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COMBUSTION CHARACTERIZATION OF BENEFICIATED COAL-BASED FUELS

QUARTERLY REPORT NO. 5 FOR THE PERIOD MAY 1990 TO JUNE 1990

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DISCLAIMER

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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 three-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 being run at the DOE/EPRI cleaning facility in Homer City, Pennsylvania, 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 Sciences, Inc. Technology Company (PSIT) and the University of North Dakota Energy and Environmental Research Center (UNDEERC).

Twenty fuels will be characterized during the three-year base program: three feed coals, fifteen BCFs, and two conventionally cleaned coals for the 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 1990, the following technical progress was made.

- Evaluated the ignitibility and reactivity characteristics of the spherical oil agglomeration process beneficiated products, including flammability indices, TGA, and BET surface areas.

- Completed pilot-scale combustion and ash deposition tests of the Illinois No. 6 and Pittsburgh No. 8 spherical agglomeration products.

- Continued 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 microfine pulverized coal (DMPC).

Nine 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 agglomeration product
8. Pittsburgh #8 spherical agglomeration product
9. Upper Freeport spherical agglomeration product

All fuels except #7 and #8 were tested during the previous three quarters.

The Illinois #6 and Pittsburgh #8 spherical agglomerates were dried and pulverized in the bowl mill prior to being fired in the FPTF in May and June, respectively.

TASK 2 - BENCH-SCALE TESTS

All test fuels are fully characterized using various standard and advanced analytical techniques (Figure 1). 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.

Nine fuels are being characterized. These include: (1) Upper Freeport mvb, Pittsburgh #8 hvAb, and Illinois #6 hvCb; (2) three microbubble flotation products (MFPs) prepared from the above parent coals; and (3) three spherical oil agglomeration products (SOAPs) prepared from the same parent coals.

The following milestones have been accomplished on all nine coal and BCF samples: (1) complete chemical analyses; 2) flammability index measurements; (3) weak acid leaching; (4) TGA reactivities, and (5) BET surface areas of chars produced from the nine fuels in the DTFS-1 under specific conditions. Most of these data have been reduced and are reported herein. Refer to the previous quarterly report, dated June, 1990, for testing procedures. Results are presented below.

The chemical analyses of the test fuels are given in Table 1. It is noteworthy that the microbubble flotation process (MFP) and spherical oil agglomeration process (SOAP) performed on Illinois #6, Pittsburgh #8, and Upper Freeport coals led to the following results: ash contents reduced by more than 50% in most cases; pyritic sulfur contents reduced by more than 80% in most cases; calorific values increased by more than 4% in all cases. However, from an ash deposition standpoint, these two coal cleaning processes did not appear to improve the ash qualities, due perhaps to selective removal of certain mineral species (e.g., silicates), enrichment of others (e.g., alkali metals and alkaline earths), and the overall lower fusibility temperatures of the BCF ashes.

Ignitibility Characteristics of Test Fuels

The Flammability Index (FI) was used as a measure of the ignitibility characteristic of each test fuel. This test entails feeding 0.2 grams of sized fuel in an oxygen atmosphere heated until the fuel ignites. Two fuel sizes were tested: 200x0 mesh standard for pulverized coal, and 325x0 mesh, more representative of the finely ground BCFs. Results are as follows:

SPECIALIZED SMALL-SCALE TESTS

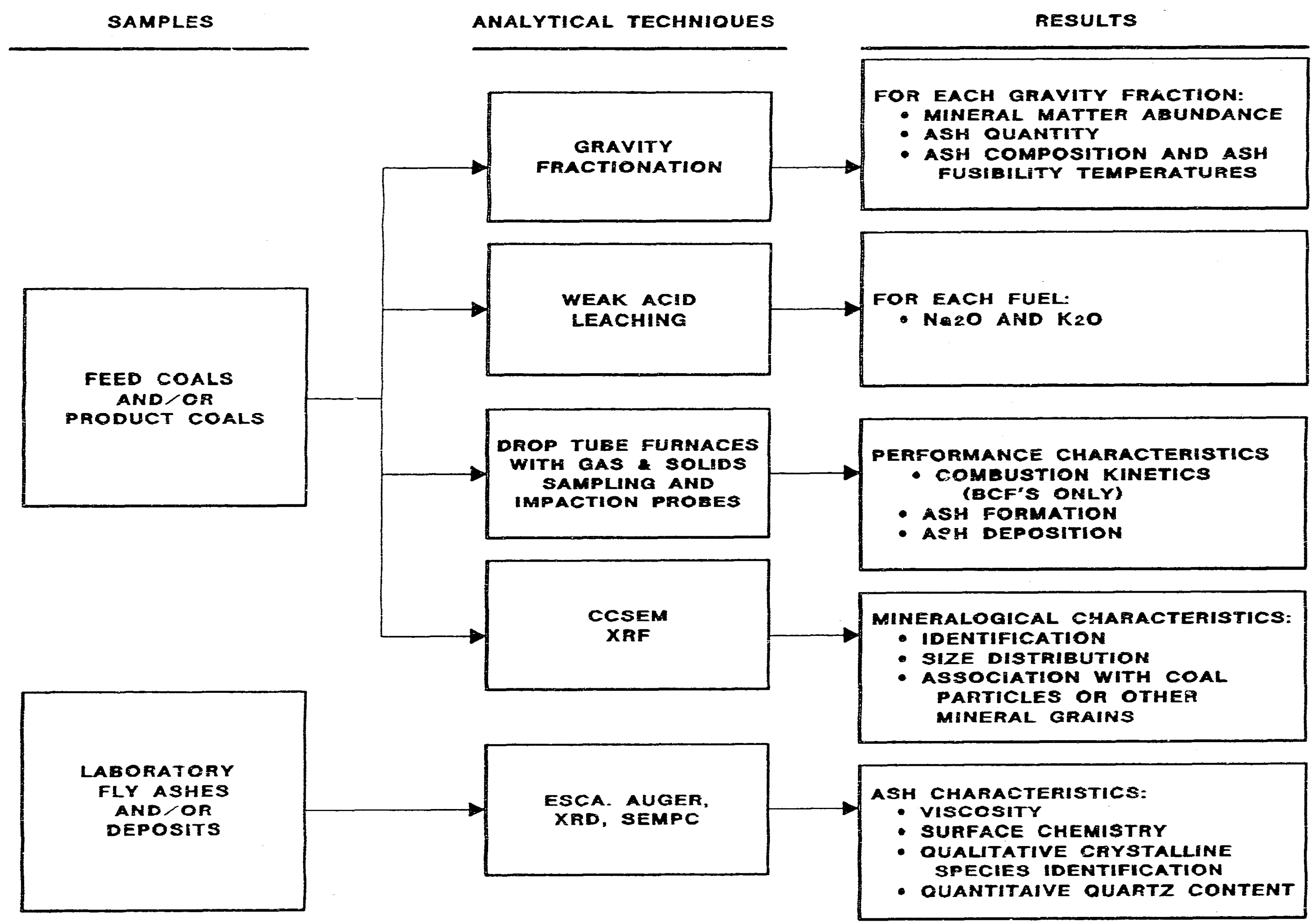


FIGURE 1

Table 1.1

ASTM STANDARD ANALYSES OF FEED COALS AND THEIR MFPs*

QUANTITY	ILLINOIS #6 hvCb		PITTSBURGH #8 hvAb		UPPER FREEPORT mvb	
	FEED COAL	MFP	FEED COAL	MFP	FEED COAL	MFP
Proximate (Wt.%)						
Volatile Matter	38.6	40.4	38.9	41.6	28.1	27.4
Fixed Carbon	52.4	55.4	51.6	55.1	61.2	67.2
Ash	9.0	4.2	9.5	3.3	10.7	5.4
HHV (Btu/lb)	12675	13185	13025	14030	13615	14525
Ultimate (Wt.%)						
Hydrogen	5.0	4.8	5.0	5.4	4.7	5.1
Carbon	69.3	75.5	71.4	77.3	76.9	81.3
Sulfur	3.0	2.7	4.5	3.3	1.8	1.3
Nitrogen	1.3	1.0	1.2	1.4	1.3	1.5
Oxygen	12.4	11.8	4.6	5.4	8.4	9.3
Ash	9.0	4.2	9.5	3.3	10.7	5.4
Carbon/Ash Ratio	7.7	18.0	7.5	23.4	7.2	15.1
Forms of Sulfur (Wt.%)						
Pyritic	0.53	0.09	1.34	0.05	0.49	0.05
Sulfate	0.35	0.40	0.55	0.56	0.44	0.51
Organic	2.12	2.2	2.72	2.74	0.76	0.78
Ash Fus. Temps. (RED. ATM)						
IDT (°F)	2000	2020	2130	1900	2010	1960
ST (°F)	2280	2180	2390	1980	2380	2120
HT (°F)	2420	2230	2440	2020	2450	2380
FT (°F)	2530	2280	2490	2120	2400	2430
Ash Composition (Wt.%)						
SiO_2	51.7	42.0	39.3	34.1	43.8	41.0
Al_2O_3	20.7	19.3	20.2	22.3	24.2	25.1
Fe_2O_3	16.9	21.2	31.4	27.7	18.8	18.1
CaO	2.2	3.7	3.0	4.6	3.1	3.3
MgO	0.9	1.4	0.8	1.3	0.9	1.2
Na_2O	0.5	2.3	0.5	2.2	0.3	1.6
K_2O	2.0	2.3	1.5	1.6	2.2	2.6
TiO_2	0.8	2.2	1.0	1.8	0.9	2.0
P_2O_5	0	0.1	0.1	0.2	0.2	0.2
SO_3	2.1	3.4	2.1	3.2	3.9	3.1

* All analyses are reported on dry basis
MFP = Microbubble Flotation Product

Table 1.2

ASTM STANDARD ANALYSES OF FEED COALS AND THEIR SOAPs*

QUANTITY	ILLINOIS #6 hvCb		PITTSBURGH #8 hvAb		UPPER FREEPORT mvb	
	FEED COAL	SOAP	FEED COAL	SOAP	FEED COAL	SOAP
Proximate (Wt.%)						
Volatile Matter	38.3	42.9	37.3	41.7	24.8	30.5
Fixed Carbon	46.6	52.8	53.1	53.9	51.9	64.3
Ash	15.4	4.3	9.6	4.4	23.3	5.2
HHV (Btu/lb)	12222	13880	13635	14720	11764	14395
Ultimate (Wt.%)						
Hydrogen	4.8	5.8	5.0	5.6	3.8	4.7
Carbon	67.9	75.7	75.5	79.1	65.3	81.2
Sulfur	3.7	2.8	2.6	1.9	3.8	1.5
Nitrogen	1.3	1.5	1.4	1.6	1.2	1.4
Oxygen	7.2	9.9	5.9	6.0	2.6	7.4
Ash	15.4	4.3	9.6	4.4	23.3	5.2
Carbon/Ash Ratio	4.4	17.6	7.9	18.0	2.8	15.6
Forms of Sulfur (Wt.%)						
Pyritic	1.57	0.37	1.46	0.17	2.33	0.08
Sulfate	0.10	0.02	0.03	0.51	0.04	0.31
Organic	1.98	2.41	1.14	1.43	1.40	0.91
Ash Fus. Temps. (RED. ATM)						
IDT (°F)	2086	1850	2020	2000	2090	2100
ST (°F)	2287	1910	2169	2160	2281	2150
HT (°F)	2388	1950	2243	2200	2369	2190
FT (°F)	2510	2000	2360	2450	2453	2300
Ash Composition (Wt.%)						
SiO_2	50.6	40.2	41.2	38.7	46.8	41.2
Al_2O_3	19.7	19.9	19.6	24.1	21.1	24.5
Fe_2O_3	16.4	25.6	18.9	19.7	20.1	19.2
CaO	4.1	3.4	7.1	5.3	3.1	3.3
MgO	0.9	1.4	1.3	1.4	1.0	1.2
Na_2O	0.8	1.6	0.7	1.1	0.3	1.6
K_2O	2.1	2.4	3.5	1.6	2.7	2.5
TiO_2	1.0	2.5	0.9	1.7	0.9	1.9
P_2O_5	0.2	0.2	1.6	0.4	0.4	0.3
SO_3	2.7	2.0	5.0	3.9	2.4	2.7

* All analyses are reported on dry basis
SOAP = Spherical Oil Agglomeration Product

Fuel	Flammability Index °F (200x0 mesh)	(325x0 mesh)
Upper Freeport mvb Coal	1060	1060
Upper Freeport MFP	850	840
Upper Freeport SOAP	895	865
Illinois #6 hvCb Coal	950	950
Illinois #6 MFP	850	840
Illinois #6 SOAP	850	840
Pittsburgh #8 hvAb Coal	940	920
Pittsburgh #8 MFP	850	850
Pittsburgh #8 SOAP	895	865

Comparatively, the FI results in the CE data bank show 800-950°F for lignites, 900-1050°F for subbituminous coals, 1050-1250°F for bituminous coals and 1450-1700+°F for anthracites. As such, the present results indicate two important things: (1) the two particle size fractions used gave essentially the same FI values, implying that they can be used interchangeably, as far as this test is concerned; and (2) each of the feed coals and BCFs has good ignitibility characteristics and should not cause ignitibility/flame turndown problems under normal pulverized-fuel firing conditions.

Weak Acid Leaching (WAL)

This test is designed to determine the concentrations of alkali metals in an ash sample, which are leachable by a weak acid. Results are indicative of volatilizable alkali metals, which are known to contribute to ash fouling. Results obtained from this study are as follows:

Fuel	Alkali Metals in Ash, Wt.%				Volatilizable	
	ASTM Method		WAL Method		Alkali Metals, Wt.%	
	(Na_2O)	(K_2O)	(Na_2O)	(K_2O)	(Na_2O)	(K_2O)
UF mvb	0.3	2.2	0.1	0.1	33	5
UF MFP	1.6	2.6	0.9	0.1	35	6
UF SOAP	0.5	3.2	0.3	0.1	60	3
Pitts #8 hvAb	0.5	1.5	0.2	0.1	40	6
Pitts #8 MFP*	---	---	---	---	--	-
Pitts #8 SOAP	1.1	1.6	0.7	0.1	64	6
Ill #6 hvCb	0.5	2.0	0.3	0.1	60	5
Ill #6 MFP*	---	---	---	---	--	-
Ill #6 SOAP	1.6	2.4	1.0	0.2	63	8

*Data Analysis Incomplete

These results show enrichments of alkali metals in the BCF products, compared with their respective coal feed stocks. Thus, they indicate that the BCFs would have higher fouling potentials. The exacerbation of the BCF ash fouling may, however, be tempered by the fact that these BCFs have much lower ash contents than their feed stock counterparts.

Reactivities and Physical Characteristics of Test Fuel Chars

CE normally conducts TGA and BET tests on 200x400 mesh char samples. The rationale for including 325x0 mesh char samples in this study is from the fact that the microbubble process produces, by design, very fine products (73% -325 mesh, 75% -325 mesh (i.e., 45 micron) and 87% -325 mesh for Upper Freeport, Pittsburgh #8 and Illinois #6 products, respectively), as shown below.

Screen Size, X (Micron)	Weight Percent Greater than X		
	(Upper Freeport MFP)	(Pittsburgh #8 MFP)	(Illinois #6 MFP)
1180	0.1	---	---
600	0.2	---	0.1
300	0.6	0.4	0.4
150	5.0	3.0	3.3
75	19.5	11.0	8.6
45	27.5	25.3	12.7

The TGA results from this study are presented in Figures 2 and 3 along with those obtained previously on chars prepared from reference coals with which CE has field experience. The BET data are shown below.

DOE Fuels	BET Surface Area of Char, m^2/g(daf)	
	(200x400 mesh)	(325x0 mesh)
Upper Freeport Coal	23.6	28.8
Upper Freeport MFP	17.8	32.1
Upper Freeport SOAP	35.4	55.0
Illinois #6 Coal	33.1	32.5
Illinois #6 MFP	31.0	39.4
Illinois #6 SOAP	42.0	55.0
Pittsburgh #8 Coal	29.3	4[illegible]8
Reference Coals		
Wyoming subA Coal	64.0	--
W. Virginia mvb Coal	11.9	--
Pennsylvania Anthracite	2.6	--

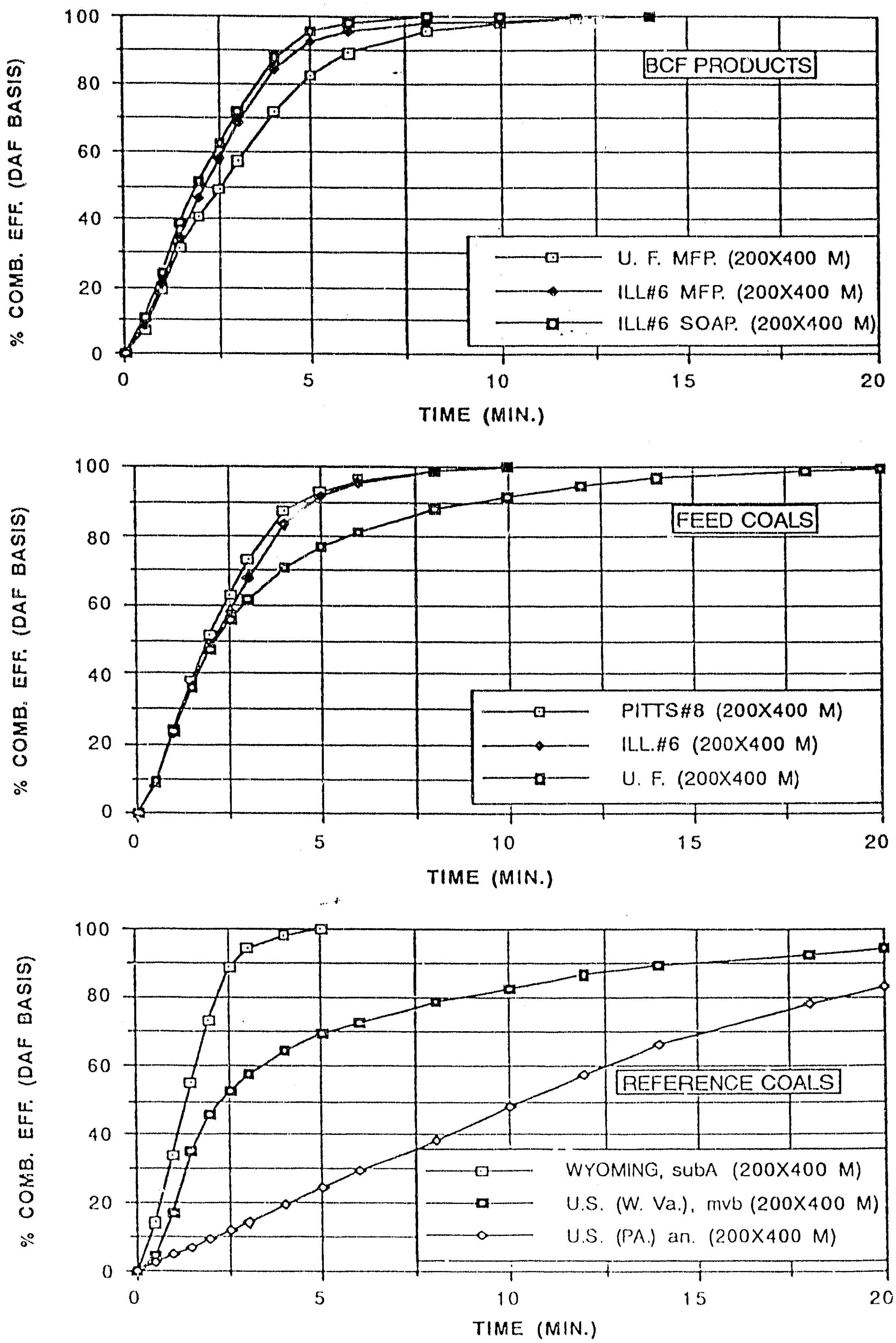


FIGURE 2 TGA BURN-OFF CURVES IN AIR AT 700°C FOR BCF AND REFERENCE COAL CHARS SIZED TO 200X400 MESH

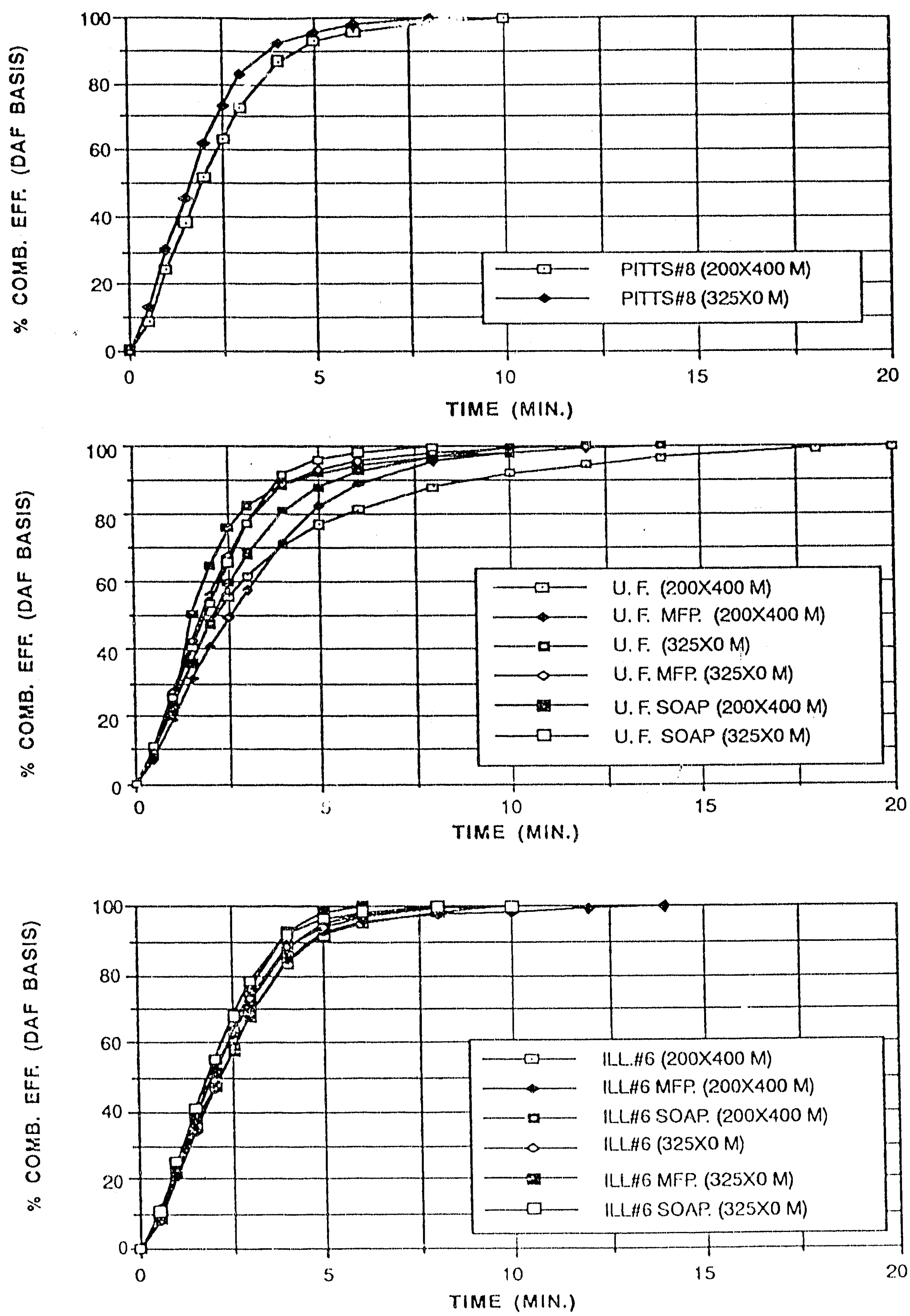


FIGURE 3 TGA BURN-OFF CURVES IN AIR AT 700° C FOR BCF CHARS SIZED TO 200X400 MESH AND 325X0 MESH

The TGA burn-off curves indicate that: (1) the microbubble flotation and spherical oil agglomeration coal cleaning processes did not adversely affect the reactivities of Illinois #6 and Upper Freeport coal chars; (2) the impact of particle size on reactivity is more pronounced for the least reactive coal char (i.e., the one prepared from the Upper Freeport coal); and (3) all the chars studied to date are considered to have good combustion reactivities (they are all significantly more reactive than a char prepared from a West Virginia medium volatile bituminous coal, which is successfully burned in a CE utility boiler). The BET specific pore surface areas given above are generally in support of the TGA burn-off curve results.

Thus, these results indicate that beneficiated coal-based products prepared by the microbubble flotation process are much finer (over 90% -200 mesh) than a normal commercial boiler grind of pulverized coal (~70% - 200 mesh). The microbubble flotation and spherical oil agglomeration cleaning processes led to significant reductions in ash and pyritic contents and increases in calorific values of Illinois #6, Pittsburgh #8 and Upper Freeport coals. However, these processes did not appear to materially improve the qualities of the BCF ashes, due perhaps to selective removal of certain mineral species and enrichment of others. Neither cleaning process appears to have adversely affected the ignitibility/flame turndown and reactivity characteristics of the beneficiated coal-based products studied to date.

Mineralogical Characteristics of Test Fuels at UNDEERC

The Loss on ignition (LOI), ash fusion, and initial XRF analyses of the specific gravity fractions of the Upper Freeport and Pittsburgh No. 8 parent coals were completed by EERC. Tables 2 and 3 list the yield, ash content, composition, and ash fusion temperatures of the specific gravity fractions of the Upper Freeport and Pittsburgh No. 8 parent coals. Similar data for the Illinois No. 6 parent and MFP fuels is given in the February through April 1990 quarterly technical progress report.

Although XRF was run on all of the samples listed in Tables 2 and 3, the data for the Upper Freeport 2.5 float, 2.9 float, and 2.9 sink, and the Pittsburgh No. 8 2.9 float and 2.9 sink could not be reduced because the iron contents of those samples is so high that no standard was available to allow the appropriate corrections to be applied, A solution to the problem is being pursued. Also, ash fusion temperatures could not be determined for the Pittsburgh No. 8 2.9 sink fraction because not enough sample was available. Ash fusion temperatures for the 2.9 float samples could not be determined because the ash cones densified and shrank uniformly rather than melting.

A comparison of the Upper Freeport data in Table 2 with the data from similar analyses performed at CE on the bulk Upper Freeport coal shows that the compositions of the bulk and 1.4 float samples are very similar, with only somewhat less sulfur in the ash of the 1.4 float than in the bulk coal. However, the ash content of the 1.4 float is only half that of the bulk, although the softening temperature (ST) of the 1.4 float ash is 140°F lower than the ST of the bulk.

In contrast, the composition of the Pittsburgh No. 8 1.4 float is significantly reduced in Fe and enriched in Si and Al compared to the bulk coal. The composition of the 1.4 x 2.5 ash is more similar to that of the bulk coal ash than is the 1.4 float ash. The 1.4 x 2.5 ash is somewhat depleted in Fe, but substantially enriched in Ca and S compared to the bulk coal ash. The enrichment of Ca and S may indicate that a portion of the gypsum ($CaSO_4.2H_20$) is excluded from the coal and so could concentrate in the specific gravity fraction that includes the specific gravity of gypsum (sp. gr. ~ 2.3).

Like the Upper Freeport specific gravity fractions, the ash fusion temperatures of the specific gravity fractions of the Pittsburgh No. 8 coals are substantially lower than those of the parent coal. The ST of the 1.4 float ash is 300°F lower than that of the bulk coal ash, whereas the ST of the 1.4 x 2.5 fraction is 340°F lower.

TABLE 2

ANALYSES OF SPECIFIC GRAVITY FRACTIONS OF THE UPPER FREEPORT PARENT COAL

Specific Gravity				
Fraction	< 1.4	1.4-2.5	2.5-2.9	> 2.9
Yield (Wt. %)	87.9	10.2	1.1	0.8
Ash (Wt. %, MF[1])	5.1	5.1	53.7	67.6
Composition (Wt.%)[2]				
SiO_2	43.7	ND[4]	ND[4]	ND[4]
Al_2O_3	27.0			
Fe_2O_3	18.0			
TiO_2	2.1			
P_2O_5	0.2			
CaO	2.7			
MgO	1.6			
Na_2O	< 0.5			
K_2O	3.0			
SO_3	1.7			
Closure	100.6			
Ash Fusion (°F)[3]				
IDT	2100	1900	ND[4]	2050
ST	2240	1950		2120
HT	2300	2180		2240
FT	2340	2290		2380

1. Moisture-free
2. ASTM ash composition (Normalized Wt. %)
3. Reducing atmosphere
4. Not determined

TABLE 3

ANALYSES OF SPECIFIC GRAVITY FRACTIONS OF PITTSBURGH NO. 8 PARENT COAL

Specific Gravity Fraction	< 1.4	1.4-2.5	2.5-2.9	> 2.9
Yield (Wt. %)	83.5	14.9	0.6	1.0
Ash (Wt. %, MF[1])	5.3	23.6	47.4	59.1
Composition (Wt.%)[2]				
SiO_2	44.5	43.6	ND[4]	ND[4]
Al_2O_3	25.6	20.8		
Fe_2O_3	20.0	24.5		
TiO_2	1.4	0.8		
P_2O_5	0.1	0.1		
CaO	3.3	4.4		
MgO	1.3	0.9		
Na_2O	< 0.5	<0.5		
K_2O	2.2	1.6		
SO_3	2.1	4.5		
Closure	100.7	101.8		
Ash Fusion (°F)[3]				
IDT	1990	1890	ND[4]	ND[4]
ST	2090	1950		
HT	2250	2050		
FT	2270	2160		

1. Moisture-free
2. ASTM ash composition (Normalized Wt. %)
3. Reducing atmosphere
4. Not determined

In addition to the specific gravity fractionation work, CCSEM analyses in conjunction with partially automated image analyses of the discrete mineral matter in the Pittsburgh No. 8 and Upper Freeport parent coals were completed long with the CCSEM analyses of the FPTF samples from the combustion tests of those coals. Modifications were made to the FORTRAN program that is used to classify the particles analyzed by the CCSEM. The modifications include additional phases and some tightening of mineral definitions. Also, the output will include the number of particles that were analyzed in each category so that the standard deviation in the data based on counting statistics can be determined easily. This is especially necessary when analyzing the CCSEM data from the cleaned fuels, because the small number of larger particles can contribute greatly to the measured area. The new CCSEM mineral definitions and all previously reported CCSEM data will be rerun through the new program. The rerun data, as well as the data from the analyses of the Pittsburgh No. 8 and Upper Freeport parent coal and FPTF samples, will be reported in the next quarterly report.

The Malvern particle size and XRD (including quantitative quartz) analyses of the ash produced in the drop-tube furnace testing of the Illinois No. 6 parent and MFP, Upper Freeport parent and Pittsburgh No. 8 parent coals were completed. Typical combustion conditions are listed in Table 4. In order to achieve complete combustion of the coals, excess air levels were maintained at several hundred percent.

Figures 4, 5, 6, and 7 show the size distributions of the ash prepared in the drop-tube furnace during testing of the Illinois No. 6 parent, Illinois No. 6 MFP, Upper Freeport parent, and Pittsburgh No. 8 parent samples, respectively. The size distributions were determined by Malvern using ethyl alcohol as a suspending medium.

Table 4

Typical Combustion Conditions Used in the UNDEERC Drop-Tube Furnace System

Coal Feed	- 0.15 g/min
Primary Air	- 0.8 l/min
Secondary Air	- 3.2 l/min
Secondary Air Preheat	- 1130°C
Upper Furance	- 1500°C
Lower Furnace	- 1490°C
Residence Time	- 1.2 sec

A comparison of Figures 4 and 5 indicates that the microbubble flotation process caused larger ash particles to form in the drop-tube furnace system than formed from the parent coal. However, the drop-tube ash size distributions for both the Illinois No. 6 parent and MFP fuels are much larger than the size distribution of the FPTF ashes as indicated by CCSEM analyses. Optical microscopic examination of the drop-tube furnace ashes shows that the larger size of the drop-tube ash is real and that a number of large, white cenospheres were present. In other words, the larger size distribution indicated by Malvern is not due to agglomeration of many ash particles into larger masses. The larger size of the drop-tube ash as compared to the FPTF ash may be because of increased coalescence of coal particles during combustion in the drop-tube furnace leading to the formation of larger ash particles, or because the samples collected in the FPTF do not contain the large, heavy particles that dropped out to form the bottom ash. The CCSEM and XRF analyses of the drop-tube ashes that will be performed in the next quarter will indicate which explanation is correct.

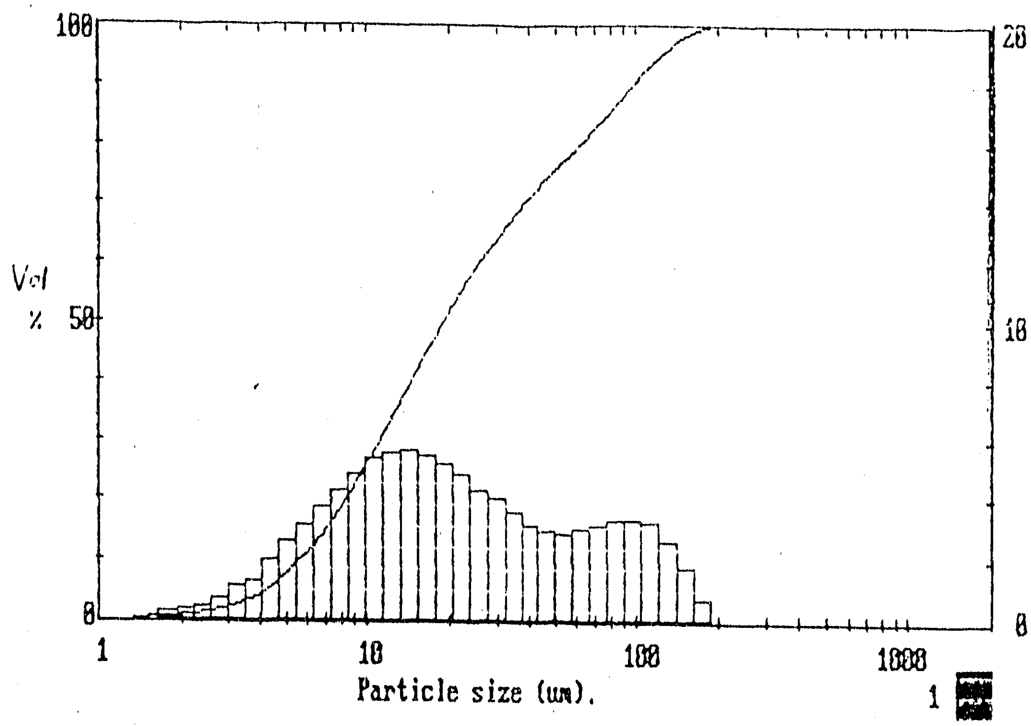


Figure 4. The size distribution of the ash produced during drop-tube furnace testing of the Illinois No. 6 parent coal.

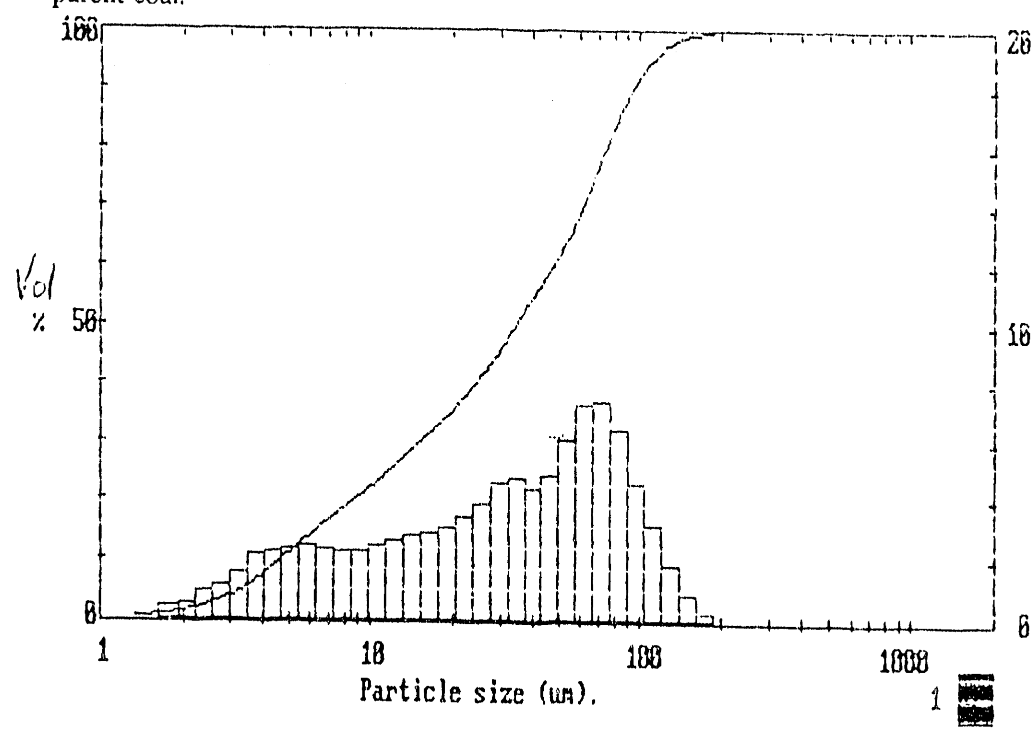


Figure 5. The size distribution of the ash produced during drop-tube furnace testing of the Illinois No. 6 MFP fuel.

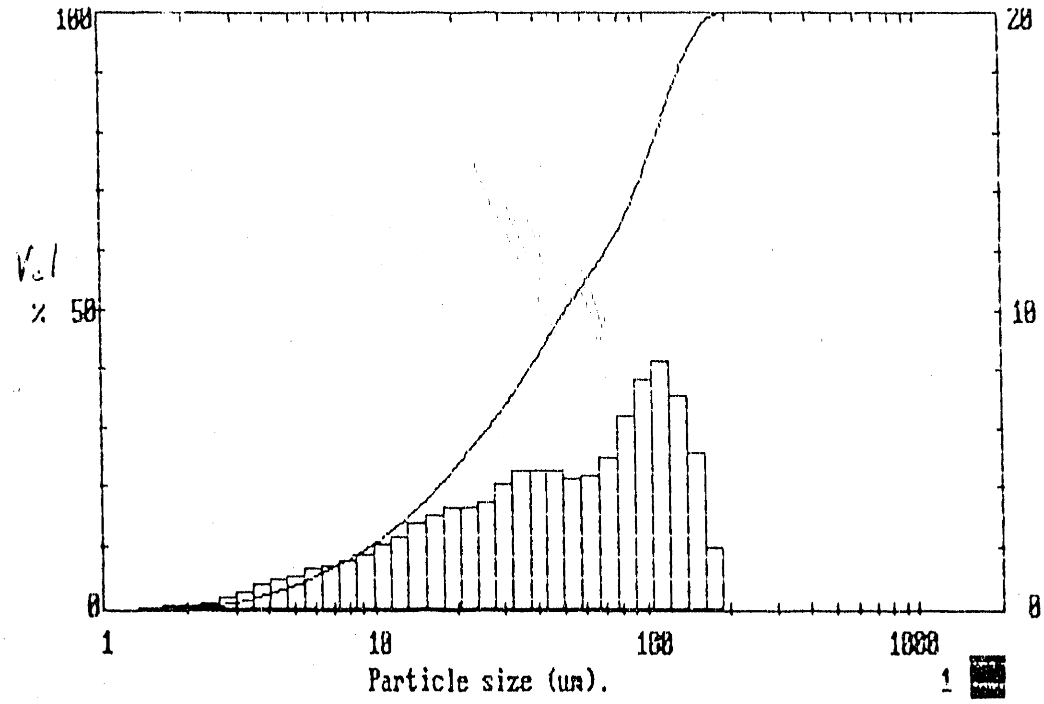


Figure 6. The size distribution of the ash produced during drop-tube furnace testing of the Upper Freeport parent coal.

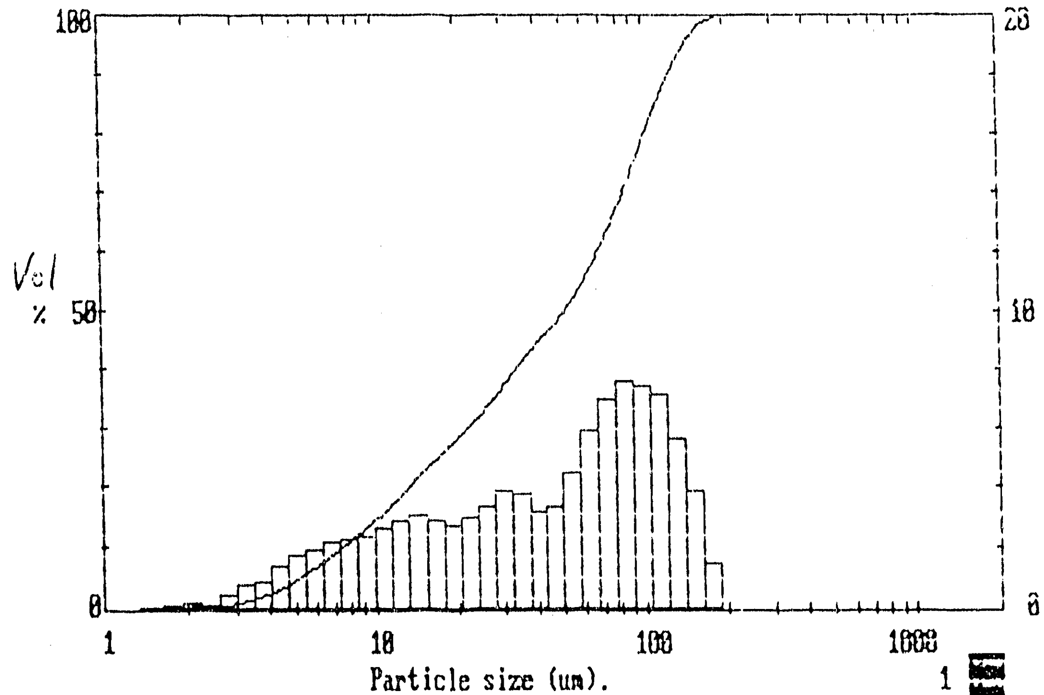


Figure 7. The size distribution of the ash produced during drop-tube furnace testing of the Pittsburgh No. 8 parent coal.

TABLE 5
CRYSTALLINE PHASES AND QUARTZ QUANTITIES IN DROP-TUBE FURNACE ASHES

Coal	Major	Minor	Quartz (Wt. %)
Illinois No. 6 Parent Coal	Maghemite Quartz	Mullite Lime (?)	4.3
Illinois No. 6 MFP	Maghemite	Quartz Mullite (?) Plagioclase (?) Lime (?)	2.5
Upper Freeport Parent Coal	Maghemite	Quartz Mullite Lime (?)	2.3
Pittsburgh No. 8 Parent Coal	Maghemite	Quartz Lime (?)	2.3

In addition to sizing the ash collected during drop-tube furnace testing, the ash was analyzed by XRD to determine the crystalline phases present as well as quantify the amount of quartz present in each of the ashes. Table 5 lists the crystalline phases and quantities of quartz present in each of the samples. The quantities were determined by the reference intensity ratio method using rutile as an internal standard.

The crystalline phases present in the drop-tube furnace ashes are similar to those found in the FPTF in-flame solids samples. The most dominant crystalline species are maghemite (gamma Fe_20_3) and $Si0_2$, with smaller amounts (so small they are questionable in most cases) of mullite, lime, or plagioclase. One phase that is conspicuously absent from the drop-tube furnace samples is hercynite ($FeAl_20_4$), which was found in the Illinois No. 6 MFP FPTF samples as a major phase and in a Pittsburgh No. 8 FPTF sample as a minor phase. This does not mean that there were no interactions between iron containing species and aluminosilicates during drop-tube combustion, but rather that the interactions led to the formation of glasses in the drop-tube samples rather than the crystalline hercynite that was evident in the two FPTF samples.

Drop Tube Furnace Combustion Tests at MIT

Drop-tube tests on the combustion characteristics of the spherical-agglomerated beneficiated Upper Freeport coal were completed during the reporting period. Because of the fine particle size of the beneficiated coal, feeding this fuel into the drop tube furnace was difficult. The coal particles tended to agglomerate and feed as a clump rather than single particles. The coal feeding system of the drop tube was modified to improve the feeding of these samples. A tiny cyclone was installed in the feed line to the drop tube furnace, which captured the agglomerated particles. This arrangement allowed the feeding of clouds of suspended single particles of the beneficiated coal into the furnace.

The samples collected in these experiments will have to be chemically analyzed before the actual carbon burnout can be calculated. However, based on the small particle size, the burnout times are expected to be low.

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.

3.1 Pilot-Scale Atomization, Combustion, and Emissions Tests at MIT

The overhaul and modernization of the existing coal feeding system was completed in May. Level indicators were added throughout the feeding system, and various control systems for feeding were upgraded. Tests of the system with flames on the warm-up coal supplied by Combustion Engineering proved the new feeding system to be operational.

Pilot-scale combustion tests in the MIT Combustion Research Facility flame tunnel began on the raw Upper Freeport coal during the last week of May and were completed in June. The flames were generated using a prototype multi-annular burner. In the design of the new burner, mass flow rates for each of three air supplies, namely primary air, secondary air, and tertiary air, external to the fuel gun, can be independently controlled, and for each supply the swirl can be adjusted over a wide range by means of an independent moveable block swirler. A shroud diffuser is used to maintain physical separation of the secondary and tertiary air jets entering the combustion chamber.

Three flames were established, sampled, and mapped: (1) the base case with 222°C air preheat and 3.5% oxygen in the flue, (2) a case with 215°C air preheat and 2.5% oxygen in the flue, and (3) a low NOx case with 209°C air preheat and 4.5% oxygen in the flue. The surprising thing about all three cases was the low NOx emissions from them: 320, 260, and 200 ppm, respectively (not corrected to equivalent oxygen levels). The burner air flow arrangement was changed for the third test. The burnout appeared to be excellent, with no streakers observed in the exit of the firebox.

CO emissions were also observed to be low; the CO concentration measured in the flue gas for the three cases was ≤50 ppm. However, the carbon burnouts obtained were not very high (~96%). During the experiments, it was observed that large char particles were collected on the filter papers during sampling of the fly ash from the flue gas. It is these particles that are responsible for lowering the carbon burnout levels.

An important conclusion that can drawn from these experiments is the fact that, through proper internal staging of the flame, low NOx emissions as well as high carbon conversion levels are attainable. The NOx emission level from the internally staged flame (Case 3) was lower than that of Case 1 in which similar carbon burnout levels were achieved. Data reduction and analysis on these flames is expected to last through the end of September, 1990.

3.2 Combustion Performance Tests - CE

The combustion and ash performance of nine test fuels have been evaluated in CE's Fireside Performance Test Facility (FPTF) shown in Figure 8. These fuels included Illinois No. 6, Upper Freeport, and Pittsburgh No. 8 microbubble flotation products (MFPs), spherical oil agglomeration products (SOAPs) and their respective parent coals. Since the MFPs were received in wet filter cake form, one was tested as a microfine coal-water fuel (MCWF) and the other two as well as the three SOAPs were tested in dry microfine pulverized coal form (DMPC).

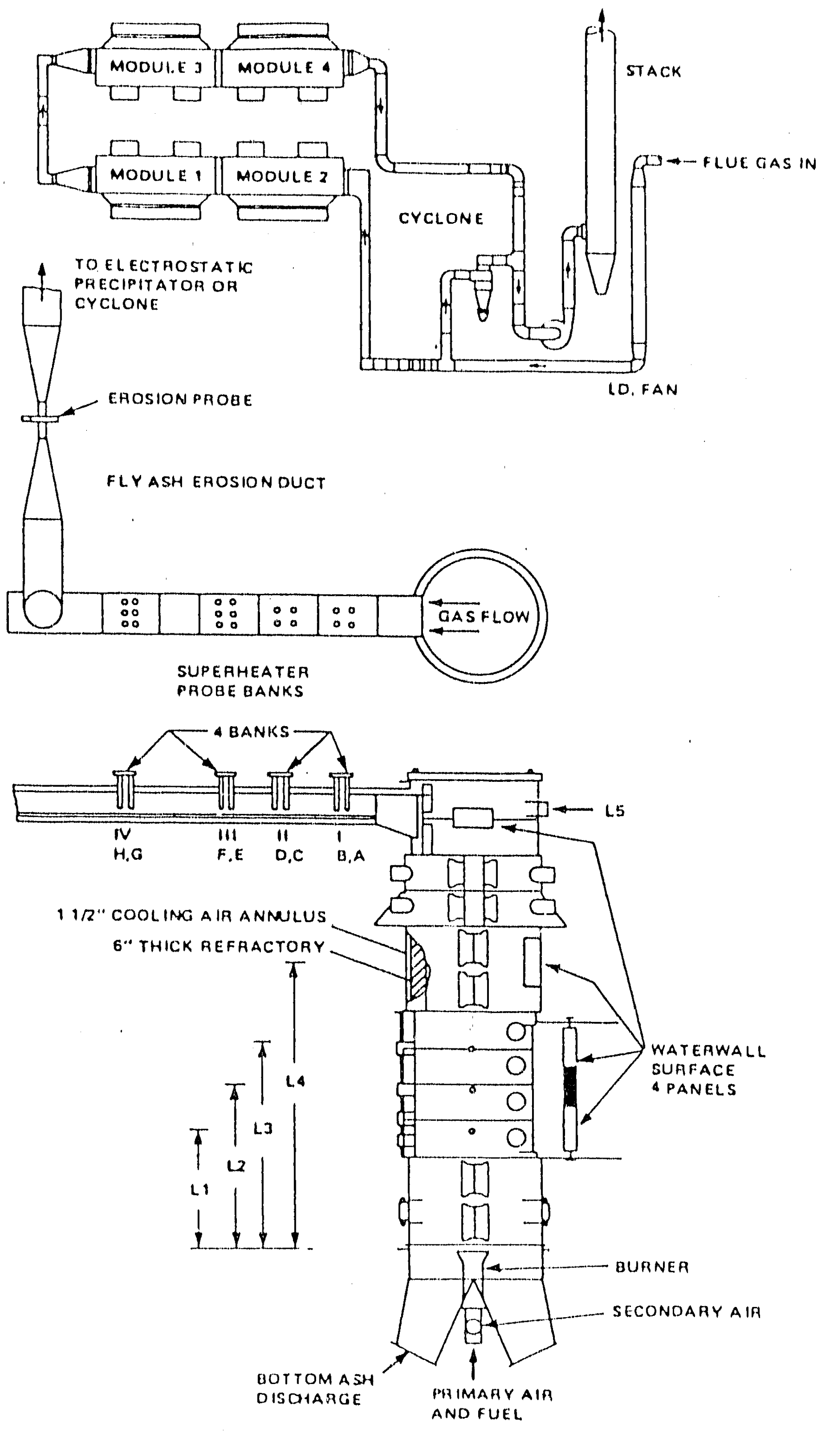


Figure 8 FIRESIDE PERFORMANCE TEST FURNACE

The test conditions for the nine fuels are summarized in Table 6. Firing rates between 3.5 x 10^6 and 4.0 x 10^6 Btu/h were performed at different furnace flame temperatures by varying the secondary air preheat. Each test was conducted with approximately 20% excess air. The Upper Freeport MFP MCWF was preheated to 230°F fuel temperature to improve atomization during testing. Furnace residence times varied from 1.01 sec. to 1.25 sec. The FPTF furnace gas temperature profiles during these tests are illustrated in Figures 9 to 11.

Data obtained from the FPTF on the furnace slagging, convection pass fouling, fly ash erosion and fly ash collectability characteristics of the nine fuels are being analyzed. The preliminary results are summarized below.

Furnace Slagging Characteristics

The FPTF test results indicate that firing the BCFs improved waterwall heat transfer characteristics. However, there was no improvement in deposit cleanability compared to their respective parent coals.

The waterwall Panel 1 heat flux from test runs at 4 x 10^6 Btu/h firing rate and similar gas temperature for the nine fuels are illustrated in Figure 12. During the initial few hours, heat flux decreased with time for each fuel, reflecting deposit accumulation on the waterwall surface. After this period, waterwall heat flux with the parent coals continued to drop, whereas with the BCFs it remained relatively high and constant, indicating the deposit buildup approached steady state and had no further impact on heat transfer.

Soot blowing evaluations conducted at the end of each test run showed that, although the waterwall deposits from the BCFs were thinner than those of the parent coals, their cleanability was not improved. The critical furnace temperatures where deposits were still cleanable by wall blowers remained in the same temperature range as the parent coal for each BCF.

Convection Pass Fouling Characteristics

In general, firing the MFPs produced more tightly bonded deposits, whereas the SOAPs produced deposits with bonding strengths relatively similar to their respective parent coals. Convection tube deposit buildup rates were reduced with most of the BCFs, with the exception of Upper Freeport MFP MCWF. The ash fouling characteristics of the MFPs appeared to be related to their enrichments of alkali and alkaline earth constituents in the ash, as well as the overall lower ash fusibility temperatures due to the relative increases of basic constituents in the ash of each BCF.

Fly Ash Erosion

Firing the BCFs produced significantly less erosion than the parent coals, as shown in Figure 13. These results were due to the reduction in ash loadings and probably selective removal of the more erosive constituents (such as quartz) in the ash. Analysis is ongoing to determine the chemical composition and particle size distribution of the fly ash samples from each fuel.

Fly Ash Collectability

Firing the BCFs generally reduced the ESP collection efficiencies. However, this effect was partially offset by the reduction of ash loading of the BCFs. Bench-scale fly ash resistivity measurements and data reduction are ongoing to better understand the differences between the BCFs and parent coals.

TABLE 6
COMBUSTION PERFORMANCE TEST MATRIX
20% EXCESS AIR

FUEL TYPE	FIRING MODE	FIRING RATE (10^6 Btu/h)	AVG FLAME TEMPERATURE (°F)	TEST DURATION (h)
ILLINOIS #6				
Parent	PC	3.75	2740	12
		4.00	2870	24
		4.00	2980	24
MFP	DMPC	4.00	3030	24
		4.00	2960	24
SOAP	DMPC	3.75	2940	12
		3.50	2900	12
		4.00	3030	24
UPPER FREEPORT				
Parent	PC	3.75	2910	12
		4.00	2990	24
MFP	MCWF	4.00	2970	20
SOAP	DMPC	4.00	3010	24
		3.75	2930	24
PITTSBURGH #8				
Parent	PC	3.75	2920	12
		4.00	2990	12
		3.50	2860	12
MFP	DMPC	3.75	2960	24
		4.00	2980	24
SOAP	DMPC	3.75	2920	12
		4.00	2980	24

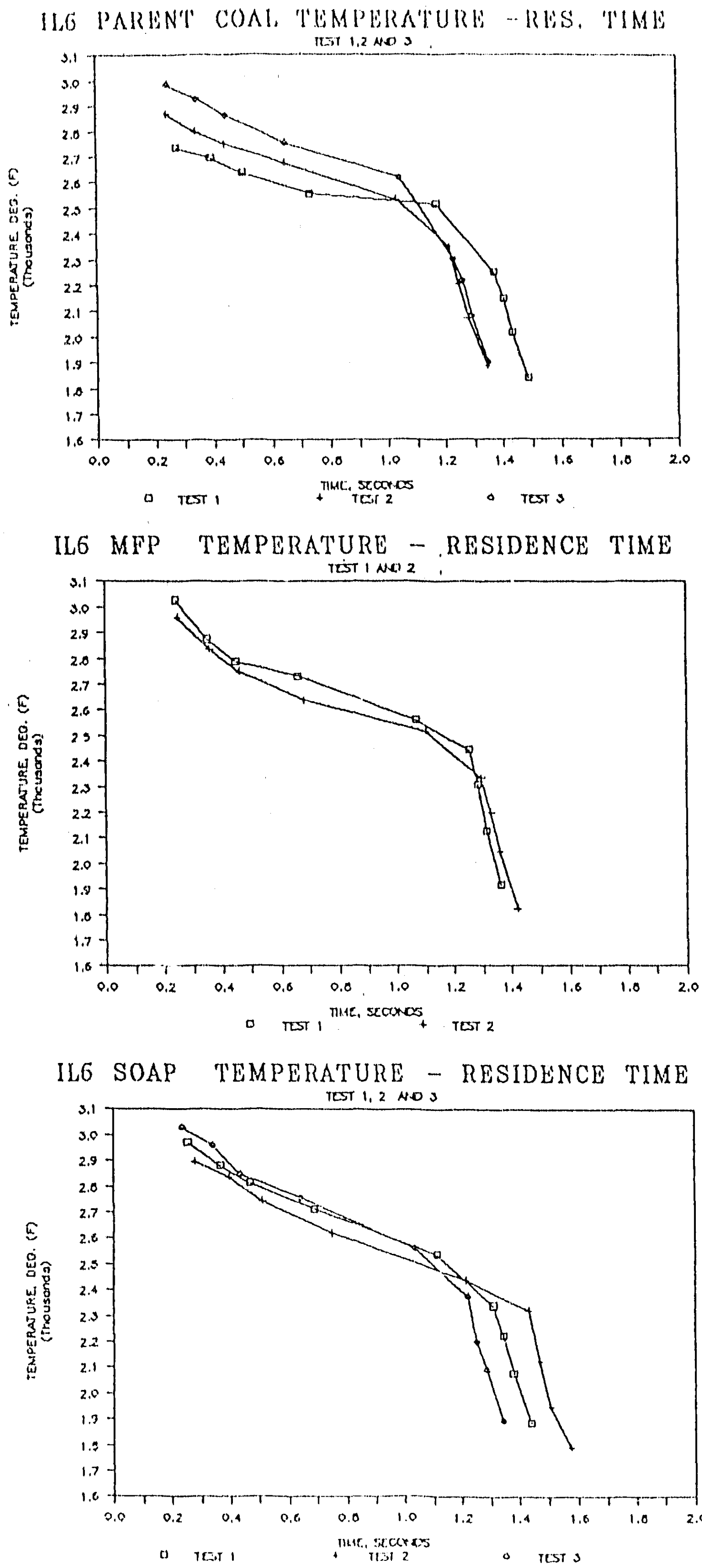
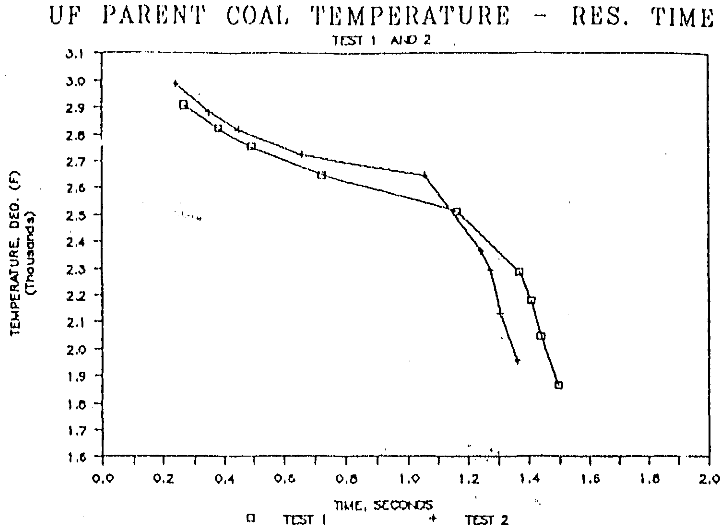
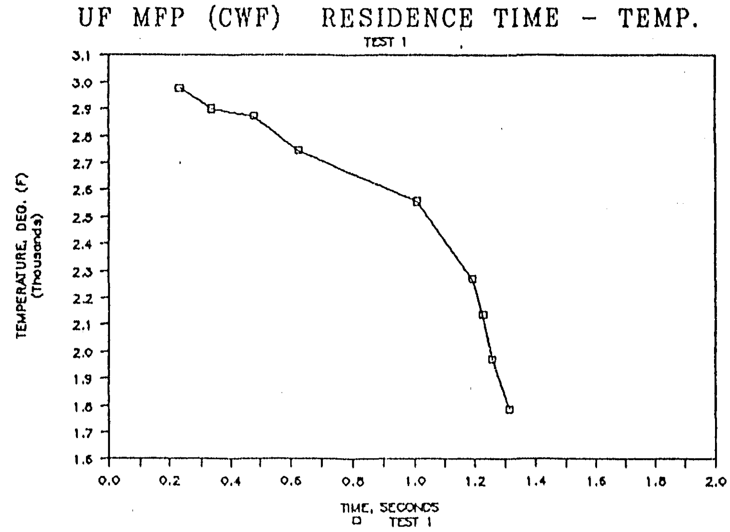

IL6 PARENT COAL TEMPERATURE -RES. TIME
TEST 1,2 AND 3
TEMPERATURE, DEG. (F) (Thousands)
TIME, SECONDS
TEST 1
TEST 2
TEST 3
IL6 MFP TEMPERATURE - RESIDENCE TIME
TEST 1 AND 2
TEMPERATURE, DEG. (F) (Thousands)
TIME, SECONDS
TEST 1
TEST 2
IL6 SOAP TEMPERATURE - RESIDENCE TIME
TEST 1, 2 AND 3
TEMPERATURE, DEG. (F) (Thousands)
TIME, SECONDS
TEST 1
TEST 2
TEST 3

FIGURE 9


UF PARENT COAL TEMPERATURE - RES. TIME
TEST 1 AND 2
TEMPERATURE, DEG. (F)
(Thousands)
3.1
3.0
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
TIME, SECONDS
TEST 1
TEST 2


UF MFP (CWF) RESIDENCE TIME - TEMP.
TEST 1
TEMPERATURE, DEG. (F)
(Thousands)
3.1
3.0
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
TIME, SECONDS
TEST 1

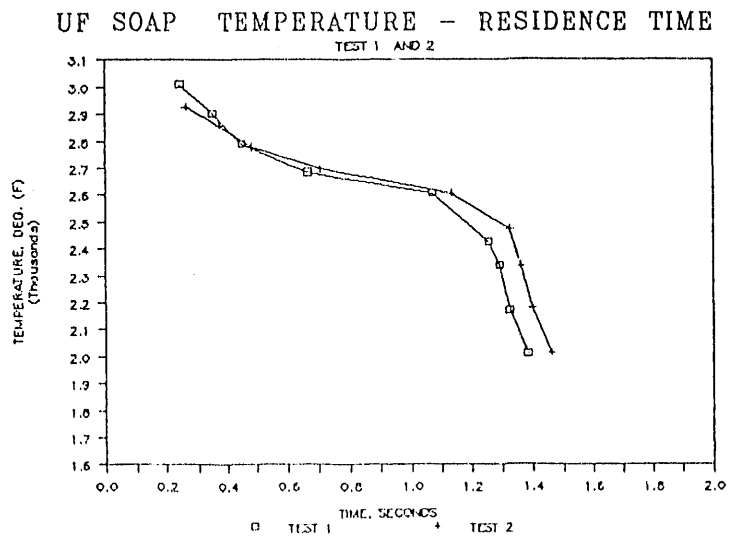
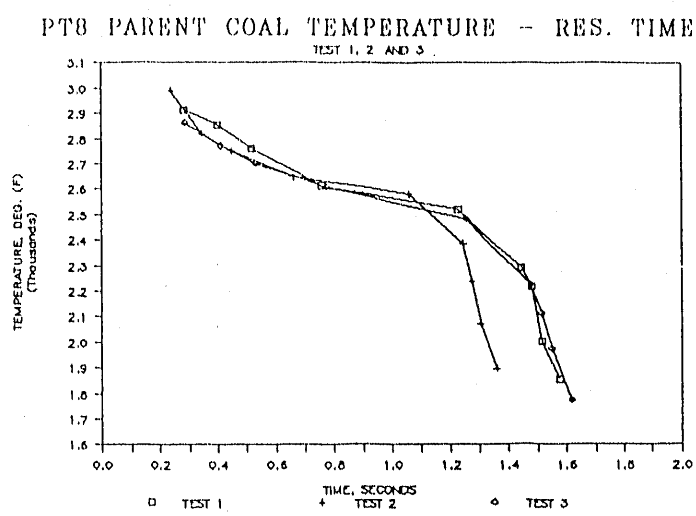
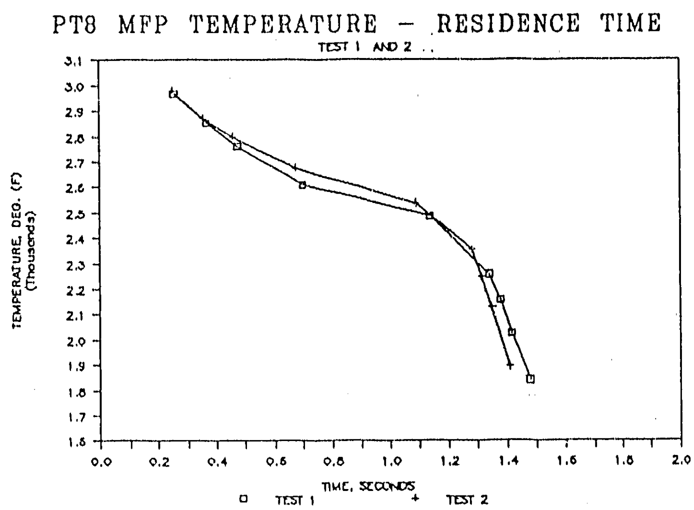

UF SOAP TEMPERATURE - RESIDENCE TIME
TEST 1 AND 2
TEMPERATURE, DEG. (F)
(Thousands)
3.1
3.0
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
TIME, SECONDS
TEST 1
TEST 2

FIGURE 10


PT8 PARENT COAL TEMPERATURE – RES. TIME
TEST 1, 2 AND 3
TEMPERATURE, DEG. (F)
(Thousands)
TIME, SECONDS
TEST 1
TEST 2
TEST 3


PT8 MFP TEMPERATURE – RESIDENCE TIME
TEST 1 AND 2
TEMPERATURE, DEG. (F)
(Thousands)
TIME, SECONDS
TEST 1
TEST 2

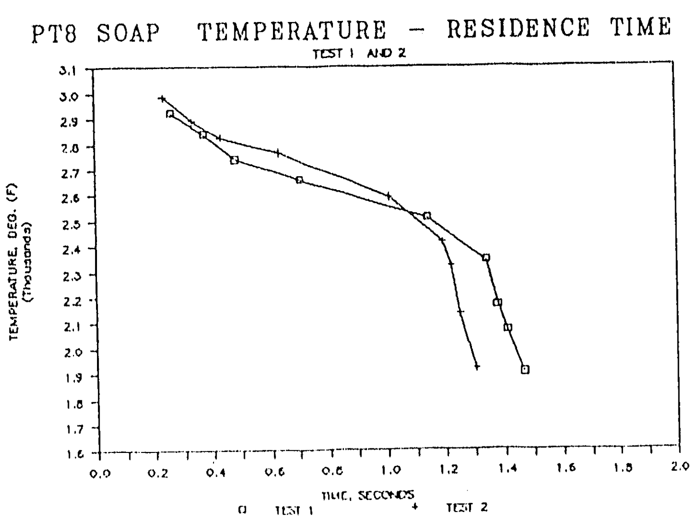

PT8 SOAP TEMPERATURE – RESIDENCE TIME
TEST 1 AND 2
TEMPERATURE, DEG. (F)
(Thousands)
TIME, SECONDS
TEST 1
TEST 2

FIGURE 11

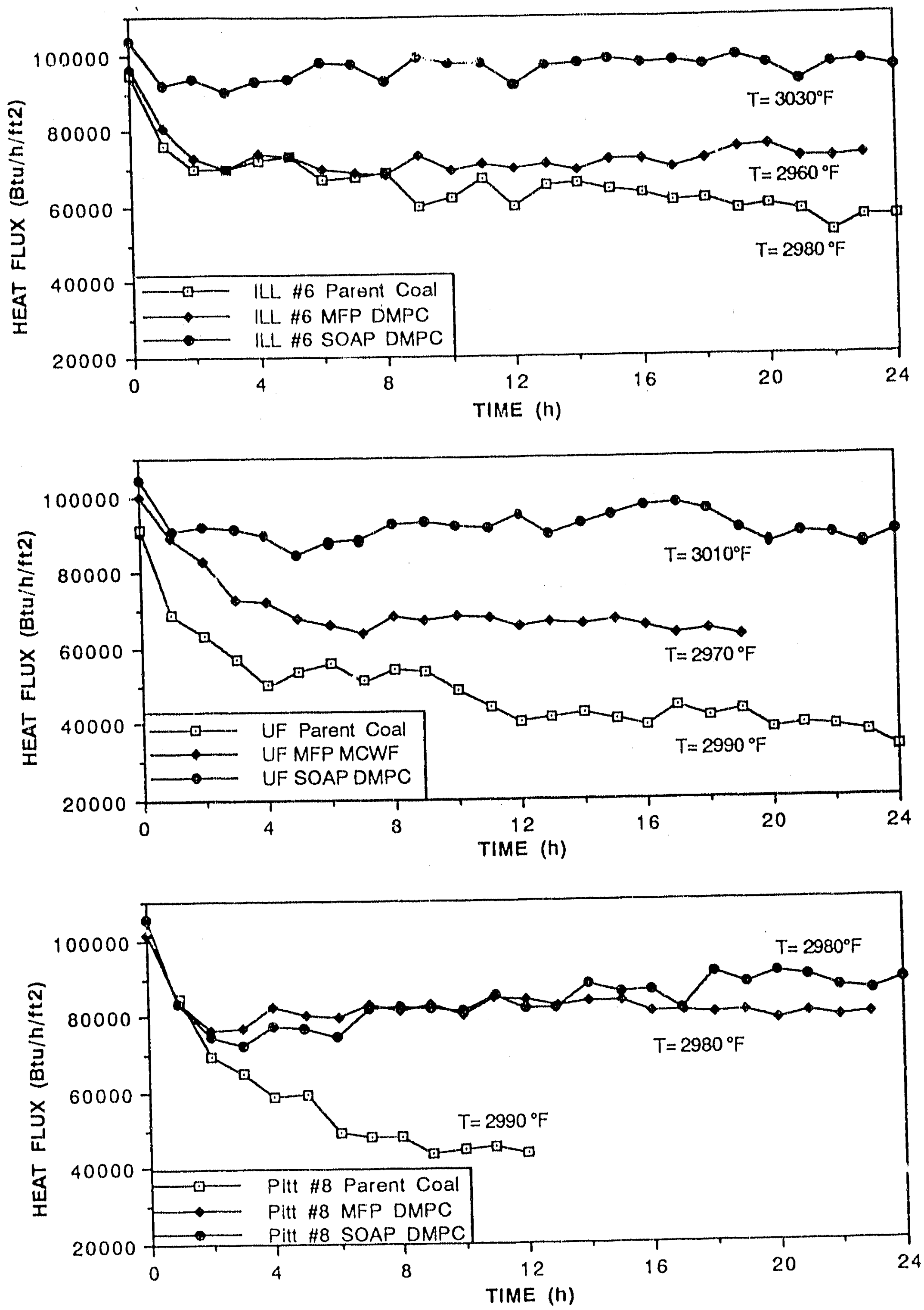
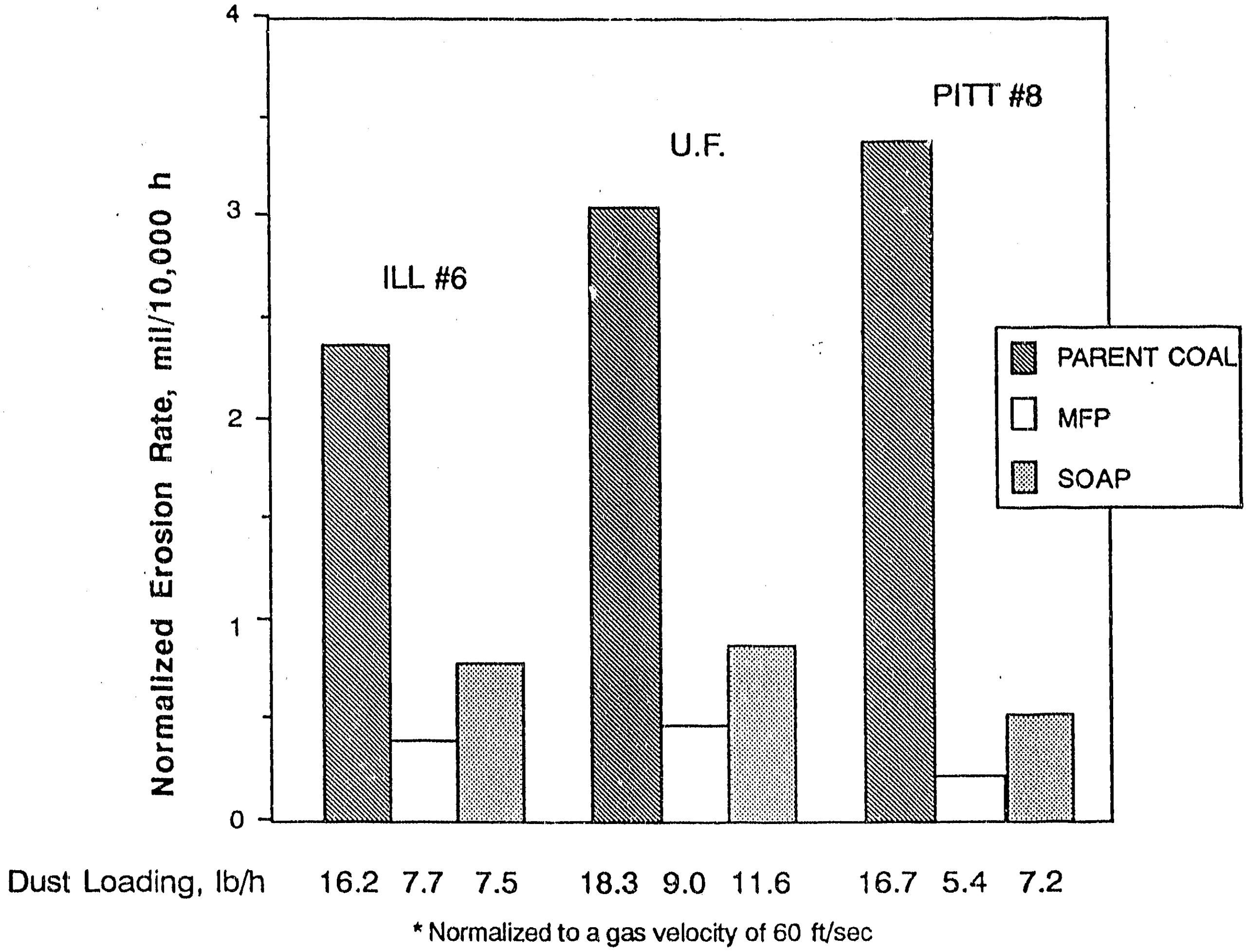


FIGURE 12

COMPARISON OF WATERWALL HEAT TRANSFER CHARACTERISTICS BETWEEN BCFs AND PARENT COALS AT $4x10^6$ Btu/h



Comparison of Fly Ash Erosion Between BCFs and Parent Coals

FIGURE 13

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 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 were submitted to the DOE.

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 continued.

WORK PLANNED FOR NEXT QUARTER

- Continue standard bench-scale tests.
- Continue drop tube furnace tests at CE and UND.
- Analyze data from pilot-scale combustion tests and ash deposition tests.
- Complete report describing the Task 5 boilers.

END

DATE FILMED

6/12/92