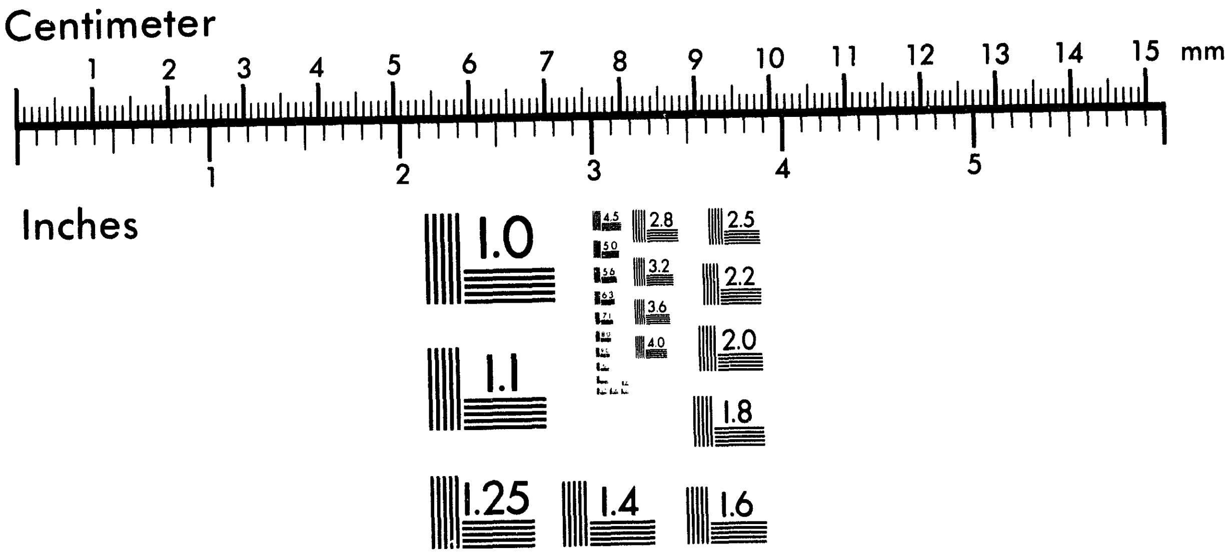
**AIIM**

**Association for Information and Image Management**

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910

301/587-8202




MANUFACTURED TO AIIM STANDARDS
BY APPLIED IMAGE, INC.

1 of 1

DOE/PC/88654--T13

# COMBUSTION CHARACTERIZATION

# OF BENEFICIATED COAL-BASED FUELS

QUARTERLY REPORT NO. 13 FOR THE PERIOD APRIL TO JUNE 1992

PREPARED BY

COMBUSTION ENGINEERING, INC.
1000 PROSPECT HILL ROAD
WINDSOR, CT. 06095

PROJECT MANAGER
MICHAEL J. HARGROVE

PRINCIPAL INVESTIGATORS
OSCAR K. CHOW
N. Y. NSAKALA

SEPTEMBER 1992

PREPARED FOR

U.S. DEPARTMENT OF ENERGY
PITTSBURGH ENERGY TECHNOLOGY CENTER
UNDER CONTRACT NO. DE-AC 22-89 PC 88654

## DISCLAIMER



## ACKNOWLEDGEMENTS

The authors gratefully acknowledge the following contributors to this report: B. F. Griffith, K. W. Johnson and R. L. Patel of Combustion Engineering, Inc; and S. A. Benson, J. P. Hurley and T. M. Strobel of the University of North Dakota Energy and Environmental Research Center.

**QUARTERLY REPORT**

**TABLE OF CONTENTS**

## 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 ultra fine coal (DUC) form, and six BCFs will be in coal-water fuel (CWF) form. Additional BCFs would be characterized during optional project supplements.

## SUMMARY

During the second quarter of 1992, the following technical progress was made.

- Continued analyses of drop tube furnace samples to determine devolatilization kinetics.
- Completed analyses of the samples from the pilot-scale ash deposition tests of unweathered Upper Freeport feed coal.
- Published two technical papers at conferences.
- Prepared for upcoming tests of new BCFs being produced.

## 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 microfine pulverized coal (DMPC).

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

1. Illinois #6 feed coal
2. Pittsburgh #8 feed coal
3. Upper Freeport feed coal
4. Illinois #6 microbubble flotation product
5. Pittsburgh #8 microbubble flotation product
6. Upper Freeport microbubble flotation product
7. Illinois #6 spherical oil agglomeration product
8. Pittsburgh #8 spherical oil agglomeration product
9. Upper Freeport spherical oil agglomeration product
10. Fresh Upper Freeport feed coal

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 obtained for testing to evaluate the effects of aging or "weathering". The next BCFs for testing are being produced during the second and third quarters of 1992.

## 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 alia, 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 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) combustion kinetics. All these data have been reduced and reported in the Quarterly Reports for July to September, 1990, January to March 1991, and October to December, 1991, as well as in papers by Nsakala, et alia, 1990 and 1991, and the draft Topical Report issued in June, 1991.

Work during this quarter focused on completing the CE Drop Tube Furnace System-1 (DTFS-1) devolatization testing of the BCFs. The analysis of the samples collected during the tests also continued.

## TASK 3 - PILOT-SCALE TESTING

The pilot-scale studies were designed to provide key information for the technical and economic assessment of the BCFs for commercial applications. Comprehensive tests were conducted in the CE Fireside Performance Test Facility (FPTF) to evaluate the combustion, furnace slagging, convective pass fouling and fly ash erosion characteristics of the BCFs prepared in both dry (micro-fine) and wet (micro-fine coal-water fuel) forms. Studies were also carried out to evaluate the effect of BCF fly ashes on electrostatic precipitator (ESP) collection performance. Additionally, representative in-flame solids and ash deposit samples collected were analyzed in detail to enhance the understanding of mineral matter transformation and ash deposition and to relate these to fuel mineral distributions and combustion conditions. Also, complementary experiments were carried out in the MIT Combustion Research Facility (CRF) to provide more detailed information on the combustion and emission characteristics of selected BCFs. These experiments focused on application of the coal-water fuel form.

Nine test fuels were evaluated for combustion and performance testing from October, 1989, to June, 1990. These fuels included Illinois No.6, Upper Freeport, Pittsburgh No.8 microbubble flotation products (MFPs), spherical oil agglomeration products (SOAPs), and the MFP parent coals. The pilot-scale results were reported in three previous quarterly reports: May to June, 1990, October to December, 1990, and January to March, 1991. Results are also included in the papers by Barta, et alia, 1991, and Chow, et alia, 1991, as well as the draft Topical Report issued in June, 1991.

Upper Freeport fresh parent coal was tested in the CE FPTF in October, 1991 for comparison to the previous Upper Freeport feed coal, which had aged for approximately eighteen months, stored in sealed drums. During this quarter, UNDEERC completed the analyses of the samples taken during testing of fresh Upper Freeport feed coal in the FPTF. The results are shown in Appendix A.

## 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 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) will be 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.

No activity was scheduled for Task 5 during this quarter.

## TASK 6 - TECHNICAL REPORTING

A technical paper on the ash deposition results (Hurley, et al.) was presented at the Coal and Slurry Technology Conference in April, 1992. A paper was also prepared for the Contractors' Conference.

## WORK PLANNED FOR NEXT QUARTER

- Continue standard bench-scale tests.
- Analyze data from pilot-scale combustion tests and ash deposition tests.
- Procure more BCFs for testing.

## BIBLIOGRAPHY


Barta, L.E., Toqan, M.A., Beer, J.M., Sarofim, A.F. and Hargrove, M.J., "Transformation of Mineral Matter During Combustion of Parent and Beneficiated Upper Freeport Coal," 16th International Conference on Coal & Slurry Technologies, Clearwater, Florida, April 22-25, 1991.

Barta, L.E., G. Vámos, M.A. Toqan, J.D. Teare, J.M. Beér and A.F. Sarofim; "A Statistical Investigation on Particle to Particle Variation of Fly ash Using SEM-AIA-EDAX Technique". Material Research Society, 1989. Fall Meeting, Boston, Paper W1.6.

Barta, L.E., Horváth, F., Beér, M.J., Sarofim, F.A.; Mineral Matter Distribution in Individual Pulverized Coal Particles; Application of the "URN" model. Presented at the "Twenty-third International Symposium on Combustion". Orléan, France July 22-27, 1990.

Barta, L.E. and J.M. Beér; "Distribution Functions of Chemical Compounds and Viscosity of Fly Ash Originated from Monosize Coal Particles in the Case of Total Mineral Coalescence", Internal Report, MIT Cambridge, MA, June, 1990.

Beer, J.M., Proc. Anthracite Conference, Bull. 75, Mineral Industries Experiment Station, The Pennsylvania State University, September, 1961.

Chow, O.K., Hargrove, M.J., and Levasseur, A.A., "The Impact of Beneficiated Coal-Based Fuels on Boiler Performance," 16th International Conference on Coal & Slurry Technologies, Clearwater, Florida, April 22-25, 1991.

Chow, O.K., Lexa, G.F., Levasseur, A.A. and Mehta, A.K. "Combustion Characterization of the Kentucky No. 9 Cleaned Coals," EPRI Final Report CS-4994, February 1987.

Durant, J.F., Kwasnik, A.F., Levasseur, A.A. and Baumann, P.D., "Impacts of Cleaning Texas Lignite on Boiler Performance and Economics," EPRI Final Report GS-6517, August 1989.

Feeley, III, T.J., and Hervol, J.D., "Testing of Advanced Physical Coal Cleaning Processes--Current Status," Presented at Fourth Annual Pittsburgh Coal Conference, Pittsburgh, Pennsylvania, September 28-October 2, 1987.

Field, M.A., Gill, D.W., Morgan, B.B., and Hawksley, P.G.W., "The Surface Reaction Rate of Carbon with Oxygen," Combustion of Pulverised Coal, BCURA, Leatherhead, England, 1967, p. 329.

Goetz, G.J., Nsakala, N., and Patel, R.L., "Combustion and Gasification Kinetics of Chars from Four Commercially Significant Coals of Varying Rank," Proc. International Conference on Coal Science, 1983, p. 571.

Griffith, B.F., Lexa, G.F., Teigen, B.C., Levasseur, A.A. and Mehta, A.K., "Pilot-Scale Combustion Characterization of Two Illinois Coals," EPRI Final Report CS-6009, November 1988.

Hargrove, M.J., et al., "Commercial Applications and Economics of Coal-Water Fuels," Final Report Volume 6, DOE Contract DE-AC-22-82 PC 50271, November, 1989.

Huettenhain, H. and Schaal, A.M., "Advanced Physical Fine Coal Cleaning by Spherical Agglomeration," Final Report for U.S. DOE/PETC under Contract DE-AC-22-87 PC 79867, September 1990.

Huffman, G.P., Huggins, F.E., Dunmyre, G.R., Pignocco, A.J. and Lin, M.C., "Comparative Sensitivity of Various Analytical Techniques to the Low-Temperature Oxidation of Coal," Fuel, 64, 849(1985).

Hurley, J. P., Benson, S. A., Chow, O. K., and Nsakala, N. Y., "The Effects of Coal Beneficiation on Ash Formation and Deposition," 17th International Conference on Coal Utilization and Slurry Technologies, Clearwater, Florida, April, 1992.

Mitchell, R.E., "Experimentally Determined Overall Burning Rates of Coal Chars," Combustion Science and Technology, 53, 165 (1987).

Nsakala, N., Goetz, G.J., Patel, R.L., Lao, T.C., Hickerson, J.D., and Ritz, H.J., "Pyrolysis and Combustion Characterization of Pulverized Coals for Industrial Applications," 189th ACS National Meeting, Miami, Florida, April 28-May 3, 1985. CE Publication TIS-7877.

Nsakala, N., Patel, R.L. and Borio, R.W., "An Advanced Methodology for Prediction of Carbon Loss in Commercial Pulverized Coal-Fired Boilers," 1986 JPGC, Portland, Oregon, October 19-23, 1986. CE Publication TIS-8211.

Nsakala, N. Patel, R. L., and Hargrove, M. J., "Physical, Chemical, and Reactivity Characteristics of Beneficiated Coal-Based Fuels," 15th International Conference on Coal and Slurry Technologies, Clearwater, Florida, April 23-26, 1990.

Nsakala, N. Patel, R. L., Raymond, D. R., Hargrove, M. J., Hurley, J. P., and Benson, S. A., "Effects of Coal Natures and Cleaning Processes on the Physiochemical and Reactivity Characteristics of Beneficiated Coal-Based Products," 16th International Conference on Coal and Slurry Technologies, Clearwater, Florida, April 22-25, 1991.

Raask, E.; Mineral Impurities in Coal Combustion: Behavior, Problems, and Remedial Measures. Hemispheres Publishing Corporation, Washington DC, 1985.

Sarofim, A.D., J.B. Howard, and P.S. Padia, "The physical transformation of mineral matter in pulverized coal under simulated combustion conditions," Combustion Science and Technology, 16, 187-204 (1977).

Schaal, A.M., and Lippsmeyer, B.C., Proof-Of-Concept Results Using the Arcanum/Bechtel Spherical Agglomeration Approach to Clean Ultra-fine Coals," EPRI's 15th Annual Fuel Science Conference, Palo Alto, California, June 19-21, 1990.

Smouse, S.M., McIlvried, T.S. and Avon, B.M., "Characterization of Advanced Physical Coal-Cleaning Products," 15th International Conference on Coal & Slurry Technologies, Clearwater, Florida, April 24-27, 1989.

Straszheim, W.E., "Application of automated image analysis to the study of mineral matter in raw and processed coals," Ph.D. Thesis, Iowa State University (1986).

Walker, Jr.,P.L., Rusinko, Jr., F., and Austin, L.G., "Gas Reactions of Carbon," Advances in Catalysis, Vol 11, Academic Press, N.Y. and London, 1959, p. 133.

Watt, J.D. and F. Fereday; "The Flow Properties of Slags Formed from the Ashes of British Coals: Part 1. Viscosity of Homogeneous Liquid Slags in Relation to Slag Composition". Journal of the Institute of Fuel. March 1969.

# COMBUSTION CHARACTERIZATION OF BENEFICIATED COAL-BASED FUELS

Quarterly Technical Progress Report
for the Period April - June 1992

by

Tina M. Strobel, Research Associate
John P. Hurley, Research Supervisor
Steven A. Benson, Research Supervisor

Energy and Environmental Research Center
University of North Dakota
Box 8213, University Station
Grand Forks, North Dakota 58202

for

U.S. Department of Energy
Pittsburgh Energy Technology Center
626 Cochran Mill Road
P.O. Box 10940
Pittsburgh, Pennsylvania 15236

July 1992

Work Performed Under Subcontract to

Combustion Engineering, Inc.
Contract No. DE-AC22-89PC88654

APPENDIX 'A'

## TABLE OF CONTENTS

## LIST OF FIGURES



(continued)

| Figure | | Page |
|---|---|---|



(continued)

| Figure | | Page |
|---|---|---|

# LIST OF TABLES

Table — Page

## COMBUSTION CHARACTERIZATION OF BENEFICIATED COAL-BASED FUELS

## 1.0 INTRODUCTION

The University of North Dakota Energy and 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 are being analyzed by computer-controlled scanning electron microscopy (CCSEM) to determine the types, size distributions, and degree of affiliation with coal particles for the discrete mineral particles present in each fuel. The fuels are also being fractionated by specific gravity into four portions: <1.4, 1.4-2.5, 2.5-2.9, and >2.9. Ash content, ash composition, and fusion temperatures for each specific gravity fraction will be determined.

The EERC involvement in Task 3 consists 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.

The original Upper Freeport fuel was found to be weathered, so another set of analyses was completed for the unweathered fuel. This quarterly report will concentrate on the comparison of the unweathered and the weathered Upper Freeport fuels and their corresponding deposits.

## 2.0 TASK 2 RESULTS AND DISCUSSION

### 2.1 Fuel Analyses

#### 2.1.1 Specific Gravity Fractionation

Tables 2 and 3 list the yield, ash contents, and normalized ash compositions of the specific gravity fractions of the weathered Upper Freeport and the unweathered Upper Freeport fuels. The two data sets indicate that the particle-size distributions for both fuels are very similar.

The major element compositions of the unweathered and weathered ashes show some interesting differences. The $SiO_2$ content of the weathered ash was much less than that of the unweathered ash, and the $Fe_2O_3$ content was higher. The most dramatic difference in $Fe_2O_3$ content occurred in the 2.5-2.9 fraction. Another noticeable difference occurs in the >2.9 fraction where the $SO_3$ content of the unweathered ash is less than that of the weathered ash. The differences in composition between the two fuels may be due to differences in sampling techniques or variability with the coal seam.

The ash fusion temperatures also show differences between the weathered and the unweathered ashes. The weathered ash fusion temperatures were 100° to 300°F less than the ash fusion temperatures for the unweathered material. The lower ash fusion temperatures may be explained by the lower $SiO_2$ content and the higher $Fe_2O_3$ content of the unweathered ashes, when compared to the weathered ashes. The lower ash fusion temperatures indicate that the unweathered Upper Freeport fuel is less likely to produce slag deposits in the boiler.

TABLE 1

EERC Analyses of FPTF Samples

| Sample | Composition | Fusion | SEMPC | CCSEM | XRD |
|---|---|---|---|---|---|
| In-Flame Solids | | | | | |
| Waterwall | X | | | X | X |
| Furnace Outlet | X | | | X | X |
| Waterwall Deposits | | | | | |
| T1 | | | | | |
| Inner Layer | X | X | X | | X |
| Outer Layer | X | X | X | | X |
| Waterwall Deposits | | | | | |
| T2 | | | | | |
| Inner Layer | X | X | | | X |
| Outer Layer | X | X | | | X |
| Superheater Deposits | | | | | |
| T1 | | | | | |
| Inner Layer | X | X | X | | X |
| Outer Layer | X | X | X | | X |
| Superheater Deposits | | | | | |
| T2 | | | | | |
| Inner Layer | X | X | | | X |
| Outer Layer | X | X | | | X |
| Fly Ash | X | X | | X | X |
| Bottom Ash | X | X | | | |

### 2.1.2 CCSEM Analyses of Unweathered and Weathered Upper Freeport Fuels

The cumulative size distributions of the mineral particles in the Upper Freeport 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. The weathered and unweathered Upper Freeport fuels show very similar particle-size distributions, with a majority of the particles in the <22.0-micron size range.

Figure 2 shows the relative quantities of the different types of mineral particles detected by CCSEM in the two fuels. Both fuels contain mainly quartz, aluminosilicate material, potassium aluminosilicate material, pyrite, and unknowns. The unweathered fuel contains more aluminosilicate material, potassium aluminosilicate material, and quartz. The weathered fuel has higher concentrations of pyrite and unknowns. The large amount of mineral matter in the weathered fuel labeled "unknown" in composition appears to be mixtures of quartz, aluminosilicates, and pyrite with overall compositions that lie outside any of the more pure mineral categories. The lower concentrations of aluminosilicate material in the unweathered fuel can be explained by differences in sampling techniques and/or differences in the coal seam or sample location.

TABLE 2

Analyses of Specific Gravity Fractions of the Upper Freeport Weathered Coal

| Specific Gravity Fraction | <1.4 | 1.4-2.5 | 2.5-2.9 | >2.9 |
|---|---|---|---|---|
| Yield (wt%) | 88.0 | 10.3 | 0.9 | 0.8 |
| Ash (wt%, mf[1]) | 5.1 | 5.1 | 53.7 | 67.6 |
| Ash Composition (wt%)[2] | | | | |
| $SiO_2$ | 43.6 | 44.8 | 55.4 | 3.9 |
| $Al_2O_3$ | 27.0 | 26.9 | 20.8 | 5.1 |
| $Fe_2O_3$ | 18.0 | 20.3 | 13.4 | 88.0 |
| $TiO_2$ | 2.1 | 1.4 | 0.9 | 0.4 |
| $P_2O_5$ | 0.2 | 0.1 | 0.1 | <0.1 |
| CaO | 2.7 | 2.4 | 2.2 | 0.7 |
| MgO | 1.6 | 1.7 | 1.2 | 1.8 |
| $Na_2O$ | <0.5 | <0.5 | <0.5 | <0.5 |
| $K_2O$ | 3.0 | <0.5 | 2.5 | <0.5 |
| $SO_3$ | 1.7 | 2.4 | 3.5 | 0.5 |
| Closure | 100.1 | 94.8 | 96.7 | 107.9 |
| Ash Fusion (°F)[3] | | | | |
| IDT | 2098 | 1902 | ND[4] | 2046 |
| ST | 2245 | 1952 | | 2122 |
| HT | 2301 | 2181 | | 2239 |
| FT | 2335 | 2288 | | 2379 |

[1]Moisture-free.
[2]ASTM ash composition (normalized wt%).
[3]Reducing atmosphere.
[4]Not determined.

TABLE 3

Analyses of Specific Gravity Fractions of the Upper Freeport Unweathered Coal

| Specific Gravity Fraction | <1.4 | 1.4-2.5 | 2.5-2.9 | >2.9 |
|---|---|---|---|---|
| Yield (wt%) | 80.4 | 17.9 | 1.2 | 0.6 |
| Ash (wt%, mf[1]) | 4.5 | 29.7 | 69.3 | 62.5 |
| Ash Composition (wt%)[2] | | | | |
| $SiO_2$ | 50.5 | 56.9 | 64.5 | 13.3 |
| $Al_2O_3$ | 27.4 | 30.2 | 22.0 | 2.3 |
| $Fe_2O_3$ | 11.1 | 6.5 | 7.0 | 71.8 |
| $TiO_2$ | 1.2 | 0.9 | 0.9 | 0.0 |
| $P_2O_5$ | 0.7 | 0.3 | 0.2 | 0.2 |
| CaO | 2.4 | 0.6 | 0.4 | 0.2 |
| MgO | 1.2 | 1.0 | 0.8 | 0.0 |
| $Na_2O$ | 0.3 | 0.2 | 0.2 | <0.5 |
| $K_2O$ | 2.5 | 2.5 | 2.1 | <0.5 |
| $SO_3$ | 2.9 | 0.9 | 1.9 | 12.1 |
| Closure | 100.7 | 106.4 | 101.7 | 106.7 |
| Ash Fusion (°F)[3] | | | | |
| IDT | 2211 | 2675 | 2510 | 2586 |
| ST | 2420 | 2761 | 2601 | 2588 |
| HT | 2502 | +2800 | 2634 | 2589 |
| FT | +2800 | +2800 | +2800 | 2601 |

[1]Moisture-free.
[2]ASTM ash composition (normalized wt%).
[3]Reducing atmosphere.

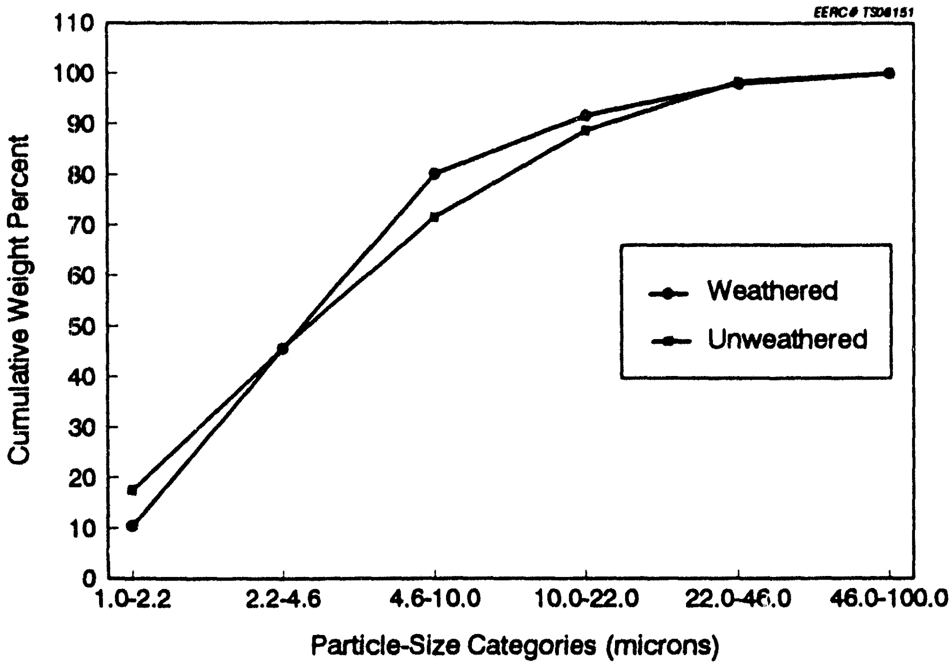



Figure 1. Cumulative size distributions of the inorganic particles with sectioned diameters between 1 and 100 microns in the Upper Freeport unweathered and weathered fuels.

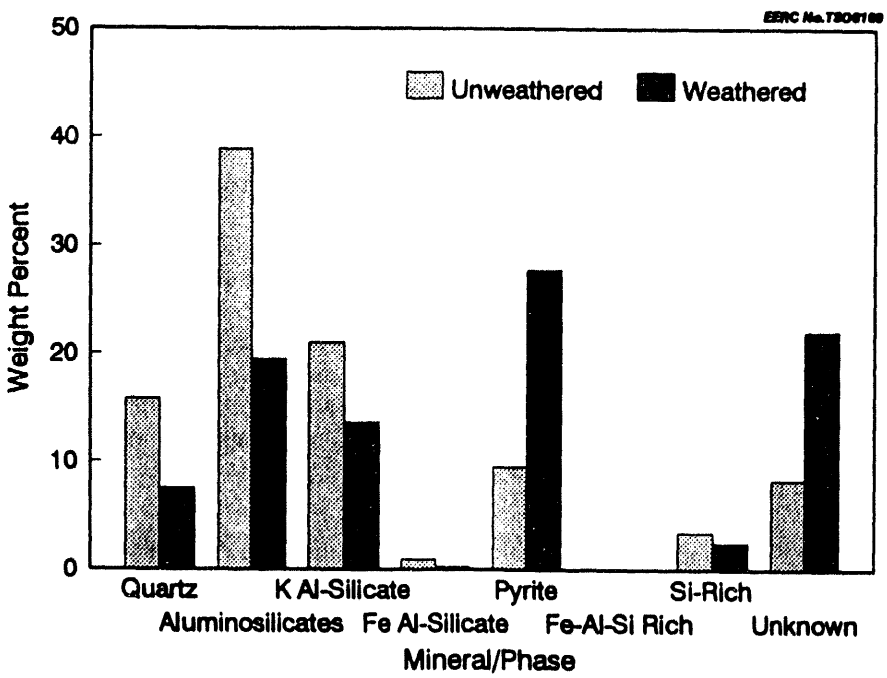



Figure 2. The composition distributions of the inorganic particles with sectioned diameters between 1 and 100 microns in the Upper Freeport unweathered and weathered fuels.

The differences in mineral composition of the two fuels correspond to the bulk chemical compositions listed in Tables 2 and 3. The unweathered fuel contained more $SiO_2$ in all size fractions, explaining the higher concentration of quartz, and the weathered fuel contained more $Fe_2O_3$, explaining the higher concentration of pyrite.

## 2.2 FPTF Samples

### 2.2.1 In-Flame Particulates--Waterwall

The data from the CCSEM analyses of the in-flame particulate samples collected near the waterwall during testing of the Upper Freeport weathered and unweathered fuels are shown in Figures 3 and 4. Figure 3 shows that the weathered waterwall ash particulates have a similar particle-size distribution as the unweathered ash particulates collected 18" from the waterwall (WW18"). The unweathered ash particles collected 3" from the waterwall (WW3") show slightly higher concentrations in the smaller particle sizes. Both the weathered and unweathered ash particulates show higher concentrations in the smaller particle sizes than the original mineral particles in the corresponding fuels. The reduction in particle size from the fuel minerals to the waterwall ash may be due to fragmentation of particles during combustion or deposition of the larger particles before they reach the waterwall.

Figure 4 shows the composition distributions of the 1- to 100-micron diameter waterwall ash particles as determined by CCSEM. The major constituents of the Upper Freeport waterwall particulates are quartz, aluminosilicates, K Al-Silicate and Fe Al-Silicate materials. All of the Upper Freeport waterwall particles have more Fe Al-Silicate and Fe-Al-Si-rich material than the original fuels. Pyrite was oxidized during combustion. The iron oxide originating from the pyrite coalesced with some of the aluminosilicate material to form the Fe Al-Silicate and Fe-Al-Si-rich material.

Similar to the fuels, the unweathered Upper Freeport particles have a slightly higher concentration of quartz and a significantly higher concentration of aluminosilicate material than the weathered waterwall particulates. The weathered waterwall particulates have a higher concentration of Fe Al-Silicate material than both the WW3" and WW18" unweathered particulates. The weathered particulates show a decrease in unknowns when compared to the original weathered fuel. This decrease is most likely due to the oxidation of the pyrite followed by coalescence with aluminosilicate particles to form iron aluminosilicate material.

### 2.2.2 Waterwall Panel Slag Deposits

Figures 5a-d illustrate the differences in the concentrations of the major elements in the coal ash, in-flame particulates, deposits, and fly ash of the weathered and unweathered Upper Freeport fuels. The lines in the figures connect the coal ash and deposit data, while the particulate samples are not connected. The data points are arranged in order of distance from the FPTF burner and, therefore, decreasing gas temperatures and increasing residence times. The data were determined by x-ray fluorescence analysis.

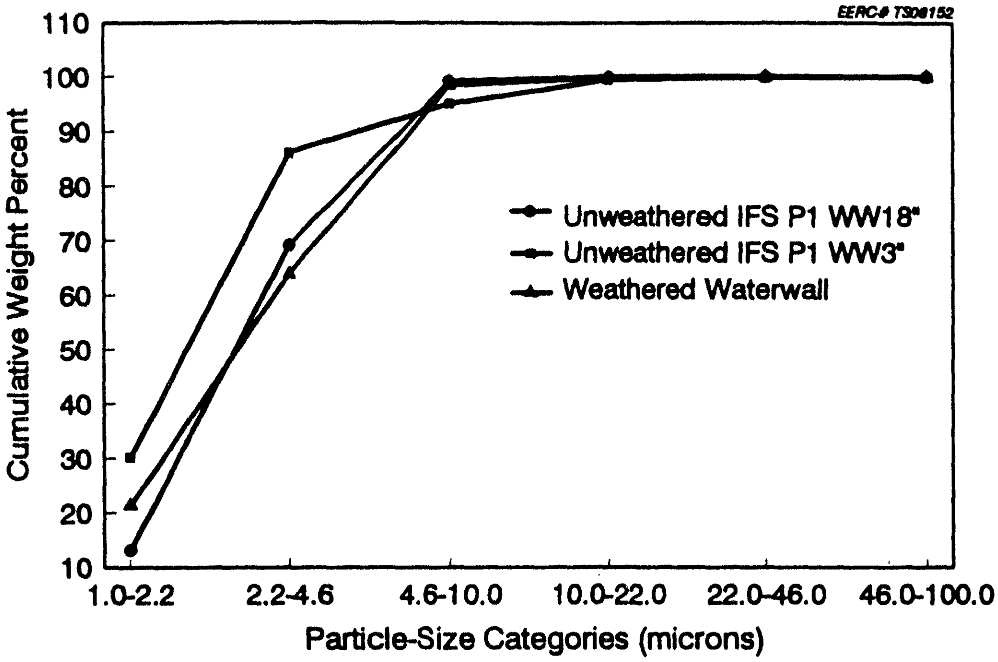



Figure 3. Cumulative size distributions of the inorganic particles with sectioned diameters between 1 and 100 microns in the Upper Freeport unweathered and weathered particulate ashes collected in the FPTF near the waterwall.

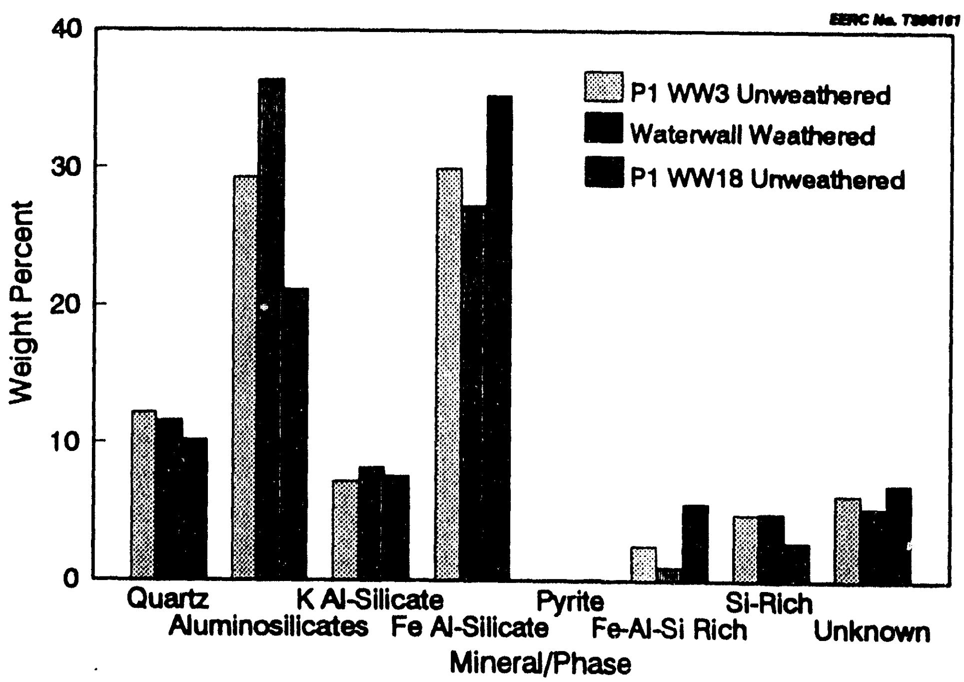
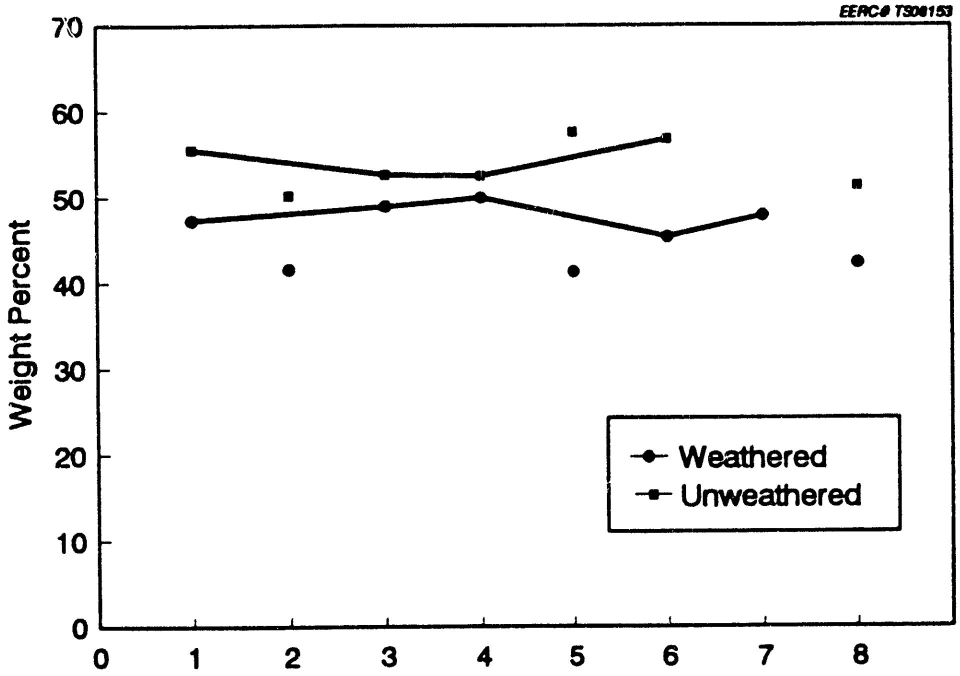



Figure 4. The composition distributions of the inorganic particles with sectioned diameters between 1 and 100 microns in the Upper Freeport unweathered and weathered particulate ashes collected in the FPTF near the waterwall.




(a) $SiO_2$ concentrations

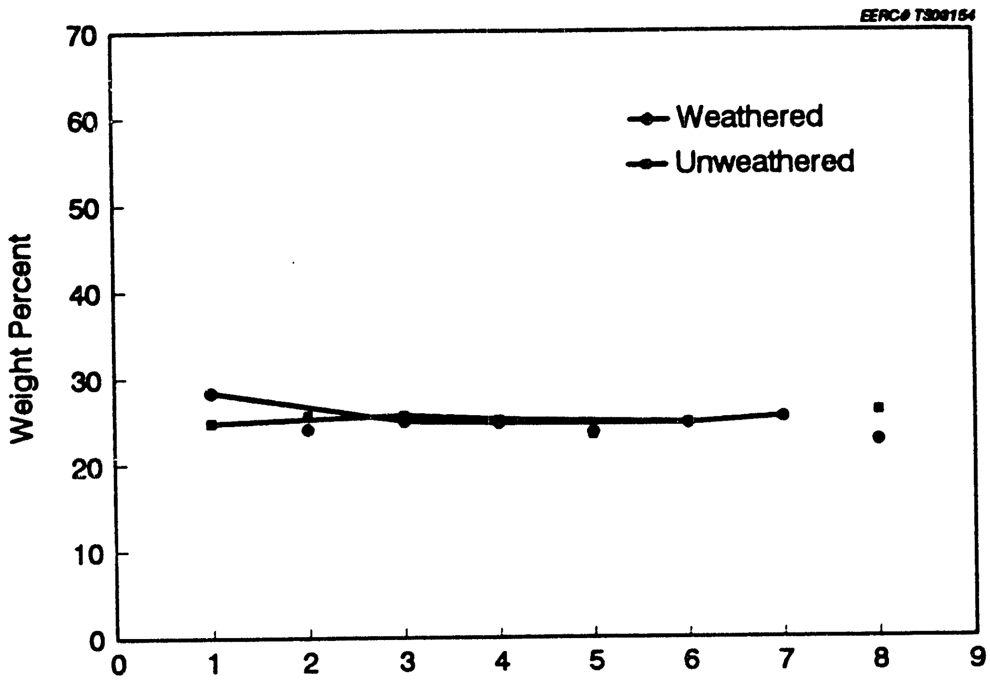
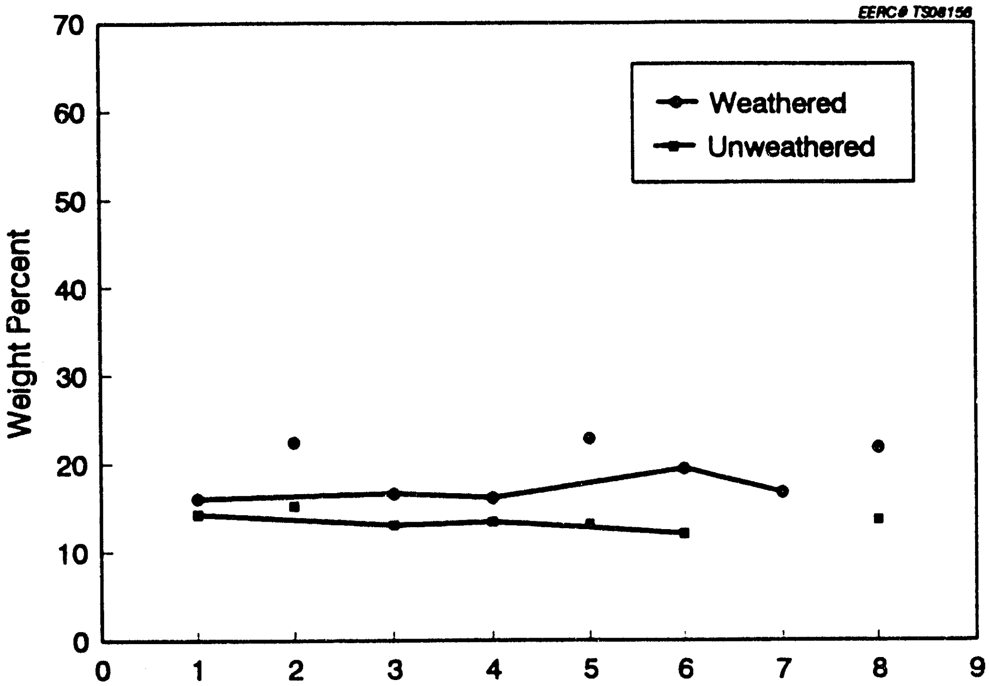
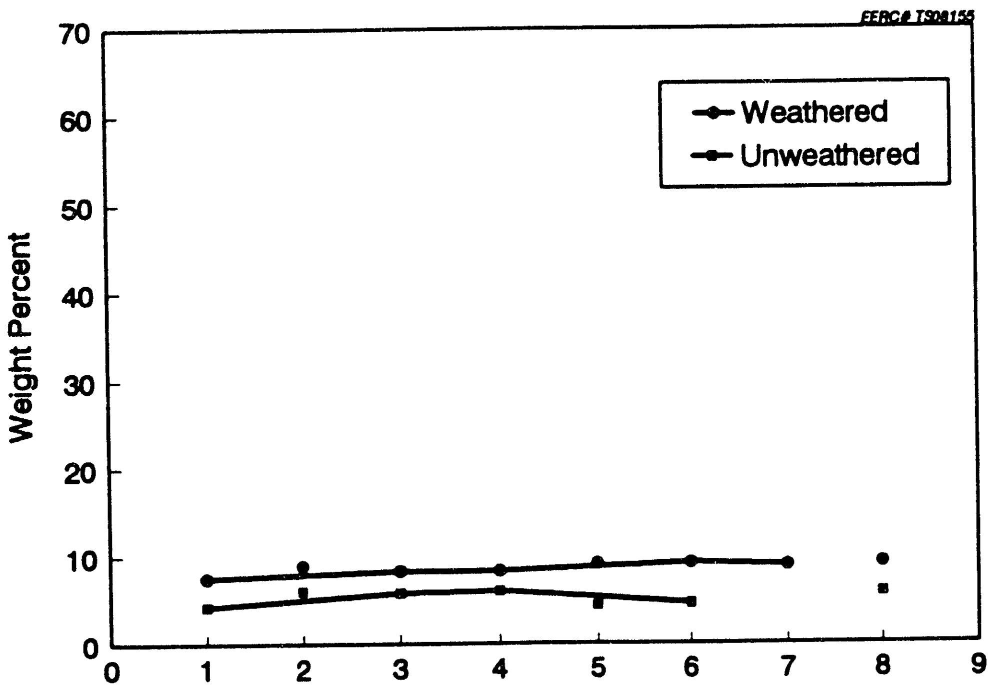



Figure 5. Differences in composition of the Upper Freeport unweathered and weathered fuel ash, in-flame particulate, deposits, and fly ash: (a) $SiO_2$, (b) $Al_2O_3$. Point designations are 1 = fuel ash, 2 = waterwall particulates, 3 = Panel 1 slag outer layer, 4 = Panel 4 slag outer layer, 5 = furnace outlet particulates, 6 = Tube 1a outer deposits, 7 = Tube 2c outer deposits, 8 = fly ash.




(c) $Fe_2O_3$ concentrations




(d) sum of alkali and alkaline earth elements

Figure 5. (cont.) Differences in composition of the Upper Freeport unweathered and weathered fuel ash, in-flame particulate, deposits, and fly ash: (c) $Fe_2O_3$, (d) sum of alkali and alkaline earth elements. Point designations are 1 = fuel ash, 2 = waterwall particulates, 3 = Panel 1 slag outer layer, 4 = Panel 4 slag outer layer, 5 = furnace outlet particulates, 6 = Tube 1a outer deposits, 7 = Tube 2c outer deposits, 8 = fly ash.

A comparison of the compositions of the deposits (connected symbols) with the particulate ash samples shows that the coal ash and deposits had higher $SiO_2$ and lower $Fe_2O_3$ contents than the particulates for the unweathered Upper Freeport tests. Since the deposit composition is similar to that of the coal ash, preferential ash deposition is not indicated. Instead, preferential particulate ash collection is indicated, most likely a preference in aerodynamic size. The unweathered fuel tests do not show this preference.

The weathered Upper Freeport ash particulates and deposits have lower $SiO_2$ concentrations than the unweathered fuel samples, which correspond to the lower $SiO_2$ and lower quartz concentrations in the weathered coal. The $Al_2O_3$ and alkali and alkaline earth concentrations for the weathered and unweathered samples were similar, although the weathered materials have slightly higher concentrations of alkalis and alkaline earths. The weathered fuel ash had a significantly higher $Fe_2O_3$ concentration than the unweathered fuel ash in the Tube 1a outer deposits. These differing concentrations in the fuel ashes were reflected in the CCSEM analyses for the original fuels. The CCSEM results indicated that the weathered fuel contained higher concentrations of pyrite, which would explain the higher concentrations of $Fe_2O_3$ in the fuel ash.

The reducing atmosphere softening temperatures of the outer waterwall panel and the steam-tube deposits are illustrated in Figure 6. The softening temperatures for the unweathered P2 slag and Tube 2C deposits were unavailable due to insufficient amounts of these samples. In general, the softening temperatures for the weathered fuels were a few hundred degrees Fahrenheit lower than those of the unweathered fuel deposits. The higher $Fe_2O_3$ concentrations in the weathered deposits would explain why these deposits have lower softening temperatures.

It is also important to determine the relative fluidity of the material, which can be determined by the viscosity distributions of these materials. This information may also be used to differentiate the compositions of the more fluid phases from those that are more viscous. The determination of the viscosity distributions is particularly important when the ash has not completely fused, which will occur in the cooler regions of the combustor.

Figure 7 shows the viscosity distributions of the amorphous material in the outer deposits that formed on the Panel 1 waterwall. The data were acquired from scanning electron microscope point count (SEMPC) analyses which were used to determine the composition distributions in the deposits. The composition distribution data were then used to calculate a viscosity distribution of the amorphous material using an algorithm developed by Kalmanovitch and Frank. The temperature used in the calculations is an average gas temperature at the level of Panel 1 during many FPTF runs. The data indicate that the weathered Panel 1 deposits have a lower viscosity distribution than the unweathered deposits. Therefore, the sintering rates will be higher because viscosity and sintering rates are inversely proportional.

Figures 8a-d show the normalized major element compositions of the amorphous points in the unweathered and the weathered Upper Freeport Panel 1 deposits that have calculated viscosities greater than 250 poise and less than 250 poise at 1650°C. The value of 250 poise was selected because it is the standard value for determining the flow characteristics of a slag. Slags with higher viscosities tend to be difficult to tap from a furnace, whereas slags

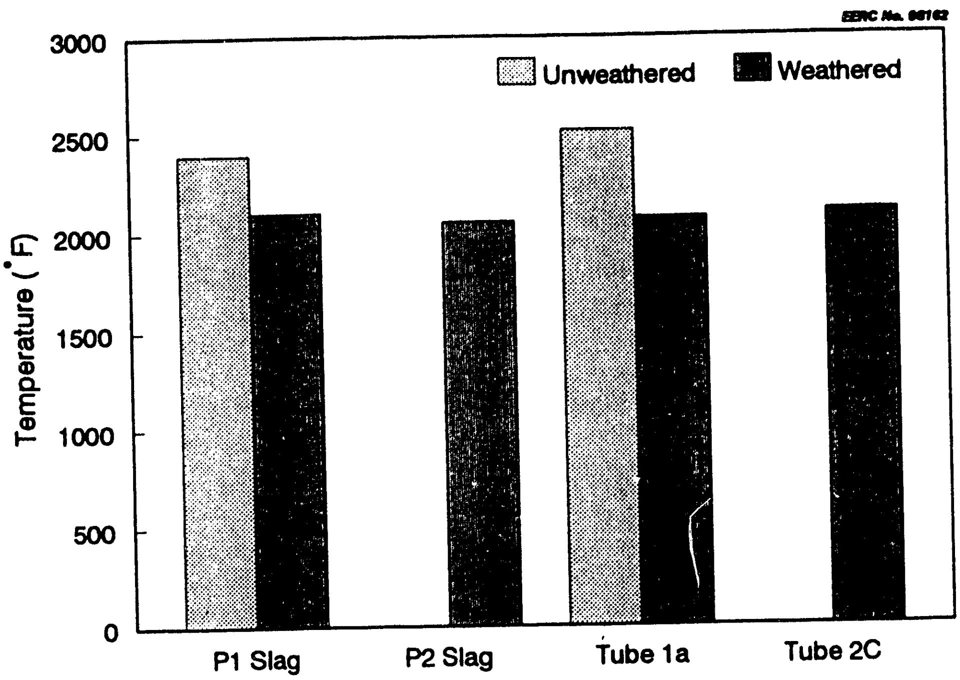



Figure 6. Reducing atmosphere ash fusion softening temperatures for the outer waterwall panel and steam-tube deposits (values not given for unweathered P2 slag and Tube 2C due to insufficient amount of sample).

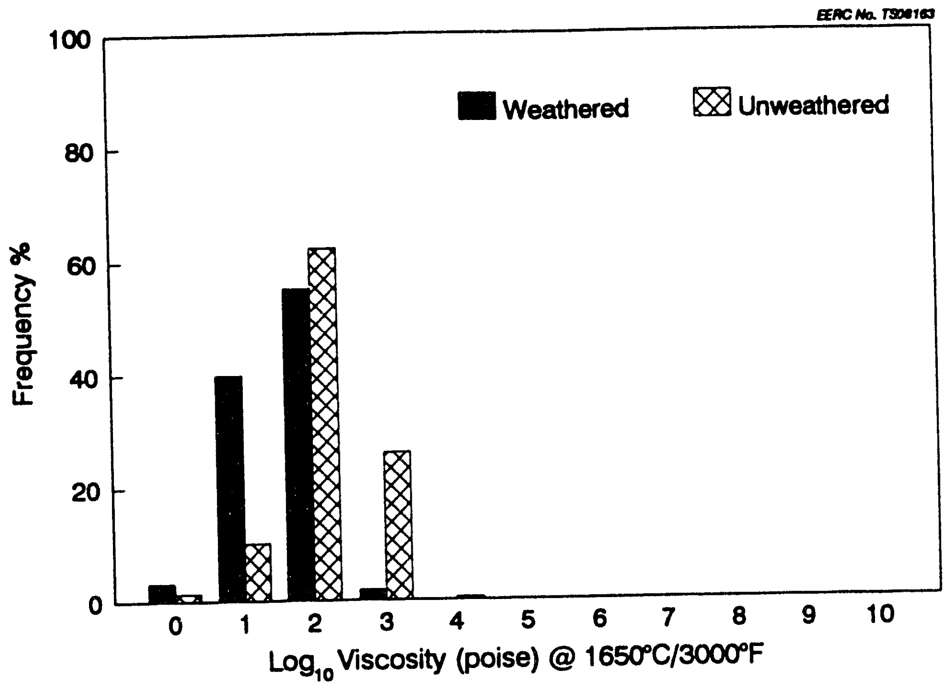



Figure 7. Calculated viscosity distributions in the waterwall Panel 1 outer deposits.

with lower viscosities usually can be tapped. The higher viscosity material is concentrated in the silica and alumina portion of the graph. The lower viscosity points have somewhat higher iron contents than the higher viscosity points. Usually, the lower the iron contents in the ash, the less likely the ash will form running slag deposits in the boiler.

Figures 8c and 8d show the normalized major element compositions of the points in the weathered Upper Freeport Panel 1 deposits. Similar to the unweathered deposits, the few points in the higher viscosity plot of the weathered deposits contain high silica and alumina concentrations. The low viscosity points for the weathered deposits are more widely scattered when compared to the unweathered low viscosity points (Figure 8b). The graphs show that the lower viscosity points of the weathered deposits often have more iron and calcium than the high viscosity points. The lower viscosity values for the weathered deposits, as compared to the unweathered deposits, may be explained by the higher iron content and the lower silica content of the weathered deposits.

### 2.2.3 <u>In-Flame Particulates--Furnace Outlet</u>

Figures 9 and 10 show the cumulative size distributions and composition distributions of the in-flame particulate ash collected at the furnace outlet. The data were determined by CCSEM analysis of ash particles with sectioned diameters between 1 and 100 microns. Nearly 100% of the unweathered ash particles (collected 3" and 18" from the furnace outlet) are less than 10 microns in diameter, and approximately 80% of weathered ashes are concentrated in this particle-size range. The weathered Upper Freeport ash has a slightly larger size distribution than that of the waterwall, indicating either agglomeration from the waterwall to the furnace outlet, or removal of larger particles by deposition before they reached the furnace outlet. The weathered ash particles would be more susceptible to agglomeration because of their higher iron content and lower viscosities.

Figure 10 shows the composition distributions of the in-flame particulate samples collected at the furnace outlet. The composition distribution is similar to those of the ash collected at the level of the waterwall. The quartz content of the unweathered outlet particles showed a slight increase, and the amount of iron aluminosilicate material showed a slight decrease from the waterwall to the furnace outlet.

### 2.2.4 <u>Convective Pass Fouling Deposits</u>

The bulk composition and reducing atmosphere fusion temperatures for the fouling deposits that formed on the simulated steam tubes in the convective pass of the FPTF were shown in previous sections in this report. In general, the softening temperatures for the weathered fuels were 200° to 400°F lower than those of the unweathered fuel deposits. The higher $Fe_2O_3$ concentrations in the weathered deposits would explain their lower softening temperatures.

The calculated viscosity distributions of the outer deposits that formed on Steam Tube 1a are shown in Figure 11. The temperature used in the calculations, 1250°C, is an average gas temperature in the region of the tubes during a typical fuel test. The figure shows that the weathered deposits have a slightly lower viscosity distribution than the unweathered deposits.

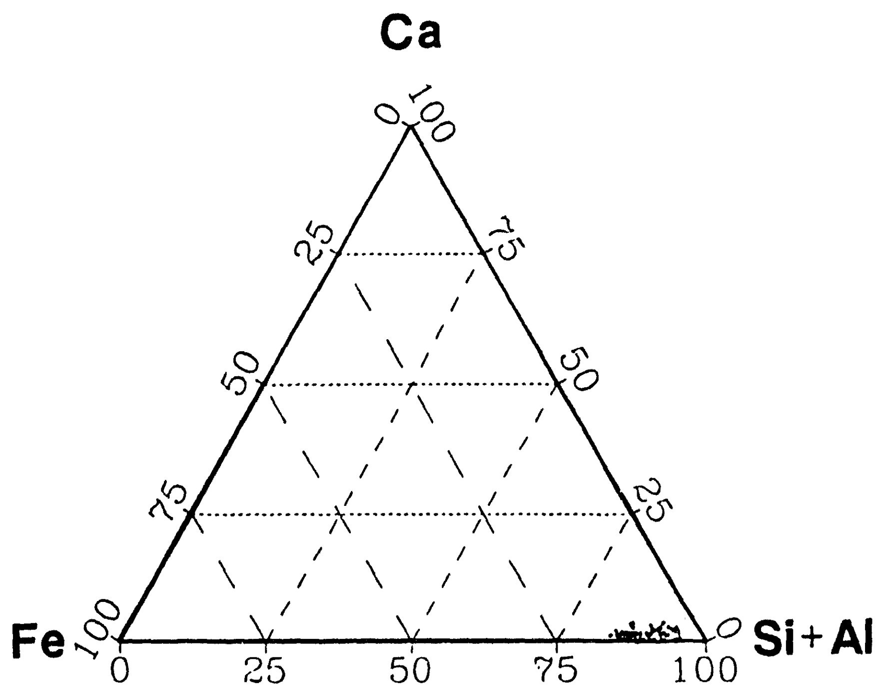



Figure 8a. The normalized major element compositions of the points in the unweathered Upper Freeport waterwall Panel 1 outer deposits that have calculated viscosities at 1650°C of greater than 250 poise.

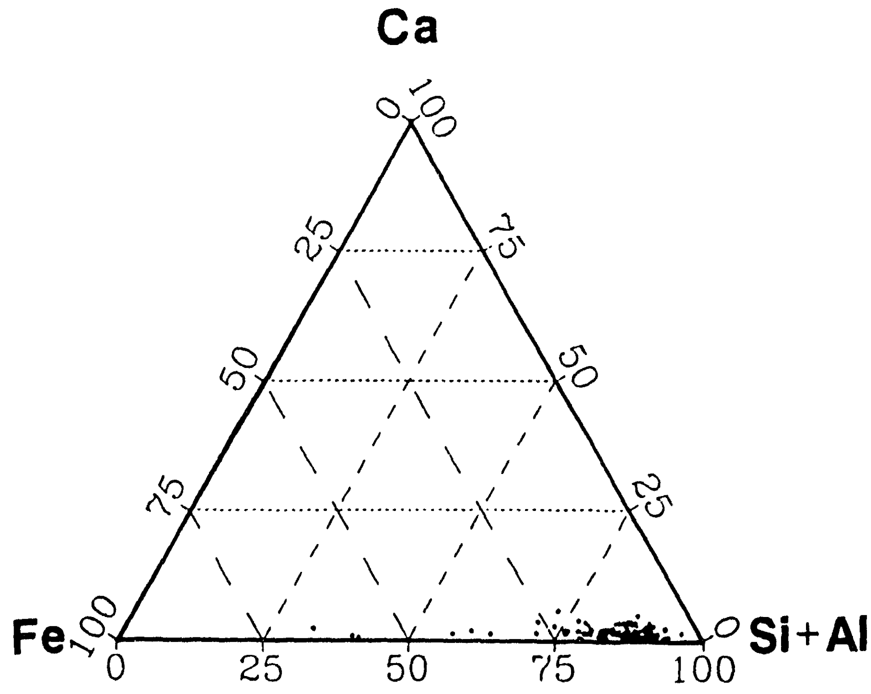



Figure 8b. The normalized major element compositions of the points in the unweathered Upper Freeport waterwall Panel 1 outer deposits that have calculated viscosities at 1650°C of less than 250 poise.

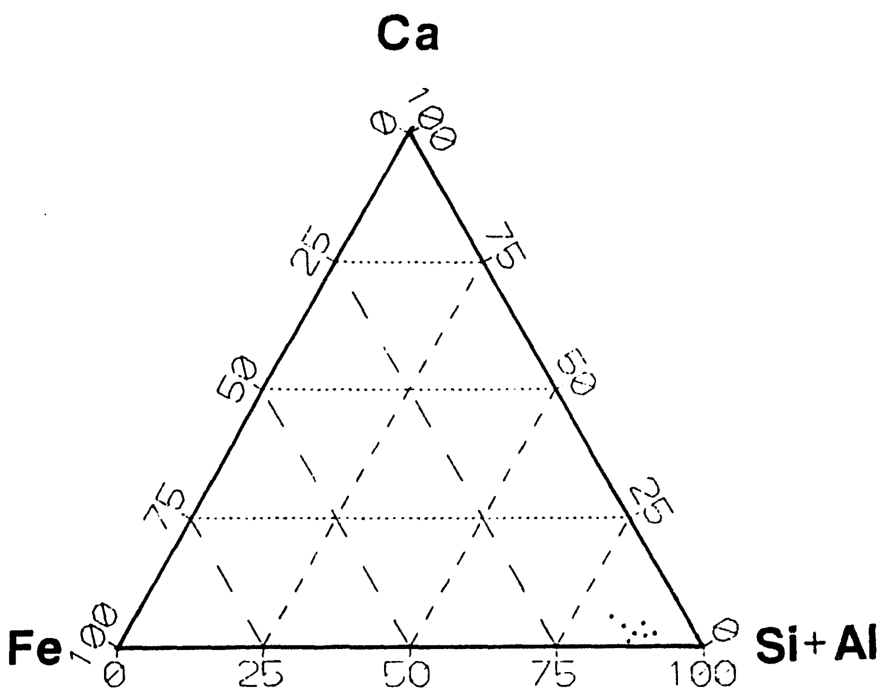



Figure 8c. The normalized major element compositions of the points in the weathered Upper Freeport waterwall Panel 1 outer deposits that have calculated viscosities at 1650°C of greater than 250 poise.

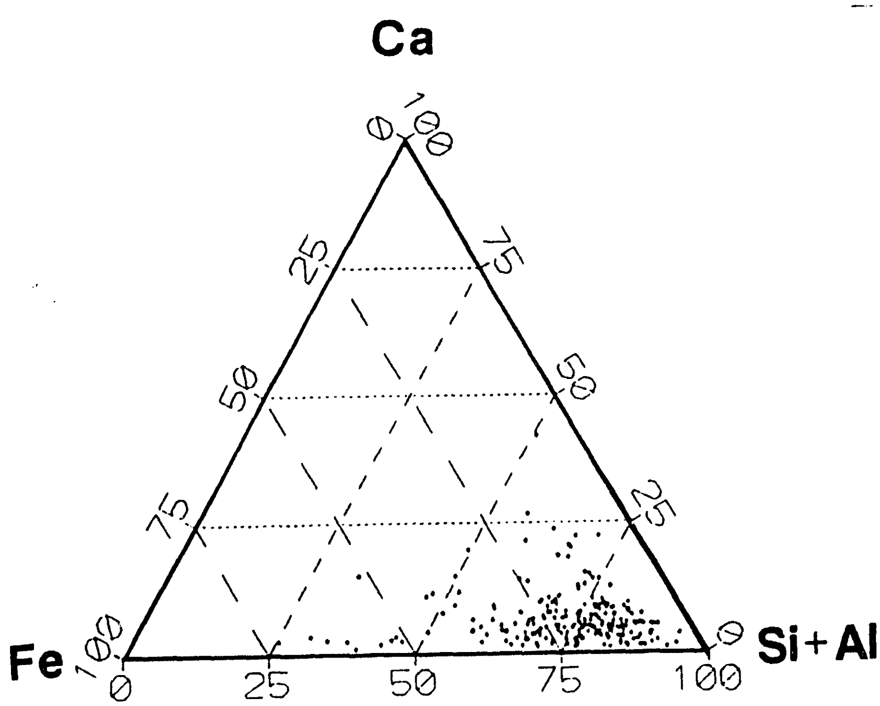



Figure 8d. The normalized major element compositions of the points in the weathered Upper Freeport waterwall Panel 1 outer deposits that have calculated viscosities at 1650°C of less than 250 poise.

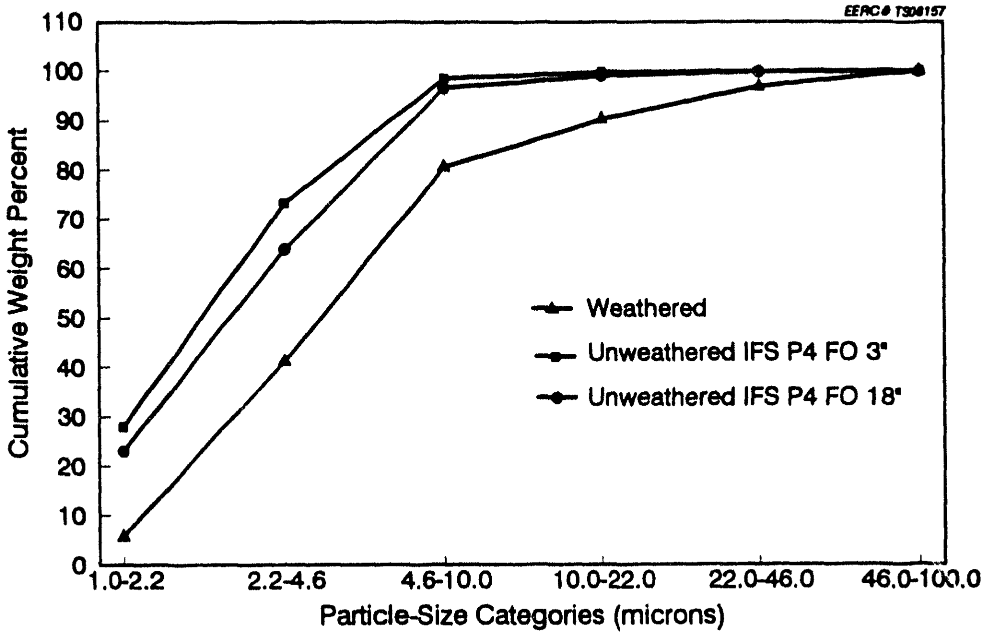



Figure 9. Cumulative size distribution of the inorganic particules with sectioned diameters between 1 and 100 microns in the Upper Freeport weathered and unweathered particulate ashes collected in the FPTF at the furnace outlet.

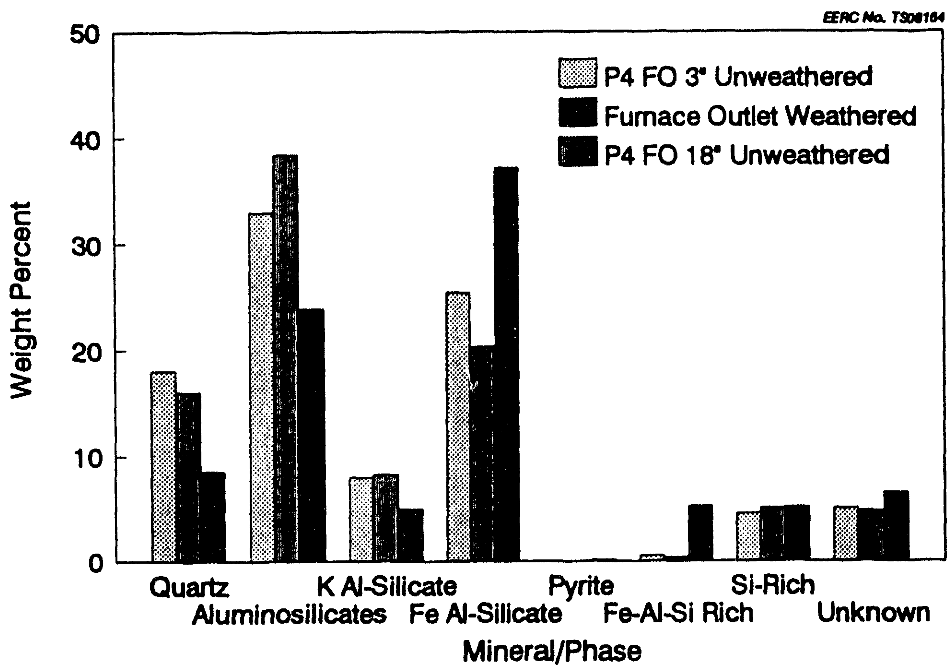



Figure 10. The composition distributions of the inorganic particles with sectioned diameters between 1 and 100 microns in the Upper Freeport weathered and unweathered particulate ashes collected in the FPTF at the furnace outlet.

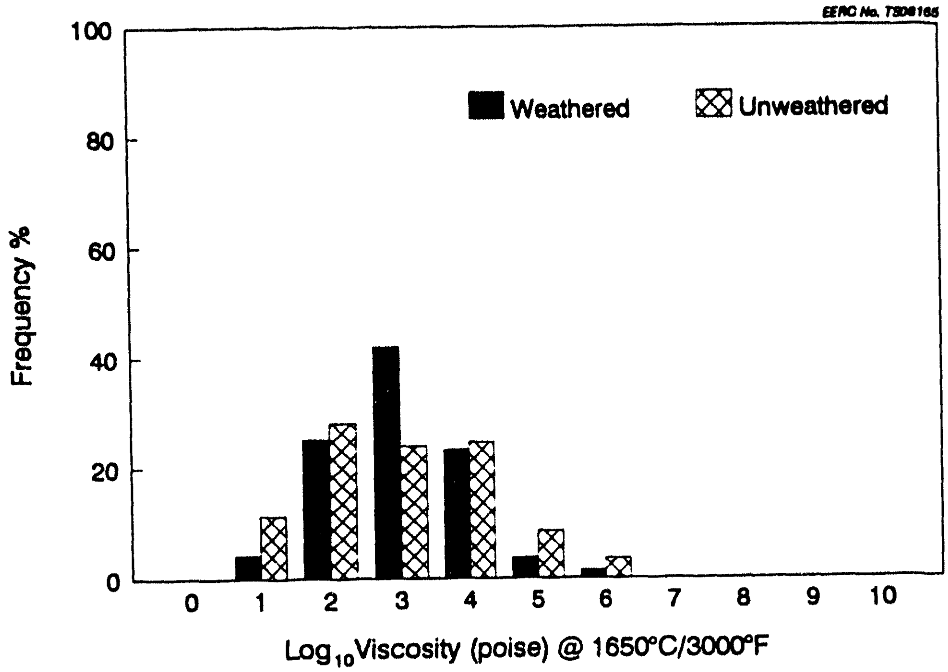



Figure 11. Calculated viscosity distributions in the Steam Tube 1a outer deposits in accordance with the viscosity distributions of the previous deposits, with the weathered deposits having lower viscosity distributions.

The normalized major element compositions of the points in the unweathered Steam Tube 1a outer deposits with calculated viscosities greater than and less than 250 poise, at 1250°C are shown in Figures 12a and 12b, respectively. Similar to the data from the waterwall panel slag deposits, the higher viscosity regions tend to have higher silica and alumina concentrations, whereas the lower viscosity regions tend to have higher iron or calcium. Iron content seems to be the controlling factor for viscosity in the Tube 1a deposits.

Figures 12c and 12d show the normalized major element compositions of the points in the weathered Tube 1a outer deposits with calculated viscosities greater than and less than 250 poise, respectively. Similar to the unweathered deposits, the higher viscosity regions contain higher concentrations of silica and alumina. The lower viscosity points contain more iron and calcium.

### 2.2.5 Fly Ash

Figure 13 shows the cumulative size distribution of the fly ash collected from the convective pass near the erosion test equipment. Nearly 100% of the unweathered fly ash particles are less than 10 microns, whereas approximately 80% of the weathered fly ash particles are found in this particle-size range. The fly ashes and furnace-outlet ashes have similar particle-size distributions and therefore may be explained by the same mechanisms. The weathered material, due to higher iron content and lower viscosities, may have experienced agglomeration. Larger particles in the unweathered fuel may have been removed by deposition before reaching the convective pass.

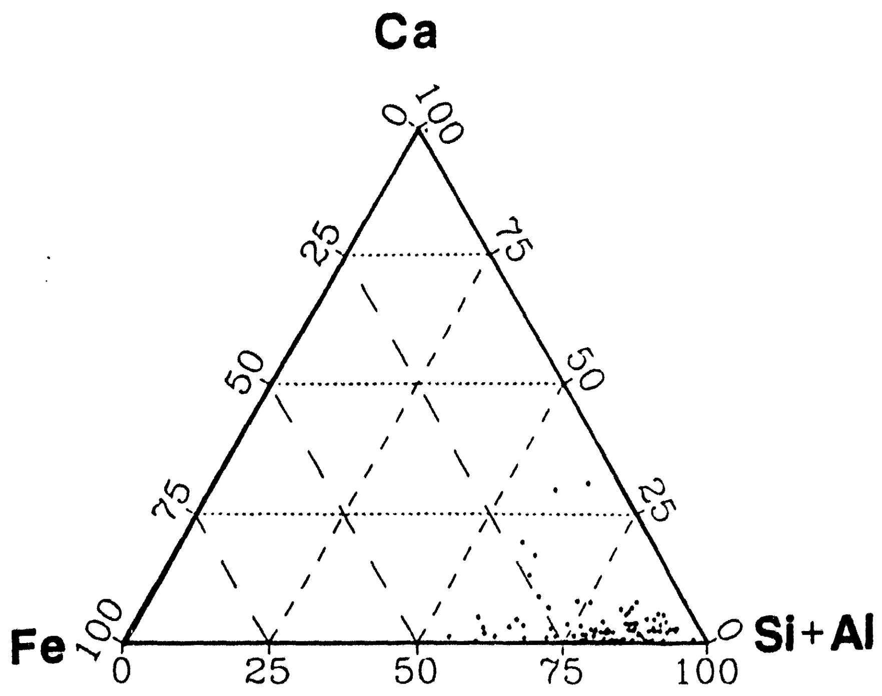



Figure 12a. The normalized major element compositions of the points in the unweathered Upper Freeport Steam Tube 1a outer deposits that have calculated viscosities at 1650°C of greater than 250 poise.

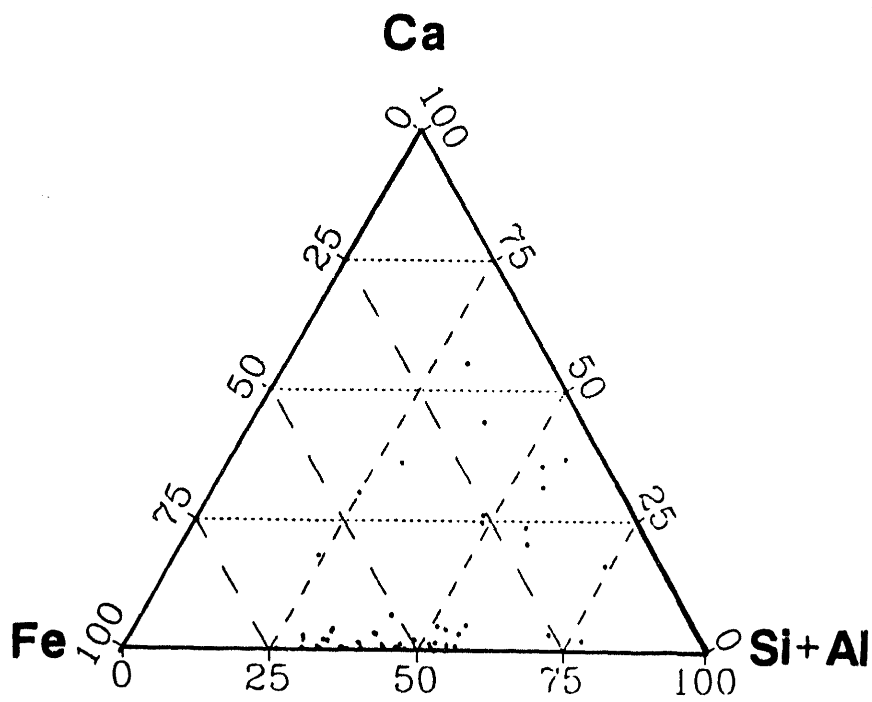



Figure 12b. The normalized major element compositions of the points in the unweathered Upper Freeport Steam Tube 1a outer deposits that have calculated viscosities at 1650°C of less than 250 poise.

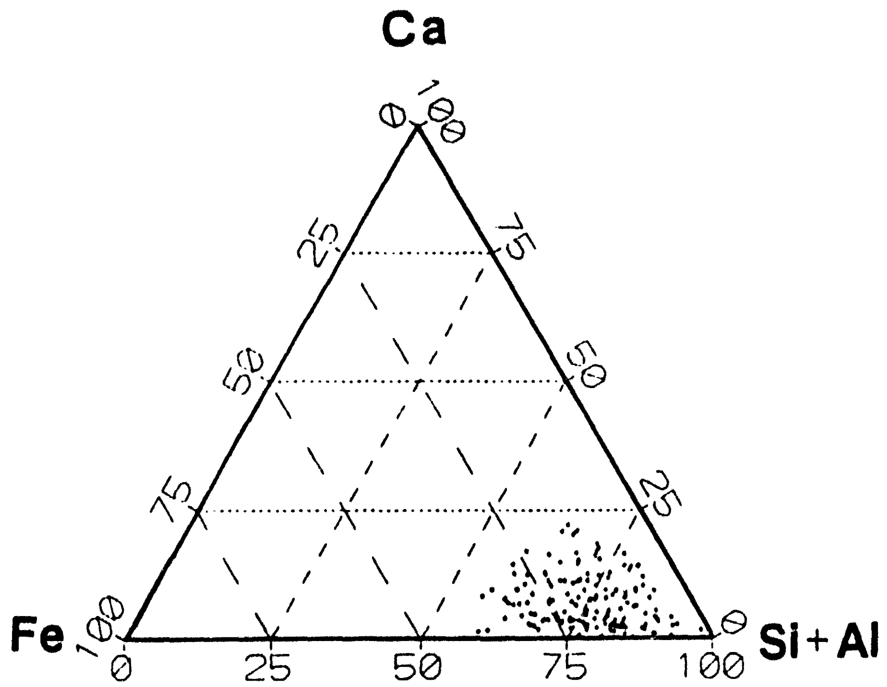



Figure 12c. The normalized major element compositions of the points in the weathered Upper Freeport Steam Tube 1a outer deposits that have calculated viscosities at 1650°C of greater than 250 poise.

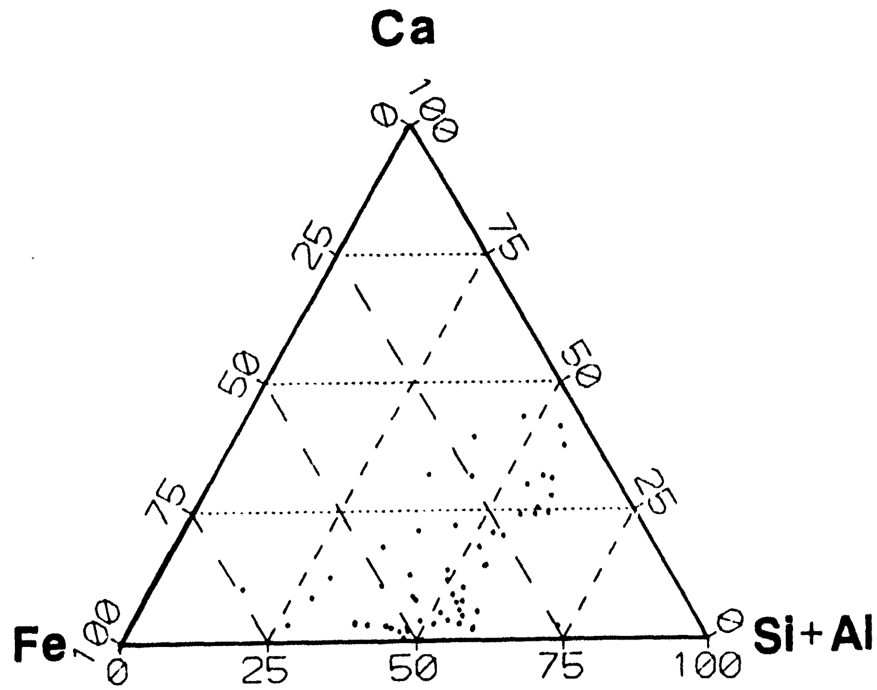



Figure 12d. The normalized major element compositions of the points in the weathered Upper Freeport Steam Tube 1a outer deposits that have calculated viscosities at 1650°C of less than 250 poise.

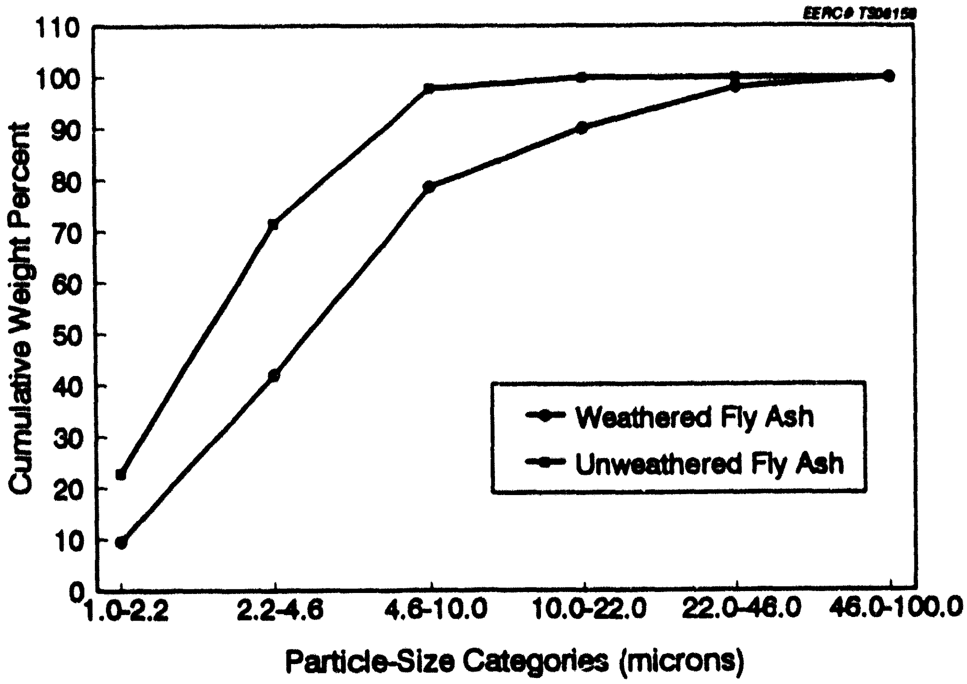



Figure 13. Cumulative size distributions of the inorganic particles with sectioned diameters between 1 and 100 microns in the Upper Freeport unweathered and weathered fly ashes.

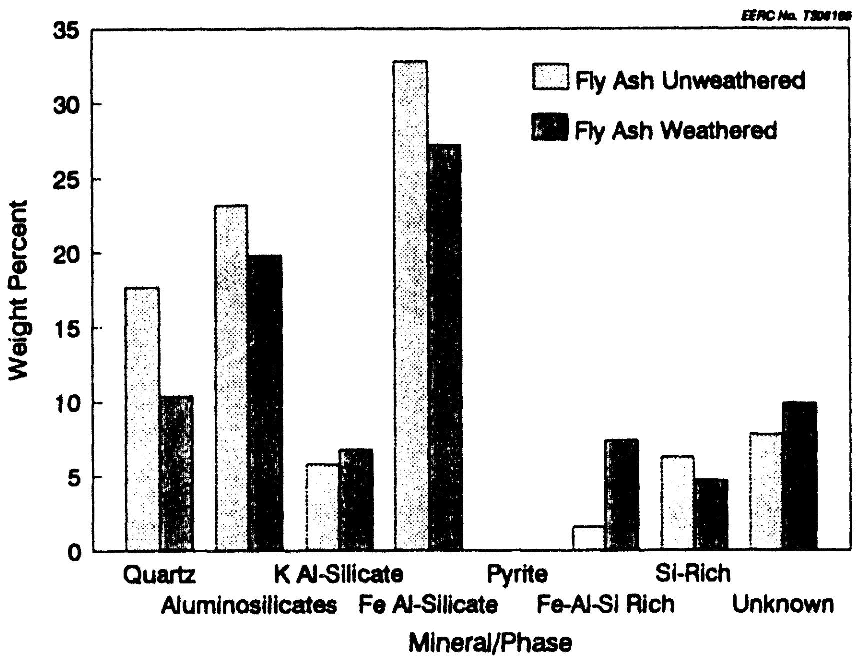



Figure 14. The composition distributions of the inorganic particles with sectioned diameters between 1 and 100 microns in the Upper Freeport unweathered and weathered fly ashes.

The composition distribution of the fly ashes as determined by CCSEM is shown in Figure 14. Both fly ashes from the weathered and unweathered Upper Freeport fuels contain mainly iron aluminosilicates, aluminosilicates, and quartz. The unweathered fly ash contains higher amounts of these constituents when compared with the weathered fly ash. Of the minor constituents, the weathered deposits contain higher amounts of potassium aluminosilicate material, silica-rich material, iron-aluminosilicate-rich material, and unknowns.

## 3.0 REFERENCES

1. Kalmanovitch, D.P.; Frank, M. "An Effective Model of Viscosity for Ash Deposition Phenomena," *In Mineral Matter and Ash Deposition from Coal*; Engineering Foundation, 1988.

# DATE FILMED

8 /31 / 94

# END