ABSTRACT

This research will guide both current researchers and potential users of the ISGS Aggregate Flotation (AF) Fine Coal Cleaning Process. Our overall goal is to hasten the commercial development of AF by using scale up methodologies to explore limits of operation. The specific objectives of this work are to: 1) significantly extend the AFCFU data base in terms of quality and quantity, 2) incorporate data and algorithms from historical record and ongoing characterization and cleaning studies to provide necessary model input parameters and improvements and 3) develop exercise and extend a computer code that can be used to estimate AFCFU performance and optima. Three tasks coordinated with Mineral Engineering at ISGS are executed by Northwestern University Coal Research Lab (NUCRL) personnel to meet the objectives and include: TASK I: planning and data acquisition, TASK II: system model calibration and TASK III: system and subsystem model testing, evaluation and extension.

Accomplishments and conclusions are noted:
1) PCFU Pilot Continuous Flow Unit tests were conducted in four sequences from June through Nov. 1988, testing two coals and various operating conditions principally flow rate, grind size, reagent doses and aeration including staging of these for optimum effect.
2) Residence Time Distributions for both pulp and froth were obtained for one series of PCFU tests. A mathematical model was developed to interpret results. These show close adherence to completely mixed cells for most, but not all conditions.
3) We continued to assist ISGS researchers on interpretation of batch flotation tests to determine chemical interaction effects.
4) Two flotation simulator models FLOTI (1987 version) for +200 M and FLOT2 for -200 M were further developed. A PASCAL code for FLOTE has been prepared for fast microcomputer use. A Nicol - Firth cell was prepared to and calibrate portions of FLOT2 independent of PCFU tests.
4) The CFU was successfully operational by mid July and four operating conditions examined. The analytical work (grade and recovery by size fraction is still underway at NUCRL.
5) An extension of the project through July or Aug. 1989 was requested to complete all tasks outlined, particularly added calibration and prospective testing.
EXECUTIVE SUMMARY

INTRODUCTION AND BACKGROUND

We proposed three tasks to advance the ISGS AF process for enhanced separation of pyrite and ash from Illinois coals. The specific objectives of this work are to: 1) significantly extend the AFCFU data base in terms of quality and quantity, 2) incorporate data and algorithms from historical record and ongoing characterization and cleaning studies to provide necessary model input parameters and improvements and 3) develop exercise and extend a computer code that can be used to estimate AFCFU performance and optimai. Three tasks accomplish these goals.

TASK I: planning and data acquisition
TASK II: system model calibration
TASK III: system and subsystem model testing, evaluation and extension.

An extended background and introduction is included in the February quarterly technical report. A brief recap is included herein as part of the discussion of accomplishments and conclusions.

PROCEDURES

The project plan is formulated on Table 1. Two series of CFU tests are done under task I to extract measured coal (BTU) recovery and grade (particularly pyritic sulfur and ash) by size class under independent variation of liquid and solids flow rates, feed consist (size) and variables affecting selectivity. Data are then used for model calibration and extension in tasks II and III. Temporal order of elements is indicated by ">" meaning that this activity follows the noted step.

Since model development and use is a major part of this project, it is given most emphasis and includes elements of calibration and testing. Models are improved in an iterative process. Modeling steps include selection of model form, model parameter estimation, parameter sensitivity analysis and prospective testing. Model type and form are both addressed in selecting improvements and sensitivity of model improvements are screened following normal regression procedures. Extension of the model(s) follow and utilize the procedures already outlined, i.e. the metasystem AF process models, FLOT1 and FLOT2 are employed at a system level with, e.g. the DOE CPPS (Coal Preparation Plant Simulator) to estimate reciprocal interactions and performance in conjunction with other upstream coal preparation plant unit operations.

RESULTS AND DISCUSSION

Principal accomplishments in the project are noted in four areas:

1) PCFU Pilot Continuous Flow Unit tests were conducted in four sequences from June through Nov. 1988, testing two coals and various operating conditions principally flow rate, grind size, reagent doses and aeration including staging of these for optimum effect. Shakedown test of the PCFU was done with ISGS workers in June using a Homer City EPRI coal. Results were given in the annual report by Read et. al. (1988). The series of tracer tests and performance and calibration tests using Illinois coal bank No. 6 samples done in July with example conditions illustrated for two runs on Table 2. Three periods of testing are still required and outlined in a more detailed timetable on Table 3.

The July tests consisted in two tasks: 1) residence time distributions were obtained for each of the flotation cells for each performance condition using methods adapted to our PCFU and 2) Performance data (concentrate and tail composite samples obtained and analyzed by ASTM methods to determine recovery and grade by size classes to -400 mesh) are collected under independent variation of several chemical and physical independent variables.

Approximately one half of the PCFU data (from the eight run conditions) on size grade and recovery were obtained by the end of this project period. Some material balances are still incomplete on these. This laboratory work will continue at a low level after grant termination in order that progress can continue during the extension of this study. Approximately 50 samples must be obtained by sieving analysis to below 10 microns and then each samples is analyzed for BTU, moisture, ash and pyrite.
2) Residence Time Distributions for both pulp and froth were obtained for a series of four PCFU tests employing the F - Tracer test method. A mathematical model was developed to interpret results. These show close adherence to completely mixed cells for most, but not all conditions. Some operational problems on sampling of pulp and froth required use of compressed air and preservation of small sample volumes until analysis could be done precluded some samples from being analyzed accurately. Some dead volume or short-circuiting exists in each of the PCFU cells, though the major volume can be considered perfectly mixed. Future RTD F tests are planned using only two cells in series and new vials with better sealing will be used to prevent evaporation of samples.

Froth modeling considered extensions from the recent work of Ross and Deventer (1988) and includes a material balance on portions of the cell as well as models to describe the mixing characteristics of the CFU. The major transport processes in the cell include: (a) transfer of hydrophobic particles from the pulp to the froth, (b) transfer of material from the froth over the cell lip, (c) drop-back of material from the froth phase to the slurry and (d) recovery of fine particles in the concentrate by hydraulic entrainment. Hydraulic entrainment is expected to be an important contributory mechanism to the recovery of fine particles which, when coupled with a low rate of genuine flotation, can account for much of the observed behavior of such fine particles. Parallel experiments were planned to examine the effect of the hydraulic entrainment.

3) We assisted ISGS researchers on interpretation of batch flotation tests to determine chemical interaction effects. Furthermore, in order to get the basic information on froth depth, reagent emulsification, etc. a Nicol - Firth modified Denver cell was constructed but not tested. A new rod mill was setup and tested to match any batch conditions of grind size with that of ISGS workers.

4) We have improved understanding and possible improved control of ISGSAF and extensions beyond subaeration cells. Two flotation simulator models FLOT1 (1987 version) for +200 M and FLOT2 for -200 M were further developed. A PASCAL code for FLOTE has been prepared for fast microcomputer use. The Nicol - Firth cell can now be used to calibrate portions of FLOT2 independent of PCFU tests. FLOTE and FLOT1 have been extended to utilize characterization, e.g. mineral association, data to describe response in fine but not yet ultrafine sizes. These two models are presently coal and reagent specific in that they are calibrated for a given coal with a specific liberation and reagent dose regime. This can be extended now to another grind with supporting petrography. Parameter estimation as part of the model calibration has been carried out for one set of PCFU runs from this year. In the extension of this grant we intend to exercise the models (Task III) to determine parameter and control action sensitivity. First, we need to obtain several sets of parameters for the two coals tested this year. Principal efforts during continuation would be directed to fine (200m x 0) and ultrafine (400m x 0) coals.

The metasystem AF process models, FLOT1 and FLOT2 are employed at a system level with, e.g. the DOE CPPS (Coal Preparation Plant Simulator) to estimate reciprocal interactions and performance in conjunction with other upstream coal preparation plant unit operations. In a continuation, we hope to define fluid flow, mixing and cell loading conditions to maximize recovery subject to grade constraints.

We have delayed continuing our initial work on modeling selective froth drainage of coal and gangue species until we are able to interpret the recent PCFU run data sets. A steady state mass balance has been outlined to describe limiting ranges of froth residence times. When completed, this will be compared to the results of recent tracer tests. A second effort has identified some data where ultrafine particle recovery in both pulp and froth phase is determined. This, along with early fall 1988 tests will provide data on a very wide range of sizes from conventional to ultrafine flotation necessary for rapid model calibration at least for intermediate (-100 mesh) size coal.

Modeling of pulp processes had two principal foci during this project: 1) description of particle bubble collision and attachment phenomena and 2) froth process description including residence time. A very thorough literature review of pulp process modeling was presented and guidelines for further research discussed including "physical" and "chemical" factors.
Table 1. 1988 - 89 FULL PLAN FOR ISGS SCALE-UP
(milestone date in parentheses)

I. Planning and Data Acquisition
   A. Plan Phase I and II tests - Pilot CFU
      determine variable ranges, etc. (2/88)
      determine required ancillary tests and measures (2/88)
      perform preliminary tests and measures on CFU (2/88)
   B. Perform PCFU runs - phase I (6-8/88)
      obtain overall run data from ISGS researchers (7/88)
      analyze select physical samples of feeds, concentrates, etc. (8/88)
      analyze instrument data logs for variability (7/88)
      balance raw data for feeds, concentrates and tails (8/88)
   C. Plan phase II tests (>IIA) (8/88)
      select conditions for phase II tests
      to extend predictions
      to improve model utility
      repeat IA as necessary
   D. Perform PCFU runs - phase II (>IC) (8-12/88)
      analyze select physical samples of feeds, concentrates, etc.
      analyze instrument data logs for variability
      balance raw data for feeds, concentrates and tails

II. Model Calibration
   A. Generation of input and model parameters (11/88-1/89)
      select two to three model forms for AF (2/88)
      estimate parameters for each model (1-2/89)
   B. Retrospective tests (1-3/89)
      test each model retrospectively with calibration data sets
      improve parameter selection or subprocess description
      repeat process as needed

III. Model testing, evaluation and extension
   A. Model evaluation - I (>IIA) (2-4/89)
      perform prospective tests with independent data sets
      perform sensitivity analyses
      select best model form and parameter values
   B. Model evaluation - II (>ID) (4-5/89)
      compare measured and predicted yield and grade for CFU
      draw conclusions regarding robustness, etc. of model(s)
      and scale effects - (batch>>>PCFU, scale I > scale II)
      suggest necessary further tests at scales I - II as appropriate
   C. Extension - For Illinois Coal Preparation Operation (5-7/89)
      utilize merged CPPS/ FLOT1 (5-6/89)
      estimate parameters as needed
      run ISGS - AFCFU for conditions measured
      suggest necessary further follow up research and
      scale up tests at scale I - II (7/89)
   D. Documentation of model(s) and code(s) for users (7/89)
Table 2. Example of Measured PCFU Run Characteristics

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<tr>
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<tr>
<td>DATE</td>
<td>2</td>
<td>4</td>
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<tr>
<td>RUN NUMBER</td>
<td>IBCSP # 6</td>
<td>IBCSP # 6</td>
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<tr>
<td>FEED SIZE (90% PASSING MESH SIZE)</td>
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<td>270</td>
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<td>ESTD. FEED PULP DENSITY (% SOLIDS)</td>
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<td>3.8 - 4.2</td>
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<td>SLURRY FLOW RATE (LITERS/MIN.)</td>
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<td>.25, .25, .25, .25</td>
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<td>AERATION RATE (VOL. AIR/VOL PULP)</td>
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<td>CELL NO. PT. OF CHEMICAL ADDITION</td>
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<td>COLLECTOR DOSE (ML/MIN)</td>
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<td>VOLUME COLLECTED FOR MATBAL(GAL)</td>
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<td>WASH WATER FLOW (ML/MIN)</td>
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<td>COMMENTS</td>
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Table 3. PCFU INDEPENDENT VARIABLES AND RANGES for first series

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<th>VALUE</th>
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<tr>
<td>COAL TYPE</td>
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<td>ICSBP No. 6</td>
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<tr>
<td>GRIND</td>
<td>(90% passing MESH)</td>
<td>270, 100</td>
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<td>FLOW RATE</td>
<td>(L/MIN)</td>
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<td>AERATION</td>
<td>(VOL/VOL)</td>
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<tr>
<td>TOTAL REAGENT</td>
<td>(LB/TON)</td>
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<tr>
<td>STAGED ADDITION</td>
<td>(CELLS)</td>
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<td>ROUGHER CELLS ONLY</td>
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<td>AGITATION</td>
<td>(RPM)</td>
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<td>PULP DENSITY</td>
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