PREMIUM FUEL DEVELOPMENT

MAHESH C. JHA, FRANK J. SMIT, GENE L. SHIELDS, NICK MORO
AMAX R&D CENTER / ENTECH GLOBAL INC.
5950 MCINTYRE STREET, GOLDEN, COLORADO 80403
Phone: (303) 273-7242 Fax: (303) 273-7204

CONTRACT NO. DE-AC22-92PC92208

The goal of this project entitled, "Engineering Development of Advanced Physical Fine Coal Cleaning for Premium Fuel Applications" was to develop engineering design data for fine coal cleaning plants based on Advanced Column Flotation and Selective Agglomeration processes for premium fuel production and near-term applications. The scope of the project included laboratory research and bench-scale testing of each process followed by design, construction, operation, and evaluation of a 2 ton/hour process development unit (PDU). Removal of toxic trace elements was also investigated and the cost of producing premium coal water slurry fuel (CWF) on a commercial scale estimated.

Amax R&D (part of Cyprus Amax Minerals Company) was the prime contractor. Entech Global managed the project and performed most of the research and development work as an on-site subcontractor. Other participants in the project were Cyprus Amax Coal Company, Arcanum, Bechtel, University of Kentucky, and Virginia Tech. Dr. Doug Keller of Syracuse University and Dr. John Dooher of Adelphi University were consultants. The PDU was constructed by TIC and Mech El, Inc., both of Colorado.

The cost-shared project started in October 1992 and is scheduled for completion by September 1997. Proceedings of previous PETC contractors conferences contain reports of project activities completed in the past. This paper focuses on the activities completed since the last contractor's meeting and also serves as a summary paper for the project.

NEAR-TERM APPLICATION

One of the main objectives of the project was the engineering development of the two advanced fine coal cleaning processes for near-term applications. Specifically, the goal was to develop an economic application of either technology at a coal preparation plant for processing coal fines that are usually rejected to waste ponds. Three coal preparation plants owned by AMAX (now Cyprus Amax) were investigated along with three product forms - filter cake, dry fines, and briquettes. It was concluded that installation of flotation columns at the Lady Dunn plant in West Virginia to produce clean filter cake offered the most attractive return on investment. Virginia Tech installed a 30-inch Microcel™ column for slip stream testing on the cyclone overflow stream. The results indicated that a clean coal product with 8 to 10 percent ash could be produced at 80 to 85 percent combustible recovery. For dewatering, a screen-bowl centrifuge was found to be a better choice than vacuum filters. While the production of binderless briquettes was found to be technically feasible yielding products with >100 lb crush strength and >12,900 Btu/lb heating value, it was not found to be commercially attractive at this time.

Based on the excellent results obtained during this testing, three commercial size (4 meter diameter, largest in the coal industry) Microcel™ columns were installed at the Lady Dunn plant in 1996 to process minus 60-mesh material overflowing the desliming cyclones. The product (filter cake) is blended with other washed coal products from the plant. The columns have been performing as projected from the pilot work. Thus, the project goal of development of a near-term application was achieved.

PREMIUM FUEL APPLICATION

The goal of premium fuel application is to produce an ultra-clean coal water slurry fuel (CWF) that can replace oil in some utility and industrial boilers as well as be suitable for advanced combustors currently under development. To comply with Clean Air Act requirements, the fuel should contain less than 1 to 2 lb ash/MBtu and less than 0.6 lb sulfur/MBtu. To avoid derating of the boilers, the CWF should contain 60 percent coal or more. The project goals also stipulated recovery of more than 80 percent of the energy contained in the run-of-mine (ROM) coal and a total production cost of less than $2.50/MBtu including the cost of the ROM coal.

The first task of the project involved identification and selection of feed coals. Over two dozen coals representing various ranks and production areas were examined to select the following five bituminous and one subbituminous coals for laboratory and bench-scale testing: Taggart (Wentz and Steer Branch Mines, Virginia), Winifrede (Sandlick Mine, West Virginia), Elkhorn No. 3 (Chapperal Mine, Kentucky), Indiana VII (Minnehaha Mine, Indiana), Sunnyside (Sunnyside Mine, Utah) and Dietz (Spring Creek Mine, Montana). Laboratory-scale testing indicated that the Dietz coal could not be cleaned by flotation and the performance was marginal at best even for the selective agglomeration process. Based on bench-scale test results, the Taggart, Indiana VII, and Sunnyside coals were selected for the PDU program. During the PDU operation, the Sunnyside mine was closed and therefore Hiawatha coal from a nearby mine in Utah was used.

In order to clean the coals to the desired low ash contents, the coals needed to be ground to a fine particle size for adequate mineral liberation. It was found that in general, selective agglomeration required a somewhat finer grind than flotation, but it also recovered more clean coal at the same product quality. Since fine grinding is expensive and adversely affects the solids loading during slurry formulation, an optimum grind had to be determined for each coal and each process. This optimum grind size was found to vary from a D80 of about 50 microns for the Hiawatha coal when cleaned by flotation to a D80 of about 20 microns for the Indiana VII coal when cleaned by selective agglomeration.

For the advanced column flotation process, the laboratory research was performed at Amax R&D, the University of Kentucky, and Virginia Tech using 4-inch diameter columns. The emphasis was on selection of column design and flotation reagents. Based on the results, 12-inch diameter Ken-Flote™ and Microcel™ columns were selected for bench-scale (100 lb/hr) development work using MIBC as frother and diesel fuel as collector. It was found that the Taggart coal could be cleaned to less than 1 lb ash/MBtu and the other bituminous coals to less than 2 lb ash/MBtu at the proper operating conditions. Based on superior performance and scale up considerations, the Microcel™ column was selected for testing in the PDU.

For the selective agglomeration process, the laboratory research was performed at Amax R&D and Arcanum Corporation in Ann Arbor, Michigan. The emphasis was on comparative evaluation of two reactor designs (a conventional high-shear phase-inversion stage followed by a low-shear growth stage vs a single reactor for both stages) using heptane and pentane as agglomerating agents. Based on the results obtained as well as the considerations for design scale-up, it was decided to use the conventional design with heptane as the agglomerating agent. The bench-scale unit with a capacity of 25 to 50 lb/hour proved the viability of steam stripping of heptane for recovery and recycle.

Clean coals produced in laboratory research and bench-scale development programs were used for coal water slurry formulation studies. Use of A-23 dispersant at 0.5 to 1 percent dosages was required for high solids loading. The required amount was mainly affected by the particle size distribution and the rank of the coal. Thus, loadings as high as 70 percent were attained with the Taggart coal while for the Indiana VII coal, loadings were less than 50 percent. Slurries were generally not very stable and will have to be used quickly or agitated during storage.

DESIGN AND CONSTRUCTION OF THE PDU

The conceptual and detailed design of the PDU was performed by Bechtel. It was designed to produce 2 tons/hour of Sunnyside coal at 2 lb ash/MBtu. It was capable of producing similar tonnages of Taggart coal at 1 lb ash/MBtu but had a lower capacity for the Indiana VII coal. Minus 2-inch raw or washed coal received from the mines was crushed off-site to minus 1/2 inch. The PDU grinding circuit (Area 100) consisted of two ball mills and one fine grinding mill in closed circuit with cyclones and vibrating screens. The ground coal slurry was fed to the column flotation module (Area 200) or the selective agglomeration module (Area 300). The dewatering section of the plant (Area 400) consisted of a vacuum drum filter and two filter presses (obtained from another DOE project) for clean coal, and a thickener and two filter presses (existing in the AMAX R&D facility) for the tailings. While the use of these existing filters cut down the cost of the project, it did limit dewatering capacity during 72-hour continuous production runs.

The flotation module basically consisted of a six-ft diameter Microcel™ column, a feed tank, a product holding tank to break the froth, and tanks and pumps for metering the reagents. Auxiliary equipment included a compressor, a large recirculation pump, and an-in-line mixer for generation of microbubbles. The selective agglomeration module consisted of two high-shear vessels, one low-shear vessel, a vibrating screen for recovering the agglomerates, and a froth skimmer to recover any coal present in the tailings (screen underflow) before it was sent to thickener. The heptane recovery circuit included two steam strippers, a condenser, and a gravity separator for heptane/water separation. In addition, the selective agglomeration module included auxiliary equipment such as a boiler, heat exchangers, nitrogen blanket system, relief system, and a flare. The entire plant was well instrumented for computer monitoring, control, and data acquisition.

The PDU and the flotation module was constructed by TIC of Steamboat Springs, Colorado, in 1995. The selective agglomeration module was constructed by Mech El, Inc. of Aurora, Colorado, in 1996. Details of the plant design, lay out, and equipment specifications are contained in two Design Packages submitted to DOE.

OPERATION OF THE PDU FLOTATION MODULE

Shakedown testing of the PDU Flotation module was performed using Taggart coal. A Test Plan was developed that included parametric testing, followed by optimization tests to determine the best operating conditions for each coal. These conditions were then used for 72-hour production runs. Parts of the production products (clean coal filter cakes) were sent to a DOE-designated contractor (Penn State) for combustion testing. In all, the flotation module was operated for about one year during which it processed about a thousand tons of Taggart, Indiana VII and Hiawatha coals (in that order). The plant was normally staffed with a crew of four operators. Most equipment performed as designed. The only instrument that proved unreliable was the nuclear density gauge used to monitor the percent solids in the feed. The computer monitoring and data acquisition system was found to be very helpful.

The results from parametric testing indicated that the particle size distribution (PSD) obtained in the grinding circuit had the most influence on the quality of the product and the energy recovery. Different grinding circuit configurations were necessary to obtain the desired PSD for each coal. Details are presented in the Topical Report submitted for Task 8.5 to DOE. Other variables that affected the grade and recovery were frother dosage, wash water flow rate, and tailings slurry recirculation rate which determined the bubble size. In general, the PDU 6-ft column gave higher product recovery at somewhat lower grade than the 1-ft bench-scale column. Table 1 shows selected PDU results obtained for each coal.

Table 1. Selected Results From PDU Flotation Module Operation.

Coal	Grind D80, µm	Feed Rate ton/hr	Product Ash lb/MBtu	Product Sulfur lb/MBtu	Btu Recovery, %
Taggart	51	2.10	0.99	0.47	96.9
Hiawatha	48	2.15	1.89	0.44	88.0
Indiana VII	23	1.60	2.33	0.40	82.0

OPERATION OF THE PDU SELECTIVE AGGLOMERATION MODULE

Shakedown testing of the PDU Selective Agglomeration Module was performed using the Hiawatha coal, followed by completion of a parametric test plan for each coal. It should be noted that while the flotation results generally followed a grade recovery curve, selective agglomeration test conditions were found to either work or not. Particle size distribution was again found to be the most important variable. In general, finer grinding was required for selective agglomeration than for column flotation to meet the quality goal. On the other hand, the energy recovery was much higher for agglomeration, as can be seen in the data presented in Table 2. Detailed results from PDU operations are presented in the Task 9.4 Topical Report.

Table 2. Selected Results From PDU Selective Agglomeration Module Operation.

Coal	Grind D80, µm	Feed Rate ton/hr	Product Ash lb/MBtu	Product Sulfur lb/MBtu	Btu Recovery, %
Taggart	30	1.65	1.06	0.42	99.2
Hiawatha	42	1.92	1.93	0.35	98.9
Indiana VII	21	1.30	1.91	0.40	99.9+

For each coal, after the required grind was established, the testing focused on determining the agglomeration conditions (heptane dosage, residence time, and energy input in the high- and low-shear stages) that resulted in steady operation and formation of 2-3 mm agglomerates during low shear. Testing of different vibrating screen inclinations indicated that a downward inclination gave the best results. Under this condition, the agglomerates formed a thin layer on the screen which allowed better washing for displacement of mineral-matter bearing process water. While the froth skimmer recovered some of the coal present in the tailings (screen underflow), the design was not satisfactory. A simple column with an overflow launder might have performed better.

The two-stage counter-current steam stripping circuit performed well. The emphasis of testing was on determining how the temperature (and therefore pressure) and residence time in the two stages affected the steam requirements. The most stable operation was obtained with a temperature of about 210°F (2-5 psig) in the first stage and a temperature of 240°F (5-10 psig) in the second stage. Steam consumption was about 1800 lb per ton of coal. The clean coal typically contained between 2000 and 5000 ppm heptane on a dry solids basis, indicating that the plant recovered about 99 percent of the heptane for recycle. The tailings contained about 500 ppm heptane on a dry weight basis and should not pose a disposal problem.

The process conditions for 72-hour production runs were established as a compromise between the process technical goals (throughput rate and product quality) and the limited dewatering capacity, particularly at the finer grinds, that would allow uninterrupted round-the-clock operation. Portions of the production run products (clean coal filter cakes) were sent to a DOE-designated contractor (Penn State) for combustion testing. In all, the selective agglomeration module was operated for about nine months during which it processed about 800 tons of Hiawatha, Taggart, and Indiana VII coals (in that order). The plant was normally staffed with a crew of five operators. Most equipment performed as designed with the exception of the froth skimmer and the stripper feed tank. All instruments, including those detecting oxygen in the process and heptane in the plant, worked well. The computer monitoring and data acquisition system was found to be very helpful. The safety systems installed in the plant were found to be very effective.

REMOVAL OF TOXIC TRACE ELEMENTS

One of the objectives of the project was to determine the capability of the two processes for removal of the following 12 toxic trace elements: antimony, arsenic, beryllium, cadmium, chromium, cobalt, lead, manganese, mercury, nickel, selenium, and chlorine. Samples of clean coal, tailings, and feed coal from PDU operations of both modules using all three coals were analyzed for these elements to determine their distribution between the clean coal and tailings. The results have been included in two topical reports and also submitted for publication in a special issue of Coal Preparation journal. the main conclusions are summarized below.

1. The residual concentration of the 12 elements in the coal depended on the source coal. For example, the Indiana VII clean coal contained four times as much antimony as the Taggart coal and 30 times as much as the Hiawatha coal. Similarly, lead was detected in the Taggart but not the Hiawatha coal.
2. Mercury and selenium are high on the priority list for possible future regulations. The clean coals produced by the PDU contained less than 0.02 ppm mercury and less than 2.2 ppm selenium.
3. Substantial reductions in concentrations (lb/MBtu basis) of arsenic, chromium, cobalt, lead, manganese, mercury, selenium, and chlorine were observed for certain coals.
4. The column flotation and selective agglomeration processes were found equally effective in removal of toxic trace elements.

COMMERCIAL CWF PRODUCTION COST STUDIES

Based on the results obtained from the PDU operation, Bechtel performed a conceptual design of a commercial plant to produce premium quality coal water slurry fuel which contains less than 2 lb ash/MBtu, less than 0.6 lb sulfur/MBtu, and 60 to 62 percent solids (8900 Btu/lb). The plant, with a capacity of 1.5 million tons clean coal per year, would be located in an Ohio Valley state close to an industrial site. This would insure the availability of good quality feed coals such as Taggart, Elkhorn No. 3, Sunnyside, Hiawatha, or a blend of these coals at a reasonable cost of $1.24/MBtu (about $30 per ton delivered). The CWF product would be shipped to nearby customers by truck or train for use soon after arrival. It was further assumed, in the case of the selective agglomeration plant, that steam would be purchased from a nearby power plant.

The plant design was similar to that of the PDU except that multiple trains were included for the large plant, which would be more than 100 times larger than the PDU. The grinding circuit would consist of ball mills and cyclones only (elimination of fine grinding mill and screens). The flotation plant would consist of 12 flotation columns of 14-ft diameter each. The selective agglomeration plant would consist of ten parallel trains of high- and low-shear vessels, each processing about 23 tons of coal per hour. Six vacuum filters would be used for dewatering the clean coal before its formulation into CWF slurry. The capital costs were estimated at $69.6 million for the flotation case and $97.2 million for the agglomeration case. The working capital for the two cases was estimated at $10 and $11 million, respectively.

The operating costs were estimated at $2.15/MBtu for the flotation plant and $2.42/MBtu for the agglomeration plant. The cost of feed coal at $1.24/MBtu accounted for more than half of the cost. The capital charges of $0.27/MBtu and $0.37/MBtu, for the flotation and agglomeration plants, respectively, were calculated based on a

15% rate of return over a 20 year plant life. Variable operating and maintenance costs were estimated at \$0.64/MBtu and \$0.81/MBtu, respectively, for the two plants. The CWF dispersant additive cost was the most important contributor at \$0.23/MBtu.

A production cost sensitivity study indicated that the cost of feed coal was the most important factor. The second most important factor was not achieving the design plant capacity whether due to scheduling or under-performance of the equipment.

It was thought that the scale up from 2 tons per hour to over 200 tons per hour might still present some technical risks, particularly for the selective agglomeration process. As such, it would be desirable to design and build a prototype plant of about 20 to 25 tons/hour capacity using a single train of the largest size equipment that could be purchased as a standard item or designed and built with minimum risk. The product would be used for active plant testng. Based on the operating experience of such a prototype plant and its cost data, private companies would be in a better position to design and build premium fuel plants when market economics justify it.

SUMMARY

The PDU operation was concluded in July 1997. Currently, the PDU is being dismantled for shipment of equipment to a DOE-designated site. Coal samples, chemicals and reagents, and other materials and supplies are being disposed of in an environmentally acceptable manner. The pilot plant facility will then be restored to its original condition..

A Project Final Report is currently under preparation for submittal to DOE as the final project deliverable. It summarizes all the work completed on the project during the last five years. The main accomplishments are listed below.

The program met the goal of near-term application. Microcel™ flotation columns were installed at the Lady Dunn plant in West Virginia based on the work performed under this project.

The program met the technical goals of the premium fuel program. Several coals were identified which are mined in large tonnage and which can be cleaned to less than 1 to 2 lb/ash and less than 0.6 lb/MBtu sulfur while recovering more than 80 percent of the energy from the run-of-mine coal. These results were obtained on laboratory, bench, and PDU scale indicating that the processes can be scaled up with confidence. The clean coal product can be formulated into coal-water-slurry fuel at about a 60 percent solids loading so that its heat content is about 8900 Btu/lb, suitable for combustion in retrofit boilers as well as new design combustors. The PDU modules were operated for about one year each confirming the robustness of the equipment and the reproducibility of the data. Almost 2,000 tons of coal were processed. There were no safety or environmental related incidents.

The PDU results were used to perform the conceptual design of a commercial plant. The cost of producing premium quality CWF was estimated at \$2.14 and \$2.45/MBtu for the flotation and agglomeration processes, respectively. This again met the project goal of less than \$2.50/MBtu including the cost of the raw coal.