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Engineering Development of Advanced Physical Fine Coal Cleaning for Premium Fuel Applications

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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 September 1997.

During Quarter 19 (April - June, 1997) the Subtask 3.2 topical report covering the engineering development of near term applications of the advanced flotation and selective agglomeration processes was issued. Work continued this quarter on a second topical report covering Subtask 3.3 activities, which investigated the development of a novel hydrophobic dewatering process.

Under Subtask 6.5, the topical report covering the continuous bench-scale selective agglomeration testing was issued, completing all Task 6 work.

As part of Subtask 8.1, the final four truckloads of Indiana VII coal were ordered for use in the Subtask 9.3 PDU selective agglomeration testing. Under Subtask 8.5, work continued on the advanced froth flotation topical report.

Under Subtask 9.3, the Hiawatha coal parametric testing, Hiawatha coal production run, Taggart coal parametric testing, and the Taggart coal Production run were all completed this reporting quarter. Work also began on the Indiana VII coal parametric testing. Results indicate that the product ash specification of 2 lb/MBtu, 1 lb/MBtu for the Taggart coal, could be met at grind size D_{80}s of 40, 30, and 20 microns for the Hiawatha, Taggart, and Indiana VII coals, respectively.

As part of Subtask 9.4, work began on the selective agglomeration topical report with the analysis of Hiawatha and Taggart coal production run samples for ash properties.

Task 10 covers the decommissioning of the PDU and disposal of equipment and materials. A list of available equipment was submitted to DOE to determine if there is any interest in this equipment by FETC or any of its contractors.

The Task 11 topical report "Commercial CWF Production Cost Study", an economic assessment of the production of premium fuel by advanced flotation and selective agglomeration, was issued this quarter. The findings of this report indicate that the advanced flotation plant would be less expensive to place into service than the selective agglomeration plant. Total annualized costs for producing CWF by the two cleaning methods were estimated to be $2.15/MBtu and $2.42/MBtu (including the delivered cost of the feed coals) for advanced column flotation and selective agglomeration, respectively. Also under Task 11, initial drafts of a number of the sections of the project final report were prepared.

TABLE OF CONTENTS

Section **Page**

List of Tables

Table **Page**

List of Figures

Figure **Page**

EXECUTIVE SUMMARY

This project is a major step in the Department of Energy's (DOE) 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 September 1997. This report discusses the progress made during the 19th quarter of the project from April 1 to June 30, 1997.

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, Inc. 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.

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 testing, along with design, construction, and operation of a 2 ton/hr PDU.

Tonnage quantities of the ultra-clean coals are being produced in the PDU for combustion testing. Near-term application of advanced cleaning technologies to existing coal preparation plants was also investigated.

ACCOMPLISHMENTS DURING QUARTER

Activities continued during April - June 1997 on Phases I, II, and III of the project. Work was carried out under Tasks 3, 6, 8, 9, 10, and 11 as described below.

Task 3 Development of Near-Term Applications

Under Subtask 3.2, the Lady Dunn Preparation Plant of the Cannelton Coal Company in West Virginia served as the host site for studying a near-term application of advanced column flotation technology. The on-site engineering development testing was supervised by the Center for Coal and Mineral Processing (CCMP) at Virginia Tech. A topical report covering this Subtask 3.2 work, as well as the engineering analyses completed under Subtask 3.1, was issued on April 25, 1997.

Subtask 3.3, investigating a novel dewatering process for advanced flotation products, was also performed by CCMP. The topical report covering the Subtask 3.3 dewatering work is currently being written.

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, 6.4 CWF Formulation Studies, and 6.6 Conceptual Design of the Selective Agglomeration PDU Module have been completed and were reported during previous quarters. There was activity on Subtask 6.5 Bench-scale Testing and Process Scale-up during this quarter.

Subtask 6.5 Bench-Scale Testing and Process Scale-up

The Subtask 6.5 Topical Report was completed this reporting quarter and issued on June 27, 1997. This report represents the findings of Subtask 6.5 Selective Agglomeration Bench-Scale Testing and Process Scale-up. During this work, six project coals, namely Winifrede, Elkhorn No. 3, Sunnyside, Taggart, Indiana VII, and Hiawatha were processed in a 25 lb/hr continuous selective agglomeration bench-scale test unit.

During Subtask 6.5, the coals were ground in pilot scale equipment and then cleaned by the selective agglomeration process consisting of a high-shear step, a low-shear step, and product recovery by screening. In order to meet the product ash specification of 2 lb/MBtu (1 lb/MBtu for the Taggart coal), the coals had to be ground to various sizes ranging from the coarsest grind for the Elkhorn No. 3 coal with an 80% passing size of 68 microns to the finest grind for the Winifrede coal with an 80% passing size of 12 microns. Btu recoveries were generally in the 98 to 99% range. Typically, 30 to 60 seconds of high-shear residence time at impeller tip speeds from 10 to 18 m/s were required, followed by 2 to 5 minutes low-shear residence time at impeller tip speeds of 5 m/s to form 2 to 3 mm agglomerates. Screening to recover the product was found to be most affected by the size of the agglomerates produced in low shear, with larger (2 to 3 mm) agglomerates providing the lowest ash product.

Following agglomeration, the heptane was recovered from the product by direct contact steam stripping in two stages. The first stage of stripping recovered the bulk of the heptane and was carried out at about 5 minutes residence time and ambient pressure boiling points. The second stage of steam stripping removed additional heptane during 10 minutes of residence time at elevated pressures and temperatures. Residual heptane concentrations were typically in the 1000 to 3000 ppm range (on a dry solids basis), with minimal heptane found in the process tailings when successful agglomeration was achieved.

Task 8 PDU and Advanced Column Flotation Module

Work carried out this reporting quarter under Task 8 focused on Subtask 8.1 Coal Selection and Procurement and Subtask 8.5 Advanced Flotation Topical Report.

Subtask 8.1 Coal Selection and Procurement

Two hundred and fifteen tons of Indiana VII washed compliance coal was purchased from the Kindill No. 3 Mine during May for the PDU selective agglomeration module operation. Kindill No. 3 is the new name for the Minnehaha Mine which was the source of the Indiana VII coal during the flotation and agglomeration Phase I laboratory and bench-scale process development work as well as the Phase II 2 t/hr PDU advanced flotation module operation. The analysis provided with the coal showed 18% moisture, 7.9% ash and 0.38% sulfur. Four more loads are scheduled for delivery in July for completion of the PDU selective agglomeration module production run.

All of the left-over coal that had been stored at the American Coal Company yard in Denver was given to the Public Service Company of Colorado for disposal at their Arapaho Station. All of the left-over Taggart and Hiawatha coals at Ralston Development Company and at Amax R&D have also been discarded.

Subtask 8.5 Advanced Flotation Topical Report

Work continued on the Froth Flotation Topical Report during this reporting quarter. Completion of this report is scheduled for next month (July, 1997).

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 was integrated with the existing PDU facility constructed during Subtask 8.2 and operated under Subtask 8.4. During operation of the SA module, the existing coal handling and grinding circuits are being used to produce ground coal slurry feed for the selective agglomeration process. Similarly, the existing product and tailings dewatering circuits are also being used.

Just like the advanced flotation PDU, selective agglomeration process performance is being optimized at the 2 t/hr scale, and bulk lots of ultra-clean coal are being produced for each of the three test coals. Toxic trace element distributions are also being determined during the production runs. The ultra-clean coals are being delivered to Penn State for end-use testing.

As of the end of the previous reporting quarter, construction, start-up, and shakedown testing of the PDU SA module had been completed and reported upon. The bulk of the Hiawatha coal parametric testing was also completed during the previous quarter.

Subtask 9.3 SA Module Operation and Clean Coal Production

During this reporting quarter, the following Subtask 9.3 activities were completed:

- Hiawatha coal parametric testing
- Hiawatha coal production run
- Taggart coal parametric testing
- Taggart coal production run
- The bulk of the Indiana VII coal parametric testing

Hiawatha Coal Parametric Testing - Parametric testing of the Hiawatha Coal was concluded with the completion of six additional parametric tests covering the following:

- Evaluation of the froth skimmer unit operation
- Evaluation of high-shear energy input
- Confirmation testing prior to production run

Froth Skimmer Evaluation - Testing of the froth skimmer with and without the use of nitrogen was completed for comparison purposes. Results of this testing indicated that there was no effect on plant performance when the nitrogen purge was used as compared to when it was not used. In particular, there was no effect (not attributable to small changes in grind size) on the ash content of the froth skimmer product, froth skimmer tailings, final plant tailings, and final plant product streams.

In general it was found throughout the Hiawatha coal testing, that the froth skimmer is ineffective in removing carbonaceous material from the plant tailings stream. This is believed to be due to the presence of too much surface area for froth collection (leading to a thin froth layer), the possible readsorbtion of heptane from the gas blanket system on to the material that floats (leading to the formation of a stiff cake layer), and poor distribution of the nitrogen bubbles throughout the froth skimmer.

High Shear Evaluation - One test run was completed during this quarter to evaluate the effect of a lower high-shear energy input on the selective agglomeration plant performance. For this test a high-shear impeller tip speed of 11 m/s was used, as compared to the 14 m/s tip speed tested previously. This reduced impeller tip speed resulted in a reduction of high-shear energy input by almost half, from approximately 28 kwhr/ton feed coal (11.2 kwhr/1000 gallon slurry) to 16.1 kwhr/ton feed coal (6.2 kwhr/1000 gallon slurry). The results from this test indicated no detrimental effect on either product quality or plant Btu recovery as a result of this high-shear energy reduction.

Confirmation Testing - Prior to the start of the production run, one test run was completed at constant operating conditions, in which three separate sample sets were obtained. This was carried out to confirm that the conditions chosen for the production run would consistently provide a product which met the target ash content of 2 lb/MBtu. Results of this test did confirm acceptable plant performance over an extended time period, and as such, the identical conditions were used for the Hiawatha coal production run.

Hiawatha Coal Production Run - The Hiawatha coal production run was carried out during the week of April 14, 1997. The production run met the 2 lb ash/MBtu product specification for all of the sample periods evaluated. The following is a list of average values of the most critical production run operating conditions and results:

- Dry coal feed rate - 3839 lb/hr
- Plant feed grind D80 - 42.1 microns
- Heptane dosage utilized - 31.3% on a dry ash free coal basis
- Total agglomeration (high- and low-shear) energy input - 17 kwhr/ton feed coal (6.9 kwhr/1000 gallon slurry)
- Screen spray water rate - 500 gallons/ton product
- Steam consumption - 1380 lb/ton dry product (1.8 lb/gallon slurry stripped)
- Plant product ash content - 1.93 lb/MBtu (2.78%)
- Plant product residual heptane content - 2951 ppm on a dry coal basis
- Plant Tailings ash content - 80.4%
- Plant tailings residual heptane content - 1470 ppm on a dry solids basis
- Plant yield - 92.8%
- Plant Btu recovery - 98.9%

During the Hiawatha coal production run there were two plant shutdowns. Both shutdowns were due to the failure of the stripping circuit feed diaphragm pump. The first shutdown was for 1 hour to clear blockage in the pump suction and discharge lines. The second shutdown was of 14-1/2 hours duration during which failed diaphragms were replaced and the pump rebuilt. As such, of the total 71 hour run duration, there were 15-1/2 hours of down time.

Taggart Coal Parametric Testing - Based on the parametric testing results from the Hiawatha coal testing, it was determined that the following operating conditions would not be evaluated for the Taggart coal:

- Vibrating screen in uphill or level orientation since downhill orientation was shown to reduce both agglomerate bed depth and product ash content.
- Low-shear vessel operated full since this was found to make agglomerate growth difficult to control and the half-full configuration provided sufficient residence time for agglomerate growth to the 2 to 3 mm size range.
- Low (<10%) high-shear solids concentration since these were found to provide no reduction in ash content while increasing high-shear energy requirements.

The Taggart coal parametric testing was carried out with a total of 23 operating test points evaluated. Work completed included the following:

- Evaluation of high-shear A impeller tip speed and energy input effects
- Evaluation of high-shear B impeller tip speed and energy input effects
- Evaluation of low-shear solids concentration effects
- Evaluation of low-shear impeller tip speed and energy input effects
- Evaluation of stripping circuit solids concentration effects
- Testing to determine the grinding requirements to achieve the target 1 lb ash/MBtu product specification

High-Shear Impeller Tip Speed Evaluation - During the high-shear evaluation testing of both high-shear vessels, A and B, the impeller tip speed was incrementally reduced to determine the point at which inversion at the high-shear discharge was lost. For each high-shear energy input level (impeller tip speed), low-shear samples were taken, rinsed on a 48-mesh screen, and the product and tailings analyzed for ash content.

As expected, the quality of the inversion exiting the high-shear circuit decreased as the high-shear impeller tip speed was reduced. However, it was found that even under high-shear conditions resulting in very poor inversion, agglomerate growth in the low-shear vessel was still sufficient to afford good agglomerate recovery.

The main effects of reducing high-shear energy input were:

- A small decrease in product ash content
- A decrease in tailings ash content
- A small decrease in yield and Btu recovery

High-Shear Energy Input Evaluation - A series of tests was carried out to determine the effect of decreasing high-shear energy input, at a constant impeller tip speed (11 m/s), on product ash content. To accomplish this, the coal feed rate to the plant was incrementally increased and only high-shear vessel A was used. Evaluation of these tests was based on low-shear product samples which were screened in the lab.

As the plant coal throughput was increased, decreasing high-shear energy input on a coal and slurry basis, the inversion quality achieved from high shear decreased. As a result of decreasing degrees of inversion, both the tailings ash and Btu recovery decreased. These trends are due to increasing degrees of "incomplete agglomeration" resulting in more coal losses to the tailings as energy input on a coal basis was decreased. A similar trend of decreasing product ash content was also observed. As such, it was determined that reductions in high-shear energy input could be used to achieve small reductions in product ash content with corresponding reductions in Btu recovery.

Low-Shear Solids Concentration Effects - Testing was carried out to evaluate the effect of low-shear solids concentration on product ash content. While attempts were made to maintain all other plant conditions at similar conditions, problems with the weigh belt feeder resulted in a finer grind size for some of these tests. Results from this work indicated that there was no effect on product ash content when the low-shear solids concentration was decreased.

Low-Shear Impeller Tip Speed Effect - It was found during this testing that increasing the low-shear impeller tip speed resulted in a slight increase in product ash content.

Stripping Circuit Solids Concentration Effect - It was found that reducing the solids concentration used during steam stripping had no effect on the residual heptane concentration in the product from either the first or second stage of steam stripping. As such, subsequent testing was carried out at the higher solids concentration to reduce the steam required during steam stripping.

Other Parametric Testing - Additional parametric testing carried out with the Taggart coal focused on decreasing the plant feed rate so that a finer grind was produced and the product ash target of 1 lb/MBtu achieved. Results of these tests indicated that a grind with a D_{80} of approximately 30 to 32 microns was required to achieve the 1 lb ash/MBtu target product grade.

At this D_{80} of 30 to 32 microns, a tailings ash content in the 60% range was needed to insure that the product grade was met. To achieve these conditions the high-shear energy (tip speed) was adjusted as required. It was found that at a dry coal feed rate of approximately 3300 lb/hr and a high-shear solids concentration of about 10%, the desired product ash could be achieved at a high-shear impeller tip speed in the 10 m/s range. As such, these conditions were chosen as the target operating parameters for the production run.

Taggart Coal Production Run - The Taggart coal production run was carried out during the week of May 19, 1997. The average product ash content was 1.06 lb/MBtu, with the range of product ash contents for the individual set points from 1.01 to 1.12 lb/MBtu. The following is a list of average values of the critical production run operating conditions and results:

- Dry coal feed rate - 3305 lb/hr
- Plant feed Grind D_{80} - 30.3 microns
- Heptane dosage utilized - 39.2% on a dry ash free coal basis
- Total agglomeration (high- and low-shear) energy input - 16.1 kwhr/ton feed coal (6.2 kwhr/1000 gallon slurry)
- Screen spray water rate - 566 gallons/ton product
- Steam consumption - 1553 lb/ton dry product (1.8 lb/gallon slurry stripped)
- Plant product ash content - 1.06 lb/MBtu (1.59%)
- Plant product residual heptane content - 5115 ppm on a dry coal basis
- Plant Tailings ash content - 63.0%
- Plant tailings residual heptane content - 4094 ppm on a dry solids basis
- Plant yield - 96.7%
- Plant Btu recovery - 99.2%

During the Taggart coal production run, there was one plant shutdown due to the failure of the stripping circuit feed diaphragm pump. This shutdown was of 2 hours duration during which failed diaphragms were replaced. As such, of the total 72 hour run duration, there were 2 hours of down time.

Other problems encountered with equipment during the production run, none of which forced a plant shutdown, were as follows:

- Plugging of the grinding circuit cyclones. These were unplugged on line, allowing operation to continue.
- Failure of the control valve that maintained the correct operating level in the gravity separator. This was overcome by manually controlling the water discharge from the gravity separator for the duration of the production run.
- The fine grinding mill tripped out resulting in the reduction of feed to the Area 300 feed storage tank for approximately 30 minutes. The grinding circuit circulating load was rerouted to the secondary ball mill until the fine grinding mill could be restarted.

Indiana VII Coal Parametric Testing - A total of 20 different sets of operating conditions were evaluated this reporting quarter for the Indiana VII coal. These 20 tests included one start-up test, nine complete plant tests, and ten tests in which the samples from the low-shear vessels were used as the basis for evaluation. The 19 parametric tests were carried out to evaluate the following:

- The effects of high-shear energy input and asphalt dosage
- The effect of low-shear solids concentration
- The effect of low-shear tip speed
- The effect of agglomerate size
- The effect of both steam stripping temperatures
- The effect of screen spray water flowrate

Start-Up Test - During the initial start-up test, an asphalt dosage of 9.5 lb/ton coal was used and high-shears A and B operated in series at their maximum achievable tip speeds of 17.4 and 14 m/s, respectively. At these operating conditions, only marginal inversion (rating of 2 on a 1 to 10 scale) was achieved. This poor inversion at these high asphalt and energy levels is attributed to the low solids concentration (7%) used during high shear. It was found during start up, that the asphalt emulsion utilized contained large pieces of what appeared to be tar. These large particles bound up the asphalt pump (gear type), causing the loss of asphalt flow on several occasions. During these periods of no asphalt flow, inversion was lost completely resulting in coal loss to the tailings stream.

High-Shear Asphalt Dosage Effect - After the initial start-up test, subsequent testing with the Indiana VII coal was completed to determine the asphalt dosage and high-shear energy input required to achieve inversion at the high-shear circuit discharge.

Testing to evaluate the effect of asphalt indicated that in every case, increasing the asphalt dosage improved the quality of inversion achieved. This effect was also seen in the tailings ash values which consistently increased with higher asphalt dosages. It was found that when the lower asphalt dosages were used, more unagglomerated filmy material was observed in the low-shear samples. There also appeared to be a small effect of asphalt dosage on product ash content, with higher asphalt dosages resulting in slightly higher product ash values for some of the tests.

High-Shear Energy Effect - Results indicated that decreasing the high-shear tip speed (energy input) reduced the quality of inversion achieved. This effect was also seen in the tailings ash values which consistently decreased with lower energy input indicating incomplete agglomeration, as observed by the presence of more unagglomerated filmy material floating in the low-shear samples. It was also found that there is a clear effect of high-shear energy input on product ash content, with lower energy consistently resulting in higher product ash values. This is due to the production of better formed agglomerates at the higher energy levels, subsequently resulting in better screening, i.e., improved drainage of associated mineral-matter bearing process water.

Combined Asphalt Dosage and High-Shear Energy Effect - It was found that when the asphalt dosage was increased and the high-shear energy decreased simultaneously to achieve similar inversion, a higher product ash content resulted. This suggests that if the goal of the process is to achieve the lowest product ash content at a given grind size, the asphalt utilized should be minimized and sufficient energy used to achieve the formation of good agglomerates.

High-Shear Solids Concentration Effect - While no test was performed specifically to evaluate the effect of high-shear solids concentration on the energy and/or asphalt required to achieve inversion, a comparison of pertinent tests illustrates the effect. These comparisons indicate that when similar asphalt dosage and high-shear tip speed are used, better inversion is achieved at higher solids concentrations. This is attributed to more particle to particle contact, at similar energy inputs, for the higher solids loading.

Low-Shear Solids Concentration and Tip Speed Effect - One series of tests was carried out to evaluate the effect of low-shear solids concentration and tip speed on the operability of the low-shear vessel and the product ash content. Results indicated that a higher solids loading in low shear did not have a detrimental effect on product ash content. It was also found that no difficulties were encountered when operating the low shear at the higher solids concentration.

Considering the effect of low-shear tip speed on product ash content, it was found that when the tip speed was increased from 5 to 6.5 m/s, no effect on ash content was observed. When the tip speed was decreased from 5 to 3 m/s, however, while no effect on product ash was observed, poor agglomerate growth resulted in a significant decree in both tailings ash content and Btu recovery.

Screen Spray Water Flowrate Effect - Two tests were completed to evaluate the effect of screen spray water flowrate on product ash content. Unfortunately, due to problems with the weigh belt feeder, the feedstock grind size decreased between the two tests from a D_{80} of 23.0 microns for the low screen spray rate test, to a D_{80} of 21.1 microns for the high screen spray rate test. While a product ash content decrease of 0.13% was observed at the higher screen spray rate, only a 0.05% decrease was observed in the low-shear samples rinsed in the lab. This indicates that, possibly, the higher screen spray rate resulted in some product ash content reduction not attributable to the finer grind size.

Stripping Circuit Evaluation - During virtually all of the Indiana VII coal testing completed to date, residual heptane concentrations have been in the 5000 ppm range on a dry coal basis (dcb). However, for one test, in which a high asphalt dosage (approximately 19 lb/ton) was used, a higher residual heptane concentration (7300 ppm dcb) was found. It should be noted, however, that during this test, the material in the strippers was very foamy and difficult to pump. As such, this higher residual heptane content is attributed to poor operational control rather than the presence of greater amounts of asphalt. Tailings residual heptane contents for the Indiana VII coal testing have been in the 300 to 1000 ppm dcb range.

One pair of tests was carried out to evaluate the effect of stripper operating temperature on the product residual heptane content. For the first test, the steam strippers were operated at pressures of 1 and 5 psi (199 and 231°F) in strippers A and B, respectively.

For the second test, the stripper operating pressures were increased to approximately 6 and 10 psi (210 and 240°F), respectively. Results of these tests indicated that there was no significant reduction in the final plant product residual heptane concentration as a result of the increased stripping temperatures.

Agglomerate Size Effect - Testing was carried out to evaluate the effect of agglomerate size on product ash content. Results indicated that there was virtually no difference in product ash content when both 2 mm and 0.5 mm agglomerates were rinsed in the lab. This result is surprising since during previous testing, larger agglomerates consistently resulted in lower product ash values.

Feedstock PSD Effect - Throughout the Indiana VII coal testing to date, PSDs with D_{80}s in the 20 to 26 micron range have been evaluated. During this work, product ash values ranged from a high of 3.58% (2.56 lb/MBtu) to a low of 2.71% (1.92 lb/MBtu).

To date, the project product ash content goal of 2 lb/MBtu has been met at only the finest grinds evaluated (D_{80}s of 20 to 21 microns). Due to the difficulty in producing the 20 micron grind and filtering the product, no further testing specifically targeting the product ash goal is planned.

Yield and Btu Recovery - Throughout the Indiana VII coal testing, relatively high (85 to 92%) tailings ash contents have been consistently achieved. For the few tests in which the tailings ash values were below this range, insufficient asphalt and/or energy was used during high-shear agglomeration. Given these high tailings ash values, it is not unexpected that Btu recoveries have been consistently greater than 99% with yields in the 90 to 92% range. However, based on the calculation procedure used to determine Btu recovery (Btu content of the product stream divided by the Btu content of the feed stream and adjusted for yield), the values have been consistently greater than 100%. While this is not possible, it is attributed to a combination of the asphalt content of the product and the residual heptane content of the product.

Summary - The following is a summary list of observations and conclusions based on the Task 9.3 testing completed to date:

- While the SA module can be run at a 2 t/hr coal feed rate, a more stable operation is achieved at a slightly lower feed rate (3800 lb/hr).
- For the Hiawatha coal, a grind with a D_{80} of approximately 40 microns is sufficiently fine to achieve the 2 lb ash/MBtu product target ash level.
- For the Taggart coal, a grind with a D_{80} of approximately 30 microns is sufficiently fine to achieve the 1 lb ash/MBtu product target ash level.
- For the Indiana VII coal, a grind with a D_{80} of approximately 20 microns is sufficiently fine to achieve the 2 lb ash/MBtu product target ash level.
- For the Hiawatha coal, there appears to be no effect of high-shear energy input on product ash content.
- For the Taggart coal, the product ash content is affected by the high-shear energy input, with lower energy resulting in lower product ash contents. This

is attributed to the increasing loss of coal to the tailings (decreasing Btu recovery) with decreasing energy input.

- For the Indiana VII coal, the product ash content is affected by the high-shear energy input, with lower energy resulting in higher product ash contents and decreased Btu recovery. This is attributed to the poor formation of agglomerates at lower energy levels, and subsequent poor drainage of mineral-matter bearing process water during screening.
- For the Indiana VII coal, an asphalt dosage in the 5 to 10 lb/ton of coal is required for inversion to take place, with lower asphalt and higher energy providing lower product ash contents than higher asphalt and lower energy.
- Higher asphalt dosages result in slightly higher product ash contents.
- Operation of the low-shear vessel half full provides sufficient residence time for agglomerate growth to a recoverable size.
- Operation of the low-shear vessel full results in unstable cyclic growth.
- No effect on residual heptane concentration is observed as a function of stripping circuit solids concentration.
- Final product residual heptane concentrations are typically 3000, 5000, and 5000 ppm dcb for the Hiawatha, Taggart, and Indiana VII coals, respectively.
- Plant tailings residual heptane content is primarily a function of tailings ash content and has ranged from a low of about 400 ppm (dry coal basis) at a tailings ash of 90%, to a high of 5000 ppm at a tailings ash of 60%.
- Overall, plant Btu recoveries are very high, with analysis indicating Btu recoveries consistently >97%, and often >99%.

Subtask 9.4 Selective Agglomeration Topical Report

Work began on the Task 9 Selective Agglomeration Topical Report with the analysis of the Hiawatha and Taggart coal production run feed and clean coal samples for ash properties. In addition, samples from these production runs were also submitted for toxic trace element analyses.

Ash Properties of Clean Coals - Hazen Research, Inc., of Golden, Colorado, determined the ash chemistry and fusion properties of composite feed and product (clean coal) samples from the Taggart and Hiawatha coal production runs in the PDU SA module. It was found that the selective agglomeration process increased the base/acid ratio of the ash and decreased the silica/alumina ratio. The overall results indicated a decline in the reducing atmosphere fusion temperature of the ash in the Taggart coal and small increase in the fusion temperatures of the ash in the Hiawatha coal as shown below:

	Softening Temperature	
	Feed	Product
Taggart Coal	2552°F	2396°F
Hiawatha Coal	2145°F	2181°F

Except for titanium dioxide, and possibly iron oxide in the case of the Taggart coal and phosphorus pentoxide in the case of the Hiawatha coal, the concentrations of the ash constituents were significantly reduced on a heating value (lb/MBtu) basis by selective agglomeration in the PDU module during the production runs.

Toxic Trace Elements - Samples of the crushed feed coal, ground selective agglomeration feed, product (clean coal), and tailings from the Taggart and Hiawatha production runs have been submitted to Huffman Laboratories for analysis of the twelve toxic trace elements of interest.

Task 10 Disposition of the PDU

Task 10 of this project involves the decommissioning and disposal of the PDU and all ancillary equipment acquired with DOE funds. In particular, Task 10 will include the flushing of coal and reagents from the PDU, removal of all PDU equipment and piping, numbering or otherwise identifying all equipment, packaging/shipping and/or sale of all equipment, disposal of all excess reagents and chemicals, and restoration of the site.

Work on these tasks began during June, 1997, with the submittal of a complete equipment list to DOE. This list was posted on a computer network for review by FETC project managers to determine if any equipment was appropriate for use in other DOE projects. To date, some interest has been expressed in several of the reagent pumps and smaller vessels.

The Task 10 work will begin in earnest during August with initial efforts, to be carried out by Entech personnel, focusing on the flushing of all coal and reagents from the PDU, removal of all plant piping, and removal of handleable pieces of equipment such as pumps and small vessels. The removal of the bulk of the equipment, particularly the larger pieces, will be carried out by an outside contractor who will be required to disassemble and reassemble the plant buildings, as required, for equipment removal.

Task 11 Project Final Report

Following discussions between Amax R&D, Bechtel, and DOE, it was decided that in addition to the project final report (summarizing all work completed during the course of the project), a separate topical report should be prepared by Bechtel. This topical report, titled "Commercial CWF Production Cost Study," would present an economic assessment for the production of premium fuels utilizing the advanced flotation and selective agglomeration processes.

Commercial Cost Study Topical Report

The Task 11 topical report "Commercial CWF Production Cost Study" was issued during June 1997. This report is an economic assessment of the commercial-scale production of premium fuel by the advanced flotation and selective agglomeration processes. It was prepared by Bechtel.

Capital and operating costs for this economic assessment were based on conceptual plants for producing 1.5 million short tons per year (dry basis) of clean coal to be marketed as coal-water-slurry fuel (CWF). Feedstock for these plants would be purchased from mines in the central Appalachian area that produce coals with upgrading properties similar to the Elkhorn No. 3, Taggart, Sunnyside and Hiawatha test coals used for the bench-scale and 2 t/hr process development work. The CWF would contain 60 to 62% coal (8,900 to 9,400 Btu/lb), less than 2.0 lb ash/MBtu, and less than 0.6 lb sulfur/MBtu and would have a viscosity of less than 500 cP.

Bechtel developed equipment flowsheets and levellized cost projections for producing premium CWF by advanced column flotation and selective agglomeration. The conceptual plants include sections for coal receiving and storage, crushing and grinding, advanced physical cleaning (flotation/agglomeration), clean coal dewatering, CWF preparation, storage and load-out, tailings handling, and water clarification. The selective agglomeration advanced cleaning section also included facilities for heptane recovery and reuse. An advanced flotation premium fuel plant would be less expensive to place into service than a selective agglomeration plant as indicated below:

	Estimated Cost, $ (millions)	
	Flotation	Agglomeration
Project Capital Cost	69.6	97.2
Working Capital	10.0	11.0
Total	**79.6**	**108.2**

Total fixed and variable operating and maintenance (O&M) costs for producing CWF by the two cleaning methods were estimated to be $2.15/MBtu and $2.42/MBtu for advanced column flotation and selective agglomeration, respectively. The cost of the feed coal delivered to the premium fuel plants ($1.24/MBtu) is included in these costs.

As one would expect, variation in the price of the feed coal had the most impact upon the cost of the CWF since feed coal accounts for half of the production cost of CWF. The annual rate of production also had a significant impact upon the production cost. Variations in other sensitivity parameters such as feed coal ash content, labor, electricity, reagent costs, and capital costs had lesser impacts on process economics.

The A-23M dispersant added to reduce the CWF viscosity was one of the most costly items among the O&M costs. A savings of $0.23/MBtu would be accomplished by formulating the CWF without A-23M. Such CWF would contain 54% coal instead of 60 to 62% and have a heating value of 8,100 Btu/lb instead of 8,900 to 9,400 Btu/lb.

Project Final Report

Initial drafts of several project final report sections have been prepared. The remaining sections will be drafted when PDU testing is completed next month (July, 1997).

INTRODUCTION

The goal 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 (DOE) 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 September 30, 1997. This report discusses the technical progress made during the nineteenth quarter of the project, April 1 to June 30, 1997. Eighteen quarterly reports have been issued previously [1-18].

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. Twelve toxic trace elements have been targeted. They are antimony, arsenic, beryllium, cadmium, chromium, cobalt, lead, manganese, mercury, nickel, selenium, and chlorine. 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 (now part of Cyprus Amax Minerals Company) 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, which was built by TIC and Mech El, Inc., two Colorado based construction companies.

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 during Phase I included:

- Production of ultra-clean coal test lots by bench-scale column flotation and selective agglomeration for end-use testing
- 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

<u>Phases II and III</u>

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 is being optimized at the PDU-scale, and bulk lots of ultra-clean coal are being produced by each process for each of the three test coals. The toxic trace element distribution is also being determined during the production runs. The ultra-clean coal bulk lots are being delivered to a DOE designated contractor (Penn State) for end-use testing.

<u>Phase IV</u>

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

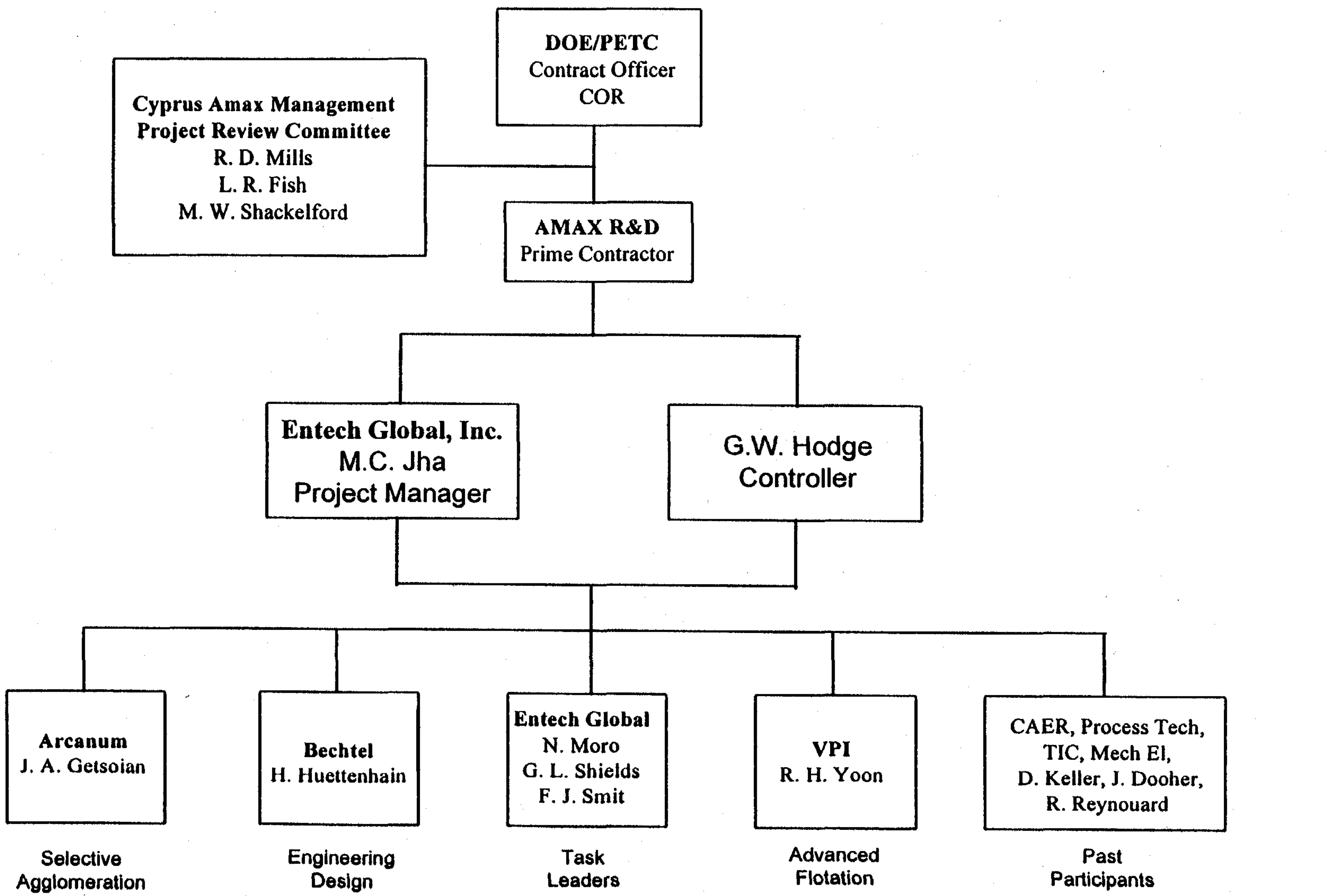


Figure 1. Project Management Organization Chart

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

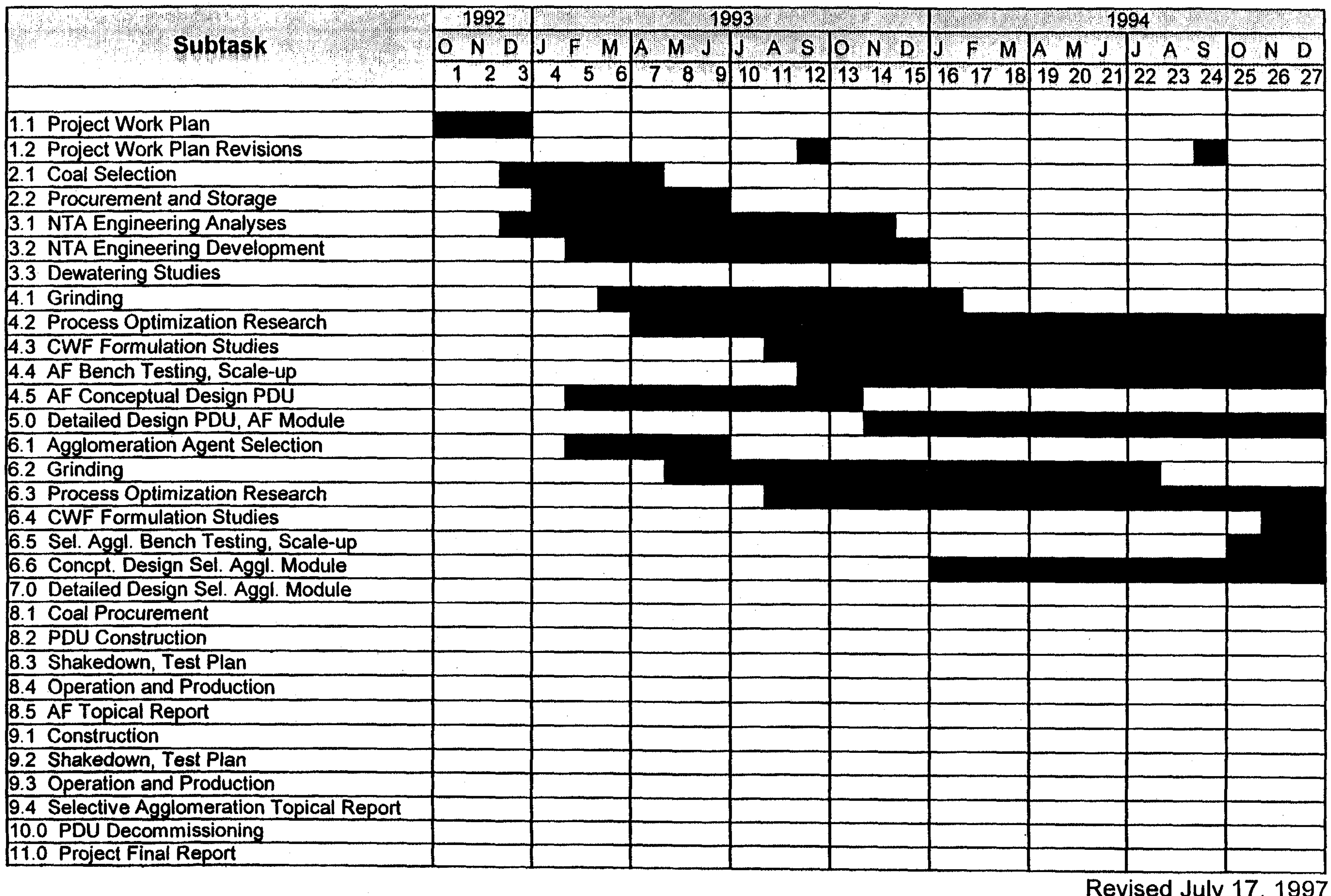
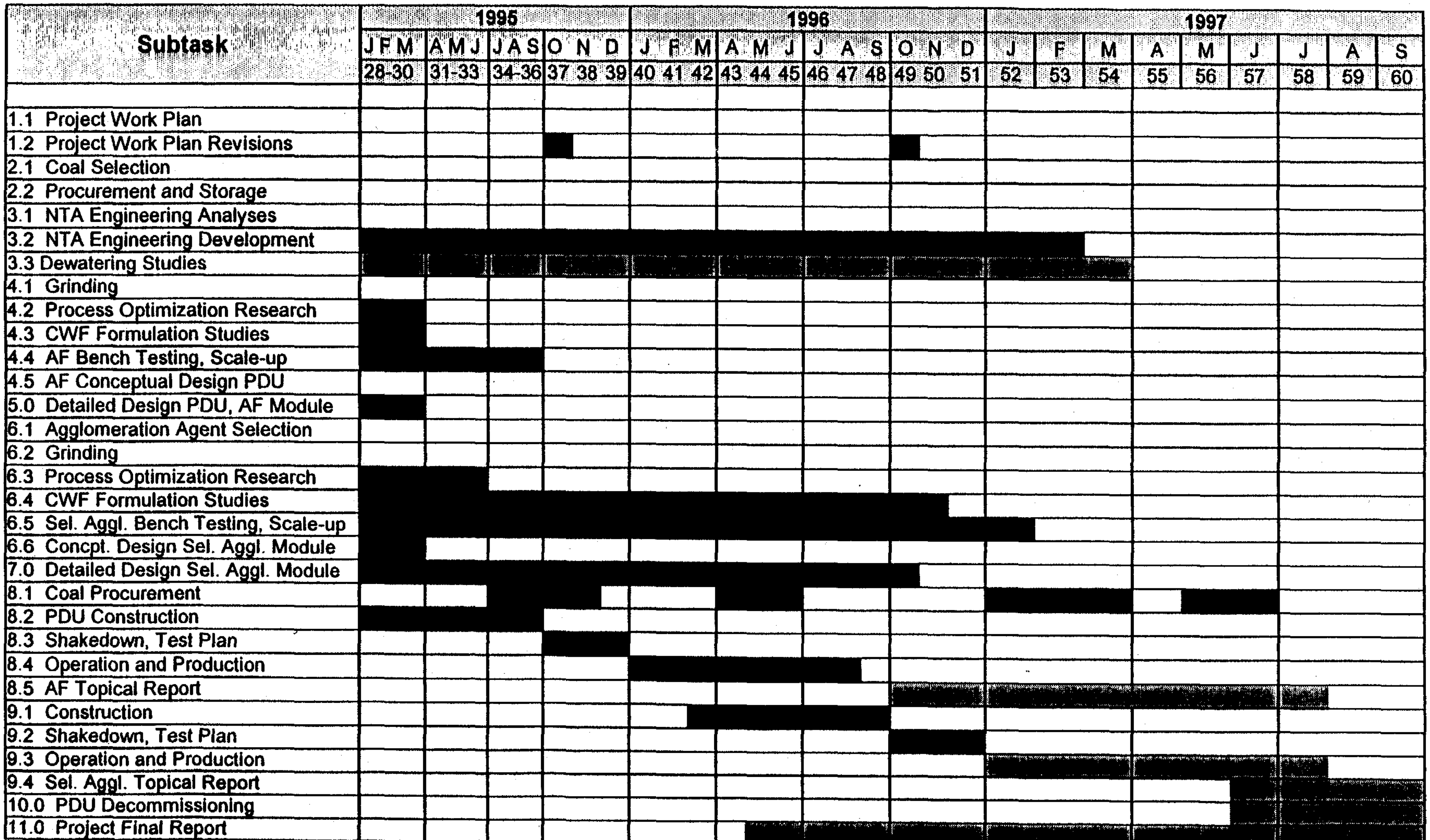


Figure 2. Project Schedule



Revised July 17, 1997

Figure 2. Project Schedule (Cont'd)

ACCOMPLISHMENTS DURING QUARTER

Work was carried out on Tasks 3, 6, 8, 9, 10, and 11 during the nineteenth quarterly (April 1 to June 30, 1997) reporting period. Good progress was made on these tasks as discussed below.

TASK 3 DEVELOPMENT OF NEAR-TERM APPLICATIONS

The Subtask 3.1 engineering analysis [19] found that column flotation recovery of fine coal at the Lady Dunn Preparation Plant of the Cannelton Coal Company in West Virginia would be an attractive near-term application since the plant was scheduled for a major expansion. As a result of this analysis, the Center for Coal and Mineral Processing (CCMP) at Virginia Tech conducted on-site testing of the Microcel™ column flotation process at Lady Dunn under Subtask 3.2. Subtask 3.3, investigating a novel dewatering process for flotation products, was also performed by CCMP.

Subtask 3.2 Engineering Development

As described during previous Quarterly Progress Reports [11,12,13,14,15,16], an existing 30-inch diameter Microcel™ flotation column was refurbished, installed, and tested in the Lady Dunn Plant for the engineering development of advanced flotation. The preliminary testing results were such that Cannelton included column flotation in a plant expansion that was placed into service during 1996. Auxiliary testing was also conducted to convert the clean coal slurry produced by the Microcel™ column into marketable forms. This auxiliary testing utilized clean coal from the 30-inch column and included centrifuge and filtration dewatering tests, CWF slurry preparation tests, and roll-press briquetting tests.

A comprehensive topical report [20] of all these Task 3 near-term application activities was issued on April 25, 1997. This report covered the preliminary laboratory testing and feasibility studies, the on-site column flotation testing, and the subsequent auxiliary testing to convert the clean coal to a marketable form.

A technical paper [21] providing an account of the installation and successful start up of a 4-meter Microcel™ flotation column for recovering fine coal in the expanded Lady Dunn preparation plant was presented at the Coal Prep '97 Conference in Lexington, Kentucky.

Subtask 3.3 Dewatering Studies

This work, performed by Virginia Tech, was aimed at developing a novel hydrophobic dewatering (HD) process for efficiently removing moisture from clean coal fines without the expense associated with mechanical dewatering or thermal drying. A hydrophobic substance such as butane was added to coal slurry during the HD process to displace water from the surface of the coal. The volatile hydrophobic substance was then recovered and reused. Laboratory-scale testing showed that the HD process reduced the moisture content of fine coal to a very low level and determined the potential loss of butane by adsorption onto the coal during the procedure.

Currently, Virginia Tech is completing a separate Subtask 3.3 Dewatering Studies topical report discussing this work. Scale-up methods and cost projections will be developed and included in this report, which will be issued during the next reporting quarter.

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, 6.4 Coal-Water-Fuel Formulation Studies, 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 remaining Subtask, Bench-scale Testing and Process Scale-up, during this quarter.

Subtask 6.5 Bench-Scale Testing and Process Scale-up

The Subtask 6.5 Topical Report [22] was completed this reporting quarter and issued on June 27, 1997. This report presents the findings of Subtask 6.5 Selective Agglomeration Bench-Scale Testing and Process Scale-up. During this work, six project coals, namely Winifrede, Elkhorn No. 3, Sunnyside, Taggart, Indiana VII, and Hiawatha were processed in a 25 lb/hr continuous selective agglomeration bench-scale test unit.

During Subtask 6.5, the coals were ground in pilot scale equipment and then cleaned by the selective agglomeration process. The process unit operations consisted of a high-shear step to achieve phase inversion and microagglomerate formation, a low-shear step for agglomerate growth to 2 to 3 mm in size, and product recovery by screening. Both commercial and pure grades of heptane were used as the agglomerant during this testing. Asphalt in the form of an emulsion was also used as an agglomeration promoter for the Indiana VII coal.

In order to meet the product ash specification of 2 lb/MBtu (1 lb/MBtu for the Taggart coal), the coals had to be ground to various sizes ranging from the coarsest grind for the Elkhorn No. 3 coal with an 80% passing size (D_{80}) of 68 microns to the finest grind for the Winifrede coal with a D_{80} of 12 microns. When ground to the appropriate size, the product ash specification was met for each coal tested at Btu recoveries generally in the 98 to 99% range. Typical operating conditions used during this testing provided 30 to 60 seconds of high-shear residence time at impeller tip speeds from 10 to 18 m/s. Low-shear growth was best achieved in 2 to 5 minutes residence time at impeller tip speeds of 5 m/s. Screening to recover the product was found to be most affected by the size of the agglomerates produced in low shear, with larger (2 to 3 mm) agglomerates providing the lowest ash product.

Following agglomeration, the heptane was recovered from the product by direct contact steam stripping in two stages. The first stage of stripping recovered the bulk of the heptane and was carried out at about 5 minutes residence time and ambient pressure boiling points. The second stage of steam stripping removed additional heptane during 10 minutes of residence time at elevated pressures and temperatures, typically 10 psi and 117°C, respectively. Residual heptane concentrations were typically in the 1000 to 3000 ppm on a dry solids basis, with minimal heptane found in the process tailings when successful agglomeration was achieved. Recovered heptane and water vapor were then condensed, cooled, separated, and recycled to the process for reuse.

TASK 8 PDU AND ADVANCED COLUMN FLOTATION MODULE

The Task 8 work completed this reporting quarter focused on Subtask 8.1 Coal Selection and Procurement and Subtask 8.5 Advanced Flotation Topical report, as discussed below.

Subtask 8.1 Coal Selection and Procurement

Nine truck loads (215 tons) of Indiana VII washed compliance coal was obtained from the Kindill No. 3 Mine during May for the PDU selective agglomeration module operation. Kindill No. 3 is the new name for the Minnehaha Mine which was the source of the Indiana VII coal used during the Phase I laboratory and bench-scale process development testing as well as the Phase II 2 t/hr PDU advanced flotation operation. This mine is now operated by the Kindill Mining Company. The analysis provided with the coal indicated 18% moisture, 7.9% ash, and 0.38% sulfur. Four more truck loads of this coal will be delivered during July for completion of the PDU selective agglomeration module production run.

All of the left-over coal that had been stored at the American Coal Company yard in Denver was given to the Public Service Company of Colorado for disposal at their Arapaho Station. The remaining Taggart and Hiawatha coals at Ralston Development Company and at Amax R&D were also discarded.

Subtask 8.5 Advanced Flotation Topical Report

Work continued on the Advanced Froth Flotation Topical Report during this reporting quarter. Completion of this report is scheduled for next month (July, 1997).

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 was integrated with the existing PDU facility constructed during Subtask 8.2 and operated under Subtask 8.4.

During operation of the SA module, the existing coal handling and grinding circuits (Plant Area 100) are used to produce ground coal slurry feed for the selective agglomeration process. Similarly, the existing product and tailings dewatering circuits (Plant Area 400) are also used. As such, the SA module (Plant Area 300) essentially replaced the Microcel™ flotation column (Plant Area 200), with the remainder of the plant remaining intact.

Just like the advanced flotation PDU, selective agglomeration process performance is being optimized at the 2 t/hr scale, and bulk lots of ultra-clean coal produced for each of the three test coals. Toxic trace element distributions are also being determined during the production runs. The ultra-clean coals are being delivered to a DOE designated contractor, Penn State, for end-use testing.

As of the end of the previous reporting quarter, construction (Subtask 9.1) and start-up and shakedown testing (Subtask 9.2) of the PDU SA module had been completed and reported upon. The bulk of the Hiawatha coal parametric testing (Subtask 9.3) was also completed during the previous quarter.

Subtask 9.3 SA Module Operation and Clean Coal Production

During this reporting quarter, the following Subtask 9.3 activities were completed:

- Hiawatha coal parametric testing
- Hiawatha coal production run
- Taggart coal parametric testing
- Taggart coal production run
- The bulk of the Indiana VII coal parametric testing

Hiawatha Coal Parametric Testing

Parametric testing of the Hiawatha Coal was concluded with the completion of six additional parametric tests covering the following:

- Evaluation of the froth skimmer unit operation
- Evaluation of high-shear energy input
- Confirmation testing prior to production run

The results for these six tests are shown in Appendix A, along with the Hiawatha coal production run results discussed later in this report.

Froth Skimmer Evaluation - Testing of the froth skimmer, with and without the use of nitrogen, was completed during Test 13. For this test, nitrogen to the froth skimmer was used during Test H-13-A, followed by test H-13-B, identical except that the nitrogen flow to the froth skimmer was turned off.

Results of this test indicated that there was no effect on plant performance when the nitrogen purge was used as compared to when it was not used. In particular, there was no effect (not attributable to the small change in grind size) on the ash content of the following plant streams:

- Froth skimmer product
- Froth skimmer tailings
- Final plant tailings
- Final plant product

In general, it has been found throughout the Hiawatha coal testing, that the froth skimmer is ineffective in removing carbonaceous material from the plant tailings stream. This is believed to be due to the following:

- The presence of too much surface area for froth collection in the froth skimmer. This factor, combined with the very small amount of material floating in the skimmer, prevents the buildup of a sufficient froth layer for removal.
- The possible readsorbtion of heptane from the gas blanket system on to the material that does float in the froth skimmer. This results in the formation of a stiff cake-like layer, which cannot be removed by the rotating scraper paddle.
- Poor distribution of the nitrogen bubbles throughout the froth skimmer.

As such, the use of nitrogen in the froth skimmer was not tested further.

It should be noted that for application in a commercial plant, the floating material that is recovered in the froth skimmer would probably be constantly overflowed and recycled to the high-shear agglomeration unit operation, rather then combined directly with the plant product stream.

High-Shear Evaluation - One test run was completed during this quarter (H-14-A) to evaluate the effect of a lower high-shear energy input on the selective agglomeration plant performance. For this test a high-shear impeller tip speed of 11 m/s was used, as compared to the 14 m/s tip speed tested for the bulk of the previous Hiawatha coal parametric testing. This resulted in a reduction of high-shear energy input by almost half, from approximately 28 kwhr/ton feed coal (11.2 kwhr/1000 gallon slurry) to 16.1 kwhr/ton feed coal (6.2 kwhr/1000 gallon slurry).

The results from this test indicated no detrimental effect on either product quality or plant Btu recovery as a result of this high-shear energy reduction. As such, this lower high-shear tip speed was chosen for use during the production run.

Confirmation Testing - Prior to the start of the production run, one test run (H-15) was completed at constant operating conditions, in which three separate sample sets were obtained. This was carried out to confirm that the conditions chosen for the production run would consistently provide a product which met the target ash content of 2 lb/MBtu.

The results of this test did confirm acceptable plant performance over an extended time period, and as such, the identical conditions were used for the Hiawatha coal production run.

Hiawatha Coal Production Run

The Hiawatha coal production run was carried out during the week of April 14, 1997. The operating conditions and results for the production are shown in Appendix A, along with the previously discussed parametric testing results.

As can be seen from the data in Appendix A, the production run met the 2 lb ash/MBtu product specification for all of the sample periods evaluated. The following is a summary list of average production run operating conditions and results:

- Dry coal feed rate - 3839 lb/hr
- Plant feed Grind D80 - 42.1 microns
- Plant feed solids concentration - 10.24%
- Plant feed ash content - 8.34%
- Heptane dosage utilized - 31.3% on a dry ash free coal basis
- Total agglomeration (high- and low-shear) energy input - 17 kwhr/ton feed coal (6.9 kwhr/1000 gallon slurry)
- Screen spray water rate - 500 gallons/ton product
- Steam consumption - 1380 lb/ton dry product (1.8 lb/gallon slurry stripped)
- Plant product ash content - 1.93 lb/MBtu (2.78%)
- Plant product residual heptane content - 2951 ppm on a dry coal basis
- Plant Tailings ash content - 80.4%
- Plant tailings residual heptane content - 1470 ppm on a dry solids basis
- Plant yield - 92.8%
- Plant Btu recovery - 98.9%

The following represents an approximate summary of the operating schedule for the Hiawatha coal production run:

- Run start: 7:00 April 14
- Shutdown due to stripping circuit pump failure: 7:45 April 15 (24-3/4 hours run time)
- Run restart: 8:45 April 15 (1 hour down time)
- Shutdown due to stripping circuit pump failure: 19:30 April 15 (10-3/4 hours run time)
- Run restart: 10:00 April 16 (14-1/2 hours down time)

- Run end: 6:00 April 17 (20 hours run time)
- **Total approximate run time: 55-1/2 hours**
- **Total approximate down time: 15-1/2 hours down time**
- **Total run duration: 71 hours**

Both periods of down time during the production run were due to problems with the stripper feed diaphragm pump. This pump was rebuilt during the 14-1/2 hour down time period and was found to have a broken diaphragm caused by a wooden wedge lodged within the pump.

Taggart Coal Parametric Testing

Based on the parametric testing results on the Hiawatha coal, it was determined that the following operating conditions would not be evaluated for the Taggart coal:

- Vibrating screen in uphill or level orientation since downhill orientation was shown to reduce both agglomerate bed depth and product ash content.
- Low-shear vessel operated full since this was found to make agglomerate growth difficult to control and the half-full configuration provided sufficient residence time for agglomerate growth to the 2 to 3 mm size range.
- Low (<10%) high-shear solids concentration since these were found to provide no reduction in ash content while resulting in higher high-shear energy input requirements.

A total of 23 operating test points were evaluated to complete the Taggart coal parametric testing. Work completed included the following:

- Evaluation of high-shear A impeller tip speed and energy input effects
- Evaluation of high-shear B impeller tip speed and energy input effects
- Evaluation of low-shear solids concentration effects
- Evaluation of low-shear impeller tip speed and energy input effects
- Evaluation of stripping circuit solids concentration effects
- Testing to determine the grinding requirements to achieve the target 1 lb ash/MBtu product specification

Operating conditions and results for all of these parametric tests are shown in Appendix B along with the Taggart coal production run operating conditions and results which will be discussed later in this report.

High-Shear Impeller Tip Speed Evaluation - During the high-shear evaluation testing of both high-shear vessels, A and B, the impeller tip speed was incrementally reduced to determine the point at which inversion at the high-shear discharge was lost. In addition, for each high-shear energy input level (impeller tip speed), low-shear samples were taken, rinsed on a 48-mesh screen, and the product and tailings analyzed for ash content.

Pertinent results for this work are shown in Table 2.

Table 2. Initial High-Shear Tip Speed Evaluation - Taggart Coal

Test	Grind D80	Tip Speed m/s	Kwhr per ton coal	Kwhr per 1000 gal	Inversion Quality	Prod ash, %	Tails ash, %	Yield %	Btu Rec %
High Shear B Evaluation									
T-1-1	35.5	14.0	26.7	11.1	V. Good	1.59	76.5	97.1	99.4
T-1-2	35.5	11.5	16.2	6.7	Fair	1.58	72.3	96.9	99.3
T-1-3	35.5	9.0	8.3	3.4	Poor	1.60	68.6	96.7	99.1
High Shear A Evaluation									
T-2-1	38.4	17.4	12.0	5.2	V. Good	1.73	81.3	97.7	99.7
T-2-2	38.4	15.1	8.6	3.7	Good	1.69	78.5	97.5	99.6
T-2-3	37.1	11.0	3.6	1.8	V. Poor	1.60	63.1	96.8	98.9
T-6-1	34.4	13.0	6.5	2.8	V. Good	1.70	73.1	97.4	99.3
T-6	35.6	11.0	3.9	1.7	Good	1.63	68.6	97.2	99.1

As expected, the quality of the inversion exiting the high-shear circuit decreased as the high-shear impeller tip speed was reduced. This was found to hold true for all three sets of tests shown in Table 2. However, it was found that even under high-shear conditions resulting in very poor inversion, agglomerate growth in the low-shear vessel was still sufficient to afford good agglomerate (and therefore Btu) recovery.

As can be seen from this data, the main effects of reducing high-shear energy input were:

- A small decrease in product ash content
- A decrease in tailings ash content
- A small decrease in yield and Btu recovery

Due to an increasingly worse high shear A shaft seal leak, one additional series of tests was carried out utilizing high-shear B in which the coal feed rate was held constant and the impeller tip speed reduced. This work was completed to determine at what energy input (impeller tip speed), the product ash target of 1 lb/MBtu could be met at a feed grind size with a D_{80} of approximately 30 microns. Pertinent results for these tests are shown in Table 3.

As can be seen from this data, as the high-shear impeller tip speed was decreased from 11.0 to 9.5 m/s, product ash content, tailings ash content, and Btu recovery all decreased as expected.

However, in test T-14, where the tip speed was decreased to 8.5 m/s, the reverse effect was seen. While the T-14 results are considered an anomaly, they may be partially due to the increased high-shear solids concentration, which is known to reduce high-shear energy requirements.

Table 3. High-Shear B Tip Speed Evaluation - Taggart Coal

Test	Grind D80	High-Shear Operating Conditions Solids %	Tip Spd m/s	Kwhr per ton coal	Kwhr per 1000 gal	Inver. Quality	Product Ash %	Product Ash lb/MBtu	Tails Ash %	Btu Rec %
T-12	30.2	10.1	11.0	16.3	6.7	Good	1.54	1.02	63.5	98.6
T-13	29.1	10.4	9.5	10.8	4.5	Poor	1.45	0.96	55.6	98.1
T-14	31.4	11.1	8.5	7.3	3.3	V. Poor	1.77	1.18	62.0	99.0

It should be noted that due to the limited supply of Taggart coal, the results from these three tests were used to select operating conditions for the Taggart coal production run. It was decided to operate the production run at conditions similar to those shown in Appendix A for tests T-12 and T-13, except that a high-shear impeller tip speed of 10 m/s would be used. This was anticipated to provide a product ash content of approximately 1 lb/MBtu.

High-Shear A Energy Input Evaluation - A series of tests was carried out to determine the effect of decreasing high--shear energy input, at a constant impeller tip speed (11 m/s), on product ash content. To accomplish this, the coal feed rate to the plant was incrementally increased. Evaluation of these tests was based on low-shear product samples which were screened in the lab. It should be noted that the changing coal throughput rate also effected the energy input into low shear. Pertinent results for these tests are shown in Table 4.

Table 4. High-Shear A Energy Input Evaluation - Taggart Coal

Test	Grind D80	Coal Feed lb/hr	Kwhr per ton coal	Kwhr per 1000 gal	Inversion Quality	LS Rinse Basis Ash (%) Prod	LS Rinse Basis Ash (%) Tails	Btu Rec %
T-10-1	32.0	2553	5.8	2.4	Fair	1.60	69.0	99.1
T-10-2	32.1	3003	4.8	2.0	Poor	1.55	59.9	98.6
T-10-3	32.2	3517	4.1	1.7	V. Poor	1.47	50.7	97.8
T-10-4	30.7	3765	3.8	1.6	None	1.53	45.0	97.3

As can be seen from this data, as the plant coal throughput was increased, decreasing high-shear energy input on a coal and slurry basis, the inversion quality achieved from high-shear decreased as expected. As a result of decreasing degrees of inversion, the tailings ash decreased along with the Btu recovery.

These trends are due to increasing degrees of "incomplete agglomeration" resulting in more coal losses to the tailings as energy input on a coal basis was decreased. As such, a similar trend of decreasing product ash content is generally observed. The high product ash content for Test T-10-4 (1.53%) is considered an anomaly, however, especially since this test had a slightly finer feed coal grind size.

As such, it was determined that reductions in high-shear energy input could be used to achieve small reductions in product ash content with corresponding small reductions in Btu recovery.

Low-Shear Solids Concentration Effects - Tests T-7 and T-8 were carried out to evaluate the effect of low-shear solids concentration on product ash content. While attempts were made to maintain all other plant conditions at similar set points, problems with the weigh belt feeder resulted in a finer grind size for test T8. Results for these test are shown in Table 5.

Table 5. Low-Shear Parameter Effects - Taggart Coal

			Low Shear		LS Rinse		Full Plant	
	Grind	%	Imp Tip	Res Time	Ash (%)		Ash (%)	
Test	D80	Solids	Speed (m/s)	Seconds	Prod	Tails	Prod	Tails
T-7	35.6	8.4	5.2	131	1.63	67.6	1.63	69.7
T-8	33.2	7.1	5.2	116	1.63	64.6	1.64	67.2
T-9	35.2	8.6	6.6	131	1.72	72.2	1.68	75.3

As can be seen from the data in Table 5, no effect on product ash was observed when decreasing the low-shear solids concentration from 8.4 to 7.1% in Tests T-7 and T-8, respectively. In fact, since T-8 had a slightly finer grind, the reduced solids concentration was definitely not advantageous.

Low-Shear Impeller Tip Speed Effect - Also shown in Table 5 are the results of Test T-9, which evaluated the effect of a higher low-shear impeller tip speed. When comparing the effect of increasing the low-shear impeller tip speed from 5.2 m/s in test T-7, to 6.6 m/s in test T-9, an increase in product ash is observed. As such, no additional testing was done at the higher low-shear impeller tip speed for the Taggart coal.

Stripping Circuit Solids Concentration Effect - Table 6 presents results for two tests completed at different stripping circuit solids concentrations (T-8 and T-9).

As can be seen from this data, reducing the steam stripping circuit solids concentration had no effect on the residual heptane concentration of the product, from either the first or second stage of steam stripping. As such, subsequent testing was carried out at the higher solids concentration to reduce the steam required during steam stripping.

Table 6. Stripper Solids Concentration Effects - Taggart Coal

	First Stage Steam Stripper (A)		Second Stage Steam Stripper (B)	
Test	% Solids	Residual heptane, ppm dcb	% Solids	Residual heptane, ppm dcb
T-8	29.6	9953	28.7	4716
T-9	21.2	9762	20.7	5082

Other Parametric Testing - Additional parametric testing carried out with the Taggart coal focused on decreasing the plant feed rate such that a finer grind could be achieved so the product ash target of 1 lb/MBtu could be met. Results of these tests indicated that a grind with a D_{80} of approximately 30 to 32 microns was required to achieve the 1 lb ash/MBtu target product grade.

Figure 3 shows the results of all the Taggart coal parametric testing as product grade in lb ash/MBtu vs Grind size D_{80} in microns.

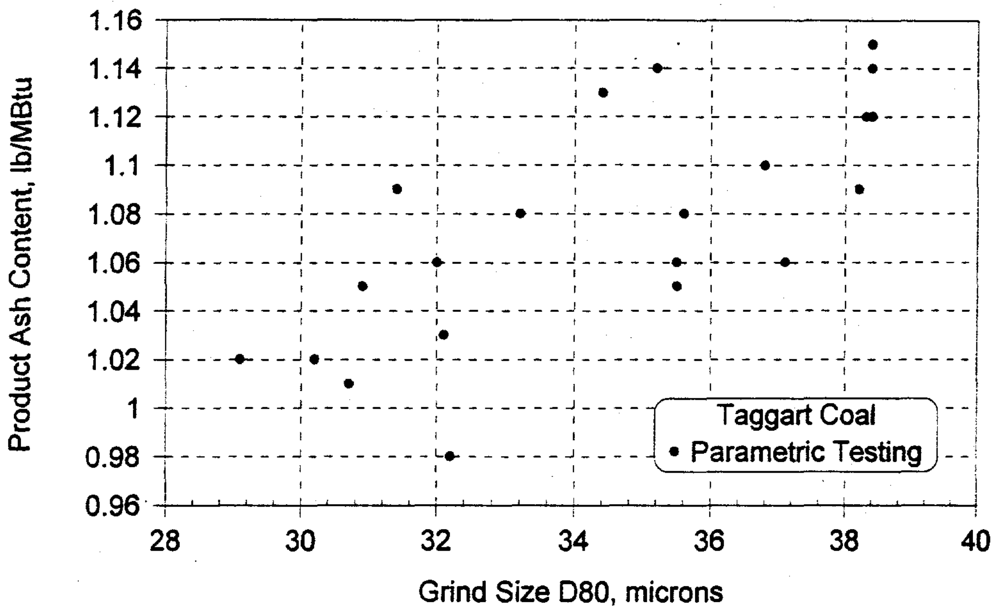


Figure 3. Taggart Coal Parametric Testing Results

As can be seen from the data in Figure 3, while there is scatter in the data attributed to the various operating conditions tested, the general trend of decreasing product ash content with decreasing grind size D_{80} is evident.

At this D_{80}=30 micron grind size it was found that a tailings ash content in the 60% range was needed to insure that the product grade was met. To achieve these conditions the high-shear energy (tip speed) was adjusted as required. It was found that at a dry coal feed rate of approximately 3300 lb/hr and a high-shear solids concentration of about 10%, the desired product ash could be achieved at a high-shear impeller tip speed in the 10 m/s range. As such, these conditions were chosen as the target operating parameters for the production run.

Taggart Coal Production Run

The Taggart coal production run was carried out during the week of May 19, 1997. John Getsoian from Arcanum was on site during the production run to provide operations support and videotape the PDU operation. Individual set point and average operating conditions and results for the production run are shown in Appendix B along with the Taggart coal parametric testing results discussed previously.

As can be seen from this data, the average product ash content was 1.06 lb/MBtu, slightly higher than the 1 lb/MBtu target. The range of product ash contents for the individual samples was from 1.01 to 1.12 lb/MBtu. The following is a summary list of average production run operating conditions and results:

- Dry coal feed rate - 3305 lb/hr
- Plant feed Grind D_{80} - 30.3 microns
- Plant feed solids concentration - 10.02%
- Plant feed ash content - 3.64%
- Heptane dosage utilized - 39.2% on a dry ash free coal basis
- Total agglomeration (high- and low-shear) energy input - 16.1 kwhr/ton feed coal (6.2 kwhr/1000 gallon slurry)
- Screen spray water rate - 566 gallons/ton product
- Steam consumption - 1553 lb/ton dry product (1.8 lb/gallon slurry stripped)
- Plant product ash content - 1.06 lb/MBtu (1.59%)
- Plant product residual heptane content - 5115 ppm on a dry coal basis
- Plant tailings ash content - 63.0%
- Plant tailings residual heptane content - 4094 ppm on a dry solids basis
- Plant yield - 96.7%
- Plant Btu recovery - 99.2%

The following represents an approximate summary of the operating schedule for the Taggart coal production run:

- Run start: 7:15 May 19
- Shutdown due to stripping circuit feed pump failure: 20:15 May 19 (13 hours run time)
- Run restart: 22:15 May 19 (2 hours down time)
- Run end: 7:15 May 22 (57 hours run time)
- **Total approximate run time: 70 hours**
- **Total approximate down time: 2 hours**
- **Total run duration: 72 hours**

The two hours of down time during the production run was due to worn diaphragms in the stripping circuit feed pump. This problem was expected since replacement diaphragms of the correct material (viton) had been ordered and were to be installed prior to the production run. However, the wrong diaphragms were shipped, and as such, the production run was started on schedule, but with the old diaphragms in place. The new viton diaphragms arrived the day the production run was started and were installed when the pump failed.

Other problems encountered with equipment during the production run, none of which forced a plant shutdown, were as follows:

- Shortly after start up, the grinding circuit cyclones were found to be plugged. These were unplugged on line, allowing operation to continue.
- Failure of the control valve that maintained the correct operating level in the gravity separator. This was overcome by manually controlling the water discharge from the gravity separator for the duration of the production run.
- The fine grinding mill tripped out resulting in the reduction of feed to the Area 300 feed storage tank for approximately 30 minutes. The grinding circuit circulating load was rerouted to the secondary ball mill until the fine grinding mill could be restarted.

Indiana VII Coal Parametric Testing

A total of 20 different sets of operating conditions were evaluated this reporting quarter for the Indiana VII coal. Operating conditions and results for all of these test are shown in Appendix C. The breakdown of these 20 different tests is as follows:

- One start-up test
- Nine complete plant tests, i.e., a full compliment of Area 300 samples were taken
- Ten tests in which the samples form the low-shear vessels were used as the basis for evaluation

The 19 parametric tests were carried out to evaluate the following:

- The effects of high-shear energy input and asphalt dosage
- The effect of low-shear solids concentration
- The effect of low-shear tip speed
- The effect of agglomerate size
- The effect of steam stripping temperature
- The effect of vibrating screen spray water flowrate

Start-Up Test - During the initial start-up test (I-1) an asphalt dosage of 9.5 lb/ton coal was used and high-shears A and B operated in series at their maximum achievable tip speeds of 17.4 and 14 m/s, respectively. At these operating conditions, only marginal phase inversion (a rating of 2 on a 1 to 10 scale) was achieved. This poor inversion at these relatively high asphalt and energy levels is attributed to the low solids concentration (6.96%) used during high shear. This low solids concentration resulted in a less efficient high-shear unit operation due to less particle to particle contact than would be achieved at a higher solids loading. This low solids loading also reduced the available high-shear residence time due to the high volumetric flowrate required to maintain the target dry coal throughput rate.

It was also found, during this start-up test, that the asphalt emulsion utilized contained large pieces of what appeared to be tar. These large particles were found to bind up the asphalt pump (gear type), causing the asphalt pump to stop pumping on several occasions. During these periods of no asphalt flow, inversion was lost completely resulting in the loss of coal to the tailings stream. As such, the tailings ash content for this start-up test was only 73%. For this start-up test, the product ash content was 2.2 lb/MBtu and the Btu recovery was 97.9%.

High-Shear Evaluation - After the initial start-up test, subsequent testing with the Indiana VII Coal was performed to determine the asphalt dosage and high-shear energy input required to achieve inversion at the high-shear circuit discharge. During this testing, additional operating and feedstock parameters known to effect the high-shear unit operation, namely feedstock PSD and high-shear solids concentration, were also varied. As such, data presented here for high-shear energy and asphalt dosage effects on inversion, are independent of these variables.

Asphalt Effect - Table 7 presents 4 pairs of tests results, using low-shear product samples screened and rinsed in the lab, to illustrate the effect of asphalt dosage on product ash content and inversion quality with all other variables held relatively constant.

Table 7. Asphalt Effects on Inversion and Product Ash Content - Indiana VII Coal

Test	Grind D80	% solids	Asphalt lb/ton	HS Tip Speed m/s	High Shear Kwhr per ton coal	High Shear Kwhr per 1000 gal	Inversion Quality (1-10)	LS Rinse Basis Ash (%) Prod	LS Rinse Basis Ash (%) Tails
I-2	23.9	8.80	**8.5**	14.0	49.0	17.4	**4**	**3.14**	**85.2**
I-3-1	23.3	8.83	**11.3**	14.0	48.9	17.4	**6**	**3.15**	**88.8**
I-6	26.0	11.34	**8.5**	14.0	38.8	17.6	**2**	**2.96**	**84.1**
I-7-1	26.2	11.75	**13.3**	14.0	37.4	17.5	**5**	**3.07**	**92.2**
I-9-3	20.0	12.40	**4.8**	14.0	46.8	23.1	**2**	**2.65**	**86.2**
I-9-2	21.1	12.42	**7.7**	14.0	46.7	23.0	**6**	**2.76**	**91.3**
I-10-3	22.8	12.11	**4.9**	14.0	40.3	19.4	**3**	**2.95**	**85.2**
I-10-2	22.5	12.28	**6.8**	14.0	39.7	19.3	**5**	**2.93**	**89.1**

As expected, it can be seen from this data that in every case, increasing the asphalt dosage improved the quality of inversion achieved. This effect can also be seen in the tailings ash values which consistently increased with higher asphalt dosages. It was found that when the lower asphalt dosages were used, resulting in lower tailings ash values, more unagglomerated filmy material was observed in the low-shear samples.

It can also be seen from this data, that there appears to be a small effect of asphalt dosage on product ash content, with higher asphalt dosages resulting in slightly higher product ash values for 2 of the 4 pairs of results presented. However, for the other two pairs there was no effect at all.

High-Shear Energy Effect - Table 8 presents 2 pairs of tests results, using low-shear product samples screened in the lab, to illustrate the effect of high-shear energy input on product ash content and inversion quality, with all other variables held constant.

Table 8. High-Shear Energy Effects - Indiana VII Coal

Test	Grind D80	% solids	Asphalt lb/ton	HS Tip Speed m/s	High Shear Kwhr per ton coal	High Shear Kwhr per 1000 gal	Inversion Quality (1-10)	LS Rinse Basis Ash (%) Prod	LS Rinse Basis Ash (%) Tails
I-3-1	23.3	8.83	11.3	**14.0**	48.9	17.4	**6**	**3.15**	**88.8**
I-3-2	23.3	8.83	11.3	**11.0**	26.6	9.4	**2**	**3.23**	**83.8**
I-7-1	26.2	11.75	133	**14.0**	37.4	17.5	**5**	**3.07**	**92.2**
I-7-2	26.2	11.75	13.3	**12.0**	27.3	12.7	**3**	**3.23**	**90.4**

As expected, it can be seen from this data that for both cases, decreasing the high-shear tip speed (energy input) reduced the quality of inversion achieved. This effect can also be seen in the tailings ash values which consistently decreased with lower energy input indicating incomplete agglomeration, as observed during testing by the presence of more unagglomerated filmy material floating in the low-shear samples.

It can also be seen from this data, that there is a clear effect of high-shear energy input on product ash content, with lower energy resulting in higher product ash values for both pairs of results presented. This is due to the production of better formed agglomerates at the higher energy levels, subsequently resulting in better screening, i.e., improved drainage of associated mineral-matter bearing process water.

Combined Asphalt Dosage and High-Shear Energy Effect - Table 9 presents 4 pairs of tests results, using low-shear product samples screened and rinsed in the lab, to illustrate the combined effect of simultaneously increasing asphalt dosage and decreasing high-shear energy input on product ash content, with all other variables held relatively constant.

Table 9. Combined Asphalt & High-Shear Energy Effects - Indiana VII Coal

Test	Grind D80	% solids	Asphalt lb/ton	HS Tip Speed m/s	High Shear Kwhr per ton coal	High Shear Kwhr per 1000 gal	Inversion Quality (1-10)	LS Rinse Basis Ash (%) Prod	LS Rinse Basis Ash (%) Tails
I-2	23.9	8.80	**8.5**	**14.0**	49.0	17.4	4	**3.14**	85.2
I-3-1	23.3	8.83	**11.3**	**11.0**	26.6	9.4	2	**3.23**	83.8
I-4	26.1	8.50	**11.8**	--	59.7	20.4	9	**3.19**	90.1
I-5	26.4	8.80	**18.9**	--	38.0	13.4	5	**3.30**	88.2
I-6	26.0	11.34	**8.5**	**14.0**	38.8	17.6	2	**3.07**	92.2
I-7-1	26.2	11.75	**13.3**	**12.0**	27.3	12.7	3	**3.23**	90.4
I-9-3	20.0	12.40	**4.8**	**14.0**	46.8	23.1	2	**2.65**	86.2
I-9-4	20.1	12.61	**9.5**	**12.0**	34.2	17.0	1	**2.81**	89.1

As can be seen from this data, when the asphalt dosage was increased and the high-shear energy decreased simultaneously, a higher product ash content resulted. This data combined with the results presented in the previous two tables indicate that if the goal of the process is to achieve the lowest product ash content at a given grind size, the asphalt dosage should be minimized and sufficient energy used to achieve the formation of good agglomerates.

Solids Concentration Effect - No test was performed specifically to evaluate the effect of high-shear solids concentration on the energy and/or asphalt required to achieve inversion. However, a comparison of tests I-2 and I-3-1 to I-8-1, as shown in Table 10, illustrates this effect to some degree.

Table 10. High-Shear Solids Concentration Effect on Inversion - Indiana VII Coal

Test	Grind D80	% solids	Asphalt lb/ton	HS Tip Speed m/s	High Shear Kwhr per ton coal	High Shear Kwhr per 1000 gal	Inversion Quality (1-10)
I-2	23.9	**8.80**	8.5	14.0	49.0	17.4	**4**
I-3-1	23.3	**8.83**	11.3	14.0	48.9	17.4	**6**
I-8-1	23.7	**12.40**	9.7	14.0	46.4	22.8	**8**

As can be seen from this data, Test I-8-1, which utilized an asphalt dosage in the same range as the previous tests, achieved better inversion quality at the same high-shear tip speed and similar energy inputs. This is attributed to the increased solids concentration in high shear which results in more particle to particle contact at similar energy inputs.

Low-Shear Evaluation - One series of tests (I-8-1, I-8-2, and I-8-3) was carried out to evaluate the effect of low-shear solids concentration and tip speed on the operability of the low-shear vessel and the product ash content.

Solids Concentration Effect - Unfortunately during the completion of this test series, the grind size was increasing, and as such, a direct comparison of low-shear sample rinse product ash contents as a function of these two variables can not be made. It should be noted, however, that even though the grind size increased from Test I-8-1 to I-8-2 (D_{80} of 23.7 to 25.1 microns) and the solids concentration was increased from 7.7 to 12.7%, no significant increase in product ash content (3.11 to 3.16%) was observed. This indicates that the higher solids loading during low shear does not have a detrimental effect on product ash content.

Considering the operability of the low-shear vessel at the higher solids concentration, no difficulties were encountered. This was somewhat surprising since previous testing of the low-shear unit operation at high solids concentration resulted in very difficult to control agglomerate growth. It is possible that the use of asphalt during high shear to achieve inversion, and its subsequent presence during low shear, may make agglomerate growth more controllable, i.e., less sensitive to the heptane dosage utilized.

Low-Shear Tip Speed Effect - In comparing Tests I-8-1 and I-8-3, when the low-shear tip speed was increased from 5 to 6.5 m/s during Test I-8-3, and the grind was coarser (D_{80}=27.5 microns as compared to 23.7 microns during Test I-8-1), only a relatively small increase in product ash content (3.11 to 3.22%) was observed. This indicates no significant increase in product ash content due to the higher low-shear impeller tip speed.

One additional test (I-10-1) was completed to evaluate the effect of utilizing a lower low-shear impeller tip speed. It was found that the 3 m/s tip speed tested resulted in poor agglomerate growth with the agglomerates appearing overdosed with heptane even though they were not. During this test, some of the agglomerates grew very large (6 mm) while much of the coal remained in the microagglomerate form, i.e., no growth. This observation is confirmed by the relatively low (81.5%) tailings ash value achieved during rinsing of the low-shear sample in the lab. Completion of this low low-shear impeller tip speed test was attempted on three different occasions with similar results, indicating that the 3 m/s tip speed does not supply sufficient energy for consistent agglomerate growth, i.e., sufficient mixing to achieve thorough particle to particle contact in the low-shear vessel.

Screen Spray Water Flowrate Evaluation - Two tests (I-9-1 and I-9-2) were performed to evaluate the effect of screen spray water flowrate on product ash content. Both of these tests were full plant tests in which a full compliment of selective agglomeration module samples were taken. However, due to continuing problems with the weigh belt feeder, the feedstock grind size decreased between the two tests from a D_{80} of 23.0 microns for Test I-9-1 (low screen spray rate) to a D_{80} of 21.1 microns for Test I-9-2 (high screen spray rate).

Results form these tests indicate a decrease in the final plant product ash content of 0.13% from 2.84 to 2.71%. However, when comparing the low-shear samples rinsed in the lab, a decrease of only 0.05% from 2.81 to 2.76% was observed. As such, it is possible that the higher screen spray rate resulted in some product ash content reduction not attributable to the finer grind size.

Stripping Circuit Evaluation - One pair of tests (I-9-1 and I-9-2) was carried out to evaluate the effect of stripper operating temperature on the product residual heptane content. For the first test, the steam strippers were operated at pressures of approximately 1 and 5 psi in strippers A and B, respectively. For the second test, the stripper operating pressures were increased to approximately 6 and 10 psi, respectively. Stripper operating temperatures and residual heptane concentrations for these two test are shown in Table 11.

Table 11. Stripper Temperature Effects - Indiana VII Coal

	First Stage Steam Stripper (A)		Second Stage Steam Stripper (B)	
Test	°F	Residual heptane, ppm dcb	°F	Residual heptane, ppm dcb
T-9-1	199	13487	231	5152
T-9-2	210	11771	240	4917

As can be seen from this data, there appears to be no significant reduction in the final plant product residual heptane concentration as a result of the increased stripping temperatures. However, the temperature increase resulted in a reduction of the first stage stripping product residual heptane content.

During virtually all of the Indiana VII coal testing completed to date, residual heptane concentrations have been in the 5000 ppm range on a dry coal basis (dcb). However, for one test (I-5), in which a high asphalt dosage (approximately 19 lb/ton) was used, a higher residual heptane concentration (7300 ppm dcb) was found. It was noted during this test that the material in the strippers was very foamy and difficult to pump. As such, this higher residual heptane content is attributed to poor operational control rather than the presence of greater amounts of asphalt. Tailings residual heptane contents for the Indiana VII coal testing have been in the 300 to 1000 ppm dcb range.

Agglomerate Size Effect - Two tests (I-10-3 and I-10-4) were carried out to evaluate the effect of agglomerate size on product ash content. For these tests, all conditions were held constant and the low-shear product sampled at two different times, once when the agglomerates were about 2 mm in size, and once when the agglomerates were about 0.5 mm in size. Results of these two tests, using low-shear samples rinsed in the lab, indicate virtually no difference in product ash content. This result is surprising since during previous testing (particularly during Subtask 6.5, bench-scale testing) larger agglomerates consistently resulted in lower product ash values.

Feedstock PSD Effect - Throughout the Indiana VII coal testing to date, PSDs with D_{80}s in the 20 to 26 micron range have been tested. During this testing, product ash values ranged from a high of 3.58% (2.56 lb/MBtu) to a low of 2.71% (1.92 lb/MBtu). In addition, one laboratory rinsed low shear sample achieved a product ash content of 2.65% (1.88 lb/MBtu).

To date, the project product ash content goal of 2 lb/MBtu has been met at only the finest grinds evaluated (D_{80}s of 20 to 21 microns during tests I-9-2, I-9-3, and I-9-4). Attempts to repeat these results during the I-10 series of tests were unfortunately spoiled by coarser PSDs (D_{80}s in the 22 to 24 micron range).

Due to the difficulty in producing the 20 micron grind and the difficulty in filtering the product at this fine size, no further testing specifically targeting the 2 lb/MBtu product ash goal is planned.

As such, additional testing will evaluate the increase in product ash content as a function of coarser feedstock PSDs. In this manner, subsequent testing will focus on finding grinding and agglomeration operating conditions which:

- Produce a consistent feedstock PSD
- Produce a consistent product ash content
- Produce a product that can be continuously filtered

These results will be used to select the operating conditions for the Indiana VII coal production run.

Yield and Btu Recovery - Throughout the Indiana VII coal testing to date, relatively high (85 to 92%) tailings ash contents have been consistently achieved. For the few tests in which the tailings ash values were below this range, insufficient asphalt and/or energy was used during high-shear agglomeration. Given these high tailings ash values, it is not unexpected that Btu recoveries are consistently greater than 99% with yields in the 90 to 92% range.

However, based on the calculation procedure used to determine Btu recovery (Btu content of the product stream divided by the Btu content of the feed stream and adjusted for yield), the values have been consistently greater than 100%. While this is not possible, it is attributed to a combination of the asphalt content of the product and the residual heptane content of the product. Attempts will be made to develop an alternative method for determining more accurate plant Btu recoveries.

Summary

The following is a summary list of observations and conclusions based on the Task 9.3 testing completed to date:

- While the SA module can be run at a 2 t/hr coal feed rate, a more stable operation is achieved at a slightly lower feed rate (3800 lb/hr).
- For the Hiawatha coal, a grind with a D_{80} of approximately 40 microns is sufficiently fine to achieve the 2 lb ash/MBtu product target ash level.
- For the Taggart coal, a grind with a D_{80} of approximately 30 microns is sufficiently fine to achieve the 1 lb ash/MBtu product target ash level.
- For the Indiana VII coal, a grind with a D_{80} of approximately 20 microns is sufficiently fine to achieve the 2 lb ash/MBtu product target ash level.
- For the Hiawatha coal, there appeared to be no effect of high-shear energy input (in the range investigated) on product ash content.
- For the Taggart coal, the product ash content was affected by the high-shear energy input, with lower energy resulting in lower product ash contents. This is attributed to the increasing loss of coal to the tailings (decreasing Btu recovery) with decreasing energy input.
- For the Indiana VII coal, the product ash content was affected by the high-shear energy input, with lower energy resulting in higher product ash contents and decreased Btu recovery. This is attributed to the poor formation of agglomerates at lower energy levels, and subsequent poor drainage of mineral-matter bearing process water during screening.
- For the Indiana VII coal, an asphalt dosage in the 5 to 10 lb/ton of coal is required for inversion to take place, with lower asphalt and higher energy providing lower product ash contents than higher asphalt and lower energy.

- Higher asphalt dosages result in slightly higher product ash contents.
- Operation of the low-shear vessel half full provides sufficient residence time for agglomerate growth to a recoverable size.
- Operation of the low-shear vessel full results in an unstable (cyclic growth) pattern.
- No effect on residual heptane concentration is observed as a function of stripping circuit solids concentration.
- Final plant product residual heptane concentrations were typically 3000, 5000, and 5000 ppm on a dry coal basis for the Hiawatha, Taggart, and Indiana VII coals, respectively.
- Plant tailings residual heptane content is primarily a function of tailings ash content and has ranged from a low of about 400 ppm (dry coal basis) at a tailings ash of 90%, to a high of 5000 ppm at a tailings ash of 60%.
- Overall, plant Btu recoveries are very high, with analysis indicating Btu recoveries consistently >97%, and often >99%.

Subtask 9.4 Selective Agglomeration Topical Report

Work began on Task 9 Selective Agglomeration Topical Report with the analysis of the Hiawatha and Taggart coal production run feed and clean coal samples for ash properties. In addition, samples from these production runs were also submitted for toxic trace element analyses.

Ash Properties of Clean Coals - Hazen Research, Inc., of Golden, Colorado, determined the ash chemistry and fusion properties of composite feed and product (clean coal) samples from the Taggart and Hiawatha coal production runs in the PDU SA module. It was found that the selective agglomeration process increased the base/acid ratio of the ash and decreased the silica/alumina ratio. The overall results indicated a decline in the reducing atmosphere fusion temperature of the ash in the Taggart coal and a small increase in the fusion temperatures of the ash in the Hiawatha coal.

The softening (spherical) temperatures are compared in Figure 4 to illustrate the difference caused by the cleaning.

The complete set of fusion temperatures are presented in Table 12.

The ash compositions of the coals are presented in Table 13 along with slag viscosity calculations and assessments of the slagging and fouling characteristics of the ash. The calculated viscosities agree with the fusion temperature measurements. Except for titanium dioxide, and possibly iron oxide in the case of the Taggart coal and phosphorus pentoxide in the case of the Hiawatha coal, the concentrations of the ash constituents were significantly reduced on a heating value (lb/MBtu) basis by selective agglomeration in the PDU.

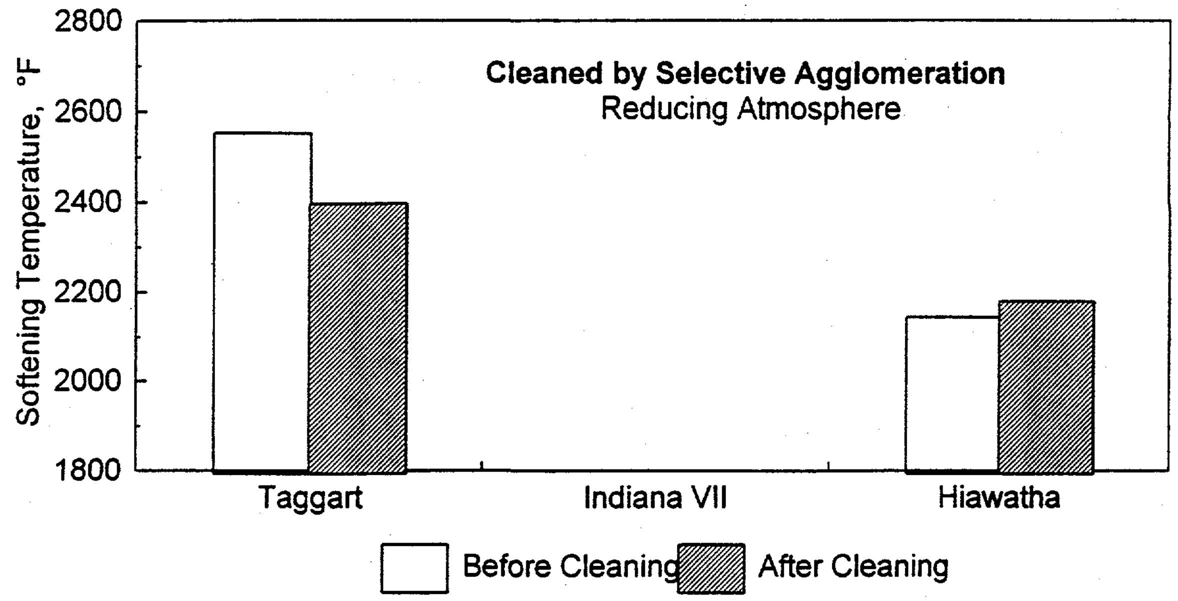


Figure 4. Softening Temperatures of Ash in Test Coals

Table 12. Coal Ash Fusion Temperatures (°F) Before and After Agglomeration

	Taggart Coal		Hiawatha Coal	
	Before Cleaning	After Cleaning	Before Cleaning	After Cleaning
Oxidizing Atmosphere:				
Initial	2570	2485	2170	2290
Softening	2657	2618	2230	2306
Hemispherical	2695	2630	2300	2319
Fluid	2710	2680	2445	2333
Reducing Atmosphere:				
Initial	2286	2236	2084	2120
Softening	2552	2396	2145	2181
Hemispherical	2600	2475	2255	2195
Fluid	2664	2600	2346	2220

Table 13. Ash Chemistry of Test Coals Cleaned by Selective Agglomeration

	Taggart Coal			Hiawatha Coal		
	Before Cleaning	After Cleaning	Reduction Percent*	Before Cleaning	After Cleaning	Reduction Percent*
Ash Constituent, %:						
SiO_2	47.83	46.24	56	51.18	38.54	74
Al_2O_3	26.97	28.81	51	17.25	21.87	56
TiO_2	1.10	1.92	20	0.95	2.22	20
Fe_2O_3	10.10	14.12	36	5.24	7.29	52
CaO	1.60	2.05	41	11.60	8.49	75
MgO	0.72	0.60	62	1.02	0.78	74
Na_2O	1.21	0.81	69	2.48	4.30	40
K_2O	2.96	2.27	65	0.64	0.56	70
P_2O_5	0.23	0.29	42	0.51	1.03	30
SO_3	1.24	1.52	44	9.16	10.20	62
Ash Viscosity Calculations:						
Base Content, %	17.94	20.50		23.22	25.48	
Acid Content, %	82.06	79.50		76.78	74.52	
Dolomite Ratio	13.98	13.35		60.15	43.28	
Base/Acid Ratio	0.22	0.26		0.30	0.34	
Silica/Alumina Ratio	1.77	1.60		2.97	1.76	
T(cv), °F	2800	2675		2455	2395	
T250 Temp, °F	2677	2603		2541	2480	
Equiv Silica, %	79.87	73.39		74.13	69.95	
Viscosity at 2600 °F, P	740.95	261.13		294.90	149.01	
Ash Type	High Rank	High Rank		Lignite	Lignite	
Slagging/Fouling Characteristics:						
Slagging Type	Low	Low		Medium	Medium	
Fouling Type	Medium	Medium		Low	Medium	

* Percentage reduction calculated on a heating value (lb/MBtu) basis

Toxic Trace Elements - Samples of the crushed feed coal, ground selective agglomeration feed, product (clean coal), and tailings from the Taggart and Hiawatha production runs were submitted to Huffman Laboratories for analysis of the twelve toxic trace elements of interest.

TASK 10 DISPOSITION OF THE PDU

Task 10 of this project involves the decommissioning and disposal of the PDU and all ancillary equipment acquired with DOE funds and restoration of the site. In particular, Task 10 will include the following tasks:

- Cleaning (flushing of coal and reagents) from all PDU equipment and piping
- Removal of all PDU equipment and piping from within the Amax R&D facility
- Numbering or otherwise identifying all equipment to facilitate reassembly

- Packaging of all equipment
- Shipment of all equipment to DOE designated site and/or local sale of the equipment
- Disposal of all excess reagents and chemicals used throughout the project
- Acceptable restoration of Amax R&D facility

Work on these tasks began during June, 1997 with the submittal of a complete equipment list to DOE. This list was posted on a computer network for review by FETC project managers to determine if any equipment was appropriate for use in other DOE projects. To date, some interest has been expressed in several of the reagent pumps and smaller vessels.

Work on the PDU decommissioning will begin in earnest during August, following conclusion of the Subtask 9.3 operations at July end. Initial Task 10 efforts, to be carried out by Entech Global, Inc. personnel, will focus on the following:

- Flushing of all coal and reagents from the PDU system
- Removal of all plant piping
- Removal of electrical conduit where required for equipment removal
- Removal of handleable pieces of equipment such as pumps and small vessels

Once removed, this material and equipment will be identified and stored outside.

The removal of the bulk of the equipment, particularly the larger pieces, will be carried out by an outside contractor. This contractor will complete the following tasks:

- Disassemble the pilot plant buildings as required for equipment removal.
- Remove all equipment to yard
- Reassemble the pilot plant buildings following equipment removal
- Package all equipment to be shipped to a DOE designated site.

Ultimately, the fate of the DOE property depends on DOE's decision as to whether to sell the equipment locally, or ship the property to a DOE designated site. Entech global will acquire bids for either option.

TASK 11 PROJECT FINAL REPORT

Following discussions between Amax R&D, Bechtel, and DOE, it was decided that in addition to the project final report (summarizing all work completed during the course of the project), a separate topical report should be prepared by Bechtel. This topical report, titled "Commercial CWF Production Cost Study," would present an economic assessment for the commercial-scale production of premium fuels utilizing the advanced flotation and selective agglomeration processes.

Commercial Cost Study Topical Report

The Task 11 topical report "Commercial CWF Production Cost Study" [23] was issued during June 1997. This report is an economic assessment of the commercial-scale production of premium fuel by the advanced flotation and selective agglomeration processes. This topical report was prepared by Bechtel. The economic assessment was based upon the PDU plant designs developed during Tasks 5 and 7 for the flotation and agglomeration modules, respectively, and revised to reflect the results obtained during the Tasks 8 and 9 pilot-scale operation of the PDU advanced flotation and selective agglomeration modules, respectively.

Capital and operating costs for this study were based on conceptual plants located in the Ohio Valley Region. The plants would produce 1.5 million short tons per year (dry basis) of clean coal to be marketed as coal-water-slurry fuel (CWF). Feedstock for the plant would be purchased from mines in the central Appalachian area that produce coals that can be upgraded in a manner similar to the Elkhorn No. 3, Taggart, Sunnyside, and Hiawatha test coals used for the bench-scale and 2 t/hr process development work. The CWF would contain 60 to 62% coal (8,900 to 9,400 Btu/lb), less than 2.0 lb ash/MBtu, and less than 0.6 lb sulfur/MBtu and would have a viscosity of less than 500 cP.

Bechtel assembled capital and operating data for the report and developed equipment flowsheets and levellized cost projections for producing premium CWF by advanced column flotation and selective agglomeration. The conceptual plants include sections for coal receiving and storage, crushing and grinding, advanced physical cleaning (flotation or agglomeration), clean coal dewatering, CWF preparation, storage and load-out, tailings handling, and recycle water clarification. The selective agglomeration advanced cleaning section also included facilities for heptane recovery and reuse.

The advanced flotation premium fuel plant was found to be less expensive to place into service than the selective agglomeration plant as shown in Table 14.

Table 14. Commercial Scale Capital Costs

	Estimated Cost, $ (millions)	
	Flotation	Agglomeration
Project Capital Cost	69.6	97.2
Working Capital	10.0	11.0
Total	**79.6**	**108.2**

Total fixed and variable operating and maintenance (O&M) costs for producing CWF by the two cleaning methods were estimated to be $2.15/MBtu and $2.42/MBtu for advanced column flotation and selective agglomeration, respectively. The cost of the feed coal delivered to the premium fuel plants ($1.24/MBtu or about $32.40/st) was included in these costs. A breakdown of the O&M costs for each technology is presented in Table 15.

Table 15. Variable and Fixed O&M Costs and Total Cost of Coal-Water Fuel		
	Estimated Cost, $/MBtu	
	Advanced Flotation	Selective Agglomeration
Capital Charges Including Interest on Working Capital	0.27	0.37
CWF Additive (A-23M)	0.23	0.23
Labor	0.13	0.17
Electric Power	0.11	0.15
Flotation Reagents and Flocculants	0.07	0.03
Heptane and Steam		0.16
Btu Losses	0.05	0.01
Others	0.05	0.06
Total O&M Costs	**0.91**	**1.18**
Coal (Delivered to Plant)	**1.24**	**1.24**
Total Cost of Coal-Water Fuel	**2.15**	**2.42**

As shown in Table 15, the A-23M dispersant added to reduce the viscosity of the CWF was one of the most costly items among the O&M costs. A savings of $0.23/MBtu would be realized by formulating the CWF without this dispersant. The resulting CWF would contain 54% coal instead of 60 to 62% and have a heating value of 8,100 Btu/lb instead of 8,900 to 9,400 Btu/lb.

As one would expect, variation in the price of the feed coal had the most impact upon the cost of the CWF since feed coal accounts for half of the production cost of the CWF. The annual rate of production also had a significant impact upon the unit production cost. Variations in other sensitivity parameters such as feed coal ash content, labor, electricity, reagent costs, and capital costs had lesser impacts on the process economics.

Project Final Report

Initial drafts of a number of the sections of the final report have been prepared. The remaining sections will be drafted when the PDU testing is completed next month (July, 1997).

PLANS FOR NEXT QUARTER

The following activities are planned for the twentieth and final quarterly reporting period (July - September, 1997) of the project:

- The Subtask 3.3 Dewatering Studies Topical Report will be issued which will include a flowsheet for continuous bench-scale hydrophobic dewatering and an initial review of the economics of the process.
- Under Subtask 8.1, The final four loads of Indiana VII coal will be purchased and the yard at Ralston Development Company cleared of any left-over coal.
- The advanced flotation topical report will be issued completing the Subtask 8.5 and Task 8 efforts.
- Under Subtask 9.3, the PDU SA module parametric testing and production run with the Indiana VII coal will be carried out completing the Task 9.3 selective agglomeration test work.
- The selective agglomeration topical report will be issued completing the Subtask 9.4 and Task 9 efforts.
- The site decommissioning plan will be finalized and executed under Task 10.
- The Task 11 project final report will be issued completing the project effort.

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APPENDIX A

HIAWATHA COAL AGGLOMERATION RESULTS

PDU Selective Agglomeration Operating Conditions and Results - Hiawatha Coal

		PSD	Plant Feed					High Shear Agglom		Low Shear Agglom			Vibr Screen		Steam		Steam Stripper A				Steam Stripper B			LS	Plant Product			Plant Tails		Perform.	
Run	Date	Grind D80	Sol (%)	Coal (lb/hr)	Ash (%)	Hept maf (%)	Ves	kwhr/t Feed Coal	kwhr/ 1000 g slurry	Sol (%)	kwhr/t Feed Coal	kwhr/ 1000 gal slurry	Bed Depth (in)	Spray gal/t Prod	lb/t coal	lb/ gal	Product Sol (%)	Product Hept ppm	Res Time (min)	Slurry Temp (F)	Prod Sol (%)	Res Time (min)	Slurry Temp (F)	Rinse Ash (%)	Ash (%)	Ash lb/ Mbtu	Hept dcb ppm	Tails Ash (%)	Hept dcb ppm	Yield %	Btu Rec (%)
Froth Skimmer Evaluation																															
H-13-A	4/3/97	37.6	9.53	3571	8.45	31.9	B	28.7	11.2	7.54	2.9	0.9	0.50	546	1379	1.8	28.2	11251	17.4	210	26.6	21.7	240	2.79	2.66	1.88	3446	78.5	--	92.4	97.8
H-13-B	4/3/97	40.7	9.88	3704	8.29	31.3	B	27.6	11.2	7.82	2.7	0.9	0.38	522	1402	1.8	28.8	--	16.4	210	28.2	21.4	239	2.74	2.79	1.94	3146	83.2	--	93.2	99.2
High Shear Evaluation																															
H-14-A	4/7/97	42.8	9.48	3551	8.36	31.1	B	16.1	6.2	7.44	2.9	0.9	0.25	547	1496	1.9	26.5	--	16.8	210	25.3	20.7	239	2.76	2.74	1.91	3392	79.6	--	92.7	97.5
Confirmation Testing																															
H-15-A	4/8/97	41.8	9.91	3714	8.12	33.5	B	14.8	6.0	7.09	2.8	0.8	0.50	524	1105	1.3	27.5	--	15.1	211	25.5	15.9	235	2.69	2.73	1.90	2970	75.1	--	92.6	97.0
H-15-B	4/8/97	40.3	9.48	3551	8.35	32.7	B	15.5	6.0	6.77	2.9	0.8	0.50	551	956	1.1	26.1	--	15.3	210	26.1	16.4	240	2.70	2.60	1.81	3824	74.6	--	92.0	98.8
H-15-C	4/8/97	41.3	10.04	3769	8.01	32.9	B	14.6	6.0	7.19	2.8	0.8	0.50	510	897	1.1	26.5	--	15.0	210	26.0	16.0	238	2.60	2.82	1.97	3519	83.5	--	93.6	100.0
Production Run																															
H-P-1	4/14/97	42.1	9.66	3620	8.37	31.4	B	15.3	6.1	7.33	2.9	0.9	0.50	537	1533	2.0	28.7	--	16.5	210	26.9	17.7	239	2.69	2.73	1.90	2633	78.2	2661	92.5	99.5
H-P-2	4/14/97	42.7	10.64	3996	8.19	31.7	B	13.9	6.0	7.99	2.6	0.9	0.50	484	1385	1.9	29.9	8052	15.6	210	27.8	17.2	239	2.67	2.81	1.96	2835	80.2	1120	93.0	98.2
H-P-3	4/14/97	42.9	10.52	3949	8.06	31.9	B	14.1	6.0	7.90	2.6	0.9	0.50	491	1335	1.9	30.9	--	16.5	210	29.4	17.3	239	2.63	2.69	1.86	3213	77.9	1130	92.9	98.7
H-P-4	4/15/97	40.0	10.26	3850	8.05	31.3	B	14.2	5.9	7.71	2.7	0.9	0.50	502	1434	1.9	29.6	--	15.7	209	26.9	17.9	238	2.57	2.87	2.01	3011	79.3	1597	93.2	97.6
H-P-5	4/15/97	41.8	10.45	3923	7.96	30.5	B	13.9	5.9	7.86	2.7	0.9	0.50	491	1298	1.9	27.2	8756	16.8	210	26.3	17.0	239	2.71	2.91	2.02	2929	81.1	1079	93.5	99.6
H-P-6	4/15/97	41.8	10.41	3893	8.17	31.9	B	14.0	6.0	7.82	2.7	0.9	0.50	494	1494	1.8	28.3	--	15.0	209	27.4	16.9	238	2.68	2.78	1.94	2841	86.9	1024	93.6	99.4
H-P-10	4/16/97	39.6	9.92	3719	9.06	31.2	B	14.8	6.0	7.50	2.8	0.9	0.50	528	1295	1.6	27.7	--	15.9	210	26.7	17.7	239	2.77	2.74	1.91	3369	78.4	1547	91.6	98.7
H-P-11	4/16/97	42.9	10.22	3836	8.79	30.9	B	14.3	6.0	7.62	2.7	0.8	0.50	508	1300	1.7	29.0	6091	15.8	210	27.0	16.9	239	2.66	2.75	1.92	2789	81.5	1406	92.3	99.2
H-P-12	4/16/97	44.7	10.05	3768	8.39	30.8	B	14.6	6.0	7.49	2.8	0.8	0.50	516	1348	1.7	28.4	--	15.8	210	27.1	16.6	239	2.59	2.70	1.88	2934	80.2	1664	92.7	99.0
Average Production Run Performance and Conditions																															
H-P	Average	42.1	10.24	3839	8.34	31.3	B	14.3	6.0	7.69	2.7	0.9	0.50	505	1380	1.8	28.9	7633	15.9	210	27.3	17.3	239	2.66	2.78	1.93	2951	80.4	1470	92.8	98.9

APPENDIX B

TAGGART COAL AGGLOMERATION RESULTS

PDU Selective Agglomeration Operating Conditions and Results - Taggart Coal

Run	PSD Grind D80	Plant Feed Sol (%)	Plant Feed Coal (lb/hr)	Plant Feed Ash (%)	Hept maf (%)	Ves	High Shear Agglommeration Imp Tip (m/s)	High Shear Agglommeration Res Time (sec)	High Shear Agglommeration kwhr/ Ton Coal	High Shear Agglommeration kwhr/ 1000g slurry	Inv Qual	Low Shear Agglom Sol (%)	Low Shear Agglom Imp Tip (m/s)	Low Shear Agglom Res Time (sec)	Low Shear Agglom kwhr/ Ton Coal	Low Shear Agglom kwhr/ 1000g slurry	Vib Screen Bed Dpth (in)	Vib Screen Spray gal/t Prod	Steam lb/t coal	Steam lb/ gal	Steam Stripper A Product Sol (%)	Steam Stripper A Product Hept ppm	Steam Stripper A Res Time (min)	Stripper B Prod Sol (%)	Stripper B Res Time (min)	Low Shear Rinse Basis Prod Ash (%)	Low Shear Rinse Basis Prod Ash lb/ MBtu	Low Shear Rinse Basis Tails Ash (%)	Low Shear Rinse Basis Yield (%)	Low Shear Rinse Basis Btu Rec (%)	Plant Product Ash (%)	Plant Product Ash lb/ Mbtu	Plant Product Hept dcb ppm	Plant Tails Tails Ash (%)	Plant Tails Hept dcb ppm	Perf Yield %
High Shear Impeller B Tip Speed Evaluation																																				
T-1-1	35.5	10.17	3816	3.78	31.7	B	14.0	55	26.7	11.1	VG	8.1	5.2	126	2.9	1.0	--	--	--	2.2	--	--	17.8	--	13.8	1.59	1.05	76.5	97.1	99.3	--	--	--	--	--	--
T-1-2	35.5	10.17	3814	3.78	33.6	B	11.5	55	16.2	6.7	F	7.9	5.2	123	2.8	0.9	--	--	--	2.2	--	--	17.3	--	15.3	1.58	1.05	72.3	96.9	99.1	--	--	--	--	--	--
T-1-3	35.5	10.17	3816	3.78	36.0	B	9.0	54	8.3	3.4	P	7.7	5.2	119	2.8	0.9	--	--	--	2.1	--	--	15.8	--	16.7	1.60	1.06	68.6	96.7	99.0	--	--	--	--	--	--
High Shear A Impeller Tip Speed Evaluation																																				
T-2-1	38.4	10.64	4038	3.57	33.4	A	17.4	31	12.0	5.2	VG	8.2	5.2	120	2.6	0.9	--	--	--	2.1	--	--	15.5	--	16.4	1.73	1.15	81.3	97.7	99.6	--	--	--	--	--	--
T-2-2	38.4	10.64	3996	3.57	35.7	A	15.1	31	8.6	3.7	G	8.1	5.2	119	2.6	0.9	--	--	--	2.1	--	--	15.0	--	17.1	1.69	1.12	78.5	97.5	99.5	--	--	--	--	--	--
T-2-3	37.1	10.78	4051	3.54	33.3	A	11.0	31	3.6	1.6	P	8.0	5.2	116	2.6	0.9	--	--	--	1.7	--	--	14.3	--	17.9	1.60	1.06	63.1	96.8	98.8	--	--	--	--	--	--
High Shear A Full Plant Test																																				
T-3	38.4	10.71	4024	3.50	35.5	A	15.1	31	8.6	3.7	G	8.2	5.2	119	2.6	0.9	1.0	457	1621	2.1	30.6	7679	15.5	29.0	16.9	1.72	1.14	79.2	97.7	102.1	1.79	1.25	4060	79.6	1243	97.8
High Shear A Full Plant Tests																																				
T-4-1	38.2	10.74	4033	3.58	35.8	A	15.1	31	8.6	3.7	G	8.0	5.2	116	2.6	0.8	--	--	--	1.9	--	--	15.0	--	17.4	1.64	1.09	76.2	97.4	99.4	--	--	--	--	--	--
T-4-2	38.3	10.67	4007	3.45	36.2	A	15.1	31	8.7	3.7	G	7.9	5.2	116	2.6	0.8	0.8	460	1439	1.8	30.7	9300	14.9	29.8	17.6	1.69	1.12	77.9	97.7	99.4	1.70	1.13	4268	76.5	1512	97.7
Reduced Feed Rate - PSD Evaluation																																				
T-5	36.8	11.09	3670	3.60	36.6	A	11.0	35	3.9	1.7	P	8.2	5.2	131	2.9	1.0	--	445	1507	2.0	30.8	9313	17.3	29.8	17.7	1.65	1.10	71.4	97.2	99.5	1.67	1.11	4108	70.4	1438	97.2
High Shear A Tip Speed/Energy Evaluation																																				
T-6	35.6	11.17	3697	3.50	37.8	A	11.0	35	3.9	1.7	G	8.3	5.2	131	2.8	1.0	1.3	439	1421	1.8	30.9	--	16.5	29.7	18.8	1.63	1.08	68.6	97.2	99.1	1.61	1.07	--	70.5	--	97.3
T-6-1	34.4	10.78	3560	3.57	39.2	A	13.0	35	6.5	2.8	VG	8.0	5.2	132	2.9	0.9	--	--	--	1.7	--	--	15.1	--	18.4	1.70	1.13	73.1	97.4	99.3	--	--	--	--	--	--
Low Shear % Solids, Low Shear Tip speed/Energy, and Stripper % Solids Evaluation																																				
T7	35.6	11.34	3754	3.51	38.0	A	11.0	35	3.8	1.8	G	8.4	5.2	131	2.8	1.0	1.0	438	1473	2.0	31.0	11184	17.5	29.6	18.7	1.63	1.08	67.6	97.2	99.1	1.63	1.08	4983	69.7	3148	97.2
T8	33.2	10.95	3621	3.63	38.7	A	11.0	35	3.9	1.7	G	7.1	5.2	116	2.9	0.8	2.3	446	1585	2.1	29.6	9953	17.3	28.7	17.6	1.63	1.08	64.6	96.8	98.9	1.64	1.09	4716	67.2	3683	97.0
T9	35.2	11.57	3830	3.51	38.5	A	11.0	35	3.7	1.7	G	8.6	6.6	131	3.8	1.3	0.8	428	1927	1.8	21.2	9762	11.1	20.7	12.2	1.72	1.14	72.2	97.5	99.3	1.68	1.12	5082	75.3	2773	97.5
High Shear A Energy Evaluation																																				
T-10-1	32.0	10.18	2653	3.53	36.8	A	11.0	47	5.8	2.4	F	7.5	5.2	173	4.0	1.2	--	--	--	--	--	--	--	--	--	1.60	1.06	69.0	97.1	99.1	--	--	--	--	--	--
T-10-2	32.1	10.05	3003	3.59	36.6	A	11.0	39	4.8	2.0	P	7.4	5.2	146	3.4	1.0	--	--	--	--	--	--	--	--	--	1.55	1.03	59.9	96.5	98.6	--	--	--	--	--	--
T-10-3	32.2	10.05	3517	3.62	37.1	A	11.0	33	4.1	1.7	VP	7.5	5.2	125	3.0	0.9	--	--	--	--	--	--	--	--	--	1.47	0.98	50.7	95.6	97.8	--	--	--	--	--	--
T-10-4	30.7	10.04	3765	3.60	37.5	A	11.0	31	3.8	1.6	N	7.4	5.2	116	2.8	0.8	--	--	--	--	--	--	--	--	--	1.53	1.01	45.0	95.2	97.3	--	--	--	--	--	--
T-11	30.9	10.04	3312	3.74	35.1	A	11.0	35	4.5	1.8	?	7.4	5.2	132	3.1	0.9	1.0	658	1659	2.0	27.6	6760	17.6	26.6	18.7	1.59	1.05	51.6	95.7	97.9	1.53	1.02	4775	58.6	5121	96.1
High SHear B Energy Evaluation																																				
T-12	30.2	10.12	3345	3.92	36.6	B	11.0	62	16.3	6.7	G	7.3	5.2	129	3.2	0.9	0.8	501	1608	2.2	29.4	10374	19.5	28.6	20.7	1.53	1.02	64.8	96.2	98.6	1.54	1.02	3888	63.5	4740	96.2
T-13	29.1	10.41	3436	3.69	39.4	B	9.5	62	10.8	4.5	P	7.9	5.2	134	3.0	1.0	1.0	489	1623	1.9	28.9	11179	16.5	27.5	19.3	1.54	1.02	55.7	96.0	98.2	1.45	0.96	5278	55.6	5583	95.9
T-14	31.4	11.06	3659	3.38	40.1	B	8.5	61	7.3	3.3	VP	8.2	5.2	131	2.9	1.0	1.0	453	1591	2.2	29.6	--	18.0	28.5	18.9	1.64	1.09	61.6	97.1	98.9	1.77	1.18	--	62.0	--	97.3
Production Run																																				
T-P-1	33.2	10.34	3416	3.62	38.2	B	10.0	62	12.5	5.2	G	7.7	5.2	132	3.1	1.0	0.8	547	1551	1.9	29.6	--	17.7	28.8	19.4	1.59	1.05	63.7	96.7	98.9	1.60	1.06	4623	62.4	5401	96.7
T-P-3	29.3	10.21	3372	3.78	39.5	B	10.0	62	12.6	5.2	G	7.6	5.2	132	3.1	1.0	0.8	540	1556	1.9	29.1	--	17.6	27.8	18.9	1.67	1.11	67.5	96.8	100.5	1.61	1.08	5579	64.8	4562	96.6
T-P-4	29.5	10.12	3339	3.77	36.8	B	10.0	62	12.7	5.2	G	7.5	5.2	132	3.2	1.0	0.8	563	1608	1.9	27.5	11633	17.3	27.0	18.2	1.61	1.07	66.3	96.7	100.2	1.58	1.05	4532	65.5	3569	96.6
T-P-5	30.7	10.18	3361	3.72	38.3	B	10.0	62	12.7	5.2	G	7.6	5.2	132	3.1	1.0	0.8	563	1556	1.8	28.2	--	17.0	26.8	18.0	1.54	1.02	63.8	96.5	99.4	1.58	1.05	5489	60.0	4126	96.3
T-P-6	29.6	10.00	3300	3.43	39.0	B	10.0	62	12.9	5.2	G	7.4	5.2	132	3.2	1.0	0.8	569	1498	1.8	28.2	--	17.4	26.8	18.8	1.52	1.01	67.5	97.1	99.7	1.55	1.03	5424	65.3	3858	97.1
T-P-7	30.3	9.64	3179	3.44	40.3	B	10.0	62	13.4	5.2	G	7.1	5.2	132	3.3	1.0	0.8	592	1567	1.8	26.7	12314	17.2	26.0	19.0	1.57	1.04	65.1	97.1	99.7	1.52	1.01	5065	64.4	3537	96.9
T-P-8	29.6	9.70	3199	3.52	40.1	B	10.0	62	13.3	5.2	G	7.2	5.2	132	3.3	1.0	0.8	589	1579	1.8	26.9	--	17.2	25.6	18.3	1.56	1.03	67.6	97.0	99.3	1.53	1.01	5431	61.2	3379	96.7
T-P-9	29.0	10.06	3321	3.63	39.8	B	10.0	62	12.8	5.2	G	7.5	5.2	132	3.2	1.0	0.8	567	1512	1.8	27.6	--	16.9	26.4	18.1	1.59	1.05	69.4	97.0	99.7	1.62	1.08	5158	64.5	3728	96.8
T-P-10	29.5	10.12	3340	3.87	40.5	B	10.0	62	12.7	5.2	G	7.5	5.2	131	3.1	1.0	0.8	554	1558	1.9	28.0	12274	17.1	26.9	18.0	1.55	1.03	65.6	96.4	99.3	1.69	1.12	4875	62.5	4670	96.4
T-P-11	32.1	9.78	3228	3.65	39.5	B	10.0	62	13.2	5.2	G	7.3	5.2	132	3.3	1.0	0.8	577	1550	1.8	27.3	--	17.1	26.2	18.4	1.67	1.11	65.4	96.9	99.1	1.61	1.08	4976	59.3	4112	96.5
Average Production Run Performance and Conditions																																				
Average	30.3	10.02	3305	3.64	39.2	B	10.0	62	12.9	5.2	G	7.4	5.2	132	3.2	1.0	0.8	566	1553	1.8	27.9	12074	17.2	26.8	18.5	1.58	1.05	66.2	96.8	99.6	1.59	1.06	5115	63.0	4094	96.7

APPENDIX C

INDIANA VII COAL AGGLOMERATION RESULTS

PDU Selective Agglomeration Operating Conditions and Results - Indiana VII Coal

Run	Date	PSD D80	Plant Feed Sol (%)	Plant Feed Coal (lb/hr)	Plant Feed Ash (%)	Hept maf (%)	Asph lb/t	High Shear Agglom Imp Tip m/s A	High Shear Agglom Imp Tip m/s B	High Shear Agglom Res Time (sec)	High Shear Agglom kwhr/ton Coal	High Shear Agglom kwhr/1000 g slur	Inv qual 1-10	Low Shear Agg Sol (%)	Low Shear Agg kwhr/ton Coal	Low Shear Agg kwhr/1000 g slur	Vib Screen Bed Dpth (in)	Vib Screen Spry gal/t Prd	Steam lb/t coal	Steam lb/gal	Steam Stripper A Sol (%)	Steam Stripper A Product Ash (%)	Steam Stripper A Hep ppm	Steam Stripper A Res Time (min)	Steam Stripper A Temp (F)	Stripper B Prod Sol (%)	Stripper B Res Time (min)	Stripper B Temp (F)	LS Rinse Basis Prod Ash (%)	LS Rinse Basis Prod Ash lb/Mbtu	LS Rinse Basis Agg Size mm	LS Rinse Basis Tails Ash (%)	Plant Product Ash (%)	Plant Product Ash lb/Mbtu	Plant Product Hept dcb ppm	Plant Tails Ash (%)	Plant Tails Hept dcb ppm
Indiana VII Coal Start-Up Test																																					
I-1	6/11	23.5	6.96	2760	9.8	43.4	9.5	17.4	14.0	81	--	--	2	5.5	--	--	--	632	1931	1.7	--	--	--	16.9	211	20.7	15.5	240	3.04	2.16	--	86.1	3.08	2.20	--	73.0	--
High Shear Energy and Asphalt Dosage Evaluation																																					
I-2	6/12	23.9	8.80	2551	10.0	42.4	8.5	14.0	14.0	110	49.0	17.4	4	6.4	4.1	1.1	0.50	586	1684	1.8	25.0	3.15	13767	21.4	210	24.1	22.3	241	3.14	2.23	2.00	85.2	3.10	2.20	4633	90.4	339
I-3-1	6/12	23.3	8.83	2584	10.0	41.7	11.3	14.0	14.0	110	48.9	17.4	6	6.3	4.0	1.0	--	--	--	--	--	--	--	--	--	--	--	--	3.15	2.24	1.50	88.6	--	--	--	--	--
I-3-2	6/12	23.3	8.83	2556	10.0	43.2	11.3	11.0	11.0	110	28.6	9.4	2	6.3	4.2	1.1	--	--	--	--	--	--	--	--	--	--	--	--	3.23	2.30	2.00	83.8	--	--	--	--	--
High Shear Energy and Asphalt Dosage Evaluation																																					
I-4	6/18	26.1	8.50	2455	10.2	41.3	11.8	17.4	14.0	111	59.7	20.4	9	6.1	4.2	1.1	0.50	606	1795	1.8	25.8	3.14	12328	20.5	210	25.1	20.8	241	3.19	2.27	1.75	90.1	3.21	2.29	4355	89.5	686
I-5	6/18	26.4	8.80	2547	9.7	39.3	18.9	--	14.0	70	38.0	13.4	5	6.4	4.1	1.1	--	576	1696	1.9	25.8	3.22	13155	26.0	209	23.3	34.6	241	3.30	2.35	2.00	88.2	3.58	2.56	7307	89.1	369
High Shear Energy and Asphalt Dosage Evaluation																																					
I-6	6/19	26.0	11.34	2360	10.1	40.3	8.5	--	14.0	97	38.8	17.6	2	7.5	4.4	1.3	0.50	547	1633	1.8	25.8	2.96	13445	24.1	210	24.1	25.0	241	2.96	2.10	2.00	84.1	3.11	2.23	4647	86.2	1006
I-7-1	6/19	26.2	11.75	2447	10.2	38.0	13.3	--	14.0	96	37.4	17.5	5	7.8	4.2	1.4	--	--	--	--	--	--	--	--	--	--	--	--	3.07	2.18	1.75	92.2	--	--	--	--	--
I-7-2	6/19	26.2	11.75	2450	10.2	38.9	13.3	--	12.0	96	27.3	12.7	3	7.8	4.2	1.3	--	--	--	--	--	--	--	--	--	--	--	--	3.23	2.30	1.75	90.4	--	--	--	--	--
Low Shear Solids Concentration and Tip Speed Evaluation																																					
I-8-1	6/23	23.7	12.40	2584	10.2	39.2	9.7	14.0	14.0	151	46.4	22.8	8	7.7	4.0	1.3	0.50	504	1606	1.8	27.8	3.02	--	22.2	209	26.6	24.1	240	3.11	2.21	1.50	90.7	3.07	2.18	--	90.1	--
I-8-2	6/23	25.1	12.71	2661	10.0	37.1	9.4	14.0	14.0	150	45.1	22.8	8	12.7	3.7	1.9	0.75	492	1503	1.8	29.5	3.16	--	23.0	209	28.5	24.9	240	3.16	2.25	1.50	93.1	3.02	2.15	--	90.5	--
I-8-3	6/23	27.5	12.92	2702	10.1	37.4	9.3	14.0	14.0	151	44.4	22.8	8	8.2	5.2	1.7	--	--	--	--	--	--	--	--	--	--	--	--	3.22	2.29	1.50	94.4	--	--	--	--	--
Stripper Temperature, Screen Spray, and High Shear Evaluation																																					
I-9-1	6/25	23.0	13.39	2815	10.2	40.2	7.1	14.0	14.0	149	43.1	22.8	6	8.0	3.6	1.2	0.75	468	1556	1.8	27.8	2.74	13487	20.5	199	27.3	15.9	231	2.81	1.99	2.00	90.5	2.84	2.01	5152	90.0	310
I-9-2	6/25	21.1	12.42	2595	10.3	40.9	7.7	14.0	14.0	150	46.7	23.0	6	7.7	4.0	1.3	0.75	841	1811	1.9	24.5	2.75	11771	20.8	210	23.6	17.5	240	2.76	1.95	1.50	91.3	2.71	1.91	4917	89.8	279
I-9-3	6/25	20.0	12.40	2590	10.3	42.3	4.8	14.0	14.0	151	46.8	23.1	2	7.7	4.0	1.2	--	--	--	--	--	--	--	--	--	--	--	--	2.65	1.88	2.00	86.2	--	--	--	--	--
I-9-4	6/25	20.1	12.61	2634	10.1	40.1	9.5	12.1	12.0	150	34.2	17.0	1	7.7	3.9	1.2	--	--	--	--	--	--	--	--	--	--	--	--	2.81	1.99	1.00	89.1	--	--	--	--	--
Low Shear Evaluation, asphalt effect, and I-9-2 Semi-repeat																																					
I-10-1	6/30	24.8	14.33	2990	10.1	37.8	6.7	14.0	14.0	151	34.1	19.4	5	8.5	1.6	0.6	--	--	--	--	--	--	--	--	--	--	--	--	2.91	2.07	0-6	81.5	--	--	--	--	--
I-10-2	6/30	22.5	12.28	2567	10.1	41.9	6.8	14.0	14.0	150	39.7	19.3	5	7.6	4.0	1.2	--	513	1800	2.1	26.4	2.93	0	23.0	211	25.3	19.2	242	2.93	2.08	1.75	89.1	2.93	2.08	0	90.3	0
I-10-3	6/30	22.8	12.11	2528	10.1	43.9	4.9	14.0	14.0	151	40.3	19.4	3	7.5	4.1	1.2	--	--	--	--	--	--	--	--	--	--	--	--	2.95	2.09	2.00	86.2	--	--	--	--	--
I-10-4	6/30	23.7	12.12	2530	10.1	43.9	4.9	14.0	14.0	151	40.2	19.4	3	7.5	4.1	1.2	--	--	--	--	--	--	--	--	--	--	--	--	2.98	2.12	0.50	88.2	--	--	--	--	--