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**COMBUSTION CHARACTERIZATION OF
BENEFICIATED COAL-BASED FUELS**

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QUARTERLY REPORT NO. 2 FOR THE PERIOD AUGUST TO OCTOBER 1989

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OBJECTIVE AND SCOPE

This three-year research project at Combustion Engineering, Inc. (CE) will assess the potential economic and environmental benefits derived from coal beneficiation by various advanced cleaning processes. The objectives of this program include the development of a detailed generic engineering data base, comprised of fuel combustion and ash performance data on beneficiated coal-based fuels (BCFs), which is needed to permit broad application. This technical data base will provide detailed information on fundamental fuel properties influencing combustion and mineral matter behavior as well as quantitative performance data on combustion, ash deposition, ash erosion, particulate collection, and gaseous and particulate emissions. Program objectives also address the application of this technical data base to predict performance impacts associated with firing BCFs in various commercial boiler designs as well as assessment of the economic implications of BCF utilization. Additionally, demonstration of this technology, with respect to large-scale fuel preparation, firing equipment operation, fuel performance, environmental impacts, and verification of prediction methodology, will be provided during field testing.

Twenty fuels will be characterized during the three-year base program: three feed coals, fifteen BCFs, and two conventionally cleaned coals for the field test. Approximately nine BCFs will be in dry ultra fine coal (DUC) form, and six BCFs will be in coal-water fuel (CWF) form. Up to 25 additional BCFs would be characterized during optional project supplements.

SUMMARY

During the third quarter of 1989, the following technical progress was made.

- ° Evaluated ignitibility and reactivity characteristics of the Illinois, Pittsburgh, and Upper Freeport feed coals, including flammability indices, TGA, and BET surface areas.
- ° Completed pilot-scale combustion tests of the Upper Freeport and Pittsburgh #8 feed coals in standard pulverized form.
- ° Started analyses of as-fired fuels and resulting ash deposits.

TASK 1 - FUEL PREPARATION

Beneficiated coals (BCs) and feed coals are acquired from other DOE projects and shipped to CE. These fuels are then processed into either a dry pulverized coal form by CE or a coal-water fuel (CWF) form using OXCE Fuel Company technology. The feed coals are fired as standard grind (70% minus 200 mesh) pulverized coal (PC), while the dry beneficiated fuels are generally dry ultra fine coal (DUC).

Six twenty-ton batches of test fuels had been stored at PETC in sealed, inerted drums since the last quarter of 1987. These fuels included:

1. Illinois No. 6 feed coal
2. Pittsburgh No. 8 feed coal
3. Upper Freeport feed coal
4. Illinois No. 6 microbubble flotation product
5. Pittsburgh No. 8 microbubble flotation product
6. Upper Freeport microbubble flotation product

Three feed coals and their three microbubble flotation products were shipped from PETC to CE. The total number of drums for each fuel were as follows:

	<u>Feed Coals</u>	<u>Products</u>
Illinois No. 6	117	153
Pittsburgh No. 8	93	143
Upper Freeport	97	106

These fuels are being stored in their original drums until they need to be prepared for laboratory testing (Tasks 2 and 3).

The costs for installing the proposed drying system for filter cake products was re-estimated to be approximately double the original estimate. Since this was considered to be too high, trials were conducted drying the microbubble products in large trays in a heated room. This method easily dried the filter cake sufficient for feeding into the bowl mill or for making coal-water fuel. Therefore, this approach was adopted for use on all filter cake products, and the Illinois No. 6 filter cake was dried in preparation for Task 3 tests.

Information on obtaining large (20 ton) batches of beneficiated coal products for testing during 1990 was solicited. Additional products from the selective agglomeration (SA) process being run at Homer City could be obtained at reasonable cost. Homer City could also make batches of 3 to 4% ash product using conventional cleaning at half the cost of the SA products. Otisca Industries quoted a price for product from their oil-agglomeration process; the cost would be similar to the SA product cost. All of these fuels were being considered for use in this project.

The Pittsburgh No. 8 and Upper Freeport feed coals were pulverized in the FPTF bowl mill prior to testing (Task 3). The Upper Freeport sample for MIT's pilot scale test was also pulverized and shipped in drums.

TASK 2 - BENCH-SCALE TESTS

All test fuels are fully characterized using various standard and advanced analytical techniques. These tests evaluate the impacts of parent coal properties and beneficiation processes on the resulting BCF's qualities.

A few selected fuels are tested in a laminar flow drop tube furnace to determine fly ash particle size and chemical composition. Results include mineral matter measurements and modeling of fly ash history.

A swirl-stabilized, entrained flow reactor is used to characterize the surface compositions and the states of ash particles formed during combustion. Deposition rates on a target are determined, and the size and compositions of the deposits from different fuels are compared.

2.1 Laboratory Analyses at MIT

Mineral analyses on both the raw Upper Freeport coal and its microbubble-beneficiated product by computer-controlled scanning electron microscopy (CCSEM) were performed. The number-based size distribution of the minerals in the raw Upper Freeport coal is shown in Figure 2.1.1. Similarly, the size distribution of the minerals found in the beneficiated coal is shown and compared with the size of the minerals from the raw coal in Figure 2.1.2. As expected, the size of the minerals in the beneficiated coal is substantially reduced from the raw fuel.

2.2 Drop Tube Furnace System Combustion Tests at CE

Work during this quarter focused on evaluating the effect of particle size of each of the three parent coals (Upper Freeport, Pittsburgh No. 8, and Illinois No. 6) on ignitibility and reactivity characteristics. The flammability index of coal was used as a relative measure of its ignitibility characteristic, and the TGA and BET surface area of each coal char were used to characterize its reactivity. This work was carried out because of the anticipated fine particle sizes (100 percent through 325 mesh) of the microbubble BCFs.

Flammability Index (FI)

A 200x0 mesh size-fraction of each feed coal was used to determine its FI in accordance with CE's standard procedure. Also, a 325x0 mesh size-fraction was used to measure the FI value of the same coal. The following results were obtained:

<u>Coal</u>	<u>Flammability Index, °F</u>	
	(200x0 mesh)	(325x0 mesh)
Upper Freeport	1060	1060
Pittsburgh No. 8	940	920
Illinois No. 6	950	950

These results indicate two important things: (1) the two particle sizes used gave essentially the same FI values, and (2) each of these three coals has good ignitibility characteristics, based on results in CE's data bank and field experience.

TGA and BET

These tests are conducted on chars prepared from the parent coals under specific conditions. The standard procedure entails pyrolyzing a 200x400 mesh size fraction of coal in the Drop Tube Furnace System-1 (DTFS-1) (Figure 2.2.1) in nitrogen atmosphere at 2650°F to drive off the volatile matter, and subjecting a 200x400 mesh size-fraction of the resulting char to the TGA burn-off in air at 1290°F and BET surface area measurement in nitrogen. To evaluate the effect of particle size, a 325x0 mesh coal was pyrolyzed in the DTFS-1 and a 325x0 mesh size grade of the resulting char was used for TGA and BET measurements. These procedures are depicted in Figure 2.2.2.

Number based size distribution of Upper
Freeport mineral inclusions
Number of particles
analysed : 4525

Figure 2.1.1

Number based size distribution of Upper
 Freeport mineral inclusions
 Parent : solid Product : dashed
 No. 4525 No. 1212

Figure 2.12 . Particle size (μm)

Figure 2.2.1 Schematic of Drop Tube Furnace System-1 (DTFS-1)

FIGURE 2.2.2

TGA AND BET EVALUATION OF COAL CHAR

CHAR PREPARATION

CHAR EVALUATION

I. TGA

II. BET

The BET specific pore surface areas of the chars are:

<u>Parent Coal</u>	<u>BET Surface Area, m²/g (daf)</u>	
	<u>(200x400 mesh)</u>	<u>(325x0 mesh)</u>
Upper Freeport	23.6	28.8
Pittsburgh No. 8	29.3	49.8
Illinois No. 6	33.1	32.5

The TGA burn-off curves in air at an isothermal temperature of 1290°F are presented in Figures 2.2.3a and 2.2.3b. All of these results indicate that: (1) Upper Freeport coal char is the least reactive one; and (2) the finer size grade char (325x0 mesh) is more reactive than its coarser counterpart, the effect being more pronounced for the least reactive char. The BET specific pore surface area data are generally in support of the TGA results.

Based on CE's data bank information and field experience, it can be stated that the medium volatility Upper Freeport coal has the highest potential of causing carbon loss-related problems in pulverized coal firing applications. Future modeling studies on this and other fuels (Task 5) will enable the specification of conditions amenable to the minimization of carbon loss-related problems, among other things.

Results presented here constitute a data base against which those to be obtained similarly from beneficiated coal-based fuels will be compared. This will enable the elucidation of the effect of coal cleaning on physical, chemical, ignitibility, and reactivity characteristics.

2.3 Drop Tube Furnace Combustion Tests at MIT

Fuel preparation for the drop tube experiments at MIT has begun. Starting with a sample of the raw Upper Freeport coal, a centrifugal elutriator was used to remove the fine particles (less than 10 microns) from the coal sample. The resulting coarse fraction was sieved to nominally size the coal particles into 7 size ranges: less than 38 microns, 38-45 microns, 45-63 microns, 63-75 microns, 75-90 microns, 90-106 microns, and greater than 106 microns. These sized samples will be used for future tests.

FIG. 2.2.3a TGA CHAR BURN-OFF CURVES

FIG. 2.2.3b TGA CHAR BURN-OFF CURVES

TASK 3 - PILOT-SCALE TESTING

Combustion experiments are conducted with selected fuels in MIT's Combustion Research Facility (CRF) to characterize the effects of fuel type, beneficiation process, and firing mode upon flame stability, carbon conversion, and gaseous emissions. Combustion tests are also run in CE's Fireside Performance Test Facility (FPTF) with most of the base project fuels, to evaluate combustion performance, furnace wall slagging, convection pass fouling, fly ash erosion, electrostatic precipitator performance, and emissions.

Performance Tests

Pilot scale combustion tests were completed for the Illinois No. 6 (tests run last quarter), Pittsburgh No. 8, and Upper Freeport parent coals in the Fireside Performance Test Facility (Figure 3.1). A total of eight tests were performed, three with the Illinois No. 6 coal, two with the Upper Freeport coal, and three with Pittsburgh No. 8 coal. Test conditions are summarized in Table 1 for the three feed coals.

A single low firing rate (3.75 MBtu/hr fuel heat input and two high firing rate (4.0 MBtu/hr) tests were performed with the Illinois No. 6 parent coal. The two high firing rate tests were performed at different furnace flame temperatures by varying the secondary air preheat. Test durations were 12 hours, 23 hours, and 23 hours, respectively. The length of tests were dictated by slow deposit buildup rates on the waterwall test surfaces. During the low firing rate Test 1, steady state conditions on the lower waterwall panel (Panel 1) were never reached (steady state is defined as the time when deposit buildup rate slows and the average waterwall heat absorption over the last three hours of testing does not decrease by more than 5% of the average for the previous three hours). However, the test was ended due to a limited fuel supply.

TABLE 1
PARENT COAL TEST MATRIX

ILLINOIS NO. 6

<u>Test Number</u>	<u>Fuel Heat Input (10⁶ Btu/hr)</u>	<u>Test Duration (Hours)</u>	<u>Avg. Flame Temperature (°F)</u>	<u>Gas Temperature Entering Convective Pass</u>
1	3.75	12	2750	2250
2	4.00	23	2850	2375
3	4.00	23	2975	2325

UPPER FREEPORT

1	3.75	12	2875	2270
2	4.00	24	2995	2370

PITTSBURGH NO. 8

1	3.75	12	2940	2310
2	4.00	12	3010	2425
3	3.50	12	2850	2240

Figure 3.1 FIRESIDE PERFORMANCE TEST FACILITY

High firing rate Test 2 and Test 3 were performed at average furnace flame temperatures of 2850°F and 2975°F, respectively. In both cases, after 23 hours of test firing, heat flux rates leveled-off, indicating a steady state condition had been achieved. Sootblowing was then conducted to evaluate deposit cleanability and heat flux recovery.

Low and high firing rate tests were performed with the Upper Freeport parent coal. Test durations were 12 and 24 hours, respectively. Similar to the Illinois No. 6 low firing rate test, the Upper Freeport low firing rate Test 1 was ended before achieving steady state conditions on the waterwall test panel. This also was a result of a slow deposition rate and fuel supply limitations. The Upper Freeport high firing rate Test 2 was run for 24 hours. Steady state conditions were achieved on Panel 1 and sootblowing was conducted at the end of the test to evaluate deposit cleanability and heat flux recovery.

Three 12-hour tests were performed firing Pittsburgh No. 8 coal. In comparison with the Illinois No. 6 and Upper Freeport parent coal tests, waterwall panel deposition rates were greater with the Pittsburgh No. 8 fuel, thereby requiring shorter test periods to reach steady state conditions.

Preliminary results indicate a critical furnace gas temperature for slagging of approximately 2850°F. Above this temperature, wall blower effectiveness to control deposition was marginal to poor. Over the range of conditions evaluated, fouling performance was acceptable with respect to typical coal-fired steam generator design practice. Deposit build-up rates were moderate and in-situ deposit-to-tube bond strengths were moderate-to-low. Convective pass deposit build-up characterization was performed throughout the tests. Waterwall deposits, convective probe deposits, furnace bottom ash and ESP hopper ash were collected at the completion of testing. Waterwall deposit samples, convective probe deposit samples, in-flame solids samples, and fly ash samples were also collected on-line during each test run. Sample analyses and data reduction efforts are in progress.

Furnace Slagging Characterization

The furnace slagging characteristics for each coal are assessed by determining deposit coverage, its effect on waterwall panel heat flux, deposit cleanability, and deposit physical and chemical characteristics. The criteria used to classify the slagging potential of a fuel in the FPTF are based on the maximum thermal loading and critical flame temperature at which waterwall deposits are still cleanable by sootblowing.

Deposit coverage on the waterwall panel is monitored and documented throughout the duration of each test run. The rate of deposit accumulation on the waterwall panel is reflected by panel heat absorption. When deposit build-up slows and begins to approach long term characteristics, the waterwall heat absorption rate begins to level off. The rate of change of the heat flux was used to quantify waterwall deposition stabilization. This point was established when the average heat flux over the last three hours did not decrease by more than 5% of the average for the previous three hours.

At the completion of each test, waterwall deposit cleanability was evaluated using a sootblowing technique designed to simulate the removal forces of commercial wall blowers. A comparison of the heat flux after deposit removal and the "clean panel" heat flux along with visual observations, is used as an indicator of soot blower effectiveness.

Waterwall panel heat flux values were recorded on an hourly basis and plotted against test duration. Heat flux values obtained during the Illinois No. 6 parent coal test and the Upper Freeport parent coal tests are shown in Figures 3.2 and 3.3, respectively. The effect of sootblowing at the completion of each test on deposit removal and Panel 1 heat flux is evident in Figures 3.2 and 3.3. For the Illinois coal tests, sootblowing removed deposits and resulted in an appreciable heat flux gain at the end of Test 1 and 2. However, during Test 3, the Panel 1 deposits were unaffected and the heat flux remained constant at approximately 57,000 Btu/hr-ft². These data indicate the critical furnace temperature range where deposits become difficult to control with commercial wall blowers as being between the Test 2 and Test 3 operating conditions (2850°F to 2975°F).

Figure 3.2

DOE BCF PROGRAM

WW PANEL 1 HEAT FLUX DATA ILL#6

Figure 3.3

DOE BCF PROGRAM

WW PANEL 1 HEAT FLUX DATA UP FREEPORT

Similarly, during Upper Freeport Test 1, sootblowing removed the panel deposit and resulted in a gain in heat flux from 36,500 to 83,000 Btu/hr-ft². Sootblowing was ineffective during Test 2 and the Panel 1 heat flux remained constant at approximately 33,000 Btu/hr-ft². These data indicate the critical furnace temperature range where deposits become difficult to control with commercial wall blowers as being between the Test 1 and Test 2 operating conditions (2875°F to 2995°F).

Atomization, Combustion, Emissions Tests at MIT

Preparations continue for the combustion tests on the raw Upper Freeport coal and the Upper Freeport macrobubble product CWF (i.e., the procurement of consumables, testing of probes, etc). The combustion tunnel of the MIT Combustion Research Facility is currently configured for the pilot-scale tests on the pulverized coal. The combustion tests will commence in February, 1990.

In order to correctly evaluate the burnout characteristics of a coal-water fuel, the atomization quality at given conditions must be known. A new technique is being developed for the MIT Spray Test Rig that would allow the point values of spray droplet size and droplet concentration to be determined from a series of diffraction patterns obtained by traversing the spray with the Malvern Particle Sizer. The mathematical technique, known as tomography, is being tested by computer simulation, and tests on water sprays are anticipated in February, 1990. The possibility exists in such a spray of blocking too much of the incipient laser light, so that a correction for multiple scattering of the laser light is being implemented.

TASK 4 - SCALE-UP TESTS

The purpose of the scale-up tests is to verify that the results obtained from tests done at bench and pilot scales in Tasks 2 and 3 can be used to provide reasonable estimates of the performance effects when firing BCFs in commercial-scale furnaces. Two beneficiated fuels will be fired in either a small utility boiler or a full-scale test furnace.

The only activities in this task were discussions on fuel procurement, alternative test facility selection, and scheduling. Recommendations will be submitted to the DOE during the next quarter.

TASK 5 - TECHNICAL-ECONOMIC EVALUATIONS

The results of bench-scale, pilot-scale, and scale-up tests (Tasks 2, 3, and 4) are used to predict the performance of three commercial boilers. The boilers include: a 560 MW coal-designed utility unit; a 600 MW oil-designed utility unit; and an 80,000 lb/hr oil-designed, shop-assembled industrial unit. Eight of the base project BCFs are used in models of each unit to calculate performance.

The writing of a report describing the commercial boilers which will be evaluated was started.

WORK PLANNED FOR NEXT QUARTER

- ° Prepare Illinois No. 6 and Pittsburgh No. 8 microbubble products for testing as dry pulverized fuel.
- ° Process Upper Freeport microbubble filter cake into CWF for testing at CE and MIT.
- ° Continue standard bench-scale tests.
- ° Start drop tube furnace tests at CE and MIT.
- ° Test Upper Freeport feed coal and BCF in MIT's CRF.
- ° Test Illinois No. 6, Upper Freeport, and Pittsburgh No. 8 BCFs in CE's FPTF.
- ° Complete report describing the Task 5 boilers.

END

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