QUARTERLY TECHNICAL PROGRESS REPORT 14
JANUARY - MARCH, 1996

ENGINEERING DEVELOPMENT OF ADVANCED PHYSICAL FINE COAL CLEANING FOR PREMIUM FUEL APPLICATIONS

Prepared for
U. S. Department of Energy
Pittsburgh Energy Technology Center
Pittsburgh, Pennsylvania 15236

By
Nick Moro, Gene L. Shields, Frank J. Smit, Mahesh C. Jha
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Golden, Colorado 80403-7499

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Amax R&D Project No. 91455

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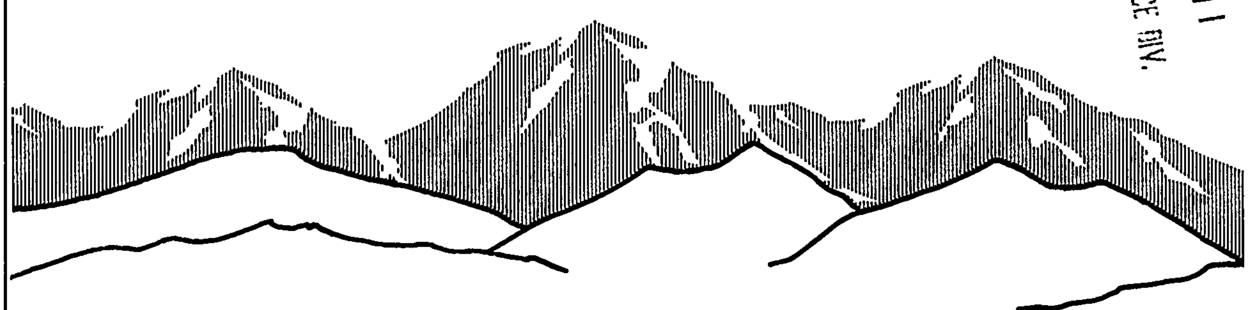

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ABSTRACT

The primary goal of this project is the engineering development of two advanced physical fine coal cleaning processes, column flotation and selective agglomeration, for premium fuel applications. The project scope includes laboratory research and bench-scale testing on six coals to optimize these processes, followed by the design, construction, and operation of a 2-t/hr process development unit (PDU). The project began in October, 1992, and is scheduled for completion by June 1997.

During Quarter 14 (January - March 1996), parametric testing of the 30-inch Microcel™ flotation column at the Lady Dunn Plant continued under Subtask 3.2. Also under this Subtask, it was found that at a projected viscosity of 500 cp, slurry loadings of 62, 63 and 68 percent coal could be achieved for blends of the froth product containing 0, 10 and 40 percent of the ground spiral concentrate, respectively.

Subtask 3.3 testing, investigating a novel Hydrophobic Dewatering process (HD), continued this quarter with parametric testing of the batch dewatering unit. Coal product moistures of 3 to 12 percent were achieved, with higher percent solids slurry feeds resulting in lower product moistures. For a given percent solids feed, the product moisture decreased with increasing butane to dry coal ratios. Stirring time, stirring rate, and settling time were all found to have little effect on the final moisture content.

The final version of the Subtask 4.4 topical report, containing bench-scale flotation and the toxic trace element reduction data was issued.

Continuing Subtask 6.4 work, investigating coal-water-fuel slurry formulation for coals cleaned by selective agglomeration, indicated that pH adjustment to 10 resulted in marginally better (lower viscosity) slurries for one of the two coals tested. Subtask 6.5 agglomeration bench-scale testing results indicate that the new Taggart coal requires a grind with a d_{80} of approximately 33 microns to achieve the 1 lb ash/MBtu product quality specification. Also under Subtask 6.5, reductions in the various trace element concentrations accomplished during selective agglomeration were determined.

Work was essentially completed on the detailed design of the PDU selective agglomeration module under Task 7 with the issuing of a draft report.

PDU Flotation Module operation began under Subtask 8.4. Efforts were directed to parametric testing of the Taggart coal in the selective grinding circuit and Microcel™ column flotation unit. The PDU was also operated for an extended period of time in order to demonstrate the reliability of each unit operation as well as the overall system.

A contractor was selected, a subcontract was signed, and construction of the PDU selective agglomeration module began under Subtask 9.1. The bulk of the capital equipment for this construction effort was also purchased.

EXECUTIVE SUMMARY

This project is a major step in the Department of Energy's program to show that ultra-clean coal-water slurry fuel (CWF) can be produced from selected coals and that this premium fuel will be a cost-effective replacement for oil and natural gas now fueling some of the industrial and utility boilers in the United States, as well as for advanced combustors currently under development. The replacement of oil and gas with CWF can only be realized if retrofit costs are kept to a minimum and retrofit boiler emissions meet national goals for clean air. These concerns establish the specifications for maximum ash and sulfur levels and combustion properties of the CWF.

This multi-year cost-share contract started on October 1, 1992 and is scheduled for completion by June 1997. This report discusses the progress made during the 14th quarter of the project from January 1 to March 31, 1996.

SPECIFIC OBJECTIVES OF PROJECT

The project has three major objectives:

- The primary objective is to develop the design base for prototype commercial advanced fine coal cleaning facilities capable of producing ultra-clean coals suitable for conversion to coal-water slurry fuel for premium fuel applications. The fine coal cleaning technologies are advanced column flotation and selective agglomeration.
- A secondary objective is to develop the design base for near-term application of these advanced fine coal cleaning technologies in new or existing coal preparation plants to efficiently process minus 28-mesh coal fines and convert them to marketable products in current market economics.
- A third objective is to determine the removal of toxic trace elements from coal by advance column flotation and selective agglomeration technologies.

APPROACH

The project team consists of Cyprus Amax Minerals Company through its subsidiaries Amax Research & Development Center (Amax R&D) and Cyprus Amax Coal Company (Midwest and Cannelton Divisions), Arcanum Corporation, Bechtel Corporation, Center for Applied Energy Research (CAER) of the University of Kentucky, and the Center for Coal and Mineral Processing (CCMP) of the Virginia Polytechnic Institute and State University. Entech Global manages the project for Amax R&D and provides research and development services. Dr. Douglas Keller of Syracuse University and Dr. John Dooher of Adelphi University are both consultants to the project. During this reporting quarter, Mech EL Contracting, Inc. of Aurora, Colorado, was awarded a subcontract for the construction of the Process Development Unit (PDU) Selective Agglomeration Module.

The project effort has been divided into four phases which are further divided into eleven tasks including coal selection, laboratory and bench-scale process optimization research and design, along with design, construction, and operation of a 2 ton/hr PDU. Tonnage quantities of the ultra-clean coals will be produced in the PDU for combustion testing. Near-term applications of advanced cleaning technologies to existing coal preparation plants is also being studied.

ACCOMPLISHMENTS DURING QUARTER

Activity continued during January - March 1996 on Phases I, II, and III of the project. Work was carried out under Tasks 3, 4, 6, 7, 8, and 9 as described below.

Task 3 Development of Near-Term Applications

A 1993 Bechtel engineering analysis evaluating potential column flotation and selective agglomeration applications found a column flotation application at the Lady Dunn Preparation Plant particularly attractive since the plant was being considered for a major capacity expansion. Because of the potential advantages of installing column flotation rather than mechanical flotation cells in the expanded fine coal cleaning circuit, Lady Dunn management was pleased to offer their plant as the study site for a near-term application of column flotation. The Microcel™ flotation column was selected for this study and the Center for Coal and Mineral Processing (CCMP) at Virginia Tech was assigned the responsibility for the on-site test work. Subtask 3.3, investigating a novel dewatering process for advanced flotation products is also being performed by CCMP.

Subtask 3.2 Engineering Development

As described in the last three Quarterly Progress Reports, an existing 30-inch diameter Microcel™ flotation column was refurbished and installed in the Lady Dunn Plant. A high-quality product of about 10% ash was produced at approximately 80% combustible matter recovery. Based on these results, Cannelton plans to include column flotation in its 1996 plant expansion. In the meantime, parametric testing is continuing in order to quantify the flotation characteristics of coarse coal particles (0.75 x 0.15 mm) in the feed to the column. Sixteen of the planned parametric tests have been completed but progress has been slow due to the intermittent operating schedule of the plant and weather and construction delays.

Slurry Preparation. Marketing clean coal from near-term column flotation as a slurry fuel rather than a filter or centrifuge cake was considered. Slurry preparation tests were performed on the froth product from the Microcel™ testing at the Lady Dunn plant.

The tests were on both the froth product alone and on the froth product blended with coarser material prepared by stage grinding spiral concentrate to minus 48 mesh. The spiral concentrate was from a separate test program at the Lady Dunn plant. It was found that at a projected viscosity of 500 cp, slurry loadings of 62, 63 and 68% coal could be achieved for blends containing 0, 10, and 40% of the ground spiral concentrate, respectively. In each case, the slurry contained 1% A-23 dispersant on a dry coal basis.

These results indicate that if a niche market was found in the Charleston area, one might sell the fine coal from the Lady Dunn plant as a slurry fuel containing about 60% coal. However, at present it appears that dewatering the fines in a centrifuge and blending the cake with the normal plant product is the best alternative in terms of cost and marketability.

Subtask 3.3 Dewatering Studies

This work, being performed by Virginia Tech, is aimed at developing a novel hydrophobic dewatering (HD) process for clean coal fines. In this process a hydrophobic substance is added to a coal-water slurry to displace water from the coal surface. The hydrophobic substance is then recovered for recycle to the process. Three coals will be tested including the product from near-term testing at the Lady Dunn plant (Subtask 3.2). The work conducted during this reporting period focused on Subtask 3.3.3.2, Batch Dewatering tests.

Subtask 3.3.3 - Process Development - Under Subtask 3.3.3.2, previous work involved the design, construction, shakedown testing, and modification of a batch dewatering unit. Parametric testing of this HD Process unit began this quarter using minus 100-mesh column flotation product from the Middlefork Preparation Plant near Lebanon, Virginia. This is a fine-particle-size froth and generally produces a product moisture content in the mid 20's from screen-bowl centrifuges.

Testing utilized 5, 15, and 30% solids coal slurries and liquid butane to dry coal ratios ranging from 0.5 to 2.0 by mass. At a butane to dry coal ratio of 1.0 the HD unit produced coal product moistures ranging from 3 to 12%, with the higher percent solids slurry feeds resulting in lower product moistures. For a given percent solids feed, the moisture also decreased with increasing butane to dry coal ratios. Stirring time and stirring rate (rpm) were both found to have little effect on the final moisture content. Similarly, settling time had little effect on the final moisture content.

These results will be further evaluated during the next quarter. Future testing will also attempt to determine the butane absorption onto the coal surface. If successful, this will provide a quantitative indication of the potential butane consumption/losses to be expected with the HD process.

Task 4 Engineering Development of Froth Flotation

Task 4 is divided into five subtasks. Subtasks 4.1 Grinding, 4.2 Process Optimization Research, 4.3 Coal-Water-Fuel Formulation Studies, and 4.5 Conceptual Design of the PDU and Advanced Froth Flotation Module have been completed and were reported during previous quarters. There was activity on the remaining subtask, 4.4, during the fourteenth quarter of this project.

Subtask 4.4 Bench-Scale Testing and Process Scale-Up

The draft Subtask 4.4 Topical Report containing bench-scale flotation and toxic trace element reduction data was revised to incorporate comments from project team members. The final version of this report was issued on February 6, 1996.

Task 6 Engineering Development of Selective Agglomeration

Task 6 is divided into six subtasks. Subtasks 6.1 Agglomerating Agent Selection, 6.2 Grinding Studies, 6.3 Process Optimization Research, and 6.6 Conceptual Design of the Selective Agglomeration PDU Module have been completed and were reported during previous quarters. There was activity on the two remaining subtasks during the reporting quarter.

Subtask 6.4 CWF Formulation Studies

The primary objective of Subtask 6.4 is to evaluate the formulation of coal-water-fuel (CWF) slurries from selective agglomeration products. The slurry feedstocks used for this work are generated during Subtask 6.5 testing, Selective Agglomeration Bench-scale Testing and Process Scale-up.

While much of this test work will evaluate the effect of various parameters on slurry quality, there are two other objectives for the Subtask 6.4 work. First, this test work will provide a comparison between similar slurries formulated from flotation and agglomeration products, providing some insight into whether one process generates a product inherently more amenable to highly-loaded slurry formulation than the other. Second, the Subtask 6.4 work will attempt to determine slurry quality guidelines for commercial production. To this end, determinations of required slurry coal loadings, stabilities, and viscosities will be carried out.

Previous Work - Previous Subtask 6.4 test work involved particle size distributions (PSD) characterization and preliminary slurry formulation of Subtask 6.5 testing final products, i.e., product from the steam stripping circuit used to remove heptane from the recovered agglomerates. This focused on providing a comparison between the formulation of slurries from advanced flotation and selective agglomeration products. Based on this work, it was found that while slurries of similar characteristics were formulated regardless of which cleaning process was used, the agglomeration product slurries were somewhat better in that they had slightly lower viscosities. This work was carried out for the Taggart, Sunnyside, Elkhorn No. 3 and Indiana VII coals.

New Work - During this reporting quarter, a total of eight additional CWF slurries were formulated utilizing the Elkhorn No. 3 and Indiana VII coals. These tests were carried out to evaluate the effect of pH adjustment on slurry properties. For these tests, the pH was adjusted to 10 using Ammonium Hydroxide during slurry formulation. In contrast, when pH adjustment is not incorporated, the natural slurry pH is in the 5 to 7 range.

For the Elkhorn No. 3 coal, four slurries were formulated using a blend of 70% "as-received" agglomeration product and 30% of the agglomeration product reground for 30 minutes in the attritor mill. The dispersant level used in the formulation of these slurries was 0.5% on a dry coal basis. The results indicated that the increased pH had a small effect on the coal loading vs slurry viscosity relationship for the 70/30 regrind blend, i.e., at similar coal loadings the viscosities were slightly lower when the pH was adjusted to 10.

For the Indiana VII coal, these pH adjusted slurries were formulated using 100% "as-received" agglomeration product. The dispersant level used in the formulation of these slurries was 1.0% on a dry coal basis. The results indicate that the increased pH had virtually no effect on the coal loading vs slurry viscosity relationship for the Indiana VII coal, i.e., at equivalent coal loadings the viscosities were similar regardless of the pH utilized during slurry formulation. The effect of pH adjustment on slurry formulation characteristics will be further investigated for other project coals during future testing.

Future Work - Work yet to be completed under Subtask 6.4 includes the evaluation of slurries formulated from the Hiawatha, Winifrede, and new Taggart coals.

The new Taggart coal slurry feedstock to be used for this work will be Subtask 6.5 agglomerated product generated utilizing a grind from PDU operations under Subtask 8.4. This grind was found to provide sufficient liberation to meet the target product ash content of 1 lb ash/MBtu during bench-scale agglomeration testing. This grind has a mass mean diameter of approximately 23 microns. The Hiawatha coal slurry feedstock will be Subtask 6.5 agglomerated product generated utilizing a closed-circuit 150-mesh topsize grind in the 4' x 4' ball mill. This grind has a mass mean diameter of approximately 27 microns and provided sufficient liberation to meet the quality specification in bench-scale testing. The Winifrede coal slurry feedstock material to be utilized was generated via closed-circuit 4' x 4' ball mill and open-circuit Drais Mill grinding and has a mass mean diameter of approximately 7 microns.

Subtask 6.5 Bench-Scale Testing and Process Scale-up

Previous Work - During previous testing with the 25 lb/hr bench-scale unit, evaluation of the first Taggart coal along with the Sunnyside, Elkhorn No. 3, and Winifrede coals were completed. It should be noted, that the original Taggart coal and Sunnyside coal have since been replaced with a new Taggart coal and a Hiawatha coal, respectively, and as such will not be tested further. Previous testing also evaluated the Indiana VII coal, indicating that product ash specifications could be met at the selected 325-mesh topsize grind. Additional testing with the Indiana VII coal will be carried out later in the test program utilizing ground coal generated in the PDU grinding circuit under Subtask 8.4.

During the last reporting quarter, a number of continuous agglomeration tests were carried out using the Hiawatha coal closed-circuit ground in the 4' x 4' ball mill with a 150-mesh screen. Product ash for these tests ranged from approximately 1.4 to 2.3 lb ash/MBtu, indicating that sufficient liberation was achieved at the 150-mesh topsize grind to meet the desired 2 lb ash/MBtu product specification.

During previous testing, the new Taggart coal was closed-circuit ground to both 62- and 100-mesh topsizes for evaluation, with results indicating that a product ash content of approximately 1.3 - 1.5 lb ash/MBtu were achieved at both sizes. As such, additional liberation studies were carried out with this coal during this quarter to determine the grind required to insure that a product ash content of 1 lb ash/MBtu can be met in the 25 lb/hr continuous selective agglomeration bench-scale unit.

Liberation Studies - For this work, the new Taggart coal was batch ground in the attritor mill to various sizes, followed by batch agglomeration testing. In addition, three different feedstocks generated during PDU operation were also evaluated via batch agglomeration testing. The results of this work indicates that the poorest liberation (highest product ash content at similar 80% passing sizes) was achieved for the batch attritor ground feedstock tests. In contrast, the best liberation (lowest product ash content at similar 80% passing sizes) was achieved when the coal was ground in the PDU grinding circuit. This improvement in mineral matter liberation, at similar overall grind sizes, is attributed to the use of selective regrinding of the coarse material, via cyclone separation, in the PDU grinding circuit. Based on these results, additional continuous agglomeration testing with the new Taggart coal was carried out on feedstock generated in the PDU grinding circuit.

Continuous Testing - Seventeen continuous agglomeration tests were carried out during this quarter using two different feedstocks of the new Taggart coal, both generated in the PDU grinding circuit. Ten of these tests utilized a feedstock with an 80% passing size (d_{80}) of approximately 75 microns. This grind was generated by operating the PDU grinding circuit in closed-circuit with cyclones and a 100-mesh screen, with the oversize material recycled to the secondary ball mill. The remaining seven tests utilized feedstock with a d_{80} of approximately 33 microns. This grind was generated by operating the PDU grinding circuit in closed-circuit with cyclones and a 70-mesh screen, with the oversize material recycled to the Netzsch fine-grinding mill.

The bench-scale agglomeration unit operated well for all of these tests, with the production of well formed agglomerates that screened easily. As with the bulk of previous testing, Btu recoveries were high (>94%) for all of these tests. The 75 micron d_{80} PDU grind did not provide sufficient liberation to achieve the target product ash content of 1 lb ash/MBtu. Instead, product ash contents in the 1.17-1.29 lb ash/MBtu range were achieved, with Btu recoveries of greater than 96%.

In contrast, this testing indicated that the 33 micron d_{80} PDU grind provided liberation resulting in product ash contents in the 1.0-1.15 range, with Btu recoveries approaching 99%. It is anticipated that even lower product ash values may be achieved with additional process optimization. From this work, it appears that only the solids concentration had a significant effect on the product ash content, with the higher solids loading resulting in higher product ash levels.

Based on these results, the 33 micron d_{80} grind is considered sufficiently fine to achieve the project objective of 1 lb ash/MBtu, and as such, will be utilized for additional testing in the bench-scale unit, and for initial testing during PDU selective agglomeration module operations with the new Taggart coal under Subtask 9.3.

Reactor Design - As discussed in previous reports, much difficulty had been encountered when operating the low-shear vessel full, i.e., when utilizing both mixing zones separated by a horizontal baffle. Based on observations, it appeared that the transfer of agglomerates from the lower to upper section of the low-shear vessel was a bottleneck. As such, the opening in the horizontal baffle was increased from 1-1/2 inches to 5-1/2 inches diameter in an attempt to improve the flow to the upper zone. To date, this modification has been successful, with good transport of agglomerates to the upper mixing zone observed. As such, future test work will utilize this horizontal baffle arrangement.

Toxic Trace Elements - The reduction in toxic trace element concentrations accomplished by selective agglomeration was studied by assaying the products from selected parametric bench-scale tests and calculating the distribution of the trace elements between the clean coal and waste. Except for the Elkhorn No. 3 coal, the grind sizes for these tests were the same as the grind sizes of the coals examined for trace element reduction during the bench-scale column flotation testing.

The toxic trace elements of interest were antimony, arsenic, beryllium, cadmium, chromium, cobalt, lead, manganese, mercury, nickel, selenium and chlorine. A perchloric acid decomposition and inductively coupled plasma (ICP) spectroscopy procedure was used for most of the analyses. Mercury was by cold vapor spectroscopy, and chlorine was by a total halides coulometric method.

In most cases good mass balance closures were achieved (plus or minus 20 percent). Mass balance closures were not possible for mercury in the Taggart, Sunnyside, and Indiana VII coals because the amounts present in the clean coals were below the detection limit for mercury (0.01 part per million or 10 parts per billion). Mass balances were not calculated for cadmium since it was not detected in any of the samples except for the Elkhorn No. 3 and Indiana VII raw coals.

The reductions in the various trace element concentrations accomplished during the selective agglomeration tests were calculated on a heating value basis. As reported earlier for the column flotation samples, the concentrations of arsenic, beryllium, cobalt, lead, manganese, mercury and selenium in the raw coals were clearly reduced by the combined conventional washing and advanced cleaning steps. Much of the reduction was accomplished during washing at the mine-site preparation plant. Very definitely, selective agglomeration reduced the concentrations of arsenic, chromium, manganese, and nickel remaining in the ground washed coals. It appears that chromium and nickel may have been introduced into the coal slurries during grinding and processing which may explain the erratic reductions in concentration of these two elements.

Selective agglomeration had little impact upon the beryllium, cobalt, lead, mercury, and selenium concentrations and it appears that at times the antimony and chlorine concentrations increased on a heating value basis. Such results could indicate a preferential association of these seven elements with the carbonaceous portion of the coal.

Task 7 PDU Selective Agglomeration Module Detailed Design

Work was essentially completed on the detailed design of the PDU selective agglomeration module during previous reporting periods. Work carried out during the fourteenth quarter of this project involved the completion and issuing of a draft Detailed Design Package on February 20, 1996. This Package will be finalized upon completion of the Selective Agglomeration Module Construction to reflect the as-built design and include equipment drawings from vendors.

Task 8 PDU and Advanced Column Flotation Module

Operation of the PDU Flotation Module commenced in January 1996. Most efforts were directed to parametric testing of Taggart coal in the selective grinding circuit and Microcel™ column flotation unit. The selective grinding/classification circuit required more time and effort than originally anticipated due to difficulty in obtaining the desired size consist/mineral liberation.

The PDU Flotation Module was also operated for an extended period of time in order to demonstrate the reliability of each unit operation as well as the overall system. The round-the-clock continuous run was conducted during the last week of March. About 150 tons of Taggart coal was processed. Aside from a failed belt splice on a tailings filter, the production run was entirely successful without any downtime.

Preparations are underway to ship the Taggart clean coal generated during the extended production run to Penn State University for slurry formulation and combustion testing.

Subtask 8.4 PDU Operation and Clean Coal Production

Parametric Testing of PDU Selective Grinding/Classification Circuit - Parametric testing of the PDU selective grinding/classification circuit was completed during the quarter. The test work was performed to determine the best grinding scenario for optimum liberation of mineral matter. Laboratory testing has shown that adequate liberation is achieved when grinding the Taggart coal to a d_{80} of 50 microns (80% passing 50 microns).

The 25 tests conducted during this time period revealed that the mineral liberation goal (d_{80}=50 microns) and clean coal quality objective (1 lb ash/MBtu) could be obtained at the following grinding/classification circuit setpoints:

- Feed Rate: 4,200 lb/hr
- Primary Water: 15 GPM
- Primary Mill Load: 13,628 pounds
- Secondary Mill Load: 14,057 pounds
- Cyclone Water: 25 GPM
- Cyclones: 3 inch
- Screen Cloth: 140 mesh
- Screen Water: 36 GPM
- Recirculation: Secondary Ball Mill

Parametric Testing of PDU Flotation Module (Taggart Coal) - Parametric testing of the PDU Flotation Module (6 foot Microcel™) was completed during this reporting quarter. A test matrix was established to determine the effects of independent variables such as air rate, % solids, feed rate, wash water, and reagent dosage on response variables such as product ash and yield. Twenty tests were conducted during the period.

Like the Taggart coal evaluated in the 12-inch Microcel™ unit (Fall, 1994), the feedstock used in the PDU flotation module was easily floatable. In fact, the natural floatability of the Taggart coal produced comparable yield and quality values regardless of the change in the input parameters. Noticeable changes in the yield and quality were typically observed only when the input parameters were varied dramatically.

During the testing, the overall quality goal of 1 lb ash/MBtu was met or exceeded in four tests. The clean coal yield varied from 58.5 to 96.6% while the energy recovery and product quality varied from 60.1 to 98.0% and 0.77 to 1.23 lb ash/MBtu, respectively. The testing also shows that the target clean coal quality of 1 lb ash/MBtu should be optimally achieved at an approximate yield of 95% and an energy recovery of 97%. Future optimization test work scheduled for next quarter should confirm this prediction.

Extended Production Run of PDU Flotation Module (Taggart Coal) - An extended production run of the PDU Flotation Module was successfully completed during the week of March 25, 1996. About 150 tons of Taggart coal was processed during the round-the-clock operation. Aside from a failed belt splice, the operation was entirely successful. The PDU was operated at a feed rate of approximately 3,800 lb/hr due to filter capacity limitations previously determined during parametric testing. Overall, 275,340 pounds of coal (137.67 tons) was processed in the PDU Flotation Module while 220 bags of clean coal filter cake were produced.

Delivery of Taggart Clean Coal to Penn State University - Approximately 200 tons of clean coal filter cake is slated for shipment to Penn State's (PSU) Coal Utilization Laboratory for slurry formulation and combustion testing. Supersacks with full bottom discharge were purchased for use and transport to PSU. Currently, PSU lab technicians are completing the shakedown/startup procedures for their coal slurry circuit. Final approval for shipment is expected during April 1996.

Task 9 Selective Agglomeration Module

Phase III of this project involves the construction and operation of a 2 t/hr selective agglomeration (SA) PDU module. This SA module will be integrated with the existing PDU facility constructed during Subtask 8.2 and currently being operated under Subtask 8.3. During operation of the SA module, the existing coal handling and grinding circuits will be used to generate ground slurry feed for the selective agglomeration process. Similarly, the existing product and tailings dewatering circuits will also be used. As such, the SA module will essentially replace the Microcel™ flotation column, with the remainder of the plant remaining intact.

Just like the advanced flotation PDU, selective agglomeration process performance will be optimized at the 2 t/hr scale, and 200 ton lots of ultra-clean coal will be produced for each of the three test coals. Toxic trace element distributions will also be determined during the production runs. The ultra-clean coals will be delivered to DOE or some other user for end-use testing.

Subtask 9.1 PDU Selective Agglomeration Module Construction

Construction Contractor Selection - During the previous reporting quarter, Amax R&D (Entech Global), with help from Bechtel, prepared a Request for Quotation (RFQ) package describing the work and contract provisions in detail. This package was sent to four construction companies, based on their interest and qualifications.

We received proposals from three of these organizations which were then evaluated by Amax R&D with help from Bechtel. One proposal was eliminated because it was significantly higher in cost than the other two bids.

The bids from the other two contractors were broken down by labor and material costs under 15 different categories. Amax R&D and Bechtel personnel evaluated these proposed costs and held discussions with each bidder to clarify the intended scope of work. Following these discussions, revised bids (within 6% of each other) were received from each contractor, confirming that both bids represented similar levels of effort and that the prices were competitive.

Based on the bid reviews and discussions with each contractor Mech EL Contracting, Inc. (MEI) of Aurora, Colorado was selected for the following reasons with all other things being equal:

- MEI provided a higher level of comfort in terms of electrical and instrumentation work completion
- MEI's proposed on-site personnel, especially the proposed project manager and supervisor for the electrical and instrumentation areas, appeared more qualified
- MEI's price was approximately 6% lower than the competitor
- MEI is a local (Denver area) based contractor

Following the selection of MEI to complete the construction, a number of changes were made on the Process and Instrument Diagrams, and their cost impact incorporated into the proposed contract price. The construction contract was signed and MEI mobilized on site to begin construction during the week of March 11, 1996. Construction is scheduled for completion by August 16, 1996.

Construction Scope of work - MEI will construct the SA Module following the detailed design prepared by Bechtel. MEI will provide all the labor and materials for the construction except the major pieces of equipment which will be provided by Amax R&D.

The work to be performed by MEI will include:

- Excavation and concrete foundation work for equipment as required
- Structural steel installation and modifications
- Installation of Equipment
- Installation of piping and valves to connect equipment
- Installation of MCC and electrical lines from existing switchgear to equipment
- Installation of various instruments and expanded process control system
- Sheeting and painting
- Assistance during plant shakedown testing (mechanical/electrical modifications)

Material Requisitions - Material requisitions (MR) for the bulk of the capital equipment to be purchased for the construction of the Selective Agglomeration Module were issued during the last reporting quarter. MR's were issued for the remaining major capital equipment items during January and February of this year.

Equipment Purchasing - Orders were placed and Purchase Orders issued for thirty-nine (39) different capital equipment items during this quarter. Orders were also placed for a number of miscellaneous electrical items. It is anticipated that the bulk of the capital equipment will be received in the mid April to late May time frame. All of the process instrumentation items have yet to be purchased. The following non-electrical/instrumentation items remain to be purchased and/or rented:

- Conditioner Tank Agitator - Used or new purchase
- Gas Holder - New purchase
- Carbon Filter - Rental or new purchase
- Boiler Package - Rental or used purchase

The remainder of the capital equipment to be utilized for the PDU Selective Agglomeration Module are used equipment already on-site. These equipment require various levels of reconditioning work and miscellaneous replacement parts.

Construction - Work completed on the construction of the selective agglomeration PDU in Plant Area 300 during this quarter was as follows:

- Removal of the air handling unit from the roof and removal of the roof itself
- Demolition of the existing steel
- Removal of the existing concrete floor, excavation and disposal of the gravel located under the existing pad, and back-filling and compaction of new fill material
- Pouring of new concrete pad
- Relocation of oven transformer and other miscellaneous electrical installations in preparation of new MCC installations
- Running of various feeder conduits from existing switch gear to new MCC and DCS locations

The following summarizes the work completed as of the end of this reporting period:

- Mobilization, excavation, concrete, and foundation work - 86% complete
- Structural Steel & Platework - 12% complete
- Electrical & instrumentation installation - 13% complete
- Overall construction effort - 13% complete

INTRODUCTION AND BACKGROUND

The main purpose of this project is the engineering development of advanced column flotation and selective agglomeration technologies for premium fuel applications. Development of these technologies is an important step in the Department of Energy program to show that an ultra-clean coal-water slurry fuel (CWF) can be produced from selected United States coals and that this fuel will be a cost-effective replacement for a portion of the oil and natural gas burned by electric utility and industrial boilers in this country, as well as for advanced combustors currently under development. Capturing even a relatively small fraction of the total utility and industrial oil-fired boiler fuel market would have a significant impact on domestic coal production and reduce national dependence on petroleum fuels. Significant potential export markets also exist in Europe and the Pacific Rim for cost-effective premium fuels prepared from ultra-clean coal.

The replacement of oil and natural gas with CWF can only be realized if retrofit costs and boiler derating are kept to a minimum. Also, retrofit boiler emissions must be compatible with national clean air goals. These concerns establish the specifications for the ash and sulfur levels and combustion properties of ultra-clean coal as discussed below.

This multi-year cost-shared contract effort began on October 1, 1992, and is scheduled for completion by June 30, 1997. This report discusses the technical progress made during the fourteenth quarter of the project, January 1 to March 31, 1996. Thirteen quarterly reports have been issued previously [1-13].

SPECIFIC OBJECTIVES OF THE PROJECT

The three main objectives of this project are discussed below.

The primary objective is to develop the design base for commercial prototype advanced fine coal cleaning facilities capable of producing ultra-clean coals suitable for conversion to stable, highly loaded coal-water slurry fuels. These slurry fuels should contain less than 2 lb ash/MBtu HHV (860 grams ash/gigajoule) and preferably less than 1 lb ash/MBtu HHV (430 grams ash/gigajoule), and less than 0.6 lb sulfur/MBtu HHV (258 grams sulfur/gigajoule). The advanced fine coal cleaning technologies to be employed are advanced column froth flotation and selective agglomeration. Operating conditions during the advanced cleaning processes should recover at least 80 percent of the heating value in run-of-mine source coals at an annualized cost of less than $2.50/MBtu ($2.37/gigajoule), including the cost of the raw coal.

A secondary objective of the work is to develop a design base for near-term commercial applications of these advanced fine coal cleaning technologies. These applications should be suitable for integration into new or existing coal preparation plants for the purpose of economically and efficiently processing minus 28-mesh coal fines. The design base will also include the auxiliary systems required to yield a shippable, marketable product such as a dry clean coal product.

A third objective of the work is to determine the distribution of toxic trace elements between clean coal product and refuse during the cleaning of various coals by advanced froth flotation and selective agglomeration technologies. Eleven toxic trace elements have been targeted. They are antimony, arsenic, beryllium, cadmium, chromium, cobalt, lead, manganese, mercury, nickel, and selenium. The results will show the potential for removing these toxic trace elements from coal by advanced physical cleaning.

APPROACH

A team headed by Amax Research & Development Center (Amax R&D) was formed to accomplish the project objectives. Figure 1 shows the project organization chart. Entech Global, Inc. is managing the project for Amax R&D and also performing laboratory research and bench-scale testing. Entech Global is also responsible for the operation and evaluation of the 2 t/hr process development unit (PDU). Cyprus Amax Coal Company is providing operating and business perspective, the site for the near-term testing, and some of the coals being used in the program. Bechtel Corporation is providing engineering and design capabilities, and the operating experience it gained while managing similar proof-of-concept projects for DOE. The Center for Applied Energy Research (CAER) at the University of Kentucky and the Center for Coal and Mineral Processing (CCMP) at the Virginia Polytechnic Institute and State University are providing research and operating experience in the column flotation area. Arcanum Corporation is providing similar experience in the selective agglomeration area. Dr. Douglas Keller of Syracuse University is serving as a consultant in the area of selective agglomeration and Dr. John Dooher of Adelphi University is serving as a consultant in the area of coal-water slurry formulation. Robert Reynouard was retained as a consultant to help with electrical and instrumentation systems in the PDU. Mech EL Contracting, Inc. is constructing the Selective Agglomeration Module of the PDU.

The overall engineering development effort has been divided into four phases with specific activities as discussed below. As shown in Table 1, Work Breakdown Structure, the four phases of the project have been further divided into tasks and subtasks, with specific objectives which may be inferred from their titles. Figure 2 shows the project schedule.

Phase I

Phase I encompassed preparation of a detailed Project Work Plan, selection and acquisition of the test coals, and laboratory and bench-scale testing. The laboratory and bench-scale work determined the cleaning potential of the selected coals and established design parameters and operating guidelines for a 2 t/hr PDU containing both advanced column flotation and selective agglomeration modules. A conceptual engineering design was prepared for a fully integrated and instrumented 2 t/hr PDU incorporating the features determined from the laboratory and bench-scale studies.

Additional activities to be completed during Phase I include:

- Production of ultra-clean coal test lots by bench-scale column flotation and selective agglomeration for end-use testing by DOE or a designated contractor
- Determination of toxic trace element distribution during production of these test lots
- Evaluation of the rheological properties of slurry fuels prepared from ultra-clean coals
- Evaluation of methods for applying these advanced cleaning technologies to existing coal preparation plants in the near term

Phases II and III

Phases II and III cover the construction and operation of the 2 t/hr PDU. Phase II is for advanced column flotation while Phase III is for selective agglomeration. Process performance will be optimized at the PDU-scale, and 200 ton lots of ultra-clean coal will be produced by each process for each of the three test coals. Toxic trace element distributions will also be determined during the production runs. The ultra-clean coals will be delivered to DOE or a designated contractor for end-use testing.

Phase IV

Phase IV activities will include decommissioning of the PDU, restoration of the host site, and preparation of the final project report.

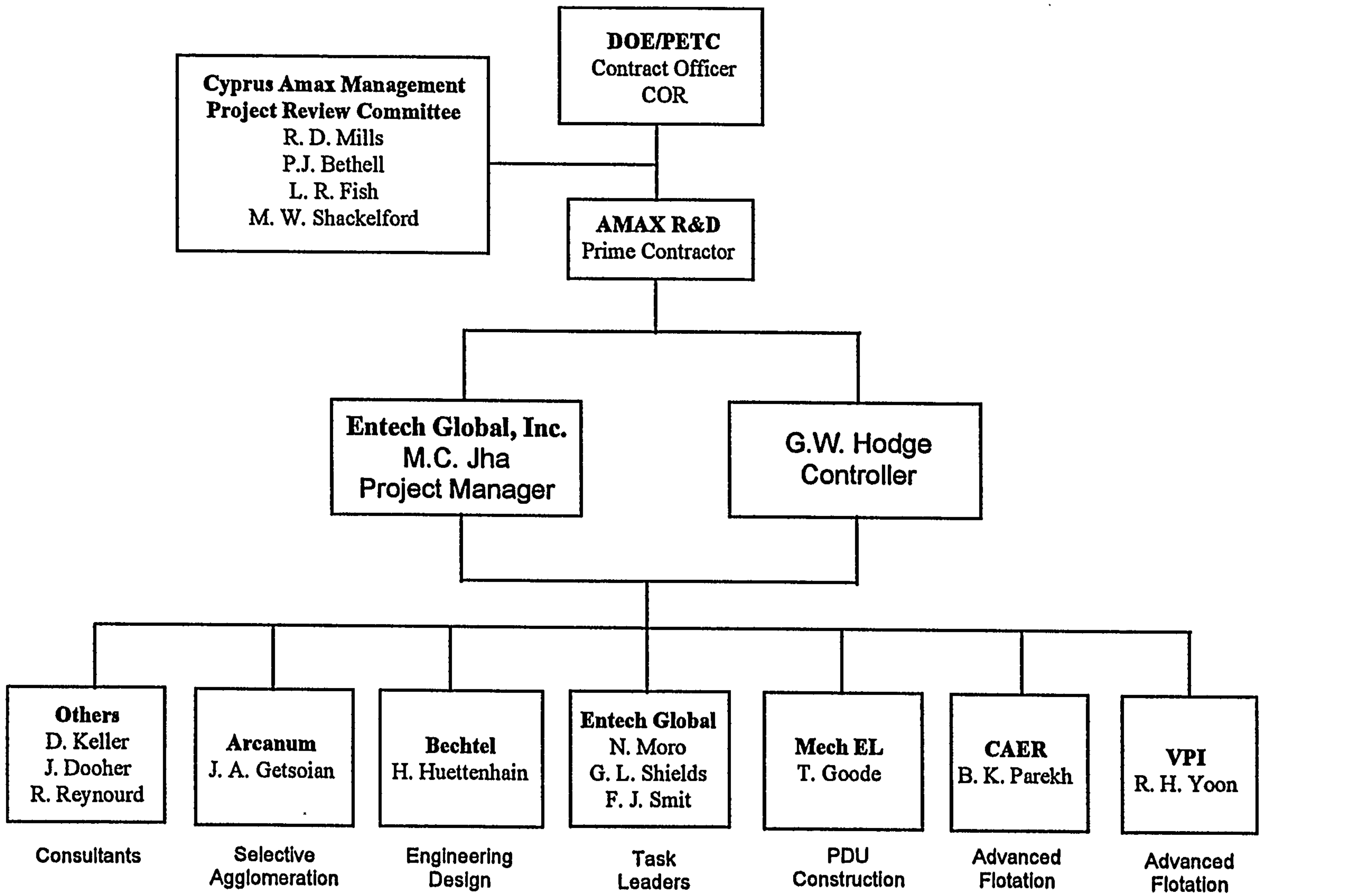
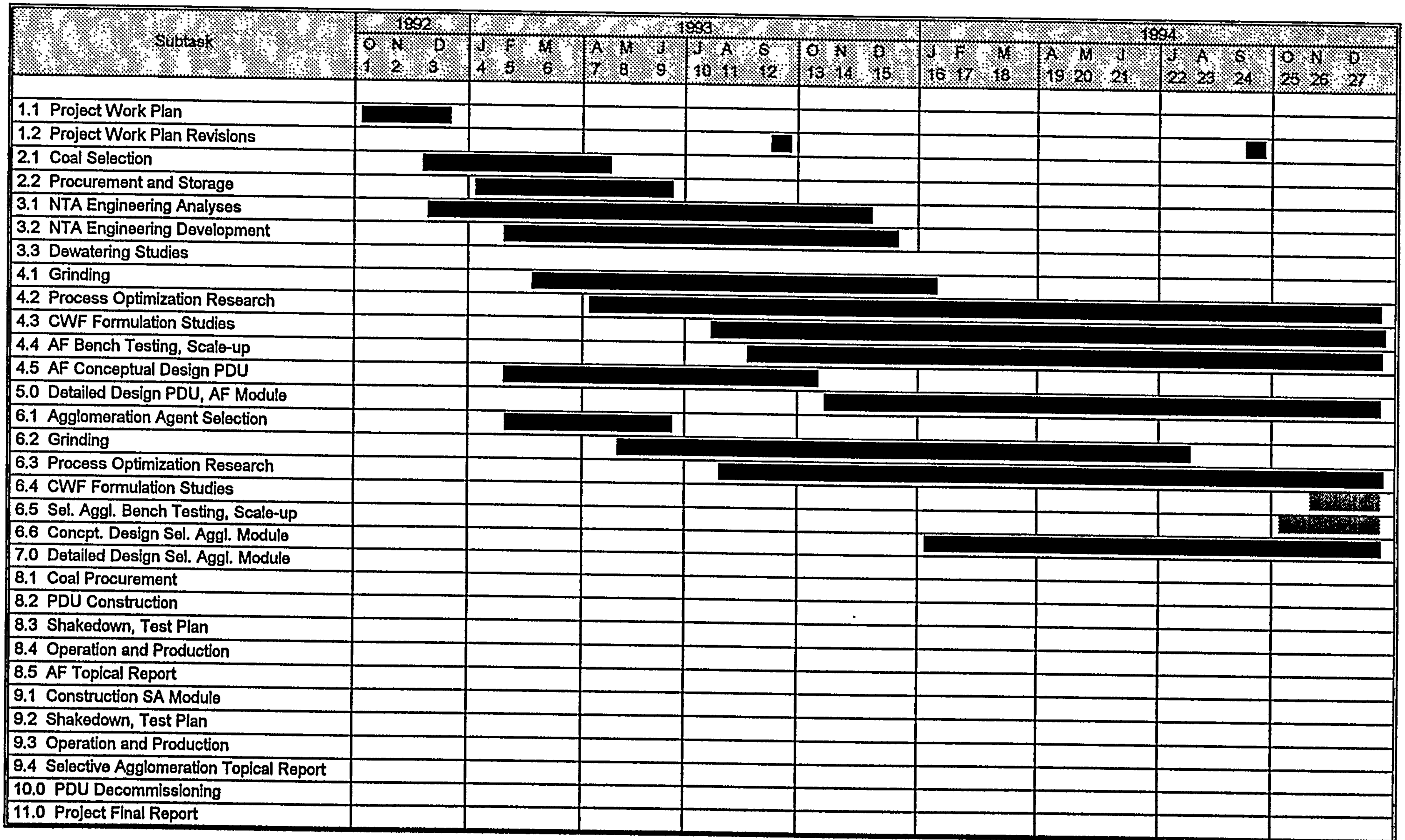


Figure 1. Project Management Organization Chart

Table 1. Outline of Work Breakdown Structure

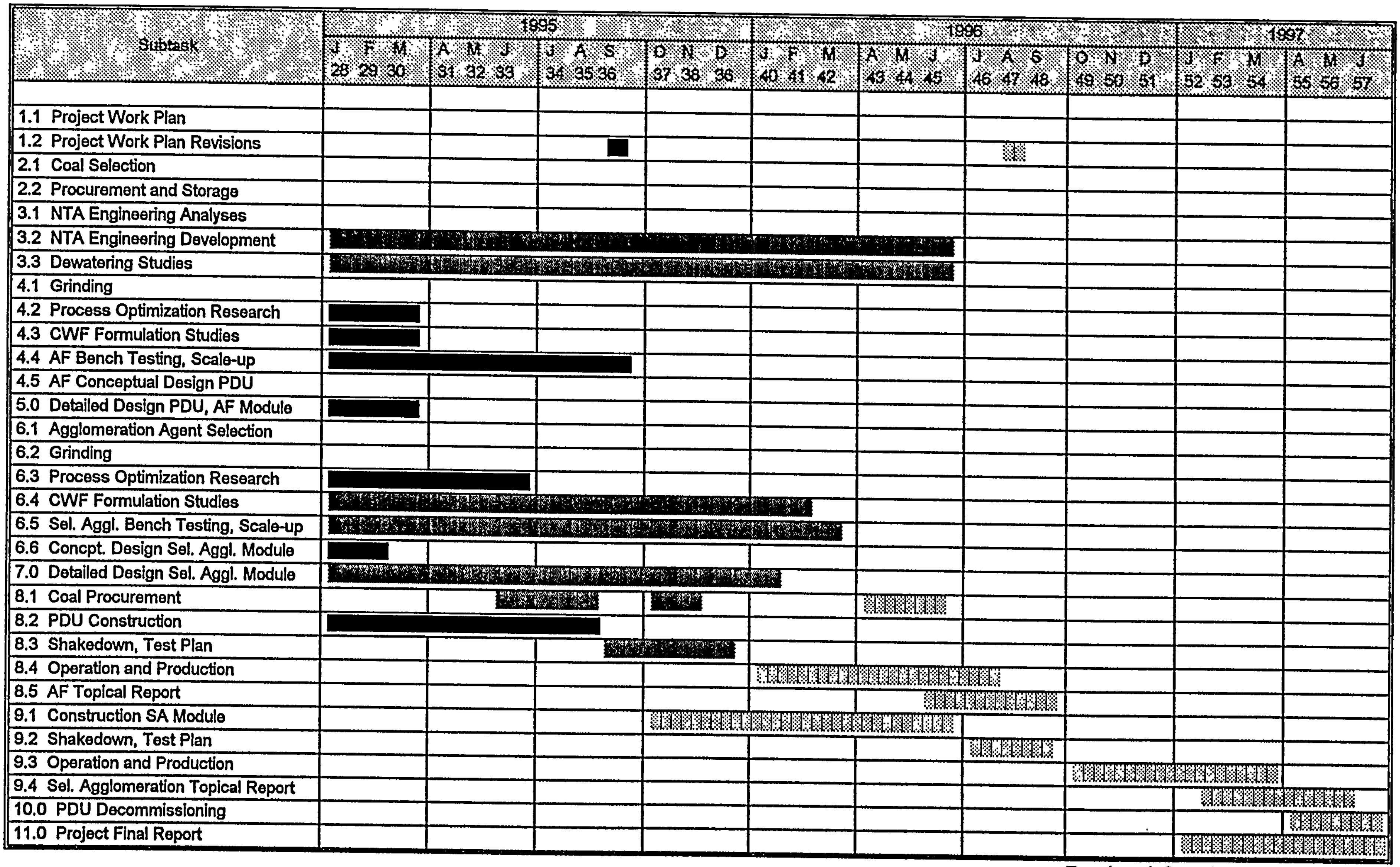
	Phase I. Engineering Analysis and Laboratory and Bench-Scale R&D
Task 1.	Project Planning
Subtask 1.1.	Project Work Plan
Subtask 1.2.	Project Work Plan Revisions
Task 2.	Coal Selection and Procurement
Subtask 2.1.	Coal Selection
Subtask 2.2.	Coal Procurement, Precleaning and Storage
Task 3.	Development of Near-Term Applications
Subtask 3.1.	Engineering Analyses
Subtask 3.2.	Engineering Development
Subtask 3.3	Dewatering Studies
Task 4.	Engineering Development of Advanced Froth Flotation for Premium Fuels
Subtask 4.1.	Grinding
Subtask 4.2.	Process Optimization Research
Subtask 4.3.	CWF Formulation Studies
Subtask 4.4.	Bench-Scale Testing and Process Scale-up
Subtask 4.5.	Conceptual Design of the PDU and Advanced Froth Flotation Module
Task 5.	Detailed Engineering Design of the PDU and Advanced Flotation Module
Task 6.	Selective Agglomeration Laboratory Research and Engineering Development for Premium Fuels
Subtask 6.1.	Agglomeration Agent Selection
Subtask 6.2.	Grinding
Subtask 6.3.	Process Optimization Research
Subtask 6.4.	CWF Formulation Studies
Subtask 6.5.	Bench-Scale Testing and Process Scale-up
Subtask 6.6.	Conceptual Design of the Selective Agglomeration Module
Task 7.	Detailed Engineering Design of the Selective Agglomeration Module
	Phase II. PDU and Advanced Column Flotation Module Testing and Evaluation
Task 8.	PDU and Advanced Column Froth Flotation Module
Subtask 8.1.	Coal Selection and Procurement
Subtask 8.2.	Construction
Subtask 8.3.	PDU and Advanced Coal Cleaning Module Shakedown and Test Plan
Subtask 8.4.	PDU Operation and Clean Coal Production
Subtask 8.5.	Froth Flotation Topical Report
	Phase III. Selective Agglomeration Module Testing and Evaluation
Task 9.	Selective Agglomeration Module
Subtask 9.1.	Construction
Subtask 9.2.	Selective Agglomeration Module Shakedown and Test Plan
Subtask 9.3.	Selective Agglomeration Module Operation and Clean Coal Production
Subtask 9.4.	Selective Agglomeration Topical Report
	Phase IV. PDU Final Disposition
Task 10.	Disposition of the PDU
Task 11.	Project Final Report

Revised April 25, 1995



Revised October 16, 1995

Figure 2. Project Schedule



Revised October 16, 1995

Figure 2. Project Schedule (Cont'd)

ACCOMPLISHMENTS DURING QUARTER

Work was carried out on Tasks 3, 4, 6, 7, 8, and 9 during the fourteenth quarter (January 1 to March 31, 1996) reporting period. Good progress was made on these tasks as discussed below.

TASK 3 DEVELOPMENT OF NEAR-TERM APPLICATIONS

During 1993, Bechtel performed an engineering analysis evaluating potential applications for column flotation and selective agglomeration at three coal preparation plants operated by what is now Cyprus Amax Coal Company [14]. Economic projections favored column flotation over selective agglomeration and an application at the Lady Dunn Preparation Plant (Cannelton Coal Company) in West Virginia was found to be particularly attractive since the plant was being considered for a major capacity expansion. Because of the potential advantages of installing column flotation rather than mechanical flotation cells in the expanded fine coal cleaning circuit, Lady Dunn management was pleased to offer their plant as the study site for a near-term application of column flotation. The Microcel™ flotation column was selected for this study and the Center for Coal and Mineral Processing (CCMP) at Virginia Tech was assigned the responsibility for the on-site column testing under Subtask 3.2 "Engineering Development." Subtask, 3.3 "Dewatering Studies", investigating a novel dewatering process for advanced flotation products is also being performed by CCMP.

Subtask 3.2 Engineering Development

As described during previous Quarterly Progress Reports [11, 12, 13], an existing 30-inch diameter Microcel™ flotation column was refurbished and installed in the Lady Dunn Plant for this engineering development work. A high-quality product, containing about 10% ash was produced at approximately 80% combustible matter recovery [13]. Based on these results, Cannelton plans to include column flotation in its 1996 plant expansion. In the meantime, parametric testing is continuing to quantify the flotation characteristics of the coarse coal particles (0.75 x 0.15 mm) in the feed to the column. Sixteen of the planned parametric tests have been completed but progress has been slow because of the intermittent operating schedule of the plant and because of weather and construction delays.

Slurry Preparation. Marketing the clean coal from the column flotation as slurry fuel rather than filter or centrifuge cake was investigated. Slurry preparation tests were performed on froth product from the Microcel™ testing at the Lady Dunn plant. The tests utilized both froth product alone and froth product blended with coarser material prepared by stage grinding spiral concentrate to minus 48 mesh. The spiral concentrate was from a separate test program at the Lady Dunn plant.

The spiral concentrate contained more ash and slime than anticipated so it was deslimed to provide a lower-ash source of coarse material for slurry fuel preparation. Desliming lowered the spiral concentrate ash content to 15.96%, with the rejected minus 150-mesh slimes containing 44.71% ash. The deslimed spiral concentrate was then stage-ground to minus 48-mesh (simulating a closed-circuit grinding system). The stage-ground product was 20% +65 mesh and 54% +150 mesh, and as such, provided a good source of coarse particles for blending with the very fine column froth product to formulate a highly loaded slurry fuel. Two blends were prepared, one containing 10% coarse material and 90% fine coal and the other containing 40% coarse material and 60% fine coal, both on a dry coal basis. Properties of the two blends are compared to the properties of the column froth product and the ground spiral concentrate in Table 2.

Table 2. Lady Dunn Product Slurry Feedstock Characterization

	100% Microcel™ Froth	100% 48M x 0 Stage-Ground Spiral Concentrate	10% Coarse 90% Fine Blend	40% Coarse 60% Fine Blend
Ash (dry basis), %	6.86	15.96	7.77	10.50
Nominal Top Size, mesh	100	48	48	48
Minus 100 mesh, %	97.0	62.7	93.8	83.3
Minus 400 mesh, %	74.8	22.3	70.1	53.6
MMD, µm	37	130	45	74

The particle size distributions (PSD) for these four slurry feedstocks are also plotted in Figure 3. These are Rosin-Rammler plots, and as one would expect, the Microcel™ froth follows the usual distribution for a ground material; that is, it is nearly linear on a Rosin-Rammler grid. Also as one would expect, the stage-ground spiral concentrate shows more weight in the coarser end of the distribution than one would expect when simply grinding coal. The extra amount of coarse material also shows up as an upward curvature in the particle size distributions for the two blends.

The first of the slurry preparation tests was on filtered Microcel™ froth using a bottle rolling technique with 1% A-23 dispersant in the mixture. A slurry containing 60.1% coal was prepared in this manner. Its viscosity was 430 cp at 100 sec^{-1}. A loading of 61.8% coal at 500 cp was projected by extending the trend line to 500 cp as shown in Figure 4. Ten percent dry 48-mesh x 0 ground spiral concentrate was next added to the filter cake slurry to prepare a 10% coarse, 90% fine blend. The additional coarse material raised the coal loading to 61.4% and dropped the viscosity to 370 cp. A projected loading of 63.2% coal at 500 cp could only be guessed since the small dilution appears to have increased, rather than decreased, the viscosity of the slurry as one would expect.

The 40/60 blend was obtained by mixing the 10% blend slurry with more of the 48-mesh x 0 ground spiral concentrate. In this case the spiral concentrate was first mixed with 1% A-23 and water to form a paste. A loading of 68% coal at 500 cp viscosity was projected for this blend as shown in Figure 4.

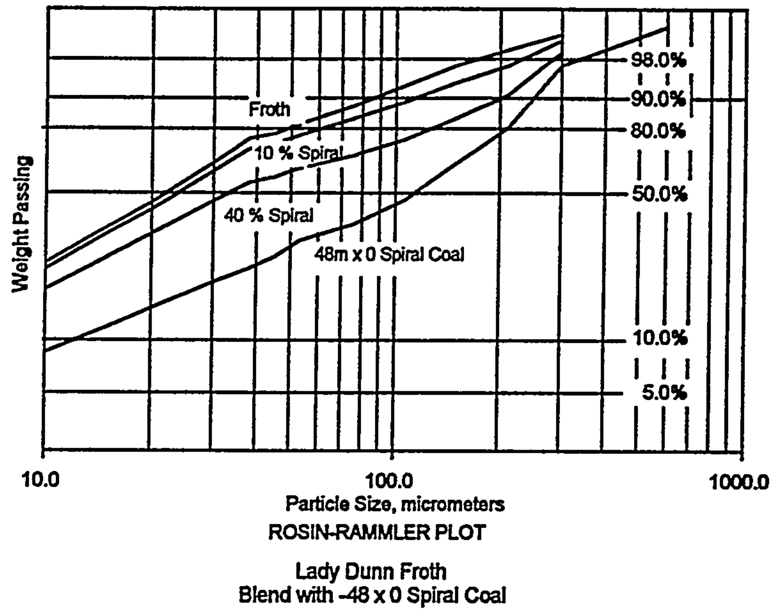


Figure 3. PSD's of various Microcel™ Product Slurry Feedstocks

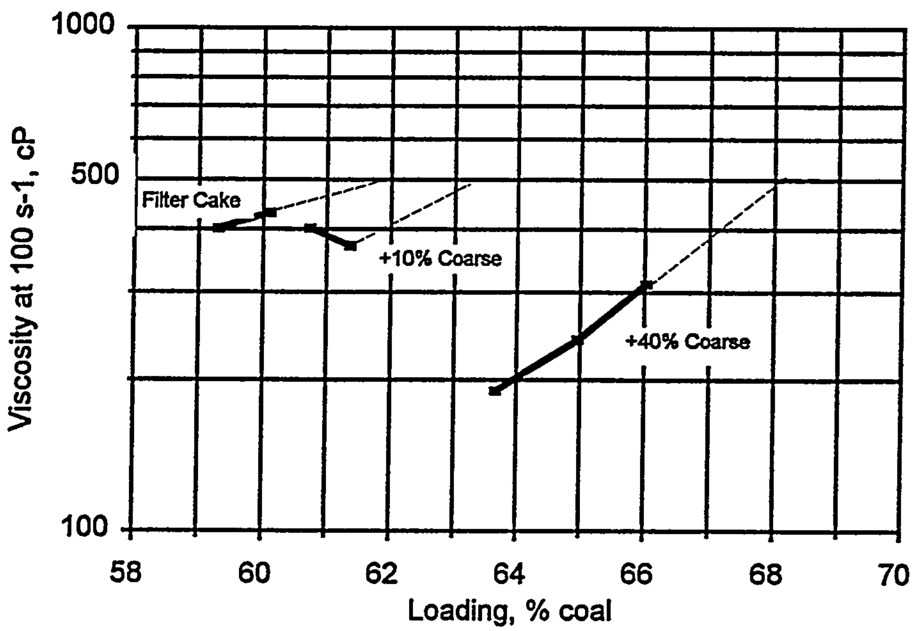


Figure 4. Lady Dunn Slurry Fuels, Viscosity vs Coal Loading

All of the slurries prepared from the Lady Dunn coal were pseudoplastic, and the blended slurries had very good overnight stability. As such, it appears that a useful coal slurry fuel containing approximately 62% coal can be prepared from the "as received" Lady Dunn Microcel™ froth product. A slurry of about 68% coal can be prepared by blending coarser coal with the froth product.

If a niche market can be found in the Charleston area, it may be possible to sell the fine clean coal as a slurry eliminating some of the dewatering requirements. However, at present it appears that dewatering the froth in a centrifuge and blending the cake with the normal plant production is the best alternative in terms of cost and marketability. No further slurry preparation testing is planned for near-term applications at this time.

Subtask 3.3 Dewatering Studies

This work, being performed by Virginia Tech, is aimed at developing a novel hydrophobic dewatering (HD) process for clean coal fines. This HD process will be capable of efficiently removing moisture from fine coal without the expense and other related drawbacks associated with mechanical dewatering or thermal drying. In this process a hydrophobic substance is added to a coal-water slurry to displace water from the coal surface. The hydrophobic substance is then recovered for recycle to the process. The success of this process hinges on finding the appropriate hydrophobic substances that can readily displace free moisture from the surface of the coal and that can be easily recovered and recycled. Three coals will be tested including the product from near-term testing at the Lady Dunn plant (Subtask 3.2). Subtask 3.3 is divided into five additional subtasks as follows:

- Subtask 3.3.1 - Project Planning
- Subtask 3.3.2 - Identification of Hydrophobic Substances
- Subtask 3.3.3 - Process Development
- Subtask 3.3.4 - Design/Operation of Continuous Bench-scale Unit
- Subtask 3.3.5 - Economic Analysis

The work conducted during this reporting period focused on Subtask 3.3.3.2, Batch Dewatering tests. Additional work performed on other Subtasks was insufficient for reporting at this time.

Subtask 3.3.3 - Process Development

Under Subtask 3.3.3.2, a batch dewatering unit was designed and constructed to test this HD process during a previous reporting quarter [12]. The design incorporates the following:

- A high pressure cell to keep the hydrocarbons in a liquid form
- A variable speed mixer to provide adequate mixing

- A transparent window for visual observation
- A pressurized sampling vessel
- Continuous monitoring of temperature, pressure, and mixer speed

Shakedown testing and modification of the HD process unit were carried out last quarter using Lady Dunn plant samples and butane as the hydrophobic substance.

Subtask 3.3.3.2, Batch Dewatering Tests - Parametric testing of the HD Process unit began this quarter and is well underway. The coal slurry used was the minus 100-mesh column flotation product from the Middlefork Preparation Plant near Lebanon, Virginia. This is a fine-particle-size froth and generally produces a product moisture content in the mid 20's from screen-bowl centrifuges.

The first series of tests utilized 5, 15, and 30% solids coal slurries and liquid butane to dry coal ratios ranging from 0.5 to 2.0 by mass. At a butane to dry coal ratio of 1.0 the HD unit produced coal product moistures ranging from 3 to 12%, with the higher percent solids slurry feeds resulting in lower product moistures. For a given percent solids feed, the moisture also decreased with increasing butane to dry coal ratios.

Stirring time and stirring rate (rpm) were both found to have little effect on the final moisture content. Similarly, settling time had little effect on the final moisture content. This was especially true at the highest solids feed concentration tested (30%), with settling times from 1 to 60 minutes producing a constant final product moisture content.

The rapid speed at which dewatering occurs can be explained by the high contact angle of the liquid butane spontaneously displacing the water from the coal surface. This process has been detailed in previous quarterly reports [12, 13].

These results will be further evaluated during the next quarter. Future testing will also attempt to determine the butane absorption onto the coal surface. If successful, this will provide a quantitative indication of the potential butane consumption/losses to be expected with the HD process.

TASK 4 ENGINEERING DEVELOPMENT OF ADVANCED FROTH FLOTATION

Task 4 activity during this reporting quarter involved work under Subtask 4.4, Bench-scale Testing and Process Scale-up.

Subtask 4.4 Bench-Scale Testing and Process Scale-Up

The draft version of the Subtask 4.4 Topical Report containing the bench-scale flotation work and the toxic trace element reduction data was updated to incorporate project team member comments. The final version of this report was issued on February 6, 1996. The report contains the flotation performance data from the 1-foot KenFlote™ and Microcel™ column testing and also the toxic trace element analyses and distributions for selected tests on each coal.

With the submission of this report, all the activities under Task 4 are completed.

TASK 6 ENGINEERING DEVELOPMENT OF SELECTIVE AGGLOMERATION

Task 6 activity during this reporting quarter focused on Subtask 6.4 CWF Formulation Studies, and Subtask 6.5 Bench-scale Testing and Process Scale-up.

Subtask 6.4 Coal-Water-Fuel Formulation Studies

The primary objective of Subtask 6.4 is to evaluate the formulation of coal-water-fuel (CWF) slurries from selective agglomeration products. The slurry feedstock, i.e., selective agglomeration products, used for this work are generated during Subtask 6.5, Selective Agglomeration Bench-scale Testing and Process Scale-up.

While much of this test work will evaluate the effect of various parameters on slurry quality, there are two other objectives for the Subtask 6.4 work. First, this test work will provide a comparison between similar slurries formulated from flotation and agglomeration products. This information will provide some insight into whether one process generates a product inherently more amenable to highly-loaded slurry formulation than the other process. Second, the Subtask 6.4 work will attempt to determine slurry quality guidelines for commercial production. To this end, determinations of required slurry coal loadings, stabilities, and viscosities will be carried out.

Previous Subtask 6.4 test work involved particle size distributions (PSD) characterization and preliminary slurry formulation of Subtask 6.5 testing final products, i.e., product from the steam stripping circuit used to remove heptane from the recovered agglomerates. This previously reported work [12, 13] focused on providing a comparison between the formulation of slurries from advanced flotation and selective agglomeration products. Based on this work, it was found that while slurries of similar characteristics were formulated regardless of which cleaning process was used, the agglomeration product slurries were somewhat better in that they had slightly lower viscosities. This work was carried out for the Taggart, Sunnyside, Elkhorn No. 3, and Indiana VII coals.

Elkhorn No. 3 Coal

During this reporting quarter, four CWF slurries were formulated utilizing the Elkhorn No. 3 coal. These tests were carried out to evaluate the effect of pH adjustment on slurry properties. For these tests, the pH was adjusted to 10 using Ammonium Hydroxide during slurry formulation. In contrast, when pH adjustment is not incorporated, the natural slurry pH is in the 5 to 7 range. These four slurries were formulated using a blend of 70% "as-received" agglomeration product and 30% of the agglomeration product reground for 30 minutes in the attritor mill. The dispersant level used in the formulation of these slurries was 0.5% on a dry coal basis.

The results for these four tests, along with results for similar slurries formulated at the natural pH of 5 to 7 are shown in Figure 5.

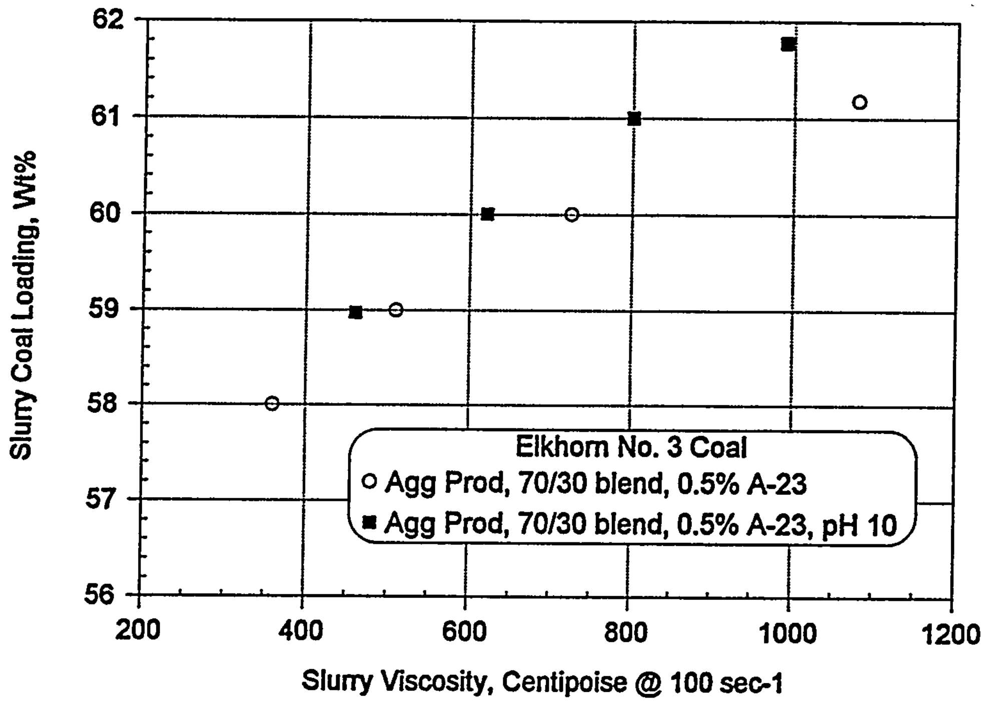


Figure 5. Elkhorn No. 3 Coal, pH Effect on Slurry Formulation

These results indicate that the increased pH had a small beneficial effect on the coal loading vs slurry viscosity relationship for the 70/30 regrind blend. As can be seen, at similar coal loadings the viscosities were lower when the pH was adjusted to 10 during slurry formulation.

Indiana VII Coal

Four CWF slurries were formulated utilizing the Indiana VII coal this reporting period. Just like the Elkhorn No. 3 coal, these slurries were formulated to evaluate the effect of pH adjustment on slurry properties. For these tests, the pH was adjusted to 10 using Ammonium Hydroxide during slurry formulation. In contrast, when pH adjustment is not incorporated, the natural slurry pH is in the 5 to 7 range. These four slurries were formulated using 100% "as-received" agglomeration product. The dispersant level used in the formulation of these slurries was 1.0% on a dry coal basis.

The results for these four tests, along with results for similar slurries formulated at the natural pH of 5 to 7 are shown in Figure 6.

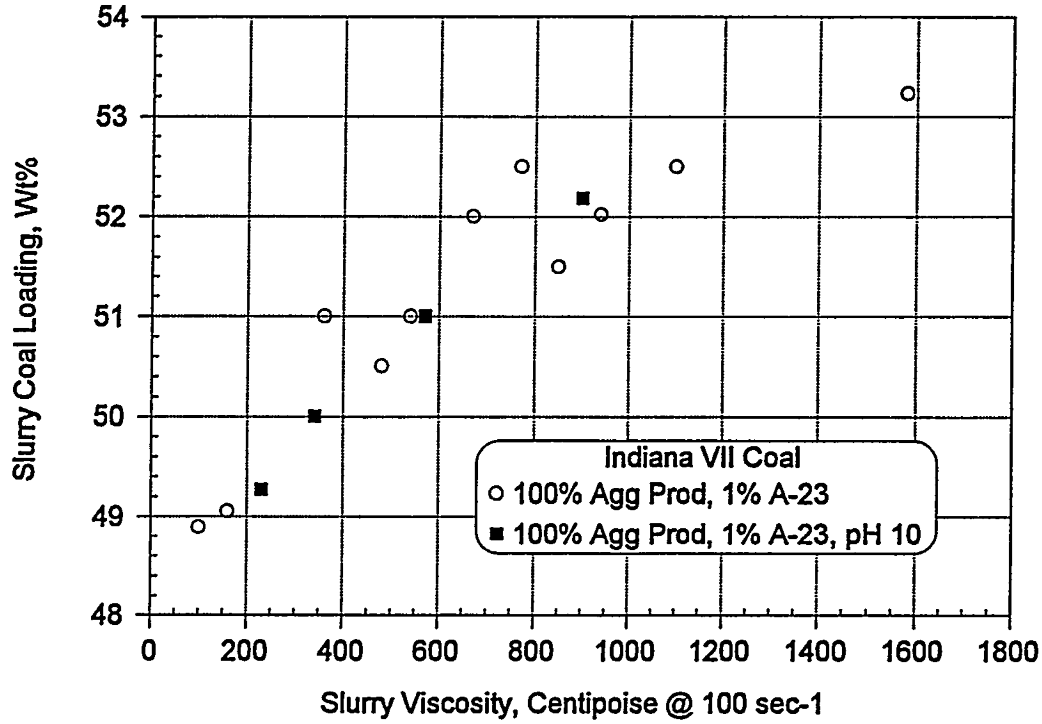


Figure 6. Indiana VII Coal, pH Effect on Slurry Formulation

These results indicate that the increased pH had virtually no effect on the coal loading vs slurry viscosity relationship for the Indiana VII coal. As can be seen, at equivalent coal loadings the viscosities were similar regardless of the pH utilized during slurry formulation.

The effect of pH adjustment on slurry formulation characteristics will be further investigated for other project coals during future testing.

Future Work

Other future work to be completed under Subtask 6.4 includes the evaluation of slurries formulated from the Taggart (new sample), Hiawatha, and Winifrede coals. The approximate particle size distributions (PSD) of the slurry feedstock material for these three coals is shown in Table 3.

It should be noted that the Taggart coal PSD shown here represents the agglomeration feed PSD generated during PDU operations under Subtask 8.4. This grind was found to provide sufficient liberation to meet the target product ash content of 1 lb ash/MBtu during bench-scale agglomeration testing under Subtask 6.5. The Hiawatha coal PSD shown in Table 3 represents the agglomeration feed material generated during a closed-circuit 150-mesh topsize grind in the 4' x 4' ball mill. This grind provided sufficient liberation for the Hiawatha coal under Subtask 6.5 bench-scale operations. While the actual material utilized for future slurry work for the Taggart and Hiawatha coals will be the product rather than the feed (as represented in Table 3), it is anticipated that the PSD's will be very similar.

Table 3. Approximate PSD's for Future Slurry Work

Microns	Taggart*	Hiawatha	Winifrede
	Cumulative Percent Passing		
212	100.00	100.00	100.00
150	99.52	100.00	100.00
106	98.46	100.00	100.00
75	96.08	96.85	100.00
53	93.05	88.68	100.00
45	88.84	77.87	100.00
38	84.32	74.21	99.96
30	77.60	63.39	99.84
20	59.12	45.53	88.57
15	47.28	35.12	84.31
10	32.56	23.83	79.11
8	26.62	19.84	76.82
6	20.35	15.44	67.64
4	12.58	10.07	51.72
3	8.24	7.17	37.98
2	3.66	4.12	22.29
1	0.51	0.86	3.56
MMD**	22.75	27.43	7.07

* New sample is coal from Steer Branch mine being used in the PDU

** Mass Mean Diameter = Sum of size interval midpoint (microns) times weight fraction of particles in that interval (percent)

Subtask 6.5 Bench-Scale Testing and Process Scale-up

During previous testing with the 25 lb/hr bench-scale unit, evaluation of the Taggart, Sunnyside, Elkhorn No. 3, and Winifrede coals were completed. It should be noted that the Sunnyside coal has since been replaced with the Hiawatha coal, and as such will not be tested further. Additional test work will be performed using the new sample of the Taggart coal (from the Steer Branch mine), which is currently being tested in the PDU.

Previous testing also evaluated the Indiana VII coal, indicating that product ash specifications could be met at the selected 325-mesh topsize grind. Additional testing with the Indiana VII coal will be carried out later in the test program utilizing ground coal generated in the PDU grinding circuit under Subtask 8.4. This will provide valuable information to be used during Subtask 9.3 PDU operations with the Indiana VII coal.

During the last reporting quarter, a number of continuous agglomeration tests were carried out using the Hiawatha coal closed-circuit ground in the 4' x 4' ball mill with a 150-mesh screen. Product ash for these tests ranged from approximately 1.4 to 2.3 lb ash/MBtu, indicating that sufficient liberation was achieved at the 150-mesh topsize grind to meet the desired 2 lb ash/MBtu product specification. As such, during future testing of this coal will evaluate a 100-mesh topsize grind as well as PDU grinding circuit product from Subtask 8.4 operations.

Other recent work completed as part of Subtask 6.5 involved the testing of several different low-shear discharge arrangements. Based on this work, it was determined that the location of the discharge ports at the impeller height resulted in improved agglomerate discharge, confirming the low shear PDU design.

Taggart Coal

During previous testing, a sample of the new Taggart coal was closed-circuit ground to both 62- and 100-mesh topsizes for evaluation, with results indicating that a product ash content of approximately 1.3 - 1.5 lb ash/MBtu was achieved at both sizes. As such, additional liberation studies were carried out with this coal during this quarter to determine the grind required to insure that a product ash content of 1 lb ash/MBtu can be met in the 25 lb/hr continuous selective agglomeration bench-scale unit.

Liberation Studies - For this work, the Taggart coal was batch ground in the attritor mill to various sizes, followed by batch agglomeration testing. In addition, three different feedstocks generated during PDU operation were also evaluated via batch agglomeration testing. The results of this work are shown in Figure 7 which shows product ash content vs the particle size distribution 80% passing size in microns.

As can be seen from this data, the poorest liberation (highest product ash content at similar 80% passing sizes) was achieved for the batch attritor ground feedstock tests. In contrast, the best liberation (lowest product ash content at similar 80% passing sizes) was achieved when the coal was ground in the PDU grinding circuit. It appears that the 4' x 4' ball mill continuous grind falls somewhere between these other two grinding methods in terms of liberation (at equivalent 80% passing sizes).

This improvement in mineral matter liberation, at similar overall grind sizes, is attributed to the use of selective regrinding of the coarse material, via cyclone separation, in the PDU grinding circuit. Based on these results, additional continuous agglomeration testing with the Taggart coal was carried out on feedstock generated in the PDU grinding circuit.

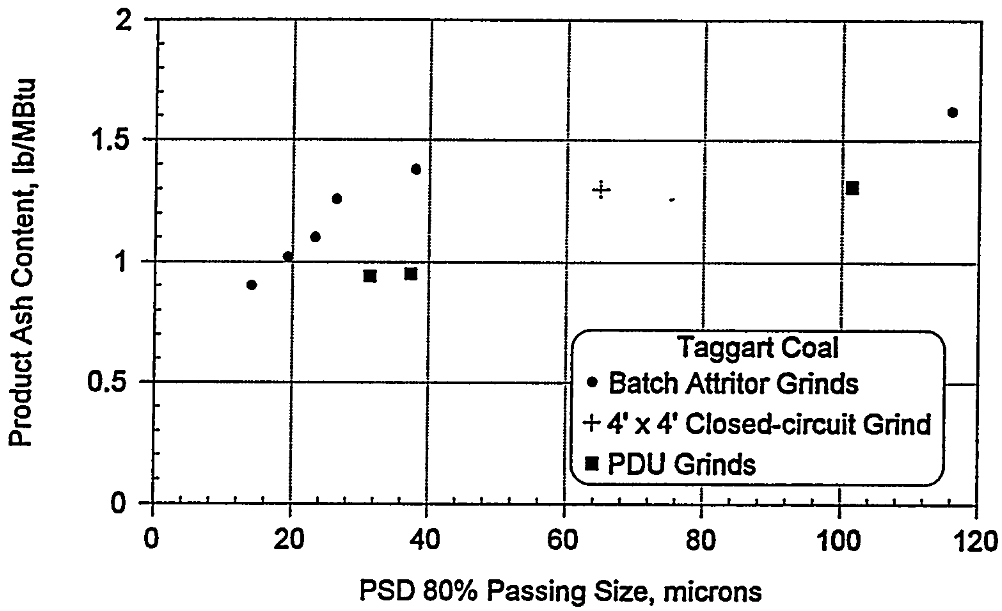


Figure 7. Taggart Coal, Product Ash vs Grind Size - Batch Testing

Continuous Testing - Seventeen continuous agglomeration tests were carried out during this quarter using two different Taggart coal feedstocks, both generated in the PDU grinding circuit. Operating conditions and results for all of these tests are shown in Appendix A.

Ten of these tests (T4A1-T4A10) utilized a feedstock with an 80% passing size (d_{80}) of approximately 75 microns. This grind was generated by operating the PDU grinding circuit in closed-circuit with cyclones and a 100-mesh screen, with the oversize material recycled to the secondary ball mill. The remaining seven tests (T5A1-T5A7) utilized feedstock with a d_{80} of approximately 33 microns. This grind was generated by operating the PDU grinding circuit in closed-circuit with cyclones and a 70-mesh screen, with the oversize material recycled to the Netzsch fine-grinding mill. Full particle size distributions for these two different PDU grinds of the Taggart coal are shown in Table 4.

The bench-scale agglomeration unit operated well for all of these tests, with the production of well formed agglomerates that screened easily. As with the bulk of previous testing, Btu recoveries were high (>94%) for all of these tests.

Results for all of these tests are presented in Figure 8 which shows Btu Recovery vs product ash content in lb ash/MBtu. As can be seen in Figure 8, the 75 micron d_{80} PDU grind did not provide sufficient liberation to achieve the target product ash content of 1 lb ash/MBtu. Instead, product ash contents in the 1.17-1.29 lb ash/MBtu range were achieved, with Btu recoveries of greater than 96%.

Table 4. Taggart Coal Agglomeration Feed PSD's - PDU Closed-Circuit Grinds

	75 micron d_{80}	33 Micron d_{80}
Microns	Cumulative % Passing	
212	100.00	100.00
150	99.40	99.52
106	92.82	98.46
75	80.14	96.08
53	68.18	93.05
45	57.17	88.84
38	50.00	84.32
30	43.87	77.60
20	30.11	59.12
15	23.62	47.26
10	16.16	32.56
8	13.32	26.52
6	9.90	20.35
4	5.87	12.58
3	3.92	8.24
2	2.09	3.66
1	0.50	0.51
MMD*	45.70	22.96

* Mass Mean Diameter = Sum of size interval midpoint (microns) times weight fraction of particles in that interval (percent)

In contrast, the 33 micron d_{80} PDU grind provided liberation resulting in product ash contents in the 1.0-1.15 range, with Btu recoveries approaching 99%. It is anticipated that even lower product ash values may be achieved with additional process optimization.

For those tests results shown in Figure 8, the primary process variables changed were the feed solids concentration and the coal feed rate, which in turn changed the residence time in both the high- and low-shear agglomeration steps. The results indicated that only the solids concentration had an effect on the product ash content, with the higher solids loading resulting in higher product ash levels. This trend can be seen in Figure 9 which presents Btu Recovery vs product ash content by feed solids concentration for the PDU grind with a d_{80} of 33 microns. While there appears to be some scatter in this limited data, a general trend of lower product ash contents at lower agglomeration solids concentration is evident.

Based on these results, the 33 micron d_{80} grind is considered sufficiently fine to achieve the project objective of 1 lb ash/MBtu. As such, it will be utilized for additional testing in the bench-scale unit, and for initial testing during PDU selective agglomeration operations with the Taggart coal under Subtask 9.3.

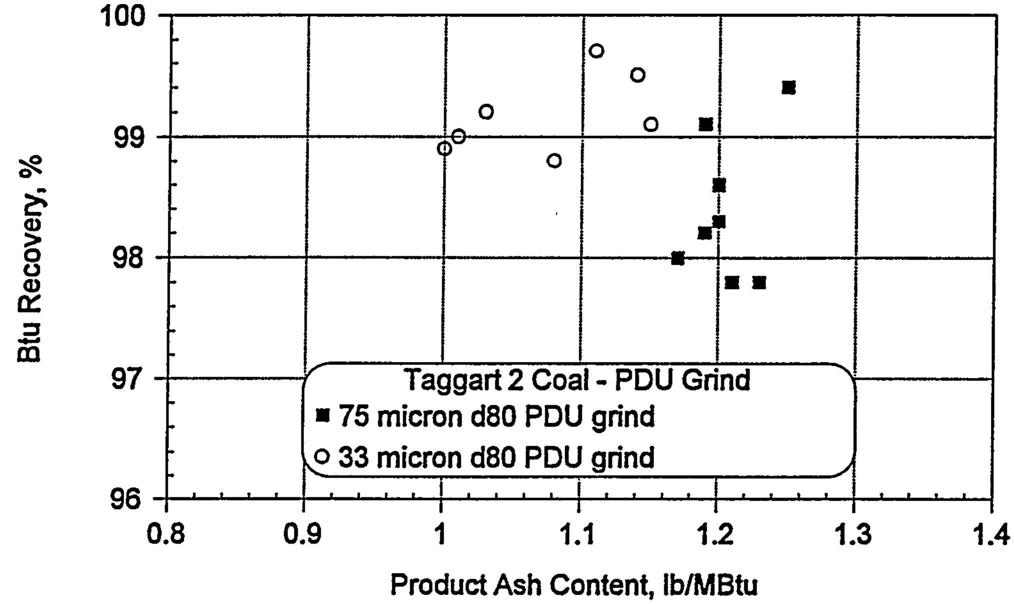


Figure 8. Taggart 2 Coal Continuous Agglomeration Results

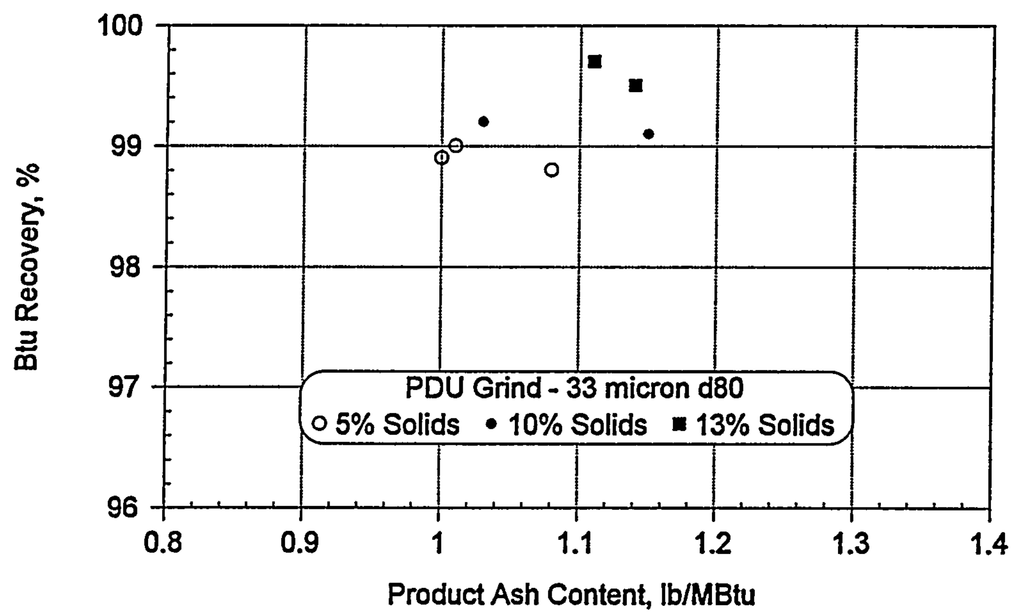


Figure 9. Taggart Agglomeration - Solids Concentration Effect

Reactor Design - As discussed in previous reports, much difficulty had been encountered when operating the low-shear vessel full, i.e., when utilizing both mixing zones separated by a horizontal baffle. Based on observations, it appeared that the transfer of agglomerates from the lower to upper section of the low-shear vessel was a bottleneck. As such, the opening in the horizontal baffle was increased from 1-1/2 inches to 5-1/2 inches diameter in an attempt to improve the flow to the upper zone.

Of the seventeen tests completed this reporting period, the last nine (as indicated in the Appendix) utilized this new horizontal baffle while operating the vessel full. To date, this modification has been successful, with good transport of agglomerates to the upper mixing zone observed. As such, future test work will utilize this horizontal baffle arrangement.

Continuous Steam Stripper Testing

No structured Steam-stripping tests for heptane recovery were carried out during November. Steam stripping of agglomerated coal continued on a regular basis, however, to allow for coal disposal. Random analysis of steam stripper products confirmed that heptane concentrations in the 5000 ppm (dry coal basis) range were produced.

Toxic Trace Elements

The reduction in toxic trace element concentrations accomplished by selective agglomeration was studied by assaying the products from selected parametric bench-scale tests and calculating the distribution of the trace elements between the clean coal and waste. Products from the tests identified in Table 5 were used for this work.

Table 5. Subtask 6.5 Tests Used for Trace Elements Analysis

Test	Coal	Nominal Top-Size	Residual Ash lb/MBtu	Heating Value Rec., %
E1A28	Elkhorn No. 3	100 mesh	1.80	98.1
I1A4	Indiana VII	325 mesh	1.95	99.0
S2A14	Sunnyside	150 mesh	1.76	99.1
10	Taggart	62 mesh	0.97	99.9
W1A11	Winifrede	20 μm	1.91	99.2

Except for the Elkhorn No. 3 coal, the grind sizes for these tests were the same as the grind sizes of the coals examined for trace element reduction during the bench-scale column flotation testing [11].

The toxic trace elements of interest were antimony, arsenic, beryllium, cadmium, chromium, cobalt, lead, manganese, mercury, nickel, selenium and chlorine. The analyses were done by Huffman Laboratories since they reported consistent results and low detection limits on a previous set of samples [10]. Huffman used perchloric acid decomposition and inductively coupled plasma (ICP) spectroscopy for most of the analyses. Mercury was by cold vapor spectroscopy, and chlorine was by a total halides coulometric method.

A listing of the ranges for reported elemental concentrations and mass balance closures is shown in Table 6. The average of all of the mass balance closures was 104%, and the closures were generally within 20% of the amount reported in the feed to the agglomeration circuit. Mass balance closures were not possible for mercury in the Taggart, Sunnyside, and Indiana VII coals because the amounts present in the clean coals were below the detection limit for mercury (0.01 part per million or 10 parts per billion). Mass balances were not calculated for cadmium since it was not detected in any of the samples except for the Elkhorn No. 3 and Indiana VII raw coals. The residual concentrations of the toxic trace elements in the various clean coals from agglomeration are compared in Figure 10.

The reductions in the various trace element concentrations accomplished during the selective agglomeration tests were calculated on a heating value basis. The calculated ranges of the trace-element reductions from the raw coal and from the washed selective agglomeration feed are shown in Table 7. As reported earlier for the column flotation samples [11], the concentrations of arsenic, beryllium, cobalt, lead, manganese, mercury, and selenium in the raw coals were clearly reduced by the combined conventional washing and advanced cleaning steps. Much of the reduction was accomplished during washing at the mine-site preparation plant. Very definitely, selective agglomeration reduced the concentrations of arsenic, chromium, manganese, and nickel remaining in the ground washed coals. It appears that chromium and nickel may have been introduced into the coal slurries during grinding and processing, and this could account for the erratic reduction in the concentrations of these two elements in the final clean coal.

Selective agglomeration had little impact upon the beryllium, cobalt, lead, mercury, and selenium concentrations, and it appears at times that the antimony and chlorine concentrations increased on a heating value basis. Such results could indicate a preferential association of these seven elements with the carbonaceous portion of the coal.

Table 6. Trace Element Concentration Results

	Trace Element Concentration, ppm										Mass Balance Closure, percent		
	Raw Coal		Agglomer. Feed		Clean Coal		Fine Refuse		Calculated Flotation Feed				
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Average
Antimony (Sb)	0.06	1.2	0.1	1.2	0.1	1.9	0.2	0.3	0.1	1.7	98	159	122
Arsenic (As)	0.83	7.3	0.7	4.7	0.6	2.4	7.6	42	0.9	4.3	92	127	103
Beryllium (Be)	0.8	3.2	0.5	2.8	0.5	2.5	0.6	5.3	0.5	2.7	93	102	98
Cadmium (Cd)	< 0.1	0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	n. d.	n. d.	n. d.
Chromium (Cr)	9.2	29	14	100	6	56	190	930	12.5	101	89	101	95
Cobalt (Co)	2.2	11	0.7	8.5	0.6	9	4.6	31	0.8	9.0	93	111	104
Lead (Pb)	3	14	2	9	2	7	13	42	2.3	8.9	85	127	107
Manganese (Mn)	27	200	7.3	44	4	17	81	700	7.3	43	95	99	97
Mercury (Hg)	0.02	0.04	< 0.01	0.03	< 0.01	0.02	0.07	0.12	< 0.01	0.03	n. d.	153*	122*
Nickel (Ni)	1.7	30	20	46	15	33	90	930	21.6	38	83	108	97
Selenium (Se)	0.78	5.9	0.6	2.5	0.5	2.3	1.3	6.9	0.6	2.5	94	104	99
Chlorine (Cl)	38	1180	47	1100	58	1080	31	214	58	1034	85	123	104
											Grand Average:		104

"<" = Below indicated detection limit.
"n. d." = not determined
* For two of five tests

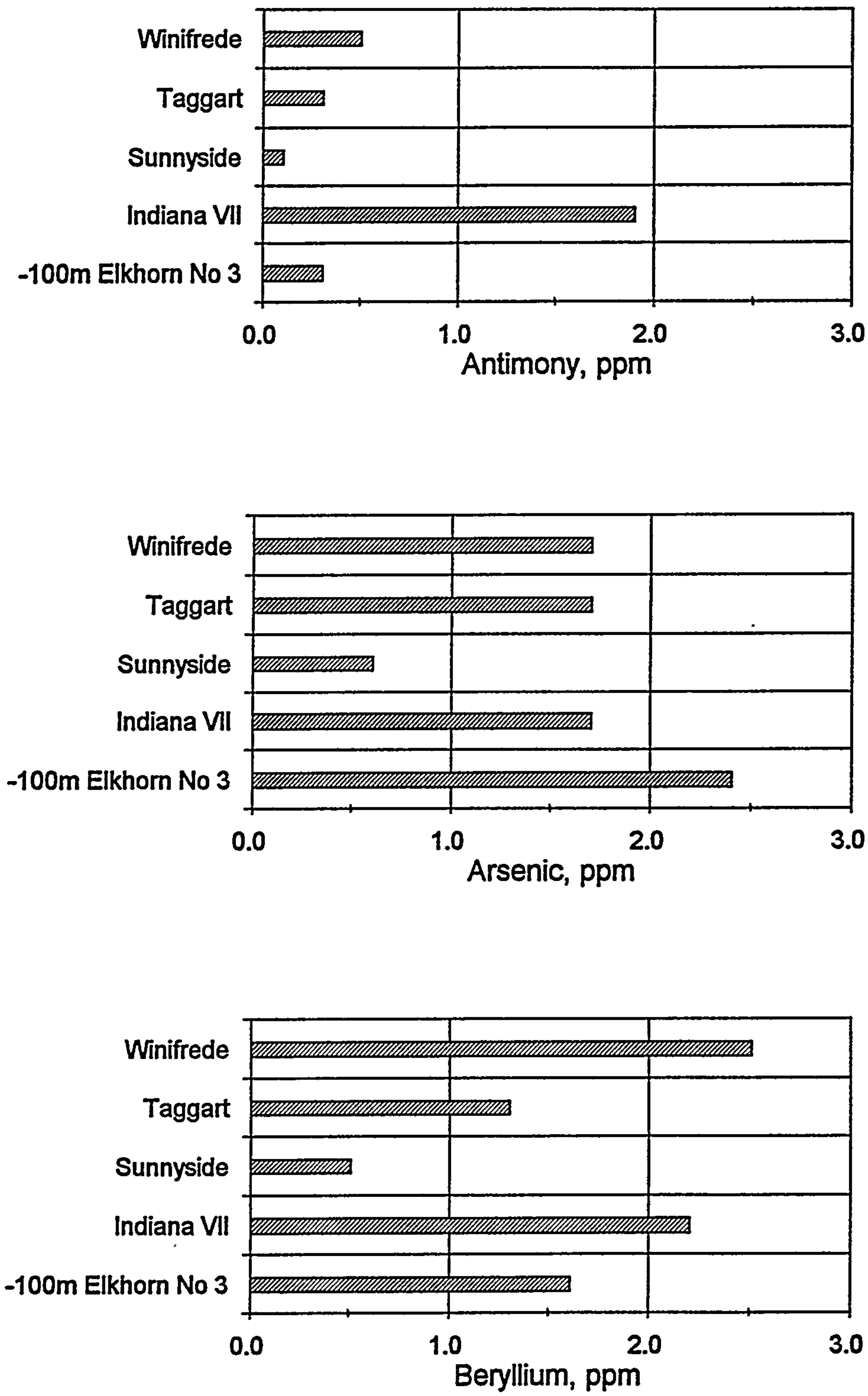
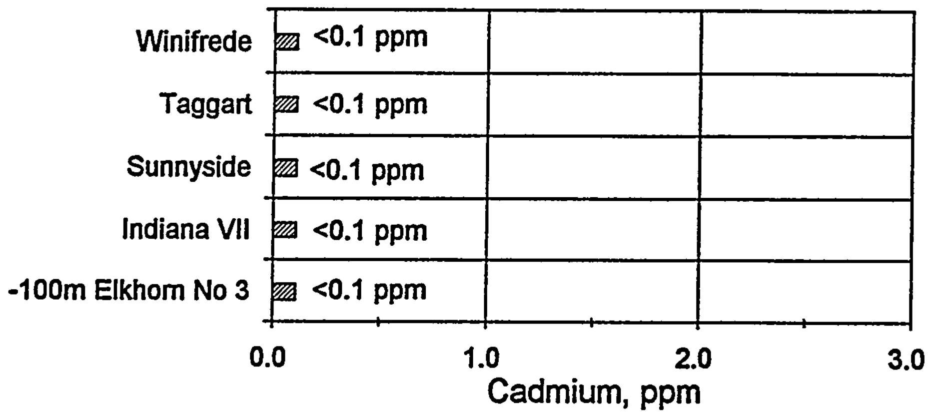
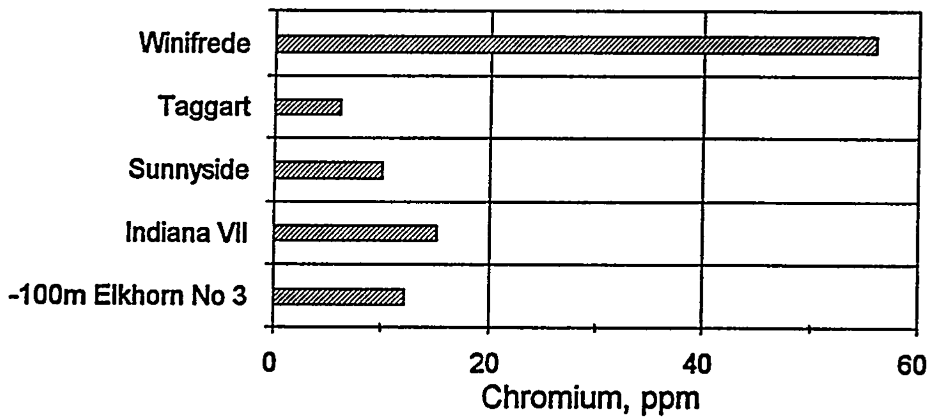


Figure 10. Residual Toxic Trace Elements in Clean Coals





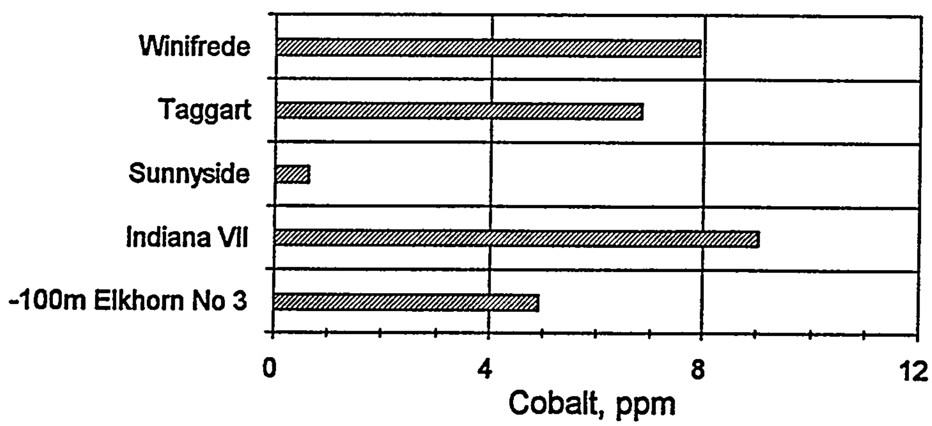


Figure 10 (Cont'd). Residual Toxic Trace Elements in Clean Coals

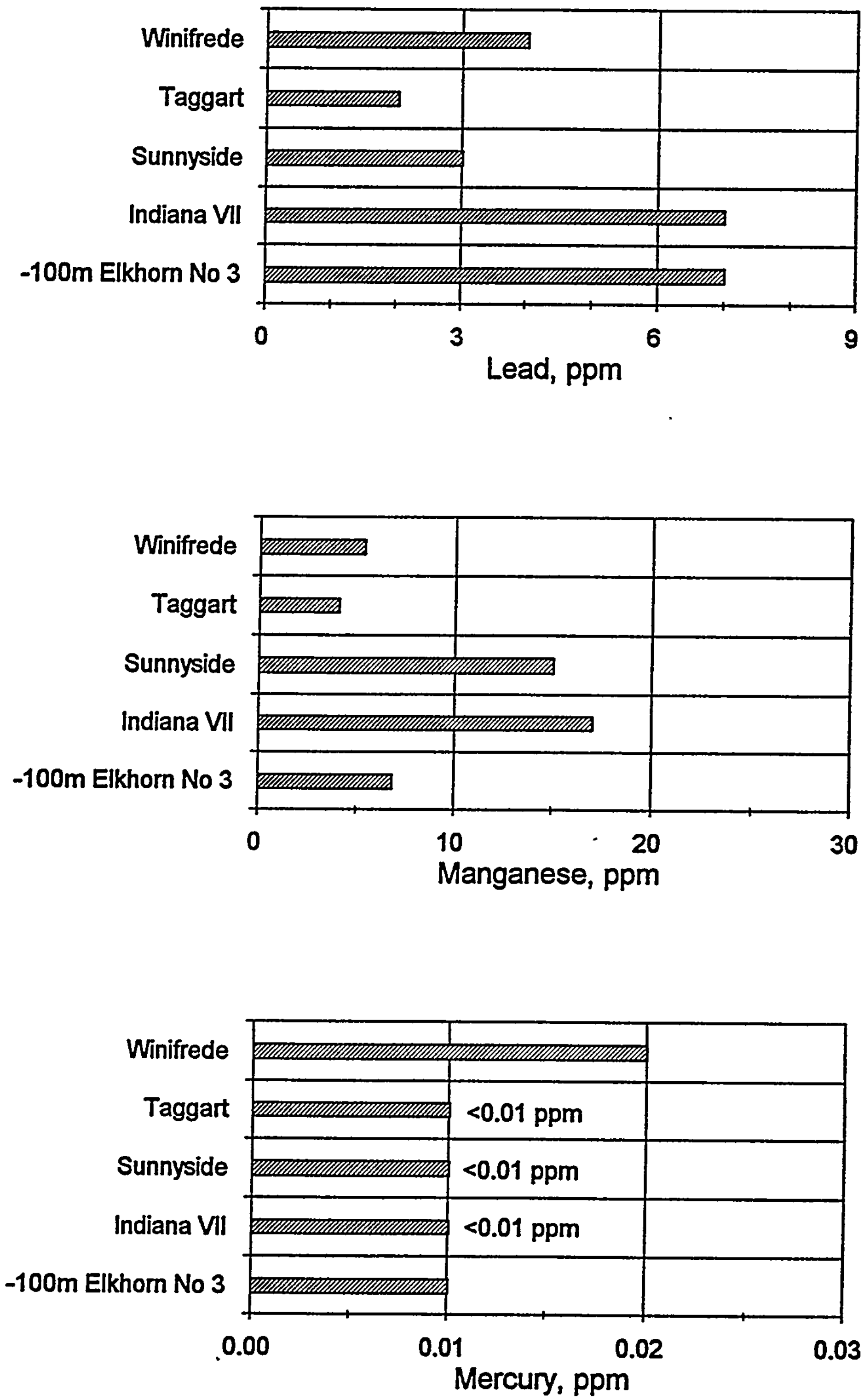
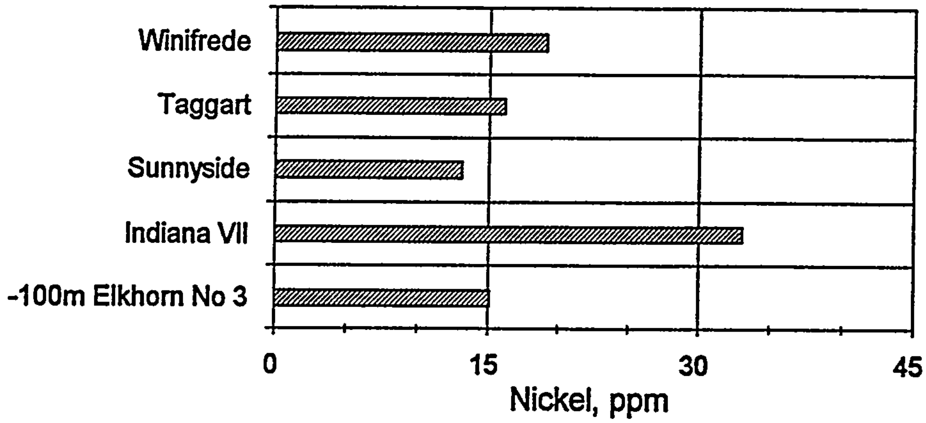
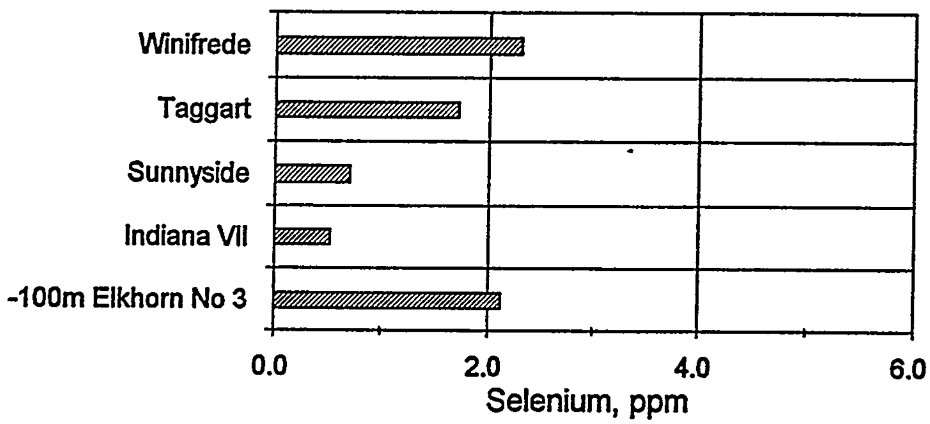


Figure 10. (Cont'd). Residual Toxic Trace Elements in Clean Coals





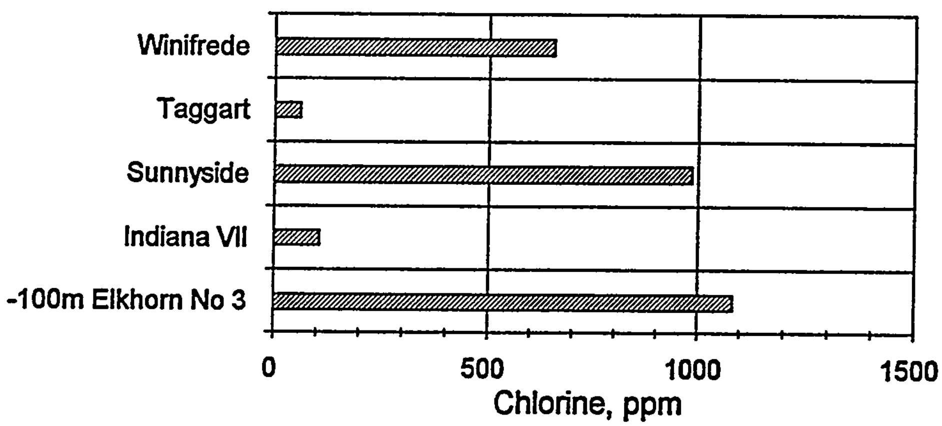


Figure 10 (Cont'd). Residual Toxic Trace Elements in Clean Coals

Table 7. Reduction in Toxic Trace Element Concentration, HHV Basis

	From Raw Coal, %			From Agglomeration Feed, %		
	Minimum	Maximum	Average	Minimum	Maximum	Average
Antimony (Sb)	-45	16	-13	-56	3	-19
Arsenic (As)	37	83	70	15	51	35
Beryllium (Be)	42	63	50	3	16	8
Cadmium (Cd)	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.
Chromium (Cr)	-59	81	33	48	69	57
Cobalt (Co)	34	76	57	2	17	9
Lead (Pb)	7	70	47	1	47	16
Manganese (Mn)	69	98	89	45	67	57
Mercury (Hg)	57	82	68	1	38	11
Nickel (Ni)	-564*	35	-8**	24	68	39
Selenium (Se)	32	76	63	1	23	12
Chlorine (Cl)	-58	54	13	-23	15	-4

Notes: Negative sign indicates increase in element lb/MBtu concentration
"n. d." = not determined
* Sunnyside Coal
** Not including Sunnyside Coal

TASK 7 PDU SELECTIVE AGGLOMERATION MODULE DETAILED DESIGN

Work was essentially completed on the detailed design of the PDU selective agglomeration module during previous reporting periods. Work carried out during the fourteenth quarter of this project involved the completion and issuing of a draft Task 7 report on February 20, 1996 [15].

This report will be finalized upon completion of the Selective Agglomeration Module Construction to reflect the as-built design and include equipment drawings from the vendors.

TASK 8 PDU AND ADVANCED COLUMN FLOTATION MODULE

The Task 8 work completed this reporting quarter focused on Subtask 8.4 PDU Operation and Clean Coal Production as discussed in the next section of this report.

Subtask 8.4 PDU Operation and Clean Coal Production

Operation of the PDU Flotation Module commenced in January 1996. Most efforts were directed to parametric testing of Taggart coal in the selective grinding circuit and Microcel™ column flotation unit. The selective grinding/classification circuit required more time and effort than originally anticipated due to difficulty obtaining the desired size consist/mineral liberation.

The PDU Flotation Module was also operated for an extended period of time in order to demonstrate the reliability of each unit operation as well as the overall system. The round-the clock continuous run was conducted during the week of March 25 with the Taggart coal. Aside from a failed belt splice on a tailings filter, the production run was entirely successful without any downtime.

Preparations are underway to ship the Taggart clean coal product generated during the extended production run to Penn State for slurry formulation and combustion testing.

Parametric Testing of PDU Selective Grinding/Classification Circuit

Parametric testing of the PDU selective grinding/classification circuit commenced during the month of January and was concluded in February. The test work was performed to determine the best grinding scenario for optimum liberation of mineral matter. Because the Taggart coal (from the Steer Branch mine) currently being evaluated in the PDU flotation module has a higher ash content than the Taggart coal (from the Wentz mine) used in the 12-inch Microcel™ column (4.01% vs. 2.08 %), additional liberation is required. Laboratory testing has shown that adequate liberation is achieved when this new Taggart coal sample is ground to a d_{80} of 50 microns (80 percent passing 50 microns). The challenge faced by the PDU staff was to determine which grinding arrangement would produce a similar size distribution.

Twenty-five tests aimed at optimizing the grinding circuit were conducted during the quarter. Specifically, the effects of feed rate, cyclone size, screen opening size, and circuit type (open or closed) were evaluated. The results are shown in Table 8.

With the exception of tests T-17 and T-19, all oversize material from the cyclones and screens was recirculated to the secondary ball mill. The oversize material was recirculated to the primary mill during test T-17 and to the Netzsch mill during test T-19.

Observation of the data indicates that the desired clean coal quality of 1 lb ash/MBtu was achieved at a d_{80} of 52 microns during test T-21. The changes made to the grinding circuit prior to the start of test T-21 were:

- Loading of the primary and secondary ball mills was increased from 10,000 lbs each to 13,628 lbs and 14,057 lbs respectively
- 140-mesh screen cloth was used in the Sizetec screens
- Sizetec screen sprays were changed from 35 degrees to 50 degrees

As a result of this effort, the following grinding arrangement was established for use in all Microcel™ parametric test work utilizing the Taggart coal:

- Feed Rate: 4,200 lb/hr
- Primary Water: 15 gpm
- Primary Mill Load: 13,628 pounds

- Secondary Mill Load: 14,057 pounds
- Cyclone Water: 25 gpm
- Cyclones: 3 inch
- Screen Cloth: 140 mesh
- Screen Water: 36 gpm
- Recirculation: Secondary Ball Mill

Table 8. Parametric Testing of PDU Flotation Module

Test #	Date	Screen Cloth Size	Cyclone Size	Feed Rate lb/hr	Fuel Oil lb/ton	MIBC lb/ton	% Solids	Air Rate CFM	Wash Water GPM	Particle Size d80	PDU Yield	PDU Energy Recov.	Product Ash lb/MBtu
T-1	1/10/96	70 M	3 inch	4,200	0.50	0.75	7.50	55	71	50	95.60	96.78	1.02
T-2	1/10/96	70 M	3 inch	4,200	0.50	0.75	7.50	55	71	115	96.45	97.26	1.20
T-3	1/11/96	70 M	N/A	4,200	0.50	0.75	7.50	55	71	100	96.25	97.82	1.30
T-4	1/16/96	100 M	N/A	4,200	0.50	0.75	7.50	55	71	85	96.30	97.22	1.70
T-5	1/18/96	100 M	N/A	4,200	0.50	0.50	7.50	55	71	?	95.85	97.90	1.52
T-6	1/23/96	100 M	3 inch	4,200	0.50	0.75	7.50	55	71	76	95.38	97.58	1.09
T-7	1/24/96	100 M	N/A	4,200	0.50	0.75	7.50	55	71	94	96.50	98.59	1.27
T-8	1/24/96	100 M	N/A	4,200	0.50	0.25	7.50	55	71	90	93.21	97.21	1.18
T-9	1/30/96	100 M	3 inch	4,200	0.50	0.75	7.50	55	71	72	93.38	96.59	1.21
T-10	1/30/96	100 M	3 inch	4,200	0.75	0.75	7.50	55	71	74	96.00	98.10	1.18
T-11	2/1/96	100 M	3 inch	4,200	0.25	0.75	N/R	55	71	70	96.18	96.74	1.33
T-12	2/5/96	100 M	3 inch	4,300	0.50	0.75	6.29	55	71	64	95.62	97.00	1.33
T-13	2/6/96	70 M	3 inch	4,300	0.50	0.75	6.69	55	71	78	95.54	97.38	1.17
T-14	2/13/96	70 M	3 inch	4,300	0.50	0.75	8.04	55	71	91	95.46	97.33	1.50
T-15	2/13/96	100 M	3 inch	4,300	0.50	0.75	6.90	55	71	74	97.15	98.39	1.52
T-16	2/14/96	100 M	3 inch	4,300	0.50	0.75	7.31	55	71	68	95.09	97.47	1.22
T-17	2/15/96	100 M	3 inch	4,300	0.50	0.75	4.57	55	71	61	95.38	97.82	1.13
T-17-B	2/19/96	100 M	2 inch	4,300	0.50	0.75	N/R	55	71	80	N/R	N/R	1.16
T-18-A	2/20/96	100 M	3 inch	4,300	0.50	0.75	6.04	55	71	74	94.91	97.52	1.14
T-18-B	2/20/96	100 M	3 inch	4,300	0.50	0.75	5.41	55	71	71	95.17	97.80	1.13
T-18-C	2/20/96	100 M	3 inch	4,300	0.50	0.75	4.91	55	71	65	96.48	98.01	1.85
T-18-D	2/20/96	100 M	3 inch	4,300	0.50	0.75	6.37	55	71	81	94.31	96.46	1.42
T-19	2/21/96	70 M	3 inch	4,200	0.50	0.50	6.95	55	71	36	93.27	96.18	1.16
T-20	2/26/96	140 M	3 inch	4,200	0.50	0.50	7.15	55	71	61	96.69	98.33	1.10
T-21	2/27/96	140 M	3 inch	4,200	0.50	0.50	6.61	55	71	52	95.06	97.14	0.97

Parametric Testing of PDU Flotation Module (Microcel™) - Taggart Coal

Parametric testing of the PDU Flotation Module (6 foot Microcel™) was completed during this reporting quarter. A test matrix was established to determine the effects of independent variables such as air rate, percent solids, feed rate, wash water, and reagent dosage on response variables such as product ash and yield. The test matrix is shown in Table 9. These results reveal that three proposed tests were removed from the original matrix while one was revised. The three tests removed were those where feed rate was varied while holding the Microcel™ wash water ratio constant. In addition, a midpoint replicate test was revised to determine the effects of an extremely low frother dosage. The reason for these modifications was to conserve Taggart coal for use in the Agglomeration Module.

Table 9. PDU Flotation Module Test Matrix

Test #	Collector	Frother	% Solids	Air Rate	Wash Water	Recirculation	Feed Rate
T-21	0.50 lb/ton	0.50 lb/ton	7.50	55	71	800	4,200
T-22	0.25 lb/ton	0.50 lb/ton	7.50	55	71	800	4,200
T-23	0.75 lb/ton	0.50 lb/ton	7.50	55	71	800	4,200
T-24	0.50 lb/ton	0.25 lb/ton	7.50	55	71	800	4,200
T-25	0.50 lb/ton	0.50 lb/ton	10.00	55	71	800	4,200
T-26	0.50 lb/ton	0.50 lb/ton	5.00	55	71	800	4,200
T-27	0.50 lb/ton	0.50 lb/ton	7.50	75	71	800	4,200
T-28	0.50 lb/ton	0.50 lb/ton	7.50	35	71	800	4,200
T-29	0.50 lb/ton	0.50 lb/ton	7.50	55	100	800	4,200
T-30	0.50 lb/ton	0.50 lb/ton	7.50	55	40	800	4,200
T-31	0.50 lb/ton	0.50 lb/ton	7.50	55	71	1000	4,200
T-32	0.50 lb/ton	0.50 lb/ton	7.50	55	71	600	4,200
T-33	0.50 lb/ton	0.50 lb/ton	7.50	55	71	800	4,200
T-34	0.50 lb/ton	0.75 lb/ton	7.50	55	71	800	4,200
T-35	0.50 lb/ton	0.10 lb/ton	7.50	35	71	800	4,200
T-36	0.50 lb/ton	0.50 lb/ton	7.50	55	71	800	3,800
T-37	0.50 lb/ton	0.50 lb/ton	7.50	55	71	800	3,200
T-38	0.50 lb/ton	0.50 lb/ton	7.50	55	71	800	5,500

Like the Taggart coal evaluated in the 12-inch Microcel™ unit (Fall, 1994), the feedstock used in the PDU flotation module was easily floatable. In fact, the natural floatability of the Taggart coal produced comparable yield and quality values regardless of the change in the input parameters. Noticeable changes in the yield and quality were typically observed only when the input parameters were varied dramatically. The results of the parametric testing are shown in Table 10. This data shows that the overall quality goal of 1 lb ash/MBtu was met or exceeded in four tests. The clean coal yield varied from 58.53 to 96.64% while the energy recovery and product quality varied from 60.13 to 97.97% and 0.77 to 1.23 lb ash/MBtu respectively.

The results of the parametric testing are also shown in Figures 11 and 12 which indicate that the target clean coal quality of 1 lb ash/MBtu should be optimally achieved at an approximate yield of 95% and an energy recovery of 97%. Future optimization test work should confirm this projection.

It is important to note that the grade-yield relationships found for the Taggart coal in the PDU are different than those found during the evaluation of the 12-inch Microcel™. The difference is the result of different feedstock qualities. Specifically, the ash content of the coal used in the 12-inch Microcel™ was 2.08% while that used in the PDU flotation circuit was 4.01%. The higher ash content normally results in lower yield values at similar product qualities.

It is also important to note that the d_{80} of the Microcel™ feed is directly related to the PDU feed rate. Specifically, the higher the feed rate, the larger the d_{80} value. As a result, the clean coal quality obtained when varying feed rate is the effect of both feed rate (retention time) and the resulting d_{80} (mineral liberation).

Table 10. Parametric Testing of PDU Flotation Module

Test #	Fuel Oil lb / ton	Frother lb/ton	% Solids	Air Rate CFM	Wash GPM	Recirc GPM	Feed lb/hr	Microcel d80	PDU Yield	Energy Recov	Ash lb/MBtu
T-21	0.50	0.50	6.61	55	71	800	4,184	52	95.06	97.15	0.97
T-22	0.25	0.50	7.10	55	71	800	4,188	58	93.52	96.23	1.03
T-23	0.75	0.50	7.17	55	71	800	4,196	52	95.54	97.64	1.01
T-24	0.50	0.25	5.69	55	71	800	4,189	50	88.40	90.75	0.91
T-25	0.50	0.50	6.63	55	71	800	4,200	51	94.36	96.90	0.99
T-26	0.50	0.50	4.54	55	71	800	4,223	51	94.20	96.41	1.05
T-25-B	0.50	0.50	9.85	55	71	800	4,203	53	94.14	97.26	1.16
T-27	0.50	0.50	5.31	75	71	800	4,206	48	93.50	96.15	1.03
T-28	0.50	0.50	6.59	35	71	800	4,200	49	94.94	96.55	1.14
T-29	0.50	0.50	5.65	55	100	800	4,211	51	92.90	95.28	1.07
T-30	0.50	0.50	5.70	55	40	800	4,150	58	96.64	97.97	1.22
T-31	0.50	0.50	6.07	55	71	1,000	4,200	58	92.11	94.85	1.23
T-32	0.50	0.50	6.02	55	71	600	4,190	51	91.12	93.79	1.03
T-33	0.50	0.50	6.74	55	71	800	4,191	50	93.93	96.33	1.14
T-34	0.50	0.50	6.94	35	71	800	4,217	59	87.67	91.01	1.16
T-35	0.50	0.75	6.61	55	71	800	4,193	51	90.36	93.35	1.22
T-36	0.50	0.10	7.40	55	71	800	4,200	53	58.53	60.13	0.77
T-37	0.50	0.50	6.87	55	71	800	3,800	55	93.58	95.69	1.16
T-38	0.50	0.50	5.96	55	71	800	3,192	56	94.83	96.78	1.10
T-39	0.50	0.50	7.05	55	71	800	5,500	63	94.75	96.77	1.16
MAX	0.75	0.75	9.85	75	100	1,000	5,500	63	96.64	97.97	1.23
MIN	0.25	0.10	4.54	35	40	600	3,192	48	58.53	60.13	0.77

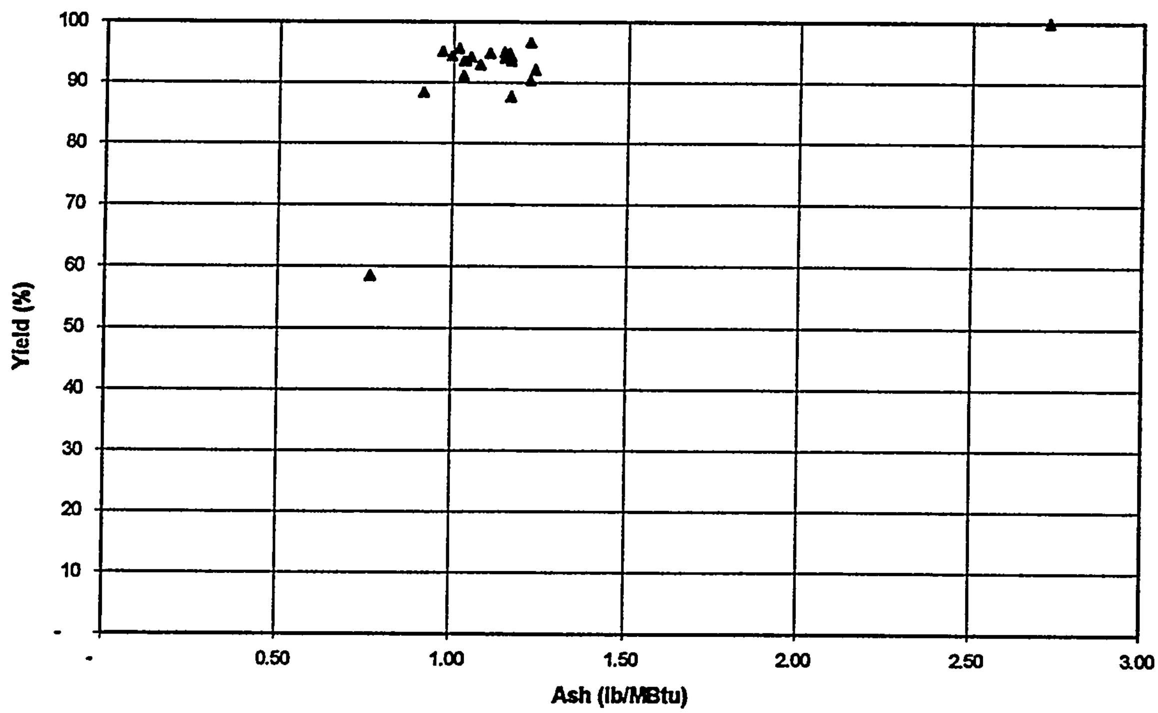


Figure 11. Taggart Coal Parametric Testing - Yield vs Product Ash

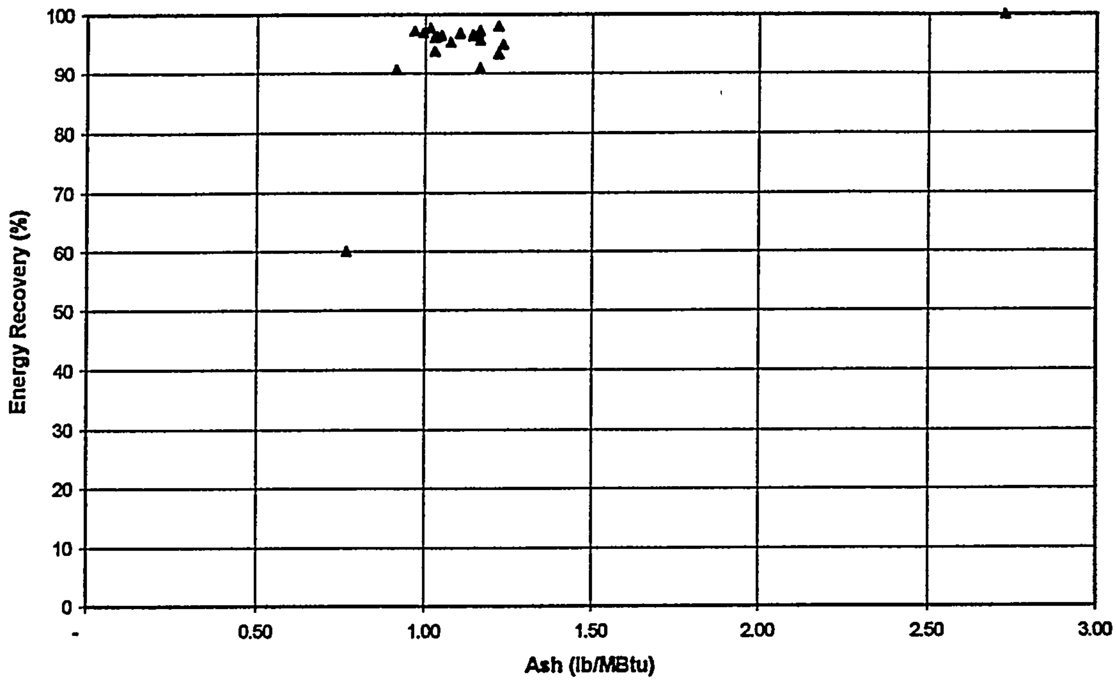


Figure 12. Taggart Coal Parametric Testing - Energy Recovery vs Product Ash

Optimization of PDU Flotation Module - Taggart Coal

Optimization of the PDU Flotation Module was planned for the month of March but had to be postponed to April in order to accommodate required plant maintenance and the extended production run. Future optimization tests on the other two coals will be performed prior to the extended run.

Extended Production Run of PDU Flotation Module - Taggart Coal

An extended production run of the PDU Flotation Module was successfully completed during the week of March 25, 1996. The effort commenced Monday, March 25 at 11:30 AM and concluded 72 hours later on Thursday, March 28 at 11:30 AM. Aside from a failed belt splice, the operation was entirely successful. The PDU Flotation Module was operated at the following parameters during the production exercise:

- Test #: T-40
- Coal: Taggart
- Nominal Feed Rate: 3,800 lb/hr
- Sizetec Screen Cloth: 100 mesh
- Grinding Circuit: Closed / 3" Cyclone / Screen / Secondary Mill
- Primary Water: 15 GPM
- Cyclone Water: 20 - 25 gpm

- Ground Product H_2O: 0 GPM
- Collector: 0.50 lb/ton (9 cc/min)
- Frother: 0.50 lb/ton (9 cc/min)
- % Solids Setpoint: 7.50
- Microcel Dilution: 0 gpm
- Air Rate: 55 CFM
- Microcel Level SP: 55 inches
- Spray Water: 71 gpm
- Launder Water: 0 gpm
- Microcel Recirculation: 800 GPM

The results of the production run are shown in Table 11.

Table 11. Extended Production Run - Taggart Coal

Date	Time	Total Hours	Feed lb / hr	Feed Solids	Feed Ash %	Tails Ash %	Product Moist %	Particle d80 (μ)	PDU Yield	BTU Rec %	Sulfur lb/MBtu	Ash lb/MBtu
3/25/96	1:00 P	1.50	3,824	7.95	3.46	31.18	32.94	N/A	94.51	96.37	0.46	1.23
3/25/96	7:00 P	7.50	3,824	8.01	3.46	38.49	33.80	N/A	95.35	96.47	0.47	1.17
3/26/96	1:00 A	13.50	3,824	7.79	3.41	42.89	33.17	N/A	95.99	97.67	0.47	1.17
3/26/96	7:00 A	19.50	3,824	7.70	3.48	43.21	34.48	N/A	96.01	97.42	0.47	1.22
3/26/96	1:00 P	25.50	3,824	7.64	3.61	40.85	32.78	68	95.63	97.00	0.47	1.28
3/26/96	7:00 P	31.50	3,824	7.67	3.65	35.96	32.77	72	94.72	96.04	0.47	1.24
3/27/96	1:00 A	37.50	3,824	7.77	3.78	35.30	31.65	71	94.20	96.08	0.47	1.23
3/27/96	7:00 A	43.50	3,824	7.29	3.57	38.10	32.01	73	95.20	96.74	0.47	1.22
3/27/96	1:00 P	49.50	3,824	7.20	3.75	36.40	32.08	N/A	94.61	96.73	0.48	1.26
3/27/96	7:00 P	55.50	3,824	6.86	3.80	40.93	32.09	N/A	94.99	96.71	0.47	1.23
3/28/96	1:00 A	61.50	3,824	6.82	3.76	44.23	31.19	N/A	95.36	97.39	0.47	1.19
3/28/96	7:00 A	67.50	3,824	7.35	3.60	45.61	31.30	N/A	95.89	97.59	0.47	1.20
3/28/96	11:30 A	72.00	3,824	6.96	3.44	42.29	33.90	N/A	96.07	97.57	0.46	1.23
AVG			3,824	7.46	3.60	39.65	32.63	71	95.27	96.91	0.47	1.22
MAX				8.01	3.80	45.61	34.48	73	96.07	97.67	0.48	1.28
MIN				6.82	3.41	31.18	31.19	68	94.20	96.04	0.46	1.17
SDEV				0.41	0.14	4.17	1.02	2	0.63	0.58	0.01	0.03

The PDU was operated at a feed rate of approximately 3,800 lb/hr due to filter capacity limitations previously determined during parametric testing. Had the feed rate been greater than 3,800 lb/hr, the PDU would have shut down prematurely due to a lack of clean coal slurry storage capacity.

Overall, 275,340 pounds of coal (137.67 tons) was processed in the PDU Flotation Module while 220 bags of clean coal filter cake was produced.

Delivery of Taggart Clean Coal to Penn State University

Communications during the quarter with DOE/PETC indicated that Penn State University (PSU) was interested in procuring the Taggart clean coal produced during the extended production run of the PDU Flotation Module. Supporting phone conversations with PSU personnel revealed that they were interested in receiving the material during the first week of April 1996. As a result, the extended production run was scheduled for the last week of March.

Approximately 200 tons of clean coal filter cake is slated for transport to PSU's Coal Utilization Laboratory. 199 supersacks with full bottom discharge were purchased for use and transport to PSU. Currently, PSU lab technicians are completing the shakedown/startup procedures for their coal slurry circuit. Final approval for shipment is expected during April 1996.

Primary and Secondary Ball Mill Loading

To improve the likelihood of producing a Taggart size distribution with a d_{80} of 50 microns, the primary and secondary ball mills were loaded with additional grinding media. Table 12 indicates each mill's current ball charge.

Table 12. Additional Ball Mill Loading

Size	Primary Mill Charge (lbs)	Secondary Mill Charge (lbs)
3 inch	1,056	0
2-1/2 inch	7,360	800
2 inch	2,292	0
1-1/2 inch	2,020	6,200
1 inch	900	6,057
1/2 inch	0	1,000
Total	13,628	14,057

Miscellaneous Accomplishments

The following miscellaneous accomplishments were made during the quarter:

- Precision Mechanical, Inc. installed a recirculation line from the fine grinding mill feed sump to the inlet of the secondary ball mill
- Replaced leaking inlet seal in secondary ball mill
- Installed hinged sample door on discharge end of Techweigh belt feeder
- Installed Microcel™ interface level indicator
- Crushed coal at Ralston Development Company
- Drained and cleaned Microcel™
- Drained and cleaned thickener
- Replaced existing Berthold nuclear density gauge with new model
- Drained and cleaned clarified water tank

- Inspected & cleaned ball seats on frother pump
- Installed air dryer on discharge of existing air compressor. Unit to prevent accumulation of unwanted water in instrument air lines
- Installed ventilation fan on east wall of pilot plant near flotation column to prevent accumulation of fuel oil and MIBC fumes
- Completed disassembly and disposal of scrap steel
- Repaired primary ball mill push water flow indicator (FIT-105)
- Cleaned air filters on tailings filter press feed pumps
- Checked accuracy of flowmeters FIT-204, FIT-205, and FIT-206
- Re-zeroed and adjusted I/P converter on flowmeter FIT-206
- Repaired drum filter discharge chute
- Backed up Honeywell CDAS hard disk
- Replaced v-belts on primary ball mill
- Installed Fuel Oil and MIBC drum storage cabinets for fire protection
- Installed ten (10) new "easy discharge" cloths on west Netzsch filter. Very little added performance observed from new fabric. Additional replacements are not recommended
- Precision Mechanical, Inc. re-routed air piping to Eimco filters and Netzsch fine grinding mill for better distribution during filter air drying cycle
- Relocated Fuel Oil and MIBC pumps adjacent to new drum storage cabinets
- Mech El, Inc. relocated power for Fuel and MIBC pumps
- Mech El, Inc. troubleshot and replaced bad circuit board in vibrating feeder control panel
- Repaired east Eimco filter conveyor guard
- Precision Mechanical, Inc. relocated filtrate sump 18 inches eastward to better accommodate clean coal super sack removal
- Cleaned SV-402 (clarified water tank makeup valve) and changed controller fuse
- Cleaned primary and secondary ball mill discharge troughs
- Lubricated PDU machinery / equipment

TASK 9 SELECTIVE AGGLOMERATION MODULE

Phase III of this project involves the construction and operation of a 2 t/hr selective agglomeration (SA) PDU module. This SA module will be integrated with the existing PDU facility constructed during Subtask 8.2 and currently being operated under Subtask 8.3.

During operation of the SA module, the existing coal handling and grinding circuits will be used to generate ground slurry feed for the selective agglomeration process. Similarly, the existing product and tailings dewatering circuits will also be used. As such, the SA module will essentially replace the Microcel™ flotation column, with the remainder of the plant remaining intact.

Just like the advanced flotation PDU, selective agglomeration process performance will be optimized at the 2 t/hr scale, and 200 ton lots of ultra-clean coal will be produced for each of the three test coals. Toxic trace element distributions will also be determined during the production runs. The ultra-clean coals will be delivered to DOE or some other user for end-use testing.

SUBTASK 9.1 SELECTIVE AGGLOMERATION MODULE CONSTRUCTION

Construction Contractor Selection

During the previous reporting quarter, Amax R&D (Entech Global), with help from Bechtel, prepared a Request for Quotation (RFQ) package describing the work and contract provisions in detail. This package was sent to the following four companies, based on their interest and qualifications.

- The Industrial Company (TIC), Steamboat Springs, CO
- Mech EL, Contracting, Inc. (MEI), Aurora, CO
- Western Industrial Contractors (WIC), Denver, CO
- Read Industrial Corporation, Wheat Ridge, CO

We received proposals from three of these organizations: TIC, MEI, and WIC. The proposals were evaluated by Amax R&D with help from Bechtel. The WIC proposal was eliminated because it was significantly higher in cost than the other two bids.

The bids from MEI and TIC were broken down by labor and material costs under 15 different categories. Amax R&D and Bechtel personnel evaluated these proposed costs and held discussions with each bidder to clarify the intended scope of work. Following these discussions, revised bids (within 6% of each other) were received from each contractor, confirming that both bids represented similar levels of effort and that the prices were competitive.

Based on the bid reviews and discussions with each contractor MEI was selected for the following reasons with all other things being equal:

- MEI provided a higher level of comfort in terms of electrical and instrumentation work completion

- MEI's proposed on-site personnel, especially the proposed project manager and supervisor for the electrical and instrumentation areas, appeared more qualified
- MEI's price was approximately 6% lower than TIC's price
- MEI is a local (Denver area) based contractor while TIC is not

Following the selection of Mech EL, Inc. to complete the construction, a number of changes were made on the Process and Instrument Diagrams, and their cost impact incorporated into the proposed contract budget. The construction contract was signed and Mech EL mobilized on site to begin construction during the week of March 11, 1996. Construction is scheduled for completion by August 16, 1996.

Construction Scope of work

MEI will construct the SA Module following the detailed design prepared by Bechtel. MEI will provide all the labor and materials for the construction except the major pieces of equipment which will be provided by Amax R&D.

The work to be performed by MEI will include:

- Excavation and concrete foundation work for equipment as required
- Structural steel installation and modifications
- Installation of equipment, piping, and valves
- Installation of MCC and electrical from existing switchgear to equipment
- Installation of various instruments and expanded process control system
- Sheeting and painting
- Assistance during plant shakedown testing

Material Requisitions

Material requisitions (MR) for the bulk of the capital equipment to be purchased for the construction of the Selective Agglomeration Module were issued during the last reporting quarter. MR's were issued for the remaining major capital equipment items during January and February of this year. The few outstanding items for which MR's were not issued are either small in nature or have a short delivery time and as such they will be procured once construction has progressed.

Equipment Purchasing

Orders were placed and Purchase Orders issued for a number of different capital equipment items during this quarter. A listing of these items, along with the selected vendor are shown in the Table 13. It is anticipated that the bulk of the capital equipment will be received in the mid April to late May time frame.

Table 13. Capital Equipment Purchased To Date

Equip #	Description	Vendor
300-C-02	High Shear Reactor-B	Process Fabricators, Inc.
300-C-03	Low Shear Reactor	"
300-C-04	Froth skimmer tank	"
300-C-05	Steam stripper A	"
300-C-06	Steam stripper B	"
300-C-07	Heptane/water separator	"
300-C-08	Heptane storage drum	"
300-C-10	Tailings surge drum	"
300-C-11	Slurry sampling pot	"
300-C-12	Emergency slop tank	"
300-C-13	Steam stripper A feed sump	"
300-C-15	Relief knock-out drum	"
300-E-01	Vapor condenser	Fluid Technology, Inc. (ITT)
300-E-02	Water preheater	"
300-E-03	Slurry cooler	"
300-E-04	Blanket gas cooler	"
400-E-01	Clarified water cooler	"
300-E-05	Vapor Condenser Air Cooler	CS Group
600-E-01	FGM Cooling Water Air Cooler	"
300-G-01	Agglomeration circuit feed pump	Quadna Pump Systems
300-G-02	Steam stripper A feed pump	"
300-G-03	Steam stripper B feed pump	"
300-G-04	Clean coal slurry pump	"
300-G-07	Tailings pump	"
600-G-02	Cooling water pump	"
600-G-03	FGM Cooling Water pump	"
300-G-08	Emergency slop tank pump	"
300-G-05	Heptane feed pump	Centennial Equipment
300-G-12	Floor sump pump	Canmac Engineering Sales
300-Y-03	High shear A impellers (4)	D.W. Daigler (Lightnin)
300-Y-04	High shear B agitator w/ VFD	"
300-Y-05	Low shear agitator w/VFD	"
300-Y-07	Froth skimmer paddle agitator	"
300-Y-08	Steam stripper feed sump agitator	"
300-Y-09	Steam stripper agitator	"
300-F-02	Flare stack	Flare Industries, Inc.
300-Y-06	Vibrating screen	Sizetech, Inc.
600-V-01	Water chiller	York International Corporation
300-V-01	Nitrogen Package w/N_2	General Air Service & Supply
--	Circuit breaker	--
--	Six VFD's	Reliance
--	6 Section MCC	Square D

With the purchase of this equipment, the following non-electrical/instrumentation items remain to be purchased and/or rented:

- Conditioner Tank Agitator - Used or new purchase
- Gas Holder - New purchase
- Carbon Filter - Rental or new purchase
- Boiler Package - Rental or used purchase

In addition, all of the process instrumentation items have yet to be purchased.

The remainder of the capital equipment to be utilized for the PDU Selective Agglomeration Module are used equipment already on-site. These equipment require various levels of reconditioning work and miscellaneous replacement parts. To this end, the used agitator to be utilized for High-Shear Reactor A (300-Y-03) was shipped to the Ekato Service Center in Denham Springs, LA for seal replacement and overall unit check-out.

Construction

Construction began on March 11, 1996. Work completed on the construction of the selective agglomeration PDU in Plant Area 300 during this quarter was as follows:

- Removal of the air handling unit from the roof
- Removal of the roof
- Demolition of the existing steel
- Removal of the existing concrete floor
- Excavation and disposal of existing gravel
- Back-filling and compaction of new fill material
- Pouring of new concrete pad
- Relocation of oven transformer
- Relocation of miscellaneous electrical installations in preparation of new MCC installations
- Running of various feeder conduits from existing switch gear to new MCC location
- Running of various feeder conduits to new DCS location

Based on the work completed as of the end of this reporting period, Table 14 presents the percent completion of each construction milestone and the overall project.

Table 14. Construction Progress by Milestone

Item	Event	Percent Complete
1	Mobilization, excavation, concrete, and foundation work	86
2	Structural Steel & Platework	12
3	Equipment Installation	--
4	Piping Installation	--
5	Electrical & instrumentation installation	13
6	Ventilation & fire protection installation	--
7	Sheeting & Painting	--
8	Shakedown testing, cleanup, & demobilization	--
	Total Contract	**13**

PLANS FOR NEXT QUARTER

Following are the activities anticipated for continued work and/or completion during the fifteenth quarterly reporting period, April - June, 1996:

- Subtask 3.2 - Near Term Applications testing will continue as follows
  - Complete the parametric tests planned for the 30-inch Microcel™ column at the Lady Dunn Preparation Plant.
  - Preparation and submission of a paper describing the joint DOE/Cannelton near-term application effort at Lady Dunn for presentation at the CoalPrep 96 conference.
- Under Subtask 3.3 batch parametric testing will continue along with determinations of butane absorption onto the coal surface.
- Test work will continue on Subtask 6.4, Selective Agglomeration CWF Formulation Studies.
- Test work will continue on Subtask 6.5, Selective Agglomeration Bench-scale Testing.
- Subtask 8.4 efforts will be directed toward the following:
  - Complete optimization testing of Taggart coal
  - Complete parametric testing of Indiana VII coal
  - Complete extended production run of Indiana VII coal
  - Commence parametric testing of Hiawatha coal
  - Commence extended production run of Hiawatha coal
- Under Subtask 9.1, the PDU Selective Agglomeration Module construction will continue.

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APPENDIX A

Taggart Coal Agglomeration Results

Appendix A - Taggart Coal - 25 lb/hr Agglomeration Test Conditions and Results

Run	Grind Top Size Mesh	System Configuration High Shear Imp in	High Shear Tip m/s	High Shear RT min	Low Shear Imp in	Low Shear Tip m/s	Low Shear RT min	Scrn Incl deg	Feed Solids %	Feed Solids lb/hr	Feed % ash	Feed Hept %.daf	Screen Product % Sol	Screen Product Size mm	Without Froth Skimming Prod % ash	Tails % ash	Agg Perform Yield %	Agg Perform Btu Rec.%	Agg Perform AR %	With Froth Skimming Product % ash	Product #ash/ MBtu	Tails % ash	Agg Perform Yield %	Agg Perform Btu Rec.%	Agg Perform AR %	ROM Perfrom Yield %	ROM Perfrom Btu Rec.%	ROM Perfrom AR %
T4A1	100*	2.4	15.0	1.3	4.8	4.8	3.2	38	9.6	25.8	3.79	27.5	43.7	2-3	1.78	61.3	96.6	98.8	54.6	1.79	1.19	66.3	96.9	99.1	54.2	62.0	93.4	98.1
T4A2	100*	2.4	15.0	1.3	4.8	4.8	3.2	38	9.5	25.8	3.71	26.0	45.5	<2	1.81	52.9	96.3	98.3	53.0	1.81	1.20	57.6	96.6	98.6	52.8	61.8	93.0	98.0
T4A3	100*	2.4	7.0	1.4	4.8	4.8	3.2	42	9.3	24.8	3.69	27.0	45.2	<1.5	1.80	44.0	95.5	97.5	53.4	1.81	1.20	52.0	96.3	98.3	52.8	61.6	92.7	98.0
T4A4	100*	2.4	7.0	1.4	4.8	3.2	3.2	42	9.6	25.4	3.75	26.4	45.7	<2	1.79	44.0	95.4	97.4	54.5	1.80	1.19	51.7	96.1	98.2	54.0	61.5	92.6	98.1
T4A5	100*	2.4	15.0	0.7	4.8	4.8	1.7	42	5.0	25.3	3.68	27.2	39.5	<1	1.82	30.5	93.5	95.5	53.7	1.83	1.21	46.0	95.8	97.8	52.4	61.3	92.2	98.0
T4A6	100*	2.4	15.0	0.7	4.8	4.8	3.6	42	4.9	24.8	3.68	24.7	38.3	<.5	1.83	20.4	90.0	91.9	55.2	1.83	1.21	36.6	94.7	96.6	52.9	60.6	91.1	98.0
T4A7	100*	2.4	15.0	0.7	4.8	4.8	3.7	42	4.9	24.6	3.70	27.3	47.5	<1.5	1.77	41.0	95.1	97.1	54.5	1.77	1.17	48.8	95.9	98.0	54.0	61.4	92.4	98.1
T4A8	100*	2.4	15.0	0.7	4.8	4.8	3.5	42	9.6	50.2	3.75	25.8	49.1	<2	1.89	70.5	97.3	99.3	51.0	1.89	1.25	74.2	97.4	99.4	50.8	62.4	93.8	97.9
T4A9***	100*	2.4	15.0	1.4	4.8	4.8	7	42	9.4	24.6	3.67	24.1	42.0	<1	1.95	25.4	92.7	94.4	50.8	1.95	1.29	36.2	95.0	96.8	49.6	60.8	91.3	97.9
T4A10***	100*	2.4	15.0	1.4	4.8	4.8	6.9	42	9.6	25.3	3.70	25.0	56.7	<2	1.85	38.2	94.9	96.9	52.5	1.86	1.23	45.9	95.8	97.8	52.0	61.3	92.2	98.0
T5A1***	70**	2.4	15.0	0.7	4.8	4.8	3.6	42	5.0	25.4	4.18	30.2	34.7	<1	1.62	33.8	92.0	94.7	64.3	1.64	1.08	66.5	96.1	98.8	62.4	61.5	93.2	98.4
T5A2***	70**	2.4	15.0	0.7	4.8	4.8	3.6	42	5.0	25.1	4.16	32.1	43.3	<1.5	1.53	55.3	95.1	97.9	65.0	1.53	1.01	70.8	96.2	99.0	64.6	61.6	93.4	98.5
T5A3***	70**	2.4	15.0	0.7	4.8	4.8	3.6	42	5.0	24.9	4.15	33.2	46.9	<2.5	1.51	63.6	95.7	98.6	65.2	1.51	1.00	68.9	96.1	98.9	65.0	61.5	93.3	98.5
T5A4***	70*	2.4	15.0	1.4	4.8	4.8	7.2	42	10.1	25.4	4.16	30.3	51.5	<1.5	1.55	62.7	95.7	98.5	64.3	1.56	1.03	72.9	96.4	99.2	63.9	61.7	93.5	98.5
T5A5***	70*	2.4	15.0	1.4	4.8	3.2	7.1	42	10.0	25.6	4.15	29.3	45.4	<1	1.73	52.3	95.2	97.8	60.3	1.73	1.15	70.4	96.5	99.1	59.7	61.7	93.4	98.3
T5A6***	70*	2.4	10.8	0.9	4.8	4.8	2.2	42	13.3	50.5	4.15	31.2	41.7	<1	1.72	59.4	95.8	98.4	60.3	1.72	1.14	78.4	96.8	99.5	59.8	62.0	93.8	98.3
T5A7***	70*	2.4	15.0	0.9	4.8	4.8	2.2	42	13.1	50.2	4.17	32.4	49.9	<2	1.67	79.7	96.8	99.5	61.2	1.67	1.11	83.5	96.9	99.7	61.1	62.0	94.0	98.4

* 75 micron D80 PDU grind

* 33 micron D80 PDU grind

*** Modified low shear horizontal baffle