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QUARTERLY TECHNICAL PROGRESS REPORT NO. 13

OCTOBER - DECEMBER 1992

**ENGINEERING DESIGN AND ANALYSIS OF ADVANCED PHYSICAL
FINE COAL CLEANING TECHNOLOGIES**

for

**U.S. DEPARTMENT OF ENERGY
PITTSBURGH ENERGY TECHNOLOGY CENTER
PITTSBURGH, PA**

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MASTER

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TABLE OF CONTENTS

		Page
1.0	INTRODUCTION	1
2.0	ADMINISTRATIVE ITEMS	2
3.0	3.1.2 - Engineering Analysis of Conventional Coarse Coal Cleaning	3
	3.1 Planned Scope of Work	3
	3.1 Technical Status	3
	3.2.1 Corrections and Updates to Task 2 Models	3
	3.2.2 Additional Modeling Issues	4
	3.3.3 Coal Cleaning Simulator Changes	
4.0	4.1.3 - Engineering Analysis of Unit Operations for Processing Fine and Ultrafine Coals	
	4.1.4 - Engineering Analysis of Advanced Technologies for Physical Cleaning of Fine and Ultrafine Coals	
	4.1 Planned Scope of Work	3
	4.1 Technical Status	3
	4.2.1 Advanced Froth Flotation	3
	4.2.2 Advanced Cycloning	
	4.2.3 Selective Agglomeration	
	4.2.4 Additional Modeling Issues	
5.0	5.1.6 - Modeling/Experimental Work	3
	5.1 Planned Scope of Work	3
	5.1 Technical Status	3
	6.2.1 Froth Flotation Experimental Work	3
6.0	APPENDIX NO. 14 WORK PLAN	9
	Appendix Chart Plan for Remaining Project Work	14

1.0 INTRODUCTION

This project is sponsored by the United States Department of Energy (DOE) for the "Engineering Design and Analysis of Advanced Physical Fine Coal Cleaning Technologies:. The major goal is to provide the simulation tools for modeling both conventional and advanced coal cleaning technologies. This DOE project is part of a major research initiative by the Pittsburgh Energy Technology Center (PETC) aimed at advancing three advanced coal cleaning technologies- heavy-liquid cycloning, selective agglomeration, and advanced froth flotation through the proof-of-concept (POC) level.

The commercially available ASPEN PLUS process simulation package will be extended to handle coal cleaning applications. Algorithms for predicting the process performance, equipment size, and flowsheet economics of commercial coal cleaning devices and related ancillary equipment will be incorporated into the coal cleaning simulator.

This report is submitted to document the progress of Aspen Technology, Inc. (AspenTech), its contractor, ICF Kaiser Engineers, Inc., (ICF KE) and CQ Inc., a subcontractor to ICF KE, for the period of October through December 1992. ICF KE is providing coal preparation consulting and processing engineering services in this work and they are responsible for recommending the design of models to represent conventional coal cleaning equipment and costing of these models. CQ Inc. is a subcontractor to ICF KE on Tasks 1-5.

2.0 ADMINISTRATIVE ITEMS

Mr. Charles Zebula was appointed the ICF KE project manager for the subcontract with AspenTech. He is replacing Mr. Kenneth Harrison who is no longer with ICF KE.

ICF KE informed AspenTech of an increase in project expenditures due to DCAA rate adjustments. The budget increase was estimated at \$36,524, for a total contract value of \$792,797. A formal request is being submitted for approval.

DOE approval was obtained to extend the project ending date until June 30, 1993, at an extra cost.

A subcontract was approved by DOE for Pennsylvania State University to carry out studies on coal liberation modeling. This experimental program and math modeling research should give the capability to predict liberation of sulfur for different grinding topsizes.

A TIMELINE project management plan was made to schedule the remaining work of the project for the purpose of carefully planning the manpower and costs. A Gantt chart showing the plan, from January 4, 1993 to June 30, 1993 is attached at the end of this report.

3.0 TASK 1.2 - Engineering Analysis of Conventional Coarse Coal Cleaning

3.1 Planned Scope of Work

The work plan for the fifth quarter of the project called for the completion of Task 2.

3.2 Technical Status

The technical status of the various Task 2 items addressed during this quarter is discussed here.

3.2.1 Correction and Updates to Task 2 Models

During this quarter, the cost block algorithms for the sieve bends and classifying cyclones were changed to be compatible with the equipment sizing routines for each device.

3.2.2 Additional Modeling Issues

Rotary Breaker. The rotary breaker model currently in the DOE Coal Preparation Simulator developed by Austin, Luckie, and Klima of Penn State University still represents the most advanced modeling effort of this unit operation. As such, this model will be incorporated into the Coal Cleaning Simulator and should be available for use in the near future.

Froth Flotation. The scale-up procedure to be used in the conventional froth flotation model was documented in a paper to be presented at the 1993 SME annual meeting in Reno, NV in February. The same information will be incorporated into the model topical report.

Documentation of other models is continuing with revisions of the dewatering topical report.

3.3.3 Coal Cleaning Simulator Changes

Model Additions. New models were added to the Coal Cleaning Simulator. These are a wet ball mill, a flotation column, a selective agglomeration model, a high-G solid bowl centrifuge and a fine sizing screen. These models may now be used with the existing CCS models for simulating coal preparation plants.

Cost models were also added for the following ancillary equipment: conical pile, unit train and refuse loadout, silo storage, coal receiving, vibrating feeders, magnetic separators, and belt conveyor.

Code Changes. Three types of code changes were made in the simulator. The first change consisted of the addition of input checking capabilities to the unit operation blocks which require user inputs. This check ensures proper input specifications to the CCS models and provides informational warning and error messages when the operating limits are violated.

The second type of code change was the addition of a water balance check around the gravity separation models and the size classification models. This was added to ensure a proper material balance around these blocks which calculate the amount of water required.

The third type of code change was performed as a result of code review. The review revealed that minor programming changes were needed to prevent portability problems in the simulator.

Additional Items. Other items completed were the development of a new PC version of CCS with ModelManager and the creation of new user documentation to accompany the graphical interface.

4.0 TASK 1.3 - Engineering Analysis of Unit Operations for Processing Fine and Ultrafine Coals

TASK 1.4 - Engineering Analysis of Advanced Technologies for Physical Cleaning of Fine and Ultrafine Coals

4.1 Planned Scope of Work

Modeling efforts in the areas of advanced froth flotation, advanced cycloning and selective agglomeration were scheduled to move from the development stage into the programming and testing state during the quarter.

4.2 Technical Status

4.2.1 Advanced Froth Flotation

Testing of the column flotation model, which utilizes an algorithm developed at the Virginia Polytechnic Institute (VPI), was completed with successful results. This model is now resident in the ASPEN PLUS system. A description of the model algorithm was given in the last quarterly technical report.

4.2.3 Advanced Cycloning

A simplified advanced cycloning model was completed, coded in FORTRAN, and supplied to AspenTech during the work period. ICF KE met with project consultants Dr. Peter Luckie and Dr. Mark Klima of Penn State University to discuss the formulation of a model for this process in September of 1992. At the meeting, the testing results of the MicroMag process developed at DOE PETC were reviewed for their potential use in the formulation of a model. The test results, primarily the d_p and e_p values, gave no useful correlation as a function of either magnetite size consist or operating pressure. However, there was a correlation between d_p and e_p as a function of particle size at two operating gravities (1.30 and 1.50).

This information was used in multi-variable regression analysis to estimate the least squares fit to the data. The resulting equation was used in a framework similar to the conventional gravity separation processes to create a model useful for predicting the results of the MicroMag process. The user input to the MicroMag process is composite separating gravity, and this is constrained to values between 1.30 and 1.50.

4.2.3 Selective Agglomeration

A model for a selective agglomeration process has been developed by Praxis Engineers as part of Southern Company's DOE Engineering Development project. The information provided by Praxis Engineers to AspenTech has been incorporated into a performance model for selective agglomeration. This model will provide the best possible predicted separation based on the feed coal washability data. The Praxis model estimates that the overall Btu recovery can be approximated by the theoretical Btu recovery in the 1.5 s.g. float fraction, and pyritic sulfur rejection is approximated as 80 percent of the pyritic sulfur rejection possible at 1.8 s.g. sink. In the simulator, these attribute constraints are met through a search on d_p and e_p in a composite partition curve generated by the logistic equation. First, the d_p value is searched upon until the desired Btu recovery is met. The e_p value is manipulated until the desired pyritic sulfur rejection value is met. The calculations are then repeated until both desired values, Btu recovery and pyritic sulfur rejection, are met within the default tolerance values. The two variable search interacts, but is imbedded so that convergence is reliable.

Results from testing of this model are currently under review. Sizing and costing algorithms for the ancillary equipment in the selective agglomeration process are yet to be provided.

4.2.4 Additional Modeling Issues

Fine Sizing Screen. A model for high frequency vibrating screens was completed during the work period. The description of the algorithm for the process and equipment sizing calculations was given in the last quarterly report. The model is useful for sizing fine coal slurries in the range of 48M to 200M.

Wet Ball Mill. A wet ball milling algorithm developed at Penn State University by Austin, Klimpel, and Luckie has been incorporated into the ASPEN PLUS simulator for grinding coal to fine sizes. The model is based upon the characteristic selection and breakage value parameters for a given coal feed utilized in a population balance model. The steps of the algorithm utilized in the adaptation of this model for ASPEN PLUS are as follows:

- 1) Users are required to input four values into the model. The first two inputs are related and are used for the mill product specification: 1. the cumulative percent passing, 2. a given product size.

The other two inputs are used for the equipment sizing calculations: 1. Bond Work Index (kw-hr/ton) and 2. estimated length to diameter ratio (L/D) of the mill.

- 2) The mill model uses an iterative procedure for converging on the user desired product specifications. First, the mill feed is ground using an initial default residence time. The

cumulative percent passing of the mill product stream is calculated and an interpolation (spline) routine is used to determine the percent passing at the user input size at the initial residence time value. If the calculated percent passing is less than the user desired value, then the residence time in the mill is increased. If the calculated percent passing is more than the user desired value, then the residence time in the mill is decreased. An equation solver resident in ASPEN PLUS (ARCONS subroutine) is used for providing the new estimated of residence time until convergence is reached.

- 3) After convergence, the mill product vector is calculated and an attribute balance is created. The routine for creating the attribute balance will be updated once the liberation modeling is complete at Penn State University.
- 4) The mill power required for the grind is calculated utilizing the Bond Equation with the user supplied work index value. The appropriate correction factors for grinding outside of Bond conditions are applied to arrive at the corrected power requirements in kw-hr/ton. This value is multiplied by the mill feed rate resulting in the total power requirements for the mill.
- 5) The mill diameter is then calculated using a Bond equation for mill power draw. The length is determined by the user supplied L/D ratio.
- 6) If the required mill power is greater than 6,000 horsepower, then the feed to the feed to the mill is split equally, resulting in multiple parallel mill lines.

The water balance calculations for the mill are simply created by equalling the feed water content with the mill product water content.

High-G Centrifuge. A model of a high-G solid bowl centrifuge has been completed and tested. This model utilizes the same algorithm as the other resident centrifuge models, with modifications for dewatering time and G-force generated by the higher speed of the centrifuge. A plot comparing model results to available literature data from Alfa-Laval Sharples was shown in the October 1992 monthly report. Data also has been collected from Alfa-Laval Sharples for programming of the equipment sizing routine for this model.

Cost Models for Several Equipment Items. Information for programming cost models for high frequency vibrating screens, column flotation cells, and ball mills was completed during the work period. The information for costs of high frequency vibrating screens and column flotation cells (Microcel™) was provided by Derrick Screen Manufacturing and ICF Kaiser Engineers, respectively.

Ball mill cost data was pooled from information published by the Canadian Institute of Mining and Metallurgy in Mining and Mineral Processing Equipment Costs. In this relationship, the ball mill cost is related to the diameter of the mill and its associated length to diameter ratio. Ball charge and mill motor costs are subsequently added to the base equipment cost of the mill.

5.0 TASK 1.6 -Modeling and Experimental Work

5.1 Planned Scope of Work

In the froth flotation program, the work plan called for the characterization of feed sample, for flotation tests, and size and specific gravity analysis for Upper Freeport, Pittsburgh, and Illinois No. 6 seam coals. The necessary data reduction was also to be conducted.

Modeling efforts were to continue in the coal liberation work.

5.2 Technical Status

The technical status of the various Task 6 items addressed during this quarter is discussed here.

5.2.1 Froth Flotation Work

Test conditions for tests with complete size and specific gravity analysis for the Upper Freeport, Pittsburgh, and Illinois No. 6 seam minus 28 mesh and minus 100 mesh samples have been selected. All analyses for the Upper Freeport seam tests are complete. The flotation testing and float/sink analyses are complete for the Pittsburgh seam coal; ash and sulfur analyses are in progress. The flotation testing for the Illinois No. 6 seam coal 28 mesh by zero samples are complete. Other testing and analysis are in progress for Illinois No. 6.

Eight different rate equations have been evaluated for use in the final model. These equations are

- Classical first-order
- First-order with rectangular distribution of floatabilities
- Fully-mixed reactor (exponential distribution of floatabilities)
- Arbiter second-order equation
- Klimpel second-order equation
- First-order with sine wave
- Classical first-order with time lag (Agar)
- Natural law equation (Lai)

Each set of data is fitted to all the equations listed above. Comparisons between actual recovery and calculated ultimate recovery has been made for each equation and a calculation of "goodness-of-fit", the standard error of estimate, has been made for each equation. The most recent data reduction revealed that the classical first-order provides the best fit and will probably be chosen for use in the model.

5.2.2 Coal Liberation Modeling

Algorithm Development. The simplified algorithms for predicting the fraction of product of size i and composition j (p_{ij}) and the attribute distribution in the product (β_{ij}) have been programmed. They are

$$p_{ij} = d_{ij} f_{ij} + \sum_{k=1, i>2}^{i-1} d_{ik} f_k \sum_l m_{j;i,k,l} f_{l;k}$$

where $m_{j;i,k,l}$ is the portion of the feed material of size k with composition l ($f_{l;k}$) that breaks to size i with composition j , and

$$\beta_{ij} = d_{ij} \phi_{ij}^0 f_{ij} + \sum_{k=1, i>2}^{i-1} d_{ik} f_k \sum_l \alpha_{j;i,k,l} f_{l;k}$$

where ϕ_{ij}^0 is the mean fraction of the attribute in the feed material of size i and composition j and $\alpha_{j;i,k,l}$ is the amount of attribute that breaks from feed material of size k and composition l into size i and composition j . The mean fraction of the attribute in the product material of size i and composition j (ϕ_{ij}) is calculated as $\phi_{ij} = \beta_{ij} / p_{ij}$.

$m_{j;i,k,l}$ is calculated as $M(c_j; i, k, l) - M(c_{j-1}; i, k, l)$ and $\alpha_{j;i,k,l}$ is calculated as

$$\int_{c_{j-1}}^{c_j} c dM(c; i, k, l)$$

The plot of $M(c_j; i, k, l)$ vs. c is the Elementary Attribute Curve. The Elementary Ash Curve based on washability data for the 100 mesh by 200 mesh size fraction of an Illinois No. 6 coal taken from the EPRI Coal Quality Information Book (EPRI CS-5421) was fitted with the function

$$c = \frac{1}{1 + e^{\alpha(1 - (M/\mu)^3)}}$$

since the data exhibited a liberation pattern in the presence of some finely dispersed ash. This gives

$$M = \mu (1 - \ln[\frac{1-c}{c}]/\alpha)^{1/3} \quad , 0 < c < 1$$

which is the function currently used in the program.

Experimental Development. The laboratory test work is producing $M(c; i, k, l)$ data by passing test samples through a roll crusher at various gap settings and then fractionating the products on the basis of size and relative density. The 6 x 8 mesh sample has been completed. Four composition classes (1.3F, 1.36 x 1.45, 1.6 x 1.8, 2.45) have been crushed at various gap settings and the products sink-floated and sized. The comminution parameters - breakage function and selection function - have been determined and forward simulations conducted. The washability data is being assembled to plot the Elementary Ash Curves. Testing has begun on the 1/4" x 4 mesh sample. The 1.3F composition class has been crushed and the product sink-floated and sized.

6.0 QUARTER NO. 14 - WORK PLAN

- Complete Task 2, including model documentation, validation, and testing.
- Complete sizing and cost models for Tasks 3 and 4 models.
- Complete documentation for Tasks 3 and 4 models.

In the Task 6 Froth Flotation Work

- Complete Pittsburgh seam test analysis. Complete Illinois No. 6 seam testing.
- Continue data reduction--fitting results to selected rate equations for determination of the rate constant and ultimate recovery and conducting a discrimination analysis to determine the best rate equation to be used in the final model.

In the Liberation modeling work

- Complete the crushing of test samples
- Examine other functions for the Elementary Ash Curve based on the Mayer Curve.
- Demonstrate the breakage-liberation algorithm.

Schedule Name : PETC92
 Responsible : P.W. GALLIER
 As-of Date : 4-Jan-93

Schedule File : PETCEND

Progress shows Spaces on Baseline
 Detail Task (Progress) Summary Task (Progress)
 Conflict Resource delay Milestone

END

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