DOE/PC/89908--T25

DE93 006434

QUARTERLY TECHNICAL PROGRESS REPORT NO. 12

JULY - SEPTEMBER 1992

ENGINEERING DESIGN AND ANALYSIS OF ADVANCED PHYSICAL FINE COAL CLEANING TECHNOLOGIES

for

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

CONTRACT NO. DE-AC22-89PC89908

SUBMITTED BY

P.W. GALLIER
PROJECT MANAGER

ASPEN TECHNOLOGY, INC.
251 VASSAR STREET
CAMBRIDGE, MA 02139

OCTOBER 20, 1992

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

TABLE OF CONTENTS

		Page
1.0	INTRODUCTION	1
2.0	ADMINISTRATIVE ITEMS	2
3.0	TASK 1.2 - Engineering Analysis of Conventional Coarse Coal Cleaning	3
	3.1 Planned Scope of Work	3
	3.2 Technical Status	3
	3.2.1 Updates, and Testing of Task 2 Models	3
	3.2.2 Additional Task 2 Model Discussions	6
	3.2.3 Coal Cleaning Simulator Changes	6
4.0	TASK 1.3 - Engineering Analysis of Unit Operations for Processing Fine and Ultrafine Coals	7
	TASK 1.4 - Engineering Analysis of Advanced Technologies for Physical Cleaning of Fine and Ultrafine Coals	7
	4.1 Planned Scope of Work	7
	4.2 Technical Status	7
	4.2.1 Advanced Froth Flotation	7
	4.2.2 Advanced Cycloning	8
	4.2.3 Selective Agglomeration	8
	4.2.4 Additional Models	9
5.0	TASK 1.6 -Laboratory Testing	11
	5.1 Planned Scope of Work	11
	5.2 Technical Status	11
	5.2.1 Froth Flotation	11
	5.2.2 Other Advanced Processes	12
6.0	QUARTER NO. 12 WORK PLAN	13

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- advanced cylconing, 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., for the period of July through September 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 and is a contractor to AspenTech on Task 6.

2.0 ADMINISTRATIVE ITEMS

As the project end is approaching the need for good planning and communication has increased. An internal project meeting was held at ICF KE on July 1 and 2, in order to plan the completion of all subtasks. To ensure continued progress toward the completion of these subtasks, weekly telephone conference calls were established.

A paper describing the project status was given at the Eighth Annual Coal Preparation, Utilization, and Environmental Control Contractors' Conference, held July 27-30 in Pittsburgh.

Arrangements were made to obtain validation data for the Coal Cleaning Simulator models from American Electric Power (AEP).

The PETC authorization for subcontracting liberation studies to the Pennsylvania State University (PSU) was received. PSU has initiated procedures to obtain coals for testing. Progress in this work will be reported under Task 6 in the upcoming reports.

3.0 TASK 1.2 - ENGINEERING ANALYSIS OF CONVENTIONAL COARSE COAL CLEANING

3.1 Planned Scope of Work

The work plan for the period called for the completion of all Task 2 items including model documentation, testing, and validation.

3.2 Technical Status

The technical status of all Task 2 items is discussed in the following sections.

3.2.1 Updates, and Testing of Task 2 Models

Horizontal and Inclined Screens

In the last work period, an algorithm utilizing a partition curve (with inefficiency defined by the sharpness index, SI, and a screen bypass) was described for use in the deslime screen algorithm. This algorithm was to be used as an alternative to one where the partition curve is represented as a step function where the inefficiency is described by the screen bypass (representing 100 minus the efficiency value for all sizes less than the separation size). The latter resulted in a stair-step function when a sensitivity analysis of the screen separation size versus screen overflow rate was examined. The new addition allowed for further use of the sensitivity analysis capabilities of the ASPEN PLUS system.

Unfortunately, the use of both algorithms described above was not compatible with the algorithm utilized for the calculation of the moisture content of screen oversize because the new algorithm placed only a small portion of the extreme fines (400M X 0) with the screen oversize stream while the latter placed a higher amount. At a meeting held on July 1, 1992 in the offices of ICF KE in Pittsburgh, it was decided that the algorithm resulting in a step-function for the partition curve was too simplistic and placed too much extreme fine material with the coarse product and should be replaced with an algorithm which puts more near size material with the screen oversize product.

The first attempt at fulfilling this requirement was to manipulate the sharpness index (defined as d_{25}/d_{75}) to achieve the user-desired screen efficiency value. This was modelled in the following way:

1) The model user supplied a screen separation size (d_{50}) along with a desired screen efficiency. Screen efficiency would be defined as 100 minus the amount of undersize particles in the oversize stream.

2) A starting sharpness index (SI=0.7) was defined in the model. Size selectivity fractional recovery coefficients were calculated using the logistic equation.

3) The separation calculations were completed and the efficiency for the separation was calculated by summing the amount of undersize present in the oversize stream over all size intervals.

4) If the calculated efficiency was not within the tolerance of the user-defined efficiency, an equation solver (ARCON subroutine in ASPEN PLUS) was used to find the SI which resulted in the user-desired efficiency value by repeating steps 2 through 4.

5) When the calculated efficiency met the user-supplied efficiency value within a set tolerance value, the yields and qualities of the oversize and undersize streams were calculated.

This approach worked well as a predictive method for converging on a user-supplied efficiency value but also placed a large amount of fine material in the screen oversize stream for low sharpness index values, making the approach once again incompatible with the moisture content algorithm. The reason for this happening is that the lowering of the sharpness index to achieve lower efficiency does not place more near size material in the oversize stream, but places more fine size particles in the oversize stream. Our objectives was to come up with a method to place more near-size material in the oversize stream to meet the user-desired efficiency.

One of the project consultants (Dr. Richard Hogg of Penn State University) was contacted to question the possibility of modifying the moisture content algorithm to be more compatible with the screen classification algorithm. It was decided to take yet a different approach for the classification algorithm. This approach resulted in success.

The new algorithm requires the user to specify the screen size and the desired efficiency as before, except that instead of changing the sharpness index (SI) to get different efficiency values, the d_{50} value would be searched upon to arrive at the appropriate value. The net result is the ability of this algorithm to place more near-size material in the screen oversize stream rather than more fine size material. The steps in the algorithm are essentially the same as discussed above. The moisture content calculation for all types of size ranges now is consistently accurate. The models converge quickly and are robust in use.

The users of these models must enter the size of the <u>screen opening</u> as an input (not the d_{50} value as before). Additionally, some of the models require additional and optional inputs as follows:

	Screen Opening	Efficiency
Deslime Screen	0.3mm	80% - 95% (user input)
Dewatering Screen	0.3mm	95% (default)
Drain and Rinse Screen	0.3mm	95% (default)
Wet Inclined Screen	0.3mm	1) Valliant Algorithm 2) 80 - 95% (user input)
Dry Inclined Screen	9.5mm	1) Valliant Algorithm 2) 80 - 95% (user input)

Centrifuge Models

As the screen models have been revised, investigators have tested and set screen model dewatering algorithm parameters to allow a good comparison between model results and screen performance. Revision of the screen models to better predict moisture content has allowed the centrifuge and disk-filter models to be finalized. The moisture results from each of the centrifuges: vibrating basket, standard basket, screen bowl, and solid bowl, and from the disk filter models all compare well with manufacturer and literature data. Some model and literature values of moisture are compared below for two of the centrifuge (vibrating and standard basket) models:

Vibrating Basket Centrifuge:

	Percent Moisture	
Size Fraction	Literature	Model
2 in. X 1/4 in.	2.0	2.14
1/2 in. X 1/4 in.	3.0	2.96
1/2 in. X 28M	5.5	6.39
1/4 in. X 28M	7.5	9.81

Standard Basket Centrifuge:

	Percent Moisture	
Size Fraction	Literature	Model
1/2 in. X 28M	4.0	4.65
1/4 in. X 28M	6.0	6.14

Gravity-based Devices

As part of additional testing for the gravity-based device models (heavy-media cyclone, concentrating table, and water-only cyclone), data from three coal cleanability characterization test programs conducted at the Coal Quality Development Center were used to compare actual probable error and specific gravity separation by size with predicted results. These three test programs used these three devices in various combinations, yielding fourteen different flowsheets to test. Results from this analysis are somewhat mixed. In several cases, model results compare very closely with actual operating results. In other cases, however, the comparisons are poor. The discrepancies between the two are being studied.

3.2.2 Additional Task 2 Model Discussions

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 an ASPEN PLUS system model and should be available for use in the near future.

3.2.3 Coal Cleaning Simulator Changes

More user input checking was added to all the models currently available in the simulator. The input checking was added to prevent incorrect model specifications, to assist the user in diagnosing problems in model performance, and to provide information on the progression of a given simulation.

A systematic review of the CCS source code (approx. 350 subroutines) was carried out. The goals of this review was to ensure that ASPEN PLUS coding standards are met and to find and correct any programming practices which may result in platform portability problems in the future.

Other changes made to the simulator included the addition of ancillary equipment cost models: silo, coal receiving, unit train and refuse loadout, vibrating feeder, magnetic separator. Testing and fine-tuning of these models will continue in October.

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

Modelling efforts in the areas of advanced froth flotation, advanced cycloning and selective agglomeration were scheduled to move into the development stage during the work quarter.

4.2 Technical Status

The technical status of Task 3 and Task 4 models is given below.

4.2.1 Advanced Froth Flotation

The Virginia Polytechnic Institute & State University (VPI) column flotation model will be used as the advanced flotation model in ASPEN PLUS. During a meeting with VPI investigators, default values for several parameters were selected that should allow an optimum configuration for the column flotation cell. The model has been coded in FORTRAN as a stand-alone program outside the ASPFN PLUS framework and some initial tests show that the model gives reasonable results for predicting column performance and size. Wash water, aeration rate, and recirculation pump requirements are calculated as part of the simulation.

The user inputs the required BTU recovery for the column flotation circuit. If desired, users of the model can overwrite the default value of bubble size (0.06 cm). The model tracks all size and gravity fractions in the feed and products, requiring the estimation of the probability of adhesion (P_a) parameter of each specific gravity fraction. Based on findings by VPI in their work defining hydrophobicity as a function of composition and some of the findings by Penn State as part of the Task 6 froth flotation work, the gravity distribution has been divided into three sections representing fast-floating (given a P_a of 0.9), slow-floating (given a P_a of 0.2), and a non-floating component (given a P_a of 0). Coal that floats at a 1.30 specific gravity is defined as slow-floating; coal that sinks at 1.3 but floats at 1.9 specific gravity is defined as slow-floating; and coal that sinks at 1.9 is defined as non-floating. Fundamental research is being conducted at laboratories around the world to better define these relationships, however, conclusions from this research may not be available for years. The estimates given represent good engineering judgement based on our current knowledge. To increase or decrease the overall calculated BTU recover using these estimates of P_a to meet that required by the user input, the fractional recovery of each size and gravity fraction is proportionally increased or decreased through a convergence algorithm.

The probability of collision and probability of detachment are calculated using the approximation developed by Luttrell and Yoon of VPI. These values, along with estimates of the residence time of the particles, are used in the Levenspiel equation to calculate the recovery of each component.

With the recovery of each component then known, the quantity and quality (ash, sulfur, and BTU content) of the products are calculated. Knowing the size and specific gravity of the froth product, the carrying capacity of the cell is estimated using the relationship developed by Espinoza-Gomez et al. The carrying capacity is then used to calculate the number and diameter of columns to process the desired flow rate of coal. The equipment size parameter, column diameter, is related to purchased cost by a relationship for the Microcel™ (VPI column flotation technology licensed to ICF Kaiser Engineers).

4.2.2 Advanced Cycloning

ICF KE met with Professors Peter Luckie and Mark Klima of Penn State University on September 21, 1992 concerning the development of a mathematical model to represent the Micro-Mag process developed at DOE PETC. All aspects of the experimental program conducted at DOE PETC were discussed; including the relationships between process performance and cyclone operating pressure drop, magnetite size consist and coal feed size consist. It became apparent that the data did not support all of these parameters and their confounding affects. With the concurrence of all present at the meeting, a decision was made to develop a model similar to those developed for gravity separation processes in Task 2. The information required for the development of such model is the relationship of relative density of separation (d_p) and probable error (e_p) with particle size. Professor Klima is assembling this information for ICF KE due to his first hand knowledge in the development of the process for DOE PETC.

4.2.3 Selective Agglomeration

ICF KE and CQ Inc. received a copy of the algorithm used by Praxis Engineers for predicting the results of a selective agglomeration precess utilizing coal washability data. Praxis describes an algorithm where the results of the selective agglomeration process can be predicted based on the theoretical recovery of the BTU content of coal at 1.50 specific gravity and eighty percent of the pyritic sulfur values rejected at 1.80 specific gravity. Although the AspenTech project team hopes to develop a more complicated model in the future, we plan to incorporate this type of algorithm into the first versi' , of the Coal Cleaning Simulator for the selective agglomeration process.

4.2.4 Additional Models

Fine Sizing Screen

The algorithm used for fine sizing screens (high-frequency vibrating type) was developed by Rogers and Brame of Kennedy Van Saun Corporation. The model is based on the following relationships:

1) The separation size (d_{50} value) is calculated based on a relationship between the screen aperture size and the feed volume percent solids.

2) The sharpness index is a function of the relative relationship between d_{50} and the screen aperture.

3) The screen bypass (the a value or water split) is a function of the volume percent solids.

The information defined above is used to calculate a set of size selectivity values, c_i, in a two-parameter equation suggested by the authors for use with high-frequency vibrating screens.

The model has been found to be generally useful for predicting the size classification of fine coal slurries in the 28M to 200M range. However, the model is not accurate for predicting the water split at low solids concentrations (less than 12 percent by volume). This equation must be corrected prior to inclusion in the simulator. Two possible approaches are being considered to calculate the water split between the oversize and undersize streams.

The equipment sizing of high-frequency vibrating screens is basically a function of the gallons per minute of feed slurry per inch of screen width. Conversations held with a screen manufacturer indicate the following capacities:

Screen Aperture	Capacity
300 microns	5.0 gpm/in
150 microns	2.3 gpm/in
75 microns	0.6 gpm/in

This information will be regressed into an equation relating capacity to screen aperture for use in the simulator. Fine sizing screens are available in sizes of 4' wide by 8' long and 5' wide by 8' long. These screens are not recommended for separations less than 150 microns.

Wet Ball Mill

A wet ball milling algorithm developed at Penn state University by Austin, Klimpel, and Luckie will be 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 into a population balance algorithm. Users of the model will be required to input the desired product characteristics, that is, the required percent passing some desired particle size. The current version of the model does not include the description of the liberation process. This will be implemented once the liberation study is completed in Task 6 at Penn state University. Further discussion of this model will be given once it is incorporated into the system.

5.0 TASK 1.6 - Laboratory Testing

5.1 Planned Scope of Work

Feed sample characterizations, flotation tests, and size and specific gravity analysis were to be performed for Upper Freeport and Pittsburgh seam coals. The necessary data reduction for these seams were also to be performed. Preliminary tests of the Illinois No. 6 seam coal were to begin.

5.2 Technical Status

5.2.1 Froth Flotation

Test conditions for both the Upper Freeport and Pittsburgh seam minus 28 mesh and minus 100 mesh samples have been selected. These conditions are

Upper Freeport Seam Minus 28 Mesh:

Test 1	0.16 lb/T MIBC	
Test 2	0.65 lb/T MIBC	
Test 3	0.65 lb/T MIBC	0.65 lb/T Dodecane

Upper Freeport Seam Minus 100 Mesh:

Test 1	0.16 lb/T MIBC	
Test 2	0.65 lb/T MIBC	
Test 3	0.65 lb/T MIBC	0.65 lb/T Dodecane

Pittsburgh Seam Minus 28 Mesh:

Test 1	0.16 lb/T MIBC	
Test 2	0.65 lb/T MIBC	
Test 3	0.65 lb/T MIBC	0.33 lb/T Dodecane

Pittsburgh Seam Minus 100 Mesh:

Test 1	0.16 lb/T MIBC	
Test 2	0.65 lb/T MIBC	
Test 3	0.65 lb/T MIBC	0.65 lb/T Dodecane

Each of these tests has been replicated to produce enough material for the subsequent size and specific gravity analysis. Many of the size and specific gravity analyses for the flotation time interval samples from each of these tests have been completed, while others are still in progress. Generally, the results show that the lightest gravity fraction (1.3 float) floats more rapidly than the intermediate fractions (1.3 x 1.5, 1.5 x 1.7, 1.7 x 1.9) that float at about the same rate. The 1.9 sink fraction floats at the slowest rate. Recovery values generally follow the same trend, though essentially 100 percent recovery at eight minutes flotation time is achieved for many of the intermediate gravity fractions, except in the coarsest sizes. This behavior follows the fast-floating, slow-floating, non-floating trends observed by some investigators using M-curves generated by release analysis tests.

A sample of Illinois No. 6 seam coal from Randolph Co., Illinois, has been received and split into samples for storage under argon prior to flotation testing. Head sample characterization and preliminary froth flotation tests have begun.

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

- Classical first-order
- First-order with rectangular distribution of flotabilities
- fully-mixed reactor (exponential distribution of flotabilities)
- 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 fit to all these equations. 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. Based on the most recent data reduction, the equation to be chosen for use in the model will be either the classical first-order or the first-order with rectangular distribution of flotabilities. An analysis of the confidence intervals around the optimum values of the parameters for these two equations will be conducted in October. This analysis will form the basis of documentation for the final model selection.

6.0 QUARTER NO. 11 - WORK PLAN

- In Task 2, complete all models, complete model documentation, complete testing and validation.
- In Tasks 3 and 4 complete models and model documentation.
- In Task 6 complete Upper Freeport seam, Pittsburgh seam, and Illinois No. 6 seam testing.
- Conduct data reduction on Task 6 flotation test results for final model rate equation selection.
- Conduct laboratory studies, data analysis, and correlation on breakage and liberation at PSU for Task 6.

END

DATE FILMED

3 / 16 / 93