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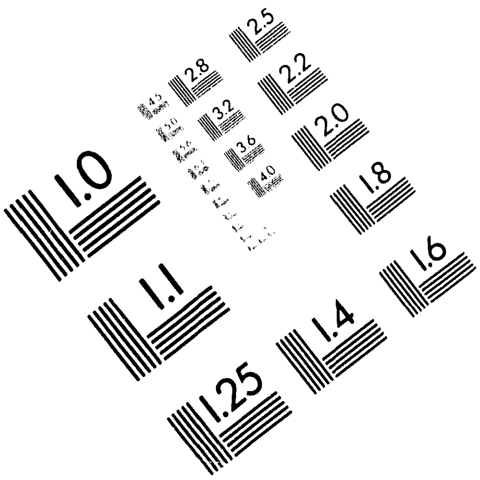

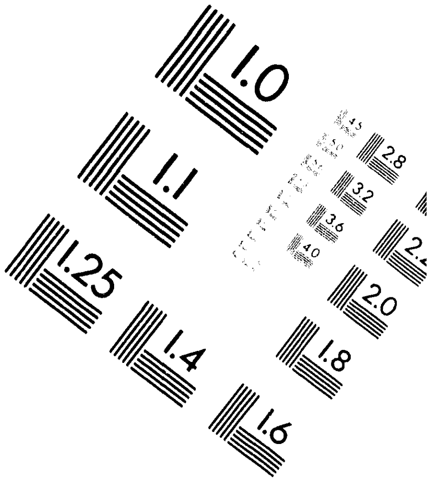

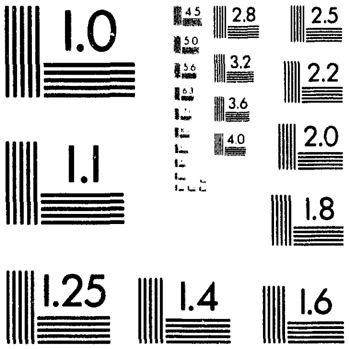

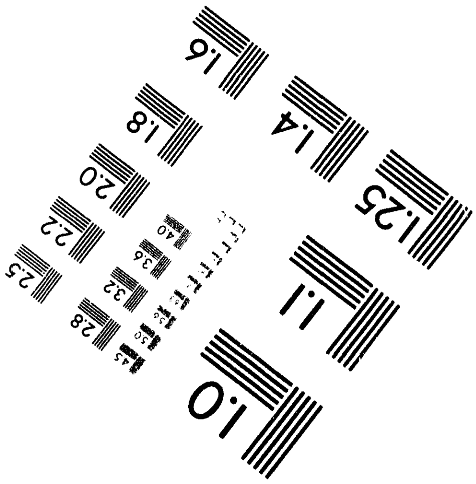

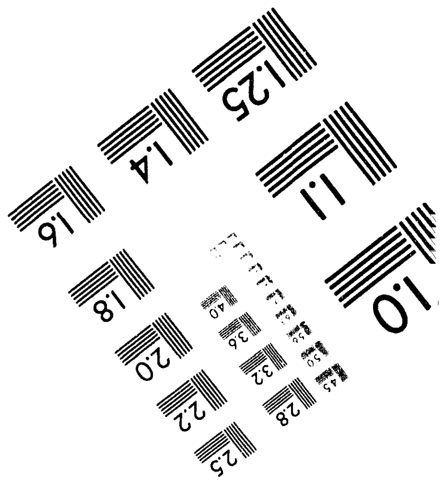

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DOE/PC/88654--T18

COMBUSTION CHARACTERIZATION
OF BENEFICIATED COAL-BASED FUELS

QUARTERLY REPORT NO. 18
FOR THE PERIOD JULY TO SEPTEMBER 1993

PREPARED BY

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PREPARED FOR

U.S. DEPARTMENT OF ENERGY
PITTSBURGH ENERGY TECHNOLOGY CENTER
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ACKNOWLEDGEMENTS

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INTRODUCTION

The Pittsburgh Energy Technology Center of the U.S. Department of Energy has contracted with Combustion Engineering, Inc. (CE) to perform a five-year project on "Combustion Characterization of Beneficiated Coal-Based Fuels." The beneficiated coals are produced by other contractors under the DOE Coal Preparation Program. Several contractor-developed advanced coal cleaning processes are run at pilot-scale cleaning facilities to produce 20-ton batches of fuels for shipment to CE's laboratory in Windsor, Connecticut. CE then processes the products into either a coal-water fuel (CWF) or a dry microfine pulverized coal (DMPC) form for combustion testing.

The objectives of this project include: 1) the development of an engineering data base which will provide detailed information on the properties of BCFs influencing combustion, ash deposition, ash erosion, particulate collection, and emissions; and 2) the application of this technical data base to predict the performance and economic impacts of firing the BCFs in various commercial boiler designs.

The technical approach used to develop the technical data includes: bench-scale fuel property, combustion, and ash deposition tests; pilot-scale combustion and ash effects tests; and full-scale combustion tests. Subcontractors to CE to perform parts of the test work are the Massachusetts Institute of Technology (MIT), Physical Science, Inc. Technology Company (PSIT) and the University of North Dakota Energy and Environmental Research Center (UNDEERC).

Twenty fuels will be characterized during the five-year base program: three feed coals, fifteen BCFs, and two conventionally cleaned coals for full-scale tests. Approximately nine BCFs will be in dry fine coal form, and six BCFs will be in various fuel forms. Additional BCFs would be characterized during optional project supplements.

SUMMARY

During the third quarter of 1993, the following technical progress was made:

- Continued with data and sample analysis from the pilot-scale tests of Upper Freeport feed coal, air-dried and mulled microagglomerate products.
- Air-dried Pittsburgh No. 8 as-is and mulled products for upcoming Task 3 combustion testing.
- Prepared two abstracts for presentation for the March 1994 Coal Utilization and Fuel Systems Conference.

TASK 1 - FUEL PREPARATION

Beneficiated coal based fuels (BCFs) 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 microfine pulverized coal (DMPC).

Thirteen twenty-ton batches of test fuel have been produced under the DOE-PETC Coal Preparation program since 1987. These fuels include:

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
7. Illinois No. 6 spherical oil agglomeration product
8. Pittsburgh No. 8 spherical oil agglomeration product
9. Upper Freeport spherical oil agglomeration product
10. Fresh Upper Freeport feed coal
11. Upper Freeport microagglomerates
12. Illinois No. 5 microagglomerates
13. Pittsburgh No. 8 microagglomerates

The first nine fuels were tested in the pilot-scale facility between October 1989 and June, 1990. Bench-scale testing continued through this quarter. Since the first six fuels had been stored in sealed drums for approximately eighteen months, a fresh 20-ton sample of Upper Freeport parent coal was tested in the fourth quarter of 1991 to evaluate the effects of aging or "weathering". The next three BCFs were produced and tested during this quarter.

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 process 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 and have been reported in previous quarterly reports and in the paper by Barta, et al, 1991.

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. Results were reported in the Quarterly Report for the period January to March, 1991.

The first ten coal and BCF samples received to date have been completely analyzed for: (1) complete chemical analyses; (2) flammability index measurements; (3) weak acid leaching; (4) TGA reactivities and BET surface areas of chars, and (5) pyrolysis and combustion kinetics. All these data have been reduced and reported in the Quarterly Reports for July to September, 1990, January to March 1991, October to December, 1991, and October to December, 1992, as well as in papers by Nsakala, et al, 1990, 1991, and 1993, and the updated draft Topical Report issued in October, 1992.

Work during this quarter focused on the analyses of the samples collected from the Upper Freeport combustion tests completed in May and June, 1993.

TASK 3 - PILOT-SCALE TESTS

The combustion test results with the beneficiated coal based fuels from the micro-bubble flotation and spherical oil-agglomerate processes indicate improvements in heat transfer and fly ash erosion performances over their parent coals. However, the beneficiation processes can change the original fuel particle size, mineral contents and mineral association, and hence affect ash behavior. The changes in performance of these fuels could not be clearly attributed to removal of mineral constituents during beneficiation or to the effect of fine grinding alone. These BCFs were ground significantly finer than the parent coal which were prepared as conventional boiler grind. Also, the beneficiated fuels can potentially provide greater advantages than conventional pulverized coals under staged low NOx firing conditions in the areas of combustion efficiency and fireside performance. Therefore, in addition to the original project goals, the objectives of the combustion performance tests were expanded to optimize the information to be generated during the pilot-scale tests and to address industry concerns as it shifts to more stringent emission controls. These objectives included the following:

- compare performance characteristics between the beneficiated fuels and their parent coals.
- identify the benefits associated with coal cleaning versus fine grinding alone.
- determine the effect of staged low NOx firing conditions on overall performance.

Under DOE/PETC's Coal Preparation Program, Southern Clean Fuels produced beneficiated fuels from Illinois No. 5, Pittsburgh No. 8 and Upper Freeport coals using the spherical agglomeration process. The Upper Freeport agglomerate product and its feed coal were selected for extensive testing, primarily due to fuel availability and the potential of greater combustion performance (carbon burnout) improvement due to beneficiation.

To date, the Southern Clean Fuels Illinois No. 5, Pittsburgh No. 8 and Upper Freeport agglomerate products were tested in the Fireside Performance Test Facility (FPTF). The test results show there was no significant improvement in performance between the Upper Freeport agglomerat product and its feed coal. These results can be explained by the fuel analyses as the level of beneficiation was relatively small. Because of the coarse sizes of the product, the effect of fine grinding was not directly assessed.

The Upper Freeport product in mulled form improve flow characteristics. However, higher mill rejection and compaction/pasting than the air-dried product were observed in bowl mill. Also, the mulled product appeared to be less easy to disperse than the air-dried product, resultin in a higher potential for lower carbon conversion efficiencies.

UNDEERC partially completed analyses of the samples taken during testing of the Upper Freeport fuels in the FPTF. The analytical data is shown in Appendix. Detailed discussion of the results will be provided in the next quarterly report when analyses on all the samples are completed.

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 boilers. Two beneficiated fuels would be fired in either a small utility boiler or a full-scale test furnace. There were no activities scheduled in this task during this 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 560MW coal-designed utility unit; a 600MW oil-designed utility unit; and an 80,000 lb/hr oil designed, shop assembled industrial unit. Eight of the base project BCFs will be used in models of each unit to calculate performance.

Boiler performance guidelines are being revised to incorporate the BCF test results. The guidelines will also be updated to reflect current theories and correlations. Modeling of the three study units was started.

TASK 6 - PROJECT MANAGEMENT AND TECHNICAL REPORTING

A paper was presented at the 1993 Contractors Conference. Two abstracts were prepared for presentation at the March 1994 Coal Utilization and Fuel Systems Conference.

WORK PLANNED FOR NEXT QUARTER

- Continue analyses on samples collected from Upper Freeport combustion tests.
- Continue standard bench-scale tests on the new BCFs
- Run pilot-scale combustion tests and ash deposition tests.
- Procure more BCFs for testing.

APPENDIX

APPENDIX

COMBUSTION CHARACTERIZATION OF BENEFICIATED COAL-BASED FUELS

1.0 INTRODUCTION

The University of North Dakota Energy & Environmental Research Center (EERC) is providing analytical and data interpretation support for the Combustion Characterization of Beneficiated Coal-Based Fuels (BCF) project. Under Task 2, all solid fuels were analyzed by computer-controlled scanning electron microscopy (CCSEM) to determine the types, size distributions, and degree of affiliation of coal particles for discrete mineral particles.

EERC involvement in Task 2 consisted of a number of different analyses of samples produced during combustion testing of the fuels in the Combustion Engineering fireside performance test facility (FPTF). The specific analyses are summarized in Table 1. This report concentrates on the second set of Upper Freeport (No. 2) parent and spherical agglomerate (SA) beneficiated fuels that were tested in the FPTF at 3.1-MMBtu/hr (staged), 3.6-MMBtu/hr (staged), and 3.6-MMBtu/hr (unstaged) firings. This second set of fuels will be called the Upper Freeport No. 2 fuels throughout the report. The CCSEM data from the fuels and deposits were classified according to mineral categories using a computer program, HIRANK. This program, which was modified in January of 1993, has proven useful in determining 90% or more of the phases in fuels and in-flame solids.

2.0 TASK 2 RESULTS AND DISCUSSION

2.1 Fuel Analyses/CCSEM Analyses of the Upper Freeport No. 2 Parent and SA Fuels

Table 2 gives the ash contents and the normalized ash compositions of the Upper Freeport No. 2 parent and SA product fuels. The SA product contained less SiO_2 and Al_2O_3 and more Fe_2O_3 than the parent fuel. The ash weight percentages were also determined for the fuels and are included in Table 2. The results indicate that the SA process had only a limited effect in decreasing the amount of ash in the fuel, from 9.0 to 6.5 wt%.

The cumulative size distributions of the mineral particles in the Upper Freeport No. 2 parent and SA fuels are illustrated in Figure 1. The data were determined by CCSEM analysis of polished coal–wax pellets. Therefore, the data are for mineral particles with cross-sectioned diameters in the range of 1 to 100 microns (μm). The cleaning process did not dramatically change the size distribution of the mineral particles in the fuel. The parent fuel contained 80% of its mineral particles in the less than 10-μm size range, and the SA product contains 90% in the same range. The SA process seems to reduce the particle size of the product very little. This conclusion is supported by previous results for the Upper Freeport fuels in the July through September 1991 quarterly technical progress report.

TABLE 1

EERC Analyses of the FPTF Samples

Sample	Composition	Fusion	SEMPC[1]	CCSEM	XRD[2]	Morphology
Composite Fuel	X			X		
L1-18 IFS WW[3]	X			X	X	
L4-18 IFS FO[4]	X			X	X	
Waterwall						X
Fly Ash	X	X		X	X	

[1] Scanning electron microscope point count.
[2] X-ray diffraction.
[3] Panel L1 in-flame solids (IFS), 18 inches from the waterwall (WW).
[4] Panel L4 in-flame solids (IFS), 18 inches from the furnace outlet (FO).

TABLE 2

Compositions of the Upper Freeport No. 2 Fuels (normalized weight percent)

Sample	Parent (CE No. 1)	SA Product (CE No. 2)
Oxide, wt%		
SiO_2	47.8	44.9
Al_2O_3	27.5	24.2
Fe_2O_3	17.1	22.6
TiO_2	0.8	1.0
P_2O_5	0.3	0.4
CaO	1.5	1.7
MgO	1.2	0.9
Na_2O	0.3	0.9
K_2O	2.2	2.2
SO_3	1.3	1.2
Closure	108.8	101.8
Ash wt% (moisture free)	9.0	6.5

The SA process also had little effect on the mineralogy of the resultant fuel. Figure 2 shows the relative quantities of the different types of mineral particles detected by CCSEM in the Upper Freeport No. 2 parent and SA fuels. Both the parent and SA analyses contained similar percentages of major phases, such as quartz, kaolinite, K–Al silicates, and pyrite. The parent contained slightly more iron oxide and K–Al silicate, and the SA product fuel contained more pyrite, pyrrhotite, and unknowns. The unknown

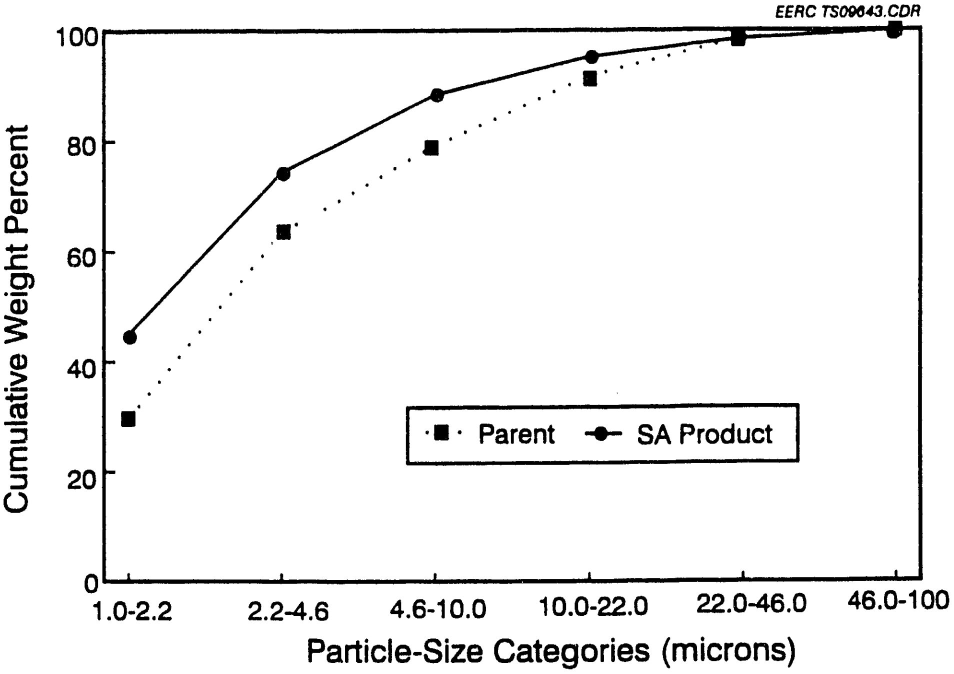

Figure 1. Cumulative size distributions of the inorganic particles with sectioned diameters between 1 and 100 μm in the Upper Freeport No. 2 parent and SA product fuels.

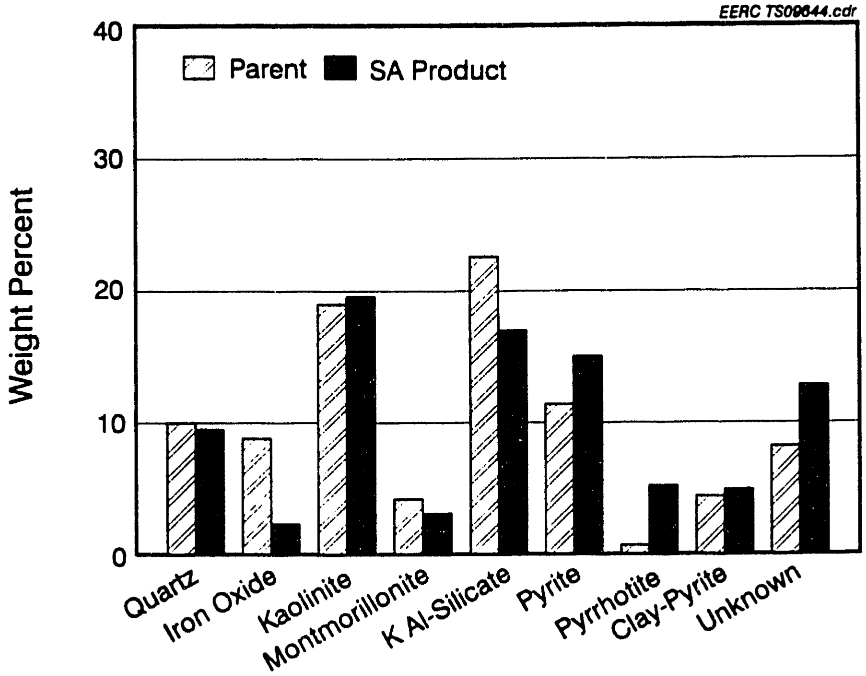

Figure 2. Composition distributions of the inorganic particles with sectioned diameters between 1 and 100 μm in the Upper Freeport No. 2 parent and SA product fuels.

analyses in both fuels were mixtures of pyrite, clay, and organic sulfur. The Fe-containing phases, which are often responsible for fouling and slagging problems, were not preferentially removed during cleaning. The composition distributions were similar for the two fuels.

Figure 3 shows the composition distributions of particles included in fuel particles. Inorganic particles locked or included within fuel particles are less easily removed during beneficiation than those that are liberated or excluded from fuel particles. Included phases also have a greater chance than liberated mineral grains of interacting and coalescing with each other during the combustion process. A large percentage of the phases present in both the parent and SA product fuels were included in fuel particles; the percentage of included mineral particles increased from the parent to the product fuel, which is expected. Most of the mineral particles, except iron oxide, in the parent fuel were included in fuel particles, which indicates that they would not easily be removed during beneficiation. The high percentage of included minerals in the parent fuel explains the small change in the particle size and composition distributions from the parent to the SA product, which indicates that the SA process had only a limited effect in cleaning mineral matter from the fuel.

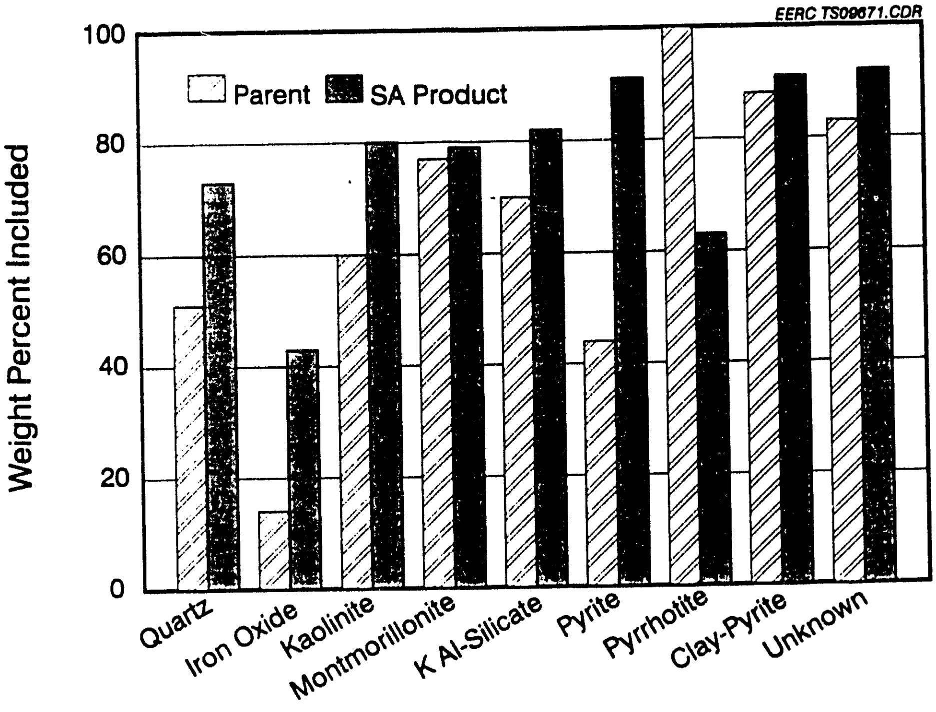

Figure 3. Composition distributions of the inorganic particles in the Upper Freeport No. 2 parent and SA product fuels that are included in fuel particles.

2.2 FPTF 3.1-MMBtu/hr Staged Firing of Upper Freeport No. 2

2.2.1 In-Flame Particulates - Waterwall

Both fuels were burned in 3.1-MMBtu/hr staged firing tests in the FPTF. The chemical and crystalline phase compositions of the Upper Freeport No. 2 parent and SA product in-flame solids or particulate ashes collected 18 in. from the waterwall (WW) are given in Table 3. The major element compositions showed differences, especially in Fe_2O_3 contents. The SA product particulates have a 10 wt% higher Fe_2O_3 content, which is a somewhat greater difference than that of the fuel compositions (Table 2). The bulk of the ashes were amorphous, but the main crystalline phases present in both ashes were quartz. Magnetite was also present in the parent ash.

Figures 4 and 5 show the cumulative size distributions and composition distributions from CCSEM analyses of the Upper Freeport No. 2 parent and SA product in-flame particulate WW ashes collected in the FPTF. Figure 4 shows that the parent ash had approximately 80% of the particles in the <10-μm size range and the SA product contained 70% in this particle-size range. The minerals in the parent WW particulates had a size distribution similar to that of the minerals in the parent fuel, but the SA product WW particulates have a larger size distribution than the parent fuel. This probably indicates preferential collection of particles with larger aerodynamic diameters.

TABLE 3

Compositions of the Upper Freeport No. 2 L1-18 IFS Waterwall Particulate Ashes for the 3.1-MMBtu/hr Staged Firing (normalized weight percent)

Sample	Parent (CE No. 3)	SA Product (CE No. 4)
Oxide, wt%		
SiO_2	50.6	45.2
Al_2O_3	27.8	21.6
Fe_2O_3	14.5	24.4
TiO_2	0.8	1.3
P_2O_5	0.3	0.4
CaO	1.4	1.9
MgO	1.0	1.1
Na_2O	0.3	1.1
K_2O	2.2	1.8
SO_3	1.0	1.4
Closure	97.2	95.7
	Crystalline Phases	Crystalline Phases
Minor Phases	Quartz (SiO_2) Magnetite (Fe_3O_4)	Quartz

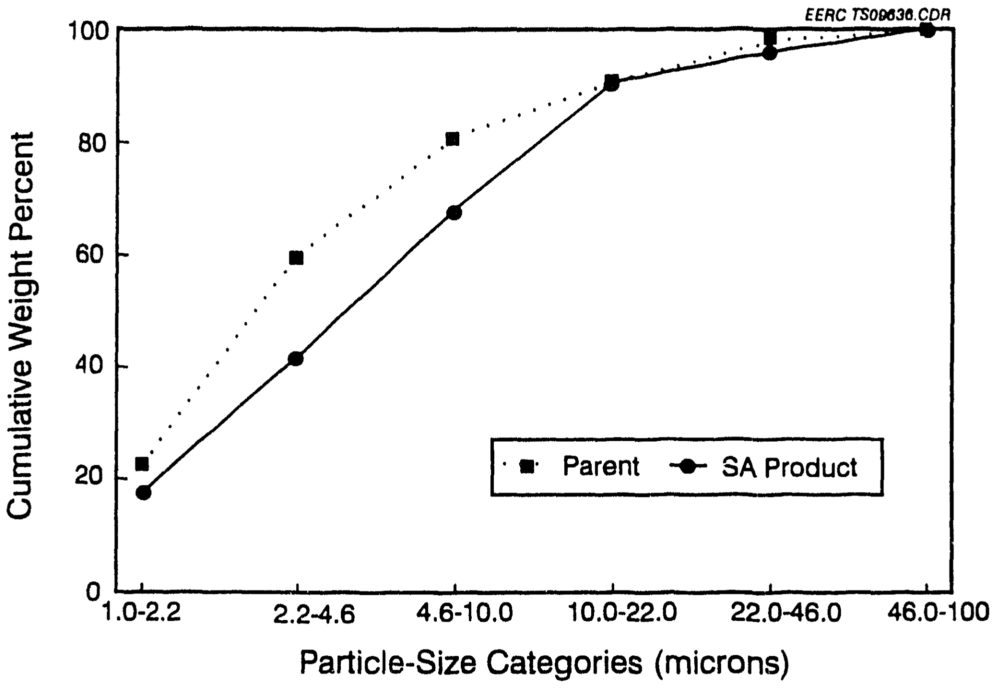

Figure 4. Cumulative size distributions of the inorganic particles with sectioned diameters between 1 and 100 μm in the Upper Freeport No. 2 parent and SA product in-flame particulate ashes collected in the FPTF near the WW (3.1-MMBtu/hr staged firing).

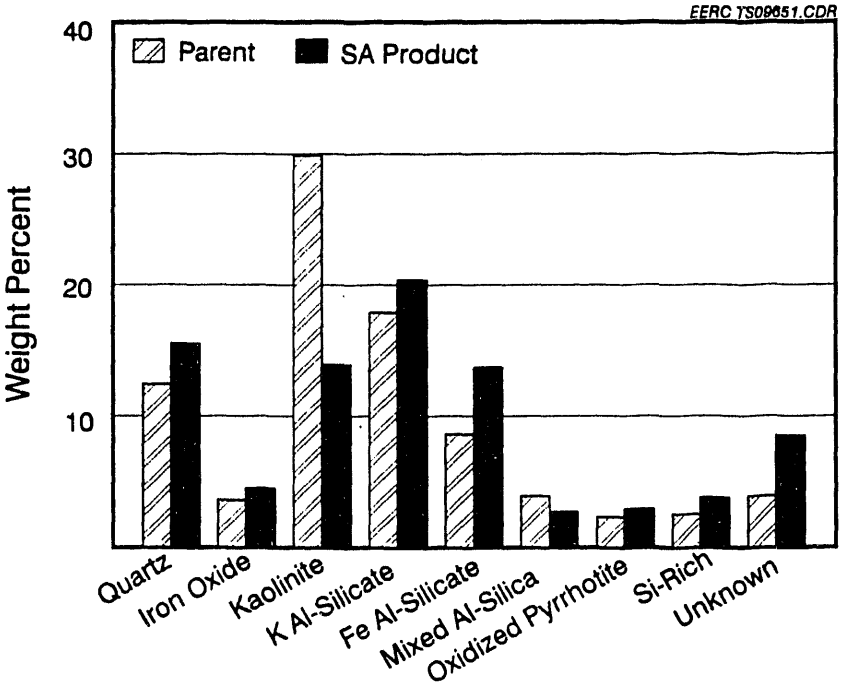

Figure 5. Composition distributions of the inorganic particles with sectioned diameters between 1 and 100 μm in the Upper Freeport No. 2 parent and SA product particulate ashes collected in the FPTF near the WW (3.1-MMBtu/hr staged firing).

Figure 5 shows that most of the particles in the WW particulates were quartz, kaolinite, K–Al silicates, and Fe–Al silicates. The parent particulates contained a higher percentage of kaolinite than the SA product ash, which contained slightly higher percentages of all other phases. The higher percentage of kaolinite in the parent may indicate preferential collection of kaolinite particles in the WW particulates. A large percentage of the unknown particles in the SA product ash were Fe-rich silicates and Fe-rich aluminosilicate particles that did not fit into other categories because of impurities. The parent fuel and parent WW particulates had similar percentages of phases present, but the WW particulates had more kaolinite, which may be related to collection bias. The SA product contained less pyrite, which interacted with aluminosilicate particles during combustion to form the Fe–Al silicate and mixed Al-silica particles. Compared to the parent particulates, the higher percentages of Fe-rich phases in the SA particulates would result in stickier particles; therefore, the SA particulates would have a greater chance of coalescing with other particles and depositing on boiler surfaces. However, this compositional difference may be related to collection or analytical bias.

2.2.2 Waterwall Panel Slag Deposits

Sacrificial WW tubes were placed in the FPTF during the 3.1-MMBtu/hr staged firing of the Upper Freeport No. 2 parent and SA products fuels. The tubes were cross-sectioned and examined in the SEM after the exposure. Thin layers of slag formed on both tubes, but not enough slag was present for XRF, ash fusion, XRD, or SEMPC analyses.

A porous layer of slag and ash particles was present on the surface of the WW tube exposed to the parent slag (Figure 6). Most of the particles were less than 50 μm in diameter, and some of these smaller particles were agglomerated. The x-ray maps of the slag/tube interface indicate that most of the particles were composed of iron oxide and Fe–Al silicates (Figure 7). Individual analyses of the Fe–Al silicate particles averaged 16 wt% Fe, 14 wt% Al, 20 wt% Si, and 43 wt% O.

The tube exposed during the firing of the SA fuel was coated with a porous deposit of fine particulate ash (Figure 8). Near the surface of the tube, some small droplets of a sulfur- (18 wt%), iron- (22 wt%), and oxygen-rich (50 wt%) phase were present, which are noted by the high sulfur concentrations on the x-ray map (Figure 9). The circular shape of the droplets indicated that they were liquid at the exposure temperature. The fine ash overlaying the tube surface had a variable porosity that decreased near the tube. The ash was composed of aluminosilicates with minor amounts of K and Fe, as indicated by the element maps. Some compositional layering was present in the ash, most evident in the S, Si, and Al maps, which show higher concentrations of these elements near the tube surface.

The presence of sulfur phases in the SA slag, which were absent in the parent slag, was a result of the cleaning process, which increased the relative percentages of pyrite and pyrrhotite in the SA product fuel (Figure 2). The Fe and S in the slags may act as fluxing agents, which results in stickier particles than the parent deposits. Also, as pyrite oxidizes during combustion, it forms an oxide–sulfide phase with a low-temperature eutectic that would also cause stickier deposits (1). The stickier deposits of the SA fuel would tend to cause impacting particles to stick more readily, thus causing more deposit buildup on the FPTF surface.

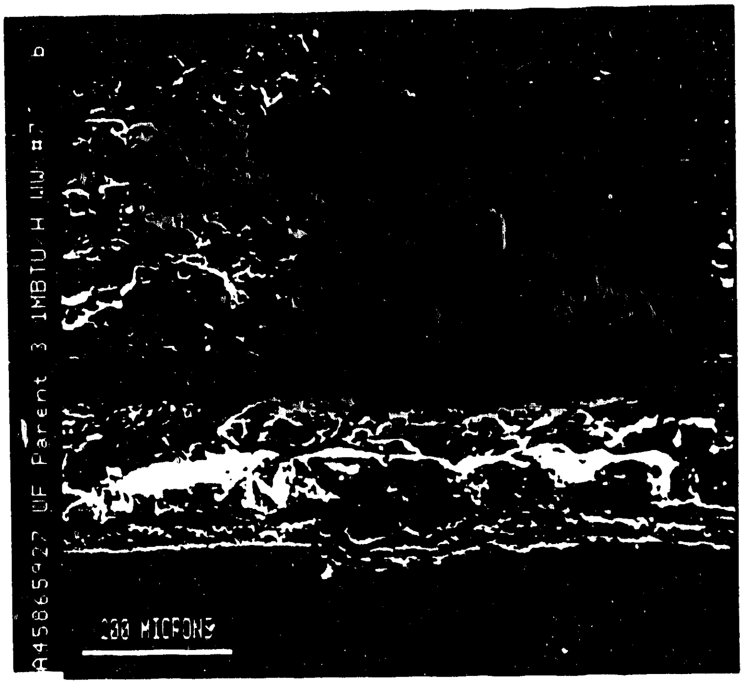

Figure 6. SEM photograph of the parent slag deposit formed on the sacrificial WW tube (3.1-MMBtu/hr staged firing).

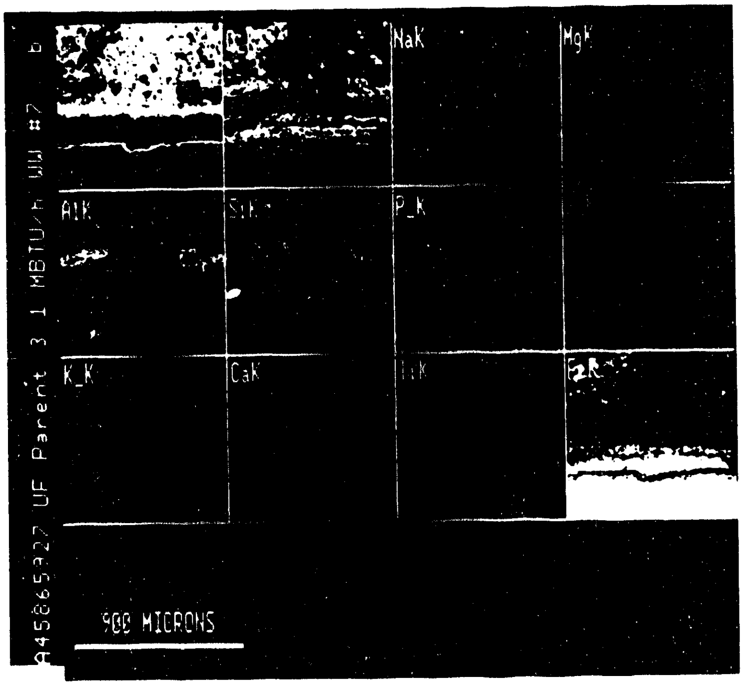

Figure 7. X-ray element maps showing the iron oxide and aluminosilicate particles on the WW tube exposed to the parent slag (3.1-MMBtu/hr staged firing).

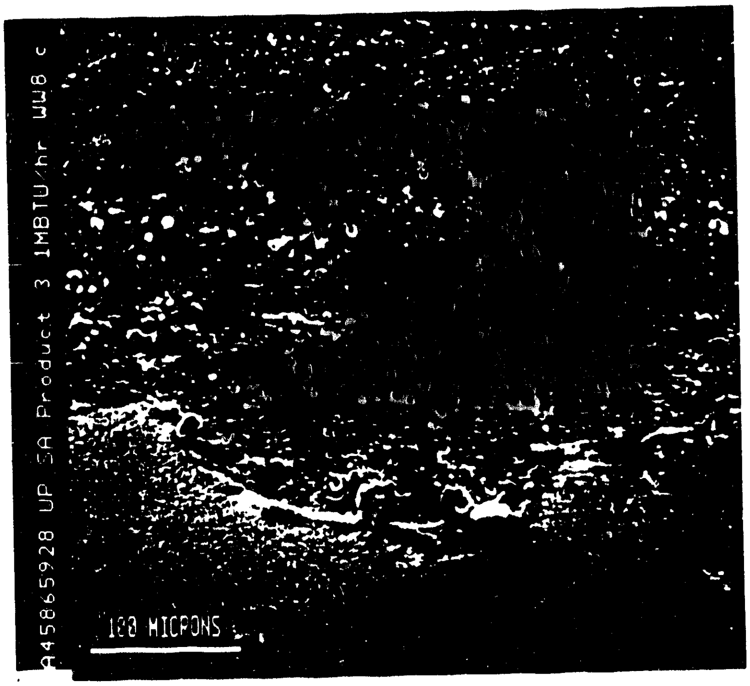

Figure 8. SEM photograph of the SA slag deposit formed on the sacrificial WW tube (3.1-MMBtu/hr staged firing).

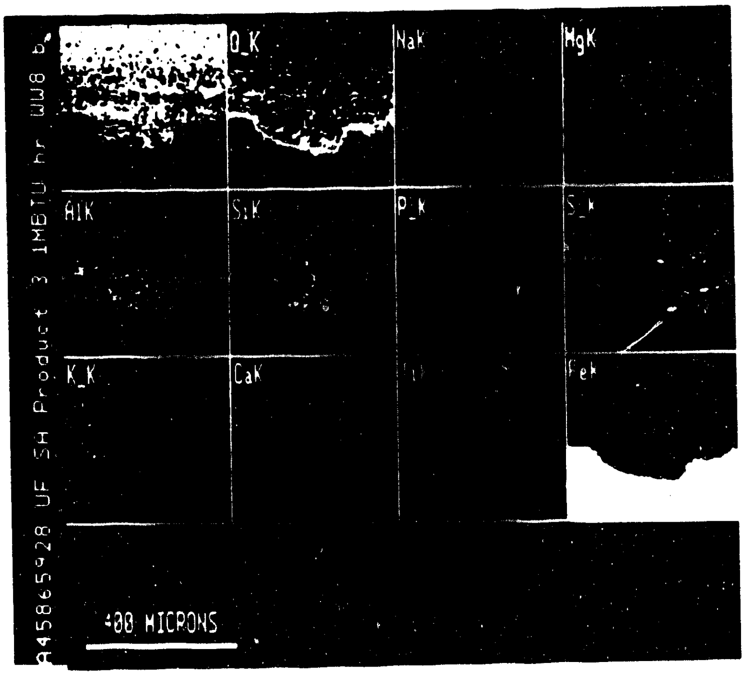

Figure 9. X-ray element maps of the SA slag deposit on the sacrificial WW tube (3.1-MMBtu/hr staged firing).

2.2.3 In-Flame Particulates – Furnace Outlet

The chemical and crystalline phase compositions of the Upper Freeport No. 2 parent and SA particulate ashes, collected 18 in. from Panel 4 near the furnace outlet (FO) in the FPTF, are given in Table 4. The major element compositions were fairly similar, with a slight difference in the Fe_2O_3 and Al_2O_3 contents. The results from the WW particulates showed a 10 wt% difference in iron content between the parent and SA product ashes, compared to the 4 wt% difference in the FO particulates. The compositions are similar to that of the original fuels (Table 2). The decrease in Fe_2O_3 content from the parent fuel to the WW parent particulates was probably a sampling bias, because the FO particulates did not show this trend. Both ashes contained quartz as the main phase and maghemite as a minor phase. The SA product ash contained minor amounts of a solid solution series of spinels, with the end members of the series being maghemite (Fe_2O_3) and hercynite ($Fe^{+2}Al_2O_3$). Both ashes also contained some amorphous material. Minor amounts of hematite were also present in the parent ash, and mullite was present in the SA product ash.

Figure 10 shows the cumulative size distributions of the CCSEM data from the Upper Freeport No. 2 parent and SA product FO particulates. The distributions of the parent and SA particulates indicated that 80% of the particles in both ashes were in the less than 10-μm size range. This was a smaller particle-size distribution than the WW particulates and the fuel mineral particles.

TABLE 4

XRF Analyses for the Upper Freeport No. 2 L4-18 IFS FO Particulates for the 3.1-MMBtu/hr Staged Firing (normalized weight percent)

Sample	Parent (CE No. 5)	SA Product (CE No. 6)
Oxide, wt%		
SiO_2	49.0	49.2
Al_2O_3	25.9	21.2
Fe_2O_3	18.3	21.8
TiO_2	1.0	1.3
P_2O_5	0.3	1.0
CaO	1.4	1.7
MgO	1.1	2.1
Na_2O	0.3	1.1
K_2O	2.0	0.7
SO_3	0.7	0.0
Closure	104.0	104.6
	Crystalline Phases	Crystalline Phases
Major Phases	Quartz	Quartz
Minor Phases	Maghemite (γ-Fe_2C_3) Hematite (Fe_2O_3)	Maghemite Mullite ($Al_6Si_2O_{13}$)

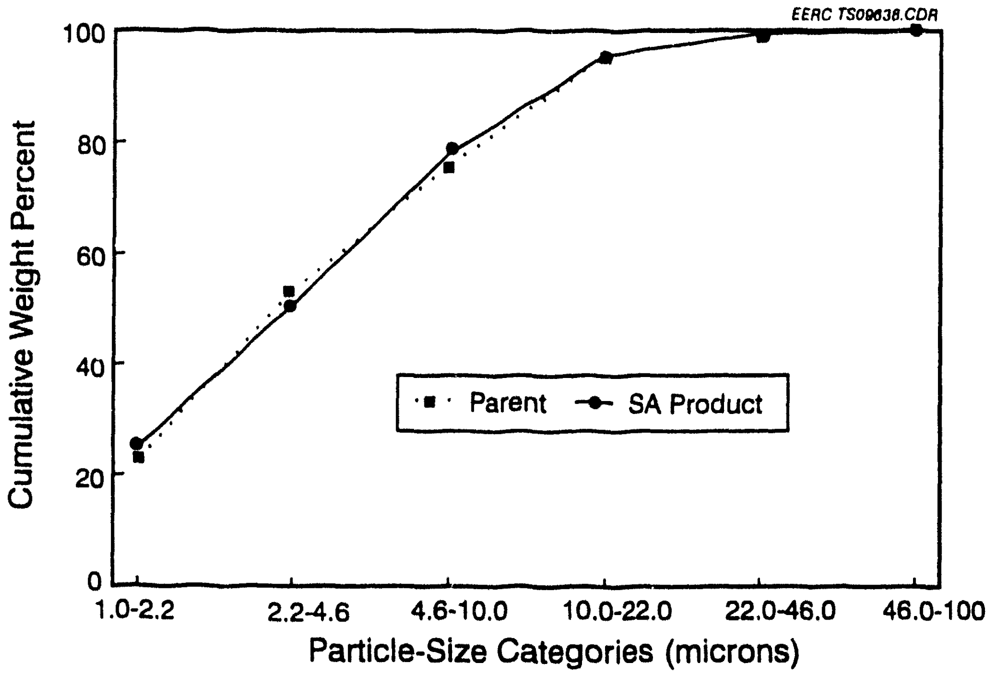

Figure 10. Cumulative size distributions of the inorganic particles with sectioned diameters between 1 and 100 μm in the Upper Freeport No. 2 parent and SA product particulate ashes collected in the FPTF near the FO (3.1-MMBtu/hr staged firing).

The composition distributions of the Upper Freeport No. 2 parent and SA product particulate ashes are shown in Figure 11. The main phases present in both ashes were quartz, kaolinite, K–Al silicate, and Fe–Al silicate. The parent ash contained more kaolinite and iron oxide, and the SA product ash contained more Fe–Al silicate and Fe–Al–Si-rich phases. The greater percentage of high-Fe phases in the SA product FO particulates may be related to the slightly greater percentage of high-Fe phases in the SA product fuel compared to the parent fuel.

Compared to the parent WW particulates, the parent FO particulates contained more iron oxide, Fe–Al silicates, and unknowns, but less kaolinite. The decrease in kaolinite, from 30 wt% in the WW ash to 16 wt% in the FO ash, was a result of either the coalescence of kaolinite particles with Fe-rich particles to form Fe–Al silicates or of the deposition of the kaolinite between the WW and the furnace outlet. Also, sampling bias may account for the high kaolinite percentage in the parent WW particulates. The SA product FO particulates had a fairly similar composition distribution to that of the SA WW particulates.

2.2.4 Conclusions for the 3.1-MMBtu/hr Staged Firing

The SA cleaning process did not dramatically change the particle-size distribution or the composition of the minerals in the Upper Freeport fuel or deposits. The only

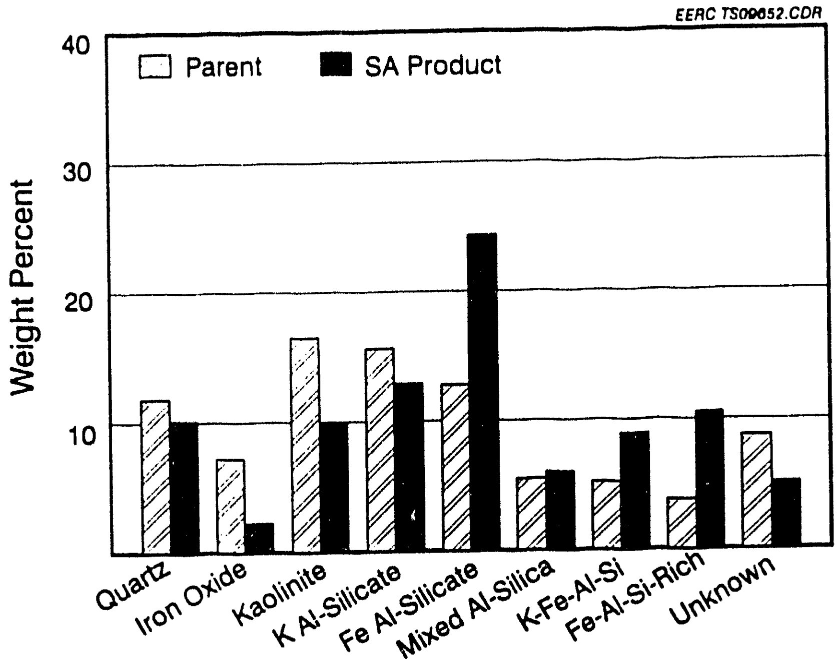

Figure 11. Composition distributions of the inorganic particles with sectioned diameters between 1 and 100 μm in the Upper Freeport No. 2 parent and SA product particulate ashes collected in the FPTF near the FO (3.1-MMBtu/hr staged firing).

difference was the kaolinite percentage and Fe_2O_3 content in the parent WW particulates, which seems to be a sampling or analytical bias.

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