SANDIA REPORT

SAND95-8250 • UC-1409
Unlimited Release
Printed July 1995

Coal Char Fragmentation During Pulverized Coal Combustion

L. L. Baxter

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94551
for the United States Department of Energy
under Contract DE-AC04-94AL85000

Approved for public release; distribution is unlimited.

SF2900Q(8-81)

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.
NOTICE: This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of the contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government, any agency thereof or any of their contractors or subconractors. The views and opinions expressed herein do not necessarily state or reflect those of the United States Government, any agency thereof or any of their contractors or subcontractors.

This report has been reproduced from the best available copy.

Available to DOE and DOE contractors from:

Office of Scientific and Technical Information
P. O. Box 62
Oak Ridge, TN 37831

Prices available from (615) 576-8401, FTS 626-8401

Available to the public from:

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Rd.
Springfield, VA 22161

UC-1409

SAND95-8250
Unlimited Distribution
Printed July 1995

COAL AND CHAR FRAGMENTATION DURING PULVERIZED COAL COMBUSTION

Milestone Report

Larry L. Baxter
Combustion Research Facility
Sandia National Laboratories
Livermore, CA 94551-0969

Abstract

A series of investigations of coal and char fragmentation during pulverized coal combustion is reported for a suite of coals ranging in rank from lignite to low-volatile (lv) bituminous coal under combustion conditions similar to those found in commercial-scale boilers. Experimental measurements are described that utilize identical particle sizing characteristics to determine initial and final size distributions. Mechanistic interpretation of the data suggest that coal fragmentation is an insignificant event and that char fragmentation is controlled by char structure. Chars forming cenospheres fragment more extensively than solid chars. Among the chars that fragment, large particles produce more fine material than small particles. In all cases, coal and char fragmentation are seen to be sufficiently minor as to be relatively insignificant factors influencing fly ash size distribution, particle loading, and char burnout.

This work was supported by the U.S. Department of Energy, Office of Fossil Energy, Pittsburgh Energy Technology Center, Advanced Research and Technology Development Program.

Introduction

Char fragmentation and flyash formation during pulverized-coal combustion impact important aspects of boiler operation including radiative heat transfer, fouling and slagging propensities, and particulate removal efficiency. Flyash that escapes particle cleanup systems constitutes a significant environmental and health hazard and is the focus of substantial legislation and regulation [Wark and Warner, 1981]. These practical, environmental, health, and legal considerations have motivated a number of theoretical and experimental studies of flyash formation.

Reported mechanisms of flyash formation include (1) vaporization and recondensation of volatile components of coal ash [Flagan, 1978; Flagan and Taylor, 1980; Neville, et al., 1980; Neville and Sarofim, 1985; Quann, et al., 1982; Quann, et al., 1990; Quann and Sarofim, 1982; Quann and Sarofim, 1986], (2) fragmentation of ash due to inorganic reaction [Baxter and Mitchell, 1992; Raask, 1984; Raask, 1985], (3) convective transport of ash during rapid organic reaction [Allen and VanderSande, 1984; Baxter, et al., 1994 (to appear)], (4) structural disintegration of chars [Flagan and Sarofim, 1984], (5) shedding of ash material from the surface of chars during combustion [Allen and VanderSande, 1984; Quann, et al., 1982; Quann and Sarofim, 1982], and (6) coalescence of ash within a char particle [Allen and VanderSande, 1984; Baxter, 1992; Quann and Sarofim, 1982].The term *fragmentation,* as used in this paper, encompasses all mechanisms that produce more than a single ash particle from a char particle and could involve any or all of the above processes.

Several mechanistic details of fragmentation are available in theoretical papers. Statistical studies ranging from number balances [Dunn-Rankin and Kerstein, 1987; Dunn-Rankin and Kerstein, 1988] to percolation models [Kang, et al., 1988; Kang, et al., 1990; Kerstein and Edwards, 1987] describe the transient development of char particle size distributions, often for a series of assumed scenarios of fragmentation. These models vary widely in their level of detail, although none describes all aspects of fragmentation and parameters used in the models do not always lend themselves to experimental measurement. While progress in this area continues, there exist no complete descriptions of fragmentation in the available literature.

Experimental techniques for studying fragmentation include both solidsampling and laser-based, in situ techniques. Typical solid-sampling studies involve size classification of flyash by a cascade of impactors. Feed material and equipment used in these studies range from mechanically classified samples of coal entrained in laminar flow facilities [Quann and Sarofim, 1982] to utility grind coal sampled from boiler ducts [Holve, 1986]. In situ techniques reported in the past [Wibberley and Wall, 1986] have also been used in laminar flow facilities. Results from various experiments appear discrepant when examined superficially. For example, the reported number of flyash particles generated per char particle varies from near one [Holve, 1986; Sarofim, et al., 1977; Wibberley and Wall, 1986] to several tens of thousands [Quann and Sarofim, 1982; Quann and Sarofim, 1986]. As will be illustrated, these discrepancies may be more superficial than actual. None of these investigations used the same analysis technique to characterize both the feed material and the flyash under combustion conditions representative of commercial boilers.

Specific objectives of this investigation are to (1) devise a fragmentation model that is sufficiently complete to analyze data collected from systems using utility grind coal as a feedstock, (2) measure experimentally the initial and final particle size distributions using the same in situ diagnostic and under conditions comparable to commercial scale operation, and (3) combine the theory and experiment to determine the extent of char fragmentation.

One of the unique aspects of these investigations is the use of the same *in situ* sizing technique to determine both char and fly ash particle sizes. Experiments are conducted in the Multifuel Combustor (MFC) using utility-grind, pulverized coal in an environment simulating that of a utility-scale boiler. Size distributions are measured immediately after coal devolatilization and at the end of char combustion (greater than 99% daf burnout as determined from tracer analysis of solid samples).

The extent of char fragmentation, as indicated by the number of fly ash particles formed per char particle, is found to depend on (in order of importance): (1) char structure, (2) initial char particle size, (3) ash content, and (4) mineral grain size distribution. The first three dependencies are clearly indicated by existing data. The fourth is postulated pending further investigation of mineral grain size distributions in these coal samples.

The analysis of the data collected from the MFC is similar to a previously published model of char fragmentation [Baxter, 1992]. This analysis is briefly reviewed here. The experimental design is also briefly reviewed. The bulk of the discussion centers on the results and their implications.

Theoretical Analysis

The fragmentation model described below relates the initial char (not coal) feedstock and final fly ash size distributions. The model is written in terms that are convenient for laboratory analyses. That is, the char particles have physical properties that can vary as a function of size but, at a given size, are described by a single-valued function. Particle-to-particle variations in physical properties *at a given size* are neglected. Also, transient developments in particle size distributions, as discussed by many of the previously cited authors, are neglected. Size distributions of the initial char and final fly ash can be related, in general, through a particle number balance.

$$\int_{d_{a1}}^{d_a} n'_a(x)\,dx = \int_{d_c=0}^{d_c=\infty}\int_{d_{a1}}^{d_a} g(x|y)\,dx\,n'_c(y)\,dy \tag{1}$$

The functions n'_a and n'_c represent particle concentration density functions for fly ash and char, respectively, with typical units of particles/(m^3 μm). Dummy variables x and y are used in the integrands to represent fly ash (d_a) and char (d_c) particle diameters, respectively. Integration of n' with respect to particle diameter represents the cumulative concentration of particles with sizes between the limits of integration. Thus, the integral on the left represents the total concentration of fly ash particles with diameters larger than d_{a1} and smaller than d_a.

The function $g(x|y)$ is a conditional fly ash particle size distribution (psd); it indicates the *ultimate* size distribution of fly ash particles formed from a char particle with *initial* size y. This represents the only portion of the above equation that is not determined experimentally in this investigation.

Several published theoretical and experimental results suggest general forms of the function. One example [Quann and Sarofim, 1986] provides data from which $g(x|y)$ can be

determined for one char particle size. In that study, coal particles were mechanically sieved to a 140 μm nominal diameter and combusted at a particle temperature of about 2000 K in a 20 % O_2 environment. The number of fly ash particles generated was deduced as a function of fly ash particle size.

The function *g(x|y)* for this literature data [Quann and Sarofim, 1986] can be generated by differentiating the cumulative size distribution with respect to particle size. This is illustrated in Figure 1. The linearity of the data when plotted in this way suggests that the the data follow a power-law distribution, i.e.,

$$g(x|y) = \begin{cases} a(y)x^b, & \text{for } x_1(y) \le x \le x_2(y), \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

where x_1 and x_2 represent the diameters of the smallest and largest fly ash particle generated, respectively. This conditional psd describes a power-law size distribution between the limits x_1 and x_2 for fly ash particles generated from each char particle of size y. Note that this functional form can only describe the results from an ensemble of initial char particles with size y. The functional form of g for a single char particle is series of Dirac delta functions.

Values for a and b of 3260 and -3.21, respectively, fit the literature data [Quann and Sarofim, 1986] with a coefficient of determination [Canavos, 1984] (r^2) greater than 0.99 (in logarithmic coordinates with x expressed in microns). The original data of Quann and Sarofim have been recast in number density form, and this correlation is compared with these recast data in Figure 1. The authors state that the smallest particles (those smaller than about 0.6 μm) are generated by vaporization-recondensation mechanisms, whereas the larger particles are believed to be generated by surface drop shedding or disintegration of char structures. If the data at sizes smaller than 0.6 μm are eliminated, values for a and b of 2370 and -2.95, respectively, fit the remaining data, also with a coefficient of determination greater than 0.99. Therefore, the functional form for *g(x|y)* given by Eq. 2 represents at least this set of data regardless of the mechanism of fragmentation and the value of b used in the conditional psd can be assumed to be approximately -3.

Results of a percolation model of char fragmentation [Dunn-Rankin and Kerstein, 1988] provide further theoretical motivation for this functional form of this conditional pdf. This formulation has been used in other theoretical studies of the transient evolution of char particle size distributions [Kerstein and Edwards, 1987].

A mass balance on the fly ash determines the function *a(y)*, as follows:

$$m_a(y) = \int_0^\infty \frac{\pi}{6}\rho_a x^3 g(x|y)\,dx = \frac{\pi}{6}\rho_a a(y)\Delta x(y) = \omega_a(y) m_c = \omega_a(y)\frac{\pi}{6}\rho_c y^3 \tag{3}$$

where ρ represents density, ω represents ash mass fraction, and Δx represents x_2-x_1. Note that the density of the *initial* char particle (ρ_c) represents the density of the total particle, not just the organic portion. Also, the density of the *final* ash particle and the ash mass fraction

in the char particle (ρ_a and ω_a, respectively) represent values of *ash,* as opposed to the mineral matter from which the ash is formed. It follows from Eq. 3 that,

$$a(y) = \frac{\omega_a(y)\rho_c y^3}{\rho_a \Delta x(y)} \tag{4}$$

For convenience in determining the upper and lower bounds of g, a parametric function $f(y)$ is designated the *fragmentation factor* and is defined as follows:

$$f(y) \equiv \frac{(\omega_a \rho_c/\rho_a)^{1/3} y}{x_2} \tag{5}$$

The numerator represents the size of the fly ash particle that obtains when all of the ash in a char particle coalesces, i.e., no fragmentation occurs. The function f equals the ratio of this hypothetical size to the size of the largest fragment actually generated from a char particle (x_2); f increases with an increase in the *extent* of fragmentation. In the limit of no fragmentation, f is unity, independent of either initial char particle size (y) or char size

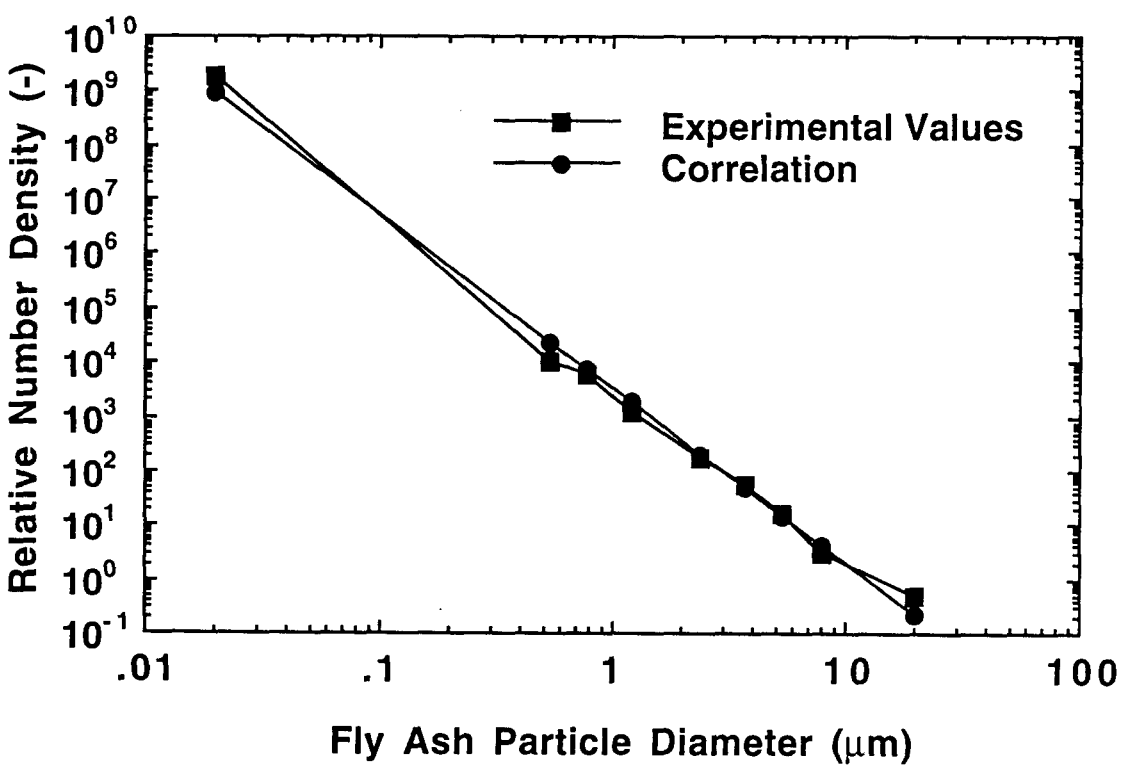


Figure 1. Power law function $g(x|y)$ correlated with the power-law size distribution. Data are from the literature [Quann and Sarofim, 1986].

dependencies in either ρ or ω. (This statement may appear to contradict the explicit dependence of f on y indicated in Eq. 5. However, in the case of no fragmentation, this explicit dependence cancels with the implied dependence of x_2 and of the physical properties on y.) In general, f is expected to be greater than or equal to 1. The parameter f indicates the extent of fragmentation in that it increases as the extent of fragmentation increases. If char were to produce a monodispersion of fly ash particles as a consequence of fragmentation, the total number of fragments produced would be equal to f^3.

A second function $s(y)$, designated the *fragment size ratio,* is defined as

$$s(y) \equiv \frac{x_1(y)}{x_2(y)} \tag{6}$$

and represents the *mode* of fragmentation in the sense that s decreases as the range of fragment sizes produced from a char particle increases. If there is no fragmentation, both f and s are unity. As s decreases from unity toward zero, the range of sizes of fragments produced from a single char particle increases.

Equation 2 can be written in terms of the parameters f and s as

$$g(x|y) = \begin{cases} \dfrac{\omega_a \rho_c y^3}{\rho_c \Delta x} x^{-3} & \text{for } x_1(y) \le x \le x_2(y) \\ 0 & \text{otherwise} \end{cases} \tag{7}$$

yielding

$$\int_{d_{a1}}^{d_a} g(x|y)\,dx = \frac{f^3}{2}\left(\frac{1-s^2}{s^2-s^3}\right) + \min\left\{\frac{f^3}{2(1-s)}\left[\left(\frac{x_2}{\min(x_2, d_{a1})}\right)^2 - \left(\frac{1}{s}\right)^2\right], 0\right\} + \min\left\{\frac{f^3}{2(1-s)}\left[1-\left(\frac{x_2}{\max(x_1, d_a)}\right)^2\right], 0\right\} \tag{8}$$

where s, f and x_2 depend on y. The second term on the right side is negative for all y where $d_{a1} > x_1$ and the third term is negative for $d_a < x_2$. Otherwise, both terms are zero. If all particle sizes are included in the integration ($d_{a1} = 0$ and d_a larger than the largest char or fly ash particle in the stream), the only nonzero term on the right side of the equation is the first term, which represents the ratio of the total numbers of fly ash and char particles.

In general, both f and s depend on initial char particle size y. However, the qualitative relationship between initial char and fly ash particle size distributions is conveniently illustrated by assuming that f, s and the ratio $(\omega_a \rho_c)/\rho_a$ are independent of initial char particle size and can be treated with average values. This means the char particles are homogeneous, or size-invariant, with respect to both their physical properties and their

In general, both f and s depend on initial char particle size y. However, the qualitative relationship between initial char and fly ash particle size distributions is conveniently illustrated by assuming that f, s and the ratio $(\omega_a \rho_c)/\rho_a$ are independent of initial char particle size and can be treated with average values. This means the char particles are homogeneous, or size-invariant, with respect to both their physical properties and their fragmentation properties and that the behavior of particles in a given size range can be represented by statistical averages of properties. Under these assumptions,

$$x_2 = \left(\frac{\omega_a \rho_c}{\rho_a}\right)^{1/3} \frac{y}{f} \equiv py \tag{9}$$

and

$$x_1 = sx_2 = psy \tag{10}$$

where p is independent of y and typically has a value of order 0.5 or less. This allows the integral of the conditional psd to be expressed analytically in terms of y only. If all ash particles are included in the integration ($d_{a1} = 0$), the relationship between char and fly ash concentration distributions can be written as

$$\int_0^{d_a} n_a'(x)\,dx = \int_0^{d_a/(ps)} n_c'(y)\frac{f^3}{2}\left(\frac{1-s^2}{s^2-s^3}\right)dy + \int_{d_a/p}^{d_a/(ps)} n_c'(y)\frac{f^3}{2(1-s)}\left[1-\left(\frac{py}{d^a}\right)^2\right]dy \tag{11}$$

A linear transformation of this equation relates directly to the experimentally measured cumulative particle size distributions reported later. This transformed expression is

$$K_a(d) \equiv \int_d^{\infty} n_a'(x)\,dx = \int_0^{\infty} n_a'(x)\,dx - \int_0^{d} n_a'(x)\,dx \tag{12}$$

where the integral from 0 to ∞ is a constant (independent of d_a). A similar expression defines the function K_c for the char particles.

$$K_c(d) \equiv \int_d^{\infty} n_c'(x)\,dx = \int_0^{\infty} n_c'(x)\,dx - \int_0^{d} n_c'(x)\,dx \tag{13}$$

Limiting forms of Eq.1, other than Eq. 11, are useful to consider. If the initial char particles are monodisperse (n'_c is a Dircac delta function), the integral on the left represents the total number of fly ash particles produced per char particle. Assuming Eq. 2 as the appropriate description for g, the total number of fly ash particles generated per char particle becomes

$$g = \frac{f^3}{2}\left(\frac{1+s}{s^2}\right) \tag{14}$$

Eq. 14 indicates the dependence of the number of fly ash particles on the parameters f and s. For a given value of f, the number of fly ash particles increases dramatically as s decreases (recall that s is always less than or equal to 1). Similarly, as f increases for a given value of s, the total number of fly ash particles increases as f^3.

The valid range of the functions f and s illustrate that this theoretical approach is applicable only to ensembles of particles, not to individual particles. For example, when the ash *in an individual particle* coalesces to form a single fly ash particle ($f = 1$), there is only one size fly ash particle produced ($s = 1$). However, only a fraction of the particles in an ensemble of nominally identical char particles may behave this way. Therefore, f can assume a value of unity for the ensemble without limiting the range of values s can assume. In the application of this theory in this work, the only theoretical limitations on these two parameters are that $f \geq 1$ and $s \leq 1$. The functions are independent of each other.

Experimental Conditions

The Multifuel Combustor (MFC) (Fig. 2) and a Particle Counter Sizer Velocimeter (PCSV) are the primary experimental facility and diagnostic, respectively, used in this work. The MFC provides careful control of gas temperature and composition in a long-residence-time facility. The MFC was operated at a firing rate of 0.07 MBtu/hr with overall oxygen concentrations varying from 5 to 3 mole % during char oxidation, conditions similar to commercial-scale boiler operation. Particle residence time is varied by moving the location of the coal injection lance to various ports along the length of the combustor.

The PCSV performs *in situ* measurements of particle frequency (count), size and speed at the base of the combustor. The PCSV is based on near-forward light scattering from laser beams focused at the center of the reactor flow. Two laser beams are used, one for large particles (> 3 μm) and the second for small particles. The measurements are based on individual particles passing through an approximately ellipsoidal diagnostic volume with a major axis of about 1 mm and minor axes of approximately 300 μm for one beam and 50 μm for the second. The diagnostic is discussed more fully in the literature [Holve and Self, 1979a; Holve and Self, 1979b; Holve, et al., 1981].

The accuracy of the instrument is verified by passing monosized standards through the diagnostic volume and comparing the measured particle sizes with the known actual sizes. Standards used included glass beads entrained in air and transparent discs etched in an opaque reticule. The standards varied from 0.6 to 60 μm and indicate that the PCSV reports particle sizes within one size bin or 0.1 μm of the correct size, whichever is larger.

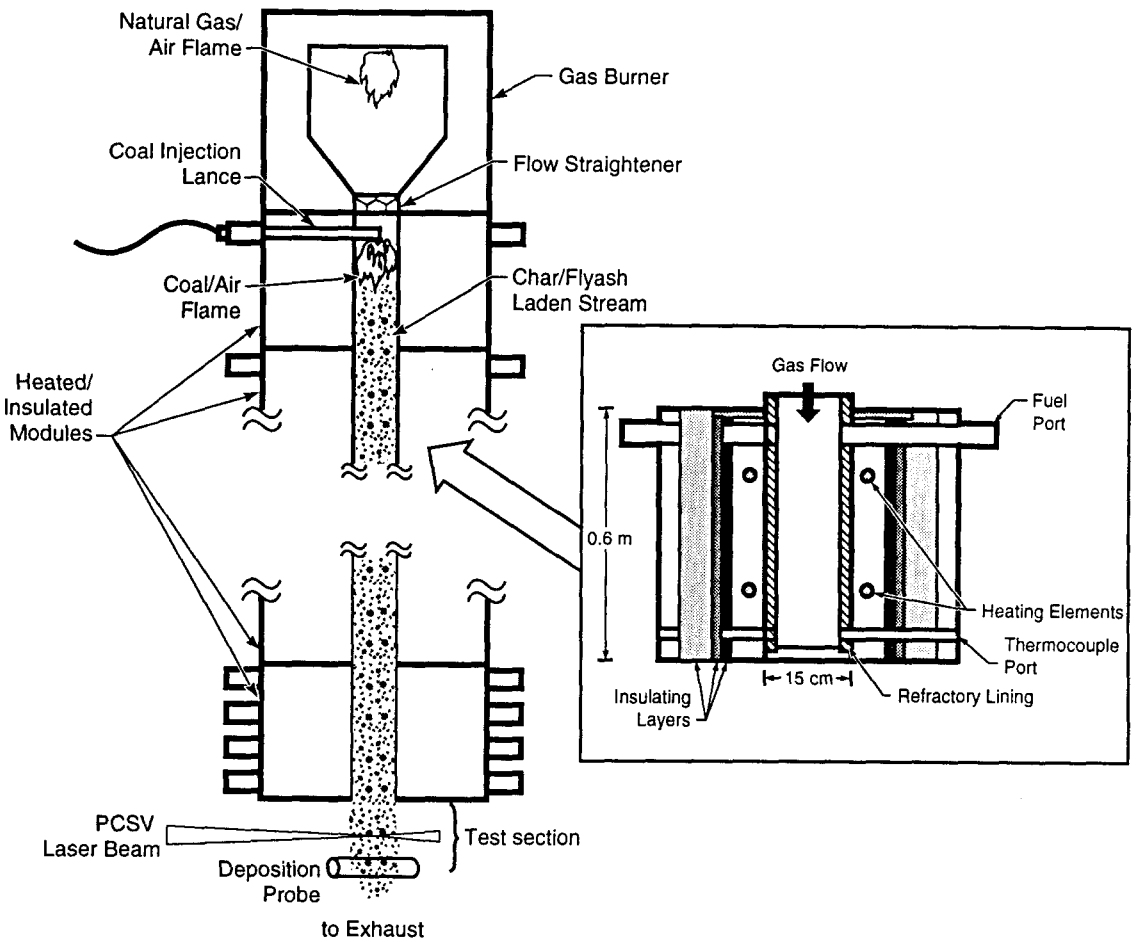


Figure 2. Schematic diagram of the Sandia Multifuel Combustor. The laser beam from the PCSV particle sizing system is illustrated in the test section of the combustor.

The precision of the data is determined by repeating measurements of coal and fly ash in the MFC under nominally identical conditions and computing coefficients of variation from the results. At least five, and as many as twelve, replicate experiments were performed for each coal at each sampling height. The coefficient of variation thus determined includes experimental uncertainty as well as actual fluctuations due, for example, to turbulent fluctuations and variations in coal feed rates. The impact of such fluctuations on the data can be minimized by computing the total mass flowrate from the measured particle concentrations and normalizing all the results to this value. Confidence intervals presented below are based on these measured coefficients of variation and standard statistical techniques.

The upper and lower detection limits of the PCSV are determined in these experiments by the points at which the agreement among the repeated tests becomes poor, as indicated by

the statistical confidence intervals. The lower limit is 0.4 - 0.7 μm and is controlled primarily by signal-to-noise levels in the detector. The upper limit is controlled by sampling statistics in this experiment. Approximately 160,000 individual particles were sampled per measurement, and each measurement was repeated 5 to 12 times. Under these conditions, the upper detection limit is about 100 μm.

Reasonably complete analyses of all the coals used in these experiments are included in the appendix. The data in the appendix include all of the coals used in the program to date. There are several samples of coal with the same name. These are distinguished by numbers, for example, Illinois #6 (2) is a different coal sample than Illinois #6 (1).

The nominal conditions under which these experiments were conducted are summarized in Table 1. Under these experimental conditions, the particles form a dilute phase in the gas, with the total particle volume fraction far less than one percent of the overall gas volume. Consequentially, the probability of particle-particle collisions producing agglomerated fly ash is vanishingly small.

Coals and Coal Properties

Table 2 summarizes the properties of the coals whose fragmentation rates were studied. The coals span a range of rank from lignite to low-volatile bituminous and a range of ash concentrations from 2.8 to 52 %, with an average value of sligthly greater than 10 %. Representatives from essentially every commercially significant coal-producing region of the country are included among the coals studied. More complete analyses of the coals are provided in Appendix A. These analyses include: (1) moisture content; (2) proximate analysis; (3) ultimate analysis; (4) ash chemistry; (5) ash fusion temperatures under reducing and oxidizing environments; (6) sulfur forms; (7) particle size distributions determined by sieves; (8) particle size distributions determined by Malvern optical analyses, (9) chlorine content (for coals containing appreciable chlorine), and (10) heating value. In all cases, the data are averages of several replicated measurements.

Table 1

Typical Local Gas and Particle Properties in the MFC at the Initial Char and the Fly Ash Measurement Locations

Property	Initial Char	Fly Ash
Gas temperature (°C)	1100	900
Oxygen mole fraction	0.06	0.04
Particle residence time τ (s)	0.2	2.1
Particle burnout (daf)	0.65	0.99+
Particle temperature (°C)	1250	900

Fragmentation data for all of the coals are available. There is a great deal of similarity and consistency among the data for similar coals. Representative results illustrating trends with initial particle size, ash loading, coal type, and char structure are presented here. In the discussion below, we focus upon the important trends observed in these collections of data.

Table 2

Characteristics of utility-grind coals studied during this investigation.

Coal	Parr Values* Fixed Carbon [-]	Volatile Matter [-]	Heating Value Btu/lb	Ash† [-]	Rank
Pocahantas #3 (1)	85.8	14.2	15712	7.1	lv Bituminous
Upper Freeport¥	71.45	28.55	15342	21.66	mv Bituminous
Mingo Logan	64.18	35.82	15141	9.34	hv A Bituminous
Pittsburgh-Seam	59.01	40.99	15154	8.40	hv A Bituminous
Illinois #6 (3)	57.32	42.68	15023	5.62	hv A Bituminous
Pittsburgh #8 (2)	61.51	38.49	14843	6.55	hv A Bituminous
Massey Sprouce	62.85	37.15	14786	8.33	hv A Bituminous
Eastern Kentucky	59.76	40.24	14724	10.15	hv A Bituminous
Pittsburgh #8 (1)	56.44	43.56	14695	10.68	hv A Bituminous
Utah Blind Canyon	51.92	48.08	14276	10.40	hv A Bituminous
Kentucky #11¥	57.38	42.62	13269	22.21	hv B Bituminous
Illinois #6 (2)	56.34	43.66	13083	12.33	hv B Bituminous
SOAP§	57.6	42.4	12900	2.8	hv C Bituminous
Kentucky #9¥	57.15	42.85	12791	14.64	hv C Bituminous
Hanna Basin	57.59	42.41	12053	11.05	hv C Bituminous
Illinois #6 (1)¥	55.68	44.32	11997	10.13	hv C Bituminous
Roland-Seam	52.85	47.15	11494	6.29	Subbituminous A
Decker	53.92	46.08	10726	5.11	Subbituminous A
Black Thunder	42.27	57.73	10675	6.46	Subbituminous A
Belle Ayr	49.02	50.98	10130	6.04	Subbituminous B
Wyodak	51.79	48.21	10059	6.22	Subbituminous B
Antelope	54.53	45.47	9918	5.51	Subbituminous B
Eagle Butte¥	51.68	48.32	9286	6.40	Subbituminous C
Beulah Lignite¥	51.28	48.72	8202	13.86	Lignite A
Texas Lignite¥	39.98	60.02	7513	51.96	Lignite A
		Blends			
Eastern Blend	67.77	32.23	15312	8.67	hv A Bituminous
Pitt. #8/Decker	61.3	38.7	13599	6.96	hv B Bituminous
NIPSCO Belnd (1)	54.3	45.7	12786	7.71	hv C Bituminous
NIPSCO Blend (2)	53.26	46.74	12742	7.80	hv C Bituminous
Roland/Illinois #6	54.3	45.7	12467	8.97	hv C Bituminous
Eagle Butte/Ken. #9	51.3	48.7	10592	9.39	Subbituminous A

* Fixed carbon and volatile matter are on dry, *mineral*-free (as opposed to ash-free) basis. Heating value is on a moist, mineral-free basis.

† Ash is on a dry basis.

§ Spherical Oil Agglomeration Product derived from an Illinois #6 coal.

¥ Coals obtained from PSIT as part of the original suite used in their mineral investigations.

Experimental Results and Discussion

Coal Fragmentation

Coal fragmentation (as opposed to char fragmentation) could be effected by rapid mass loss during devolatilization. The extent of coal fragmenation was analyzed in this study by comparing coal particle size probability density functions with those for char particles after devolatilization. Figure 3 illustrates cummulative particle size distribution (pdf) data for the Kentucky #9 coal. Data of these type are often presented in a histogram format. All data in this report are persented on a pdf basis. The difference can be quite large. The historgram format presents the fraction of the total data contained within some range, for example, the mass fraction of particles with sizes between two limits. The value of the ordinate is usually dimensionless, because the mass fraction is dimensionless, and changes with changes in the range of the data.

Char Fragmentation

Data derived from many coals are presented below. The discussion will first contrast a typical swelling coal (Pittsburgh #8) and a non-swelling coal (Roland coal). Results from the remainder of the coals will be presented in the context of the results from these two coals and will be shown to be consistent in their interpretation.

Cumulative size distributions for char and fly ash particles generated from the Pittsburgh #8 (2) coal are illustrated in of Fig. 3a. The mean value of the several measured distributions is indicated together with 95% confidence intervals. The coefficients of variation (standard deviation divided by mean) used in computing the confidence intervals are illustrated as a function of particle size in Fig. 3b. These experimentally determined coefficients of variation are largest at small particle sizes. Light scattering intensity is lowest for small particles and is most influenced by experimental error (detector noise, beam steering, etc.), giving rise to higher coefficients of variation.

The data illustrated in Fig. 3 are representative of all of the coals studied. Only the final results of the fragmentation analysis will be presented for the remainder of the coals studied.

The confidence intervals are largest for the submicron-sized char particles. These, however, are of little consequence to the analysis since they form fly ash particles too small to reliably detect with this technique. Over the range of char and fly ash particle sizes of interest in this study, the size distributions are determined within approximately ± 20 relative percent accuracy. The confidence intervals are much smaller over most of the range of interest.

Using these data, the fragmentation factor f is computed according to the equations indicated in the preceding discussion. The only quantity not determined from the measurements is s. Figure 4a illustrates the computed value of f for an assumed value of s of unity. This is equivalent to assuming that equal-sized fly ash particles form from a char particle of a given initial size. While this assumption is probably not realistic, it is convenient for engineering models (such as ADLVIC) that incorporate fragmentation behavior.

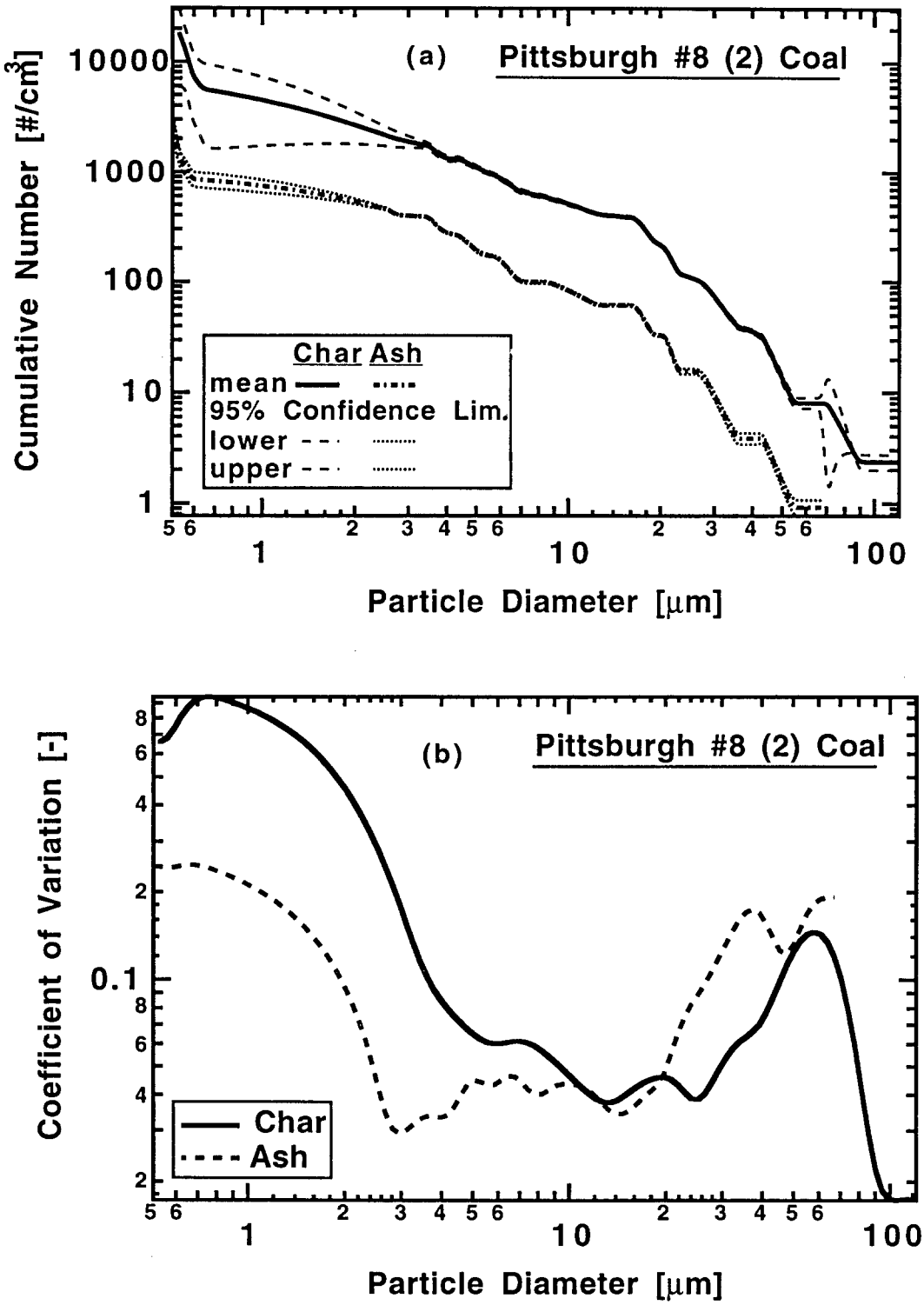


Figure 3. Cumulative particle size distributions and statistics for char and fly ash generated from the Pittsburgh #8 (2) hv A bituminous coal.

As illustrated in Fig. 4a, the value of the fragmentation factor exceeds unity only for initial char particle sizes larger than about 20 μm. The size of fragments generated by the fragmentation of these large particles is indicated by the second abscissa at the top of the figure. Fly ash particles generated through fragmentation are concentrated in the 10 μm size range.

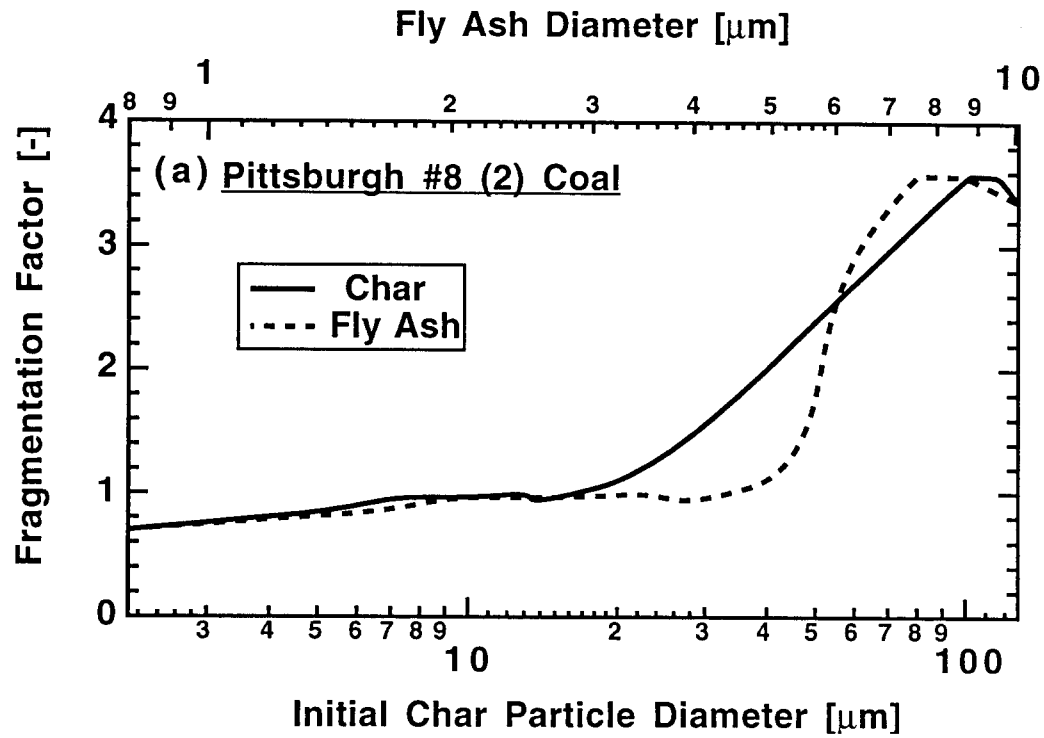
The fragmentation factor should range from 1 to larger values, as can be seen from its definition (Eq. 5). The experimental measurements indicate a fragmentation factor as low as 0.7 in some regions of char and fly ash sizes. This is probably associated with variations in the char density and ash mass fraction and the fly ash density as a function of particle size. Reliable information concerning the particle size variation of these physical properties is not available for this coal. Therefore, the properties were assumed to be equal to their average values at all particle sizes. Considering that the fragmentation factor is derived entirely from experimental data, this small deviation of the experimental value below its theoretical limit is viewed as only a minor concern in these results.

Results from similar measurements and analyses for a Roland-seam coal are illustrated in Fig. 5. The ordinates of the two panels in Fig. 5 are scaled the same as those in Fig. 4 to allow a direct comparison. The lower-rank Roland coal is seen to fragment less extensively than the Pittsburgh #8 bituminous coal. This is consistent with our previous results and with the postulate that fragmentation is strongly influenced by char structure [Baxter, 1992]. Coals that form chars that are cenospheres or 'mesospheres' (have very large voids) are more likely to fragment because they have inherently unstable structures as they burn out. Such is the case with high volatile bituminous coals. Chars that do not form cenospheres, such as the Roland coal, are stable as the char particles burn out. The fragmentation data reflect the stability of the char structure in that there are few fragments formed per original char particle.

The comparison of the Pittsburgh #8 and Roland coals is representative of all of the coals we have tested. Data for additional coals and coal blends are illustrated in Figures 6 through 10. These data are consistent with earlier observations, i.e., the extent of fragmentation generally increases with increasing char particle size, is greater for chars that form cenospheres than for more dense chars, and decreases with increasing ash loading. While these general characteristics are consistent among all of the data, some details of the data that need further explanation.

Data for the Utah Blind Canyon coal, which is borderline between hv A and hv B bituminous, indicate little fragmentation at any particle size, much the same as the Roland and other subbituminous coals and lignites examined. When compared to the other bituminous coals, the behavior of the Blind Canyon coal appears anomalous. This is only an apparent anomaly, as can be verified by a more detailed investigation of the chemistry of the Utah Blind Canyon coal.

Figure 11 indicates the detailed chemical structure of coals from many of the same seams used in this experiments, including the Blind Canyon coal. These data are taken from published NMR spectroscopy results [Solum, et al., 1989], for coals obtained from the Argonne premium coal bank, not the samples of the coals tested here. The Blind Canyon coal in the Argonne coal bank is chemically more similar to the lower-rank subbituminous coals and lignite than it is to even to the hv B bituminous samples. There are no samples of hv C available for comparison with these data. We postulate this chemical difference is the reason for the different fragmentation behavior. Coal rank is based solely on heating value and moisture content for these coals (as determined by ASTM D388-36) and is only a crude indicator of the actual chemical structure of the raw coal.



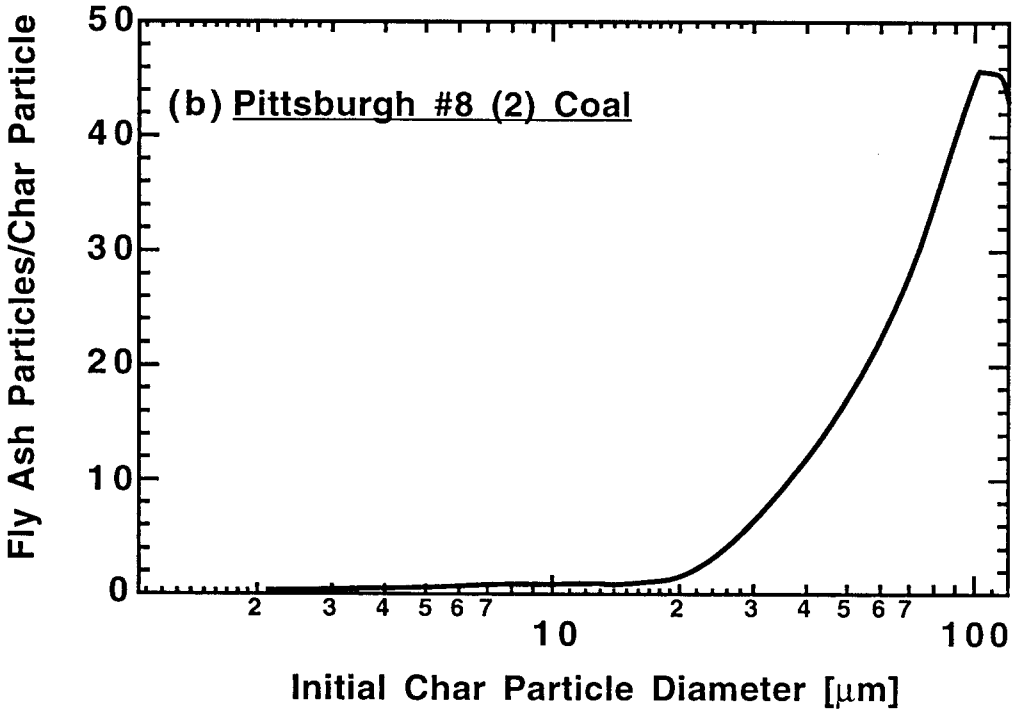
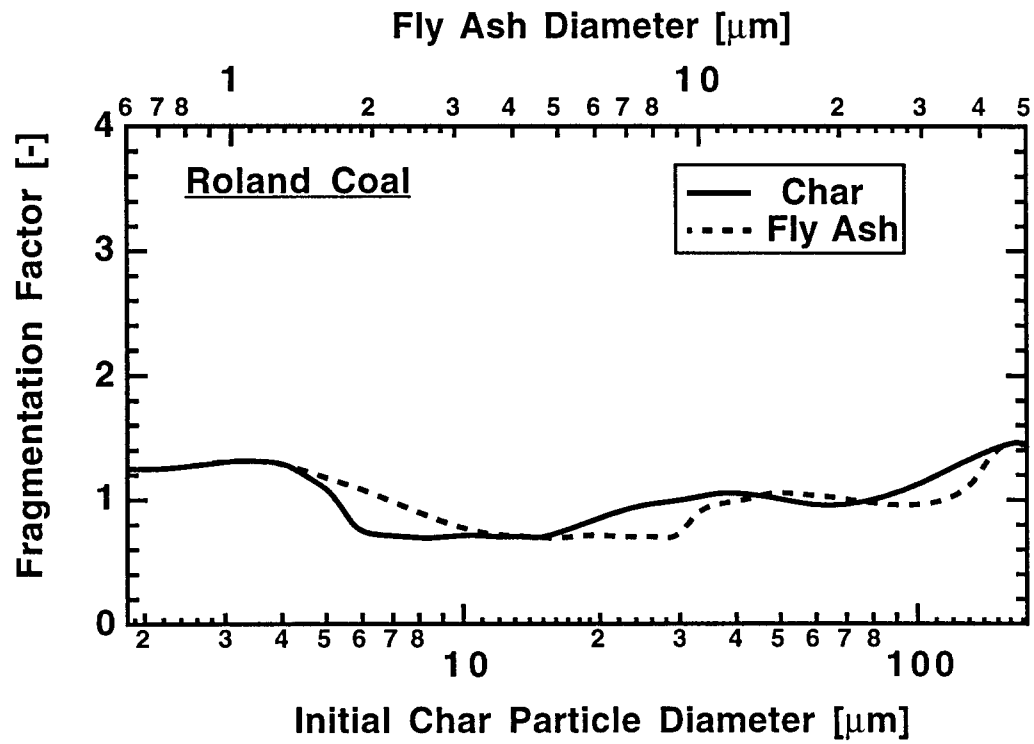


Figure 4. Variation of the fragmentation factor with initial char particle size and fly ash size (a) and the number of fly ash particles formed per char particle as a function of initial char particle size (b) for the Pittsburgh #8 hv A bituminous coal.



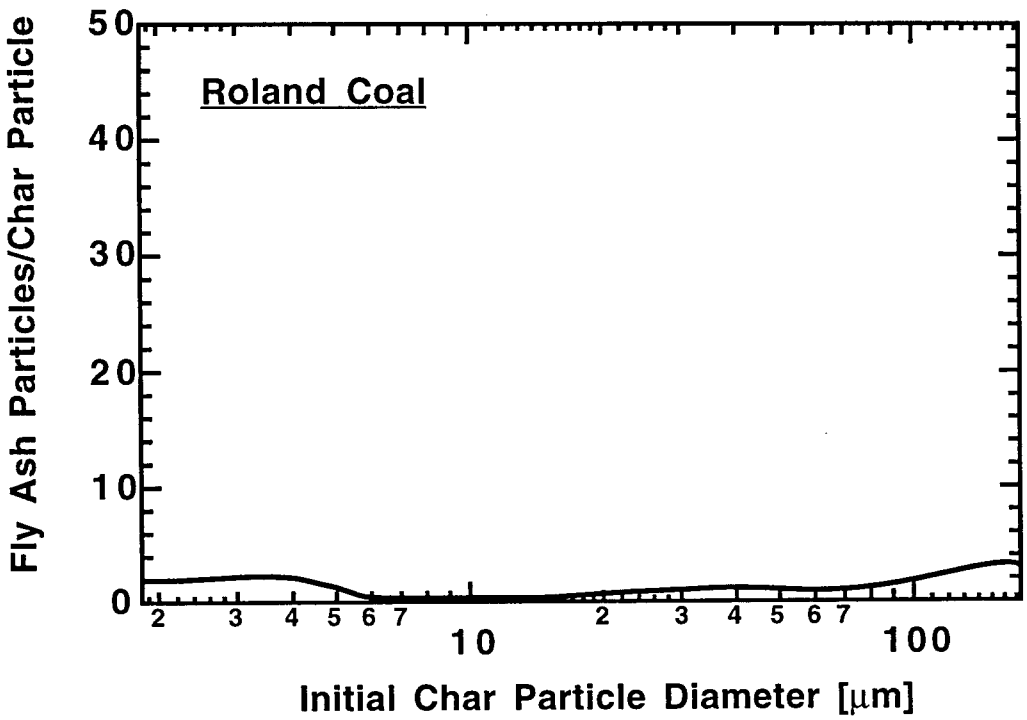
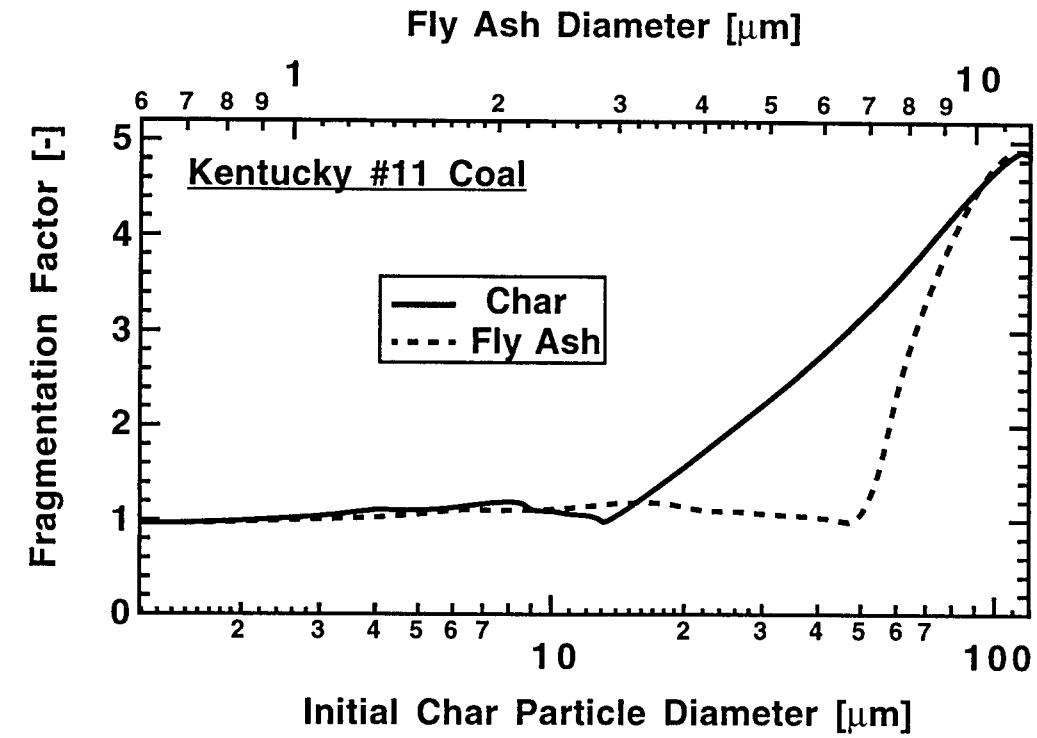


Figure 5. Variation of the fragmentation factor as a function of initial char and final fly ash particles sizes (a) and of the number of fly ash particles produced per char particle as a function of initial char particle size (b) for a Roland-seam subbituminous coal.



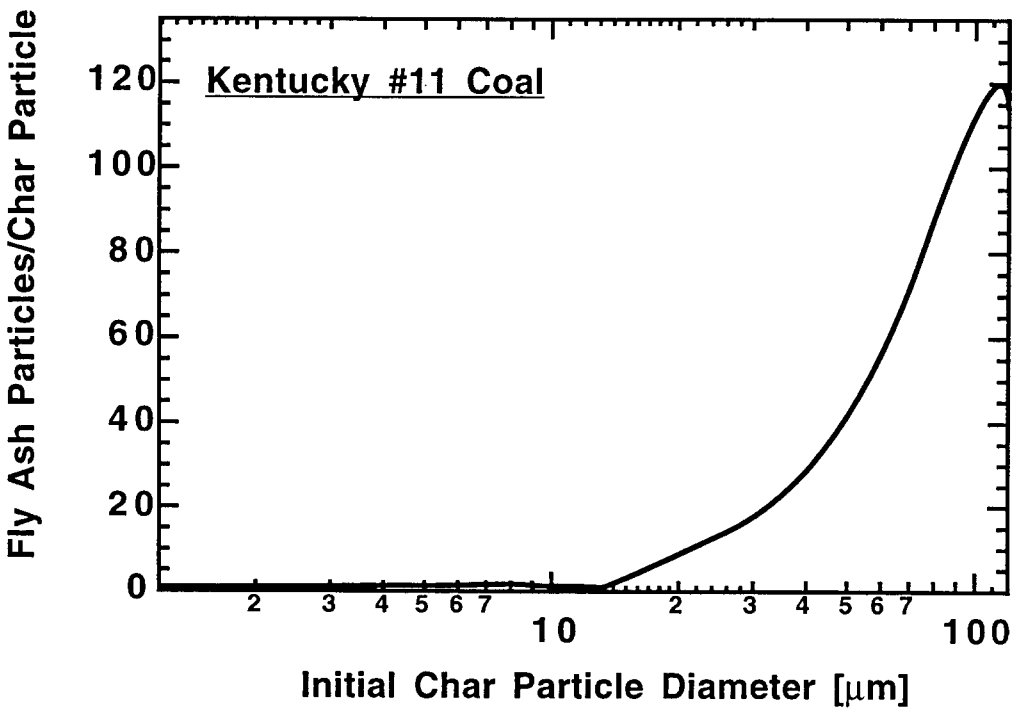
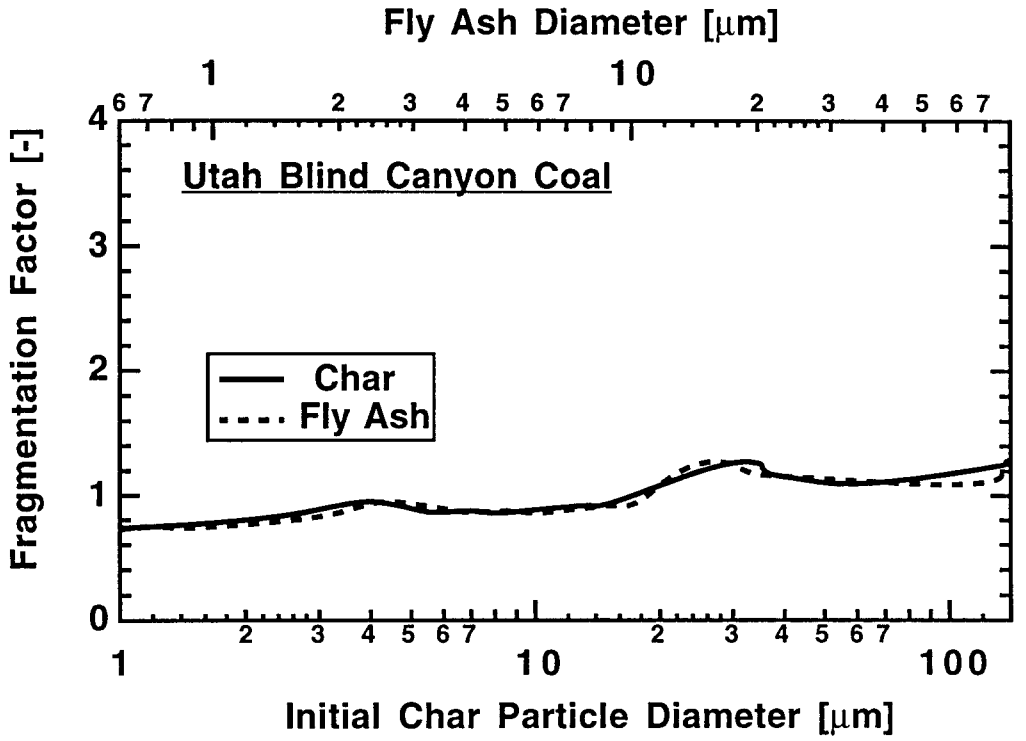


Figure 6. Variation of the fragmentation factor as a function of initial char and final fly ash particle sizes (a) and of the number of fly ash particles produced per char particle as a function of initial char particle size (b) for a Kentucky #11 hv B bituminous coal.



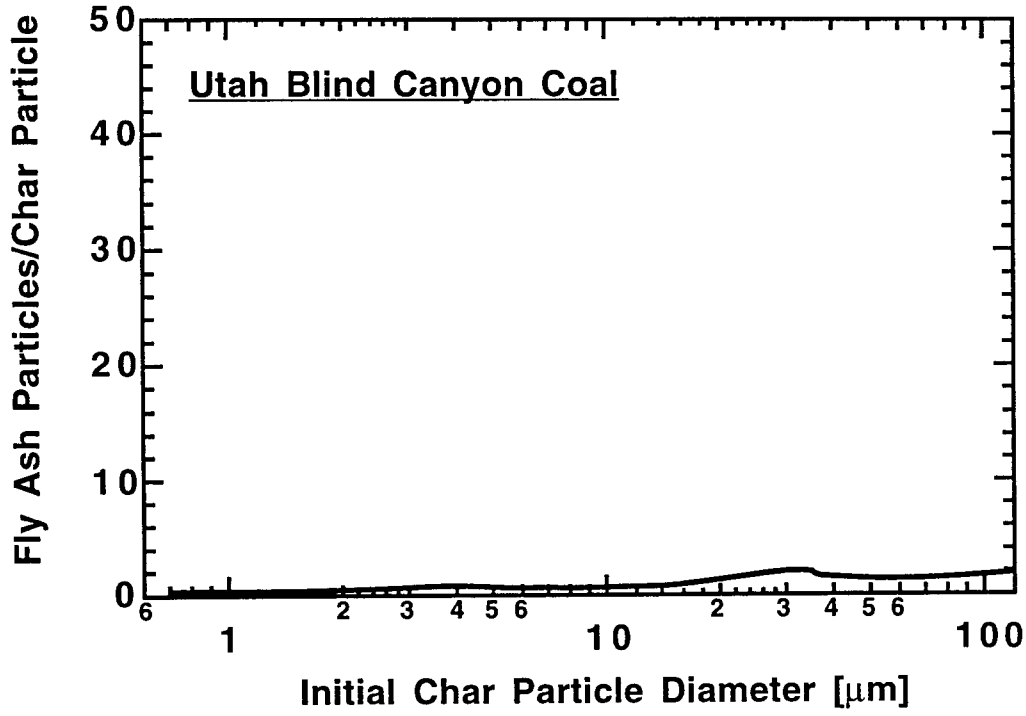
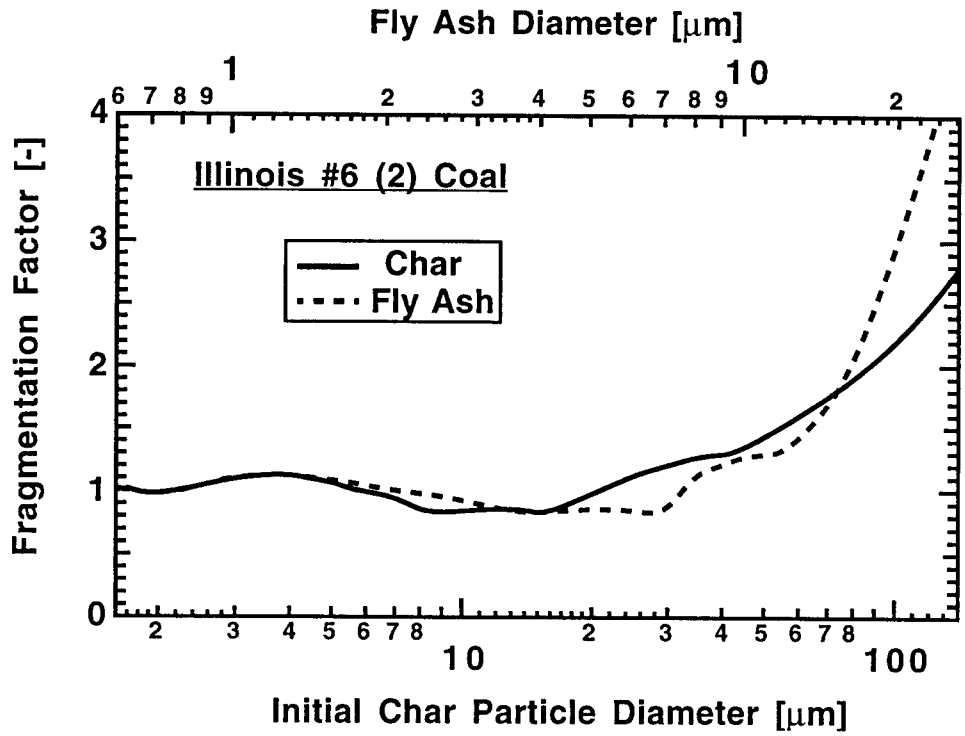


Figure 7. Variation of the fragmentation factor as a function of initial char and final fly ash particle sizes (a) and of the number of fly ash particles produced per char particle as a function of initial char particle size (b) for a Utah Blind Canyon hv A bituminous coal.



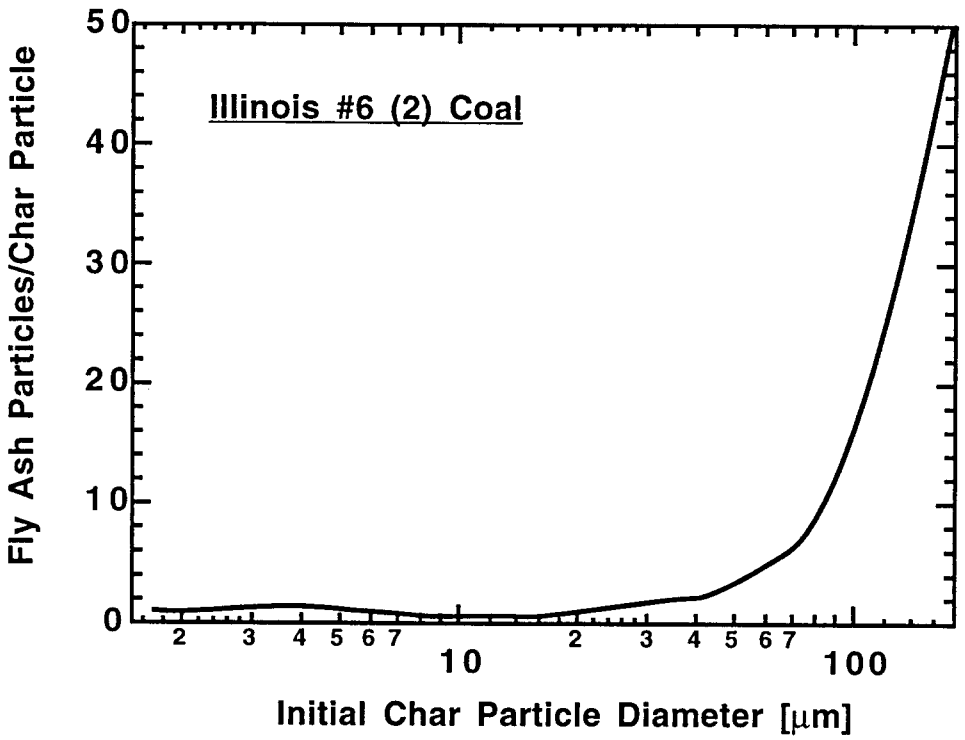


Figure 8. Variation of the fragmentation factor as a function of initial char and final fly ash particle sizes (a) and of the number of fly ash particles produced per char particle as a function of initial char particle size (b) for the Illinois #6 (2) hv B bituminous coal.

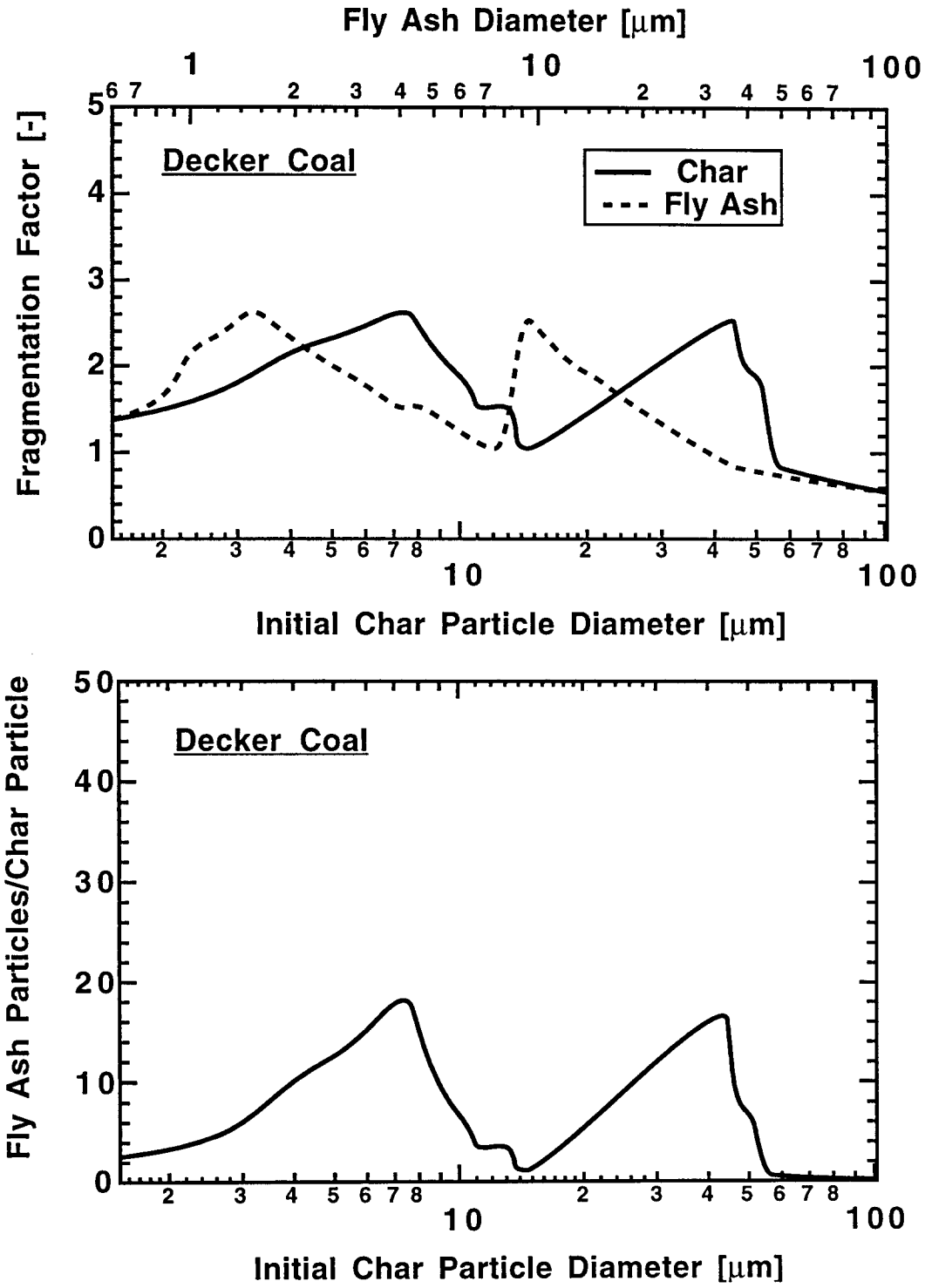


Figure 9. Variation of the fragmentation factor as a function of initial char and final fly ash particle sizes (a) and of the number of fly ash particles produced per char particle as a function of initial char particle size (b) for a Decker subbituminous A coal.

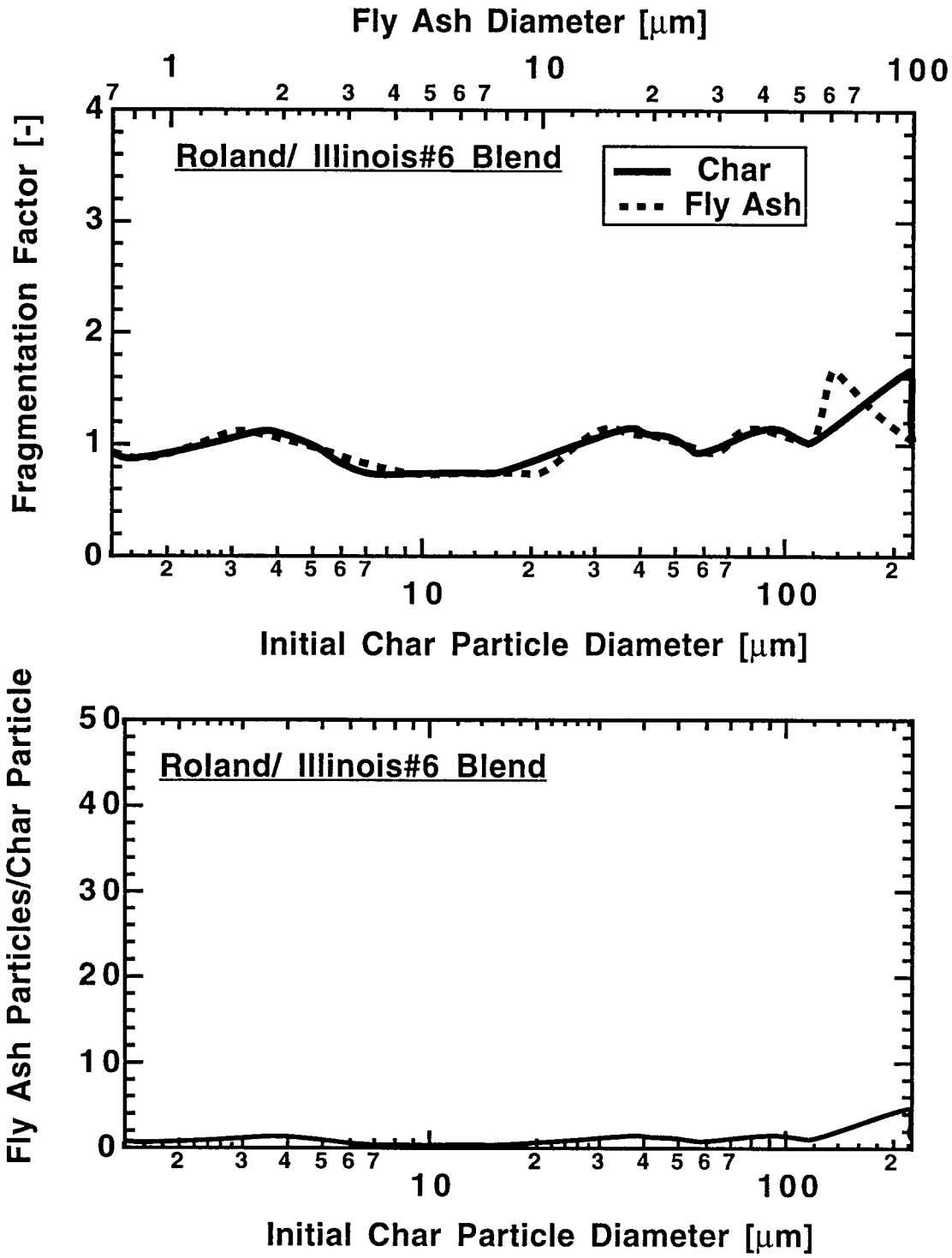


Figure 10. Variation of the fragmentation factor as a function of initial char and final fly ash particle sizes (a) and of the number of fly ash particles produced per char particle as a function of initial char particle size (b) for a blend of 70 % Roland and 30 % Illinois # 6 (2) coals.

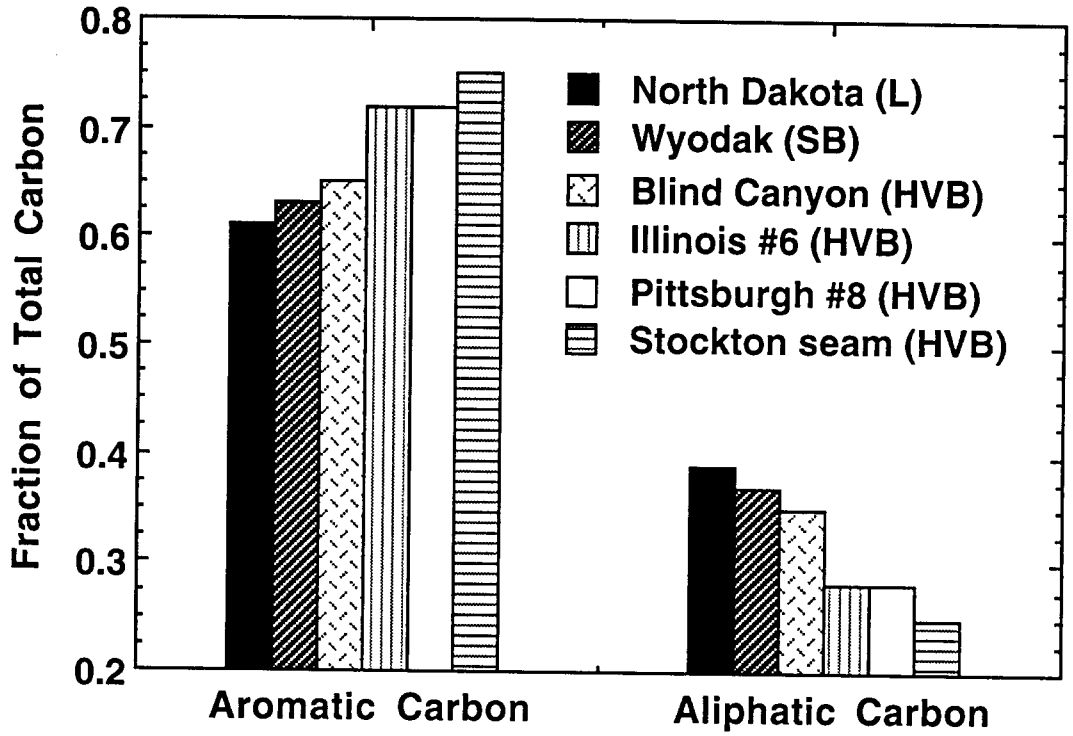


Figure 11. Comparison of the chemical composition of Argonne coal bank samples [Solum, et al., 1989] contrasting the Blind Canyon coal with coals similar to several used in these experiments.

The influence of ash loading on fragmentation behavior is minor. This can be seen by comparing results for the Kentucky #9 coal with the Illinois #6 (1) coal shown in Fig. 12 and Fig. 13. With reference to Table 2 and the appendix, these two coals are seen to be similar in most respects, with the exception that the Kentucky #9 coal has roughly 50% higher ash content than the Illinois #6 (1) coal. Comparison of the similar data for the Kentucky #9 and Illinois #6 (1) coals with the data for the Beulah lignite (Figs. 12 and 13) clearly underscores the dominant importance of coal rank on fragmentation behavior.

Conclusions

The fragmentation data investigated thus far show consistent trends in that: (1) large char particles produce far more fly ash particles than small char particles; (2) the extent of fragmentation tends to increase with increasing coal rank through hv bituminous; (3) the extent of fragmentation tends to decrease with increasing ash loading; and (4) in all cases studied thus far, the total increase in the number of particles greater than 0.6 μm in diameter by char fragmentation is less than a factor of two.

These general trends have been established for a significant number of coals over a broad range of rank, ash loading, and particle size. Our results indicate substantial agreement among experimental results previously thought to be in disagreement.

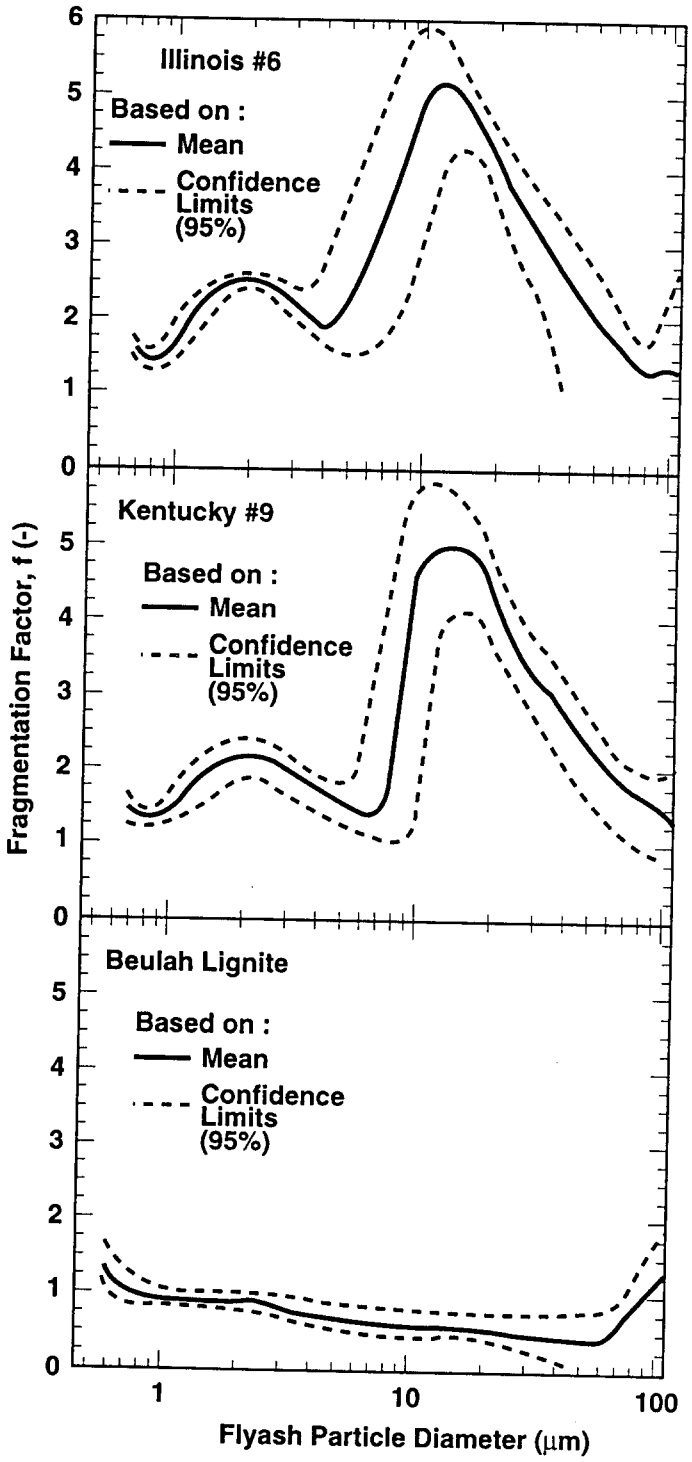


Figure 12. Variation of the fragmentation factor as a function of fly ash particle size for the Illinois #6 (1) hv C bituminous coal, the Kentucky #9 hv C bituminous coal, and the Beulah lignite.

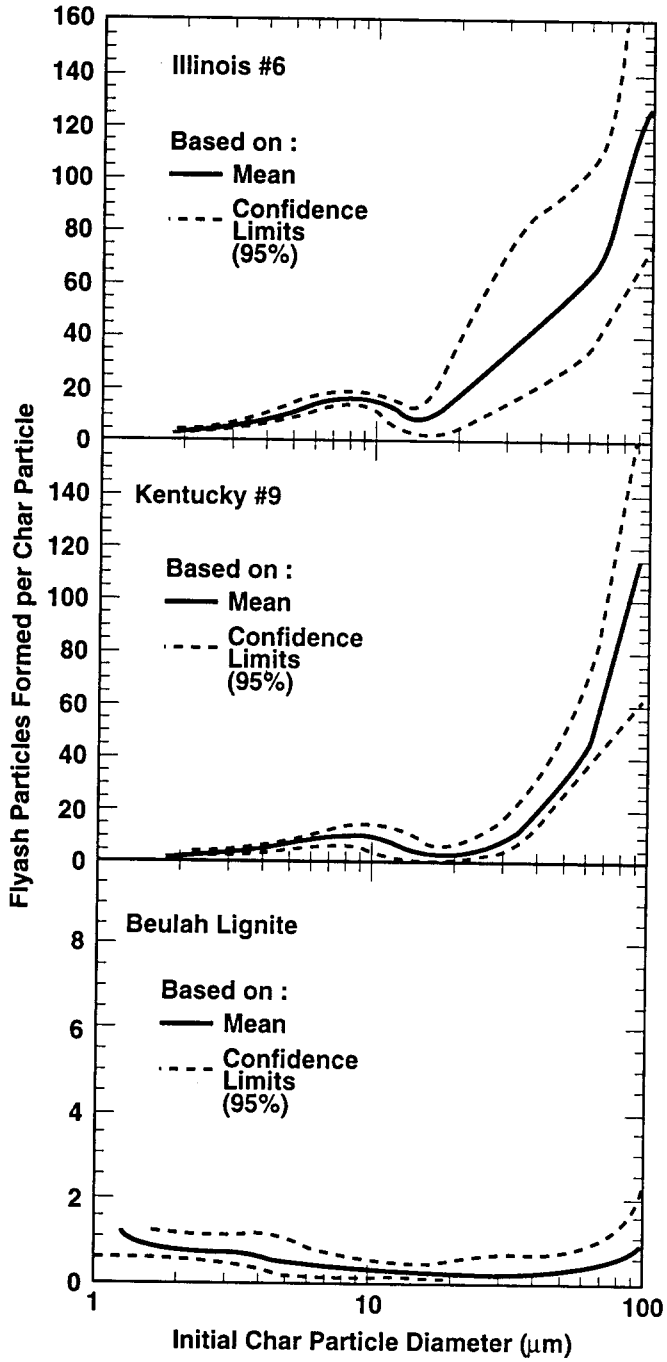


Figure 13. Variation of the number of fly ash particles produced per char particle as a function of initial char particle size for the Illinois #6 (1) hv C bituminous coal, the Kentucky #9 hv C bituminous coal, and the Beulah lignite.

In particular, the dependence of char fragmentation on char particle size had not previously been recognized when comparing results from different systems. The implications of this particle-size dependence reconcile, in part, seemingly discrepant results previously reported in the literature. This is discussed in more detail elsewhere [Baxter, 1992]. Furthermore, the current study clearly indicates that, for typical coals in typical combustion environments, the extent of fragmentation experienced at all char particle sizes is relatively minor.

Finally, based upon our extensive data sets for a broad range of coals, a mechanistic description has been developed that predicts the trends observed in the data. However, significant additional work needs to be performed to establish quantitative relationships between fly ash chemistry and the size distributions of both the char particles and the mineral grains within the char particles.

Practical Implications

Combination of the coal and char data indicate that fragmentation under typical pulverized-coal-fired conditions of particle size and oxygen concentrations: (1) is most significant for cenosphere-forming coals, (2) decreases slightly with increased ash loading, and (3) is relatively insignificant in all cases. These results have direct application to .

Acknowledgments

This work was performed under the management of Don Hardesty, whose guidance and continued interest in the work are gratefully acknowledged. The operation of the CCL and CDL laboratories during the early portions of this project was under the direction of Reginald Mitchell and Thomas Fletcher, respectively. The contributions of Nancy Yang and Don Nissen in obtaining SEM and EDS data for these samples are gratefully acknowledged. The contributions of Scott Ferko and Bill Kent in obtaining samples from the CCL and CDL are also gratefully acknowledged. A number of students, faculty, industrial visitors, contractors, Sandians, and other visitors helped in collecting data from the MFC. These include Gian Sclippa (TAD Technical Services), Alan Salmi (Sandia), Eric Harwood (UC Davis), Galen Richards (BYU), Joseph Wong (Cornell), Steve Giles (HS), Judy Lankford (HS), Howard Davis (Yale), Ed Muzio (Cornell), Robert Douglas (CONSOL), and Stan Harding (REI). The technical discussions and reviews of Robert Hurt, Judy Wornat, and Kevin Davis are also appreciated. Most of the fuel analyses on which this paper is based were performed by CONSOL Inc. as an in-kind contribution to this research.

References

Allen, R. M., and VanderSande, J. B. (1984). "Analysis of Sub-micron Mineral Matter in Coal via Scanning Transmission Electron Microscopy." ***Fuel, 63***, 24-29.

Baxter, L. L. (1992). "Char Fragmentation and Fly Ash Formation During Pulverized Coal Combustion." ***Combustion and Flame, 90***, 174-184.

Baxter, L. L., and Mitchell, R. E. (1992). "The Release of Iron During the Combustion of Illinois No. 6 Coal." ***Combustion and Flame, 88***, 1-14.

Baxter, L. L., Mitchell, R. E., and Fletcher, T. H. (1994 (to appear)). "Release of Inorganic Material During Coal Devolatilization." ***Combustion and Flame, to appear.***

Canavos, G. C. (1984). *Applied probability and statistical methods.* Boston: Little, Brown and Company.

Dunn-Rankin, D., and Kerstein, A. R. (1987). "Numerical Simulation of Particle Size Distribution Evolution during Pulverized Coal Combusiton." ***Combustion and Flame, 69***, 193-209.

Dunn-Rankin, D., and Kerstein, A. R. (1988). "Influence of Ash on Particle Size Distribution Evolution During Coal Combusiton." ***Combustion and Flame, 74***, 207-218.

Flagan, R. C. (1978). "Submicron Particles from Coal Combustion,". In *Seventeenth Symposium (International) on Combustion,*, (pp. 97-104). University of Leeds, Leeds, England: The Combustion Institute.

Flagan, R. C., and Sarofim, A. F. (1984). "Comments to Article by W. T. Reid." ***Progress in Energy and Combustion Science, 10***, 159-163.

Flagan, R. C., and Taylor, D. D. (1980). "Laboratory Studies of Submicron Particles from Coal Combustion". In *Eighteenth Symposium (International) on Combustion*, (pp. 1227-1237). Waterloo, Canada: The Combustion Institute.

Holve, D., and Self, S. (1979a). "Optical particle sizing for *in situ* measurements: Part 1." ***Applied Optics, 18***(10), 1632-1645.

Holve, D., and Self, S. A. (1979b). "Optical particle sizing for *in situ* measruements Part 2." ***Applied Optics, 18***(10), 1646-1652.

Holve, D. J. (1986). "*In Situ* Measurements of Flyash Formation from Pulverized Coal." ***Combustion Science and Technology, 44***, 269-288.

Holve, D. J., Tichenor, D., Wang, J. D. F., and Hardesty, D. R. (1981). "Design Criteria and recent developments of optical single particle counters for fossil fuel systems." ***Optical Engineering, 20***(4), 529-539.

Kang, S.-G., Helble, J. J., Sarofim, A. F., and Beér, J. M. (1988). "Time-resolved Evolution of Fly Ash During Pulverized Coal Combustion". In *Twenty-Second Symposium (International) on Combustion*, (pp. 231-238). University of Washington, Seattle, WA: The Combustion Institute.

Kang, S.-G., Kerstein, A. R., Helble, J. J., and Sarofim, A. F. (1990). "Simulation of Residual Ash Formation During Pulverized Coal Combustion: Bimodal Ash Particle Size Distribution." ***Aeerosol Science and Technology, 13***, 401-412.

Kerstein, A. R., and Edwards, B. F. (1987). "Percolation Model for Simulation of Char Oxidation and Fragmentation Time-Histories." ***Chemical Engineering Science, 42***(7), 1629-1634.

Neville, M., Quann, R. J., Haynes, B. S., and Sarofim, A. F. (1980). "Vaporization and Condensation of Mineral Matter During Pulverized Coal Combustion". In *The Eighteenth*

Symposium (International) on Combustion, (pp. 1267-1274). University of Waterloo, Waterloo, Canada: The Combustion Institute.

Neville, M., and Sarofim, A. F. (1985). "The Fate of Sodium During Pulverized Coal Combustion." ***Fuel, 64***, 384-390.

Quann, R. J., Neville, M., Janghorbani, M., Mims, C. A., and Sarofim, A. F. (1982). "Mineral Matter and Trace-Element Vaporization in a Laboratory-Pulverized Coal Combustion System." ***Environmental Science and Technology, 16***, 776-781.

Quann, R. J., Neville, M., and Sarofim, A. F. (1990). "A Laboratory Study of the Effect of Coal Selection on the Amount and Composition of Combustion Generated Submicron Particles." ***Combustion Science and Technology, 74***, 245-265.

Quann, R. J., and Sarofim, A. F. (1982). "Vaporization of Refractory Oxides During Pulverized Coal Combustion". In *Nineteenth Symposium (International) on Combustion*, (pp. 1429-1440). The Combustion Institute.

Quann, R. J., and Sarofim, A. F. (1986). "A scanning electron microscopy study of the transformations of organically bound metals during lignite combustion." ***Fuel, 65***, 40-46.

Raask, E. (1984). "Creation, capture and coalescence of coal species in coal flames." ***Journal of the Insitute of Energy, 57***, 231.

Raask, E. (1985). *Mineral Impurities in Coal Combustion*. Washington: Hemisphere Publishing Corporation.

Sarofim, A. F., Howard, J. B., and Padia, A. S. (1977). "The Physical Transformation of the Mineral Matter in Pulverized Coal Under Simulated Combustion Conditions." ***Combustion Science and Technology, 16***, 187-204.

Solum, M. S., Pugmire, R. J., and Grant, D. M. (1989). "^{13}C Solid-State NMR of Argonne Premium Coals." ***Energy & Fuels, 3***, 187-193.

Wark, K., and Warner, C. F. (1981). *Air Pollution* (Second Edition ed.). New York: Harper & Rwo.

Wibberley, L. J., and Wall, T. F. (1986). "An Investigation of Factors Affecting the Physical Characteristics of Flyash Formed in a Laboratory Scale Combustor." ***Combustion Science and Technology, 48***, 177-190.

APPENDIX A

Summaries of Analyses on Utility-Grind Samples of Coal

The following tables summarize the most commonly measured characteristics of the suite of utility-grind coals tested in the multifuel combustor during this project. Included among the data are the results of moisture, proximate, ultimate, ash, ash chemistry, heating value, forms of sulfur, oxidizing and reducing fusion temperature, and particle size distribution analyses. The tables summarize average results for an often large number of samples. Not all analyses were performed on all samples. For example, proximate and ultimate analyses were not performed on the samples of coals used in chemical fractionation tests. This leads to occasional small discrepancies in, for example, the sum of the oxides and the total ash content, even when undetermined ash is included in the sum of oxides.

Additional characterizations of many of the coals have been performed. These include size-resolved characterizations of the fraction of eastern and western coal in the blends, chemical fractionation results for about two thirds of the coals, and a variety of SEM-based and other individual-sample-based analyses. These additional analyses are available in published reports from this project but are not summarized here.

Blank entries indicate that no data are available. The most common examples include chlorine in ash (usually not measured), acid soluble alkali (available for small fraction of the coals), and one set of the Malvern size distribution data. The Malvern size data are reported in one of two alternative sets of ranges. Data from both ranges are rarely available. These Malvern data are for the pulverized, raw coal samples and they too have been averaged with several replicate measurements.

Table A.1

Summary of utility-grind coals studied during this investigation.

Coal	Parr Values* Fixed Carbon [-]	Volatile Matter [-]	Heating Value Btu/lb	Ash† [-]	Rank
Pocahantas #3 (1)	81.2	18.8	15750	4.5	lv Bituminous
Upper Freeport¥	71.45	28.55	15342	21.30	mv Bituminous
Mingo Logan	64.18	35.82	15141	9.34	hv A Bituminous
Pittsburgh #8 (3)	59.01	40.99	15154	9.01	hv A Bituminous
Illinois #6 (3)	57.32	42.68	15023	5.62	hv A Bituminous
Pittsburgh #8 (2)	61.51	38.49	14843	6.62	hv A Bituminous
Massey Sprouce	62.85	37.15	14786	8.33	hv A Bituminous
Eastern Kentucky	59.76	40.24	14724	10.15	hv A Bituminous
Pittsburgh #8 (1)	56.44	43.56	14695	10.68	hv A Bituminous
Utah Blind Canyon	51.92	48.08	14276	10.16	hv A Bituminous
Kentucky #11¥	57.38	42.62	13269	22.15	hv B Bituminous
Illinois #6 (2)	56.34	43.66	13083	12.21	hv B Bituminous
SOAP§	57.6	42.4	12900	3.99	hv C Bituminous
Kentucky #9¥	57.15	42.85	12791	15.64	hv C Bituminous
Hanna Basin	57.59	42.41	12053	9.99	hv C Bituminous
Illinois #6 (1)¥	55.68	44.32	11997	10.24	hv C Bituminous
Roland-Seam	52.85	47.15	11494	6.16	Subbituminous A
Decker	53.92	46.08	10726	5.12	Subbituminous A
Black Thunder	42.27	57.73	10675	6.46	Subbituminous A
Belle Ayr	49.02	50.98	10130	6.04	Subbituminous B
Wyodak	51.79	48.21	10059	6.18	Subbituminous B
Antelope	54.53	45.47	9918	5.51	Subbituminous B
Eagle Butte¥	51.68	48.32	9286	6.37	Subbituminous C
Beulah Lignite¥	51.28	48.72	8202	13.69	Lignite A
Texas Lignite¥	39.98	60.02	7513	52.18	Lignite A
		Blends			
Eastern Blend	67.77	32.23	15312	8.67	hv A Bituminous
Pitt. #8/Decker	61.3	38.7	13599	6.26	hv B Bituminous
NIPSCO Belnd (1)	54.3	45.7	12786	7.80	hv C Bituminous
NIPSCO Blend (2)	53.26	46.74	12742	7.71	hv C Bituminous
Roland/Illinois #6	54.3	45.7	12467	9.29	hv C Bituminous
Eagle Butte/Ken. #9	51.3	48.7	10592	8.91	Subbituminous A

* Fixed carbon and volatile matter are on dry, *mineral*-free (as opposed to ash-free) basis. Heating value is on a moist, mineral-free basis.

† Ash is on a dry basis.

§ Spherical Oil Agglomeration Product derived from an Illinois #6 coal.

¥ Coals obtained from PSIT as part of the original suite used in their mineral investigations.

Table A.2 Properties of the Pocahantas #3 coal.

Pocahantas #3

Analyses		
Proximate	Dry	As Rec'd
Fixed Carbon	77.00	76.53
Volatile Matter	18.49	18.37
Moisture	0.62	
Ultimate	Dry	As Rec'd
C	87.52	86.98
H	4.26	4.23
O	1.55	1.54
N	1.25	1.24
S	0.75	0.75
Cl	0.16	0.16
Ash	4.51	4.49
Ash Chemistry	% dry fuel	% ash
SiO2	1.68	37.24
Al2O3	1.07	23.73
TiO2	0.05	1.12
Fe2O3	0.76	16.83
CaO	0.34	7.53
MgO	0.11	2.36
K2O	0.08	1.81
Na2O	0.04	0.81
SO3	0.30	6.67
P2O5	0.00	0.10
Cl		
Undetermined	0.08	1.81
Total	4.51	100.0
Forms of Sulfur (% dry fuel)		
Pyritic	0.21	
Organic	0.54	
Sulfatic	0.00	
Fraction Free Silica	0.04	
Fraction Pyritic Iron	0.34	
Heating Value (Btu/lb, dry)		
As Fired	15052	14960
Dulong	15282	15188
Acid Sol. Alkali (ppm)	Dry	As Rec'd
Na		
Mg		
Ca		
K		
Fusion Temp.	°F	°C
Reducing Conditions		
Initial Deformation	2176	1191
Spherical	2279	1249
Hemispherical	2332	1278
Fluid	2428	1331
Oxidizing Conditions		
Initial Deformation	2366	1297
Spherical	2395	1313
Hemispherical	2439	1337
Fluid	2487	1364

Analyses					
Size Distribution	Sieves	mass % in size bin	cum. mass %		
dp>600μm	+28	0.00	0.00		
600μm>dp>300μm	28x48	0.70	0.70		
300μm>dp>149μm	48x100	3.67	4.37		
149μm>dp>74μm	100x200	14.37	18.73		
74μm>dp>44μm	200x325	15.47	34.20		
44μm>dp	-325	65.80	100.00		
Size Distribution (Malvern)*			Size Distribution (Malvern)*		
Diameter (μm)	% in size bin	cum. vol. per.	Diameter (μm)	% in size bin	cum. vol. per.
188m	0.00	100.0	118.4m2		
162m	0.05	100.0	102.1m2		
140m	0.22	99.7	88.1m2		
121m	0.50	99.2	76m2		
104m	1.15	98.1	65.6m2		
89.9m	1.90	96.2	56.6m2		
77.5m	2.97	93.2	48.8m2		
66.9m	3.68	89.5	42.1m2		
57.7m	3.95	85.6	38.3m2		
49.8m	4.05	81.5	31.3m2		
42.9m	5.55	76.0	27m2		
37.1m	6.68	69.3	23.3m2		
32m	7.40	61.9	20.1m2		
27.6m	6.90	55.0	17.4m2		
23.8m	5.57	49.4	15m2		
20.5m	4.77	44.7	12.9m2		
17.7m	4.47	40.2	11.1m2		
15.3m	4.70	35.5	9.6m2		
13.2m	4.82	30.7	8.3m2		
11.4m	4.25	26.4	7.2m2		
9.8m	3.62	22.8	6.2m2		
8.5m	2.98	19.8	5.3m2		
7.3m	2.75	17.1	4.8m2		
6.3m	2.72	14.4	4m2		
5.4m	2.70	11.7	3.4m2		
4.7m	2.50	9.2	3m2		
4.1m	2.12	7.0	2.8m2		
3.5m	1.67	5.4	2.2m2		
3m	1.20	4.2	1.9m2		
2.6m	0.92	3.3	1.6m2		
2.2m	0.87	2.4	1.4m2		
1.9m	0.70	1.7	1.2m2		

Size Statistics (Malvern Data Only)			
		Malvern	All Data
Dv.5	Volume Mean Diam.	25.00	
Dv.9	90 % volume diameter	65.85	
Dv.1	10 percentile volume diameter	5.02	
D4,3		30.10	
D3,2	Sauter Mean Diameter	11.63	
Span		2.37	
Specific Surface Area (m^3/cc)		0.54	

*These Malvern data are for the -325 mesh size fractions.

Table A.3 Summary of Properties of the Upper Freeport Coal.

Upper Freeport

Analyses		
Proximate	Dry	As Rec'd
Fixed Carbon	54.40	53.95
Volatile Matter	24.17	23.97
Moisture	0.83	
Ultimate	Dry	As Rec'd
C	66.46	65.91
H	4.16	4.12
O	4.37	4.34
N	1.48	1.47
S	2.00	1.99
Cl	0.19	0.19
Ash	21.30	21.13
Ash Chemistry	% dry fuel	% ash
SiO2	10.93	51.29
Al2O3	5.16	24.23
TiO2	0.20	0.92
Fe2O3	2.85	13.40
CaO	0.53	2.47
MgO	0.28	1.30
K2O	0.65	3.06
Na2O	0.06	0.30
SO3	0.52	2.42
P2O5	0.03	0.14
Cl		
Undetermined	0.13	0.59
Total	21.33	100.1
Forms of Sulfur (% dry fuel)		
Pyritic	1.49	
Organic	0.48	
Sulfatic	0.11	
Fraction Free Silica	0.29	
Fraction Pyritic Iron	0.65	
Heating Value (Btu/lb, dry)		
As Fired	11830	11732
Dulong	11987	11888
Acid Sol. Alkali (ppm)	Dry	As Rec'd
Na	343	343
Mg	1208	1208
Ca	3767	3767
K	2292	2292
Fusion Temp.	°F	°C
Reducing Conditions		
Initial Deformation	2177	1192
Spherical	2317	1269
Hemispherical	2376	1302
Fluid	2437	1336
Oxidizing Conditions		
Initial Deformation	2443	1339
Spherical	2513	1378
Hemispherical	2548	1398
Fluid	2604	1429

Analyses					
Size Distribution	Sieves	mass % in size bin	cum. mass %		
dp>600μm	+28	0.00	0.00		
600μm>dp>300μm	28x48	2.63	2.63		
300μm>dp>149μm	48x100	7.33	9.97		
149μm>dp>74μm	100x200	20.90	30.87		
74μm>dp>44μm	200x325	19.53	50.40		
44μm>dp	-325	49.60	100.00		
Size Distribution (Malvern)*			Size Distribution (Malvern)*		
Diameter (μm)	% in size bin	cum. vol. per.	Diameter (μm)	% in size bin	cum. vol. per.
188m	0.00	100.0	118.4m2		
162m	0.00	100.0	102.1m2		
140m	0.00	100.0	88.1m2		
121m	0.00	100.0	76m2		
104m	0.00	100.0	65.6m2		
89.9m	0.12	99.9	56.6m2		
77.5m	0.22	99.7	48.8m2		
66.9m	0.30	99.4	42.1m2		
57.7m	0.93	98.4	38.3m2		
49.8m	3.43	95.0	31.3m2		
42.9m	5.83	89.2	27m2		
37.1m	7.73	81.4	23.3m2		
32m	8.32	73.1	20.1m2		
27.6m	7.37	65.8	17.4m2		
23.8m	6.07	59.7	15m2		
20.5m	5.38	54.3	12.9m2		
17.7m	5.87	48.4	11.1m2		
15.3m	6.38	42.1	9.6m2		
13.2m	6.03	36.0	8.3m2		
11.4m	5.12	30.9	7.2m2		
9.8m	3.98	26.9	6.2m2		
8.5m	3.42	23.5	5.3m2		
7.3m	3.47	20.0	4.8m2		
6.3m	3.75	16.3	4m2		
5.4m	3.60	12.7	3.4m2		
4.7m	2.97	9.7	3m2		
4.1m	2.30	7.4	2.8m2		
3.5m	1.68	5.7	2.2m2		
3m	1.25	4.5	1.9m2		
2.6m	1.07	3.4	1.6m2		
2.2m	0.98	2.4	1.4m2		
1.9m	1.83	0.6	1.2m2		

Size Statistics (Malvern Data Only)			
		Malvern	All Data
Dv.5	Volume Mean Diam.	16.65	
Dv.9	90 % volume diameter	39.58	
Dv.1	10 percentile volume diameter	4.38	
D4,3		19.93	
D3,2	Sauter Mean Diameter	9.52	
Span		2.12	
Specific Surface Area (m^3/cc)		0.57	

*These Malvern data are for the -325 mesh size fractions.

Table A.4 Summary of Properties of the Mingo Logan Coal.

Mingo Logan

Analyses		
Proximate	Dry	As Rec'd
Fixed Carbon	57.53	56.70
Volatile Matter	33.13	32.65
Moisture	1.44	
Ultimate	Dry	As Rec'd
C	78.14	77.01
H	4.94	4.87
O	5.28	5.20
N	1.29	1.27
S	0.87	0.85
Cl	0.15	0.15
Ash	9.34	9.21
Ash Chemistry	% dry fuel	% ash
SiO2	5.14	55.07
Al2O3	2.80	29.96
TiO2	0.13	1.41
Fe2O3	0.60	6.38
CaO	0.10	1.07
MgO	0.10	1.02
K2O	0.27	2.91
Na2O	0.05	0.49
SO3	0.11	1.22
P2O5	0.01	0.09
Cl		
Undetermined	0.04	0.39
Total	9.34	100.0
Forms of Sulfur (% dry fuel)		
Pyritic	0.23	
Organic	0.64	
Sulfatic	0.00	
Fraction Free Silica	0.18	
Fraction Pyritic Iron	0.48	
Heating Value (Btu/lb, dry)		
As Fired	13805	13607
Dulong	14054	13852
Acid Sol. Alkali (ppm)	Dry	As Rec'd
Na		
Mg		
Ca		
K		
Fusion Temp.	°F	°C
Reducing Conditions		
Initial Deformation	1428	776
Spherical	1442	783
Hemispherical	1451	788
Fluid	1473	800
Oxidizing Conditions		
Initial Deformation	1445	785
Spherical	1463	795
Hemispherical	1471	799
Fluid	1486	808

Analyses				
Size Distribution	Sieves	mass % in size bin	cum. mass %	
dp>600μm	+28	0.00	0.00	
600μm>dp>300μm	28x48	0.40	0.40	
300μm>dp>149μm	48x100	4.75	5.15	
149μm>dp>74μm	100x200	17.65	22.80	
74μm>dp>44μm	200x325	19.10	41.90	
44μm>dp	-325	58.10	100.00	
Size Distribution (Malvern)*		Size Distribution (Malvern)*		
Diameter (μm)	% in size bin	cum. vol. per.	Diameter (μm)	% in size bin	cum. vol. per.
188m	0.00	100.0	118.4m2		
162m	0.00	100.0	102.1m2		
140m	0.00	100.0	88.1m2		
121m	0.00	100.0	76m2		
104m	0.00	100.0	65.6m2		
89.9m	0.00	100.0	56.6m2		
77.5m	0.08	99.9	48.8m2		
66.9m	1.13	98.8	42.1m2		
57.7m	3.25	95.6	38.3m2		
49.8m	5.65	89.9	31.3m2		
42.9m	7.50	82.4	27m2		
37.1m	8.95	73.5	23.3m2		
32m	8.60	64.9	20.1m2		
27.6m	6.95	57.9	17.4m2		
23.8m	5.83	52.1	15m2		
20.5m	5.38	46.7	12.9m2		
17.7m	5.78	40.9	11.1m2		
15.3m	5.93	35.0	9.6m2		
13.2m	5.05	29.9	8.3m2		
11.4m	4.10	25.8	7.2m2		
9.8m	3.23	22.6	6.2m2		
8.5m	3.00	19.6	5.3m2		
7.3m	3.10	16.5	4.8m2		
6.3m	3.25	13.3	4m2		
5.4m	2.90	10.4	3.4m2		
4.7m	2.33	8.0	3m2		
4.1m	1.80	6.2	2.8m2		
3.5m	1.30	4.9	2.2m2		
3m	1.05	3.9	1.9m2		
2.6m	0.98	2.9	1.6m2		
2.2m	0.85	2.1	1.4m2		
1.9m	2.08	0.0	1.2m2		

Size Statistics (Malvern Data Only)			
		Malvern	All Data
Dv.5	Volume Mean Diam.	19.38	
Dv.9	90 % volume diameter	43.00	
Dv.1	10 percentile volume diameter	4.60	
D4,3		21.03	
D3,2	Sauter Mean Diameter	10.00	
Span		2.00	
Specific Surface Area (m^3/cc)		0.62	

*These Malvern data are for the -325 mesh size fractions.

Table A.5 Summary of Properties of the Pittsburgh #8 (3) Coal.

Pittsburgh #8 (3)

Analyses		
Proximate	Dry	As Rec'd
Fixed Carbon	52.64	52.06
Volatile Matter	38.22	37.80
Moisture	1.10	
Ultimate	Dry	As Rec'd
C	76.50	75.66
H	5.07	5.02
O	4.29	4.24
N	1.39	1.38
S	3.52	3.48
Cl	0.09	0.09
Ash	9.01	8.91
Ash Chemistry	% dry fuel	% ash
SiO2	3.53	39.16
Al2O3	1.74	19.31
TiO2	0.08	0.84
Fe2O3	2.48	27.53
CaO	0.41	4.56
MgO	0.08	0.84
K2O	0.11	1.18
Na2O	0.08	0.87
SO3	0.37	4.08
P2O5	0.03	0.34
Cl		
Undetermined	0.11	1.25
Total	9.01	100.0
Forms of Sulfur (% dry fuel)		
Pyritic	2.07	
Organic	1.42	
Sulfatic	0.03	
Fraction Free Silica	0.26	
Fraction Pyritic Iron	0.61	
Heating Value (Btu/lb, dry)		
As Fired	13728	13577
Dulong	13523	13374
Acid Sol. Alkali (ppm)	Dry	As Rec'd
Na		
Mg		
Ca		
K		
Fusion Temp.	°F	°C
Reducing Conditions		
Initial Deformation	1984	1085
Spherical	2020	1104
Hemispherical	2080	1138
Fluid	2245	1229
Oxidizing Conditions		
Initial Deformation	2387	1308
Spherical	2448	1342
Hemispherical	2496	1369
Fluid	2542	1394

Analyses		
Size Distribution	Sieves	mass % in size bin	cum. mass %
dp>600μm	+28	0.00	0.00
600μm>dp>300μm	28x48	2.27	2.27
300μm>dp>149μm	48x100	4.10	6.37
149μm>dp>74μm	100x200	26.17	32.53
74μm>dp>44μm	200x325	22.33	54.87
44μm>dp	-325	45.13	100.00

Size Distribution (Malvern)*			Size Distribution (Malvern)*		
Diameter (μm)	% in size bin	cum. vol. per.	Diameter (μm)	% in size bin	cum. vol. per.
188m	0.31	99.7	118.4m2		
162m	0.83	98.9	102.1m2		
140m	1.24	97.6	88.1m2		
121m	1.59	96.0	76m2		
104m	1.70	94.3	65.6m2		
89.9m	1.91	92.4	56.6m2		
77.5m	2.24	90.2	48.8m2		
66.9m	2.69	87.5	42.1m2		
57.7m	3.26	84.2	38.3m2		
49.8m	4.84	79.4	31.3m2		
42.9m	6.24	73.2	27m2		
37.1m	7.04	66.1	23.3m2		
32m	6.28	59.9	20.1m2		
27.6m	4.81	55.0	17.4m2		
23.8m	4.35	50.7	15m2		
20.5m	4.58	46.1	12.9m2		
17.7m	4.74	41.4	11.1m2		
15.3m	4.61	36.8	9.6m2		
13.2m	4.15	32.6	8.3m2		
11.4m	3.74	28.9	7.2m2		
9.8m	3.39	25.5	6.2m2		
8.5m	3.16	22.3	5.3m2		
7.3m	3.01	19.3	4.8m2		
6.3m	2.99	16.3	4m2		
5.4m	2.96	13.4	3.4m2		
4.7m	2.73	10.6	3m2		
4.1m	2.14	8.5	2.8m2		
3.5m	1.68	6.8	2.2m2		
3m	1.30	5.5	1.9m2		
2.6m	1.16	4.4	1.6m2		
2.2m	1.11	3.3	1.4m2		
1.9m	2.38	0.9	1.2m2		

Size Statistics (Malvern Data Only)			
		Malvern	All Data
Dv.5	Volume Mean Diam.	25.04	
Dv.9	90 % volume diameter	63.86	
Dv.1	10 percentile volume diameter	4.51	
D4,3		30.11	
D3,2	Sauter Mean Diameter	10.70	
Span		2.56	
Specific Surface Area (m^3/cc)		0.66	

*These Malvern data are for the -325 mesh size fractions.

Table A.6 Summary of Properties of the Illinois #6 (3) Coal.

Illinois #6(3)

Analyses		
Proximate	Dry	As Rec'd
Fixed Carbon	58.15	56.51
Volatile Matter	36.24	35.22
Moisture	2.81	
Ultimate	Dry	As Rec'd
C	78.18	75.98
H	5.02	4.87
O	8.25	8.02
N	1.62	1.57
S	0.95	0.92
Cl	0.38	0.37
Ash	5.62	5.46
Ash Chemistry	% dry fuel	% ash
SiO2	2.98	53.00
Al2O3	1.36	24.18
TiO2	0.07	1.28
Fe2O3	0.64	11.44
CaO	0.12	2.19
MgO	0.06	1.03
K2O	0.13	2.39
Na2O	0.14	2.41
SO3	0.11	2.00
P2O5	0.01	0.24
Cl		
Undetermined	-0.01	-0.17
Total	5.62	100.0
Forms of Sulfur (% dry fuel)		
Pyritic	0.36	
Organic	0.57	
Sulfatic	0.02	
Fraction Free Silica	0.32	
Fraction Pyritic Iron	0.70	
Heating Value (Btu/lb, dry)		
As Fired	14516	14108
Dulong	13879	13489
Acid Sol. Alkali (ppm)	Dry	As Rec'd
Na		
Mg		
Ca		
K		
Fusion Temp.	°F	°C
Reducing Conditions		
Initial Deformation	1081	583
Spherical	1183	639
Hemispherical	1228	664
Fluid	1271	688
Oxidizing Conditions		
Initial Deformation	1232	666
Spherical	1258	681
Hemispherical	1280	693
Fluid	1308	709

Analyses					
Size Distribution		Sieves	mass % in size bin		cum. mass %
dp>600μm		+28	0.00		0.00
600μm>dp>300μm		28x48	0.15		0.15
300μm>dp>149μm		48x100	2.50		2.65
149μm>dp>74μm		100x200	14.10		16.75
74μm>dp>44μm		200x325	19.75		36.50
44μm>dp		-325	63.50		100.00
Size Distribution (Malvern)*			Size Distribution (Malvern)*		
Diameter (μm)	% in size bin	cum. vol. per.	Diameter (μm)	% in size bin	cum. vol. per.
188m	0.00	100.0	118.4m2		
162m	0.08	99.9	102.1m2		
140m	0.10	99.8	88.1m2		
121m	0.10	99.7	76m2		
104m	0.10	99.6	65.6m2		
89.9m	0.23	99.4	56.6m2		
77.5m	1.20	98.2	48.8m2		
66.9m	2.95	95.3	42.1m2		
57.7m	5.40	89.9	38.3m2		
49.8m	7.88	82.0	31.3m2		
42.9m	8.90	73.1	27m2		
37.1m	9.13	64.0	23.3m2		
32m	8.13	55.8	20.1m2		
27.6m	6.55	49.3	17.4m2		
23.8m	5.85	43.4	15m2		
20.5m	5.70	37.7	12.9m2		
17.7m	5.73	32.0	11.1m2		
15.3m	5.38	26.6	9.6m2		
13.2m	4.33	22.3	8.3m2		
11.4m	3.58	18.7	7.2m2		
9.8m	2.98	15.8	6.2m2		
8.5m	2.70	13.1	5.3m2		
7.3m	2.53	10.5	4.8m2		
6.3m	2.30	8.2	4m2		
5.4m	2.03	6.2	3.4m2		
4.7m	1.78	4.4	3m2		
4.1m	1.23	3.2	2.8m2		
3.5m	1.08	2.1	2.2m2		
3m	0.70	1.4	1.9m2		
2.6m	0.48	1.0	1.6m2		
2.2m	0.35	0.6	1.4m2		
1.9m	0.73	-0.1	1.2m2		

Size Statistics (Malvern Data Only)			
		Malvern	All Data
Dv.5	Volume Mean Diam.	24.13	
Dv.9	90 % volume diameter	49.83	
Dv.1	10 percentile volume diameter	6.08	
D4,3		27.03	
D3,2	Sauter Mean Diameter	13.40	
Span		1.80	
Specific Surface Area (m^3/cc)		0.45	

*These Malvern data are for the -325 mesh size fractions.

Table A.7 Summary of Properties of the Pittsburgh #8 (2) Coal.

Pittsburgh #8 (2)

Analyses		
Proximate	Dry	As Rec'd
Fixed Carbon	56.87	55.92
Volatile Matter	36.58	35.97
Moisture	1.67	
Ultimate	Dry	As Rec'd
C	78.62	77.31
H	5.14	5.06
O	6.51	6.41
N	1.50	1.48
S	1.57	1.54
Cl	0.10	0.09
Ash	6.63	6.51
Ash Chemistry	% dry fuel	% ash
SiO2	3.16	47.70
Al2O3	1.60	24.08
TiO2	0.07	1.05
Fe2O3	1.11	16.81
CaO	0.23	3.46
MgO	0.06	0.84
K2O	0.12	1.75
Na2O	0.03	0.45
SO3	0.20	2.99
P2O5	0.04	0.62
Cl		
Undetermined	0.01	0.23
Total	6.62	100.0
Forms of Sulfur (% dry fuel)		
Pyritic	0.69	
Organic	0.82	
Sulfatic	0.05	
Fraction Free Silica	0.24	
Fraction Pyritic Iron	0.74	
Heating Value (Btu/lb, dry)		
As Fired	13994	13761
Dulong	14184	13947
Acid Sol. Alkali (ppm)	Dry	As Rec'd
Na		
Mg		
Ca		
K		
Fusion Temp.	°F	°C
Reducing Conditions		
Initial Deformation	2109	1154
Spherical	2268	1242
Hemispherical	2383	1306
Fluid	2481	1360
Oxidizing Conditions		
Initial Deformation	2472	1356
Spherical	2519	1382
Hemispherical	2550	1399
Fluid	2604	1429

Analyses		
Size Distribution	Sieves	mass % in size bin	cum. mass %
dp>600μm	+28	0.00	0.00
600μm>dp>300μm	28x48	0.27	0.27
300μm>dp>149μm	48x100	1.40	1.67
149μm>dp>74μm	100x200	27.83	29.50
74μm>dp>44μm	200x325	30.83	60.33
44μm>dp	-325	39.67	100.00

Size Distribution (Malvern)*			Size Distribution (Malvern)*		
Diameter (μm)	% in size bin	cum. vol. per.	Diameter (μm)	% in size bin	cum. vol. per.
188m	0.00	100.0	118.4m2	0.08	99.9
162m	0.00	100.0	102.1m2	0.15	99.9
140m	0.00	100.0	88.1m2	0.18	99.8
121m	0.00	100.0	76m2	0.13	99.9
104m	0.00	100.0	65.6m2	1.33	98.7
89.9m	0.25	99.8	56.6m2	5.30	94.7
77.5m	0.40	99.4	48.8m2	9.88	90.1
66.9m	0.35	99.0	42.1m2	11.45	88.6
57.7m	1.05	98.0	38.3m2	10.03	90.0
49.8m	5.35	92.6	31.3m2	8.03	92.0
42.9m	9.45	83.2	27m2	8.00	92.0
37.1m	12.60	70.6	23.3m2	8.88	91.1
32m	11.95	58.6	20.1m2	7.23	92.8
27.6m	8.55	50.1	17.4m2	4.43	95.6
23.8m	6.60	43.5	15m2	3.70	96.3
20.5m	6.00	37.5	12.9m2	4.40	95.6
17.7m	6.35	31.1	11.1m2	3.90	96.1
15.3m	6.40	24.7	9.6m2	2.88	97.1
13.2m	5.25	19.5	8.3m2	1.63	98.4
11.4m	4.05	15.4	7.2m2	1.45	98.6
9.8m	2.85	12.6	6.2m2	1.50	98.5
8.5m	2.25	10.3	5.3m2	1.33	98.7
7.3m	2.00	8.3	4.8m2	1.20	98.8
6.3m	1.80	6.5	4m2	0.93	99.1
5.4m	1.65	4.9	3.4m2	0.88	99.1
4.7m	1.35	3.5	3m2	0.70	99.3
4.1m	0.90	2.6	2.8m2	0.30	99.7
3.5m	0.80	1.8	2.2m2	0.13	99.9
3m	0.50	1.3	1.9m2	0.00	100.0
2.6m	0.35	1.0	1.6m2	0.05	100.0
2.2m	0.25	0.7	1.4m2	0.00	100.0
1.9m	0.55	0.2	1.2m2	0.00	100.0

Size Statistics (Malvern Data Only)			
		Malvern	All Data
Dv.5	Volume Mean Diam.	24.78	
Dv.9	90 % volume diameter	44.78	
Dv.1	10 percentile volume diameter	18.55	
D4,3		25.52	
D3,2	Sauter Mean Diameter	14.80	
Span		1.48	
Specific Surface Area (m^3/cc)		0.39	

*These Malvern data are for the -325 mesh size fractions.

Table A.8 Summary of Properties of the Massey Sprouce Coal.

Massey Sprouce

Analyses		
Proximate	Dry	As Rec'd
Fixed Carbon	56.99	55.69
Volatile Matter	34.68	33.89
Moisture	2.28	
Ultimate	Dry	As Rec'd
C	77.89	76.11
H	5.04	4.93
O	6.26	6.12
N	1.43	1.40
S	1.05	1.03
Cl		
Ash	8.33	8.14
Ash Chemistry	% dry fuel	% ash
SiO2	4.61	55.35
Al2O3	2.18	26.22
TiO2	0.10	1.23
Fe2O3	0.97	11.62
CaO	0.12	1.42
MgO	0.07	0.86
K2O	0.19	2.28
Na2O	0.02	0.29
SO3	0.15	1.76
P2O5	0.01	0.08
Cl		
Undetermined	-0.09	-1.11
Total	8.33	100.0
Forms of Sulfur (% dry fuel)		
Pyritic	0.49	
Organic	0.53	
Sulfatic	0.03	
Fraction Free Silica	0.29	
Fraction Pyritic Iron	0.63	
Heating Value (Btu/lb, dry)		
As Fired	13768	13454
Dulong	14012	13692
Acid Sol. Alkali (ppm)	Dry	As Rec'd
Na		
Mg		
Ca		
K		
Fusion Temp.	°F	°C
Reducing Conditions		
Initial Deformation		
Spherical		
Hemispherical		
Fluid		
Oxidizing Conditions		
Initial Deformation		
Spherical		
Hemispherical		
Fluid		

Analyses					
Size Distribution		Sieves	mass % in size bin		cum. mass %
dp>600µm		+28			
600µm>dp>300µm		28x48			
300µm>dp>149µm		48x100			
149µm>dp>74µm		100x200			
74µm>dp>44µm		200x325			
44µm>dp		-325			
Size Distribution (Malvern)*			Size Distribution (Malvern)*		
Diameter (µm)	% in size bin	cum. vol. per.	Diameter (µm)	% in size bin	cum. vol. per.
188m			118.4m2		
162m			102.1m2		
140m			88.1m2		
121m			76m2		
104m			65.6m2		
89.9m			56.6m2		
77.5m			48.8m2		
66.9m			42.1m2		
57.7m			38.3m2		
49.8m			31.3m2		
42.9m			27m2		
37.1m			23.3m2		
32m			20.1m2		
27.6m			17.4m2		
23.8m			15m2		
20.5m			12.9m2		
17.7m			11.1m2		
15.3m			9.6m2		
13.2m			8.3m2		
11.4m			7.2m2		
9.8m			6.2m2		
8.5m			5.3m2		
7.3m			4.8m2		
6.3m			4m2		
5.4m			3.4m2		
4.7m			3m2		
4.1m			2.8m2		
3.5m			2.2m2		
3m			1.9m2		
2.6m			1.6m2		
2.2m			1.4m2		
1.9m			1.2m2		

Size Statistics (Malvern Data Only)		Malvern	All Data
Dv.5	Volume Mean Diam.		
Dv.9	90 % volume diameter		
Dv.1	10 percentile volume diameter		
D4,3			
D3,2	Sauter Mean Diameter		
Span			
Specific Surface Area (m^3/cc)			

*These Malvern data are for the -325 mesh size fractions.

Table A.9 Summary of Properties of the Eastern Kentucky Coal.

Eastern Kentucky

Analyses		
Proximate	Dry	As Rec'd
Fixed Carbon	53.00	52.28
Volatile Matter	36.87	36.37
Moisture	1.36	
Ultimate	Dry	As Rec'd
C	74.82	73.80
H	4.97	4.90
O	7.57	7.47
N	1.46	1.44
S	0.97	0.96
Cl	0.09	0.09
Ash	10.15	10.02
Ash Chemistry	% dry fuel	% ash
SiO2	5.86	57.67
Al2O3	3.09	30.39
TiO2	0.21	2.06
Fe2O3	0.49	4.83
CaO	0.12	1.15
MgO	0.04	0.41
K2O	0.10	0.99
Na2O	0.02	0.17
SO3	0.13	1.28
P2O5	0.01	0.13
Cl		
Undetermined	0.09	0.91
Total	10.15	100.0
Forms of Sulfur (% dry fuel)		
Pyritic	0.31	
Organic	0.66	
Sulfatic	0.00	
Fraction Free Silica	0.21	
Fraction Pyritic Iron	0.78	
Heating Value (Btu/lb, dry)		
As Fired	13226	13046
Dulong	13418	13235
Acid Sol. Alkali (ppm)	Dry	As Rec'd
Na		
Mg		
Ca		
K		
Fusion Temp.	°F	°C
Reducing Conditions		
Initial Deformation	2949	1620
Spherical	2980	1638
Hemispherical	2992	1644
Fluid	3000	1649
Oxidizing Conditions		
Initial Deformation	2960	1627
Spherical	2996	1647
Hemispherical	3000	1649
Fluid	3000	1649

Analyses					
Size Distribution	Sieves	mass % in size bin	cum. mass %		
dp>600μm	+28	0.00	0.00		
600μm>dp>300μm	28x48	0.05	0.05		
300μm>dp>149μm	48x100	1.43	1.48		
149μm>dp>74μm	100x200	32.50	33.98		
74μm>dp>44μm	200x325	30.15	64.13		
44μm>dp	-325	35.88	100.00		
Size Distribution (Malvern)*			Size Distribution (Malvern)*		
Diameter (μm)	% in size bin	cum. vol. per.	Diameter (μm)	% in size bin	cum. vol. per.
188m	0.00	100.0	118.4m2	0.05	100.0
162m	0.05	100.0	102.1m2	0.13	99.9
140m	0.05	99.9	88.1m2	0.15	99.9
121m	0.05	99.9	76m2	0.23	99.8
104m	0.05	99.8	65.6m2	1.98	98.0
89.9m	0.18	99.6	56.6m2	5.58	94.4
77.5m	0.63	99.0	48.8m2	9.70	90.3
66.9m	1.48	97.5	42.1m2	10.70	89.3
57.7m	2.98	94.6	38.3m2	8.63	91.4
49.8m	5.85	88.7	31.3m2	6.40	93.6
42.9m	8.43	80.3	27m2	6.98	93.0
37.1m	9.73	70.6	23.3m2	8.98	91.0
32m	9.08	61.5	20.1m2	7.55	92.5
27.6m	7.48	54.0	17.4m2	4.28	95.7
23.8m	6.40	47.6	15m2	3.30	96.7
20.5m	5.73	41.9	12.9m2	4.13	95.9
17.7m	5.35	36.5	11.1m2	4.35	95.7
15.3m	5.30	31.2	9.6m2	3.90	96.1
13.2m	4.95	26.3	8.3m2	2.40	97.6
11.4m	4.18	22.1	7.2m2	1.63	98.4
9.8m	3.33	18.8	6.2m2	1.68	98.3
8.5m	2.75	16.0	5.3m2	1.78	98.2
7.3m	2.50	13.5	4.8m2	1.60	98.4
6.3m	2.48	11.1	4m2	1.40	98.6
5.4m	2.43	8.6	3.4m2	1.15	98.9
4.7m	2.13	6.5	3m2	0.93	99.1
4.1m	1.65	4.9	2.8m2	0.45	99.6
3.5m	1.35	3.5	2.2m2	0.15	99.9
3m	0.93	2.6	1.9m2	0.00	100.0
2.6m	0.65	1.9	1.6m2	0.00	100.0
2.2m	0.58	1.4	1.4m2	0.00	100.0
1.9m	0.60	0.8	1.2m2	0.00	100.0

Size Statistics (Malvern Data Only)			
		Malvern	All Data
Dv.5	Volume Mean Diam.	23.48	
Dv.9	90 % volume diameter	47.54	
Dv.1	10 percentile volume diameter	6.28	
D4,3		25.23	
D3,2	Sauter Mean Diameter	13.04	
Span		1.75	
Specific Surface Area (m^3/cc)		0.45	

*These Malvern data are for the -325 mesh size fractions.

Table A.10 Summary of Properties of the Pittsbugh #8 (1) Coal.

Pittsburgh #8 (1)

Analyses		
Proximate	Dry	As Rec'd
Fixed Carbon	49.16	48.66
Volatile Matter	40.16	39.75
Moisture	1.02	
Ultimate	Dry	As Rec'd
C	71.51	70.78
H	5.03	4.98
O	6.76	6.69
N	1.24	1.23
S	4.78	4.73
Cl		
Ash	10.68	10.57
Ash Chemistry	% dry fuel	% ash
SiO2	4.42	41.40
Al2O3	2.19	20.51
TiO2	0.10	0.89
Fe2O3	3.10	29.03
CaO	0.22	2.07
MgO	0.08	0.78
K2O	0.18	1.73
Na2O	0.04	0.40
SO3	0.25	2.33
P2O5	0.02	0.15
Cl		
Undetermined	0.08	0.71
Total	10.68	100.0
Forms of Sulfur (% dry fuel)		
Pyritic	1.81	
Organic	2.82	
Sulfatic	0.15	
Fraction Free Silica	0.26	
Fraction Pyritic Iron	0.73	
Heating Value (Btu/lb, dry)		
As Fired	13004	12871
Dulong	13190	13055
Acid Sol. Alkali (ppm)	Dry	As Rec'd
Na		
Mg		
Ca		
K		
Fusion Temp.	°F	°C
Reducing Conditions		
Initial Deformation	1917	1047
Spherical	1980	1082
Hemispherical	2154	1179
Fluid	2232	1222
Oxidizing Conditions		
Initial Deformation	2438	1337
Spherical	2502	1372
Hemispherical	2518	1381
Fluid	2532	1389

Analyses			
Size Distribution	Sieves	mass % in size bin	cum. mass %
dp>600μm	+28	0.00	0.00
600μm>dp>300μm	28x48	0.20	0.20
300μm>dp>149μm	48x100	0.80	1.00
149μm>dp>74μm	100x200	22.10	23.10
74μm>dp>44μm	200x325	34.80	57.90
44μm>dp	-325	42.10	100.00

Size Distribution (Malvern)*			Size Distribution (Malvern)*		
Diameter (μm)	% in size bin	cum. vol. per.	Diameter (μm)	% in size bin	cum. vol. per.
188m			118.4m2		
162m			102.1m2		
140m			88.1m2		
121m			76m2		
104m			65.6m2		
89.9m			56.6m2		
77.5m			48.8m2		
66.9m			42.1m2		
57.7m			38.3m2		
49.8m			31.3m2		
42.9m			27m2		
37.1m			23.3m2		
32m			20.1m2		
27.6m			17.4m2		
23.8m			15m2		
20.5m			12.9m2		
17.7m			11.1m2		
15.3m			9.6m2		
13.2m			8.3m2		
11.4m			7.2m2		
9.8m			6.2m2		
8.5m			5.3m2		
7.3m			4.8m2		
6.3m			4m2		
5.4m			3.4m2		
4.7m			3m2		
4.1m			2.8m2		
3.5m			2.2m2		
3m			1.9m2		
2.6m			1.6m2		
2.2m			1.4m2		
1.9m			1.2m2		

Size Statistics (Malvern Data Only)		Malvern	All Data
Dv.5	Volume Mean Diam.		
Dv.9	90 % volume diameter		
Dv.1	10 percentile volume diameter		
D4,3			
D3,2	Sauter Mean Diameter		
Span			
Specific Surface Area (m^3/cc)			

*These Malvern data are for the -325 mesh size fractions.

Table A.11 Summary of Properties of the Utah Blind Canyon Coal.

Utah Blind Canyon

Analyses		
Proximate	Dry	As Rec'd
Fixed Carbon	45.59	44.12
Volatile Matter	43.92	42.50
Moisture	3.24	
Ultimate	Dry	As Rec'd
C	72.62	70.27
H	5.50	5.32
O	9.57	9.26
N	1.33	1.29
S	0.46	0.44
Cl	0.04	0.04
Ash	10.51	10.17
Ash Chemistry	% dry fuel	% ash
SiO2	6.06	57.69
Al2O3	1.92	18.32
TiO2	0.10	0.96
Fe2O3	0.43	4.11
CaO	0.64	6.13
MgO	0.19	1.84
K2O	0.12	1.16
Na2O	0.45	4.32
SO3	0.48	4.57
P2O5	0.03	0.33
Cl		
Undetermined	0.06	0.58
Total	10.51	100.0
Forms of Sulfur (% dry fuel)		
Pyritic	0.08	
Organic	0.37	
Sulfatic	0.00	
Fraction Free Silica	0.52	
Fraction Pyritic Iron	0.24	
Heating Value (Btu/lb, dry)		
As Fired	13108	12684
Dulong	13247	12819
Acid Sol. Alkali (ppm)	Dry	As Rec'd
Na		
Mg		
Ca		
K		
Fusion Temp.	°F	°C
Reducing Conditions		
Initial Deformation	2178	1192
Spherical	2246	1230
Hemispherical	2369	1298
Fluid	2641	1449
Oxidizing Conditions		
Initial Deformation	2220	1216
Spherical	2265	1241
Hemispherical	2400	1316
Fluid	2675	1468

Analyses				
Size Distribution	Sieves	mass % in size bin	cum. mass %	
dp>600μm	+28	0.00	0.00	
600μm>dp>300μm	28x48	0.33	0.33	
300μm>dp>149μm	48x100	5.90	6.23	
149μm>dp>74μm	100x200	24.90	31.13	
74μm>dp>44μm	200x325	21.43	52.57	
44μm>dp	-325	47.43	100.00	
Size Distribution (Malvern)*		Size Distribution (Malvern)*		
Diameter (μm)	% in size bin	cum. vol. per.	Diameter (μm)	% in size bin	cum. vol. per.
188m	0.00	100.0	118.4m2		
162m	0.00	100.0	102.1m2		
140m	0.00	100.0	88.1m2		
121m	0.00	100.0	76m2		
104m	0.00	100.0	65.6m2		
89.9m	0.08	99.9	56.6m2		
77.5m	0.28	99.7	48.8m2		
66.9m	0.63	99.0	42.1m2		
57.7m	1.35	97.7	38.3m2		
49.8m	3.68	94.0	31.3m2		
42.9m	7.55	86.5	27m2		
37.1m	9.68	76.8	23.3m2		
32m	9.13	67.7	20.1m2		
27.6m	7.45	60.2	17.4m2		
23.8m	6.28	53.9	15m2		
20.5m	5.78	48.2	12.9m2		
17.7m	5.93	42.2	11.1m2		
15.3m	6.05	36.2	9.6m2		
13.2m	5.50	30.7	8.3m2		
11.4m	4.60	26.1	7.2m2		
9.8m	3.68	22.4	6.2m2		
8.5m	3.15	19.3	5.3m2		
7.3m	3.00	16.3	4.8m2		
6.3m	2.95	13.3	4m2		
5.4m	2.78	10.5	3.4m2		
4.7m	2.35	8.2	3m2		
4.1m	1.70	6.5	2.8m2		
3.5m	1.45	5.0	2.2m2		
3m	1.05	4.0	1.9m2		
2.6m	0.88	3.1	1.6m2		
2.2m	0.83	2.3	1.4m2		
1.9m	1.20	1.1	1.2m2		

Size Statistics (Malvern Data Only)			
		Malvern	All Data
Dv.5	Volume Mean Diam.	20.25	
Dv.9	90 % volume diameter	42.45	
Dv.1	10 percentile volume diameter	4.95	
D4,3		22.58	
D3,2	Sauter Mean Diameter	10.88	
Span		1.88	
Specific Surface Area (m^3/cc)		0.58	

*These Malvern data are for the -325 mesh size fractions.

Table A.12 Summary of Properties of the Kentucky #11 Coal.

Kentucky #11

Analyses		
Proximate	Dry	As Rec'd
Fixed Carbon	42.82	41.14
Volatile Matter	34.97	33.60
Moisture	3.91	
Ultimate	Dry	As Rec'd
C	59.15	56.84
H	4.44	4.26
O	8.25	7.93
N	1.16	1.11
S	4.78	4.60
Cl	0.03	0.03
Ash	22.15	21.28
Ash Chemistry	% dry fuel	% ash
SiO2	10.14	45.76
Al2O3	4.06	18.33
TiO2	0.19	0.84
Fe2O3	4.70	21.23
CaO	0.95	4.30
MgO	0.24	1.11
K2O	0.48	2.17
Na2O	0.08	0.36
SO3	1.02	4.61
P2O5	0.04	0.20
Cl	0.02	0.09
Undetermined	0.23	1.02
Total	22.16	100.0
Forms of Sulfur (% dry fuel)		
Pyritic	2.99	
Organic	1.59	
Sulfatic	0.20	
Fraction Free Silica	0.40	
Fraction Pyritic Iron	0.80	
Heating Value (Btu/lb, dry)		
As Fired	10524	10112
Dulong	10909	10482
Acid Sol. Alkali (ppm)	Dry	As Rec'd
Na	400	400
Mg	1037	1037
Ca	4981	4981
K	3578	3578
Fusion Temp.	°F	°C
Reducing Conditions		
Initial Deformation	2238	1226
Spherical	2270	1243
Hemispherical	2310	1266
Fluid	2352	1289
Oxidizing Conditions		
Initial Deformation	2314	1268
Spherical	2354	1290
Hemispherical	2404	1318
Fluid	2446	1341

Analyses			
Size Distribution	Sieves	mass % in size bin	cum. mass %
dp>600μm	+28	0.00	0.00
600μm>dp>300μm	28x48	0.20	0.20
300μm>dp>149μm	48x100	2.70	2.90
149μm>dp>74μm	100x200	15.40	18.30
74μm>dp>44μm	200x325	22.70	41.00
44μm>dp	-325	59.00	100.00

Size Distribution (Malvern)*			Size Distribution (Malvern)*		
Diameter (μm)	% in size bin	cum. vol. per.	Diameter (μm)	% in size bin	cum. vol. per.
188m	0.00	100.0	118.4m2		
162m	0.00	100.0	102.1m2		
140m	0.00	100.0	88.1m2		
121m	0.00	100.0	76m2		
104m	0.00	100.0	65.6m2		
89.9m	0.15	99.9	56.6m2		
77.5m	0.45	99.4	48.8m2		
66.9m	0.80	98.6	42.1m2		
57.7m	1.60	97.0	38.3m2		
49.8m	3.85	93.2	31.3m2		
42.9m	6.65	86.5	27m2		
37.1m	9.55	77.0	23.3m2		
32m	9.90	67.1	20.1m2		
27.6m	8.15	58.9	17.4m2		
23.8m	6.85	52.1	15m2		
20.5m	6.20	45.9	12.9m2		
17.7m	6.20	39.7	11.1m2		
15.3m	6.35	33.3	9.6m2		
13.2m	5.70	27.6	8.3m2		
11.4m	4.75	22.8	7.2m2		
9.8m	3.50	19.3	6.2m2		
8.5m	2.90	16.5	5.3m2		
7.3m	2.80	13.6	4.8m2		
6.3m	2.75	10.9	4m2		
5.4m	2.60	8.3	3.4m2		
4.7m	2.20	6.1	3m2		
4.1m	1.55	4.5	2.8m2		
3.5m	1.15	3.4	2.2m2		
3m	0.85	2.5	1.9m2		
2.6m	0.70	1.8	1.6m2		
2.2m	0.55	1.3	1.4m2		
1.9m	1.25	0.0	1.2m2		

Size Statistics (Malvern Data Only)			
		Malvern	All Data
Dv.5	Volume Mean Diam.	19.55	
Dv.9	90 % volume diameter	39.75	
Dv.1	10 percentile volume diameter	5.20	
D4,3		21.75	
D3,2	Sauter Mean Diameter	11.25	
Span		1.80	
Specific Surface Area (m^3/cc)		0.55	

*These Malvern data are for the -325 mesh size fractions.

Table A.13 Summary of Properties of the Illinois #6 (2) Coal.

Illinois #6 (2)

Analyses		
Proximate	Dry	As Rec'd
Fixed Carbon	48.34	46.30
Volatile Matter	39.46	37.79
Moisture	4.22	
Ultimate	Dry	As Rec'd
C	68.12	65.24
H	4.74	4.54
O	9.91	9.49
N	1.22	1.17
S	3.72	3.57
Cl	0.08	0.08
Ash	12.21	11.69
Ash Chemistry	% dry fuel	% ash
SiO2	5.94	48.66
Al2O3	2.20	18.00
TiO2	0.11	0.87
Fe2O3	2.23	18.31
CaO	0.58	4.78
MgO	0.12	1.02
K2O	0.25	2.08
Na2O	0.12	1.02
SO3	0.55	4.53
P2O5	0.03	0.21
Cl		
Undetermined	0.12	0.94
Total	12.26	100.4
Forms of Sulfur (% dry fuel)		
Pyritic	1.06	
Organic	2.21	
Sulfatic	0.54	
Fraction Free Silica	0.45	
Fraction Pyritic Iron	0.44	
Heating Value (Btu/lb, dry)		
As Fired	12059	11550
Dulong	12228	11712
Acid Sol. Alkali (ppm)	Dry	As Rec'd
Na		
Mg		
Ca		
K		
Fusion Temp.	°F	°C
Reducing Conditions		
Initial Deformation	1996	1091
Spherical	2054	1123
Hemispherical	2177	1192
Fluid	2367	1297
Oxidizing Conditions		
Initial Deformation	2291	1255
Spherical	2331	1277
Hemispherical	2360	1293
Fluid	2480	1360

Analyses		
Size Distribution	Sieves	mass % in size bin	cum. mass %
dp>600μm	+28	0.00	0.00
600μm>dp>300μm	28x48	0.00	0.00
300μm>dp>149μm	48x100	1.78	1.78
149μm>dp>74μm	100x200	25.20	26.98
74μm>dp>44μm	200x325	25.88	52.85
44μm>dp	-325	47.15	100.00

Size Distribution (Malvern)*			Size Distribution (Malvern)*		
Diameter (μm)	% in size bin	cum. vol. per.	Diameter (μm)	% in size bin	cum. vol. per.
188m	0.00	100.0	118.4m2		
162m	0.02	100.0	102.1m2		
140m	0.07	99.9	88.1m2		
121m	0.08	99.8	76m2		
104m	0.08	99.8	65.6m2		
89.9m	0.08	99.7	56.6m2		
77.5m	0.42	99.3	48.8m2		
66.9m	1.72	97.5	42.1m2		
57.7m	3.88	93.7	38.3m2		
49.8m	6.70	87.0	31.3m2		
42.9m	9.10	77.9	27m2		
37.1m	9.83	68.0	23.3m2		
32m	9.15	58.9	20.1m2		
27.6m	7.75	51.1	17.4m2		
23.8m	6.55	44.6	15m2		
20.5m	5.88	38.7	12.9m2		
17.7m	5.65	33.0	11.1m2		
15.3m	5.38	27.7	9.6m2		
13.2m	4.70	23.0	8.3m2		
11.4m	3.73	19.2	7.2m2		
9.8m	2.95	16.3	6.2m2		
8.5m	2.52	13.8	5.3m2		
7.3m	2.32	11.4	4.8m2		
6.3m	2.18	9.3	4m2		
5.4m	2.07	7.2	3.4m2		
4.7m	1.75	5.4	3m2		
4.1m	1.38	4.1	2.8m2		
3.5m	1.07	3.0	2.2m2		
3m	0.85	2.1	1.9m2		
2.6m	0.58	1.6	1.6m2		
2.2m	0.42	1.1	1.4m2		
1.9m	0.50	0.6	1.2m2		

Size Statistics (Malvern Data Only)			
		Malvern	All Data
Dv.5	Volume Mean Diam.	25.65	
Dv.9	90 % volume diameter	50.57	
Dv.1	10 percentile volume diameter	6.52	
D4,3		27.65	
D3,2	Sauter Mean Diameter	13.97	
Span		1.73	
Specific Surface Area (m^3/cc)		0.44	

*These Malvern data are for the -325 mesh size fractions.

Table A.14 Summary of Properties of the SOAP.

Spherical Oil Agglomerate

Analyses		
Proximate	Dry	As Rec'd
Fixed Carbon	53.04	47.15
Volatile Matter	42.98	38.20
Moisture	11.10	
Ultimate	Dry	As Rec'd
C	74.63	66.34
H	5.21	4.63
O	11.86	10.54
N	1.20	1.06
S	3.07	2.73
Cl	0.06	0.05
Ash	3.99	3.54
Ash Chemistry	% dry fuel	% ash
SiO2	1.25	31.44
Al2O3	0.66	16.66
TiO2	0.08	2.09
Fe2O3	1.52	38.03
CaO	0.11	2.72
MgO	0.04	1.06
K2O	0.07	1.86
Na2O	0.04	1.02
SO3	0.15	3.66
P2O5	0.01	0.14
Cl		
Undetermined	0.05	1.26
Total	3.98	99.9
Forms of Sulfur (% dry fuel)		
Pyritic	0.03	
Organic	2.19	
Sulfatic	0.85	
Fraction Free Silica	0.20	
Fraction Pyritic Iron	0.02	
Heating Value (Btu/lb, dry)		
As Fired	13656	12139
Dulong	13289	11813
Acid Sol. Alkali (ppm)	Dry	As Rec'd
Na		
Mg		
Ca		
K		
Fusion Temp.	°F	°C
Reducing Conditions		
Initial Deformation	2108	1153
Spherical	2257	1236
Hemispherical	2344	1284
Fluid	2394	1312
Oxidizing Conditions		
Initial Deformation	2442	1339
Spherical	2531	1388
Hemispherical	2569	1409
Fluid	2600	1426

Analyses			
Size Distribution	Sieves	mass % in size bin	cum. mass %
dp>600μm	+28	0.27	0.27
600μm>dp>300μm	28x48	23.40	23.67
300μm>dp>149μm	48x100	6.57	30.23
149μm>dp>74μm	100x200	3.77	34.00
74μm>dp>44μm	200x325	1.80	35.80
44μm>dp	-325	64.20	100.00

Size Distribution (Malvern)*			Size Distribution (Malvern)*		
Diameter (μm)	% in size bin	cum. vol. per.	Diameter (μm)	% in size bin	cum. vol. per.
188m	0.00	100.0	118.4m2		
162m	0.00	100.0	102.1m2		
140m	0.00	100.0	88.1m2		
121m	0.00	100.0	76m2		
104m	0.00	100.0	65.6m2		
89.9m	0.00	100.0	56.6m2		
77.5m	0.00	100.0	48.8m2		
66.9m	0.00	100.0	42.1m2		
57.7m	0.02	100.0	38.3m2		
49.8m	0.03	100.0	31.3m2		
42.9m	0.10	99.9	27m2		
37.1m	0.53	99.3	23.3m2		
32m	0.92	98.4	20.1m2		
27.6m	2.05	96.4	17.4m2		
23.8m	3.80	92.6	15m2		
20.5m	5.17	87.4	12.9m2		
17.7m	6.22	81.2	11.1m2		
15.3m	7.15	74.0	9.6m2		
13.2m	7.83	66.2	8.3m2		
11.4m	8.40	57.8	7.2m2		
9.8m	8.33	49.5	6.2m2		
8.5m	7.73	41.7	5.3m2		
7.3m	6.95	34.8	4.8m2		
6.3m	6.53	28.2	4m2		
5.4m	6.18	22.1	3.4m2		
4.7m	5.53	16.5	3m2		
4.1m	4.47	12.1	2.8m2		
3.5m	3.17	8.9	2.2m2		
3m	2.23	6.7	1.9m2		
2.6m	1.73	4.9	1.6m2		
2.2m	1.43	3.5	1.4m2		
1.9m	2.58	0.9	1.2m2		

Size Statistics (Malvern Data Only)			
		Malvern	All Data
Dv.5	Volume Mean Diam.	8.98	
Dv.9	90 % volume diameter	19.92	
Dv.1	10 percentile volume diameter	3.40	
D4,3		10.42	
D3,2	Sauter Mean Diameter	6.47	
Span		1.85	
Specific Surface Area (m^3/cc)		0.83	

*These Malvern data are for the -325 mesh size fractions.

Table A.15 Summary of Properties of the Kentucky #9 Coal.

Kentucky #9

Analyses		
Proximate	Dry	As Rec'd
Fixed Carbon	46.77	43.34
Volatile Matter	37.56	34.80
Moisture	7.34	
Ultimate	Dry	As Rec'd
C	64.85	60.09
H	4.60	4.26
O	9.22	8.55
N	1.61	1.49
S	4.00	3.71
Cl	0.06	0.05
Ash	15.64	14.49
Ash Chemistry	% dry fuel	% ash
SiO2	7.12	45.54
Al2O3	3.08	19.71
TiO2	0.15	0.98
Fe2O3	3.61	23.09
CaO	0.50	3.22
MgO	0.16	1.05
K2O	0.39	2.47
Na2O	0.14	0.87
SO3	0.57	3.62
P2O5	0.02	0.14
Cl	0.03	0.17
Undetermined	-0.12	-0.77
Total	15.65	100.1
Forms of Sulfur (% dry fuel)		
Pyritic	1.70	
Organic	1.89	
Sulfatic	0.41	
Fraction Free Silica	0.34	
Fraction Pyritic Iron	0.59	
Heating Value (Btu/lb, dry)		
As Fired	11611	10759
Dulong	15493	14356
Acid Sol. Alkali (ppm)	Dry	As Rec'd
Na	694	694
Mg	830	830
Ca	2835	2835
K	2225	2225
Fusion Temp.	°F	°C
Reducing Conditions		
Initial Deformation	1979	1082
Spherical	2041	1116
Hemispherical	2170	1188
Fluid	2339	1282
Oxidizing Conditions		
Initial Deformation	2323	1273
Spherical	2414	1323
Hemispherical	2469	1354
Fluid	2526	1385

Analyses					
Size Distribution	Sieves	mass % in size bin	cum. mass %		
dp>600μm	+28	0.00	0.00		
600μm>dp>300μm	28x48	0.13	0.13		
300μm>dp>149μm	48x100	2.05	2.18		
149μm>dp>74μm	100x200	13.98	16.15		
74μm>dp>44μm	200x325	24.60	40.75		
44μm>dp	-325	59.25	100.00		
Size Distribution (Malvern)*		Size Distribution (Malvern)*			
Diameter (μm)	% in size bin	cum. vol. per.	Diameter (μm)	% in size bin	cum. vol. per.
188m	0.00	100.0	118.4m2		
162m	0.00	100.0	102.1m2		
140m	0.02	100.0	88.1m2		
121m	0.03	100.0	76m2		
104m	0.02	99.9	65.6m2		
89.9m	0.07	99.9	56.6m2		
77.5m	0.33	99.5	48.8m2		
66.9m	1.23	98.3	42.1m2		
57.7m	2.92	95.4	38.3m2		
49.8m	5.38	90.0	31.3m2		
42.9m	7.83	82.2	27m2		
37.1m	9.22	73.0	23.3m2		
32m	9.33	63.6	20.1m2		
27.6m	8.38	55.2	17.4m2		
23.8m	7.28	48.0	15m2		
20.5m	6.35	41.6	12.9m2		
17.7m	5.83	35.8	11.1m2		
15.3m	5.72	30.1	9.6m2		
13.2m	5.37	24.7	8.3m2		
11.4m	4.45	20.2	7.2m2		
9.8m	3.48	16.8	6.2m2		
8.5m	2.80	14.0	5.3m2		
7.3m	2.42	11.5	4.8m2		
6.3m	2.28	9.3	4m2		
5.4m	2.13	7.1	3.4m2		
4.7m	1.85	5.3	3m2		
4.1m	1.47	3.8	2.8m2		
3.5m	1.15	2.7	2.2m2		
3m	0.87	1.8	1.9m2		
2.6m	0.57	1.2	1.6m2		
2.2m	0.38	0.8	1.4m2		
1.9m	0.37	0.5	1.2m2		

Size Statistics (Malvern Data Only)			
		Malvern	All Data
Dv.5	Volume Mean Diam.	23.57	
Dv.9	90 % volume diameter	47.35	
Dv.1	10 percentile volume diameter	6.53	
D4,3		26.15	
D3,2	Sauter Mean Diameter	13.80	
Span		1.77	
Specific Surface Area (m^3/cc)		0.44	

*These Malvern data are for the -325 mesh size fractions.

Table A.16 Summary of Properties of the Hanna Basin Coal.

Hanna Basin

Analyses		
Proximate	Dry	As Rec'd
Fixed Carbon	50.36	45.35
Volatile Matter	39.49	35.55
Moisture	9.96	
Ultimate	Dry	As Rec'd
C	67.12	60.44
H	4.79	4.31
O	16.02	14.42
N	1.26	1.13
S	0.65	0.58
Cl	0.03	0.02
Ash	9.99	9.00
Ash Chemistry	% dry fuel	% ash
SiO2	3.63	36.34
Al2O3	1.49	14.94
TiO2	0.07	0.75
Fe2O3	0.82	8.21
CaO	2.20	22.01
MgO	0.33	3.26
K2O	0.08	0.82
Na2O	0.09	0.87
SO3	1.07	10.76
P2O5	0.07	0.66
Cl		
Undetermined	0.10	1.01
Total	9.95	99.6
Forms of Sulfur (% dry fuel)		
Pyritic	0.19	
Organic	0.43	
Sulfatic	0.03	
Fraction Free Silica	0.38	
Fraction Pyritic Iron	0.19	
Heating Value (Btu/lb, dry)		
As Fired	11921	10734
Dulong	11517	10370
Acid Sol. Alkali (ppm)	Dry	As Rec'd
Na		
Mg		
Ca		
K		
Fusion Temp.	°F	°C
Reducing Conditions		
Initial Deformation	2186	1196
Spherical	2245	1229
Hemispherical	2276	1246
Fluid	2338	1281
Oxidizing Conditions		
Initial Deformation	2275	1246
Spherical	2316	1269
Hemispherical	2349	1287
Fluid	2452	1344

Analyses					
Size Distribution	Sieves	mass % in size bin	cum. mass %		
dp>600μm	+28	0.00	0.00		
600μm>dp>300μm	28x48	0.00	0.00		
300μm>dp>149μm	48x100	6.30	6.30		
149μm>dp>74μm	100x200	25.40	31.70		
74μm>dp>44μm	200x325	24.60	56.30		
44μm>dp	-325	43.70	100.00		
Size Distribution (Malvern)*		Size Distribution (Malvern)*			
Diameter (μm)	% in size bin	cum. vol. per.	Diameter (μm)	% in size bin	cum. vol. per.
188m	0.00	100.0	118.4m2		
162m	0.05	100.0	102.1m2		
140m	0.10	99.9	88.1m2		
121m	0.15	99.7	76m2		
104m	0.20	99.5	65.6m2		
89.9m	0.15	99.4	56.6m2		
77.5m	0.45	98.9	48.8m2		
66.9m	1.90	97.0	42.1m2		
57.7m	4.25	92.8	38.3m2		
49.8m	7.45	85.3	31.3m2		
42.9m	10.35	75.0	27m2		
37.1m	10.80	64.2	23.3m2		
32m	10.05	54.1	20.1m2		
27.6m	8.30	45.8	17.4m2		
23.8m	6.30	39.5	15m2		
20.5m	5.40	34.1	12.9m2		
17.7m	5.15	29.0	11.1m2		
15.3m	5.05	23.9	9.6m2		
13.2m	4.60	19.3	8.3m2		
11.4m	3.45	15.9	7.2m2		
9.8m	2.70	13.2	6.2m2		
8.5m	2.15	11.0	5.3m2		
7.3m	1.90	9.1	4.8m2		
6.3m	1.70	7.4	4m2		
5.4m	1.60	5.8	3.4m2		
4.7m	1.40	4.4	3m2		
4.1m	1.20	3.2	2.8m2		
3.5m	0.95	2.3	2.2m2		
3m	0.75	1.5	1.9m2		
2.6m	0.50	1.0	1.6m2		
2.2m	0.35	0.7	1.4m2		
1.9m	0.25	0.4	1.2m2		

Size Statistics (Malvern Data Only)			
		Malvern	All Data
Dv.5	Volume Mean Diam.	29.70	
Dv.9	90 % volume diameter	54.20	
Dv.1	10 percentile volume diameter	7.85	
D4,3		31.15	
D3,2	Sauter Mean Diameter	16.15	
Span		1.55	
Specific Surface Area (m^3/cc)		0.38	

*These Malvern data are for the -325 mesh size fractions.

Table A.17 Summary of Properties of the Illinois #6 (1) Coal.

Illinois #6 (1)

Analyses		
Proximate	Dry	As Rec'd
Fixed Carbon	48.90	43.69
Volatile Matter	40.83	36.48
Moisture	10.65	
Ultimate	Dry	As Rec'd
C	68.50	61.20
H	5.04	4.50
O	10.40	9.29
N	1.44	1.29
S	4.33	3.87
Cl	0.10	0.09
Ash	10.24	9.15
Ash Chemistry	% dry fuel	% ash
SiO2	4.75	46.35
Al2O3	1.71	16.74
TiO2	0.09	0.88
Fe2O3	2.10	20.49
CaO	0.53	5.15
MgO	0.08	0.78
K2O	0.21	2.01
Na2O	0.13	1.28
SO3	0.51	4.95
P2O5	0.02	0.16
Cl	0.02	0.16
Undetermined	0.10	0.96
Total	10.23	99.9
Forms of Sulfur (% dry fuel)		
Pyritic	1.20	
Organic	2.78	
Sulfatic	0.36	
Fraction Free Silica	0.46	
Fraction Pyritic Iron	0.72	
Heating Value (Btu/lb, dry)		
As Fired	12182	10885
Dulong	12457	11131
Acid Sol. Alkali (ppm)	Dry	As Rec'd
Na	2256	2256
Mg	1766	1766
Ca	5977	5977
K	2380	2380
Fusion Temp.	°F	°C
Reducing Conditions		
Initial Deformation	1939	1060
Spherical	1995	1090
Hemispherical	2110	1154
Fluid	2287	1253
Oxidizing Conditions		
Initial Deformation	2266	1241
Spherical	2291	1255
Hemispherical	2346	1285
Fluid	2491	1366

Analyses			
Size Distribution	Sieves	mass % in size bin	cum. mass %
dp>600μm	+28	0.00	0.00
600μm>dp>300μm	28x48	0.05	0.05
300μm>dp>149μm	48x100	1.75	1.80
149μm>dp>74μm	100x200	14.50	16.30
74μm>dp>44μm	200x325	27.30	43.60
44μm>dp	-325	57.65	101.25

Size Distribution (Malvern)*			Size Distribution (Malvern)*		
Diameter (μm)	% in size bin	cum. vol. per.	Diameter (μm)	% in size bin	cum. vol. per.
188m	0.00	100.0	118.4m2	0.05	100.0
162m	0.03	100.0	102.1m2	0.15	99.9
140m	0.08	99.9	88.1m2	0.15	99.9
121m	0.10	99.8	76m2	0.10	99.9
104m	0.10	99.7	65.6m2	1.65	98.4
89.9m	0.10	99.6	56.6m2	5.40	94.6
77.5m	0.45	99.2	48.8m2	9.55	90.5
66.9m	1.50	97.7	42.1m2	10.95	89.1
57.7m	3.45	94.2	38.3m2	9.55	90.5
49.8m	6.15	88.1	31.3m2	7.75	92.3
42.9m	8.93	79.1	27m2	8.20	91.8
37.1m	10.63	68.5	23.3m2	9.55	90.5
32m	10.45	58.1	20.1m2	7.55	92.5
27.6m	8.88	49.2	17.4m2	4.15	95.9
23.8m	7.25	41.9	15m2	3.65	96.4
20.5m	6.20	35.7	12.9m2	4.90	95.1
17.7m	6.00	29.7	11.1m2	4.20	95.8
15.3m	5.83	23.9	9.6m2	3.00	97.0
13.2m	5.05	18.9	8.3m2	1.60	98.4
11.4m	3.88	15.0	7.2m2	1.20	98.8
9.8m	2.80	12.2	6.2m2	1.55	98.5
8.5m	2.20	10.0	5.3m2	1.35	98.7
7.3m	1.93	8.1	4.8m2	1.15	98.9
6.3m	1.85	6.2	4m2	0.80	99.2
5.4m	1.63	4.6	3.4m2	0.75	99.3
4.7m	1.28	3.3	3m2	0.70	99.3
4.1m	1.00	2.3	2.8m2	0.10	99.9
3.5m	0.80	1.5	2.2m2	0.10	99.9
3m	0.55	0.9	1.9m2	0.00	100.0
2.6m	0.33	0.6	1.6m2	0.00	100.0
2.2m	0.23	0.4	1.4m2	0.00	100.0
1.9m	0.20	0.2	1.2m2	0.00	100.0

Size Statistics (Malvern Data Only)			
		Malvern	All Data
Dv.5	Volume Mean Diam.	25.63	
Dv.9	90 % volume diameter	47.92	
Dv.1	10 percentile volume diameter	8.17	
D4,3		27.10	
D3,2	Sauter Mean Diameter	15.72	
Span		1.57	
Specific Surface Area (m^3/cc)		0.37	

*These Malvern data are for the -325 mesh size fractions.

Table A.18 Summary of Properties of the Roland Coal.

Roland

Analyses		
Proximate	Dry	As Rec'd
Fixed Carbon	48.45	43.46
Volatile Matter	45.39	40.72
Moisture	10.29	
Ultimate	Dry	As Rec'd
C	69.94	62.74
H	4.76	4.27
O	17.79	15.96
N	0.91	0.82
S	0.40	0.36
Cl	0.03	0.03
Ash	6.16	5.53
Ash Chemistry	% dry fuel	% ash
SiO2	1.87	30.42
Al2O3	0.91	14.81
TiO2	0.07	1.12
Fe2O3	0.44	7.22
CaO	1.28	20.72
MgO	0.31	5.08
K2O	0.02	0.38
Na2O	0.12	1.95
SO3	1.00	16.16
P2O5	0.07	1.08
Cl		
Undetermined	0.07	1.07
Total	6.16	100.0
Forms of Sulfur (% dry fuel)		
Pyritic	0.07	
Organic	0.27	
Sulfatic	0.00	
Fraction Free Silica	0.27	
Fraction Pyritic Iron	0.13	
Heating Value (Btu/lb, dry)		
As Fired	11877	10655
Dulong	11762	10551
Acid Sol. Alkali (ppm)	Dry	As Rec'd
Na		
Mg		
Ca		
K		
Fusion Temp.	°F	°C
Reducing Conditions		
Initial Deformation	2066	1130
Spherical	2113	1156
Hemispherical	2131	1166
Fluid	2188	1198
Oxidizing Conditions		
Initial Deformation	2132	1167
Spherical	2177	1191
Hemispherical	2202	1205
Fluid	2271	1244

Analyses			
Size Distribution	Sieves	mass % in size bin	cum. mass %
dp>600µm	+28	0.00	0.00
600µm>dp>300µm	28x48	0.80	0.80
300µm>dp>149µm	48x100	1.80	2.60
149µm>dp>74µm	100x200	26.50	29.10
74µm>dp>44µm	200x325	28.97	58.07
44µm>dp	-325	41.93	100.00

Size Distribution (Malvern)*			Size Distribution (Malvern)*		
Diameter (µm)	% in size bin	cum. vol. per.	Diameter (µm)	% in size bin	cum. vol. per.
188m	0.00	100.0	118.4m2		
162m	0.00	100.0	102.1m2		
140m	0.00	100.0	88.1m2		
121m	0.00	100.0	76m2		
104m	0.00	100.0	65.6m2		
89.9m	0.03	100.0	56.6m2		
77.5m	0.18	99.8	48.8m2		
66.9m	1.00	98.8	42.1m2		
57.7m	2.50	96.3	38.3m2		
49.8m	4.75	91.6	31.3m2		
42.9m	7.30	84.3	27m2		
37.1m	9.20	75.1	23.3m2		
32m	9.20	65.9	20.1m2		
27.6m	7.28	58.6	17.4m2		
23.8m	5.60	53.0	15m2		
20.5m	5.05	47.9	12.9m2		
17.7m	5.25	42.7	11.1m2		
15.3m	5.48	37.2	9.6m2		
13.2m	5.03	32.2	8.3m2		
11.4m	4.10	28.1	7.2m2		
9.8m	3.38	24.7	6.2m2		
8.5m	3.10	21.6	5.3m2		
7.3m	3.13	18.5	4.8m2		
6.3m	3.18	15.3	4m2		
5.4m	3.08	12.2	3.4m2		
4.7m	2.73	9.5	3m2		
4.1m	2.25	7.3	2.8m2		
3.5m	1.73	5.5	2.2m2		
3m	1.25	4.3	1.9m2		
2.6m	1.03	3.3	1.6m2		
2.2m	0.83	2.4	1.4m2		
1.9m	1.23	1.2	1.2m2		

Size Statistics (Malvern Data Only)			
		Malvern	All Data
Dv.5	Volume Mean Diam.	20.20	
Dv.9	90 % volume diameter	44.78	
Dv.1	10 percentile volume diameter	4.55	
D4,3		22.93	
D3,2	Sauter Mean Diameter	10.40	
Span		1.98	
Specific Surface Area (m^3/cc)		0.61	

*These Malvern data are for the -325 mesh size fractions.

Table A.19 Summary of Properties of the Decker Coal.

Decker

Analyses		
Proximate	Dry	As Rec'd
Fixed Carbon	51.45	42.46
Volatile Matter	43.45	35.86
Moisture	17.48	
Ultimate	Dry	As Rec'd
C	72.04	59.45
H	4.97	4.10
O	16.36	13.50
N	1.00	0.82
S	0.53	0.43
Cl	0.02	0.02
Ash	5.12	4.23
Ash Chemistry	% dry fuel	% ash
SiO2	1.32	25.78
Al2O3	0.87	16.96
TiO2	0.06	1.15
Fe2O3	0.33	6.42
CaO	0.74	14.51
MgO	0.16	3.14
K2O	0.02	0.47
Na2O	0.41	7.99
SO3	1.07	20.83
P2O5	0.05	0.93
Cl		
Undetermined	0.09	1.82
Total	5.12	100.0
Forms of Sulfur (% dry fuel)		
Pyritic	0.16	
Organic	0.33	
Sulfatic	0.04	
Fraction Free Silica	0.02	
Fraction Pyritic Iron	0.61	
Heating Value (Btu/lb, dry)		
As Fired	12424	10253
Dulong	12315	10162
Acid Sol. Alkali (ppm)	Dry	As Rec'd
Na		
Mg		
Ca		
K		
Fusion Temp.	°F	°C
Reducing Conditions		
Initial Deformation	2056	1124
Spherical	2143	1173
Hemispherical	2161	1183
Fluid	2194	1201
Oxidizing Conditions		
Initial Deformation	2333	1278
Spherical	2457	1347
Hemispherical	2472	1356
Fluid	2495	1368

Analyses					
Size Distribution	Sieves	mass % in size bin	cum. mass %		
dp>600μm	+28	0.00	0.00		
600μm>dp>300μm	28x48	0.10	0.10		
300μm>dp>149μm	48x100	4.00	4.10		
149μm>dp>74μm	100x200	23.97	28.07		
74μm>dp>44μm	200x325	25.03	53.10		
44μm>dp	-325	46.90	100.00		
Size Distribution (Malvern)*		Size Distribution (Malvern)*			
Diameter (μm)	% in size bin	cum. vol. per.	Diameter (μm)	% in size bin	cum. vol. per.
188m	0.36	99.6	118.4m2		
162m	0.95	98.7	102.1m2		
140m	1.41	97.3	88.1m2		
121m	1.78	95.5	76m2		
104m	1.89	93.6	65.6m2		
89.9m	1.96	91.7	56.6m2		
77.5m	2.05	89.6	48.8m2		
66.9m	2.48	87.1	42.1m2		
57.7m	3.40	83.7	38.3m2		
49.8m	5.38	78.4	31.3m2		
42.9m	7.54	70.8	27m2		
37.1m	9.31	61.5	23.3m2		
32m	9.10	52.4	20.1m2		
27.6m	7.10	45.3	17.4m2		
23.8m	5.41	39.9	15m2		
20.5m	4.73	35.2	12.9m2		
17.7m	4.95	30.2	11.1m2		
15.3m	5.19	25.0	9.6m2		
13.2m	4.65	20.4	8.3m2		
11.4m	3.71	16.7	7.2m2		
9.8m	2.75	13.9	6.2m2		
8.5m	2.33	11.6	5.3m2		
7.3m	2.28	9.3	4.8m2		
6.3m	2.23	7.1	4m2		
5.4m	2.01	5.1	3.4m2		
4.7m	1.53	3.6	3m2		
4.1m	1.01	2.5	2.8m2		
3.5m	0.79	1.8	2.2m2		
3m	0.54	1.2	1.9m2		
2.6m	0.31	0.9	1.6m2		
2.2m	0.31	0.6	1.4m2		
1.9m	0.49	0.1	1.2m2		

Size Statistics (Malvern Data Only)			
		Malvern	All Data
Dv.5	Volume Mean Diam.	31.06	
Dv.9	90 % volume diameter	64.68	
Dv.1	10 percentile volume diameter	7.63	
D4,3		34.15	
D3,2	Sauter Mean Diameter	15.80	
Span		1.76	
Specific Surface Area (m^3/cc)		0.40	

*These Malvern data are for the -325 mesh size fractions.

Table A.20 Summary of Properties of the Black Thunder Coal.

Black Thunder

Analyses		
Proximate	Dry	As Rec'd
Fixed Carbon	39.28	30.91
Volatile Matter	54.26	42.70
Moisture	21.30	
Ultimate	Dry	As Rec'd
C	69.90	55.01
H	5.05	3.97
O	17.09	13.45
N	0.94	0.74
S	0.48	0.38
Cl	0.08	0.06
Ash	6.46	5.08
Ash Chemistry	% dry fuel	% ash
SiO2	1.96	30.31
Al2O3	1.05	16.27
TiO2	0.08	1.27
Fe2O3	0.33	5.04
CaO	1.36	21.07
MgO	0.31	4.74
K2O	0.02	0.35
Na2O	0.09	1.41
SO3	1.13	17.46
P2O5	0.06	0.91
Cl		
Undetermined	0.08	1.17
Total	6.46	100.0
Forms of Sulfur (% dry fuel)		
Pyritic	0.08	
Organic	0.40	
Sulfatic	0.00	
Fraction Free Silica	0.19	
Fraction Pyritic Iron	0.31	
Heating Value (Btu/lb, dry)		
As Fired	12815	10085
Dulong	11993	9438
Acid Sol. Alkali (ppm)	Dry	As Rec'd
Na		
Mg		
Ca		
K		
Fusion Temp.	°F	°C
Reducing Conditions		
Initial Deformation	2121	1161
Spherical	2152	1178
Hemispherical	2172	1189
Fluid	2210	1210
Oxidizing Conditions		
Initial Deformation	2154	1179
Spherical	2192	1200
Hemispherical	2209	1209
Fluid	2269	1243

Analyses					
Size Distribution	Sieves	mass % in size bin	cum. mass %		
dp>600μm	+28	0.00	0.00		
600μm>dp>300μm	28x48	0.30	0.30		
300μm>dp>149μm	48x100	7.70	8.00		
149μm>dp>74μm	100x200	30.80	38.80		
74μm>dp>44μm	200x325	19.20	58.00		
44μm>dp	-325	42.00	100.00		
Size Distribution (Malvern)*		Size Distribution (Malvern)*			
Diameter (μm)	% in size bin	cum. vol. per.	Diameter (μm)	% in size bin	cum. vol. per.
188m	0.00	100.0	118.4m2		
162m	0.05	100.0	102.1m2		
140m	0.05	99.9	88.1m2		
121m	0.05	99.9	76m2		
104m	0.05	99.8	65.6m2		
89.9m	0.15	99.7	56.6m2		
77.5m	1.10	98.6	48.8m2		
66.9m	3.05	95.5	42.1m2		
57.7m	5.85	89.7	38.3m2		
49.8m	8.55	81.1	31.3m2		
42.9m	9.40	71.7	27m2		
37.1m	9.30	62.4	23.3m2		
32m	7.85	54.6	20.1m2		
27.6m	6.05	48.5	17.4m2		
23.8m	5.35	43.2	15m2		
20.5m	5.50	37.7	12.9m2		
17.7m	5.65	32.0	11.1m2		
15.3m	5.30	26.7	9.6m2		
13.2m	4.25	22.5	8.3m2		
11.4m	3.45	19.0	7.2m2		
9.8m	2.95	16.1	6.2m2		
8.5m	2.70	13.4	5.3m2		
7.3m	2.50	10.9	4.8m2		
6.3m	2.30	8.6	4m2		
5.4m	2.05	6.5	3.4m2		
4.7m	1.70	4.8	3m2		
4.1m	1.20	3.6	2.8m2		
3.5m	1.05	2.6	2.2m2		
3m	0.70	1.9	1.9m2		
2.6m	0.50	1.4	1.6m2		
2.2m	0.40	1.0	1.4m2		
1.9m	0.80	0.2	1.2m2		

Size Statistics (Malvern Data Only)			
		Malvern	All Data
Dv.5	Volume Mean Diam.	24.75	
Dv.9	90 % volume diameter	50.10	
Dv.1	10 percentile volume diameter	6.05	
D4,3		27.35	
D3,2	Sauter Mean Diameter	13.50	
Span		1.75	
Specific Surface Area (m^3/cc)		0.46	

*These Malvern data are for the -325 mesh size fractions.

Table A.21 Summary of Properties of the Belle Ayr Coal.

Belle Ayr

Analyses		
Proximate	Dry	As Rec'd
Fixed Carbon	45.78	34.49
Volatile Matter	48.19	36.31
Moisture	24.65	
Ultimate	Dry	As Rec'd
C	70.27	52.94
H	5.05	3.80
O	17.27	13.01
N	0.90	0.68
S	0.44	0.33
Cl	0.05	0.04
Ash	6.04	4.55
Ash Chemistry	% dry fuel	% ash
SiO2	1.74	28.81
Al2O3	0.85	14.13
TiO2	0.08	1.40
Fe2O3	0.31	5.08
CaO	1.43	23.68
MgO	0.25	4.10
K2O	0.01	0.23
Na2O	0.08	1.31
SO3	1.13	18.78
P2O5	0.06	1.04
Cl		
Undetermined	0.09	1.43
Total	6.04	100.0
Forms of Sulfur (% dry fuel)		
Pyritic	0.07	
Organic	0.37	
Sulfatic	0.00	
Fraction Free Silica	0.26	
Fraction Pyritic Iron	0.28	
Heating Value (Btu/lb, dry)		
As Fired	12781	9630
Dulong	12027	9063
Acid Sol. Alkali (ppm)	Dry	As Rec'd
Na		
Mg		
Ca		
K		
Fusion Temp.	°F	°C
Reducing Conditions		
Initial Deformation	1075	579
Spherical	1098	592
Hemispherical	1107	597
Fluid	1125	607
Oxidizing Conditions		
Initial Deformation	1070	577
Spherical	1098	592
Hemispherical	1109	598
Fluid	1126	608

Analyses				
Size Distribution	Sieves	mass % in size bin	cum. mass %	
dp>600μm	+28	0.00	0.00	
600μm>dp>300μm	28x48	0.50	0.50	
300μm>dp>149μm	48x100	9.25	9.75	
149μm>dp>74μm	100x200	24.65	34.40	
74μm>dp>44μm	200x325	17.15	51.55	
44μm>dp	-325	48.45	100.00	
Size Distribution (Malvern)*		Size Distribution (Malvern)*		
Diameter (μm)	% in size bin	cum. vol. per.	Diameter (μm)	% in size bin	cum. vol. per.
188m	0.00	100.0	118.4m2		
162m	0.03	100.0	102.1m2		
140m	0.08	99.9	88.1m2		
121m	0.05	99.9	76m2		
104m	0.03	99.8	65.6m2		
89.9m	0.23	99.6	56.6m2		
77.5m	1.10	98.5	48.8m2		
66.9m	2.70	95.8	42.1m2		
57.7m	4.95	90.9	38.3m2		
49.8m	7.10	83.8	31.3m2		
42.9m	7.85	75.9	27m2		
37.1m	7.90	68.0	23.3m2		
32m	7.03	61.0	20.1m2		
27.6m	5.90	55.1	17.4m2		
23.8m	5.63	49.5	15m2		
20.5m	5.83	43.6	12.9m2		
17.7m	5.88	37.8	11.1m2		
15.3m	5.60	32.2	9.6m2		
13.2m	4.65	27.5	8.3m2		
11.4m	4.08	23.4	7.2m2		
9.8m	3.63	19.8	6.2m2		
8.5m	3.33	16.5	5.3m2		
7.3m	3.03	13.5	4.8m2		
6.3m	2.78	10.7	4m2		
5.4m	2.43	8.3	3.4m2		
4.7m	2.08	6.2	3m2		
4.1m	1.78	4.4	2.8m2		
3.5m	1.23	3.2	2.2m2		
3m	0.88	2.3	1.9m2		
2.6m	0.78	1.5	1.6m2		
2.2m	0.50	1.0	1.4m2		
1.9m	1.13	-0.1	1.2m2		

Size Statistics (Malvern Data Only)			
		Malvern	All Data
Dv.5	Volume Mean Diam.	20.65	
Dv.9	90 % volume diameter	48.88	
Dv.1	10 percentile volume diameter	5.20	
D4,3		25.13	
D3,2	Sauter Mean Diameter	11.65	
Span		2.10	
Specific Surface Area (m^3/cc)		0.53	

*These Malvern data are for the -325 mesh size fractions.

Table A.22 Summary of Properties of the Wyodak Coal.

Wyodak

Analyses		
Proximate	Dry	As Rec'd
Fixed Carbon	48.27	38.74
Volatile Matter	45.50	36.52
Moisture	19.74	
Ultimate	Dry	As Rec'd
C	69.76	55.99
H	4.95	3.97
O	17.49	14.04
N	0.97	0.77
S	0.56	0.45
Cl	0.04	0.03
Ash	6.18	4.96
Ash Chemistry	% dry fuel	% ash
SiO2	1.61	26.06
Al2O3	0.86	13.96
TiO2	0.08	1.29
Fe2O3	0.33	5.35
CaO	1.51	24.40
MgO	0.26	4.28
K2O	0.01	0.19
Na2O	0.05	0.86
SO3	1.29	20.82
P2O5	0.06	0.99
Cl		
Undetermined	0.11	1.80
Total	6.18	100.0
Forms of Sulfur (% dry fuel)		
Pyritic	0.12	
Organic	0.40	
Sulfatic	0.04	
Fraction Free Silica	0.21	
Fraction Pyritic Iron	0.43	
Heating Value (Btu/lb, dry)		
As Fired	11927	9573
Dulong	11881	9536
Acid Sol. Alkali (ppm)	Dry	As Rec'd
Na		
Mg		
Ca		
K		
Fusion Temp.	°F	°C
Reducing Conditions		
Initial Deformation	2161	1183
Spherical	2214	1212
Hemispherical	2236	1224
Fluid	2288	1253
Oxidizing Conditions		
Initial Deformation	2154	1179
Spherical	2204	1207
Hemispherical	2231	1222
Fluid	2285	1252

Analyses					
Size Distribution		Sieves	mass % in size bin		cum. mass %
dp>600μm		+28	0.00		0.00
600μm>dp>300μm		28x48	0.00		0.00
300μm>dp>149μm		48x100	4.08		4.08
149μm>dp>74μm		100x200	19.53		23.60
74μm>dp>44μm		200x325	20.38		43.98
44μm>dp		-325	56.03		100.00
Size Distribution (Malvern)*			Size Distribution (Malvern)*		
Diameter (μm)	% in size bin	cum. vol. per.	Diameter (μm)	% in size bin	cum. vol. per.
188m	0.00	100.0	118.4m2	0.08	99.9
162m	0.05	100.0	102.1m2	0.13	99.9
140m	0.08	99.9	88.1m2	0.15	99.9
121m	0.13	99.8	76m2	0.10	99.9
104m	0.13	99.6	65.6m2	0.38	99.6
89.9m	0.13	99.5	56.6m2	3.45	96.6
77.5m	0.45	99.1	48.8m2	7.43	92.6
66.9m	1.45	97.6	42.1m2	9.40	90.6
57.7m	3.18	94.4	38.3m2	9.35	90.7
49.8m	5.58	88.9	31.3m2	8.50	91.5
42.9m	8.18	80.7	27m2	8.20	91.8
37.1m	9.88	70.8	23.3m2	8.10	91.9
32m	9.75	61.1	20.1m2	6.75	93.3
27.6m	7.98	53.1	17.4m2	5.15	94.9
23.8m	6.18	46.9	15m2	4.90	95.1
20.5m	5.30	41.6	12.9m2	5.35	94.7
17.7m	5.45	36.2	11.1m2	4.58	95.4
15.3m	5.68	30.5	9.6m2	3.70	96.3
13.2m	5.40	25.1	8.3m2	2.68	97.3
11.4m	4.45	20.6	7.2m2	2.18	97.8
9.8m	3.45	17.2	6.2m2	2.13	97.9
8.5m	2.88	14.3	5.3m2	1.90	98.1
7.3m	2.58	11.7	4.8m2	1.53	98.5
6.3m	2.43	9.3	4m2	1.28	98.7
5.4m	2.20	7.1	3.4m2	1.13	98.9
4.7m	1.90	5.2	3m2	0.88	99.1
4.1m	1.15	4.1	2.8m2	0.45	99.6
3.5m	1.08	3.0	2.2m2	0.10	99.9
3m	0.83	2.2	1.9m2	0.00	100.0
2.6m	0.53	1.6	1.6m2	0.00	100.0
2.2m	0.40	1.2	1.4m2	0.00	100.0
1.9m	0.53	0.7	1.2m2	0.00	100.0

Size Statistics (Malvern Data Only)			
		Malvern	All Data
Dv.5	Volume Mean Diam.	23.10	
Dv.9	90 % volume diameter	45.41	
Dv.1	10 percentile volume diameter	6.29	
D4,3		25.04	
D3,2	Sauter Mean Diameter	13.66	
Span		1.71	
Specific Surface Area (m^3/cc)		0.44	

*These Malvern data are for the -325 mesh size fractions.

Table A.23 Summary of Properties of the Antelope Coal.

Antelope

Analyses		
Proximate	Dry	As Rec'd
Fixed Carbon	51.22	39.49
Volatile Matter	43.27	33.36
Moisture	22.90	
Ultimate	Dry	As Rec'd
C	68.38	52.72
H	4.89	3.77
O	19.74	15.22
N	1.03	0.79
S	0.42	0.32
Cl	0.03	0.02
Ash	5.51	4.25
Ash Chemistry	% dry fuel	% ash
SiO2	1.38	25.03
Al2O3	0.63	11.36
TiO2	0.04	0.66
Fe2O3	0.45	8.18
CaO	1.59	28.88
MgO	0.31	5.60
K2O	0.01	0.25
Na2O	0.09	1.57
SO3	0.97	17.65
P2O5	0.04	0.81
Cl		
Undetermined	0.00	0.01
Total	5.51	100.0
Forms of Sulfur (% dry fuel)		
Pyritic	0.02	
Organic	0.40	
Sulfatic	0.00	
Fraction Free Silica	0.32	
Fraction Pyritic Iron	0.06	
Heating Value (Btu/lb, dry)		
As Fired	12271	9461
Dulong	11465	8840
Acid Sol. Alkali (ppm)	Dry	As Rec'd
Na		
Mg		
Ca		
K		
Fusion Temp.	°F	°C
Reducing Conditions		
Initial Deformation	2323	1273
Spherical	2355	1291
Hemispherical	2381	1305
Fluid	2411	1322
Oxidizing Conditions		
Initial Deformation	2349	1287
Spherical	2369	1298
Hemispherical	2383	1306
Fluid	2402	1317

Analyses			
Size Distribution	Sieves	mass % in size bin	cum. mass %
dp>600μm	+28	0.50	0.50
600μm>dp>300μm	28x48	12.00	12.50
300μm>dp>149μm	48x100	31.40	43.90
149μm>dp>74μm	100x200	18.90	62.80
74μm>dp>44μm	200x325	37.20	100.00
44μm>dp	-325	0.00	100.00

Size Distribution (Malvern)*			Size Distribution (Malvern)*		
Diameter (μm)	% in size bin	cum. vol. per.	Diameter (μm)	% in size bin	cum. vol. per.
188m			118.4m2		
162m			102.1m2		
140m			88.1m2		
121m			76m2		
104m			65.6m2		
89.9m			56.6m2		
77.5m			48.8m2		
66.9m			42.1m2		
57.7m			38.3m2		
49.8m			31.3m2		
42.9m			27m2		
37.1m			23.3m2		
32m			20.1m2		
27.6m			17.4m2		
23.8m			15m2		
20.5m			12.9m2		
17.7m			11.1m2		
15.3m			9.6m2		
13.2m			8.3m2		
11.4m			7.2m2		
9.8m			6.2m2		
8.5m			5.3m2		
7.3m			4.8m2		
6.3m			4m2		
5.4m			3.4m2		
4.7m			3m2		
4.1m			2.8m2		
3.5m			2.2m2		
3m			1.9m2		
2.6m			1.6m2		
2.2m			1.4m2		
1.9m			1.2m2		

Size Statistics (Malvern Data Only)		Malvern	All Data
Dv.5	Volume Mean Diam.		
Dv.9	90 % volume diameter		
Dv.1	10 percentile volume diameter		
D4,3			
D3,2	Sauter Mean Diameter		
Span			
Specific Surface Area (m^3/cc)			

*These Malvern data are for the -325 mesh size fractions.

Table A.24 Summary of Properties of the Eagle Butte Coal.

Eagle Butte

Analyses		
Proximate	Dry	As Rec'd
Fixed Carbon	47.95	37.26
Volatile Matter	45.67	35.48
Moisture	22.30	
Ultimate	Dry	As Rec'd
C	66.89	51.97
H	4.89	3.80
O	20.20	15.70
N	1.17	0.91
S	0.47	0.37
Cl	0.03	0.02
Ash	6.37	4.95
Ash Chemistry	% dry fuel	% ash
SiO2	1.78	28.00
Al2O3	0.90	14.16
TiO2	0.05	0.83
Fe2O3	0.39	6.09
CaO	1.60	25.09
MgO	0.38	5.95
K2O	0.02	0.26
Na2O	0.12	1.84
SO3	1.04	16.38
P2O5	0.04	0.67
Cl		
Undetermined	0.05	0.73
Total	6.37	100.0
Forms of Sulfur (% dry fuel)		
Pyritic	0.06	
Organic	0.40	
Sulfatic	0.01	
Fraction Free Silica	0.24	
Fraction Pyritic Iron	0.19	
Heating Value (Btu/lb, dry)		
As Fired	11516	8947
Dulong	11211	8711
Acid Sol. Alkali (ppm)	Dry	As Rec'd
Na	822	822
Mg	1891	1891
Ca	7250	7250
K	75	75
Fusion Temp.	°F	°C
Reducing Conditions		
Initial Deformation	2223	1217
Spherical	2254	1234
Hemispherical	2261	1239
Fluid	2273	1245
Oxidizing Conditions		
Initial Deformation	2184	1196
Spherical	2214	1212
Hemispherical	2229	1221
Fluid	2249	1231

Analyses					
Size Distribution	Sieves	mass % in size bin	cum. mass %		
dp>600μm	+28	0.00	0.00		
600μm>dp>300μm	28x48	0.27	0.27		
300μm>dp>149μm	48x100	2.70	2.97		
149μm>dp>74μm	100x200	17.50	20.47		
74μm>dp>44μm	200x325	22.60	43.07		
44μm>dp	-325	56.93	100.00		
Size Distribution (Malvern)*		Size Distribution (Malvern)*			
Diameter (μm)	% in size bin	cum. vol. per.	Diameter (μm)	% in size bin	cum. vol. per.
188m	0.00	100.0	118.4m2		
162m	0.00	100.0	102.1m2		
140m	0.02	100.0	88.1m2		
121m	0.03	100.0	76m2		
104m	0.03	99.9	65.6m2		
89.9m	0.08	99.8	56.6m2		
77.5m	0.27	99.6	48.8m2		
66.9m	0.88	98.7	42.1m2		
57.7m	1.87	96.8	38.3m2		
49.8m	3.78	93.0	31.3m2		
42.9m	6.80	86.2	27m2		
37.1m	9.47	76.8	23.3m2		
32m	10.13	66.6	20.1m2		
27.6m	8.87	57.8	17.4m2		
23.8m	7.38	50.4	15m2		
20.5m	6.47	43.9	12.9m2		
17.7m	6.32	37.6	11.1m2		
15.3m	6.32	31.3	9.6m2		
13.2m	5.75	25.5	8.3m2		
11.4m	4.82	20.7	7.2m2		
9.8m	3.75	17.0	6.2m2		
8.5m	3.03	13.9	5.3m2		
7.3m	2.68	11.3	4.8m2		
6.3m	2.48	8.8	4m2		
5.4m	2.25	6.5	3.4m2		
4.7m	1.88	4.6	3m2		
4.1m	1.30	3.3	2.8m2		
3.5m	1.00	2.3	2.2m2		
3m	0.70	1.6	1.9m2		
2.6m	0.48	1.2	1.6m2		
2.2m	0.32	0.8	1.4m2		
1.9m	0.27	0.6	1.2m2		

Size Statistics (Malvern Data Only)			
		Malvern	All Data
Dv.5	Volume Mean Diam.	21.37	
Dv.9	90 % volume diameter	42.02	
Dv.1	10 percentile volume diameter	6.20	
D4,3		23.20	
D3,2	Sauter Mean Diameter	12.98	
Span		1.68	
Specific Surface Area (m^3/cc)		0.47	

*These Malvern data are for the -325 mesh size fractions.

Table A.25 Summary of Properties of the Beulah Lignite.

Beulah

Analyses		
Proximate	Dry	As Rec'd
Fixed Carbon	43.44	32.96
Volatile Matter	42.95	32.59
Moisture	24.13	
Ultimate	Dry	As Rec'd
C	60.97	46.26
H	4.07	3.09
O	18.50	14.04
N	1.02	0.77
S	1.81	1.38
Cl	0.04	0.03
Ash	13.69	10.39
Ash Chemistry	% dry fuel	% ash
SiO2	2.87	20.93
Al2O3	1.89	13.78
TiO2	0.06	0.41
Fe2O3	1.65	12.08
CaO	2.21	16.13
MgO	0.60	4.40
K2O	0.03	0.22
Na2O	0.88	6.41
SO3	3.32	24.27
P2O5	0.00	0.00
Cl		
Undetermined	0.19	1.38
Total	13.69	100.0
Forms of Sulfur (% dry fuel)		
Pyritic	0.47	
Organic	1.18	
Sulfatic	0.16	
Fraction Free Silica	0.10	
Fraction Pyritic Iron	0.37	
Heating Value (Btu/lb, dry)		
As Fired	10040	7617
Dulong	10003	7590
Acid Sol. Alkali (ppm)	Dry	As Rec'd
Na	7357	7357
Mg	3321	3321
Ca	14036	14036
K	152	152
Fusion Temp.	°F	°C
Reducing Conditions		
Initial Deformation	2026	1108
Spherical	2149	1176
Hemispherical	2175	1190
Fluid	2191	1199
Oxidizing Conditions		
Initial Deformation	2290	1255
Spherical	2359	1293
Hemispherical	2365	1296
Fluid	2388	1309

Analyses			
Size Distribution	Sieves	mass % in size bin	cum. mass %
dp>600μm	+28	0.06	0.06
600μm>dp>300μm	28x48	2.88	2.94
300μm>dp>149μm	48x100	12.81	15.75
149μm>dp>74μm	100x200	22.60	38.35
74μm>dp>44μm	200x325	17.20	55.55
44μm>dp	-325	45.29	100.84

Size Distribution (Malvern)*			Size Distribution (Malvern)*		
Diameter (μm)	% in size bin	cum. vol. per.	Diameter (μm)	% in size bin	cum. vol. per.
188m	0.18	99.8	118.4m2	0.08	99.9
162m	0.49	99.3	102.1m2	0.14	99.9
140m	0.72	98.6	88.1m2	0.14	99.9
121m	0.92	97.7	76m2	0.10	99.9
104m	0.98	96.7	65.6m2	0.00	100.0
89.9m	1.20	95.5	56.6m2	1.62	98.4
77.5m	1.53	94.0	48.8m2	4.78	95.2
66.9m	1.92	92.1	42.1m2	6.62	93.4
57.7m	2.69	89.4	38.3m2	7.14	92.9
49.8m	4.01	85.4	31.3m2	7.04	93.0
42.9m	5.41	79.9	27m2	7.14	92.9
37.1m	6.32	73.6	23.3m2	7.30	92.7
32m	6.37	67.3	20.1m2	6.40	93.6
27.6m	5.98	61.3	17.4m2	5.42	94.6
23.8m	5.70	55.6	15m2	5.60	94.4
20.5m	5.48	50.1	12.9m2	6.12	93.9
17.7m	5.33	44.8	11.1m2	5.34	94.7
15.3m	5.29	39.5	9.6m2	4.64	95.4
13.2m	4.99	34.5	8.3m2	3.90	96.1
11.4m	4.64	29.8	7.2m2	3.68	96.3
9.8m	4.12	25.7	6.2m2	3.64	96.4
8.5m	3.67	22.1	5.3m2	3.10	96.9
7.3m	3.38	18.7	4.8m2	2.40	97.6
6.3m	3.31	15.4	4m2	2.14	97.9
5.4m	3.18	12.2	3.4m2	2.22	97.8
4.7m	2.90	9.3	3m2	2.06	97.9
4.1m	2.47	6.8	2.8m2	0.74	99.3
3.5m	1.82	5.0	2.2m2	0.42	99.6
3m	1.33	3.7	1.9m2	0.00	100.0
2.6m	1.11	2.6	1.6m2	0.04	100.0
2.2m	0.91	1.6	1.4m2	0.00	100.0
1.9m	1.79	-0.1	1.2m2	0.00	100.0

Size Statistics (Malvern Data Only)			
		Malvern	All Data
Dv.5	Volume Mean Diam.	18.46	
Dv.9	90 % volume diameter	49.66	
Dv.1	10 percentile volume diameter	4.44	
D4,3		23.49	
D3,2	Sauter Mean Diameter	10.24	
Span		2.35	
Specific Surface Area (m^3/cc)		0.62	

*These Malvern data are for the -325 mesh size fractions.

Table A.26 Summary of Properties of the Texas (San Miguel) Lignite.

Texas (San Miguel)

Analyses		
Proximate	Dry	As Rec'd
Fixed Carbon	17.51	14.27
Volatile Matter	30.41	24.78
Moisture	18.50	
Ultimate	Dry	As Rec'd
C	29.43	23.99
H	3.20	2.61
O	12.95	10.55
N	0.51	0.41
S	1.75	1.43
Cl	0.08	0.06
Ash	52.18	42.53
Ash Chemistry	% dry fuel	% ash
SiO2	34.36	65.85
Al2O3	10.13	19.41
TiO2	0.45	0.87
Fe2O3	0.87	1.66
CaO	1.56	2.99
MgO	0.25	0.48
K2O	0.98	1.88
Na2O	1.35	2.60
SO3	1.47	2.82
P2O5	0.00	0.01
Cl	0.01	0.02
Undetermined	0.74	1.42
Total	52.17	100.0
Forms of Sulfur (% dry fuel)		
Pyritic	0.29	
Organic	1.35	
Sulfatic	0.10	
Fraction Free Silica	0.56	
Fraction Pyritic Iron	0.41	
Heating Value (Btu/lb, dry)		
As Fired	5076	4137
Dulong	5334	4347
Acid Sol. Alkali (ppm)	Dry	As Rec'd
Na	8788	8788
Mg	1156	1156
Ca	7628	7628
K	5862	5862
Fusion Temp.	°F	°C
Reducing Conditions		
Initial Deformation	2349	1287
Spherical	2458	1348
Hemispherical	2580	1416
Fluid	2759	1515
Oxidizing Conditions		
Initial Deformation	2338	1281
Spherical	2433	1334
Hemispherical	.2576	1413
Fluid	2762	1517

Analyses					
Size Distribution	Sieves	mass % in size bin	cum. mass %		
dp>600μm	+28	0.00	0.00		
600μm>dp>300μm	28x48	2.40	2.40		
300μm>dp>149μm	48x100	9.83	12.23		
149μm>dp>74μm	100x200	18.28	30.50		
74μm>dp>44μm	200x325	17.23	47.73		
44μm>dp	-325	52.28	100.00		
Size Distribution (Malvern)*			Size Distribution (Malvern)*		
Diameter (μm)	% in size bin	cum. vol. per.	Diameter (μm)	% in size bin	cum. vol. per.
188m	0.00	100.0	118.4m2	0.10	99.9
162m	0.00	100.0	102.1m2	0.35	99.7
140m	0.00	100.0	88.1m2	0.40	99.6
121m	0.00	100.0	76m2	0.35	99.7
104m	0.00	100.0	65.6m2	0.25	99.8
89.9m	0.08	99.9	56.6m2	1.80	98.2
77.5m	0.13	99.8	48.8m2	4.90	95.1
66.9m	0.15	99.6	42.1m2	6.85	93.2
57.7m	0.22	99.4	38.3m2	7.55	92.5
49.8m	1.02	98.4	31.3m2	7.50	92.5
42.9m	2.78	95.6	27m2	7.30	92.7
37.1m	4.85	90.8	23.3m2	6.75	93.3
32m	6.48	84.3	20.1m2	6.05	94.0
27.6m	6.97	77.3	17.4m2	5.60	94.4
23.8m	6.90	70.4	15m2	5.60	94.4
20.5m	6.68	63.7	12.9m2	5.55	94.5
17.7m	6.70	57.0	11.1m2	4.80	95.2
15.3m	6.73	50.3	9.6m2	4.30	95.7
13.2m	6.45	43.8	8.3m2	3.90	96.1
11.4m	5.95	37.9	7.2m2	3.55	96.5
9.8m	5.12	32.8	6.2m2	3.30	96.7
8.5m	4.45	28.3	5.3m2	2.85	97.2
7.3m	4.05	24.3	4.8m2	2.40	97.6
6.3m	3.95	20.3	4m2	2.20	97.8
5.4m	3.78	16.5	3.4m2	2.10	97.9
4.7m	3.42	13.1	3m2	1.75	98.3
4.1m	2.88	10.2	2.8m2	0.80	99.2
3.5m	2.13	8.1	2.2m2	0.60	99.4
3m	1.58	6.5	1.9m2	0.30	99.7
2.6m	1.37	5.2	1.6m2	0.00	100.0
2.2m	1.30	3.9	1.4m2	0.10	99.9
1.9m	2.33	1.5	1.2m2	0.10	99.9

Size Statistics (Malvern Data Only)			
		Malvern	All Data
Dv.5	Volume Mean Diam.	14.76	
Dv.9	90 % volume diameter	34.26	
Dv.1	10 percentile volume diameter	3.89	
D4,3		17.45	
D3,2	Sauter Mean Diameter	8.39	
Span		2.06	
Specific Surface Area (m^3/cc)		0.76	

*These Malvern data are for the -325 mesh size fractions.

Table A.27 Summary of Properties of the Eastern Blend.

Eastern Blend

Analyses		
Proximate	Dry	As Rec'd
Fixed Carbon	61.06	60.62
Volatile Matter	30.27	30.05
Moisture	0.72	
Ultimate	Dry	As Rec'd
C	77.95	77.39
H	4.79	4.76
O	5.51	5.47
N	1.43	1.42
S	1.65	1.64
Cl		
Ash	8.67	8.61
Ash Chemistry	% dry fuel	% ash
SiO2	4.25	49.03
Al2O3	2.13	24.53
TiO2	0.09	1.00
Fe2O3	1.48	17.03
CaO	0.20	2.31
MgO	0.07	0.86
K2O	0.17	1.99
Na2O	0.03	0.36
SO3	0.17	1.92
P2O5	0.03	0.37
Cl		
Undetermined	0.05	0.60
Total	8.67	100.0
Forms of Sulfur (% dry fuel)		
Pyritic	0.89	
Organic	0.75	
Sulfatic	0.01	
Fraction Free Silica	0.25	
Fraction Pyritic Iron	0.75	
Heating Value (Btu/lb, dry)		
As Fired	13933	13833
Dulong		
Acid Sol. Alkali (ppm)	Dry	As Rec'd
Na		
Mg		
Ca		
K		
Fusion Temp.	°F	°C
Reducing Conditions		
Initial Deformation	2133	1167
Spherical	2429	1332
Hemispherical	2449	1343
Fluid	2500	1371
Oxidizing Conditions		
Initial Deformation	2497	1369
Spherical	2574	1412
Hemispherical	2602	1428
Fluid	2632	1444

Analyses				
Size Distribution	Sieves	mass % in size bin	cum. mass %	
dp>600μm	+28	0.00	0.00	
600μm>dp>300μm	28x48	0.00	0.00	
300μm>dp>149μm	48x100	1.30	1.30	
149μm>dp>74μm	100x200	26.30	27.60	
74μm>dp>44μm	200x325	26.30	53.90	
44μm>dp	-325	46.10	100.00	
Size Distribution (Malvern)*		Size Distribution (Malvern)*		
Diameter (μm)	% in size bin	cum. vol. per.	Diameter (μm)	% in size bin	cum. vol. per.
188m			118.4m2		
162m			102.1m2		
140m			88.1m2		
121m			76m2		
104m			65.6m2		
89.9m			56.6m2		
77.5m			48.8m2		
66.9m			42.1m2		
57.7m			38.3m2		
49.8m			31.3m2		
42.9m			27m2		
37.1m			23.3m2		
32m			20.1m2		
27.6m			17.4m2		
23.8m			15m2		
20.5m			12.9m2		
17.7m			11.1m2		
15.3m			9.6m2		
13.2m			8.3m2		
11.4m			7.2m2		
9.8m			6.2m2		
8.5m			5.3m2		
7.3m			4.8m2		
6.3m			4m2		
5.4m			3.4m2		
4.7m			3m2		
4.1m			2.8m2		
3.5m			2.2m2		
3m			1.9m2		
2.6m			1.6m2		
2.2m			1.4m2		
1.9m			1.2m2		

Size Statistics (Malvern Data Only)		Malvern	All Data
Dv.5	Volume Mean Diam.		
Dv.9	90 % volume diameter		
Dv.1	10 percentile volume diameter		
D4,3			
D3,2	Sauter Mean Diameter		
Span			
Specific Surface Area (m^3/cc)			

*These Malvern data are for the -325 mesh size fractions.

Table A.28 Summary of Properties of the Pittsburgh #8 - Decker Blend.

Pittsburgh #8-Decker Blend

Analyses		
Proximate	Dry	As Rec'd
Fixed Carbon	53.05	49.44
Volatile Matter	41.23	38.42
Moisture	6.81	
Ultimate	Dry	As Rec'd
C	72.94	67.98
H	5.34	4.98
O	13.11	12.22
N	1.28	1.19
S	1.04	0.97
Cl	0.07	0.06
Ash	6.26	5.84
Ash Chemistry	% dry fuel	% ash
SiO2	2.42	38.68
Al2O3	1.29	20.56
TiO2	0.06	1.03
Fe2O3	0.73	11.71
CaO	0.48	7.67
MgO	0.11	1.68
K2O	0.07	1.18
Na2O	0.21	3.38
SO3	0.65	10.39
P2O5	0.04	0.70
Cl		
Undetermined	0.04	0.62
Total	6.11	97.6
Forms of Sulfur (% dry fuel)		
Pyritic	0.41	
Organic	0.61	
Sulfatic	0.08	
Fraction Free Silica	0.20	
Fraction Pyritic Iron	0.68	
Heating Value (Btu/lb, dry)		
As Fired	13357	12448
Dulong	12948	12066
Acid Sol. Alkali (ppm)	Dry	As Rec'd
Na		
Mg		
Ca		
K		
Fusion Temp.	°F	°C
Reducing Conditions		
Initial Deformation	2139	1171
Spherical	2201	1205
Hemispherical	2243	1228
Fluid	2342	1283
Oxidizing Conditions		
Initial Deformation	2319	1271
Spherical	2338	1281
Hemispherical	2388	1309
Fluid	2443	1339

Analyses					
Size Distribution		Sieves	mass % in size bin		cum. mass %
dp>600μm		+28	0.00		0.00
600μm>dp>300μm		28x48	0.03		0.03
300μm>dp>149μm		48x100	2.83		2.87
149μm>dp>74μm		100x200	25.53		28.40
74μm>dp>44μm		200x325	26.90		55.30
44μm>dp		-325	44.73		100.03
Size Distribution (Malvern)*			Size Distribution (Malvern)*		
Diameter (μm)	% in size bin	cum. vol. per.	Diameter (μm)	% in size bin	cum. vol. per.
188m	1.83	98.2	118.4m2		
162m	4.39	93.8	102.1m2		
140m	5.51	88.3	88.1m2		
121m	5.36	82.9	76m2		
104m	3.92	79.0	65.6m2		
89.9m	2.77	76.2	56.6m2		
77.5m	3.74	72.5	48.8m2		
66.9m	4.46	68.1	42.1m2		
57.7m	4.80	63.3	38.3m2		
49.8m	5.54	57.7	31.3m2		
42.9m	6.08	51.6	27m2		
37.1m	7.15	44.5	23.3m2		
32m	6.53	38.0	20.1m2		
27.6m	5.22	32.7	17.4m2		
23.8m	4.18	28.6	15m2		
20.5m	3.63	24.9	12.9m2		
17.7m	3.50	21.4	11.1m2		
15.3m	3.51	17.9	9.6m2		
13.2m	3.24	14.7	8.3m2		
11.4m	2.72	12.0	7.2m2		
9.8m	2.09	9.9	6.2m2		
8.5m	1.65	8.3	5.3m2		
7.3m	1.46	6.8	4.8m2		
6.3m	1.40	5.4	4m2		
5.4m	1.34	4.1	3.4m2		
4.7m	1.21	2.9	3m2		
4.1m	0.86	2.0	2.8m2		
3.5m	0.67	1.3	2.2m2		
3m	0.69	0.6	1.9m2		
2.6m	0.34	0.3	1.6m2		
2.2m	0.29	0.0	1.4m2		
1.9m	0.54	-0.5	1.2m2		

Size Statistics (Malvern Data Only)			
		Malvern	All Data
Dv.5	Volume Mean Diam.	53.26	
Dv.9	90 % volume diameter	80.51	
Dv.1	10 percentile volume diameter	24.72	
D4,3		51.78	
D3,2	Sauter Mean Diameter	24.84	
Span		1.31	
Specific Surface Area (m^3/cc)		0.33	

*These Malvern data are for the -325 mesh size fractions.

Table A.29 Summary of Properties of the NIPSCO Blend (1).

NIPSCO Blend (1)

Analyses		
Proximate	Dry	As Rec'd
Fixed Carbon	48.70	44.13
Volatile Matter	43.51	39.43
Moisture	9.38	
Ultimate	Dry	As Rec'd
C	70.31	63.71
H	5.39	4.89
O	14.74	13.35
N	1.22	1.10
S	0.53	0.48
Cl	0.06	0.05
Ash	7.80	7.06
Ash Chemistry	% dry fuel	% ash
SiO2	3.27	41.91
Al2O3	1.68	21.54
TiO2	0.10	1.32
Fe2O3	0.37	4.79
CaO	1.17	15.00
MgO	0.20	2.61
K2O	0.09	1.17
Na2O	0.08	0.97
SO3	1.11	14.18
P2O5	0.05	0.69
Cl		
Undetermined	0.11	1.36
Total	8.23	105.5
Forms of Sulfur (% dry fuel)		
Pyritic	0.07	
Organic	0.49	
Sulfatic	0.00	
Fraction Free Silica	0.23	
Fraction Pyritic Iron	0.23	
Heating Value (Btu/lb, dry)		
As Fired	12979	11761
Dulong	12451	11282
Acid Sol. Alkali (ppm)	Dry	As Rec'd
Na		
Mg		
Ca		
K		
Fusion Temp.	°F	°C
Reducing Conditions		
Initial Deformation	1513	823
Spherical	1549	843
Hemispherical	1610	877
Fluid	1673	912
Oxidizing Conditions		
Initial Deformation	1554	846
Spherical	1579	860
Hemispherical	1629	887
Fluid	1688	920

Analyses				
Size Distribution	Sieves	mass % in size bin	cum. mass %	
dp>600μm	+28	0.00	0.00	
600μm>dp>300μm	28x48	0.53	0.53	
300μm>dp>149μm	48x100	8.60	9.13	
149μm>dp>74μm	100x200	28.87	38.00	
74μm>dp>44μm	200x325	19.67	57.67	
44μm>dp	-325	42.33	100.00	
Size Distribution (Malvern)*		Size Distribution (Malvern)*		
Diameter (μm)	% in size bin	cum. vol. per.	Diameter (μm)	% in size bin	cum. vol. per.
188m	1.56	98.4	118.4m2		
162m	3.84	94.6	102.1m2		
140m	5.22	89.4	88.1m2		
121m	5.92	83.5	76m2		
104m	5.40	78.1	65.6m2		
89.9m	5.44	72.6	56.6m2		
77.5m	5.25	67.4	48.8m2		
66.9m	5.10	62.3	42.1m2		
57.7m	4.90	57.4	38.3m2		
49.8m	5.80	51.6	31.3m2		
42.9m	6.16	45.4	27m2		
37.1m	6.47	38.9	23.3m2		
32m	5.89	33.0	20.1m2		
27.6m	4.49	28.5	17.4m2		
23.8m	3.58	25.0	15m2		
20.5m	3.54	21.4	12.9m2		
17.7m	3.23	18.2	11.1m2		
15.3m	3.00	15.2	9.6m2		
13.2m	2.55	12.6	8.3m2		
11.4m	2.03	10.6	7.2m2		
9.8m	1.60	9.0	6.2m2		
8.5m	1.39	7.6	5.3m2		
7.3m	1.26	6.4	4.8m2		
6.3m	1.22	5.1	4m2		
5.4m	1.15	4.0	3.4m2		
4.7m	1.00	3.0	3m2		
4.1m	0.76	2.2	2.8m2		
3.5m	0.60	1.6	2.2m2		
3m	0.44	1.2	1.9m2		
2.6m	0.32	0.9	1.6m2		
2.2m	0.30	0.6	1.4m2		
1.9m	0.55	0.0	1.2m2		

Size Statistics (Malvern Data Only)			
		Malvern	All Data
Dv.5	Volume Mean Diam.	143.33	
Dv.9	90 % volume diameter	84.47	
Dv.1	10 percentile volume diameter	21.74	
D4,3		54.68	
D3,2	Sauter Mean Diameter	26.56	
Span		1.30	
Specific Surface Area (m^3/cc)		0.30	

*These Malvern data are for the -325 mesh size fractions.

Table A.30 Summary of Properties of the NIPSCO Blend (2).

NIPSCO Blend (2)

Analyses		
Proximate	Dry	As Rec'd
Fixed Carbon	49.69	42.64
Volatile Matter	42.61	36.57
Moisture	14.17	
Ultimate	Dry	As Rec'd
C	73.93	63.45
H	4.96	4.25
O	11.70	10.04
N	1.06	0.91
S	0.59	0.51
Cl	0.08	0.06
Ash	7.71	6.61
Ash Chemistry	% dry fuel	% ash
SiO2	2.99	38.84
Al2O3	1.63	21.22
TiO2	0.10	1.27
Fe2O3	0.40	5.17
CaO	0.93	12.13
MgO	0.19	2.53
K2O	0.10	1.35
Na2O	0.07	0.96
SO3	1.15	14.91
P2O5	0.06	0.76
Cl		
Undetermined	0.07	0.87
Total	7.71	100.0
Forms of Sulfur (% dry fuel)		
Pyritic	0.07	
Organic	0.53	
Sulfatic	0.00	
Fraction Free Silica	0.18	
Fraction Pyritic Iron	0.20	
Heating Value (Btu/lb, dry)		
As Fired	13821	11863
Dulong	12942	11108
Acid Sol. Alkali (ppm)	Dry	As Rec'd
Na		
Mg		
Ca		
K		
Fusion Temp.	°F	°C
Reducing Conditions		
Initial Deformation	1147	619
Spherical	1174	634
Hemispherical	1207	653
Fluid	1241	672
Oxidizing Conditions		
Initial Deformation	1180	638
Spherical	1194	645
Hemispherical	1225	663
Fluid	1257	680

Analyses			
Size Distribution	Sieves	mass % in size bin	cum. mass %
dp>600μm	+28	0.00	0.00
600μm>dp>300μm	28x48	0.35	0.35
300μm>dp>149μm	48x100	7.65	8.00
149μm>dp>74μm	100x200	21.90	29.90
74μm>dp>44μm	200x325	19.85	49.75
44μm>dp	-325	50.25	100.00

Size Distribution (Malvern)*			Size Distribution (Malvern)*		
Diameter (μm)	% in size bin	cum. vol. per.	Diameter (μm)	% in size bin	cum. vol. per.
188m	0.00	100.0	118.4m2		
162m	0.00	100.0	102.1m2		
140m	0.00	100.0	88.1m2		
121m	0.03	100.0	76m2		
104m	0.00	100.0	65.6m2		
89.9m	0.05	99.9	56.6m2		
77.5m	0.50	99.4	48.8m2		
66.9m	2.10	97.3	42.1m2		
57.7m	4.90	92.4	38.3m2		
49.8m	7.58	84.9	31.3m2		
42.9m	8.45	76.4	27m2		
37.1m	8.33	68.1	23.3m2		
32m	7.40	60.7	20.1m2		
27.6m	6.30	54.4	17.4m2		
23.8m	5.75	48.6	15m2		
20.5m	5.60	43.0	12.9m2		
17.7m	5.73	37.3	11.1m2		
15.3m	5.50	31.8	9.6m2		
13.2m	4.55	27.2	8.3m2		
11.4m	3.83	23.4	7.2m2		
9.8m	3.35	20.1	6.2m2		
8.5m	3.08	17.0	5.3m2		
7.3m	2.90	14.1	4.8m2		
6.3m	2.73	11.4	4m2		
5.4m	2.43	8.9	3.4m2		
4.7m	2.08	6.9	3m2		
4.1m	1.63	5.2	2.8m2		
3.5m	1.23	4.0	2.2m2		
3m	0.93	3.1	1.9m2		
2.6m	0.83	2.3	1.6m2		
2.2m	0.68	1.6	1.4m2		
1.9m	1.58	0.0	1.2m2		

Size Statistics (Malvern Data Only)			
		Malvern	All Data
Dv.5	Volume Mean Diam.	21.45	
Dv.9	90 % volume diameter	47.13	
Dv.1	10 percentile volume diameter	5.05	
D4,3		24.28	
D3,2	Sauter Mean Diameter	11.30	
Span		1.95	
Specific Surface Area (m^3/cc)		0.56	

*These Malvern data are for the -325 mesh size fractions.

Table A.31 Summary of Properties of the Roland-Illinois #6 Blend.

Roland/Illinois #6 (2) Blend

Analyses		
Proximate	Dry	As Rec'd
Fixed Carbon	46.43	43.36
Volatile Matter	44.25	41.33
Moisture	6.60	
Ultimate	Dry	As Rec'd
C	68.58	64.06
H	4.73	4.42
O	14.70	13.73
N	1.09	1.02
S	1.56	1.46
Cl	0.03	0.03
Ash	9.29	8.67
Ash Chemistry	% dry fuel	% ash
SiO2	3.54	38.12
Al2O3	1.49	16.04
TiO2	0.09	0.95
Fe2O3	1.12	12.01
CaO	1.07	11.49
MgO	0.27	2.94
K2O	0.11	1.16
Na2O	0.13	1.35
SO3	1.48	15.96
P2O5	0.06	0.64
Cl		
Undetermined	-0.06	-0.65
Total	9.29	100.0
Forms of Sulfur (% dry fuel)		
Pyritic	0.58	
Organic	0.86	
Sulfatic	0.06	
Fraction Free Silica	0.36	
Fraction Pyritic Iron	0.70	
Heating Value (Btu/lb, dry)		
As Fired	12752	11911
Dulong	11835	11054
Acid Sol. Alkali (ppm)	Dry	As Rec'd
Na		
Mg		
Ca		
K		
Fusion Temp.	°F	°C
Reducing Conditions		
Initial Deformation	2044	1118
Spherical	2119	1160
Hemispherical	2195	1202
Fluid	2300	1260
Oxidizing Conditions		
Initial Deformation	2181	1194
Spherical	2208	1209
Hemispherical	2286	1252
Fluid	2378	1304

Analyses		
Size Distribution	Sieves	mass % in size bin	cum. mass %
dp>600μm	+28	0.00	0.00
600μm>dp>300μm	28x48	0.27	0.27
300μm>dp>149μm	48x100	1.77	2.03
149μm>dp>74μm	100x200	30.10	32.13
74μm>dp>44μm	200x325	28.70	60.83
44μm>dp	-325	39.17	100.00

Size Distribution (Malvern)*			Size Distribution (Malvern)*		
Diameter (μm)	% in size bin	cum. vol. per.	Diameter (μm)	% in size bin	cum. vol. per.
188m	1.93	98.1	118.4m2		
162m	4.75	93.3	102.1m2		
140m	6.18	87.2	88.1m2		
121m	6.74	80.4	76m2		
104m	6.16	74.3	65.6m2		
89.9m	5.16	69.1	56.6m2		
77.5m	4.68	64.4	48.8m2		
66.9m	5.14	59.3	42.1m2		
57.7m	5.49	53.8	38.3m2		
49.8m	6.56	47.2	31.3m2		
42.9m	6.57	40.7	27m2		
37.1m	6.14	34.5	23.3m2		
32m	5.03	29.5	20.1m2		
27.6m	3.56	25.9	17.4m2		
23.8m	2.86	23.1	15m2		
20.5m	2.83	20.2	12.9m2		
17.7m	2.83	17.4	11.1m2		
15.3m	2.63	14.8	9.6m2		
13.2m	2.18	12.6	8.3m2		
11.4m	1.75	10.9	7.2m2		
9.8m	1.46	9.4	6.2m2		
8.5m	1.37	8.0	5.3m2		
7.3m	1.33	6.7	4.8m2		
6.3m	1.31	5.4	4m2		
5.4m	1.23	4.2	3.4m2		
4.7m	1.07	3.1	3m2		
4.1m	0.80	2.3	2.8m2		
3.5m	0.68	1.6	2.2m2		
3m	0.50	1.1	1.9m2		
2.6m	0.40	0.7	1.6m2		
2.2m	0.34	0.4	1.4m2		
1.9m	0.53	-0.1	1.2m2		

Size Statistics (Malvern Data Only)			
		Malvern	All Data
Dv.5	Volume Mean Diam.	60.03	
Dv.9	90 % volume diameter	88.28	
Dv.1	10 percentile volume diameter	26.59	
D4,3		58.48	
D3,2	Sauter Mean Diameter	29.87	
Span		1.26	
Specific Surface Area (m^3/cc)		0.30	

*These Malvern data are for the -325 mesh size fractions.

Table A.32 Summary of Properties of the Eagle Butte - Kentucky #9 Blend.

Eagle Butte/Kentucky #9 Blend

Analyses		
Proximate	Dry	As Rec'd
Fixed Carbon	46.53	37.12
Volatile Matter	43.90	35.02
Moisture	20.23	
Ultimate	Dry	As Rec'd
C	68.32	54.50
H	4.76	3.80
O	14.50	11.57
N	1.11	0.89
S	1.74	1.39
Cl	0.00	0.00
Ash	8.91	7.11
Ash Chemistry	% dry fuel	% ash
SiO2	2.63	29.55
Al2O3	1.29	14.44
TiO2	0.09	1.01
Fe2O3	1.21	13.57
CaO	1.31	14.70
MgO	0.32	3.54
K2O	0.10	1.12
Na2O	0.11	1.27
SO3	1.84	20.67
P2O5	0.02	0.28
Cl		
Undetermined	0.01	0.08
Total	8.93	100.2
Forms of Sulfur (% dry fuel)		
Pyritic	0.55	
Organic	0.88	
Sulfatic	0.31	
Fraction Free Silica	0.26	
Fraction Pyritic Iron	0.49	
Heating Value (Btu/lb, dry)		
As Fired	11876	9473
Dulong	11835	9441
Acid Sol. Alkali (ppm)	Dry	As Rec'd
Na		
Mg		
Ca		
K		
Fusion Temp.	°F	°C
Reducing Conditions		
Initial Deformation	1999	1093
Spherical	2106	1152
Hemispherical	2142	1172
Fluid	2233	1223
Oxidizing Conditions		
Initial Deformation	2188	1198
Spherical	2212	1211
Hemispherical	2239	1226
Fluid	2320	1271

Analyses		
Size Distribution	Sieves	mass % in size bin	cum. mass %
dp>600μm	+28	0.00	0.00
600μm>dp>300μm	28x48	0.00	0.00
300μm>dp>149μm	48x100	8.00	8.00
149μm>dp>74μm	100x200	21.50	29.50
74μm>dp>44μm	200x325	18.60	48.10
44μm>dp	-325	51.90	100.00

Size Distribution (Malvern)*			Size Distribution (Malvern)*		
Diameter (μm)	% in size bin	cum. vol. per.	Diameter (μm)	% in size bin	cum. vol. per.
188m	0.00	100.0	118.4m2		
162m	0.00	100.0	102.1m2		
140m	0.05	100.0	88.1m2		
121m	0.05	99.9	76m2		
104m	0.05	99.9	65.6m2		
89.9m	0.05	99.8	56.6m2		
77.5m	0.15	99.7	48.8m2		
66.9m	1.15	98.5	42.1m2		
57.7m	3.10	95.4	38.3m2		
49.8m	6.10	89.3	31.3m2		
42.9m	8.80	80.5	27m2		
37.1m	9.25	71.3	23.3m2		
32m	8.60	62.7	20.1m2		
27.6m	7.15	55.5	17.4m2		
23.8m	5.70	49.8	15m2		
20.5m	5.50	44.3	12.9m2		
17.7m	5.85	38.5	11.1m2		
15.3m	5.70	32.8	9.6m2		
13.2m	5.20	27.6	8.3m2		
11.4m	4.25	23.3	7.2m2		
9.8m	3.60	19.7	6.2m2		
8.5m	3.25	16.5	5.3m2		
7.3m	2.95	13.5	4.8m2		
6.3m	2.70	10.8	4m2		
5.4m	2.40	8.4	3.4m2		
4.7m	2.10	6.3	3m2		
4.1m	1.90	4.4	2.8m2		
3.5m	1.30	3.1	2.2m2		
3m	1.10	2.0	1.9m2		
2.6m	0.70	1.3	1.6m2		
2.2m	0.45	0.9	1.4m2		
1.9m	0.30	0.6	1.2m2		

Size Statistics (Malvern Data Only)			
		Malvern	All Data
Dv.5	Volume Mean Diam.	23.90	
Dv.9	90 % volume diameter	50.60	
Dv.1	10 percentile volume diameter	6.00	
D4,3		27.15	
D3,2	Sauter Mean Diameter	13.45	
Span		1.85	
Specific Surface Area (m^3/cc)		0.45	

*These Malvern data are for the -325 mesh size fractions.

INITIAL DISTRIBUTION

Dr. Ralph Carabetta
Project Management
U.S. DOE/PETC
P.O. Box 10940
Pittsburgh, PA 15236-0940

Ms. Kay Downey
MS 58-M217
U.S. DOE/PETC
P.O. Box 10940
Pittsburgh, PA 15236-0940

Mr. James M. Ekmann
Director, Coal Combustion Division
U.S. DOE/PETC
P.O. Box 10940, MS 84-307
Pittsburgh, PA 15241

Dr. David Beecy, Director
Office of Advanced Research
Fossil Energy, FE-72
U.S. DOE/GTN
19901 Germantown Road
Germantown, MD 20585

Mr. Robert Wright
Office of Advanced Research
Fossil Energy, FE-72
U.S. DOE/GTN
19901 Germantown Road
Germantown, MD 20585

Mr. Philip M. Goldberg
Coal Utilization Division
U.S. DOE/PETC, 922-H
P.O. Box 10940
Pittsburgh, PA 15236-0940

Mr. James Hickerson
Coal Utilization Division
U.S. DOE/PETC, 922-H
P.O. Box 10940
Pittsbrugh, PA 15236-0940

Dr. Larry Ruth
Coal Utilization Division
U.S. DOE/PETC
P.O. Box 10940
Pittsburgh, PA 15236-0940

Mr. Cliff Smith
Coal Utilization Division
U.S. DOE/PETC, 922-H
P.O. Box 10940
Pittsbrugh, PA 15236-0940

Mr. James Jovanovich
PM-01, MS922-206
U.S. DOE/PETC, 922-H
P.O. Box 10940
Pittsburgh, PA 15236-0940

Mr. Laurance L. Oden
Albany Research Facility, Bureau of Mines
U.S. Department of the Interior
Albany, OR 97321

Professor János Beér
Massachusetts Institute of Tech.
Department of Chemical Engineering
66-552
Cambridge, MA 02139

Professor Robert Essenhigh
Mechanical Engineering Department
Ohio State University
206 West 18th Avenue
Columbus, OH 43210

Professor Thomas H. Fletcher
Chemical Engineering Department
Brigham Young University
350 CB
Provo, UT 84602

Professor Robert Hurt
Division of Engineering, Box D
Brown University
Providence, RI 02912

Professor Bryan M. Jenkins
University of California, Davis
Biological and Ag. Eng. Dpt.
Davis, CA 95616-5294

Dr. Michael L. Jones
Energy and Mineral Research Center
University of North Dakota
Box 8213, University Station
Grand Forks, ND 58202
Attn: Dr. Steve Benson

Professor John P. Longwell
Chemical Engineering Department
Massachusetts Institute of Technology
Room 66554
Cambridge, MA 02139

Professor Reginald E. Mitchell
High Temperature Gasdynamics Lab
Stanford University
Mechanical Engineering Department
Palo Alto, CA 94305

Professor Ronald Pugmire
Vice President for Research
University of Utah
210 Park Building
Salt Lake City, UT 84112

Professor Daniel E. Rosner
Director, High Temperature Chem Engr Lab
Yale University
P.O. Box 2159
New Haven, CT 06520-8167

Professor Adel Sarofim
Department of Chemical Engineering
Massachusetts Institute of Technology
66-466
Cambridge, MA 02139

Professor Philip Smith
Department of Chemical Engineering
University of Utah
2250 Merrill Engineering Bldg
Salt Lake City, UT 84112

Professor Terry Wall
Department of Chemical & Materials Engr.
The University of Newcastle
Newcastle, NSW 2308
Australia

Professor Jost Wendt
Department of Chemical Engineering
University of Arizona
Tuscon, AZ 85721

Dr. Seymour B. Alpert
P.O. Box 10412
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CA 94308

Dr. Richard Bain, Manager
Biomass Power Program
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, CO 80401-3393

Mr. Richard W. Borio
Combustion Engineering Inc.
1000 Prospect Hill Road, P.O. Box 500
Windsor, CT 06095
Attn: Mr. Michael Hargrove

Chester M. Bowling
Manager Tech. Support & Mrktng
ARCO Coal Company
555 Seventeenth St.
Denver, CO 80202

Mr. Richard W. DeSollar
Fuels Coordinator
Central Illinois Public Service Co.
607 East Adams Street
Springfield, Il 62701

Mr. Larry Dora
Engineering Supervisor
Northern Indiana Public Service Co.
P.O. Box M-720
Gary, IN 46401

Dr. Woodrow Fiveland, Supervisor
Heat Transfer & Fluid Mechanics Section
Babcock & Wilcox
1562 Beeson St.
Alliance, OH 44601

Dr. J. Peter Gorog
Research and Development
Pulp, Paper and Packaging
Weyerhaeuser Company
WTC 2H22
Tacoma, WA 98477

Mr. Peter Torslev Jensen
ELSAM
Fuel Department
DK-7000 Fredericia
Denmark

Dr. Flynt Kennedy, Vice President
Research & Development
Consolidation Coal Co.
4000 Brownsville Road
Library, PA 15129
Attn: Dr. Anthony Fonseca

Dr. John Lytle
Mineral Engineering Laboratory
Illinois State Geological Survey
Oak and Gregory Sts.
Champaign, IL 61820

Dr. John S. Maulbetsch
Exploratory Research
EPRI
3412 Hillview Avenue
Palo Alto, CA 94303

Dr. Arun K. Mehta
P.O. Box 10412
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CA 94308

Mr. Thomas R. Miles
Consulting Design Engineer
5475 SW Arrowwood Lane
Portland, OR 97225

Dr. Thomas Milne
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, CO 80401-3393

Dr. Ralph P. Overend
National Renewable Energy Lab
1617 Cole Boulevard
Golden, CO 80401-3393

Mr. Eric H. Reichl
P.O. Box 472
Princeton, NJ 08542

Dr. Dan Seery
United Technologies Research Center
Combustion Sciences
Silver Lane, MS 30
East Hartford, CT 06108

Mr. Ian W. Smith, Manager
Coal Utilization Program
CSIRO
51 Delhi Road, P.O. Box 136
North Ryde, NSW, 2113
Australia

Professor L. Douglas Smoot
Consulting Design Engineer
5475 SW Arrowwood Lane
Portland, OR 97225

Mr. Jerry Sullivan
Project Director
PSI Energy
1000 East Main Street
Plainfield, IN 46168

Dr. David A. Tillman
Foster Wheeler Environmental Corporation
2525 Natomas Park Drive, Suite 250
Sacramento, CA 95833-2900

Mr. Stanley Vecci, Director
Energy Systems Lab/Research Dev Div
Babcock & Wilcox
1562 Beeson Street
Alliance, OH 44601
Attn: Mr. John Berthold
Mr. Thomas Morris
Mr. Larry Rodgers
Dr. Hamid Sarv
Mr. James Warchol
Mr. Ralph Bailey
Mr. George Farthing

Mr. Ben Ziesmer
Fuel Coordinator
Northern Indiana Public Services Co.
5265 Hohman Ave.
Hammond, IN 46320

MS0701 R.W. Lynch, 6100

MS0735 D.E. Arvizu, 6200
Attn: 6211 G.A. Carlson
6212 H.R. Stephens
6203 A.P. Sylwester

MS0704 P.C. Klimas, 6201
Attn: 6215 J. Chavez
6215 K.S. Rawlinson

MS9001 J.C. Crawford, 8000
Attn: 8100 M.E. John
8113 J.C. Swearengen
8700 R.C. Wayne
8713 J.F.C. Wang
8713 D.K. Ottesen
8714 M. Perra

MS9054 W.J. McLean, 8300
Attn: 8302 W. Bauer 8351 L.A. Rahn
8304 K. Wilson 8353 F.P. Tully
8341 W. Wolfer 8355 G.A. Fisk
8342 R. Stulen 8362 R.W. Carling
8347 A. Pontau 8366 C.M. Hartwig

MS9052	A.J. Akanetuk, 8361
MS9052	L.L. Baxter, 8361
MS9052	D.R. Hardesty, 8361 (15)
MS9052	T. Linsmeyer, 8361
MS9052	J.R. Ross, 8361
MS9052	G. Sclippa, 8361
MS9052	S. Sinquefield, 8361
MS9402	N.Y.C. Yang, 8714
MS9021	Technical Communications Department, 8535 for OSTI (10)
MS9021	Technical Communications Department, 8535 Technical Library, MS0899, 13414
MS0899	Technical Library, 13414 (4)
MS9018	Central Technical Files, 8523-2 (3)