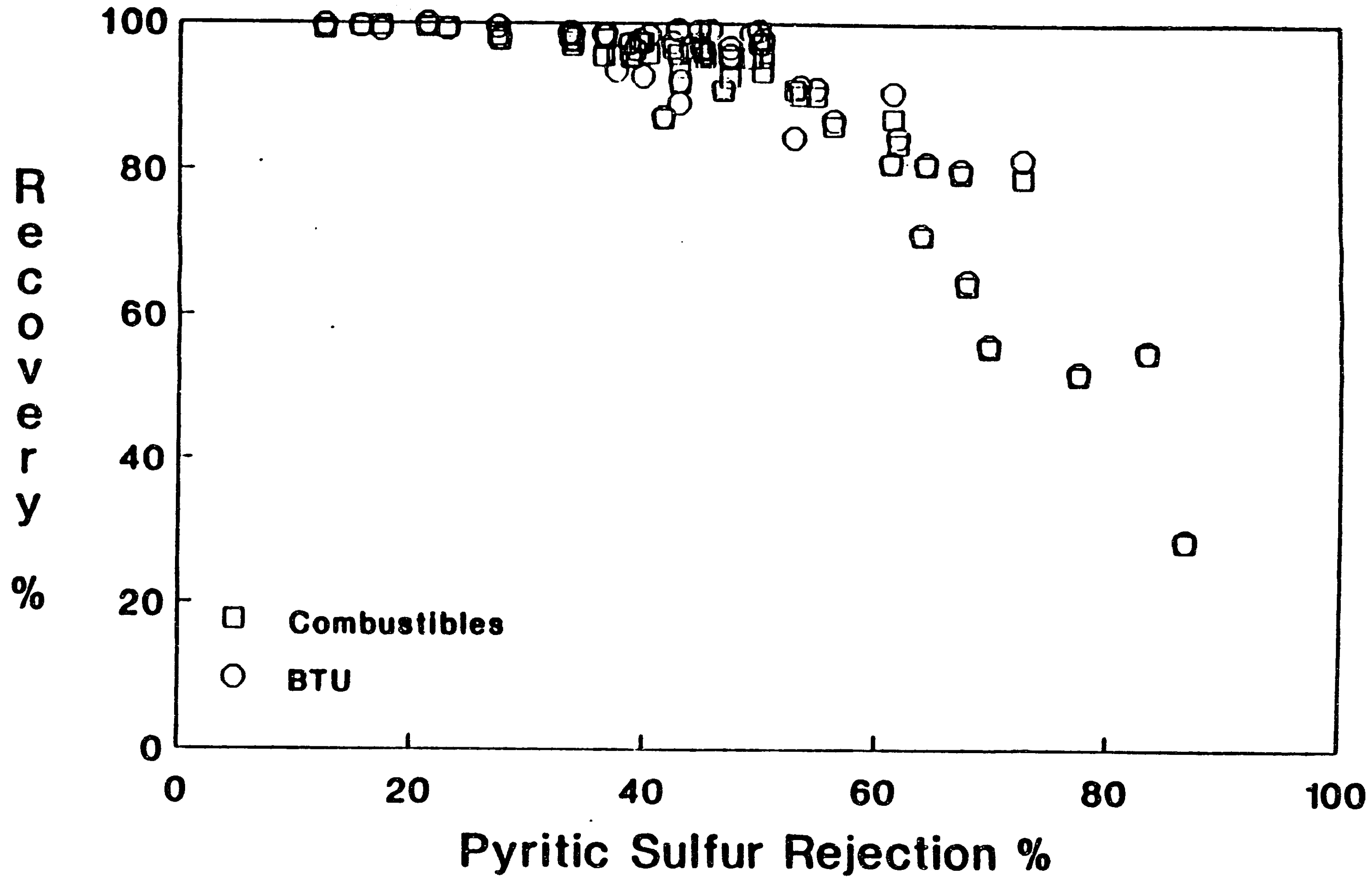


FIGURE 6.5 Btu (energy) recovery and combustible recovery as a function of pyritic sulfur rejection for all tests performed in the parametric study.

TABLE 6.5
ESTIMATED VALUES OF STANDARD DEVIATION
FOR VARIOUS ASSAYS USED IN THE PARAMETRIC TEST WORK

COMPONENT	ESTIMATED STANDARD DEVIATION
MASS YIELD (%)	0.85
PRODUCT ASH (%)	0.05
REJECT ASH (%)	2.63
FEED ASH (%)	0.41
PRODUCT SULFUR (%)	0.07
REJECT SULFUR (%)	0.16
FEED SULFUR (%)	0.21
PRODUCT BTU/#	135
FEED BTU/#	106

This fraction is commonly referred to as the bias factor. Therefore, when operating at a high gas flow rate or low wash water rate, the column is less effective in preventing the entrainment of fine mineral matter. Figure 6.6 shows the bias factor plotted as a function of the difference between the ash rejection obtained experimentally and that predicted, at the same level of recovery, from the release analysis curve. The test data indicate that a good correlation exists between the bias factor and the reduction in ash rejection calculated for each test run. This finding suggests that if the wash water is properly utilized, the grade-recovery relationship is primarily determined by the characteristic nature of the coal sample, i.e., degree of liberation and component hydrophobicity. On the other hand, operational parameters which alter the bias factor tend to produce variations in the amount of mineral matter that is nonselectively entrained into the froth product. This phenomenon tends to shift the column performance to a lower grade-recovery curve and should be avoided. Previous test work suggests that the bias factor should be greater than 0.65 in order to effectively reduce the entrainment of fine mineral matter.

The effects of the operating parameters on separation efficiency are demonstrated in Figures 6.7 and 6.8. Two different separation efficiencies have been calculated, one based on the separation of combustibles from ash and the other based on the overall separation of energy and sulfur. Combustible separation efficiency ($SE_{\text{combustible}}$) has been calculated using the expression:

$$SE_{\text{combustible}} = Y \left(\frac{100 - A_p}{100 - A_f} \right) + (100 - Y) \frac{A_r}{A_f} - 100 \qquad [1.1]$$

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

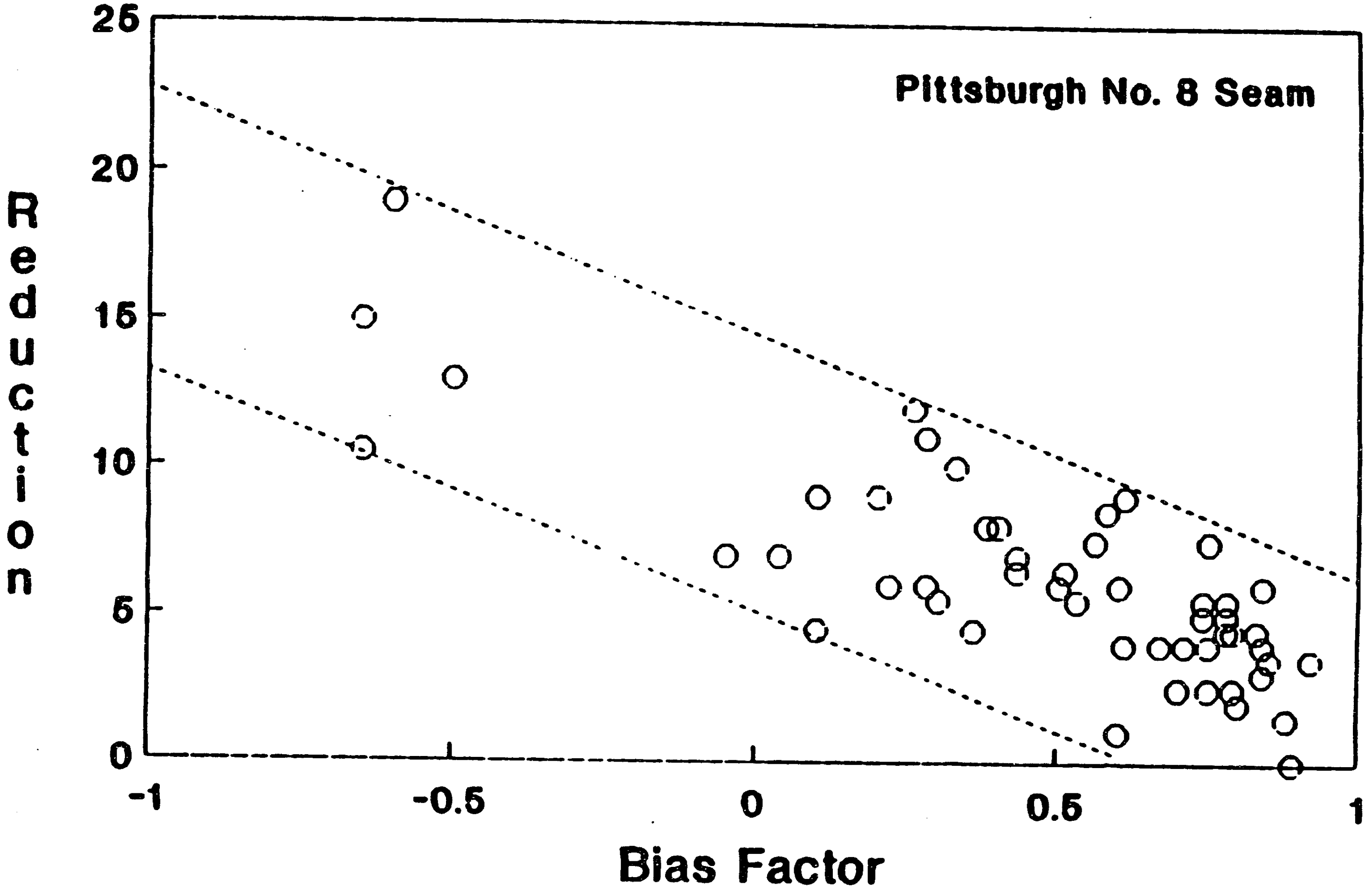


FIGURE 6.6 Reduction in ash rejection versus calculated bias factor for the Pittsburgh No. 8 seam coal.

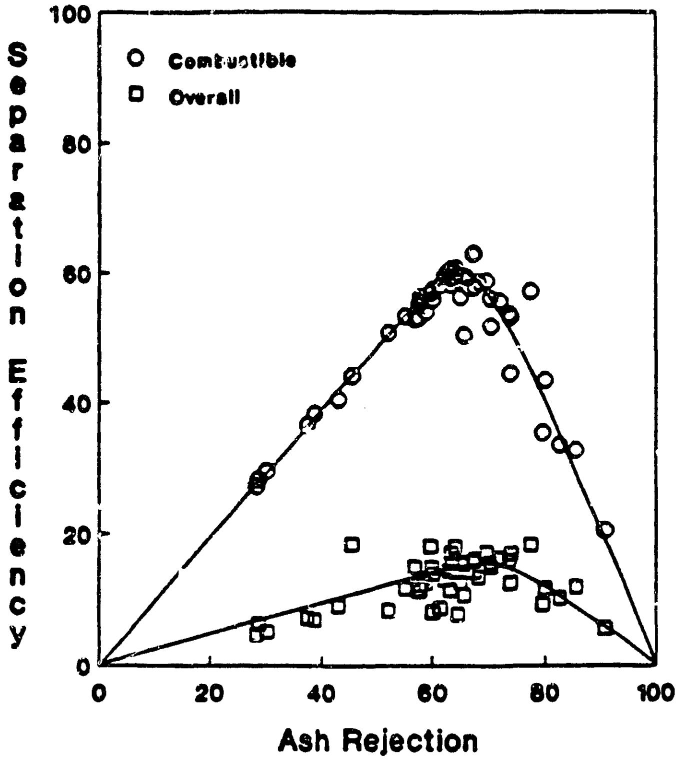


FIGURE 6.7 Combustible separation efficiency and overall separation efficiency as a function of ash rejection for all of the test conditions examined in the parametric study.

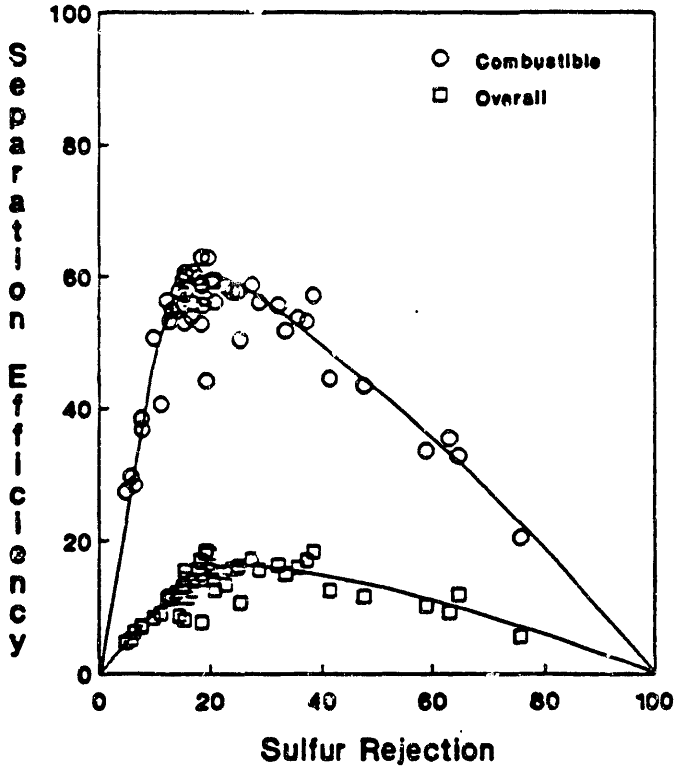


FIGURE 6.8 Combustible separation efficiency and overall separation efficiency as a function of total sulfur rejection for all of the test conditions examined in the parametric study.

$$SE_{\mathrm{overall}} = Y \frac{BTU_p}{BTU_f} + (100 - Y) \frac{S_r}{S_f} - 100 \qquad [1.2]$$

in which BTU_p and BTU_f are the respective calorific (Btu) values for the product and feed streams and S_r and S_f are the respective sulfur contents of the reject and feed streams.

The results, shown in Figure 6.7, indicate that most of the separation efficiency values fall along two distinct parabolic curves. In both cases, however, a maximum separation efficiency could be obtained at an ash rejection of approximately 65%. This value appears to be independent of whether the separation efficiency was calculated on a combustible basis or overall basis. This level of ash rejection corresponds to the "bend" or "knee" in the grade-recovery curve shown in Figure 6.3. Therefore, it can be concluded that the maximum separation efficiency for a given coal occurs at the point just before the large deterioration in yield. In the present work, the maximum separation efficiency-ash rejection relationship appears to be a function of the coal characteristics. As a result, various combinations of operating conditions can be utilized to obtain the same maximum separation efficiency.

Figure 6.8 shows the separation efficiency values calculated for the various tests as a function of sulfur rejection. As before, most of the points fall along two separate parabolic curves, with the maximum separation efficiency for each curve occurring at a sulfur rejection of approximately 20%. This value also corresponds to the abrupt bend in the grade-recovery curve shown in Figure 6.4. This finding indicates that sulfur is more difficult to reject than ash for this particular sample. This phenomenon is demonstrated more clearly in Figure 6.9 in which sulfur rejection has been plotted as a function of ash rejection. As shown, there is a distinct relationship between ash rejection and sulfur rejection. If both sulfur and ash were rejected equally, the points should fall along the dashed line shown in the figure; however, this is clearly not the case. The data plotted in Figure 6.8 suggest that the best separation point for this particular coal would be at an ash rejection of 65% and a sulfur rejection of 20%.

6.2.2 Optimum Column Cell Circuit Configuration

The primary objective of this subtask was to examine various column circuit configurations for advanced coal cleaning. The flotation circuits examined in this effort included:

a) single-stage (SS)
b) rougher-scavenger (RS)
c) rougher-cleaner (RC)
d) rougher-scavenger-scavenger cleaner (RSSC)
e) rougher-scavenger-cleaner (RSC)
f) rougher-cleaner-recleaner (RCRC).

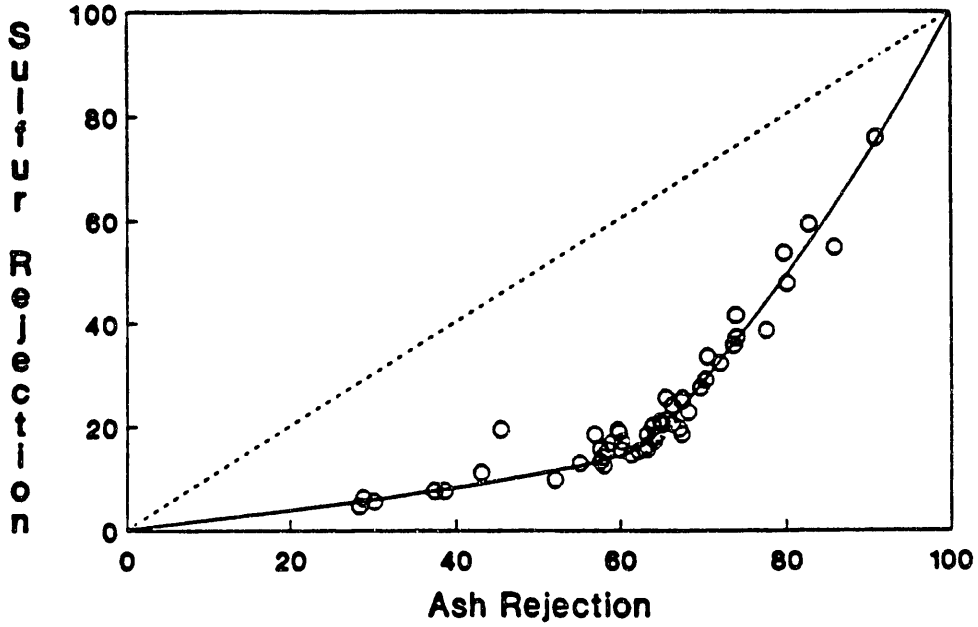


FIGURE 6.9 Relationship between ash rejection and total sulfur rejection for test results obtained during the parametric study.

Schematic representations of these circuits arrangements are provided in Figure 6.10.

6.2.2.1 Sample Preparation

The circuit tests were carried out using samples obtained from the Pittsburgh, Illinois No. 6 and Upper Freeport coal seams. These coal samples were precleaned by B&W using conventional flotation and shipped in slurry form to Virginia Tech in several 55-gallon drums. Grab samples indicated that the contents of each drum was highly variable and that blending would be required in order to obtain representative samples for testing. The homogenization of the samples was carried out in several steps. First, the contents of each drum was thoroughly agitated using a low-speed drum mixer to redisperse coarse particles which had settled to the bottom of the drum during shipment. The contents of each drum was then transferred to a 500-gallon sump which was equipped with a propeller-type mixer and pumping circuit which continuously recirculated the slurry. After emptying all drums for a given coal, representative samples of the well-mixed slurry were pumped from the sump into individual 5-gallon containers. Each container was flooded with nitrogen and sealed prior to storage.

Flotation samples were prepared by grinding each coal sample using a Union Process stirred ball mill. Samples were ground at 30% solids using 3.2 mm diameter stainless steel grinding media. The Pittsburgh sample was ground to a nominal size of -325 mesh using a grinding time of approximately 4 minutes. The Illinois No. 6 and Upper Freeport samples were each ground to a nominal -200 mesh product size using a 1.5 minute grinding time.

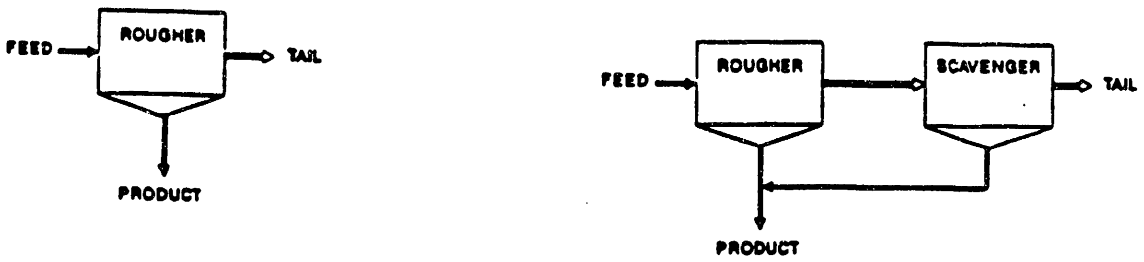
6.2.2.2 Summary

The test results obtained from the circuit testing program demonstrate that differences in the level of performance for the individual column circuits are due to shifts along a single recovery-grade curve. No changes in the location of the recovery-rejection curves were observed for any of the circuits tested to date. Therefore, there appears to be little or no metallurgical advantage in using multiple column circuits for the deep cleaning of the three base coals tested.

The fact that all of the column circuits behaved essentially the same, in terms of metallurgical performance, can be explained by developing a complete understanding the fine particle recovery mechanisms. In conventional flotation circuits, differences in performance can frequently be attributed to wide variations in the nonselective entrainment of fine particles of mineral matter into the froth product. Multiple cleaning stages are generally capable of reducing entrainment, thereby improving the final separation. However, since most flotation columns utilize a countercurrent flow of wash water to prevent entrainment of fines, multiple column circuits have little advantage for improving performance. The use of wash water also explains why

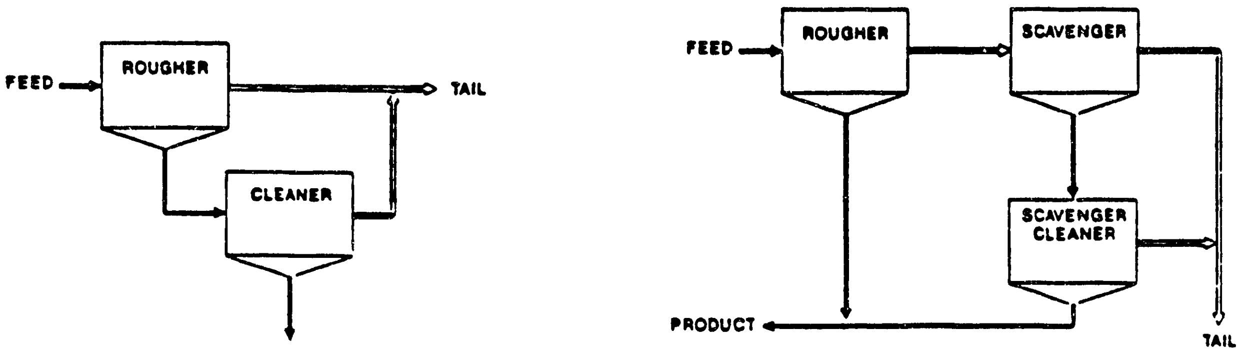
Single-Stage (SS)

Rougher-Scavenger (RS)



Rougher-Cleaner (RC)

Rougher-Scavenger-Scavenger Cleaner (RSSC)



Rougher-Scavenger-Cleaner (RSC)

Rougher-Cleaner-Recleaner (RCRC)

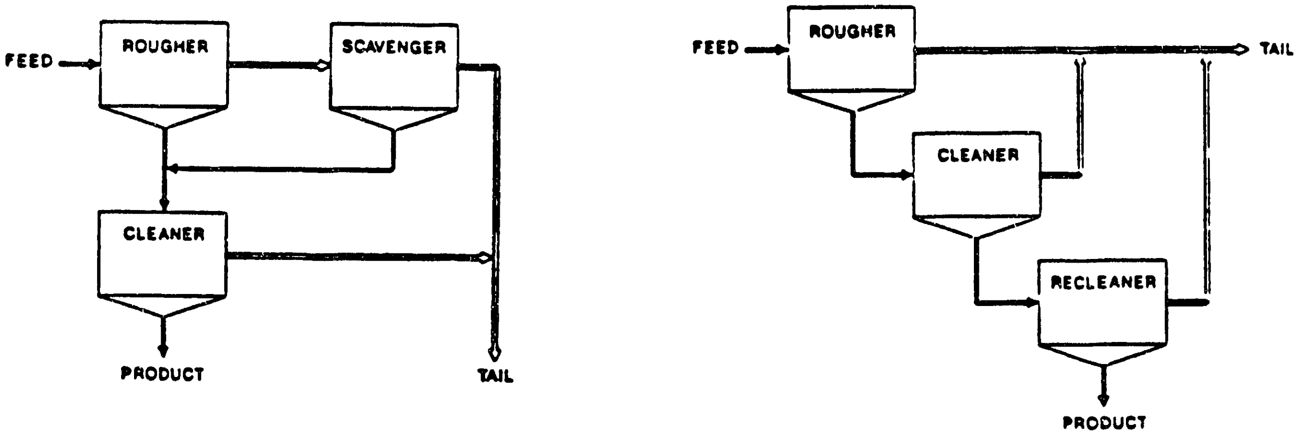


FIGURE 6.10 Schematic representations of the various circuit configurations examined in the present work.

columns are capable of achieving results similar to those attainable using release analysis. Therefore, for a properly operated flotation column, the effectiveness of the separation is primarily controlled by the characteristics of the coal and is relatively independent of the cell used to perform the separation. The results obtained in the present work suggest that single-stage column units are capable of achieving essentially the same metallurgical performance as multiple-stage circuit configurations. Therefore, other factors should be considered in the selection of an appropriate circuit for coal cleaning. For example, the use of multiple column circuits may be desirable from an operational point of view since additional columns provide safeguards in the event that one of the columns is not operating properly. For example, if one of the columns in a rougher-cleaner-recleaner circuit has a plugged wash water distributor, the performance of that column will be diminished; however, the other columns in the circuit will continue to guarantee that product quality is met for the overall circuit. As a result, the selection of column circuit arrangements which are most capable of meeting individual operational requirements will need to be made on a case-by-case basis.

6.2.2.3 Column Cell Flotation Model Development

Introduction

The unique features of flotation columns have required that many of the operational guidelines developed in the past for conventional flotation be abandoned or modified. In an attempt to help resolve this deficiency, the overall objective of this subtask was the development of a user-interactive simulation program for the prediction of column flotation performance. The simulation package should provide useful information for the design, optimization and scale-up of advanced circuits for fine coal flotation. A further purpose of the simulator is 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. Therefore, the major advantage of this approach is that it allows the effects of a wide range of operating parameters to be studied in a low-cost and time-effective manner. The simulation package may also be useful for training personnel in column operation and for trouble-shooting various operational problems. The simulator, when modified appropriately, may also be useful for the analysis and design of conventional flotation circuits.

The development of the user-interactive simulation program, called *COLMSIM*, was completed during the Task 6 work effort.

Comparisons with Experiments

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 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. Simulations were also conducted for each of the three base coals examined in the circuit evaluation test program.

Comparisons between the simulated and predicted results for each base coal are provided in Figures 6.11 through 6.13. As shown, very good agreement between the predicted and experimental recovery-grade curves were obtained, particularly for the Pittsburgh and Illinois No. 6 seam coals. The fit is particularly good in light of the fact that the experimental data were collected over a range of bubble sizes, solids contents, feed flow rates and circuit configurations. The relatively poorer fit obtained for the Upper Freeport coal can be explained by the presence of large amounts of middlings particles in the coal. Nevertheless, the very good predictions obtained with the other base coals indicate that this approach for simulating column flotation performance is promising.

7.0 EVALUATION OF BENCH-SCALE AND COMPONENT TEST RESULTS

7.1 Overview and Scope

A bench-scale and component testing report was prepared and submitted to DOE after completing Task 5 and Task 6.

The report included the preparation, presentation and analysis of all the experimental data obtained in the bench-scale and component unit operations, development and testing. A comparison of the results obtained with the expected limitations and deficiencies that occurred from bench-scale testing was compiled.

Following the evaluation of the bench-scale and component testing results, a residual needs analysis was prepared. This was prepared after comparing results learned in Tasks 5 and 6 with the original residual needs analysis.

Finally, a bench-scale testing summary was prepared. It specifically addressed the results of the bench-scale component testing in respect to the information necessary to define a commercially operating system. This included equipment selection, sizing, evaluation and operation to achieve both coal cleaning as well as the cost of system operation.

7.2 Review of Work Completed this Quarter

Task 7 report was completed during this quarter. The task report includes the analysis of all experimental data compiled from Tasks 5 and 6 and conclusions drawn from these results as compared to the preliminary conceptual design for the 20 TPH semi-works plant. The results from Tasks 5 and 6 are reported under their respective tasks and the best way to summarize these results is to examine circuit performance projections based on Tasks 5 and 6 results.

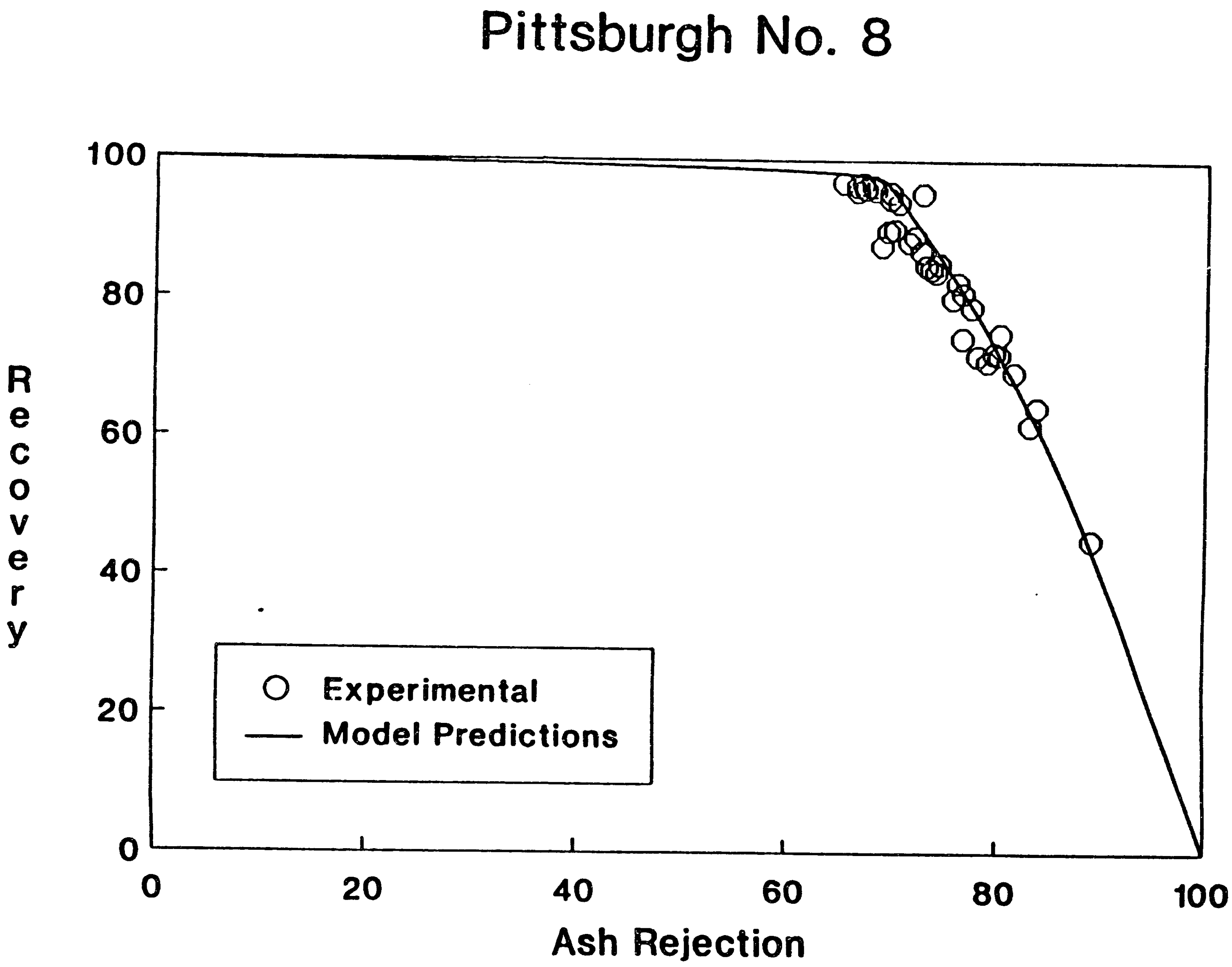


FIGURE 6.11 **Comparison of experimental results and simulator predictions for the Pittsburgh No. 8 seam coal.**

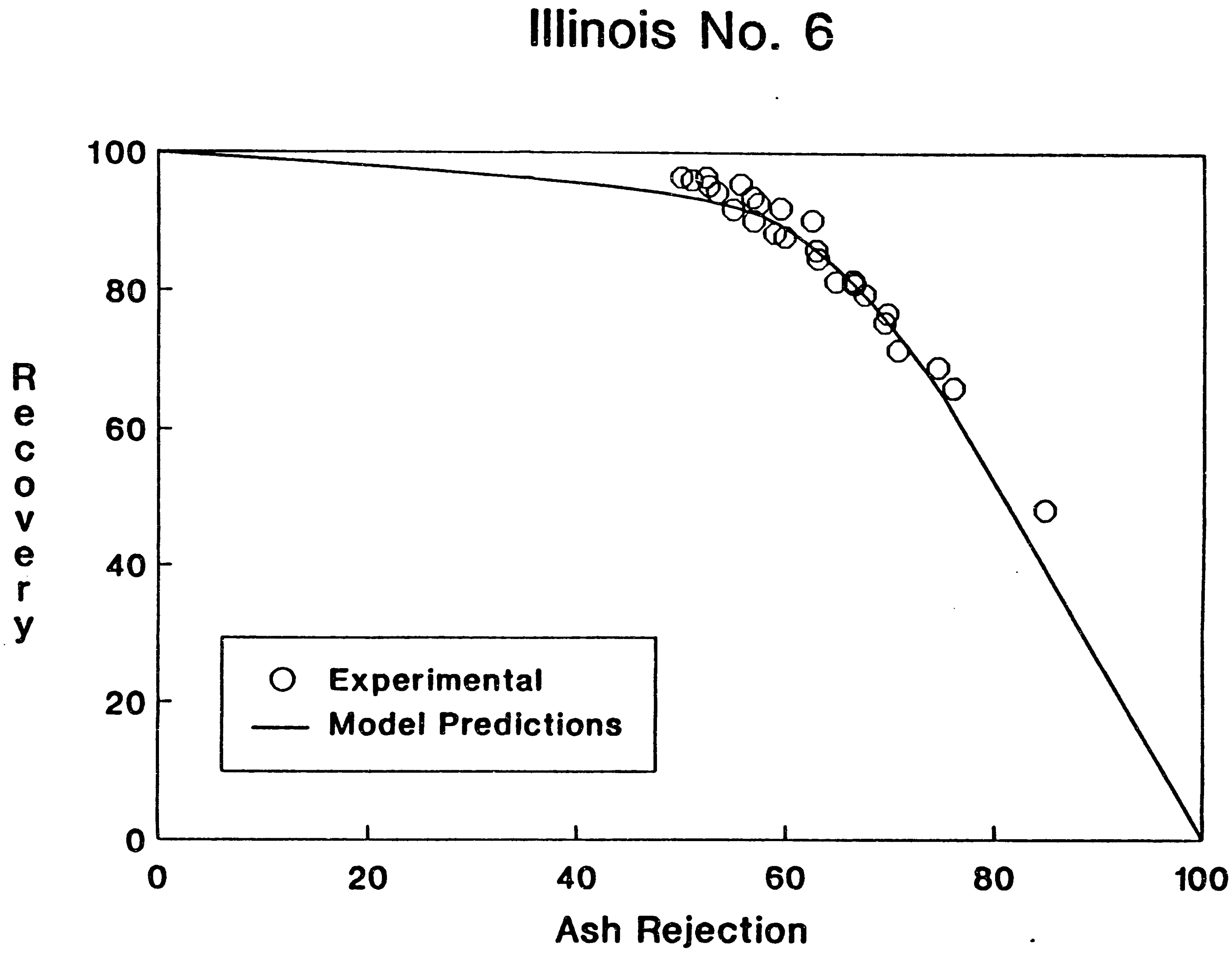
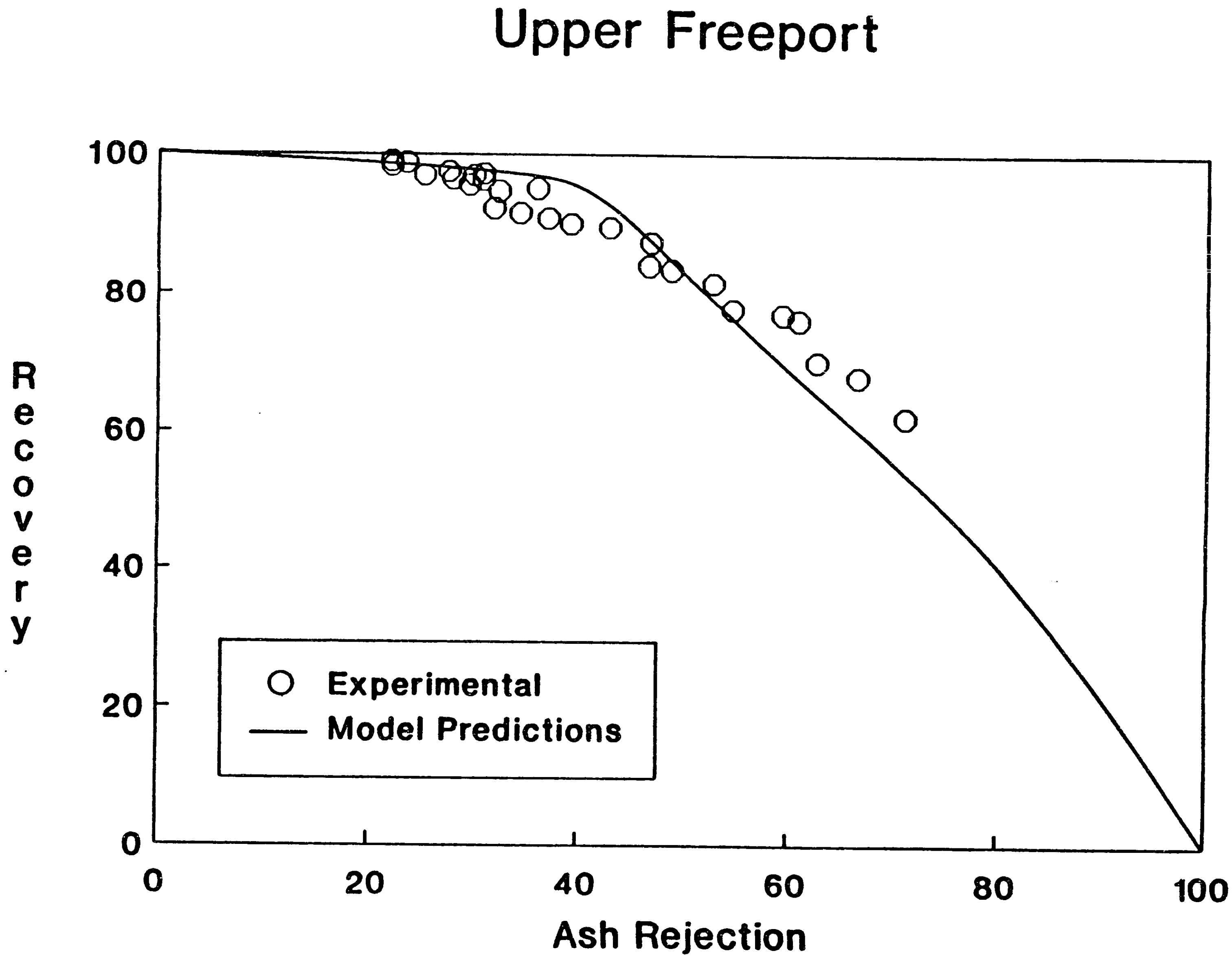


FIGURE 6.12 **Comparison of experimental results and simulator predictions for the Illinois No. 6 seam coal.**



Upper Freeport

FIGURE 6.13 **Comparison of experimental results and simulator predictions for the Upper Freeport seam coal.**

7.2.1 Circuit Performance Projections

The raw coal washability results indicate that there is theoretical potential to clean each of the three coals studied to meet the 85/85 performance goals established for this project. Results of Tasks 5 and 6, meanwhile, have addressed specific concerns related to the design and operation of individual process units required to clean the coals using approaches that would try to exploit the raw coals' potential.

Investigators utilized the continuous bench-scale testing results in order to construct overall circuit performance projections. While these projections cannot be considered definitive, the approach taken to complete the individual unit operations testing was designed to provide the data for making somewhat reasonable estimations of plant performance.

In order to provide this opportunity, investigators tested a series of unit operations on each of the coals that, if coupled and ran continuously, would approach the process philosophies established as alternatives in the preliminary conceptual flowsheet and simulated in the raw coal characterizations. For the Pittsburgh Seam testing, each individual unit was tested by itself completely uncoupled from any other sizing, cleaning or dewatering unit. Figure 7.1 shows the equipment tested on the Pittsburgh seam coal and the mass balance, which will be discussed later.

Referring to the figure, in order to allow a full flowsheet performance projection, investigators first processed the 1/4 inch x 0 Pittsburgh coal in a 6" diameter hydrocyclone. The products were sampled for the hydrocyclone performance evaluation and the clean coal was collected and reused for subsequent size reduction (to 48M x 0) and recleaning (the crushed coal) in the same 6" hydrocyclone. This approach was repeated following the flowscheme shown in Figure 7.1 so that a final clean coal could be produced that is reasonably representative of what may be expected from a continuous, completely coupled process similar to that in the figure. Since no precleaned products from the conventional coal cleaning units were extracted during this testing and the final clean coal was totally produced from the advanced column froth flotation unit, this resembles the Case C cleaning alternative. Due to the great effort required to approach optimum conditions, resources were not available to test the Case A and Case B alternatives. Realizing this, investigators narrowed the scope of this testing to the overall scheme that had the best chance of meeting the 85/85 performance goals.

Using a similar approach and also evaluating this Case C approach, investigators processed the Illinois No. 6 coal using the equipment shown in Figure 7.2. For this coal, however, investigators were able to directly couple a series of unit operations at the Institute of Materials Processing of MTU to more accurately simulate a fully continuous process. Referring to the figure, all units after the fine (48M x 0) hydrocyclone were operated in a coupled, continuous fashion. The other units were not.

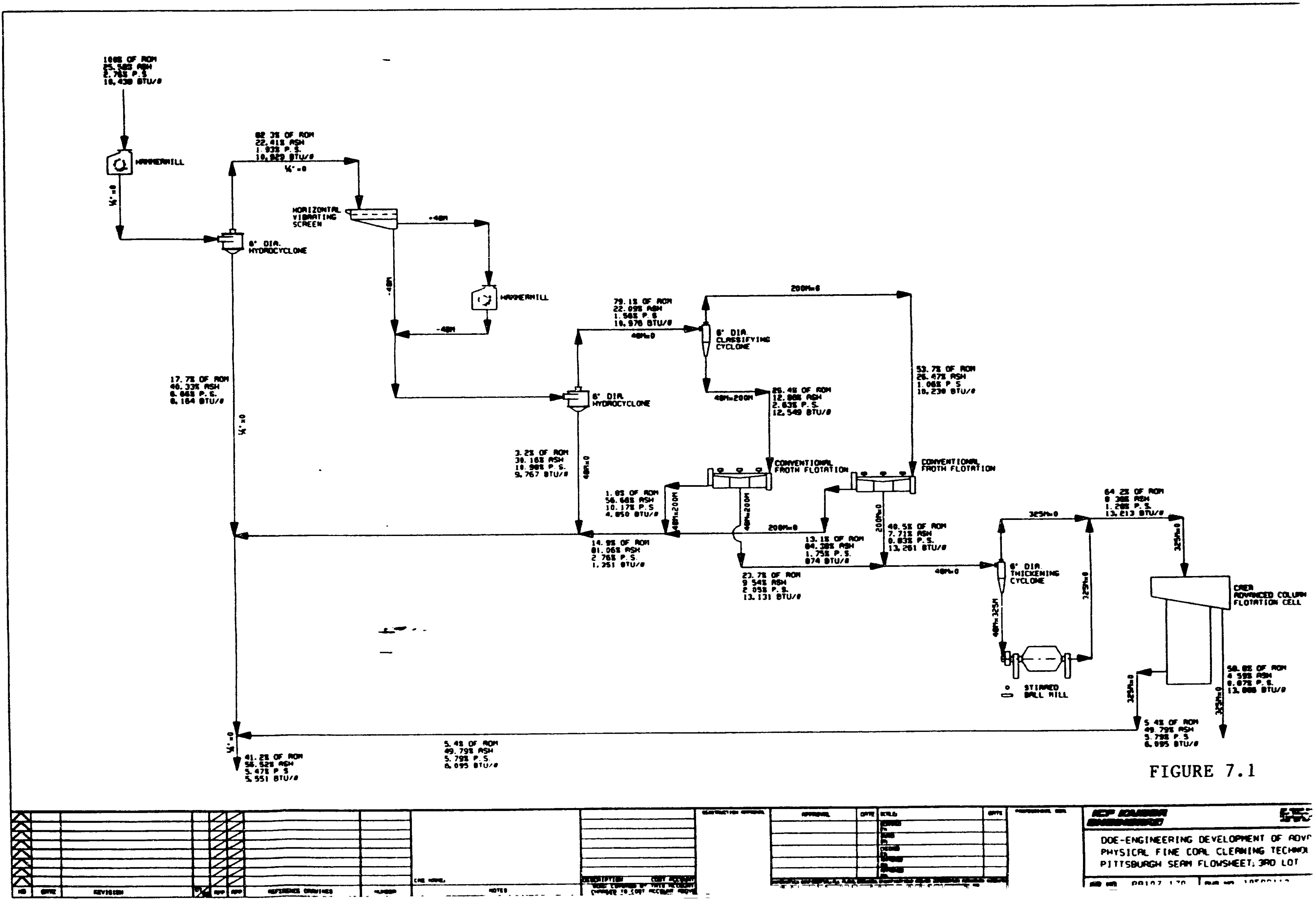

100% OF ROM
25.58% ASH
2.76% P.S
10,430 BTU/#
HAMMERMILL
¼"×0
8" DIA.
HYDROCYCLONE
82.3% OF ROM
22.41% ASH
1.93% P.S.
10,929 BTU/#
¼"×0
HORIZONTAL
VIBRATING
SCREEN
+48M
HAMMERMILL
-48M
-48M
17.7% OF ROM
40.33% ASH
6.66% P.S.
8,104 BTU/#
¼"×0
79.1% OF ROM
22.09% ASH
1.56% P.S
10,970 BTU/#
48M×0
6" DIA.
HYDROCYCLONE
8" DIA.
CLASSIFYING
CYCLONE
200M×0
48M×200M
25.4% OF ROM
12.80% ASH
2.63% P.S.
12,549 BTU/#
53.7% OF ROM
26.47% ASH
1.06% P.S
10,230 BTU/#
3.2% OF ROM
30.16% ASH
10.90% P.S.
9,767 BTU/#
48M×0
CONVENTIONAL
FROTH FLOTATION
CONVENTIONAL
FROTH FLOTATION
1.8% OF ROM
56.60% ASH
10.17% P.S
4,850 BTU/#
48M×200M
48M×200M
200M×0
200M×0
14.9% OF ROM
81.06% ASH
2.76% P.S.
1,351 BTU/#
13.1% OF ROM
84.38% ASH
1.75% P.S.
874 BTU/#
40.5% OF ROM
7.71% ASH
0.83% P.S.
13,261 BTU/#
23.7% OF ROM
9.54% ASH
2.05% P.S.
13,131 BTU/#
48M×0
6" DIA.
THICKENING
CYCLONE
48M×325M
325M×0
325M×0
STIRRED
BALL MILL
64.2% OF ROM
8.38% ASH
1.28% P.S.
13,213 BTU/#
325M×0
CAER
ADVANCED COLUMN
FLOTATION CELL
58.8% OF ROM
4.59% ASH
0.87% P.S.
13,866 BTU/#
325M×0
325M×0
5.4% OF ROM
49.79% ASH
5.79% P.S
6,095 BTU/#
¼"×0
41.2% OF ROM
56.52% ASH
5.47% P.S
5,551 BTU/#
5.4% OF ROM
49.79% ASH
5.79% P.S.
6,095 BTU/#
REVISION
REFERENCE DRAWINGS
NOTES
DESCRIPTION
APPROVAL
DATE
DOE-ENGINEERING DEVELOPMENT OF ADV
PHYSICAL FINE COAL CLEANING TECHNO
PITTSBURGH SEAM FLOWSHEET; 3RD LOT

FIGURE 7.1

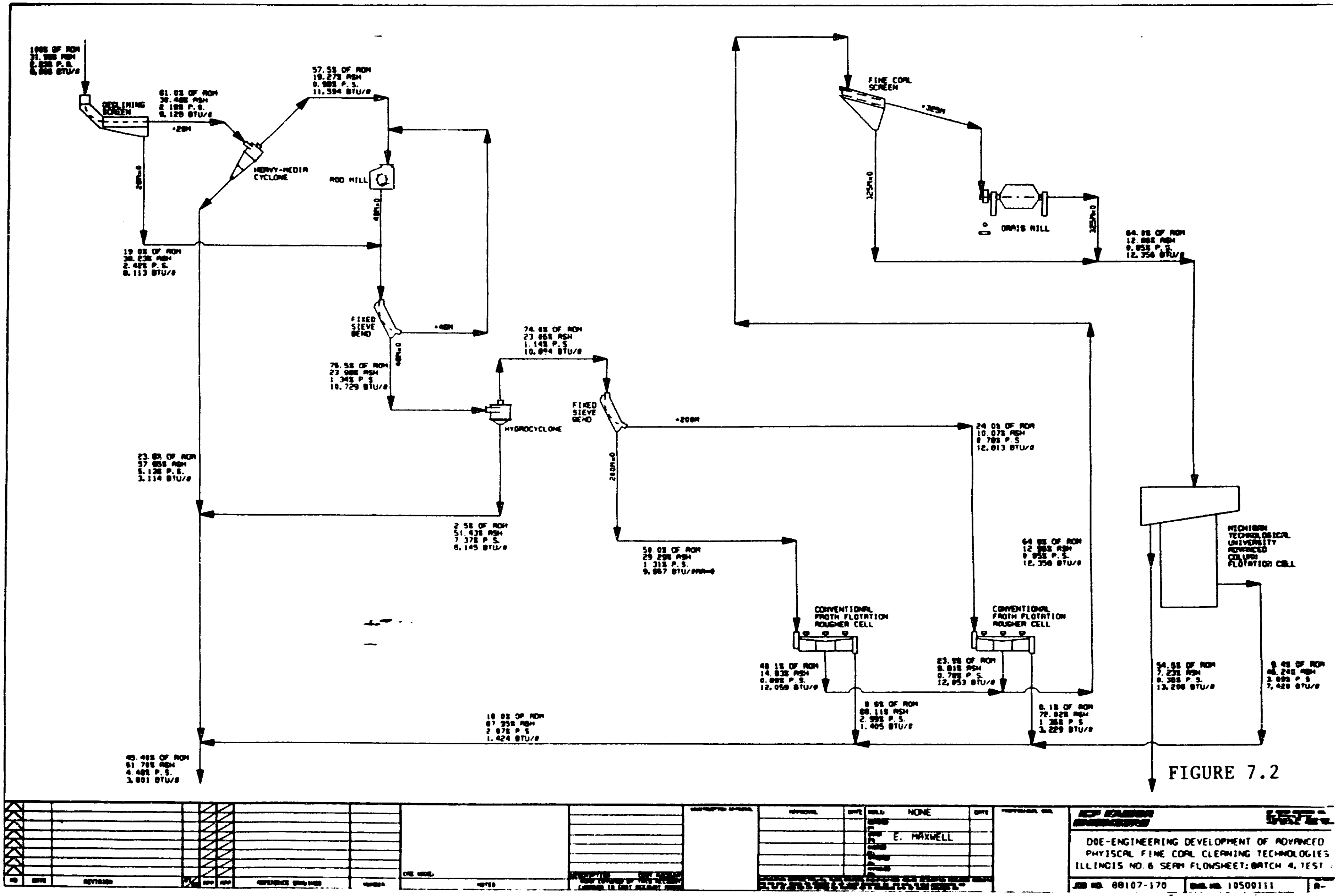

100% OF ROM
31.98% ASH
2.82% P.S.
8,800 BTU/#
DESLIMING SCREEN
+28M
28M×0
81.0% OF ROM
30.40% ASH
2.10% P.S.
8,120 BTU/#
19.0% OF ROM
38.23% ASH
2.42% P.S.
8,113 BTU/#
HEAVY-MEDIA CYCLONE
57.5% OF ROM
19.27% ASH
0.98% P.S.
11,594 BTU/#
23.6% OF ROM
57.05% ASH
5.13% P.S.
3,114 BTU/#
ROD MILL
48M×0
FIXED SIEVE BEND
+48M
48M×0
76.5% OF ROM
23.90% ASH
1.34% P.S
10,729 BTU/#
HYDROCYCLONE
74.0% OF ROM
23.06% ASH
1.14% P.S
10,894 BTU/#
2.5% OF ROM
51.43% ASH
7.37% P.S.
6,145 BTU/#
FIXED SIEVE BEND
+200M
200M×0
50.0% OF ROM
29.29% ASH
1.31% P.S.
9,967 BTU/#
24.0% OF ROM
10.07% ASH
0.78% P.S
12,813 BTU/#
CONVENTIONAL FROTH FLOTATION ROUGHER CELL
48.1% OF ROM
14.83% ASH
0.89% P.S.
12,050 BTU/#
9.9% OF ROM
80.11% ASH
2.99% P.S.
1,405 BTU/#
CONVENTIONAL FROTH FLOTATION ROUGHER CELL
23.9% OF ROM
8.81% ASH
0.78% P.S.
12,853 BTU/#
0.1% OF ROM
72.02% ASH
1.38% P.S
3,229 BTU/#
64.0% OF ROM
12.86% ASH
0.85% P.S.
12,356 BTU/#
FINE COAL SCREEN
+325M
325M×0
DRAIS MILL
325M×0
64.0% OF ROM
12.86% ASH
0.85% P.S.
12,356 BTU/#
MICHIGAN TECHNOLOGICAL UNIVERSITY ADVANCED COLUMN FLOTATION CELL
54.6% OF ROM
7.23% ASH
0.38% P.S.
13,200 BTU/#
9.4% OF ROM
48.24% ASH
3.09% P.S
7,420 BTU/#
10.0% OF ROM
87.35% ASH
2.97% P.S
1,424 BTU/#
45.40% OF ROM
61.70% ASH
4.40% P.S.
3,001 BTU/#
NONE
E. MAXWELL
DOE-ENGINEERING DEVELOPMENT OF ADVANCED
PHYSICAL FINE COAL CLEANING TECHNOLOGIES
ILLINOIS NO.6 SEAM FLOWSHEET: BATCH 4, TEST
88107-170
10500111
A-

FIGURE 7.2

Comparing Figures 7.1 and 7.2, it should be noted that different coarse precleaning units were utilized in the two flowsheets: A water-only cyclone for the Pittsburgh coal and a heavy media cyclone for the Illinois No. 6 coal (and the Upper Freeport coal). In order to make a coarse coal, high gravity separation in the Case C cleaning alternative, either unit would be acceptable as long as the circuits are properly sized. Because the proposed facility to house the POC module (the OCDO facility in Beverly, Ohio) will contain two stage heavy media circuitry, coarse coal cleaning at the POC-level will employ heavy media circuitry.

The cleaning equipment tested on the Upper Freeport coal is shown in Figure 7.3. As with the Illinois No. 6 coal testing, only the units following the fine hydrocyclone were operated continuously as a circuit (all units were coupled). The equipment used for the Upper Freeport coal cleaning was identical to that used for the Illinois No. 6 coal, however, the coal cleaning philosophy was changed. For the Upper Freeport coal, the Case B cleaning alternative was evaluated. The grab-and-run, conventional froth flotation configuration was only successfully employed on the Upper Freeport coal. This flotation approach was tried on each of the three coals, but investigators ruled out this approach for the Pittsburgh and Illinois No. 6 coals for the purposes of the continuous, bench-scale testing. In deciding whether the grab-and-run configuration was appropriate, a coal quality based criteria was used. Again, this was done because investigators only had the resources to test a single flowsheet alternative for each of the coals.

A quality specification of 6% ash from the grab product of the grab-and-run flotation tests was used by investigators in deciding the best configuration to run for the final flowsheet test series. Investigators desired to produce the coarsest clean coal product possible, but reasoned that if 6% ash could not be met, then the overall 85/85 performance goals would probably not be achieved. As will be shown later in this section, the 85/85 performance goals were not met when using either the Case C cleaning alternative to clean the Pittsburgh and Illinois No. 6 coals or the Case B approach to clean the Upper Freeport coal. Despite this, investigators maintain that these flowsheet performance projections are not conclusive, and that improved performance may be possible in a continuously operated process. Also, even though the 85/85 performance goals were not met for any of the coals, the separation efficiency results for the Illinois No. 6 and Upper Freeport Seam goals closely approach or exceed that of 85/85 performance levels (70% separation efficiency). In addition, even if the 85/85 performance goals can not be achieved, there may be a practical application for a process that can achieve near 85/85 performance, which is shown to be possible from the bench-scale testing. The cost of competing sulfur reduction strategies will ultimately determine the practicality, and indeed, a significant contribution to overall sulfur reduction efforts by a physical coal cleaning process may make sense.

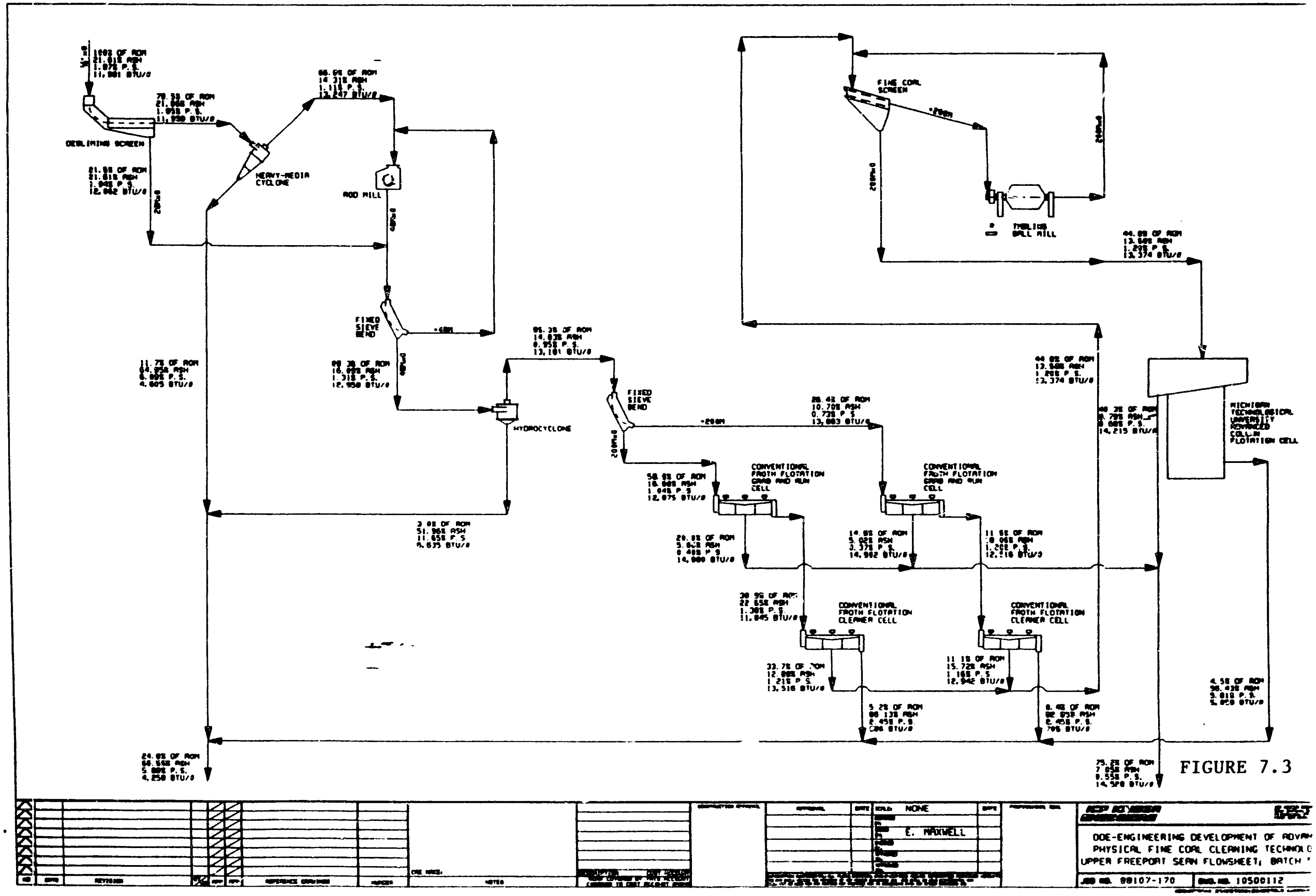

3/8"×0
100% OF ROM
21.81% ASH
1.97% P.S.
11,981 BTU/#
DESLIMING SCREEN
78.5% OF ROM
21.86% ASH
1.95% P.S.
11,950 BTU/#
21.5% OF ROM
21.81% ASH
1.94% P.S.
12,062 BTU/#
28M×0
HEAVY-MEDIA CYCLONE
66.6% OF ROM
14.31% ASH
1.11% P.S.
13,247 BTU/#
ROD MILL
48M×0
FIXED SIEVE BEND
+48M
88.3% OF ROM
16.09% ASH
1.31% P.S.
12,950 BTU/#
48M×0
11.7% OF ROM
64.95% ASH
6.09% P.S.
4,805 BTU/#
HYDROCYCLONE
85.3% OF ROM
14.83% ASH
0.95% P.S.
13,181 BTU/#
3.0% OF ROM
51.96% ASH
11.65% P.S.
6,635 BTU/#
FIXED SIEVE BEND
+200M
200M×0
58.9% OF ROM
16.00% ASH
1.04% P.S.
12,875 BTU/#
28.4% OF ROM
10.70% ASH
0.73% P.S.
13,883 BTU/#
CONVENTIONAL FROTH FLOTATION GRAB AND RUN CELL
CONVENTIONAL FROTH FLOTATION GRAB AND RUN CELL
28.0% OF ROM
5.6?% ASH
0.48% P.S.
14,800 BTU/#
14.8% OF ROM
5.02% ASH
0.37% P.S.
14,982 BTU/#
11.5% OF ROM
18.06% ASH
1.20% P.S.
12,518 BTU/#
30.9% OF ROM
22.65% ASH
1.30% P.S.
11,845 BTU/#
CONVENTIONAL FROTH FLOTATION CLEANER CELL
CONVENTIONAL FROTH FLOTATION CLEANER CELL
33.7% OF ROM
12.08% ASH
1.21% P.S.
13,518 BTU/#
11.1% OF ROM
15.72% ASH
1.16% P.S.
12,942 BTU/#
5.2% OF ROM
80.13% ASH
2.45% P.S.
686 BTU/#
6.4% OF ROM
82.85% ASH
2.45% P.S.
706 BTU/#
FINE COAL SCREEN
+200M
200M×0
200M×0
2 TABLING BALL MILL
44.0% OF ROM
13.50% ASH
1.20% P.S.
13,374 BTU/#
44.0% OF ROM
13.50% ASH
1.20% P.S.
13,374 BTU/#
MICHIGAN TECHNOLOGICAL UNIVERSITY ADVANCED COLUMN FLOTATION CELL
40.3% OF ROM
8.79% ASH
0.88% P.S.
14,215 BTU/#
4.5% OF ROM
56.43% ASH
5.01% P.S.
5,850 BTU/#
75.2% OF ROM
7.05% ASH
0.55% P.S.
14,528 BTU/#
24.8% OF ROM
66.55% ASH
5.08% P.S.
4,250 BTU/#
SCALE NONE
E. MAXWELL
DOE-ENGINEERING DEVELOPMENT OF ADVAN
PHYSICAL FINE COAL CLEANING TECHNOLO
UPPER FREEPORT SEAM FLOWSHEET, BATCH
JOB NO. 88107-170
DWG. NO. 10500112

FIGURE 7.3

7.2.2 Approach to Circuit Projections

Circuit performance projections were based on actual data obtained during the bench-scale testing phase of Task 5. Since perfect closure of a strict metallurgical balance calculation for more than one measured parameter is very unlikely even around a single unit, reasonably estimating overall plant performance by theoretically coupling the results of single-unit operations is obviously a complicated problem.

Thus, in order to obtain the desired estimates for overall circuit performance, investigators utilized a computer program that is designed for material balance data adjustment. This BILMAT program was developed by the Canadian Center for Mineral and Energy Technology (CANMET) and is the same program used to evaluate the advanced flotation round robin data. A description of the use and capabilities of this program was presented in Topical Report No. 2 which was prepared for DOE as part of this project (Round Robin Topical Report).

Actual sample data, including ash, total sulfur, pyritic sulfur, and BTU per pound, as well as an estimate of the streams solids weight ratio (expressed as a percent of plant feed) were all input into the BILMAT program for each flowstream of a particular flowsheet (Figures 7.1 through 7.3). Also, for each piece of data, a standard deviation number between 0 and 1000 is input by the user, which represents the overall confidence that is placed in the accuracy of the data. Lower values for the standard deviation indicates a higher level of confidence in its accuracy. The BILMAT program then adjusts the input data set (not including the standard deviations) to produce an estimated metallurgical balance of all unit operations and the process as a whole. The program operates so as to minimize the adjustment of data to produce a strict material and material-component (i.e. ash, sulfur, etc.) balance. The allowable magnitude of adjustment is controlled by the standard deviation inputs.

Of the analytical data used for these material balance calculations, investigators generally placed the highest level of confidence in ash data followed in decreasing order by BTU per pound, total sulfur, and pyritic sulfur. The standard deviation values were also affected by the sampling approach for a given sample, and the actual value itself (ash analyses of materials of high ash are less reliable than the same analyses for low ash materials). B&W and PTI investigators, who were involved in the equipment performance tests, provided initial standard deviation values. Additionally, upon difficulty with initial BILMAT results, ICF KE investigators finally input very high standard deviations (of 1000) to all pyritic and total sulfur data, except the clean coal sample data, for the Illinois No. 6 and Upper Freeport seam results. This was necessitated by the fact that, for many high sulfur streams, pyritic sulfur results were higher than total sulfur results. The BILMAT program could not resolve this conflict using the initially-inputted standard deviation values and did a much better job when allowed more flexibility in adjusting the sulfur results.

7.2.3 Results of Circuit Projections

Table 7.1 presents a summary of the overall flowsheet performance projections for all three coals. All BILMAT data inputs as well as the projected (adjusted) results for each coal stream shown in Figures 7.1 through 7.3 are shown in these BILMAT outputs. Table 7.1 indicates that pyritic sulfur rejections ranging from 78.1% to 91.2% were achieved at energy recoveries from 78.1% to 91.2%. As may be expected the higher the pyritic sulfur rejection the lower the energy recovery when comparing results for the three coals.

TABLE 7.1
CIRCUIT PERFORMANCE ESTIMATIONS

	COAL SEAM		
	PITTSBURGH	ILLINOIS NO. 6	UPPER FREEPORT
FLOWSHEET APPROACH	CASE C	CASE C	CASE B
PYRITIC SULFUR REJECTION (%)	81.5	91.2	78.1
ENERGY RECOVERY (%)	78.1	80.7	91.2
SEPARATION INDEX (%)	59.6	71.9	69.3
ASH REJECTION (%)	89.5	87.7	75.7
SULFUR REJECTION (%)	55.9	58.6	61.1

NOTE(S): [1] SEPARATION INDEX = % ENERGY RECOVERY - (100 - % PYRITIC SULFUR REJECTION)

The relatively poor results of the Pittsburgh seam testing are likely the result of operational problems related to the coarse water only cyclone process. Based upon these known problems and the relative theoretical performance of the Pittsburgh coal versus Illinois No. 6 coal Case C scenarios in the raw coal characterization study, it is likely that the Pittsburgh coal performance, could have more closely approached, matched or exceeded the Illinois No. 6 coal performance if operated under similar conditions.

Regardless, the overall results show that at least one of the performance criteria could be met while achieving a respectable showing for the other. For both the Illinois No. 6 coal and the Upper Freeport Coal, the efficiency indices were near 70%. Exact achievement of the 85/85 performance goals would result in an separation efficiency of 70%.

The results of the circuit performance evaluations indicate that substantial pyritic sulfur rejections can be achieved at reasonable energy recoveries by employing conventional coal cleaning processes ahead of applications of fine grinding and advanced froth flotation.

The approach used for evaluating the bench-scale data simulated full flowsheet operation for all but the final thickening and dewatering units. In actual practice, these units would produce clarified water (thickening) and dilute effluents (dewatering) for recycle to preceding processes. In material balances projections, it is assumed that solids that would be recycled with these streams would, after buildup and stabilization of the recirculating load, be placed to the correct product stream. While not identical in concept, this equates to an assumption that thickening and dewatering equipment solids recoveries are 100%. Detailed discussion of the flowsheet performance projections from each seam follow.

Pittsburgh Seam Coal

A estimated overall material balance for the continuous bench-scale testing of the Pittsburgh seam coal is presented in Table 7.2. The flowsheet and mass balance for this test was presented in Figure 7.1. Overall, the pyritic sulfur rejection for this coal was 81.5% at an energy recovery of 78.1% which does not meet the 85/85 performance goals established for the project.

Of the total pyritic sulfur rejected, 86.2% was rejected in conventional cleaning equipment while 13.8% was rejected in advanced column cell flotation. Similarly, 85.6% of the total lost energy was rejected from the conventional processes while 14.4% was rejected from the advanced column. The coarse water-only cyclone process removed nearly 43% of the raw coals pyritic sulfur while nearly 14% of the raw coal's energy was lost with the units' reject. The coarse water-only cyclone process did not perform to expectations, and it is anticipated that a properly designed circuit would achieve improved results. Overall flowsheet performance would most likely improve.

The mean particle size of the feed to advanced froth flotation was 10.3 microns (D10 - 2.6 microns, D50 - 8.6 microns, D90 - 20.9 microns). Advanced froth flotation removed 11.3% of the raw coal's pyritic sulfur and the fine water-only cyclone removed 12.7%. The refuse from each of these processes contained about 3% of the raw coal's energy. The -200M conventional froth flotation process removed 8.3% of the raw coals pyritic sulfur and 1.1% of the raw coals energy was lost with the reject. Meanwhile, +200M conventional flotation removed 6.6% of the raw coals pyrite, and 0.8% of the raw coals energy was lost in the process.

Illinois No.6 Seam Coal

The estimated flowsheet material balance for the Illinois No. 6 seam coal is presented in Table 7.3. The total mass balance predicted by the BILMAT program was provided in Figure 7.2.

The overall pyritic sulfur rejection for this flowsheet was 91.2% while the energy recovery was 80.7% which, again, does not meet the 85/85 performance goals.

TABLE 7.2
MATERIAL BALANCE FOR THE PITTSBURGH SEAM
3RD LOT

STREAM DESIGNATION	YIELD AND QUALITY						PERFORMANCE			
							UNIT FEED		TOTAL FEED	
	UNIT YIELD (%)	% OF ROM	ASH (%)	PYRT. SUL. (%)	TOT. SUL. (%)	BTU PER LB.	PYR. SUL. REJ. (%)	BTU REC. (%)	PYR. SUL. REJ. (%)	BTU REC. (%)
OVERALL										
RAW COAL FEED		100.0	25.58	2.76	4.66	10,439				
COARSE W. O. CYCLONE										
FEED		100.0	25.58	2.76	4.66	10,439				
PRODUCT	82.3	82.3	22.41	1.93	3.83	10,929	42.6	86.2	42.6	86.2
REFUSE	17.7	17.7	40.33	6.66	8.49	8,164				
FINE W. O. CYCLONE										
FEED		82.3	22.41	1.93	3.83	10,929				
PRODUCT	96.1	79.1	22.09	1.56	3.52	10,976	22.2	96.5	55.4	83.2
REFUSE	3.9	3.2	30.16	10.98	11.64	9,767				
CLASS. CYCLONE (200M)										
FEED		79.1	22.09	1.56	3.52	10,976				
OVERFLOW	67.8	53.7	26.47	1.06	2.86	10,230				
UNDERFLOW	32.2	25.4	12.86	2.63	4.89	12,549				
-200M CONV. F. FLOT.										
ROUGHER FEED		53.7	26.47	1.06	2.86	10,230				
ROUGHER CONC.	75.5	40.5	7.71	0.83	3.22	13,261	40.6	97.9	87.8	51.5
ROUGHER TAILS	24.5	13.1	84.38	1.75	1.76	874				
+200M CONV. F. FLOT.										
ROUGHER FEED		25.4	12.86	2.63	4.89	12,549				
ROUGHER CONC.	93.0	23.7	9.54	2.05	4.49	13,131	27.3	97.3	82.4	29.7
ROUGHER TAILS	7.0	1.8	56.66	10.17	10.19	4,850				
COMPOSITE CONV. F. FLOT.										
ROUGHER FEED		79.1	22.09	1.56	3.52	10,976				
ROUGHER CONC.	81.1	64.2	8.38	1.28	3.69	13,213	33.4	97.7	70.3	81.2
ROUGHER TAILS	18.9	14.9	81.06	2.76	2.77	1,351				
COLUMN CELL FLOTATION										
FEED		64.2	8.38	1.28	3.69	13,213				
CONCENTRATE	91.6	58.8	4.59	0.87	3.49	13,866	38.0	96.1	81.5	78.1
TAILS	8.4	5.4	49.79	5.79	5.82	6,095				
OVERALL PLANT										
FEED		100.0	25.58	2.76	4.66	10,439				
CLEAN COAL		58.8	4.59	0.87	3.49	13,866			81.5	78.1
REFUSE		41.2	55.52	5.47	6.31	5,551				

TOTAL CIRCUIT PERFORMANCE	
% PYRITIC SULFUR REJECTION	81.5
% BTU RECOVERY	78.1
% EFFICIENCY INDEX	59.6
% ASH REJECTION	89.5
% TOTAL SULFUR REJECTION	55.9

TABLE 7.3
MATERIAL BALANCE FOR THE ILLINOIS NO. 6 SEAM COAL (BILMAT ADJUSTED)
TEST 2, BATCH 4

	YIELD AND QUALITY						PERFORMANCE			
							UNIT FEED		TOTAL FEED	
STREAM DESIGNATION	UNIT YIELD (%)	% OF ROM	ASH (%)	PYRT. SUL. (%)	TOT. SUL. (%)	BTU PER LB.	PYR. SUL. REJ. (%)	BTU REC. (%)	PYR. SUL. REJ. (%)	BTU REC. (%)
OVERALL						#				
ACTUAL RAW COAL FEED		100.0	31.53	2.23	3.73	9,466				
RAW COAL FEED (CALC)		100.0	31.96	2.23	3.74	8,936				
DESLIME SCREEN (28M)										
FEED		100.0	31.96	2.23	3.74	8,936				
OVERSIZE	81.0	81.0	30.48	2.19	3.68	9,129				
UNDERSIZE	19.0	19.0	38.23	2.42	3.98	8,113				
HEAVY MEDIA CYCLONE										
FEED		81.0	30.48	2.19	3.68	9,129				
PRODUCT	70.9	57.5	19.27	0.98	3.01	11,594	68.2	90.1	74.8	74.5
REFUSE		12.3	77.86	8.35	7.95	2,246				
MAG. SEP. LOSSES		11.2	35.86	1.59	2.41	4,066				
REFUSE(INC MAG.SEP.LOSSES)	29.1	23.6	57.85	5.13	5.31	3,114				
WATER-ONLY CYCLONE										
FEED		76.5	23.98	1.34	3.25	10,729				
PRODUCT	96.7	74.0	23.06	1.14	3.10	10,884	17.9	98.1	62.4	90.1
REFUSE	3.3	2.5	51.43	7.37	7.82	6,145				
SIEVE BEND (200M)										
FEED		74.0	23.06	1.14	3.10	10,884				
OVERSIZE	32.4	24.0	10.07	0.78	3.02	12,813				
UNDERSIZE	67.6	50.0	29.29	1.31	3.14	9,957				
-200M CONV. F. FLOT. (ROUGHER ONLY)										
FEED	100.0	50.0	29.29	1.31	3.14	9,957				
CONCENTRATE	80.3	40.1	14.83	0.89	3.07	12,059	45.2	97.2	84.0	54.1
TAILINGS	19.7	9.9	88.11	2.99	3.41	1,405				
+200M CONV. F. FLOT. (ROUGHER ONLY)										
FEED	100.0	24.0	10.07	0.78	3.02	12,813				
CONCENTRATE	99.6	23.9	9.81	0.78	3.02	12,853	0.7	99.9	91.6	34.4
TAILINGS	0.4	0.1	72.02	1.36	1.75	3,229				
COMPOSITE CONV. F. FLOT. (48m X O)										
FEED	100.0	74.0	23.06	1.14	3.10	10,884				
CONCENTRATE	86.5	64.0	12.96	0.85	3.05	12,356	35.3	98.2	75.6	88.5
TAILINGS	13.5	10.0	87.95	2.97	3.39	1,424				
COLUMN CELL FLOTATION										
FEED		64.0	12.96	0.85	3.05	12,356				
CONCENTRATE	85.3	54.6	7.23	0.36	2.83	13,206	63.8	91.2	91.2	80.7
TAILS	14.7	9.4	46.24	3.69	4.34	7,420				
OVERALL PLANT										
FEED		100.0	31.96	2.23	3.74	8,936				
CLEAN COAL		54.6	7.23	0.36	2.83	13,206			91.2	80.7
REFUSE		45.4	61.70	4.48	4.83	3,801				

TOTAL CIRCUIT PERFORMANCE	
% PYRITIC SULFUR REJECTION	91.2
%BTU RECOVERY	80.7
% EFFICIENCY INDEX	71.9
% ASH REJECTION	87.7
% TOTAL SULFUR REJECTION	58.6

The resulting separation efficiency of 71.9%, however, exceeds that of 85/85 performance (70%). Of the total pyritic sulfur rejected in the flowsheet, 83.0% was rejected from conventional cleaning processes while 17.0% was rejected from advanced flotation. In contrast to the Pittsburgh seam results, however, only 59.6% of the total BTU losses were attributable to conventional cleaning devices while 40.4% was lost with the advanced flotation reject.

The heavy media cyclone process performed very well by removing 54% of the raw coals pyrite, while losing 8.2% of the coal's energy. Meanwhile, conventional, -200M froth flotation removed 13.2% of the raw coal's pyritic sulfur while the 48M x 0 water-only cyclone process removed 8.2%. Energy losses in these processes were 1.6% and 1.7%. Finally, beneficiation by +200M conventional froth flotation proved of no benefit. On a total feed basis, both pyritic sulfur rejection and BTU losses were less than 0.1%.

The mean particle size of the feed to advanced froth flotation was 12.5 microns (D10 - 2.6 microns, D50 - 8.8 microns, D90 - 26.6 microns). About 15.5% of the raw coals pyritic sulfur was removed in column flotation and 7.8% of the coals energy was lost in the process.

Upper Freeport Seam Coal

The estimated material balance for the Upper Freeport seam coal is presented in Table 7.4. The mass balance was shown in Figure 7.3.

Overall pyritic sulfur rejection for the Upper Freeport coal was 78.1% at an energy recovery of 91.2% which does not meet the 85/85 performance goals. The separation index based on these values was 69.3% which again closely approaches that of 85/85 performance. Ash and total sulfur rejections were 75.7% and 61.1%. Of the total pyritic sulfur removed in this test 82.1% was rejected from conventional coal cleaning devices while 17.9% was rejected from the advanced column flotation cell. The corresponding shares of total energy losses were 75.0% and 25.0%, respectively.

The mean particle size of the feed to advanced froth flotation was 24.1 microns (D10 - 3 microns, D50 - 14.8 microns, D90 - 59.5 microns). The column flotation cell rejected 14.0% of the raw coal's pyrites while losing 2.2% of the coals energy to the reject stream. The heavy media and water-only cyclone processes, meanwhile, rejected 38.1% and 18.7% of the coal's pyrites while losing 4.5% and 1.7% of the energy to refuse streams. The minus 200M conventional froth flotation circuit rejected 6.8% of the pyrites and lost 0.4% of the raw coal's energy. The +200M conventional froth flotation process was relatively ineffective in that it rejected only 0.5% of the raw coal's pyrite and improved the ash of the flotation feed from 10.70% to 9.59%. However, this circuit and the -200M conventional flotation circuit combined to yield a full 34.9% of the raw coals weight to a preclean product stream.

TABLE 7.4

MATERIAL BALANCE FOR THE UPPER FREEPORT SEAM COAL

TEST 1, BATCH 5

	YIELD AND QUALITY						PERFORMANCE			
							UNIT FEED		TOTAL FEED	
STREAM DESIGNATION	UNIT YIELD (%)	% OF ROM	ASH (%)	PYRT. SUL. (%)	TOT. SUL. (%)	BTU PER LB.	PYR. SUL. REJ. (%)	BTU REC. (%)	PYR. SUL. REJ. (%)	BTU REC. (%)
OVERALL						#				
ACTUAL RAW COAL FEED		100.0	22.53	1.98	2.42	11,878				
RAW COAL FEED (CALC)		100.0	21.81	1.87	2.42	11,981				
DESLIME SCREEN (28M)										
FEED		100.0	21.81	1.87	2.42	11,981				
OVERSIZE	78.5	78.5	21.86	1.85	2.35	11,959				
UNDERSIZE	21.5	21.5	21.61	1.94	2.71	12,062				
HEAVY MEDIA CYCLONE										
FEED		78.5	21.86	1.85	2.35	11,959				
PRODUCT	85.1	66.8	14.31	1.11	1.64	13,247	49.0	94.3	60.4	73.9
REFUSE		7.9	83.62	8.02	8.22	1,398				
MAG. SEPARATOR LOSSES		3.8	26.15	2.09	2.55	11,272				
REFUSE (INC. SEP. LOSSES)	14.9	11.7	64.95	6.09	6.38	4,605				
WATER-ONLY CYCLONE										
FEED		88.3	16.09	1.31	1.90	12,958				
PRODUCT	96.6	85.3	14.83	0.95	1.53	13,181	30.2	98.3	56.8	93.8
REFUSE	3.4	3.0	51.96	11.65	12.47	6,635				
SIEVE BEND (200M)										
FEED		85.3	14.83	0.95	1.53	13,181				
OVERSIZE	30.9	26.4	10.70	0.73	1.45	13,863				
UNDERSIZE	69.1	58.9	16.68	1.04	1.56	12,875				
-200M CONV. F. FLOT.										
ROUGHER FEED		58.9	16.68	1.04	1.56	12,875				
ROUGHER CONC.	34.0	20.0	5.06	0.40	1.16	14,880	87.0	39.2	95.7	24.8
ROUGHER TAILS	66.0	38.9	22.65	1.38	1.77	11,845				
SCAVENGER CONC.	86.7	33.7	12.88	1.21	1.71	13,516	23.7	98.9	78.2	38.0
SCAVENGER TAILS	13.3	5.2	86.13	2.45	2.14	986				
+200M CONV. F. FLOT.										
ROUGHER FEED		26.4	10.70	0.73	1.45	13,863				
ROUGHER CONC.	56.4	14.9	5.02	0.37	1.16	14,902	71.5	60.7	97.1	18.5
ROUGHER TAILS	43.6	11.5	18.06	1.20	1.83	12,516				
SCAVENGER CONC.	96.5	11.1	15.72	1.16	1.81	12,942	7.1	99.8	93.1	12.0
SCAVENGER TAILS	3.5	0.4	82.85	2.45	2.38	705				
COMPOSITE CONV. F. FLOT.										
ROUGHER FEED		85.3	14.83	0.95	1.53	13,181				
ROUGHER CONC.	40.9	34.9	5.04	0.39	1.16	14,889	83.3	46.2	92.8	43.4
ROUGHER TAILS	59.1	50.4	21.60	1.34	1.78	11,998				
SCAVENGER CONC.	88.9	44.8	13.58	1.20	1.74	13,374	20.3	99.1	71.3	50.0
FLOTATION TAILS	11.1	5.6	85.89	2.45	2.16	966				
COLUMN CELL FLOTATION										
FEED		44.8	13.58	1.20	1.74	13,374				
CONCENTRATE	89.9	40.3	8.79	0.68	1.33	14,215	48.8	95.6	85.3	47.8
TAILS	10.1	4.5	56.43	5.81	5.34	5,859				
OVERALL PLANT										
FEED		100.0	21.81	1.87	2.42	11,981				
CLEAN COAL		75.2	7.05	0.55	1.25	14,528			78.1	91.2
REFUSE		24.8	66.55	5.89	5.97	4,258				

TOTAL CIRCUIT PERFORMANCE	
% PYRITIC SULFUR REJECTION	78.1
%BTU RECOVERY	91.2
% EFFICIENCY INDEX	69.3
% ASH REJECTION	75.7
% TOTAL SULFUR REJECTION	61.1

The Upper Freeport coal was the only one of the three coals in which a precleaning product stream bypassed the advanced froth flotation process and this likely contributed to the impressive energy recovery level attained for the test. While this approach also reduced the maximum achievable pyritic sulfur rejection level, it is unlikely that a significant improvement in pyritic sulfur rejection would have been accomplished by crushing and recleaning (in the column flotation cell) the conventional flotation rougher product. Of the pyrite remaining in the total clean coal, 32.9% is contributed by the rougher product and 67.1% by the column cell product. Of the energy in the total clean 47.6% is from the rougher product and 52.4% from the column product. Thus, the rougher product is cleaner than the column product without further processing.

7.2.4 Re-Evaluation of the Preliminary Conceptual Process

Laboratory and bench-scale testing that was completed in Tasks 5 and 6 addressed many of the deficiencies that needed resolved before a final conceptual flowsheet incorporating advanced froth flotation could be designed. Unfortunately, this testing could not definitively establish whether overall process performance objectives could be achieved by any of the coal cleaning alternatives that were proposed in Task 2. Additionally, specific equipment-related design deficiencies remain to be resolved.

A database sufficient for an effective POC design has been provided for all key elements required. Specific improvements in the process design requirements include:

- A determination that potential exists in each of the raw coals to meet the 85/85 performance criteria in the Case B and Case C coal cleaning alternatives.
- The ability to properly size process circuitry and equipment based on the raw coal characterization and continuous bench-scale testing results.
- The ability to operate the key process elements in a continuous fashion.
- The ability to achieve product moisture targets.
- The ability to rule out specific operating conditions in POC testing and thus improve the chances of approaching optimized performance in the POC module.

The only specialized operating unit required for continued process development is the advanced column flotation unit. As earlier noted, the VPI design has been successfully scaled-up to a commercial application on 100M x 0 coal. Investigators feel that, based on a successful track record in previous scale-up efforts, the VPI design can be reasonably scaled-up for the POC module application on 200M x 0 or 325M x o coal. Residual design deficiencies related to the advanced flotation hardware and capabilities, however, may require modifications to the VPI design before the POC is constructed. This would be required, for instance, in order to test various mixing and distributions options related to the distribution of air bubbles, feed slurry, and wash water, which may significantly influence flotation performance. These factors will not otherwise restrict further process development.

The significant residual design deficiencies related to each problem area identified in Task 3. Based on Tasks 5 and 6 test results, the technical support group can develop a sufficient strategy for the POC module operation in order to resolve the remaining deficiencies or provide indication that advanced flotation technology is not ready for a commercial application in which the project objectives can be achieved. The additional modifications required to the VPI column design, if selected, can be achieved in a timely manner prior to the POC module installation.

While the Task 5 and 6 data has not proved the Task 2 approach capable of meeting required performance objectives (85/85 performance goals and 90% on-line process availability), the following results may be considered as positive indications for continued process development in the POC.

Overall circuit performance projections based on data from the Pittsburgh seam testing indicate that 82% pyrite rejection is possible at a 78% energy recovery. During the Pittsburgh seam tests, it was apparent that the coarse hydrocyclone did not perform as expected and it is anticipated that improved performance is possible. In the POC facility, coarse precleaning will be completed using a single- or two- stage heavy-media cyclone circuit.

Investigators still maintain that a properly designed hydrocyclone circuit will be sufficient in the final semi-works plant design to effectively produce a high ash refuse stream in the 1/4 inch x 48M size fraction, but this option will probably not be further addressed in testing.

The continuous bench-scale testing of the Illinois No. 6 seam resulted in overall performance projections of 91% pyrite rejection and 81% energy recovery. This again did not meet 85/85 performance goals, but it is anticipated that improved performance is possible since a portion of coal was lost in the heavy media cyclone, product recovery systems (drain and rinse screens and media recovery device). Logistics did not allow the recovery of coal in these systems, and the unrecoverable material was considered as a refuse stream in the flowsheet performance projections. For the same reason, the Upper Freeport seam projections of overall flowsheet performance may not be representative of that expected for the conceptual flowsheet. These projections were 78% pyrite rejection and 91% BTU recovery.

The raw coal characterizations have shown that the potential exists for each of the coals to achieve the 85/85 performance goals, and the performance projections, based on bench-scale unit operations testing, has shown that the performance criteria can be approached. Given the difficulties encountered in applying the bench-scale testing results to arrive at overall circuit projections, final determination cannot now be made whether the preliminary conceptual flowsheet can achieve the 85/85 performance goals. The results cited above are encouraging in light of the testing difficulties experienced.

POC testing results should allow an accurate assessment of the potential for meeting the 85/85 performance goals. Because the only process equipment requiring further hardware development is the advanced flotation cell and since a version of the proposed unit (VPI approach) has already been installed in a commercial application, investigators are confident that the process will be capable of 90% on-stream availability. This also can be demonstrated to a high level of certainty in the POC module operation.

Economics of specific alternatives of the preliminary conceptual design cannot be determined, to a high degree of accuracy, based on the laboratory and bench-scale testing results. Final economics will be dependent on the specific coal cleaning approach taken in the final conceptual flowsheet for each coal, and on the resulting yield of clean coal. Economics will of course significantly impact the degree to which this technology will be commercially implemented or considered by the coal industry. Previous DOE research has shown than physical coal cleaning can reduce sulfur levels in coal more effectively than competing sulfur reduction strategies. Physical coal cleaning approaches can also complement other sulfur reduction strategies by removing a bulk of the pyrites as well as other undesirable minerals prior to coal utilization.

Thus, in the end, the optimum economics of implementing advanced froth flotation technologies will balance pyritic sulfur rejection levels with the required costs to achieve these levels. The best economics may not require 85% pyrite rejection and 85% energy recovery. In order to estimate the relationship of cost to performance, the POC can be built with the flexibility to continuously test each alternative coal cleaning process of the preliminary flowsheet on each of the three coals. This is the suggested approach, and the Task 5 and 6 test results resolved design deficiencies to the extent that this approach can now be successfully implemented.

8.0 REVISED CONCEPTUAL DESIGN OF SEMI-WORKS PLANT

8.1 Overview and Scope

Following DOE authorization to proceed with this task, the preliminary conceptual design of a 20TPH semi-works plant (Task 2) was redesigned from all information available at this point in the project. This update of the conceptual design incorporated information derived about fine grinding, advanced froth flotation, and dewatering in Tasks 5 and 6. The summary report produced in

Task 7 describing bench-scale test results and component development was used as a basis.

This task complied with all of the design requirements discussed in Task 2. The process flowsheet was updated with complete energy and material balances for all process flowstreams. The equipment list was updated and supplied the base for a recalculation of the factored estimate of the capital, operating and maintenance costs. In addition, differences between the designs in Task 8 and Task 2 was highlighted and their effects on process and plant design credibility, efficiency, maintenance, operation, complexity, control, performance, and economics were discussed.

ICF Kaiser Engineers, with assistance from its sub-contractors and the Technical Support Group, were responsible for the completion of this task. This design will serve as a basis for the POC design in Task 9 and the final semi-works design in Task 15.

8.2 Review of Work Completed this Quarter

The Task 8 report was begun after the completion of Task 7. At this time only the basics have been started and no conclusions have been reached. This Task report will be completed during the next quarter.

9.0 POC MODULE DESIGN

9.1 Overview and Scope

In order to develop additional confidence in the conceptual design of the advanced froth flotation circuit, a 2-3 TPH Proof-of-Concept (POC) facility was necessary. During operation of this facility, the ICF KE team will demonstrate the ability of the conceptual flowsheets to meet the program goals of maximum pyritic sulfur reduction coupled with maximum energy recovery on three DOE specified coals. The POC circuit was designed to be integrated into the Ohio Coal Development's facility near Beverly, Ohio.

OCDO's facility will provide the precleaning unit operations and ICF KE will add the advanced froth flotation circuitry. The work in this task will include the POC conceptual design, flowsheet development, equipment list, fabrication and construction drawings, procurement specifications and bid packages and a facilities estimate at the completion of design. After DOE approval, the design was finalized for the next task.

9.2 Review of Work Completed This Quarter

The preliminary design of the flowsheet was started as well as sizing the equipment required for the POC. Work will continue into the next quarter.

10.0 TASKS 10 THROUGH 16

10.1 Review of Work Completed This Quarter

No work was scheduled for Tasks 10 through 16 this quarter.

END

DATE
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5/10/93