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FINE ASH MORPHOLOGY AND AEROSOL FORMATION - A COMPARISON OF COAL AND BIOMASS FUELS

by

Blake Charles Chenevert

A dissertation submitted in partial fulfillment of the requirements for the degree of

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Approved by _____
Chairperson of Supervisory Committee

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to Offer Degree Department of Mechanical Engineering

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Doctoral Dissertation

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Abstract

FINE ASH MORPHOLOGY AND AEROSOL FORMATION - A COMPARISON OF COAL AND BIOMASS FUELS

by Blake Charles Chenevert

Chairperson of the Supervisory Committee: Professor John C. Kramlich
Department of Mechanical Engineering

Modeling and experimental methods were used to investigate ash formation mechanisms of four industrially significant high-alkali biomass (sawdust/sanderdust) fuels. Alkali minerals tend to vaporize and recondense to form sub-micron aerosol, which poses health risks and causes special operational problems for industrial combustors.

Sawdust/sanderdust was burned in a 15 kW natural gas-fired tunnel furnace. The resulting ash was collected by a water-cooled probe, and size sorted by cascade impaction and Electrical Aerosol Size Analysis. Scanning Electron Microscopy and Energy Dispersive X-Ray Spectroscopy techniques were used to determine morphology and composition by size cut. Three ash modes were present:

1) A residual mode composed primarily of porous calcium structures with a scale length of 8 microns and larger. This mode was likely the result of direct oxide and carbonate formation. 2) A secondary residual mode near 2 microns composed of fluxed and fragmented calcium, but also containing significant amounts of Si, Fe, Mn and Al. This mode appeared to be composed of eutectic melts separated from the parent ash particle. 3) An aerosol mode composed of Na and K with Cl anion, or sulfate anion when Cl was not present. The aerosol mode diameter was found to be a function of initial nucleate number density and coagulation time. Long coagulation time or high initial number density resulted in an aerosol mode diameter near 0.1 micron.

Modeling was composed of three elements: 1) Equilibrium modeling - These calculations validated experimental evidence for alkali vaporization and condensation, predicting all alkali to enter the vapor phase as NaCl or KCl when Cl is available, or NaOH and KOH otherwise. 2) Condensation modeling - This model was used to determine the partitioning of alkali metal between homogeneous particulate matter formation (self-nucleation) and deposition on existing residual particles. It was shown that vaporized alkali can be collected on the residual particulate matter by controlling the time/temperature history just prior to self-nucleation. 3) Coagulation modeling - This code determined the ultimate diameter of nucleated aerosol particulate. Results agreed well with experimental data, showing a clear relationship between coagulation time, initial number density, and ultimate particle diameter.

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p_{sat} = plane surface saturation pressure

p_d = curved surface saturation pressure

$\overline{v}$ = specific volume of liquid

σ = surface tension

T = temperature

$\tilde{R}$ = ideal gas constant

p_1 = partial pressure of monomer

n = monomers per volume

m = mass of molecule

k = Boltzmann constant

v_m = monomer volume

s = saturation ratio

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DEDICATION

To my wife, Jean, who keeps me strong

INTRODUCTION

Coal and biomass fuels contain inorganic material that forms ash when burned. These inorganic components, which may be in the form of clays, sand and mineral nutrients, are transformed physically and chemically during combustion. The resulting ash often leads to significant obstacles for those who endeavor to design efficient, robust, and safe energy conversion facilities.

Some consequences of ash generation include:

• Slagging, fouling, and corrosion. *Slagging* is typically associated with flowing or stationary ash deposits near the primary combustion zone. Deposition is via settling or impaction. *Fouling* is more common in the heat recovery zone and the flue gas pathway. It usually occurs via impaction of gas-borne particulate matter or by thermophoresis. *Corrosion* is often a gas-phase problem, but chemically reactive ash can also lead to degradation of furnace surfaces. All of these issues affect energy conversion efficiency, facility maintenance, and the lifetime of the plant.

• Environmental and health hazards. Uncontrolled or under-controlled emissions result in particulate matter escape from the facility. This leads to various health risks and damage to the environment, depending on the composition and mobility of the particulate matter. In particular, the health risks associated with fine particulate matter has become widely recognized in recent years, and have led to regulations on particulate matter less than 2.5 μm in diameter (*i.e.* $PM_{2.5}$ regulations, EPA, 1997).

Thus, the fate and behavior of the mineral matter associated with solid fuels, particularly coal, has been a topic studied by researchers for decades.

Two general mechanisms of ash production are known: The first is the residual mechanism in which ash is formed as a residue as the char particle burns away. Factors that govern the fate of mineral matter processed through this mechanism include whether the char fragments on burning, the degree to which minerals are released at the char surface during burning, and the level of mineral coalescence and melting that take place. This mechanism normally yields ash particles larger than 0.5 μm (*e.g.* Flagan and Friedlander, 1978). The second mechanism is a vaporization/condensation process. Mineral matter is vaporized in a

high temperature region, and eventually condenses either homogeneously (forming nuclei) or heterogeneously (*i.e.* on a surface). The nuclei will eventually coagulate by Brownian motion to form larger particles, typically agglomerations with diameters on the order of 0.1 μm. Obviously, there is interaction between these general mechanisms, and there are a number of sub-mechanisms that reside within these overall processes.

Modern combustion facilities use pollution control equipment to capture post-combustion ash. Capture of large ash particles can often be accomplished using gravitational settling or cyclones. These methods are less effective as particle diameter (*i.e.* settling velocity) decreases.

Electrostatic precipitators and fabric filter devices are common ways to control fine flue-borne material. Unfortunately, both Electrostatic precipitators and fabric filters have reduced efficiencies (McCain *et al.*, 1975, Friedlander, 1977) in the size range of particles that are very efficiently captured in the alveolar region of the human lung (Morrow, 1964). It has been estimated that 50% of the particles between 0.01 μm and 0.1 μm that enter the pulmonary compartment will be deposited there (Burchard, 1974).

The risks associated with the small particles is compounded because they present condensation surfaces for volatile, toxic metals. Although only a small fraction of the total ash mass may be sub-micron in size, the high surface to volume ratio for these small particles results in large surface areas. Hence, volatile toxic metals, such as arsenic and selenium, are likely to be deposited on these particles upon condensation (Flagan and Friedlander, 1978).

Aerosols have tended to create problems as new and complex pollution control technologies are integrated into industrial plants. An example can be taken from the wood products industry: Sawdust and sanderdust, a by-product of board manufacturing, is sometimes used as a fuel for drying and curing operations. This fuel is combusted in a suspension burner, mixed with forced air to regulate the temperature, and channeled through a wood chip dryer. The hot gas stream dries the chips and picks up moisture and organic vapors in the process. Cyclones and an electrostatic precipitator remove the majority of the ash after the drying operation. The flue gas is then routed through either a catalytic or non-catalytic oxidizer to remove the organic vapors. In some facilities, the particulate matter not captured by the control systems has damaged or degraded these oxidizers. Catalytic system

are deactivated by a physical masking of the catalyst surface. In non-catalytic systems, the ceramic recuperative heat exchange surfaces are destroyed by interaction with the mineral matter. The process is complex, and it appears to include contributions from (1) the ash from the primary flame, (2) reactions between the ash and organic vapors in the curing system, and (3) processes occurring in the electrostatic precipitator.

The underlying mechanisms that give rise to these practical problems obviously depend on the characteristics of the ash generated by these biomass fuels. Sawdust and sanderdust are important fuel sources in the wood products industry and have unique mineral compositions, including very high alkali metal concentrations and an almost complete lack of the aluminosilicate minerals that are so common in coals. The behavior of this combination of minerals during combustion has not been explored in detail. The principal goal of this research is to understand the mechanisms that govern the transformation of these minerals into ash during combustion. These mechanisms provide the means of linking mineral composition, fuel characteristics, and combustion environment with the characteristics of the product ash that are important in the industrial system (*e.g.*, size distribution, and the distribution of the various ash elements across the range of particle sizes).

A secondary goal of this research is the investigation of aerosol formation in coal combustion. Previous research suggests that aerosol yield is enhanced by coal cleaning (Kramlich and Newton, 1994a). Aerodynamically sized coal fractions also exhibit an enhanced aerosol mode (Kramlich and Newton, 1994a). The implication is that coal benefication can reduce overall ash yield, but may increase aerosol yield. The coal experiments focus on coal mineral behavior, specifically dealing with certain observations involving the formation of sub-micron aerosols. This portion of the study is undertaken both on its own right, and to serve as a point of comparison for the biomass work.

MECHANISMS OF MINERAL TRANSFORMATIONS IN COAL AND BIOMASS FUELS

Chemical and physical transformations of mineral matter during coal and biomass combustion are of critical concern in practical industrial applications. The minerals in fuels affect the operability of the furnace and contribute to the environmental risk associated with the flue gas. The research community has responded to these technical and environmental challenges with a substantial research output, particularly with respect to mineral transformations in coal combustion. This literature forms the point of departure for the present study, and it is the subject of this chapter.

Section 2.1 describes the sources and form of mineral matter in coal and biomass fuels. Section 2.2 discusses the combustion process, which consists of a series of steps that include drying, devolatilization, char combustion, and burnout. These steps form the background against which the mineral transformations occur. Section 2.3 details the literature on the transformation of various inorganic components during combustion.

2.1 Sources and Form of Mineral Matter in Coal and Biomass Fuels

Coal and biomass are significantly different in their organic composition, and the physical and chemical form of their inorganic constituents. This is a natural and obvious result of the very different histories of these two fuels, and it causes them to generate significantly different ash size distributions and compositions.

An important factor in the ultimate fate of inorganic matter in coal/biomass fuel combustion is the form of the parent inorganic component. Mineral matter can generally be divided into two classifications, *included* (or inherent) and *extraneous* (or excluded, or adventitious).

Included minerals generally refers to inorganic components of the fuel that are contained within the individual organic particles (*i.e.*, the macerals in coal). These are difficult to separate by physical means, and are generally present as small mineral particles (1 to 15μm) dispersed throughout the organic matrix (Sarofim, 1977). This class also includes minerals that are chemically bound to the organic matter; sometimes referred to as "atomically dispersed" minerals.

Extraneous generally refers to discrete mineral particles (typically on the order of tens of microns or larger in diameter) either loosely bound or physically separated from the macerals. The literature disagrees somewhat on the precise definition of inherent and extraneous minerals, and thus there is not a complete consensus of the exact boundary dividing these two classes (Baxter, 1993; Wall, 1992).

In general, pulverized coal ash research is virtually inseparable from the study of its included and extraneous mineral matter. Biomass ash research, on the other hand, is almost exclusively involved with included minerals, more explicitly the fuel's atomically dispersed inorganic composition, usually in the form of plant nutrients. This is especially true for biomass fuels that are carefully harvested and collected, so that extraneous soil contamination is minimized.

2.1.1 Pulverized Coal Composition and Structure

Detailed information on coal formation mechanisms and on coal composition is covered in a number of sources (for example, Berkowitz, "Introduction to Coal Technology" ; Stach et al, "Stach's Textbook of Coal Petrology"). Only a brief overview of this large literature is presented here.

Coal is formed from biomass in a process taking up to 300 million years, depending on biomass composition, local climate and geological conditions. Diogenesis, the biochemical breakdown of vegetation, is the first phase of coal formation. Although diogenesis occurs over a short period of geologic time, it is during this stage of coal formation that biomass (including its inorganic components) becomes mixed with extraneous minerals via erosion, flooding, wind, and other transport mechanisms. Diogenesis is terminated by the flooding of the organic bed, followed by the deposit of an overlayer of silt that seals the organic material from further microbial activity (Berkowitz, 1994). A common feature of diogenesis is increasing aromaticity and acidity (Berkowitz, 1994). The metamorphic stage, driven by compression from siltation and heat flow from the interior of the earth, increases carbon content at the expense of oxygen, and eventually hydrogen.

The degree of metamorphosis is quantified in various ways, with the ASTM (1966) classification scheme commonly used in North America. The ASTM ranks coal by fixed

carbon content for fixed carbon greater than 69%, and by calorific heating value for fixed carbon less than 69%. Fixed carbon content is defined as:

$$(\text{Fixed Carbon})\% = 100\% - (\text{Moisture})\% - (\text{Volatile Matter})\% - (\text{Ash})\%$$

Moisture, volatile matter, and ash yield are all determined by specific empirical tests using carefully controlled atmospheres, temperatures, and heating rates (ASTM, 1966). In order of increasing rank, classes are lignitic, subbituminous, bituminous, and anthracite (ASTM, 1966). Some researchers also include peat as a classification, considering it to be the lowest rank of coal.

A problem plaguing coal researchers is the wide range of properties exhibited by the various coals. This makes it impossible to choose an "average" coal for research purposes. Instead, a suite of research coals have been proposed that cover the range of properties presented by most of the economically important deposits. Examination of the properties of these coals provides the best opportunity for developing generalizations about coal mineral makeup.

Smith and Smoot (1990) proposed such a set of standard research coals, selected using the following criteria:

> "(1) representative of a variety of characteristics, ranks and properties, (2) available analysis of chemical and physical properties with wide property variations among coal types and ranks, (3) availability from major producing seams, (4) future production expected, (5) wide geographical distribution within the U.S., (6) used in previous combustion work, (7) common to existing prominent coal banks, and (8) availability of small, controlled samples."

Table 2.1 shows the proximate and ultimate analysis for these research coals, as compiled by Smith and Smoot (1990). Most are bituminous coals, as is about 50% of the U.S. demonstrated reserve base (Energy Information Administration, 1982). Note that ash yield varies from 4.1% to 19.4% (as received basis), illustrating the variability of U.S. coals. Table 2.2 shows ash composition of these research coals. Although ash composition varies, note that coal is generally high in silicon, aluminum, calcium and iron - which are, not coincidentally, among the most abundant elements found in the earth's crust (Lide, 1994).

The most common noncombustable mineral species in coal is alumino-silicate clay, making up 60% to 80% of mineral matter in a typical coal (Mackowsky, in Stach *et al.*, 1982). It can be in the form of finely distributed particles, on the order of a few microns in diameter (Mackowsky, in Stach *et al.*, 1982) to macroscopic scales. Experiments performed by Raask (1985) with milled coals showed mineral enrichment with decreasing coal particle diameter, primarily driven by aluminosilicate concentrated in coal particles below 20 μm. Clay minerals are typically represented by illites (potassium aluminosilicates), kaolinite (aluminosilicate), and montmorillonite ($(1-x)Al_2O_3 \cdot x\ (MgO,NaO) \cdot 4SiO_2 \cdot H_2O$). (Berkowitz, 1994).

Silica, as quartz, also can be a significant fraction of coal, making up 15% to 20% of the ash yield. (Berkowitz, 1994). Mackowsky (in Stach *et al.*, 1982) notes that quartz usually is present with other finely dispersed minerals, likely from weathering of feldspar and mica.

Together, aluminosilicates and quartz make up 60 to 90% of total mineral matter in coal (Raask, 1985).

Carbonates are generally secondary to clays in abundance (Mackowsky, in Stach *et al.*, 1982). Typical forms are calcite ($CaCO_3$), siderite ($FeCO_3$), dolomite ($CaCO_3 \cdot MgCO_3$), and ankarite ($2CaCO_3 \cdot MgCO_3 \cdot FeCO_3$). Siderite and dolomite are deposited/formed in the first stage of coalification (Mackowsky, in Stach *et al.*, 1982), implying a fine grain size and inherent association, while calcite and ankarite are more commonly deposited during the metamorphic stage along cracks and seams (Mackowsky, in Stach *et al.*, 1982), implying a coarser and larger grain size.

Sulfur in coal can be found organically combined, or as mineral components. Non-organically bound sulfur is typically in the form of a sulfide - pyrite or marcasite (both approximately FeS_2) (Raask, 1985). It can occur as micron sized crystals, 10 μm to 40 μm framboids, or as boulder sized deposits in unprocessed coal (Calkins, 1994).

Critical to this research is alkali metal content in the parent fuel. The presence of alkali metal species in coal is summarized by Raask (1985), as shown in Table 2.3. Chlorides, sulfates, and nitrates are usually found only in trace quantities. Chlorides present in significant quantities are associated with infiltration from salt deposits. (Mackowsky, in Stach *et al.*, 1982).

2.1.2 Biomass Composition and Structure

Biomass fuel composition and combustion has not been as thoroughly reviewed as coal. Baxter *et al.* (1996) present some comprehensive data concerning the behavior of the inorganic material in biomass when fired under industrial combustor conditions. The reader may also consult Bryers (1996) for a review of the state of the art in biomass ash transformations.

The majority of biomass is composed of cellulose, hemicellulose and lignin, with wood as an obvious example (Theander, 1982). Cellulose and hemicellulose are polysaccarides (long chain carbohydrates) that make up plant cell walls; these make up 60 to 75% of the dry mass in wood (Theander, 1982). Cellulose and hemicellulose are less than 50% carbon and 50% oxygen by weight (Glasser, 1982). Lignin is 20 to 30% dry mass in wood, and provides a plant with structural support, among other properties. Lignin is more than 60% carbon and about 30% oxygen (Glasser, 1982). Hence, biomass overall has a high atomic oxygen to atomic carbon ratio, and a high atomic hydrogen to atomic carbon ratio. Baxter (1993) estimates a hydrogen to carbon ratio of 1.2 to 1.8 and an oxygen to carbon ratio of about 0.4 to 0.8 for biomass fuels. This information supports the view that biomass is composed of reactive functional groups, in contrast to more tightly bound, less reactive aromatic rings in coal.

According to Bryers (1996), 80% of the biomass used for steam generation is wood based, while 20% is agricultural waste (straw, manure, nutshells, and other material). Unlike coal, biomass ash yield is derived primarily from organically bound components, rather than from mineral based inorganics. If clay minerals are present, they are in the form of discrete contaminates, usually acquired during harvest or processing. Inorganic components vary significantly with the type of biomass material and soil conditions (*i.e.* nutrient content), but some general observations are possible.

Biomass fuels generally contain calcium, silicon, and potassium. As pointed out by Bryers (1996), these elements play specific roles in plant nutrition. Grasses and straws are generally high in silica and potassium, and low in calcium, based on the research by Osman and Goss (1983). Bryers analyzed 14 eastern Canadian barks and found these samples to

be rich in calcium (43% to 68% of ash as CaO, 1.4% to 17.8% $CaCO_3$), silicon (1.5% to 39% as SiO_2) and potassium (2.6% to 10.1% as K_2O).

Other inorganic components that may have significant concentrations are sodium, iron, phosphorous, chlorine, and aluminum. Sodium is toxic to plants, but in low concentrations can substitute for potassium (Bryers, 1996). High sodium concentrations are often caused by salt water intrusion or as a process additive (Bryers, 1996). Aluminum is usually an indicator of fuel contamination by extraneous soil. Iron is usually found in leaves, and participates in transport processes in the plant and is critical for photosynthesis (Baxter *et al.*, 1996). Phosphorous can be about 10% of ash (measured as P_2O_5) in alfalfa, cotton gin trash, barley straw, and corn stalks (Osman and Goss, 1983).

The total ash yield from biomass fuels is variable, ranging from 1.5% for olive pits to 19% for rice straw, based on proximate analysis at 950 C (Bryers, 1996). Ash yields and compositions can be very deceptive when conducted on high alkali content biomass fuels. The low boiling temperatures of some alkali minerals can result in vaporization and loss of some alkali yield if ashing is performed at or above the traditional ASTM ashing temperature of 750 C, as discussed by Bryers (1996).

Elemental composition of some typical biomass fuels are shown on Tables 2.4 and 2.5. Biomass fuels analyzed by Osman and Goss (1983), shown in Table 2.4, were ashed at 575 C prior to elemental analysis. It should be noted that their analysis neglected Al, Cl, Ti, V Cr, Mn, Ni, Cu Br, Ba and Pb, and assumed that all detected elements were in the form of oxides. Hence Osman and Goss did not achieve mass closure (right most column in Table 2.4). Biomass fuels analyzed by Baxter *et al.* (1996), shown in Table 2.5, were ashed at 500 C. Note that mass closure is not complete on these ash samples either, implying that other elements not detected by the test method are present (such as aluminum and chlorine), and the elements are not necessarily in oxide form in the ash.

Ash transformations during sawdust/sanderdust combustion is the focus of this dissertation, so examples of proximate and elemental analysis of similar wood fuels are shown in Table 2.6. Proximate ashing temperature of 950 C is implied by Bryers (1996) for wood bark fuels shown in Table 2.6.

It should be noted that sawdust/sanderdust used in the current research is a byproduct of strand board production. These wood-based fuels will contain an additional inorganic

fraction from binding resins introduced during the manufacturing process. This will be discussed in some detail with the experimental results.

2.1.3. Summary of Coal and Biomass Properties

Comparing biomass and coal directly, some generalizations can be made:

- Coal consists predominantly of carbon in the form of linked aromatic rings, in which oxygen to carbon ratio and hydrogen to carbon ratio decrease with increasing rank (Baxter, 1993). Biomass, with wood as an example, has a high oxygen to carbon ratio and high hydrogen to carbon ratio. These compositions lead to generally higher heating values for coal, and higher organic volatility for biomass fuels.

- Coal inorganic content is dominated by geologic minerals, deposited and homogenized by forces such as erosion, compaction, heating. Hence, it is made up of clays, silica, some carbonates, and pyrites. Alkali metal content is low, and is generally associated with salts and carbonates in low rank coal, and mainly silicates in higher rank coals. Mineral matter content ranges from about 5% to about 20%.

- Biomass inorganic content is mainly comprised of elements necessary for plant growth, assuming a clean (*i.e.* low soil content) source. Well dispersed silicon, calcium and potassium are primary constituents. Alkali metal content can be high, with sodium particularly high in shells, pits and some woods. Mineral matter content ranges from about 1% to 20%.

2.2 Combustion of Pulverized or Finely-Divided Solid Fuel

Much of the research concerning pulverized fuel combustion and mineral matter transformations has focused on coal. Pulverized coal and sawdust/sanderdust combustion have many common features. Thus, we describe the combustion process from a coal perspective, with exceptions and modifications noted for biomass as required. The discussion is also limited to fuel lean combustion of a pulverized or finely-divided fuel in a suspension environment.

Following the review articles by Saxena (1990), Anthony and Howard (1976) and modern interpretations by Niksa (1996), coal can be thought of as a polymer consisting of aromatic ring structures connected by aliphatic linkages and bonds containing O, S, and N. Heating induces a competitive process in which these links are the center of action. The heating either cleaves the bond, tending to release the aromatic "monomer" as a primary tar, or it generates a refractory char link that joins the two aromatic structures together permanently. The latter case is accompanied by the release of noncondensable gases (H_2, CO, CO_2, H_2O, and light hydrocarbons), and the residue becomes char. (Char is generally stable to thermal attack, only yielding to oxidation.) The tar is capable of undergoing secondary pyrolysis on the porous surface of the char. Alternately, it is released, where further reactions condense it into soot with a further release of noncondensable gases. This scenario completes the partitioning of the original coal into a refractory char particle, soot, and noncondensable gases (the "volatile matter"). This event is kinetically controlled for small particles (usually <100 μm) and it occurs on the order of tens of milliseconds.

With the above model as our road map, pulverized or finely-divided fuel combustion can be divided into stages: Drying, devolatilization, char combustion, and burnout. These stages are briefly discussed below.

2.2.1 Drying and Devolatilization

Pulverized fuel introduced into a combustion environment undergoes rapid heating. Free water is driven off (drying), and volatile matter is liberated by thermal decomposition (devolatilization). Literature suggests that the devolatilization process does not affect the phase or chemical composition of mineral matter for two reasons: First, devolatilization times are typically short compared to those of char combustion. For coal particles less than 100 μm in diameter (*i.e.* pulverized coal), the total combustion time is on the order of 1 second or less, with a devolatilization time of 0.1 second or less (Howard, 1981). Secondly, the particle temperature is most likely too cool for mineral matter liquification/vaporization. Endothermic cracking and vaporization of the volatile organic species is thought to suppress the particle temperature until devolatilization is complete.

Devolatilization can induce particle breakup (Mitchell and Akanetuk, 1996), resulting in faster burnout of residual carbon. Rapid internal generation of noncondensable volatiles,

coupled with the formation of a plastic metastate is thought to account for devolatilization-induced fragmentation.

Biomass devolatilization has not been as extensively studied as coal devolatilization. Biomass can lose more than 90% of its mass by devolatilization, owing to high hydrogen to carbon ratios, high oxygen to carbon ratios and low aromaticity (Baxter, 1993). A fraction of the inorganic material in biomass may be liberated by convective transport during devolatilization, according to Baxter (1993). Wornat *et al.* (1995) saw very little evidence of inorganic loss during devolatilization in experiments with southern pine wood and switchgrass. Wornat *et al.* (1995) attributed this to the endothermic nature of devolatilization suppressing the particle internal temperature, such that metal vaporization temperatures are not attained during devolatilization.

2.2.2 Char Combustion and Burnout

The fuel particle remaining after devolatilization is referred to as char, and is composed primarily of carbonaceous material and minerals. Review articles by Essenhigh (1981), Mulcahy and Smith (1969) and Saxena (1990) provide details on the char combustion process.

Char combustion is a heterogeneous reaction, which is fundamentally a conversion of bound carbon with freestream oxygen to form CO_2 (*e.g.*, see Glassman (1987)).

$$C + O_2 \Rightarrow CO_2 \qquad \text{eq. 6.1}$$

The details of this conversion, as well as the study of simultaneous and competing chemical reactions between other chemical species present, has resulted in very extensive literature.

Char combustion can be diffusion limited or kinetically limited. One diffusion limited hypothesis is known as the two-film model, and is shown in Figure 2.1.

In the two-film model, as described by Saxena (1990), CO is the primary reaction product at the particle surface, via the reaction:

$$C(s) + CO_2(g) \Rightarrow 2CO(g) \text{ (endothermic)} \qquad \text{eq. 6.2}$$

Depending on the diameter of the char particles and the combustion conditions, CO may also be formed by:

$$C(s) + (1/2)O_2(g) \Rightarrow CO(g) \text{ (exothermic)} \qquad \text{eq. 6.3}$$

CO diffuses outward, where it reacts with O_2 to form CO_2. Hence, the second film is CO oxidation:

$$CO(g) + (1/2)O_2(g) \Rightarrow CO_2(g) \qquad \text{eq. 6.4}$$

One half of the resulting CO_2 diffuses away from the particle and one half diffuses back to the particle surface. The CO_2 is reduced at the particle surface to 2CO, and repeats the cycle again. For large particles at high temperatures, the process becomes diffusionally limited. In this case, little O_2 penetrates to the char surface, and Reaction 6.3 is insignificant. As discussed below, for smaller particles in the kinetically-controlled regime, the clear boundaries between the diffusion zones shown in Figure 2-1 become blurred and O_2 can reach the surface.

Following Mulcahy and Smith (1969), the burning rate of char less than 100 μm in diameter, under oxidizing conditions and heating rates typically found in a pulverized fuel combustor, is a kinetically controlled process. This conclusion is drawn from the comparison of the rates of adsorption/desorption of oxides on the char surface versus the mass diffusion rate for a smooth, solid carbon particle. Mass diffusion varies inversely with particle diameter, while the chemical rate is independent of diameter. This naturally leads to a critical diameter (at a given temperature) for which the control mechanism shifts from kinetic control to mass transfer control.

Variations in particle temperature as a function of furnace wall temperature and particle diameter further complicate burning rate estimates. Shaw and Essenhigh (1991) used a two color optical pyrometer in a pulverized coal flame to observe that particulate matter temperature decreased as radiating particle surface area increased in a hot-walled furnace. They concluded that the temperature difference can be traced to the heat balance of a given particle; heat loss via conduction to the gas and loss via radiation to the walls. Their results showed that smaller particles exchange a larger fraction of their energy radiatively than the larger particles. Shaw and Essenhigh contrast their results with those of Mitchell and

McLean (1982), which show larger particles being cooler than small particles in a cold wall environment.

Char porosity has been shown to have a strong influence on char burning behavior (Glassman, 1987). Porosity is typically divided into macropores and micropores. Under kinetically-limited conditions, oxidizing species are able to penetrate the macropores, but not the micropores. This leads to a situation in which the macropores become enlarged due to oxidation, and become avenues for char fragmentation during burnout. The inability of the oxygen to penetrate the micropores generally leaves these internal surfaces under fuel-rich conditions, even when the overall char oxidation is under kinetic control. This provide opportunities for non-volatile mineral oxides (*e.g.* CaO) to be reduced to suboxide and elemental forms (*e.g.* Ca), with a significant increase in volatility. This introduces a mechanism of vaporization for what would normally be considered non-volatile species, as discussed in the next section. Lower rank coal chars tend to possess more macroporosity, and these tend to fragment most severely during char combustion.

In many cases, the char combustion process is interrupted before completion. In particular, modern low-NOx combustors delay the oxidation of the char, providing it with a longer "soak" time under high temperature, fuel rich conditions. This causes a thermal annealing of the char, resulting in a more crystalline, less reactive surface (Beeley *et al.*, 1996). This leads to higher levels of unburned carbon in the ash.

Details of biomass char combustion are limited compared to coal char combustion. The high volatile organics content of biomass chars suggests high porosity in biomass chars, so its behavior may be considered to be similar to high porosity coal chars.

Although the pathway to burnout only incrementally affects the total energy yield of a given fuel, it is of great significance relative to ash morphology; this is discussed next.

2.3 Fate of Mineral Matter in Combustion

Elemental components of a mineral matter will follow one of two simple pathways: In the first pathway, the material is vaporized and escapes the char particle. This pathway may include obstacles or dead-ends, such as diffusional resistance and capture by eutectic-forming discrete minerals. This is the preferred pathway of many alkali species.

Ultimately, vapor that escapes the particle will recondense on existing particles or surfaces, homogeneously condense, or chemically recombine to form a condensed species.

In the second pathway, mineral matter that has a low vapor pressure remains in the condensed phase. This mineral matter may stay in a solid form, become somewhat mobile in a melt phase, recombine with other non-volatiles, and/or capture volatile minerals attempting to escape the particle. This pathway is often dominated by alumino-silicate minerals in coal combustion. Although conceptually straight-forward, the details of these pathways are very complex.

Many mechanisms influence the transformations of mineral matter into the various forms of ash. These mechanisms, discussed below, exert a strong influence on both final composition and size distribution. Detailed reviews are also available elsewhere (*e.g.* Wall, 1992; Bryers, 1996).

2.3.1. Vaporized Mineral Matter and Capture Mechanisms

Work by a number of researchers shows that the fate of alkali mineral matter depends on both the original form of the alkali in the fuel, and the nature of the other mineral matter present. The research described in the following paragraphs paints an overall picture in which alkali minerals can either be vaporized, or they can be captured by other minerals. In the latter case, the "capture" is essentially the formation of an alkali-mineral complex within which the vapor pressure of the alkali is suppressed to the point that minimal vaporization occurs. The tendency to form these complexes is governed by both the chemical composition (*e.g.*, the tendency of the minerals to form low melting eutectics) and physical properties (*e.g.*, the dispersion of the mineral inclusions in the char, or over the char surface). This is a very complex problem.

Research by Neville and Sarofim (1985) demonstrates that sodium organically bound in the coal matrix, or as halide (NaCl), is volatile under combustion conditions, while sodium that is bound with silica minerals is much less volatile. Neville and Sarofim burned four coals at 1750K and 20% O_2. Sodium fraction appearing as fume was greatest for coals containing mainly organically bound sodium. Sodium fraction appearing as fume increased with Cl/Na ratio, and decreased with Si content. It was also found that organically bound sodium vaporization decreased with increasing combustion temperature. The latter

observation mirrors the increased mobility of sodium within the silica particles as temperature is increased. This mobility prevents the surface of the silica particles from becoming saturated in sodium, which would prevent further absorption.

Sodium capture appears to be a function of its original form (ion-exchangeable *vs.* organically bound) in the pulverized fuel, as can be seen in research performed by Lindner and Wall (1990). Lindner and Wall used Loy Yang brown coal, acid leached to 0.5% ash, as a baseline fuel. This baseline coal was modified with additives to form ion exchangeable sodium with discrete mineral inclusions (NaCl and quartz doping), and organically bound sodium with discrete mineral inclusions (sodium acetate and quartz doping). The doping material and coal were slurried, blended, dried, pulverized, and size fractionated to 63 -90 μm. The burning of these particles in a drop tube furnace at 1000 C, 1200 C and 1400 C revealed the following trends:

- Complexing of Na with quartz to form a silicate was three to five times greater for acetate doped coal than for NaCl doped coal (Lindner and Wall, 1990). Although Lindner and Wall do not directly explain, it is likely that the sodium chloride vapor is favored by equilibrium in the presence of quartz, reducing the availability of sodium for fluxing of the quartz crystal.

- For the NaCl doped tests, 47 to 66% of the sodium that was not complexed with the silica became submicron (0.2 μm to 0.5 μm) NaCl particles. The balance of the non-silica sodium was found as condensed NaCl species on the residual ash particles (Lindner and Wall, 1990). Although not directly stated by the authors, this appears to lend support to the favored equilibrium of vapor NaCl over silica fluxing.

An interesting secondary investigation by Lindner and Wall (1990) involved a doping a coal with NaCl and kaolin (presumably $Al_2O_3 \bullet 2SiO_2 \bullet 2H_2O$). This experiment showed that this alumino-silicate clay captured five to eight times more sodium from NaCl, than an equal mass of quartz. Additional fragmentation of kaolin (such that more reactive surface is available) is suggested by Lindner and Wall as a possible explanation.

Gallagher *et al.* (1996) performed experiments with three different coals in a drop tube furnace to investigate sodium transformations as a function of combustion temperature and the form of the sodium in the parent coal. Sodium occurrence was quantified by the ratio

of acid soluble sodium (expressed as an oxide) to alumino-silicate (expressed as oxides of silicon and aluminum). Specifically,

$$\text{Na-Si ratio} \equiv Na_2O / (SiO_2 + Al_2O_3).$$

Ash samples were collected by a cascade impactor and afterfilter, and analyzed by for Na, Si, and Al by size cut.

Gallagher *et al.* (1996) burned Kentucky No. 11, a low sodium coal (Na-Si ratio = 0.003, 0.3% Na_2O ash composition) and found that silica was moderately enriched in the small size cuts (<.65 μm), but sodium was not. Changing the peak combustion temperature from 1380 K to 1530K did not significantly change element partitioning. Gallagher *et al.* (1996) postulated that the small amount of vaporized sodium initially available was quickly scavenged by the abundant alumino-silicates.

Tests by Gallagher *et al.* (1996) with Buelah lignite (Na-Si ratio =.21, 6.1% Na_2O ash composition) showed progressive enrichment of Na as particle diameter decreased, as compared to Si and Al. Enrichment in the sub-micron range was attributed to sodium vaporization and nucleation/condensation. Further, Gallagher *et al.* (1996) noted that increasing the peak combustion temperature from 1400K to 1560K resulted in significant sodium reduction in the smaller (≤0.065 μm) size cuts and slight increase in larger size cuts. It was suggested that higher temperature increased the sodium - silicate reaction rate, resulting in an increase in sodium complexing in larger size cuts.

Tests by Gallagher *et al.* (1996) with Loy Yang 2301, a high sodium coal (Na-Si ratio = 1.7, 30.7% Na_2O ash composition), showed progressive enrichment of Na as particle diameter decreased, like Buelah lignite. Increasing peak temperatures from 1530K to 1610K did not significantly change the sodium fraction in the small particle range. It was concluded by Gallagher *et al.* (1996) that inadequate amounts of silica were available to effectively compete for sodium capture.

The rate of release of sodium from artificial char has been measured by Srinivasachar *et al.* (1990b). They find that organic Na release, in the absence of other minerals, essentially parallels char burnout. Transport-based models predict that sodium has sufficient diffusivity within the porous char matrix to be fully vaporized before char burnout is

complete (Kramlich *et al.*, 1996). The significantly slower observed vaporization rate has been interpreted as indicating kinetic control. In reality, it appears that sodium is released only as the burning char surface recedes over the site of the sodium. This observation raises issues regarding the physical mechanism of sodium capture by the residual minerals that collect at the surface of the burning char particle, *i.e.*, the proximity of the sodium release to the surface minerals. The issue of whether these conclusions hold true for sodium that is initially NaCl is not known.

Research by Kramlich and Newton (1994a,b) demonstrated that aerosol yield can be influenced by partitioning of the pulverized fuel prior to combustion. Raw pulverized coal was aerodynamically separated into a series of size cuts. Each cut was fired individually and the aerosol yields measured to determine the contribution of each size to the overall aerosol yield of the parent coal. The results showed that each cut generated more aerosol than the parent coal, indicating that the aerosol formation mechanism was modified by the sizing process. It was suggested that the aerodynamic sizing disrupted the contact between the macerals and excluded minerals, leading to a reduction in alkali vapor absorption by the minerals and generating an increased aerosol yield.

In a further series of tests by Kramlich and Newton (1994a,b), the raw coal was divided into a series of fractions by a froth flotation cleaning process. The cleaning process was accomplished in stages, with each stage generating a "float" fraction (the cleaned fuel) and a "sink" fraction (the ash-rich stream). Each new stage used the float fraction from the previous stage, which resulted in one final cleaned fuel, and a series of reject "tailings" from each stage. The combustion of each of the tailings also resulted in an increase in the aerosol yield relative to that of the unmodified coal. The sole exception was the tail from the first stage, which was the richest in mineral matter. This cut showed a significantly lower aerosol yield. Kramlich and Newton (1994a) suggested that this first cut is composed of excluded minerals that suppress the aerosol mode, either through direct absorption of vapor phase minerals or by influencing the char combustion temperature. In summary, a number of factors govern the fate of alkali (capture vs. release). These include the nature of the original bonding, the type of other minerals present, and the proximity of these minerals to the site of alkali release. The temperature also governs the ability of the minerals to absorb alkali into a non-volatile form.

One other mechanism has been proposed to account for the generation of aerosol from non-volatile minerals, such and calcium or aluminum. The fuel-rich interior of a char particle can lead to reactions that reduce refractory oxides to suboxides and elements. An example is:

$$CaO + C = Ca + CO$$

Elemental calcium will vaporize under char combustion temperatures and escape the particle. Within the boundary layer surrounding the particle the calcium reoxidized to CaO and is instantly in such a high supersaturation that it forms nanoparticles. These grow by Brownian coagulation and generate aerosol particles (Senior and Flagan, 1982; Quann and Sarofim, 1982). This reoxidation/condensation is so fast that a significant fraction of these "short-term" volatile species may be retained at the char interface and become part of the residual ash (Benson *et al.*, 1993). This mechanism was necessary to account for the large number of aerosol particles with refractory oxide cores that were noted in samples from field facilities burning low-alkali coals.

2.3.2 Residual Ash Mechanism

Fragmentation

Minerals that do not vaporize remain with the char particle. Hence, fragmentation of the char particle during combustion is important to establishing the final fate of the minerals. Char break-up separates mineral inclusions that could otherwise interact directly.

Flagan and Friedlander proposed the break-up model (1978) for residual ash formation, in which each coal particle is assumed to produce a fixed number of equal-sized char particles, and each char particle is assumed to burn out leaving its mineral matter as one residual ash particle. Thus, a known original coal size distribution and coal mineral content can be combined with an empirical "breakup number" (*i.e.*, number of char particles per parent coal particle) to derive an expected residual ash size distribution. This simple model has had some success in empirically correlating ash size distributions, but does not address mechanistic issues.

Intensive research into the mechanisms of fragmentation and coal combustion have led to more complex modeling schemes (*e.g.* Miccio and Salatino, 1992). Current research tends to suggest that fragmentation of char is primarily driven by oxidation in macropores of

porous chars (*e.g.* Mitchell and Akanetuk, 1996). Fragmentation of reactive minerals such as pyrite (Baxter, 1990, Srinivasachar *et al.* 1990a) are also a factor.

Fluxing and Coalescence

Residual inorganic material may reach its melting point, or be induced to molten stage by the presence of a fluxing agent. This results in a molten droplet that may collide (and possibly react) with other molten droplets, solid particles or furnace walls. It can also react with volatile species, or solidify in cooler regions of the combustor. Ultimate particle size is usually dependent on original particle size, but can be a complex function of other variables as well, and can result in a size mode larger or smaller than the parent material diameter. Some specific examples are given below.

Helble *et al.* (1990) examined pulverized Kentucky #11 and Illinois #6 coals fired at 7% oxygen and found that agglomeration and coalescence were dominant transformation mechanisms. Coalescence of finely divided illite, kaolinite and quartz resulted in a glassy ash particulate in Kentucky #11, with occasional enrichment with iron and potassium. Some calcite ($CaCO_3$) fragmentation was evident in the ash size distribution of the calcium carbonate-rich Illinois #6. Almost 90% of the calcite ultimately went to CaO particles, rather than combining with silicate ash particles, in Illinois #6. (Helble *et al.*, 1990).

Experiments with Beulah lignite showed that a high concentration of large (>40 μm) pyrite excluded minerals resulted in significant fragmentation, with more pronounced fragmentation as oxygen content was increased from 7% to 21% (Helble *et al.*, 1990). Some limited calcium incorporation into existing kaolinite and other silicates was noted, but calcium did not interact with quartz. San Miguel lignite, a 40% ash coal, showed very little coalescence (Helble *et al.*, 1990). This was attributed to the large mineral inclusion sizes in the parent fuel.

Kramlich and Newton (1994b) investigated the supra-micron ash distribution from pulverized coal, as measured by a cascade impactor and by a laser diffraction size analyzer. The data showed three modes: (1) the aerosol mode (<0.5 μm), most likely a result of the vaporization / condensation of volatile species, (2) a residual mode (>3 μm), which is a result of coalesced minerals, and (3) a 1-2 μm mode, which was postulated to be liberated mineral inclusions. The basic break-up model (Flagen and Friedlander, 1978) was modified to incorporate measured aerosol formation and a Gaussian size distribution of

break-up particles. The 1-2 μm mode was not predicted by the model, leading Kramlich and Newton (1994b) to conclude that a specific mechanism was responsible. Cleaned coals showed an undiminished 1-2 μm mode, indicating the mode is not from inclusions that can be liberated by grinding. The mode was most prevalent in finely ground coals, suggesting that it is a function of exposed surface area. This suggests that it is caused by shedding of inclusions near the char surface during the initial stages of char burnout.

Zygarlicke *et al.* (1992) used synthetic coal to study Ca-Si-S interactions, particularly as a function of the form of the calcium - inorganic as discrete 10 μm calcite particles, and atomically dispersed as calcium acetate. Experiments at 900 C, 1100 C and 1500 C showed increasing coalescence with temperature in the calcite system. Chemical analysis supports their conclusion that conversion of calcium to calcium silicate increases with temperature. Interestingly, this contrasts with their experiments with Na-Si-S systems, which show decreased sodium silicate interaction as temperature increases and a decrease in coalescence. It was concluded that the calcium remained with the char particle at higher temperatures, to form agglomerating calcium silicate particles, while sodium became more volatile at high temperatures, and escaped the char.

Heat Transfer Surface Deposition

Much of the research associated with residual ash has focused on deposition characteristics on heat transfer surfaces in the form of slag or fouling. Baxter (1992) identifies these mechanisms as inertial deposition, thermophoresis, condensation, and chemical reaction. An in-depth review of heat transfer surface collection mechanisms are beyond the scope of this work. It is worthwhile to note, however, that alkali-silicate interactions can play an important role in the deposition mechanism. For example, thermodynamic calculations by Wibberly and Wall (1981a) show that vapor sodium reacting with silica in the temperature range of 1300 K to 1850 K can form a low viscosity surface layer of sodium silicate on existing silica particles. This surface layer can enhance adhesion of the ash particle upon impact with a heat transfer surface. Below about 1400 K, sulfur reduces the silicate formation. In experiments (Wibberly and Wall, 1981b), formation of a sodium silicate layer on silica particles was verified. This evidence supports the "sticky particle" deposition mechanism. They concluded that a silicate layer of about 1 μm will allow capture of the bulk of impinging fly ash particles.

Table 2.1: Proximate and ultimate analysis for the recommended standard suite of U.S. research coals (from Smith and Smoot, 1990)

		Proximate Analysis *					Ultimate Analysis †						
Coal	Source of Data ††	Moist rec'd (%)	Ash rec'd (%)	Vol Mat rec'd (%)	F Carbon rec'd (%)	Cal Val rec'd (Btu/lb)	Carbon maf (%)	Hydrogen maf (%)	Nitrogen maf (%)	Sulfur maf (%)	Chlorine maf (%)	Oxygen maf (%)	Cal Val MAF (Btu/lb)
Upper Freeport (MVB)	ANL	1.13	13.03	27.14	58.70	13315	85.50	4.70	1.55	0.74	0.00	7.51	15511
Wyodak	ANL	28.09	6.31	32.17	33.43	8426	75.01	5.35	1.12	0.47	0.03	18.02	12843
(SUBC)	PSOC 1520	26.69	9.08	40.13	24.10	8277	73.78	2.77	1.11	1.38	0.03	20.95	12868
Illinois #6	ANL	7.97	14.25	36.86	40.92	10999	77.67	5.00	1.37	2.38	0.06	13.51	14140
(HVCB)	PSOC 1493	9.43	13.74	34.34	42.50	10835	78.07	4.92	1.50	5.87	0.04	9.61	14011
Pittsburgh (#8)	ANL	1.65	9.10	37.20	52.05	13404	83.20	5.32	1.64	0.89	0.12	8.83	15018
(HVAB)	PSOC 1451	2.54	13.32	33.56	50.58	12528	83.26	5.41	1.58	1.58	0.09	8.10	14713
Pocahontas #3	ANL	0.65	4.74	18.48	76.13	14926	91.05	4.44	1.33	0.50	0.20	2.47	15777
(LVB)	PSOC 1508	1.14	7.36	15.52	75.98	14376	91.48	4.38	1.10	0.69	0.06	2.30	15711
Utah Blind Canyon	ANL	4.63	4.49	43.72	47.16	13280	80.69	5.76	1.57	0.37	0.03	11.58	14613
(HVBB)	PSOC 1502	8.72	8.20	37.20	45.89	11547	80.04	5.26	1.23	0.56	0.02	12.89	13898
Upper Kanawha (MVB)	ANL	2.42	19.36	29.44	48.78	11534	82.58	5.25	1.56	0.65	0.12	9.83	14733
Beulah-Zap	ANL	32.24	6.59	30.45	30.72	7454	72.94	4.83	1.15	0.70	0.04	20.34	12185
(SUBC)	PSOC 1507	33.57	8.30	27.08	31.06	7060	71.55	5.04	0.95	1.63	0.02	20.81	12144
Lower Wilcox (LIGA)	PSOC 1443	28.54	15.31	44.17	11.98	7062	72.34	5.21	1.35	0.94	0.07	20.11	12577
Dietz (SUBB)	PSOC 1488	23.66	4.08	31.95	40.31	9557	76.00	5.23	0.94	0.53	0.04	17.27	13227
Buck Mountain (AN)	PSOC 1468	4.51	6.52	3.49	85.48	13128	95.36	1.38	0.84	0.53	0.03	1.86	14772

* Moist = moisture content, Ash = ash content, Vol Mat = volatile matter, F Carbon = fixed carbon content, Cal Val = calorific value, rec'd = analysis on an as-received basis from the mine.
† maf = analysis on a moisture ash free basis, MAF = calorific value on a moisture ash free basis.
†† ANL = data obtained from the Argonne National Laboratory for the PSCP Coals, PSOC = data obtained from the Penn State Coal Data Base for the coal number specified.

Table 2.2: Ash composition of the recommended standard suite of U.S. research coals (from Smith and Smoot, 1990)

	Upper Freeport (MVB)	Wyodak (SUBC)	Illinois #6 (HVCB)	Pittsburgh (#8) (HVAB)	Pocahontas #3 (LVB)	Utah Blind Canyon (HVBB)	Beulah-Zap (SUBC)	Lower Wilcox (LIGA)	Dietz (SUBB)	Buck Mountain (AN)
Source of Data	ANL	ANL	Penn State	Penn State	Penn State	ANL	Penn State	Penn State	Penn State	Penn State
Major & minor elements in ash (%):										
SiO_2	42.82	32.91	41.20	54.40	46.50	49.60	19.70	47.90	32.50	44.70
Al_2O_3	23.97	17.26	15.70	24.50	24.40	10.50	9.34	22.20	19.60	39.00
CaO	4.60	21.81	7.39	2.97	7.38	17.60	23.20	14.00	16.20	0.58
Fe_2O_3	21.35	6.77	23.90	9.16	8.29	6.04	12.19	3.51	5.33	8.93
SO_3	1.32	10.69	7.90	2.30	8.40	8.90	20.00	7.00	12.50	0.70
MgO	1.07	5.11	0.90	0.85	1.31	2.25	5.33	2.79	5.62	0.64
Na_2O	0.44	2.15	0.40	0.61	1.12	2.38	5.87	0.37	3.17	0.32
TiO_2	1.02	1.29	0.76	1.14	1.76	0.84	0.37	1.14	1.14	2.30
K_2O	2.46	0.33	1.70	2.02	0.53	0.06	0.69	0.55	0.37	1.45
P_2O_5	0.09	1.31	0.26	0.34	0.32	0.35	0.34	0.11	0.24	0.22
BaO	0.05	0.50								
MnO	0.05	0.04								
SrO	0.05	0.42								

Table 2.3: Alkali-metal species in low-and high-rank coals
(from Raask, 1985, Table 15.5)

Fuel Deposits	Sodium and potassium species	Comments
Vegetable matter and flood and ground waters	Organometal salts, chlorides, sulfates, and carbonates	The vegetable matter is rich in potassium, but flood and ground waters can be rich in sodium
Lignites and sub-bituminous coals	Chiefly organometal salts and soluble inorganic salts	Frequently rich in sodium, potassium content is usually low
Low-rank bituminous coals	Chiefly chlorides and silicates	Sodium is present partly as chloride and partly in silicates, potassium has a high affinity to silicates
High-rank bituminous coals and anthracites	Chiefly silicates with some chloride	High-rank, low-porosity coals have a limited capacity to hold chlorides

Table 2.4: Ash composition of typical biomass fuels, expressed as oxides in weight percent (from Osman and Goss, 1983)

I.D.#		SiO_2	Fe_2O_3	MgO	CaO	ZnO	K_2O	Na_2O	So_3	P_2O_5	Total
1	Bean Straw (I)	29.90	2.70	0.90	4.67	0.03	22.34	0.52	4.70	2.29	68.05
2	Safflower	20.46	1.20	6.10	10.84	0.03	30.01	0.91	8.36	3.64	81.65
0	Rice Hulls	94.60	0.03	0.02	0.25	0.00	2.40	0.14	2.24	0.46	100.12
3	Alfalfa	7.96	0.51	2.87	11.20	0.13	33.97	3.64	4.64	10.46	75.46
4	Cotton Gin Trash	23.20	1.93	2.87	7.18	0.19	13.00	1.59	4.24	10.00	64.20
5	Barley Straw	44.70	2.60	4.84	3.22	0.13	8.01	5.25	1.80	11.56	81.11
6	Corn Stalks	50.70	3.14	3.08	3.90	0.95	10.30	0.53	11.08	10.00	93.68
7	Rice Straw	75.20	0.58	0.83	0.72	0.00	11.90	0.28	1.51	8.87	99.89
8	Bean Straw (II)	32.70	3.93	3.65	6.30	0.15	25.30	0.82	2.28	7.30	82.43
9	Wood Chips	8.30	10.00	6.22	18.61	0.19	11.80	1.32	9.00	6.87	71.61
10	Corn Fodder	55.30	2.40	3.32	1.05	0.09	9.59	0.73	3.48	2.98	78.95
11	Paper Pellets	57.20	4.29	0.83	0.15	0.31	1.85	5.09	4.00	4.46	78.19
12	Corn Stalks (Ex.)	63.30	4.72	4.78	0.56	0.00	8.37	0.47	7.20	2.06	91.46
13	Almond Shell	22.60	3.77	2.49	12.27	0.05	14.14	5.08	8.00	5.50	73.90
14	Corn Cobs	40.30	4.06	2.49	1.27	0.22	2.04	1.19	8.74	6.87	85.53
15	Manzanita Chips	5.97	2.86	4.94	24.49	0.25	10.96	2.85	6.74	8.20	67.16
16	Tree Pruning	9.95	1.94	8.29	19.87	0.06	12.66	1.48	19.72	4.96	85.93
17	Walnut Shell	13.60	2.44	3.65	7.00	0.44	21.50	1.08	8.48	4.58	62.92
18	Olive Pits	10.50	2.20	3.48	25.89	0.12	3.13	7.60	17.20	7.56	77.74
19	Almond Shells	18.60	3.83	1.99	16.00	0.23	14.70	5.86	17.48	7.79	86.48
20	Corn Stalks	71.70	7.10	2.70	0.46	0.02	10.28	0.33	2.20	0.66	95.45
21	Cotton Stalks	33.00	2.80	6.05	3.56	0.07	21.40	1.37	6.55	6.40	83.57
22	Rice Mix	75.00	0.47	2.50	1.10	0.00	15.85	0.54	1.00	1.10	97.56
23	Wheat + Corn (1:3)	71.70	3.30	8.30	0.95	0.62	14.76	0.54	2.96	1.10	103.64
24	Rice Straw Good Bales	78.30	0.36	2.00	0.70	0.00	13.00	0.43	1.69	0.80	97.78
25	Rice Straw Decayed Bales	78.60	0.44	2.00	0.88	0.00	14.50	0.44	1.83	0.90	99.59

Table 2.5: Ash chemistry of some typical biomass fuels
(from Baxter et al., 1996)

	Waste Paper	Wheat Straw	80% Wood 20% Wheat Straw	Rice Straw	Almond Hulls	Almond Shells	Olive Pits	Wood Waste/ Almond Shells	Aspen	Chicken Litter
	1	2	3	4	5	6	7	8	9	10
Elemental Composition										
SiO_2	20.5	55.7	56.8	73.0	4.0	4.9	23.1	49.6	14.9	10.7
Al_2O_3	54.0	1.8	10.9	1.4	1.3	1.5	5.3	11.0	1.2	5.8
TiO_2	1.5	*	0.5	*	*	*	0.1	0.4	*	*
Fe_2O_3	0.1	0.7	4.9	0.6	0.4	1.3	5.1	4.6	1.2	0.8
CaO	10.2	2.6	10.2	1.9	5.0	6.9	10.9	14.4	65.2	21.4
MgO	1.9	2.4	2.4	1.8	2.9	2.6	3.0	2.7	4.3	6.2
Na_2O	1.1	0.9	3.8	0.4	0.2	0.5	29.9	2.4	0.4	3.8
K_2O	0.2	22.8	6.7	13.5	50.9	49.6	5.2	7.4	6.5	15.1
SO_3	2.3	1.7	1.9	0.7	1.2	1.6	2.4	1.4	1.8	7.0
P_2O_5	*	1.2	1.1	1.4	5.5	5.0	2.7	1.5	2.0	30.2
Total Percentage	91.8	89.8	99.2	94.7	71.4	73.9	87.7	95.4	97.5	100.0
TGA Loss on LTA, 500 °C %	8	10	9	15	26	23	20	11	--	--
Ash Fusion Temperatures										
Reducing										
I.T.	2694	2464	2065	2023	2359	1960	2340	2084	—	—
S.T. (Sph.)	2910	2466	2096	2246	2401	1981	2372	2130	—	—
S.T. (Hem.)	2910	2467	2288	2258	2408	2010	2495	2178	—	—
F.T.	2910	2474	2384	2641	2410	2071	2497	2239	—	—
Oxidizing										
I.T.	2619	1911	2084	1965	2558	1897	2448	2072	—	—
S.T. (Sph.)	2632	1913	2105	2158	2801	1899	2449	2096	—	—
S.T. (Hem.)	2910	2238	2322	2496	2818	1911	2487	2175	—	—
F.T.	2910	2316	2499	2582	2820	2348	2704	2262	—	—

* = Nil

Table 2.6: Fuel properties of eastern Canadian bark
(from Bryers, 1996)

	Balsam	Black Spruce	White Spruce	Red Spruce	Jack Pine	Poplar	Birch White	Birch Yellow	Maple Hard	Maple Soft	Elm	Beech	Tamarack	Hemlock
Proximate Analysis														
Volatile	77.4	74.7	72.5	72.9	74.3	78.9	80.3	76.5	75.1	78.1	73.1	75.2	69.5	72.0
Fixed carbon	20.0	22.5	24.0	23.7	23.6	17.2	18.0	21.0	19.9	18.9	18.8	18.9	26.3	25.5
Ash	2.6	2.8	3.5	3.3	2.1	2.2	1.7	2.5	5.0	3.0	0.1	7.9	4.2	2.5
Ultimate Analysis														
Carbon	52.8	52.0	52.4	52.1	53.4	51.8	57.4	54.5	50.4	50.1	46.9	47.5	55.2	53.6
Hydrogen	6.1	5.8	6.4	5.9	5.9	6.5	6.7	6.4	5.9	5.9	5.3	5.5	9.9	5.8
Sulfur	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nitrogen	0.2	0.1	0.1	0.1	0.2	0.3	0.3	0.6	0.5	0.3	0.6	0.6	0.7	0.2
Oxygen	38.6	39.7	38.4	38.6	38.9	38.0	33.8	26.2	39.1	40.7	39.1	38.5	31.0	37.9
Ash	2.3	2.4	3.0	2.0	3.1	3.4	1.8	2.3	4.1	3.0	8.1	7.9	4.2	2.5
Ash Analysis														
SiO_2	24.6	6.4	2.0	7.6	16.0	1.5	3.0	4.1	39.5	6.1	3.6	12.4	7.3	10.0
Al_2O_3	1.8	1.1	0.6	0.0	6.3	0.5	0.6	0.3	3.8	3.1	0.0	0.0	8.4	2.1
TiO_2	0.2	•	•	0.1	0.2	•	•	•	•	0.1	0.1	•	0.1	•
Fe_2O_3	2.5	1.1	0.7	3.1	5.0	0.6	2.9	0.8	1.7	0.8	0.3	1.1	3.6	1.3
CaO	43.2	67.6	62.9	58.4	51.6	62.3	58.2	54.2	55.5	60.4	67.1	68.3	50.3	53.6
$CaCO_3$	7.8	11.2	13.6	11.3	4.9	14.6	13.0	17.8	1.4	16.7	16.3	2.2	4.1	9.7
MgO	2.2	1.7	6.4	4.7	5.5	1.9	4.2	5.4	19.4	2.3	2.0	11.5	8.5	13.1
MnO	2.6	2.2	1.2	2.0	1.6	0.3	4.6	1.3	1.0	0.4	0.1	0.4	3.4	1.2
P_2O_5	4.6	2.2	2.6	2.2	2.8	2.0	2.9	3.8	1.1	0.3	1.3	2.3	4.7	2.1
K_2O	10.1	6.2	7.3	5.3	4.1	7.2	6.6	8.0	5.8	6.3	4.4	2.6	5.3	4.6
Na_2O	2.5	2.5	0.8	2.0	3.1	3.9	1.3	1.7	2.2	0.9	0.7	0.9	3.2	1.1
SO_3	2.7	1.4	2.2	1.3	2.6	0.6	3.2	1.3	1.4	2.0	0.8	0.8	2.6	1.9
Fusion Temperatures, °K														
Initial	1838	1760	1755	1627	1616	1744	1760	-	1727	1660	-	1633	1505	1788
Softening	1844	1784	1755	1821	1783	1810	1766	1777	1821	1738	-	1811	1533	1744
Fluid	1849	-	1760	1827	1805	1816	1771	1777	1827	1744	-	1816	1560	1799

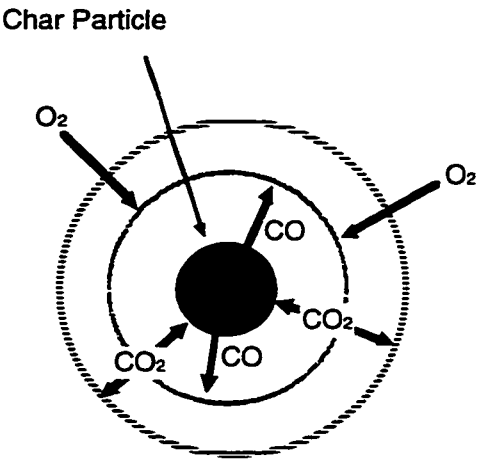


Figure 2.1: Two-film model for diffusion controlled char particle combustion (adapted from Saxena, 1990)

FOCUS AND OBJECTIVES

The principal thrust of the research presented here is modeling and characterization of mineral transformations occurring in sawdust/sanderdust combustion. Emphasis is on sub-micron aerosol production, its magnitude, and composition relative to other ash modes.

Sawdust/sanderdust fuels behave very differently from the coals described in the previous chapter, whose behavior has been much more thoroughly characterized in the literature. One unique feature is a very high alkali mineral content, suggesting very large yields of sub-micron aerosol via the vaporization/condensation mechanism. These fuels also largely lack aluminosilicate minerals, which would normally be active in both absorbing alkali vapors and in fluxing the residual ash. This ash creates unique operational and environmental barriers that must be overcome in order to use these abundant, renewable fuels as an in-plant energy source. The objectives of this work are given below.

OBJECTIVE 1: SAWDUST/SANDERDUST CHARACTERIZATION

A primary objective is to present an accurate physical and chemical characterization of the ash generated by the combustion of practical sawdust/sanderdust fuels. Ash particle morphology and composition measurements of high-alkali biomass fuels is a lightly researched field, but is of critical importance when identifying and quantifying transformation mechanisms. Fulfillment of this objective includes the following:

- Simulation of a wood-fired industrial-scale suspension burner using a laboratory scale (15 kW) tunnel furnace, with accurate measurement of relevant control variables such as temperature/time history, excess oxygen content and residence time.

- Quantitative size distribution measurements of the resulting ash using a cascade impactor for particulate matter greater than 0.4 μm, and an Electrical Aerosol Size Analyzer (EAA) for particulate matter less than 0.4 μm.

- Composition and morphology of ash particulate matter using Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Analysis (EDAX) techniques.

The output of the work supporting this objective is a physical and chemical "picture" of the state of the output mineral matter after it has been transformed by a realistic, yet well characterized combustion environment.

OBJECTIVE 2: COMPONENT MODELING OF ASH TRANSFORMATIONS

A primary objective is to present a modeling methodology for predicting the properties of the ash (*i.e.*, size distribution and chemical composition *vs.* size) as a function of the initial composition of the fuel and the environment provided by the combustor. This modeling phase is comprised of a number of components rather than a single model entity. It examines critical mechanisms that control ash transformations in the sub-micron particle size range, and is used to bridge the gap between carefully controlled laboratory results and industrial-scale combustor conditions. This objective is accomplished in parts, as listed below.

- Vaporized alkali species have two fates. They can either condense onto existing non-alkali particles, or homogeneously nucleate into an alkali aerosol. Heterogeneous condensation tends to promote formation of large particles with low number density, while homogeneous condensation promotes formation of very fine particles ($d<<0.1$ μm) with high mobility and high number density. Hence, the relative contributions of these two mechanisms are examined relative to controllable parameters such as quench rate and fuel firing density.

- Determination of equilibrium concentrations of condensed species is made using CET89, informally known as the NASA equilibrium code (Eddings, 1973). Equilibrium calculations are used to determine the favored anion and condensation temperature of critical vapor-phase species. Due to the high furnace temperatures (and thus fast reaction rates), equilibrium is expected to be a good model for gas-phase mineral chemistry. This information is also critically examined relative to processes that are likely kinetically controlled, such as condensed species formation during rapid quench conditions.

- The ultimate size distribution of sub-micron particles is examined using the coagulation program MAEROS2 (Gelbard, 1996). The coagulation rate of the highly mobile (*i.e.*

diffusionally transported) sub-micron particles is strongly driven by initial particle number density and the residence time of condensed species. MAEROS2 aids in scaling laboratory measurements of number density and residence time to the conditions used in industry.

Other ash formation mechanisms are important, but beyond the scope of this research. These include:

- Alkali-sulfur species are not predicted by equilibrium in the vapor phase, but are favored in solid phase. This observation, and experiments conducted by others, tend to indicate that sulfation is kinetically limited. This potentially extensive research area is not explored in depth.

- Residual ash, defined here as any ash component that does not enter a vapor phase, is typically on the order of 1 μm and larger. Important processes in residual ash formation include particle break-up, melting and fluxing, and aggregation. The focus of the modeling objective is the sub-micron ash yield, hence residual ash formation is only included as it pertains to influencing the sub-micron yield (*e.g.*, heterogeneous condensation surfaces).

- Organic particulate matter formation (*i.e.* sub-micron soot particles) is a well known result of incomplete combustion, but does not significantly influence this research. Factors favoring complete combustion in sanderdust burners are high excess oxygen (about 8% by volume) and long furnace residence time (about 1 second). Compared to coal, this fuel also has high volatile yield (leaving little char). The remaining char has very high porosity, which provides a large surface area for oxidation.

OBJECTIVE 3: PULVERIZED COAL CHARACTERIZATION

A secondary focus of this research is developing a database of ash morphology for a well-characterized set of research coals. This coal database serves as a source of comparison for the sawdust/sanderdust experiments, but also examines the influence of coal cleaning, size segregation and coal composition on aerosol yield.

TECHNICAL APPROACH AND EXPERIMENT APPARATUS

Objectives outlined in Chapter 3 were investigated using procedures and apparatus described below.

A laboratory-scale (15 kW) tunnel furnace was the primary experimental tool. It was designed to provide a combustion environment that is similar to that found in industrial-scale systems, but at the same time to be more idealized. The principal benefit is flexibility. The combustion environment can be directly controlled and easily characterized, allowing the research of fundamental and generic phenomena. Interpretation is eased because the myriad of complications associated with a practical combustor are avoided. A description of this facility is presented in Section 4.1.

Pulverized coal experiments were conducted with three bituminous coals, one cleaned coal, and one sized coal. Ash size distributions were obtained using a water cooled sampling probe and a cascade impactor. Procedural details and equipment are addressed in Section 4.2.

Mechanistically-based experiments were conducted using artificial chars that contain organically-bound sodium and varying amounts of bentonite macerals, calcite macerals, and pyrite macerals, respectively. Ash size distributions were obtained using a water cooled sampling probe and a cascade impactor, similar to the pulverized coal experiments. Procedural details are addressed in Section 4.3.

Sawdust/sanderdust experiments were conducted with fuels from four different sources. Experiments were conducted with the fuels using a water-cooled sampling probe and cascade impactor. Chemical analysis and scanning electron microscopy were also conducted on selected size cuts and aerosol components. These procedures are addressed in Section 4.4.

Further sawdust/sanderdust experiments were conducted with milled samples. An isokinetic sampling probe and an electrical aerosol analyzer were used to determine the size distribution of the resulting ash, as well determine the detailed size distribution of the sub-micron aerosol. These procedures are addressed in Section 4.5.

A description of the design and use of a High Velocity Thermocouple (HVTC) is given in Section 4.6. This instrument was used to conduct detailed temperature profiles at each station of the reactor.

4.1 Facility Description- Tunnel Furnace

Combustion experiments were performed using a tunnel furnace, as shown in cross-section in Figure 4.1. A high temperature refractory (Greencast 97, 1760C max, 1.5 W/m-K thermal conductivity) forms the inner walls of the combustion tunnel, with heat loss to the surroundings minimized by three layers of material with progressively lower thermal conductivity. The furnace refractory is 230 cm tall with a diameter of 91 cm, and is encased in a 6.4 mm steel jacket. To simplify construction, the furnace was cast in five sections, and then stacked. A Kaowool insulation blanket, one inch thick prior to compression, was used as a gasket material between sections. More complete details of the refractory design and construction are available in Hoffman (1994).

Primary combustion occurs at the top of the reactor, where a swirl mixed natural gas/air burner is used to produce a high temperature, oxygen rich environment. Burner design and construction, and the associated electrical safety system, is discussed in Hoffman (1994). The as-designed maximum firing rate is 15 kW (51,000 Btu/hr). Stoichiometry and overall mass flow rate (hence furnace residence time) is controlled by metering the air and natural gas independently, via rotometers. Local natural gas composition tends to be 95% methane, with the a balance of primarily ethane, N_2 and propane, resulting in well characterized combustion products (Riley, 1997, Appendix D). A 35.6 cm long by 10.2 cm diameter combustion zone (prior to the point of coal/biomass fuel injection) helps to stabilize the natural gas flame and leads to complete combustion. An observation port and a sampling port accessing the natural gas combustion zone have been blocked with refractory to limit heat loss.

The finely-divided or pulverized fuel of interest is pneumatically injected into the hot gas stream using a stainless steel, water-cooled injector. A 90° bend at the probe exit allows for fuel injection 2.5 cm above the venturi constriction leading to the reactor tunnel in the lower section. Turbulent flow at the 2.5 cm venturi constriction aids in mixing of the fuel with the oxygen-rich hot gas stream. The combustion tunnel expands from 2.5 cm to 20.3

cm diameter with a half-cone angle of approximately 7 degrees, and is a constant diameter thereafter. The expansion was designed for a uniform transition from turbulent mixing at the throat to laminar flow in the main tunnel.

To provide flexibility in setting the temperature profile, four auxiliary burners are used to internally heat the refractory. The four auxiliary burners are shown in vertical cross section in Figure 4.1. Horizontal cross sections are shown in Figure 4.2. Swirl mixed natural gas and air is burned at the lower (inlet) port of each auxiliary burner channel. This heats the common wall between the main tunnel and the channel, and then exhausts through the upper channel. Note that the stoichiometry of the auxiliary burners does not effect the stoichiometry of the main tunnel because the hot gas streams are separated by the refractory wall. The auxiliary burners are operated in pairs for radial temperature symmetry.

Ten horizontally oriented sampling ports of 2.6 cm diameter are distributed down the length of the reactor. Temperature verses furnace residence time is documented by sampling the tunnel hot gas temperature via these ports.

Schematics of the air, water, and natural gas supply systems are given in Appendix B. A brief overview of furnace and laboratory modifications not directly related to experimental results is included in Appendix B.

4.2 Pulverized Coal Experiments- Setup and Procedures

The tunnel furnace was activated and steady state conditions were achieved. Due to the large thermal inertia of the furnace, about 36 hours of warm-up with natural gas combustion was required to reach steady state. A temperature profile was taken per the procedure in Section 4.6, to verify the desired operating conditions. Repetition of temperature profiling between tests series was not required if combustion conditions were not modified between tests.

A pulverized coal was selected for testing, loaded into the coal feeder hopper, and the feed screw was primed. Equipment and preparation for coal feeding is addressed in Section 4.2.1. The feed system was verified to be ready for activation, but remained in standby until the sampling probe and impactor were in place.

The cascade impactor, sampling probe and vacuum system were prepared for testing according to the procedures outlined in Section 4.2.2. and 4.2.3.

The sampling system vacuum pump and a timer were started simultaneously. The sample flowrate was adjusted to ensure a flow of one cubic foot per minute through the impactor. The coal feeder was activated, and a second timer started. Coal flowrate was terminated after a predetermined time limit had been reached. The vacuum pump was turned off and the elapsed time noted.

The impactor was immediately disassembled, the foil stages and backup filter were placed in their proper petri dishes, and desiccated in a 110 C laboratory oven. The contents of the preseperator was washed with acetone into the earlier prepared foil cup. The connector tube, if used, was also washed into the foil cup. The foil cup and its contents were placed in the 110 C oven after the acetone wash had been evaporated at room temperature. The foil stages, backup filter and foil cup were removed after at least 30 minutes in the laboratory oven.

The foil stages, backup filter and foil cup were reweighed using the same procedures followed prior to testing, as outlined in Section 4.2.3.

4.2.1 Pulverized Coal Feed System

The pulverized coal feed system is shown in Figure 4.3. Typical pulverized coals used for experiments were about 70 μm in diameter with an aspect ratio near unity, resulting in a fuel that was amenable to screw feeding. Pulverized coal was placed in the screw feeder (AccuRate Model 310-83-0017, Whitewater, Wisconsin), with the screw motor set to the appropriate speed for the desired coal flow rate. The fuel was fed by the rotating screw to a tee junction, where the fuel was entrained by a perpendicular air stream. The fuel was conveyed by the airflow through a water cooled injector into the hot gas stream at the throat of the furnace.

Prior to testing, the screw feeder was calibrated for the fuel of interest, as follows: The screw feeder tube was disconnected from the air entrainment line, and the fuel was fed through the screw feeder at a preselected screw turn rate. The mass of coal fed over a

given time was determined by weighing the ejected coal. The procedure was repeated over a range of turn rates in order to produce a calibration curve.

4.2.2 Pulverized Coal - Ash Collection and Size Sorting

Ash collection and particulate size sorting was performed using a watercooled sampling probe and a Mark II Cascade Impactor, combined with a vacuum pump. For initial experiments, the probe was used in the horizontal orientation, along the center line of the horizontal exhaust duct leading from the furnace exit to the exhaust duct. This configuration is shown in Figure 4.4. Accurate positioning of the horizontal probe was difficult, and entrainment of water from the exhaust duct cooling system (a water atomizer), prompted the relocation of the probe to the bottom of the reactor in later tests. This configuration is shown in Figure 4.5. Clearance limitations did not allow this probe to be removed from the furnace when testing was performed with the probe in the vertical position.

4.2.3 Cascade Impactor Modifications and Preparation

A cascade impactor (Andersen Instruments Incorporated, 1 ACFM Non-Viable Ambient Particle Sizing Sampler, Mark II model, Atlanta, GA) was used to sort particles into eight size classes using inertial impaction. The lower limit of a size class is defined by the diameter of a particle having a 50% probability of capture on that stage. Aerosol, which is typically particulate matter on the order of 0.1 μm diameter, was collected on a borosilicate microfiber filter downstream of the final impaction stage. The impactor was also fitted with a preseperator, which is designed to prevent large particulate matter (greater than 10 μm in diameter) from entering the size segregating area of the impactor. The standard impactor was modified for research purposes as follows:

1) An adapter for connection of the preseperator inlet to the sample probe was constructed.

2) Rubber inter-stage O-rings were replaced by Teflon O-rings. This allowed higher operating temperatures.

3) Impactor sealing pressure was increased by replacing the manufacturer's spring loaded stage clamps with a threaded rod clamping system.

4) Aluminum foil disks were used as collection surfaces. These were supported by the manufacturer's stainless steel collection plates. Use of aluminum foil allowed for very small tare weights, increasing the accuracy of the sample mass measurement.

Standard operation of the unit is discussed in detail in the manufacturer's operating manual (Andersen Instruments Incorporated, 1985), including calibration and maintenance. Additional procedures for this test series are as follows:

The cascade impactor was disassembled. All orifice plates were visually inspected for particulate blockage, and cleared with compressed air as necessary. A low lint cloth with acetone was used to wash all components - eight orifice plates, preseperator, cap, backup filter holder, backup filter retaining ring (Teflon), and stainless steel collection plates. An acetone soaked swab was used to clean all Teflon O-rings. Components were air dried. A bore cleaning rod with an acetone soaked low lint cloth was used to clean the inner diameter of sampling probe. A rod and acetone soaked cloth was used to clean probe-to-impactor connection tube, if the tube was required for the test.

Nine aluminum foil collection disks (household Reynolds aluminum foil) were cut to fit collection plates, using a custom designed and built punch. Two foils required an additional center punch, using the custom punch. On a hard surface with a low lint cloth covering, a low lint cloth and acetone was used to smooth and clean the foils. The foils were rinsed with acetone and air dried (this step was critical in minimizing static electricity on the foil stages). Foils were handled with only an acetone-washed forceps for the remainder of the test. Eight foils were reserved for impactor stages. The remaining foil was shaped into a cup approximately 6 cm diameter and one cm deep by compressing the foil between two appropriately sized cups nested together. The foil cup was rinsed with acetone and left to air dry. The impactor was assembled (without the foil collection disks) and stored in clean environment until ready for test.

Ten inert-plastic petri dishes were obtained, and the lids were discarded. Each petri dish was inscribed with identifying labels. Cloth and acetone was used to wash the petri dishes, followed by an acetone rinse and air drying . The rinse step was critical - it minimized static electricity on the petri dishes. The foils and foil cup were placed in individual petri dishes using acetone-washed forceps. One 81 mm glass fiber filter (Glass Microfibre Filter, grade 934-AH, Whatman International Limited, Maidstone, Kent; England) was

removed from clean storage, using acetone-washed forceps, and placed in a petri dish. The petri dishes with foils and glass fiber filter were placed in a 110C laboratory oven to completely dry. After 20 minutes the dishes were removed and immediately placed in dessicator box with approximately 200 g of $CaSO_4$ (Drierite Indicating Desiccant, 8 mesh, W. A. Hammond Drierite Company, Xenia, OH) in three separate petri dishes. The petri dishes and foils were allowed to cool to room temperature in the dessicator box.

The mass scale (Mettler AE240-S, Mettler Instrument Corporation, Hightstown, NJ) was calibrated per the manufacturers instructions. Acetone washed forceps were used to remove one foil at a time from dessicator box and place it on the balance. After waiting approximately two minutes for scale to stabilize, the mass was recorded. If mass measurement was not stabilized to 0.00001 grams, it was verified that the scale was isolated from drafts and was properly anchored. The foil was carefully removed from balance with forceps, and returned to its labeled petri dish. The experimenter then waited for the scale to re-zero (approximately one minute). If scale did not rezero, it was manually reset to zero, and the foil was reweighed with the new zero. The foil was removed, and the experimenter again waited for the scale to rezero. This reweigh procedure was repeated until scale returned to zero with no load. If rezeroing failed after three attempts, the scale was recalibrated per manufacturers instructions. All (eight) foils, foil cup, and glass fiber filter were weighed. The weighed stages were stored in the dessicator box until ready for use.

The cascade impactor was preheated in a 110 C laboratory oven for approximately 30 minutes. The cascade impactor was removed from the oven and disassembled using insulated gloves. The impactor was carefully reassembled with aluminum foil collection disks placed on inverted stainless steel collection substrates, per the manufacturers instructions. The glass fiber filter was inserted below the final collection substrate, and secured with Teflon retention ring. Acetone-washed forceps were always used to handle foils, glass fiber filter, and the glass fiber filter retaining ring in the cascade impactor. The cascade impactor stack was clamped securely with the threaded rod compression system to prevent leakage. The cascade impactor was returned to the 110 C laboratory oven. The probe-to-impactor connection tube (if required for test) was placed in the oven. The impactor and connection tube were preheated for 30 minutes (minimum) prior to test.

The final assembly of the sampling system depended on the sampling location. Outlined below are procedures for sampling with the probe horizontally oriented in the exhaust duct, and for a vertically oriented probe in the main furnace body.

Horizontal Sampling Test (Figure 4.4): Using insulated gloves, the connection tube and impactor cap were removed from oven and assembled. The connection tube was connected to the sampling probe. The probe was inserted into horizontal sampling port. The probe was verified to be on the centerline of the sampling duct and at the proper insertion depth, and secured in place with a clamp stand adjacent to sampling port. The cascade impactor was removed from the oven and connected to the vacuum line. The impactor was mated to the impactor cap.

Vertical Sampling Test (Figure 4.5): Using insulated gloves, the impactor cap was removed from the oven and slid over the exit tube of the sample probe. The cascade impactor was removed from the oven and the vacuum line was secured. The impactor was placed beneath the sample probe and cap, which required the cap to be slid up the sample probe to provide clearance for the impactor. Once the impactor was positioned, the cap was lowered and sealed.

4.3 Pulverized Artificial Char Experiments

Artificial char experiments were performed following procedures identical to the pulverized coal experiments described in Section 4.2, with two notable exceptions:

1) All artificial char experiments were conducted with the sampling probe in the vertical orientation (See Section 4.2.3 and Figure 4.5).

2) The limited amount of artificial char available required that a low volume char feed system be used, as described below.

The coal screw feeder was not used for artificial char testing because the supply of artificial char was insufficient for proper operation of the screw feeder. A syringe delivery system, shown in Figure 4.6, was designed and built to replace the screw feeder.

Artificial char was loaded into three plastic 30 cc syringes, which were cut such that the syringe exit diameter was the same as the syringe body diameter. Frequent tapping of the

syringe support with a metallic rod promoted uniform syringe loading. Following loading, each syringe was inserted into the syringe block. The syringe block was milled from Plexiglas, so that artificial char feeding could be visually monitored. The air entrainment bypass was opened during syringe/char loading, and air entrainment valves to and from the syringe block were maintained closed. The syringe drive rate, corresponding to the desired feed rate, was verified.

To operate the char feeder, the air entrainment valve downstream of the syringe block was opened. The upstream entrainment valve was then opened while simultaneously activating the syringe drive. The bypass air entrainment inlet and outlet valves was then shut, respectively. At the conclusion of an experiment, the valve sequencing was reversed.

4.4 Screened Sawdust/Sanderdust Experiments

Screened Sawdust/sanderdust experiments followed procedures identical to the pulverized coal experiments described in Section 4.2, with the following important exceptions:

1) Sawdust/sanderdust experiments were conducted with the sampling probe in the vertical orientation.

2) Following collection of sized particulate matter on the cascade impactor stages and aerosol filter, some collected ash was further analyzed by Scanning Electron Microscopy and Energy Dispersive X-ray techniques.

3) Sawdust/sanderdust particle size variations and low density required a different fuel feed system, as described below:

Some changes to the existing pulverized fuel feed system were required to feed sawdust/sanderdust into the reactor, as shown Figure 4.7. Significant particle size and shape variation (in a single fuel type as well as from fuel to fuel) and low solid density of the wood led to bridging problems in the screw feeder hopper. This was moderated by increasing the screw size and hopper agitation. Frequent manual stirring of the hopper (approximately once per minute) also helped to prevent bridging.

A vertical drop was added from the screw feed exit to the air mixing area to prevent clogging. A venturi was added to the entrainment air system in order to prevent blowback

into the hopper by lowering the back pressure at the wood screw exit. Additionally, a 1/16" ID air tube was positioned at the screw exit such that compacted sawdust and sanderdust was dispersed prior to entrainment.

A new water cooled injector was built with a larger bore diameter to prevent clogging with oversized particles. A smooth turn at the exit rather than an abrupt 90 degree angle was incorporated to lower clogging susceptibility and to allow bore cleaning nearly to the tip of the injector.

Prior to testing, the screw feeder was calibrated for the fuel of interest. The screw feeder tube was disconnected from the air entrainment line, and the fuel was fed through the screw feeder at a preselected screw turn rate. The mass of fuel fed over a given time was measured. The procedure was repeated in order to produce a calibration curve for flow as a function of screw feed rate.

Due to the presence of oversized materials in some of the feed materials, jamming of the feed system was possible. For these experiments, this was avoided by prescreening the feed materials to remove these oversized wood chips. This is discussed later in conjunction with the experimental results. Prescreening, however, had the disadvantage of removing a portion of the feed material. Premilling of each of the feeds to a uniform size, as discussed in the next section, was used to avoid this problem.

4.5 Milled Sawdust/sanderdust Experiments

Experiments were conducted with milled samples of the four sawdust/ sanderdust fuels. The "As Received" sawdust was milled in a Thomas-Wiley laboratory mill to pass through a 0.5 mm diameter screen. This allowed complete use of the available fuel, aided in dispersion of the fuel at the injection point, and promoted complete combustion of char particles.

Particulate sizing of sub-micron ash particles for these tests was performed using an isokinetic sampling probe, cascade impactor and an Electrical Aerosol Analyzer (EAA), configured as shown in Figure 4.8. The cascade impactor was used primarily for removal of particles greater than the particle size of interest. To that end, stages 6 and 7 were removed for milled fuel testing. A delay tank was also added prior to the EAA to attenuate

fluctuations in sampling rate. By varying the size of the delay tank, different delay times for aerosol coagulation was also achieved.

Procedure:
The tunnel furnace was activated and steady state conditions were achieved. Due to the large thermal inertia of the furnace, about 36 hours of warm-up with natural gas combustion was required to reach steady state conditions. A temperature profile was taken to verify the desired operating conditions, per the procedure in Section 4.6. Repetition of temperature profiling between tests series was not required if combustion conditions were not modified between tests.

The feed system shown in Figure 4.7 (described in Section 4.4.1) was used to feed milled sawdust/ sanderdust. The feed system was verified to be ready for activation, but remained in standby until the impactor was in place.

The isokinetic sampling probe (described in Section 4.5.1.1), Electrical Aerosol Analyzer (described in Section 4.5.1.2) , and the cascade impactor were assembled per the schematic in Figure 4.8.

The sampling system was activated and isokinetic conditions were achieved, per the procedure described in Section 4.5.2.

The data acquisition system, described in Section 4.5.3, was activated.

The fuel feeder was started simultaneously with a timer. Fuel in the feeder hopper was continuously manually agitated with a stainless steel rod during testing. This prevented bridging of the fuel in the hopper and promoted a uniform fuel feed rate. (Minor fluctuations in the fuel feed rate could have led to significant fluctuations in Electrical Aerosol Analyzer signal). The fuel feeder was turned off after the desired test duration. The data acquisition system was turned off, and the isokinetic sampling system was turned off.

The impactor was immediately disassembled, the foil stages were placed in their proper petri dishes, and desiccated in a 110 C laboratory oven. The contents of the preseperator was washed with acetone into the earlier prepared foil cup. The foil cup and its contents were placed in the 110 C oven after the acetone wash had been evaporated at room

temperature. The foil stages and foil cup were removed after at least 30 minutes in the laboratory oven.

The foil stages and foil cup were reweighed using the same weighing procedures followed prior to testing, as outlined in Section 4.5.1.3.

4.5.1 Ash Collection and Size Sorting

4.5.1.1 Isokinetic Sampling Probe

Ash samples were collected through a water-cooled sampling probe, with a porous inner wall for dilution air addition. See Figure 4.9. This design significantly improved representative sampling in three ways: 1) isokinetic sampling was realized by metering the dilution flowrate appropriately, 2) thermophoresis was minimized by the radial dilution flow through a porous stainless-steel inner wall, and 3) the cascade impactor inlet temperature was reduced significantly. The CO_2 content of the undiluted and diluted gas streams was used as a tracer to verify isokinetic conditions.

4.5.1.2 Electrical Aerosol Size Analyzer - Particle Sizing

An Electrical Aerosol Size Analyzer (Model 3030, Thermo-Systems Incorporated, St. Paul, MN) was used to determine the size distribution of particles less than one micron in diameter. The device works on the principle that dispersion charging of sub-micron particles is a monotomically decreasing function of the particle size. In brief, aerosol particles are electrically charged by exposing the sample stream to unipolar positive ions via corona discharge. The charged particles then enter a flow tube with a negatively charged center rod. Small particles (*i.e.* high electrical mobility) migrate to the rod, and become electrically neutral. Larger particles that do not migrate fast enough to reach the rod before leaving the chamber are collected on a grounded filter. The large particles impart a current as they become grounded at the filter; this current is measured. By increasing the charge of the center rod in the main chamber, the rod collects all particles of a incrementally larger diameter, as well as the previous size of particles. The number of particles in a given size range can then be determined from the difference of the currents measured.

Theory of operation is discussed in detail in Lui *et al.* (1974) and Lui and Pui (1975), as well as the operators manual (Thermo-Systems Incorporated, undated).

4.5.1.3 Cascade Impactor Modifications and Preparation

The cascade impactor was used as a preseperator to remove residual ash particles in this test series. The residual ash was of lesser interest in the EAA experiments, and inhibited the accuracy of the EAA if it was not removed. The impactor was used as described in Section 4.2.3, except for the following modifications to the impactor and procedure:

1) The cascade impactor was operated without stages 6 and 7 and without an aerosol filter. Preparation of the two aluminum foil substrates associated with these stages and preparation of a borosilicate fiber filter was unnecessary.

2) A thermocouple was added to the impactor cap such that the impactor inlet temperature can be monitored.

3) Preheating of the cascade impactor prior to testing was not required. Dilution of the hot gas stream resulted in a dew point well below ambient conditions.

4.5.2 Determination of Isokinetic Conditions

The overall furnace mass flow rate was determined by summing the contribution from the main air and natural gas burner, and the entrainment air flowrate. Stoichiometry was calculated and then verified by measurement of CO_2 content (see Figure 4.8) of the combusted gas using a Horiba Model PIR-2000 Infrared Gas Analyzer. The analyzer was calibrated with 99.998% by volume N_2 (for zero calibration) and with 6.96% CO_2 span (for range calibration) prior to testing.

Isokinetic probe inlet flowrate was calculated, based on the cross sectional area of the probe inlet and tunnel furnace, and the total furnace flowrate. The diluent air flowrate required to achieve isokinetic conditions was calculated, based on the required flowrate of the EAA and the gas analyzer. The expected CO_2 concentration at the exit of the sample probe was calculated, based on the previously measured CO_2 concentration and the diluent air flowrate.

The CO_2 analyzer was recalibrated with 99.998% by volume N_2 (for zero calibration) and with 0.502% CO_2 span (for range calibration). The CO_2 analyzer was returned to monitor mode, and the secondary vacuum pump flowrate was adjusted until the measured CO_2 concentration indicated isokinetic conditions were achieved. The EAA, gas analyzer, and secondary vacuum pump flowrates were adjusted as necessary to meet the manufacturers flowrate requirements, while still maintaining isokinetic conditions. Steady state conditions were verified after ten minutes of operation.

4.5.3 Data Acquisition System

A Fluke 2625A Hydra Data Logger (Fluke Corporation, Everett, WA) was used to convert analog signals from the EAA, CO_2 analyzer, and cascade impactor thermocouple data to digital format. A read event was triggered automatically by the EAA using a voltage limit signal. The digital information gathered at the data logger was sent to a Zenith Z-386/AT Series Workstation where it was labeled and stored in ASCII format. A completed test was transferred to disk, and saved on a Power Macintosh 7500/100. The file was translated into Microsoft Excel format, followed by conversion of the digital voltage measurements into a size distribution.

4.6 Furnace Temperature Profiling - High Velocity Thermocouple

Furnace temperature profiling was conducted with a high velocity thermocouple (HVTC). This custom device is shown schematically in Figure 4.10. Accurate measurement of combustion product temperature was challenging because of thermal radiation exchange between the tunnel walls and bare thermocouple. A high velocity thermocouple suppresses the radiative influence by using suction to pull hot gas over the thermocouple, in combination with a ceramic shield (also heated by the convective gas stream) to limit radiative heat transfer. A HVTC is typically used in the coal industry for hot gas temperature measurements in large boilers (*e.g.*, Babcock and Wilcox, 1994) The HVTC used for these experiments is a custom designed and constructed device.

The High Velocity Thermocouple is operated as follows:

Connect air line to 90 psi air source, water inlet line to 70 to 90 psi laboratory water source, thermocouple lead to Omega DP460 thermocouple display, and water exit line to laboratory

drain. Open water flow valve at source to full. Open HVTC water valve to full. Water flow at the exit line should be at least one gallon per minute and flowing continuously. Close vacuum valve, open 90 psi air source, and verify at least 20 inHg vacuum at the eductor vacuum gauge. Maintain vacuum valve in closed position whenever the probe tip is not in the hot gas stream.

Remove 1" NPT pipe cap from port K (lowest horizontal sampling port on the tunnel furnace). Examine inner diameter of sampling port for loose ceramic. Clear port by pushing inaccessible debris with a 3/4" diameter stainless steel tube into the tunnel furnace. Slowly (2.5 cm per second or less) insert HVTC until the probe tip reaches the tunnel furnace center line. Seal the gap between the sample port tube and the HVTC tube by wrapping the junction with aluminum foil.

Slowly open the vacuum valve until the vacuum gauge indicates 15 inHg. Monitor the thermocouple temperature until a stable measurement is achieved (typically 5 minutes) and record. Multiple measurements at various insertion depths can be made in order to obtain a temperature profile at that sampling port.

Close the vacuum valve prior to removing the probe tip from the hot gas stream. Slowly back the probe tip out of the hot gas flow until it is approximately 25 cm from the hot gas zone. Hold the probe in this location until the thermocouple is below 450 C, in order to prevent thermally shocking the ceramic probe tip.

Remove the pipe cap from port J, slowly withdraw the probe from port K, and slowly insert into port J. Do not expose the ceramic tip to ambient conditions more than is necessary while the tip is hot. Repeat the procedure described above at each port. At the conclusion of testing, remove the probe from the tunnel furnace completely, and let the probe tip cool to ambient conditions. After cooling is complete, disconnect water, air, and thermocouple lines.

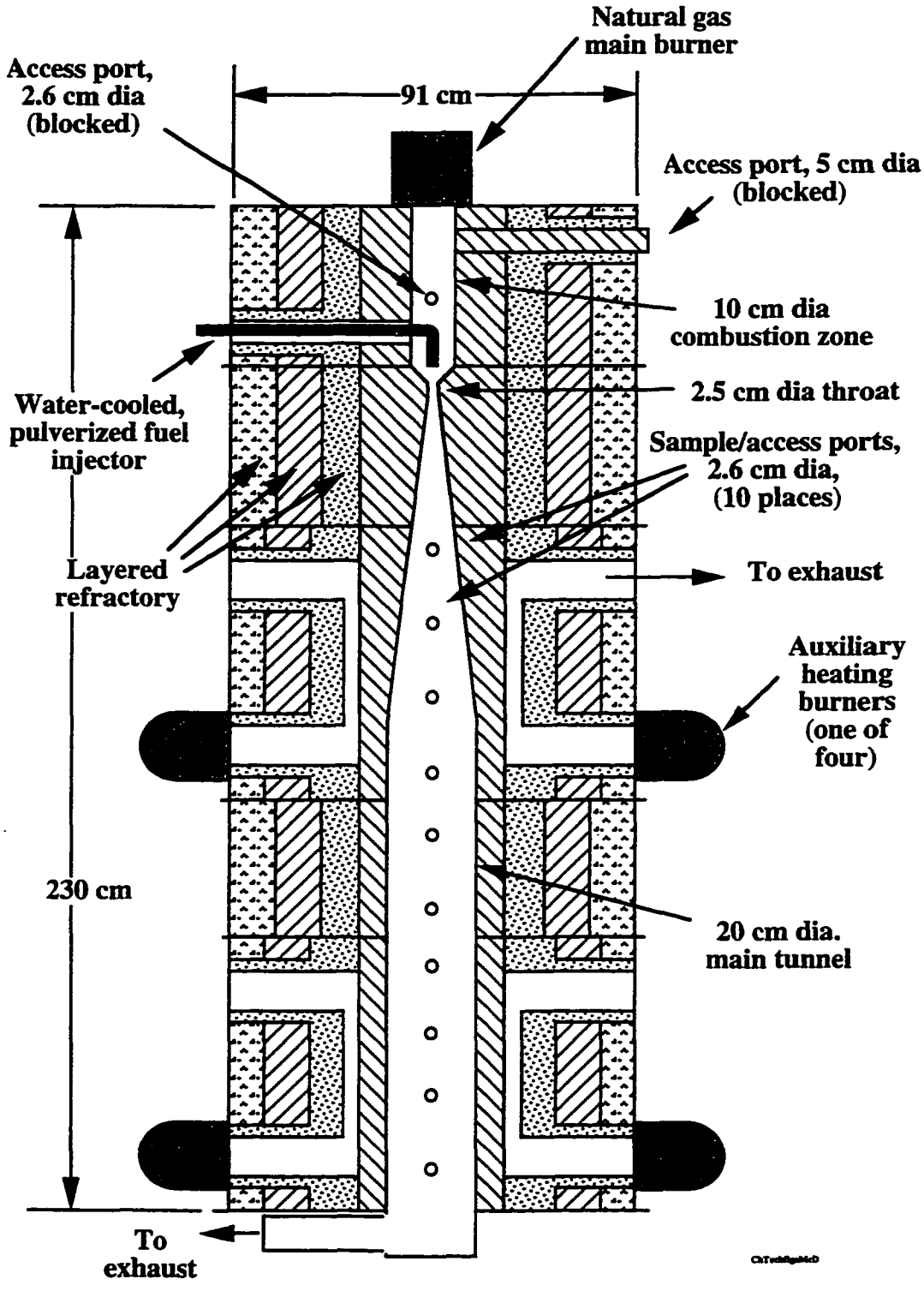


Figure 4.1: Natural gas-fired tunnel furnace
(modified from Hoffman, 1994)

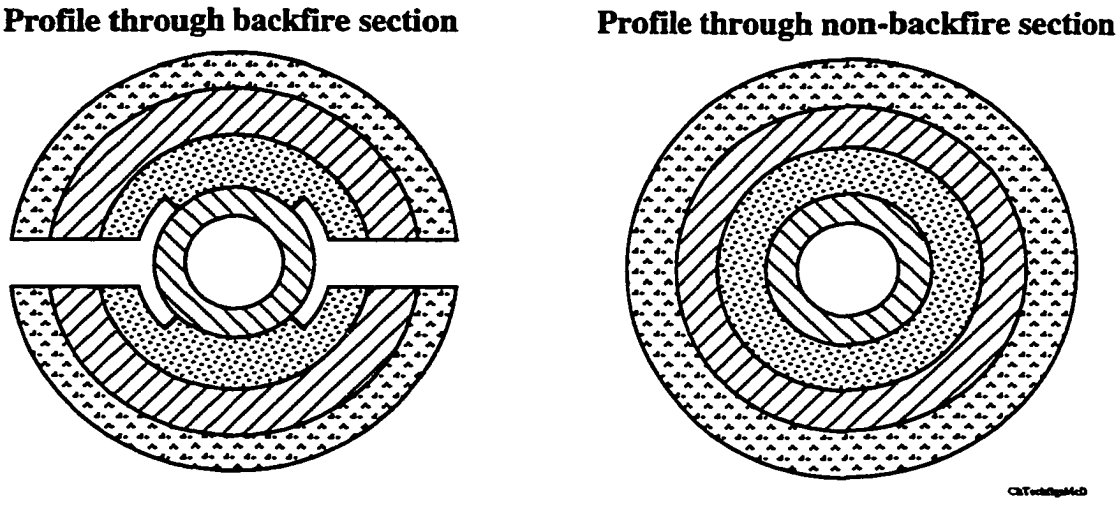


Figure 4.2: Tunnel furnace cross sections
(from Hoffman, 1994)

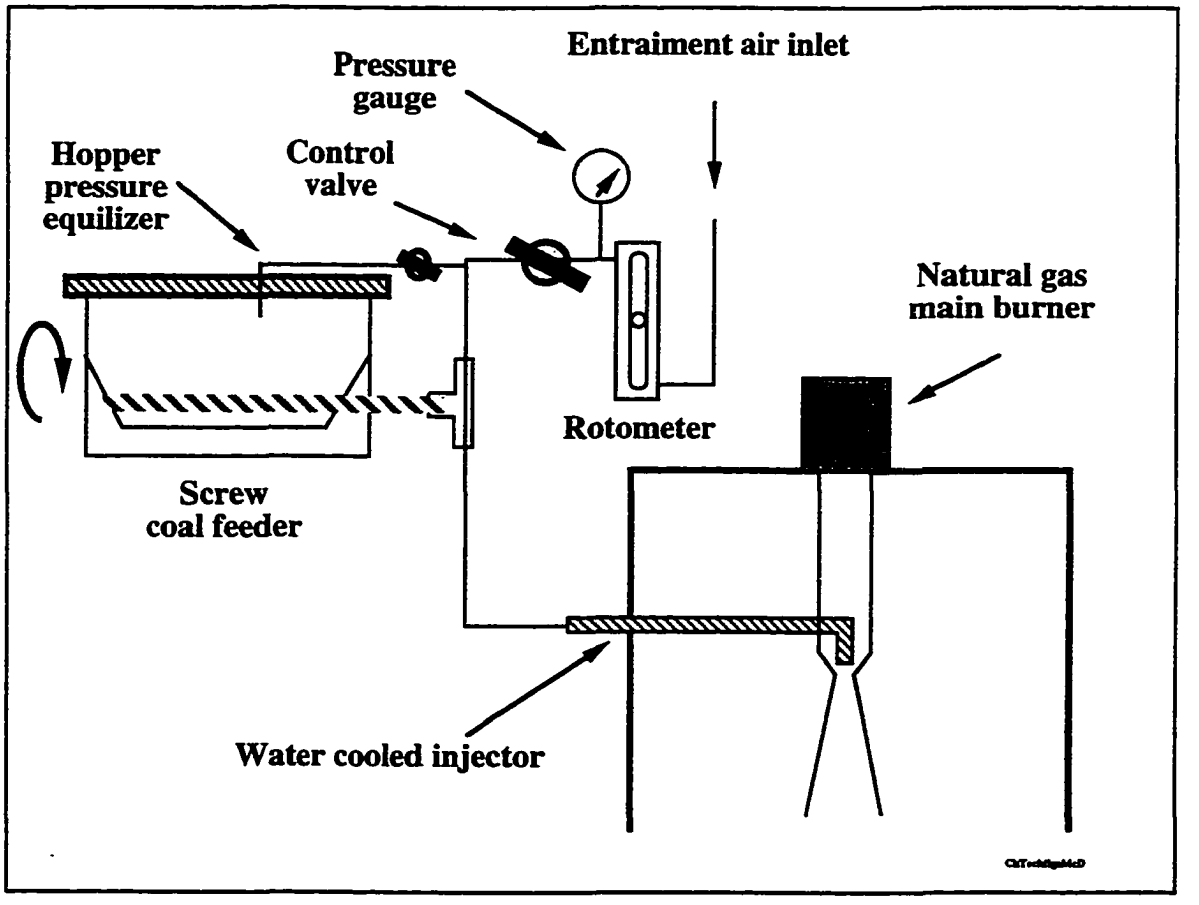


Figure 4.3: Pulverized coal feed system

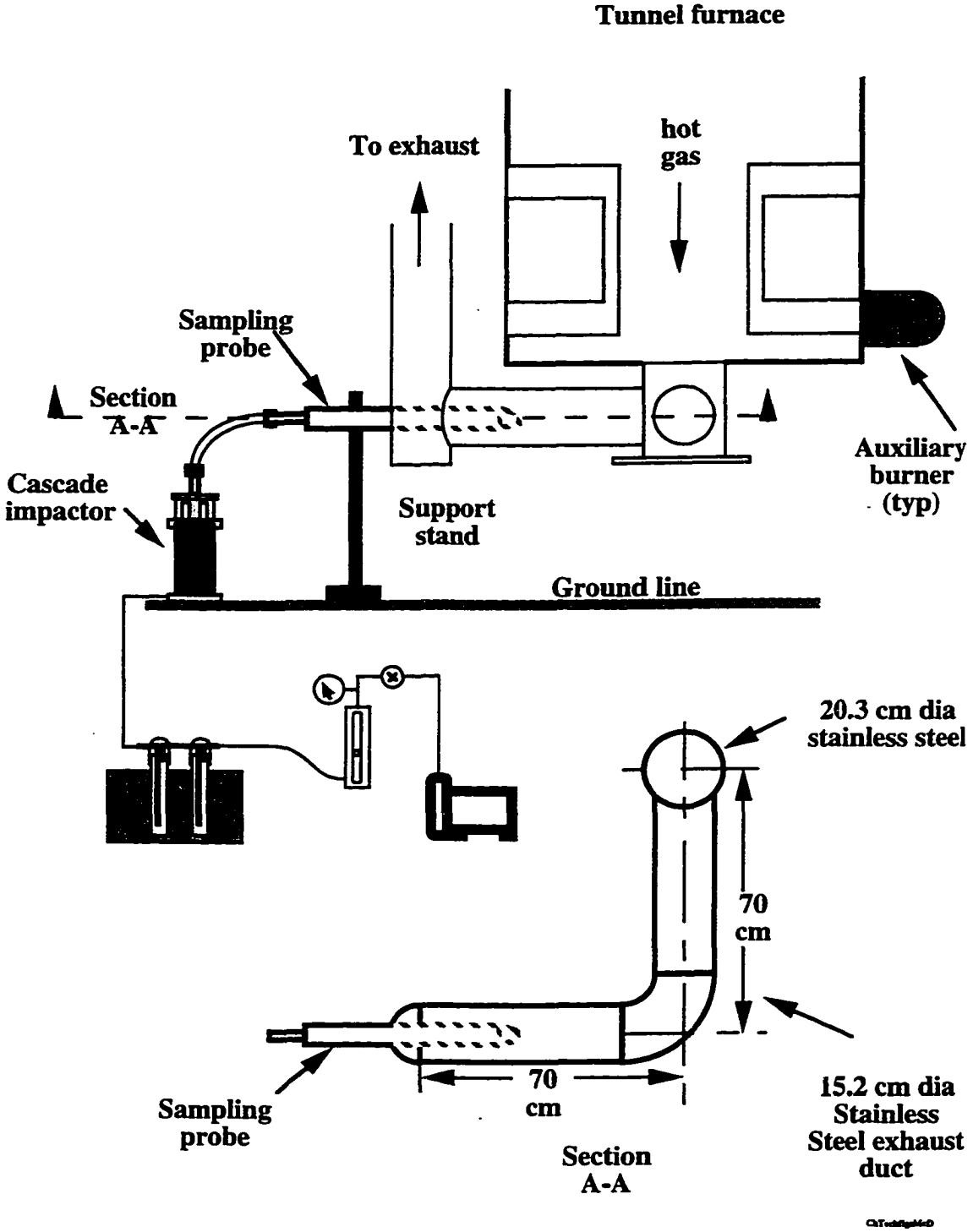


Figure 4.4: Sampling in horizontal orientation

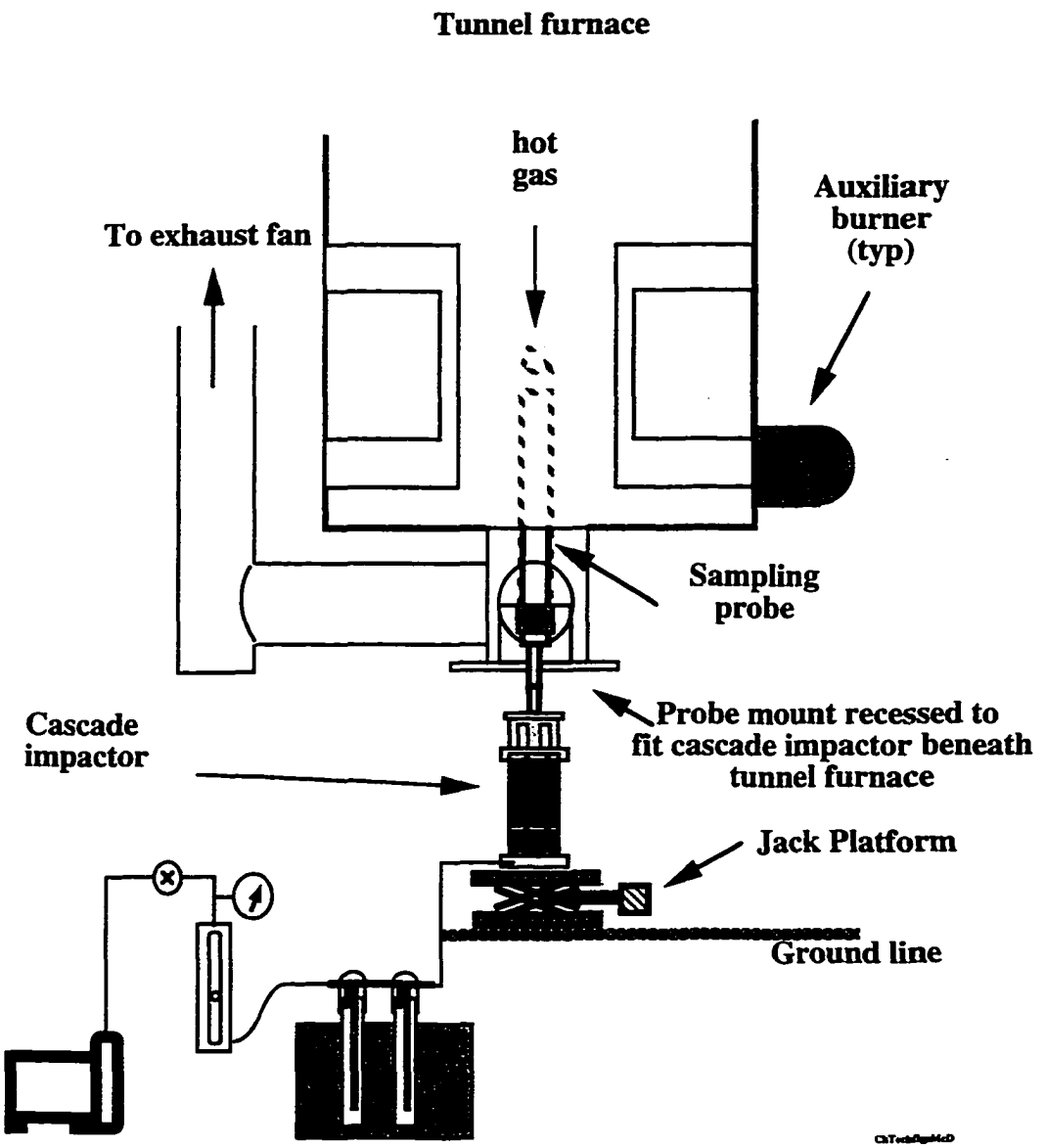


Figure 4.5: Sampling in vertical orientation

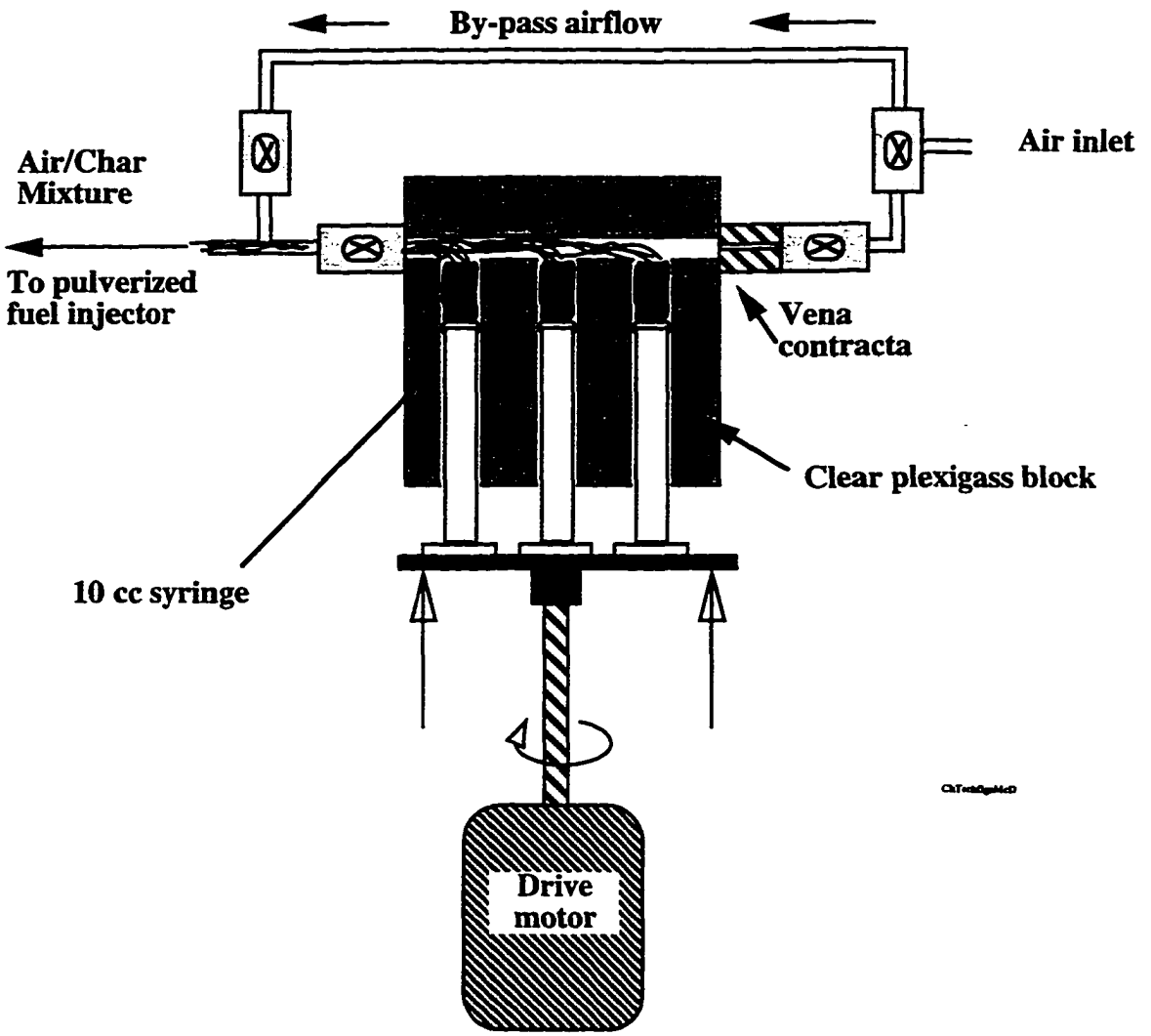


Figure 4.6: Artificial char syringe drive

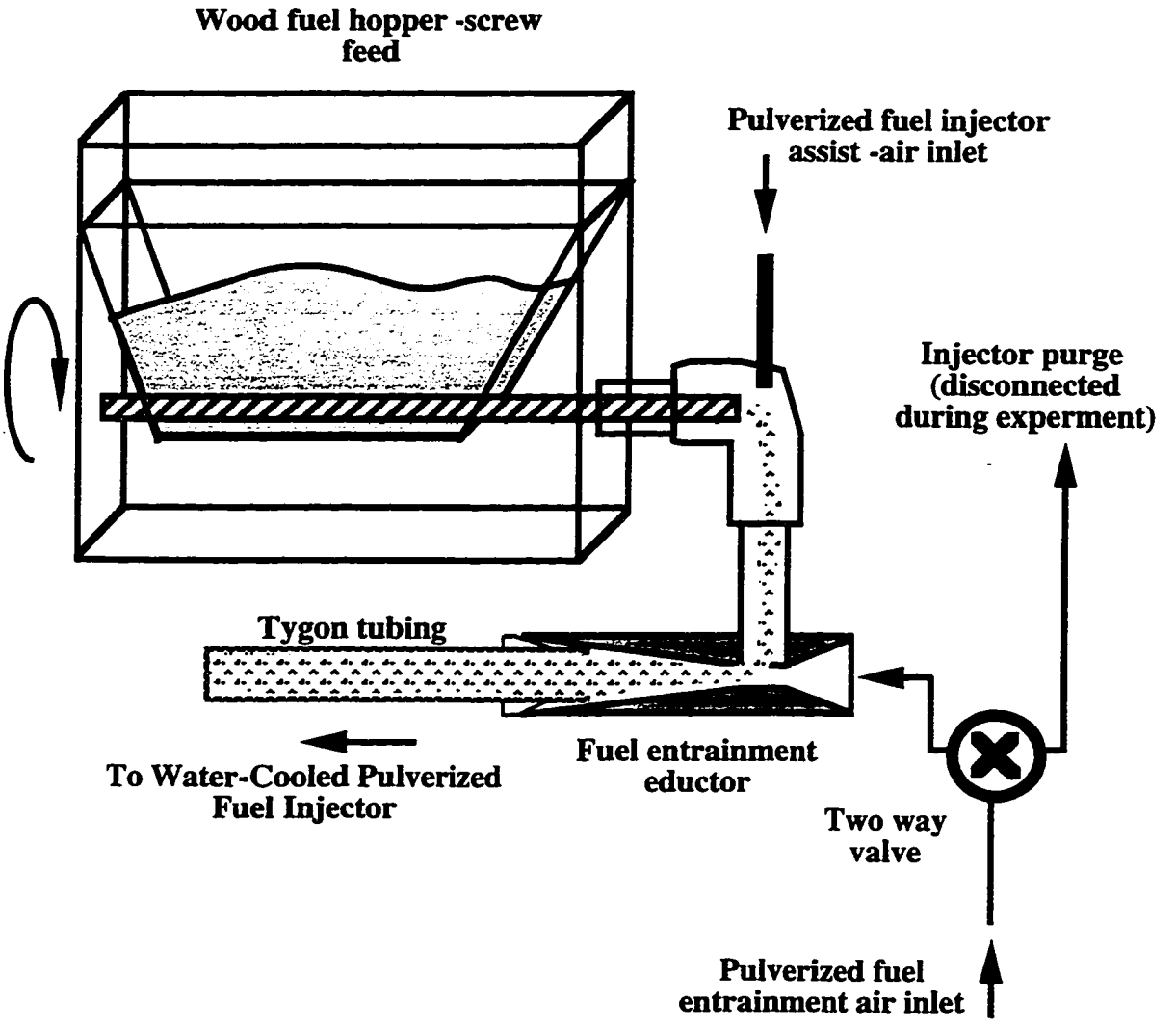


Figure 4.7: Sawdust/sanderdust feed system, modifications of existing coal feed system

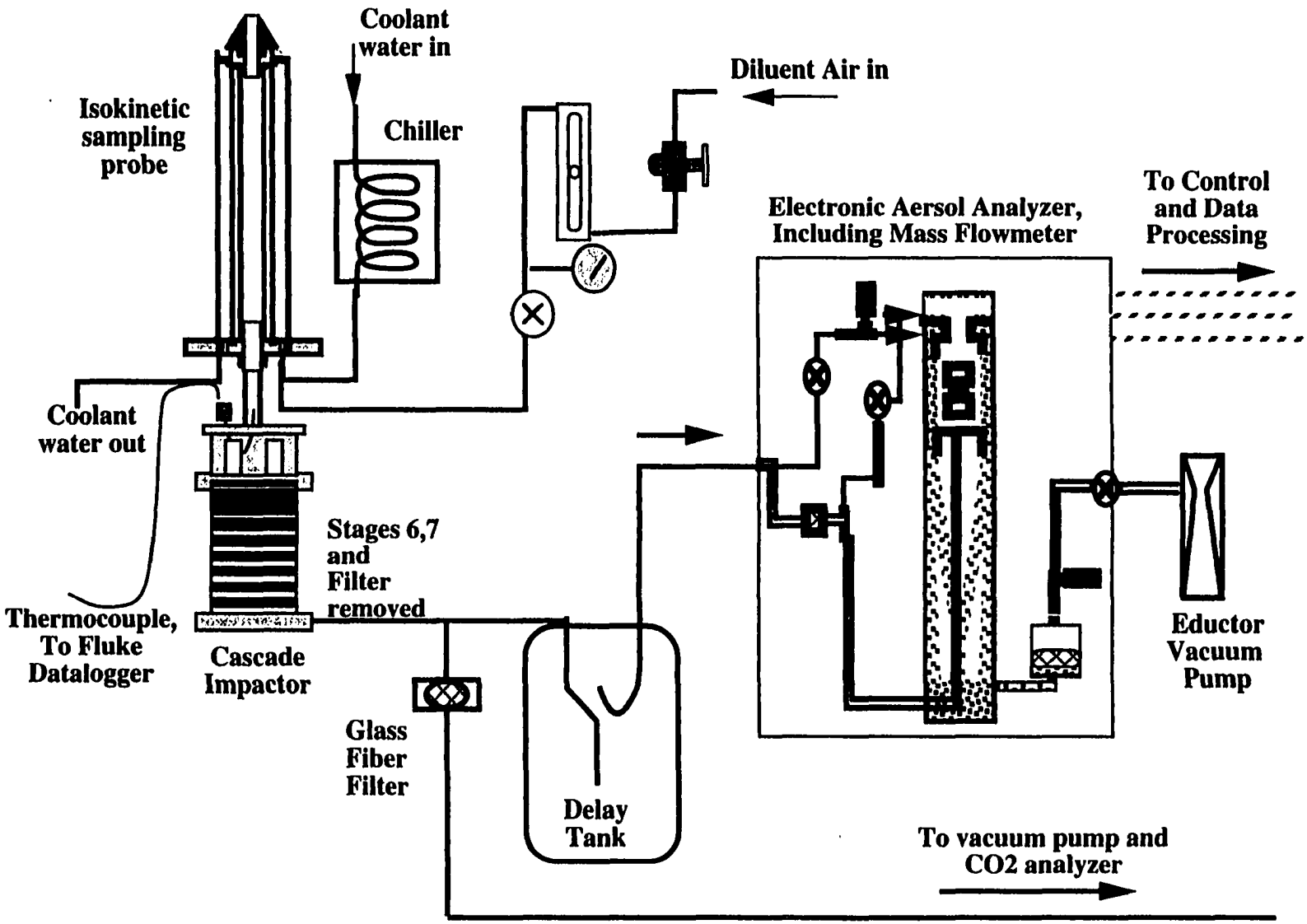


Figure 4.8: Milled sawdust/sanderdust isokinetic sampling probe, cascade impactor and EAA setup (continued next page)

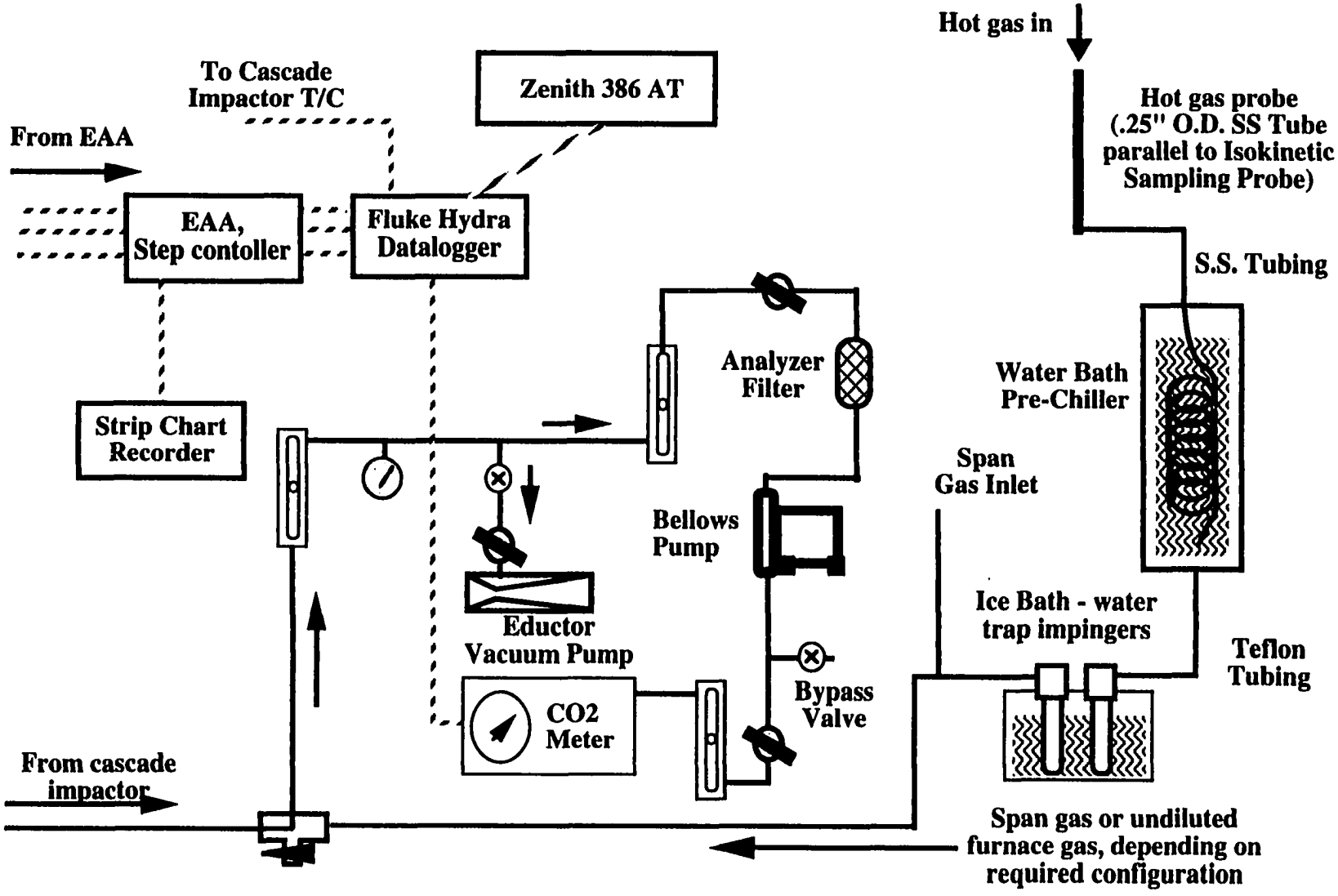


Figure 4.8 (continued): Milled sawdust/sanderdust isokinetic sampling probe, cascade impactor and EAA setup

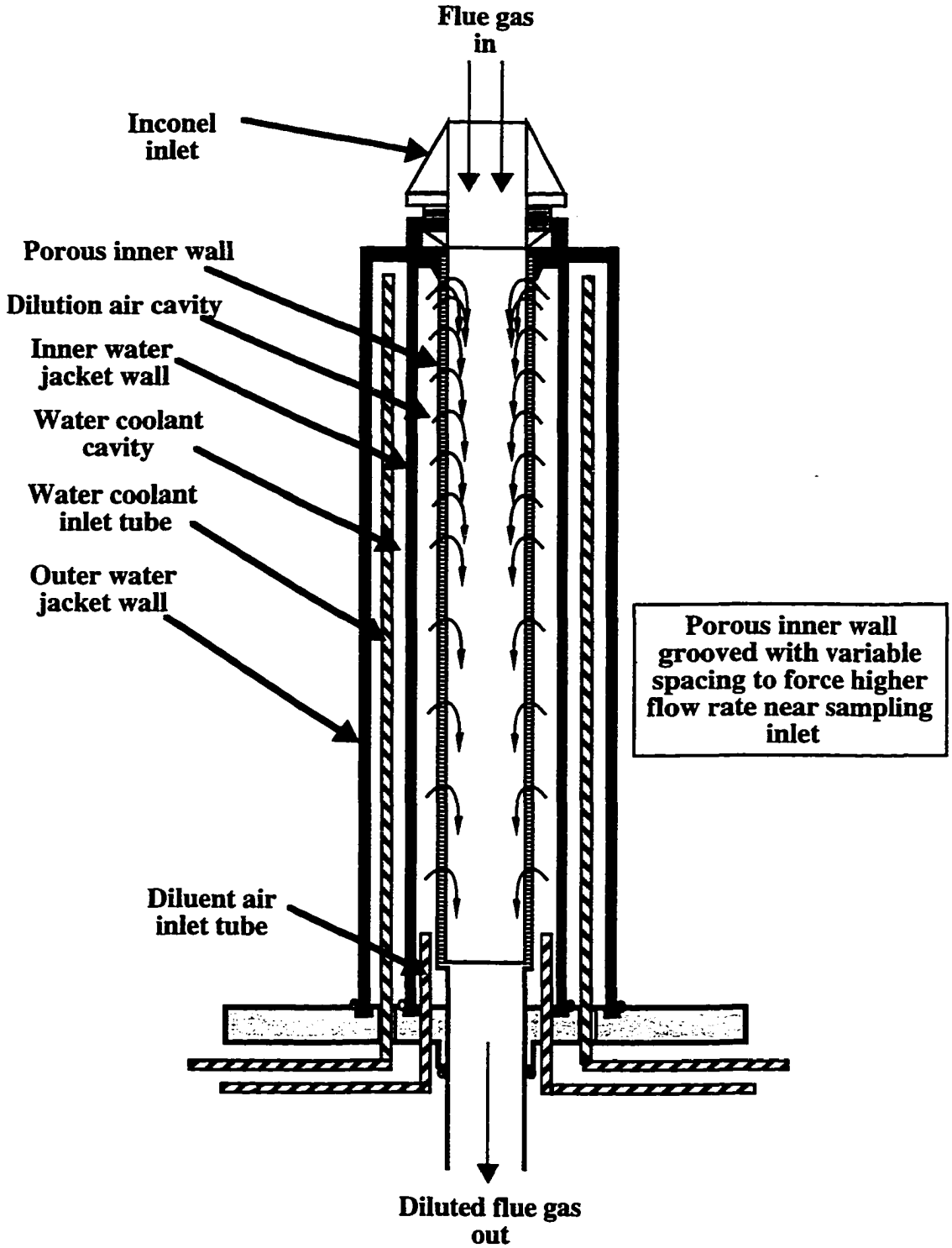


Figure 4.9: Isokinetic sampling probe schematic

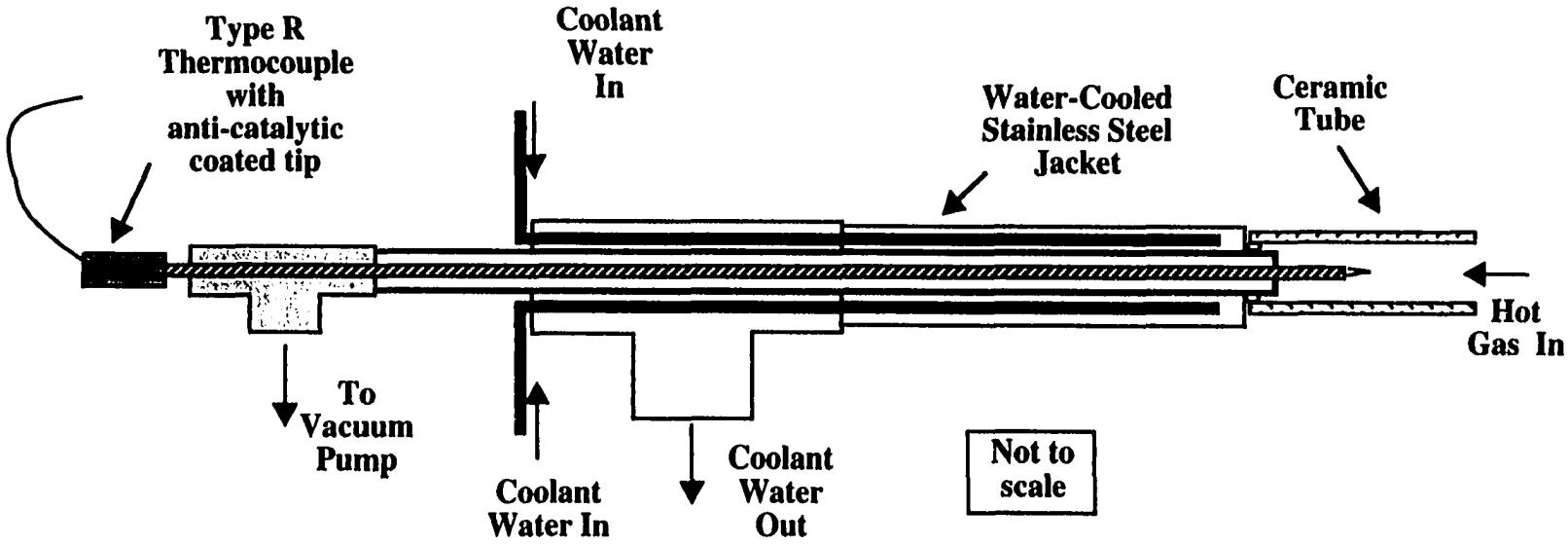


Figure 4.10: Schematic of Water-Cooled High Velocity Thermocouple

INFLUENCE OF COAL TREATMENT AND MINERAL CONTACT ON AEROSOL YIELDS

Mechanical and chemical processing of pulverized coals are known to modify the aerosol yield. This chapter presents coal and artificial char experiments conducted in order to investigate the effects of coal cleaning, pre-combustion size segregation, and coal composition on aerosol yield. The first test series involves well-characterized coals from the Department of Energy database. The second series involves the combustion of artificial chars that allow the original mineral content (including inclusion size distributions) to be preselected.

5.1 Pulverized Coal Experiments

Discrete silicon-based minerals have been shown to reduce alkali metal aerosol formation, as discussed in the Mechanisms chapter. The implications of this phenomena are investigated with three well-characterized bituminous coals - Upper Freeport, Kentucky #11, and Illinois #6. Comparisons of aerosol yield are made between the three coals, burned under similar conditions, in order to investigate variation based on fuel properties. Combustion temperature was also varied in order to examine its effect on aerosol yield.

Upper Freeport pulverized coal was further investigated by aerodynamic size-fractionating the unburned fuel and burning the resulting fractions individually. The behavior of the ash resulting from a weighed sum of the results from the individual fractions (*i.e.*, size distribution, aerosol yield) is compared with the characteristics of the ash from the unfractionated coal. This allows a determination of whether the ash characteristics are simply additive over the individual fractions, or whether interactions yield non-linear behavior (*e.g.*, the sum of the aerosol yield from the individual fractions differs from that of the unfractionated coal).

5.1.1 Coal Characterization

The three bituminous coals selected for investigation are described below. These coals were chosen to complement similar research conducted with higher sodium coals (Kramlich and Newton, 1994a, 1994b), as well as for their history of use in the Department of

Energy coal suite database. The descriptions of the fuel properties have been summarized from work by Boni *et al.* (1990). All fuels were pulverized such that 70% of the fuel mass is able to pass through 200 mesh (74 μm particle diameter). Fuel preparation was done by the Foster Wheeler Company.

Upper Freeport: This is a Appalachian Basin bituminous coal which is relatively low in sodium (0.3% as Na_2O in ash), with a moderate amount of potassium (3.1% as K_2O in ash). It contains a substantial quantity of quartz, coarse pyrite particles (FeS_2), illite (a potassium-containing aluminosilicate), and kaolinite (aluminosilicate).

Kentucky #11: This Appalachian Basin bituminous coal is similar to Upper Freeport in alkalies (0.3% as Na_2O in ash, 2.2% as K_2O in ash). It contains fine pyrite particles, which are not easily removed from the fuel matrix, as well as finely divided quartz and illite.

Illinois # 6: This Illinois Basin bituminous coal is relatively high in sodium (1.3% as Na_2O in ash) , as feldspar, and moderate in potassium (2.1% as K_2O in ash). Quartz, dolomite ($[Ca, Mg]CO_3$) and kaolinite are significant, while illite and pyrite are low.

Table 5.1 shows the Proximate analysis and Ultimate analysis of the three coals tested, along with heating value, form of sulfur, and acid soluble alkalies (acid not specified), as determined by Boni *et al.* (1990). Acid soluble sodium is six times higher for Illinois #6 coal than Upper Freeport and Kentucky #11. Note that acid solubility can be a measure of the amount of inorganically-bound sodium. The implication is that sodium is more likely to become mobile if it is organically or ionically bound, rather than tightly bound as an oxide or silicate.Table 5.2 shows the ash composition as oxides and the ash fusion temperatures. As mentioned previously, sodium content is high in Illinois #6. Fusion temperatures were obtained from Gallagher (1992).

Figure 5.1 is a summary of Computer Controlled Scanning Electron Microscopy (CCSEM) results, created from tabulated data available in Boni *et al.* (1990). Pulverized coal particles were mounted in epoxy, sectioned and polished, and examined under SEM to determine mineral inclusion sizes and discrete compositions (Boni, *et al.*, 1990). The dependent variable is the mean diameter of the inclusion. The category adjacent to the inclusion diameter, labeled "baseline", is the average mineral distribution for the whole coal, as determined by summing the inclusions. Hence, the enrichment or depletion of an

individual mineral in a mineral inclusion size range can be directly compared to the mineral content of the sum of all mineral inclusions.

Examining Figure 5.1, Upper Freeport has a significant fraction of its mineral content in the form of mineral inclusions greater than 40 μm in diameter. This size cut is enriched in illite and pyrite, and depleted in quartz and mixed silicates, compared to the average composition of the ash (*i.e.* baseline). Quartz depletion in the largest size cut is balanced by an quartz enrichment in inclusions below 40 μm.

Over 50% of the mineral mass in Kentucky #11 is in inclusions less than 10 μm in diameter, as shown in Figure 5.1. Illite is enriched in these cuts and depleted in larger size cuts. Pyrite is slightly enriched in inclusions greater than 20 μm, and depleted below 10 μm.

Illinois #6 mineral inclusions are predominately less than 40 μm in diameter. Pyrite is depleted below 10 μm, and enriched above 10 μm. Quartz, in the form of fine inclusions, and pyrite, in the form of 40 to 10 μm inclusions are a significant fraction of the total mineral mass in this coal.

A portion of the pulverized Upper Freeport coal was aerodynamically sorted by size into four cuts of <18 μm, 18 to 37 μm, 37 to 85 μm, and >85 μm. Size sorting was conducted by Vortec Products Company of Long Beach, California using a Vortec Model C-1 Particle Classifier. Conventional and Inductively Coupled Plasma analysis (AM Test, Redmond, WA) of each sized fraction is shown in Table 5.3. The largest size cut (>85 μm) has the highest ash percentage by weight. It also has about twice the Fe and S of the other size cuts. This is obviously the result of the large pyrite inclusions observed by Boni et al (1990), as discussed relative to Figure 5.1.

Acid leaching of coals is a common means of extracting the minerals for analysis. Stronger acid solutions (*e.g.*, including HF) may extract more minerals than weak acid solutions. Differences in mineral recovery are often interpreted as a means of measuring the degree of bonding strength of various mineral in the coal.

The ash composition of Upper Freeport size fractions using a strong acid (Table 5.3) and composition using a weak acid (Table 5.4) show significant differences. Most notably, silicon is two orders of magnitude lower in the weak acid-digested sample. This is no

doubt an under-reporting condition due to the strong silica bonds. ICP testing of the sized coals was originally conducted by HNO_3/HCl digestion (EPA method 3050), which is known to under-report aluminum, barium, chromium, potassium, silicon, iron, magnesium, and vanadium. Although HNO_3/HCl digestion a standard analysis technique, silica matrices are not dissolved. The analysis using HF digestion more accurately measures total ash composition. By comparing these two analysis, one may infer the bond strength (and mobility at combustion temperature) of the alkali metals. It appears that about half of the sodium and half of the potassium is tightly bound with the silicates, in all size cuts.

A limited number of tests were conducted with cleaned Upper Freeport coal. Froth floatation cleaning was performed by Hazen Research, Inc of Golden, Colorado. The cleaning process is accomplished in stages, with each stage generating a "float" fraction (the cleaned fuel) and a "sink" fraction (the ash rich stream). The first sink fraction removed is the "rougher tailing", which typically has the highest mineral content of all fractions. Each new stage uses the float fraction from the previous stage, which results in one final cleaned fuel, and a series of reject "tailings" from each stage. A summary of cleaning results are given in Table 5.5. This four stage process is usually only effective at removing excluded mineral matter.

5.1.2 Pulverized Coal Test Matrix

A series of experiments were conducted to explore the effect of coal treatment and mineral contact on aerosol yields. The test matrix is shown in Table 5.6, with individual tests detailed in Appendix G. Most experiments were run for 15 minutes sampling time. Some tests were run with shorter sampling times to prevent overloading of the cascade impactor stages. All tests were conducted with the same volumetric coal flow rate, as controlled by a screw feeder. Assuming the densities of the coal fuels are approximately the same, this corresponds to a dry fuel flow rate of 1.1 grams/minute.

A series of tests were performed with the sampling probe in the horizontal position, as described in section 4.2 and shown in Figure 4.4. This probe location is downstream of a 90 degree vertical-to-horizontal bend in the main furnace, which probably results in loss of some larger ash particulate matter. Furnace free oxygen and air to fuel ratio were maintained relatively constant during this test series, with two exceptions: Test 05069401

(Kentucky #11) was conducted with the Upper Auxiliary burner near stoichiometric, in order explore the effect of an increase the overall tunnel temperature, and test 06029401 was conducted with the auxiliary burner off.

A series of tests were also performed with the sampling probe in the vertical position, as shown in Figure 4.5. This probe position allows sampling of the hot gas/particulate prior to bends in the furnace exit duct. This leads to a more representative ash sampling. The Upper Freeport series was conducted with size sorted fuel cuts, as well as with the as-received fuel. Two Upper Freeport tests were conducted with leaner stoichiometry, for comparison to similar tests with Kentucky #11 and Illinois #6.

Two tests each of Kentucky #11 were conducted at three different stoichiometries, to explore the effect of furnace temperature. One blank test was conducted to help determine the uncertainty of measured ash yields.

Temperature profiling in the reactor was limited to three measurements per test with a bare thermocouple at available ports. The column labeled "Upper Temp" on Table 5.6 refers to the temperature as measured at a port 43 cm from the solid fuel injection point, which is the first accessible port. The column labeled "Lower Temp" refers to the temperature as measured at the last port on the furnace, which is 185 cm from the solid fuel injection point. The column labeled "Sample Temp" is the temperature measured at the inlet of the sampling probe. For horizontal tests, this location is in the furnace exhaust duct, as shown in Figure 4.4, so it is cooler than the either of the furnace temperatures. For vertical tests, the sample probe tip is two ports above the lowest port on the furnace, 155 cm from the injection point. This is shown schematically in Figure 4.5. Hence, the temperature at this location is slightly higher than the "Lower Temp" measurement.

There is an increase in reactor temperature of about 100 degrees between horizontal testing and vertical testing. This is primarily due to insulation improvements in the main burner and main combustion chamber.

Results of cascade impactor tests are reported below. Most figures are mass distributions, and are based on the following assumptions: 1) The particles are spherical, and 2) the particle density is unity (1 g/cc). Applying these assumptions is a common convention in the literature. The resulting normalized particle diameter is usually referred to as the aerodynamic diameter (*e.g.*, Friedlander, 1977). While the results are not strongly

sensitive to assumed particle density, the shape and porosity of the particles can influence capture. The lower size limit of particles captured on a particular stage is usually quantified by the D_{50} diameter, which is the diameter of a particle that has a 50% probability of capture. The upper size limit of capture is set by the D_{50} diameter of the stage directly before it.

The mass distribution is usually presented as (ΔMass/Δlog Diameter), with the independent variable expressed as the logarithm of the particle diameter. Thus, the mass over a set range of diameters is proportional to the area under the curve in that size range. This does lead to some difficulty with the tails of the size distribution (*i.e.* the preseperator and aerosol filter), since there is no clear cut-off diameter for either end of the size distribution.

Material captured on the filter stage is nominally considered to be a log-normal distribution centered at 0.1 μm, which is typically the mode location of particles formed by vaporization/ condensation (Damle, 1982).

A preseparator was used to remove particles larger than 10 μm. This material was not reliably weighed for the horizontal probe tests, and therefore is not included here. Preseperator material collected during vertical probe tests was weighed with reasonable accuracy, and is presented when appropriate. Although the preseperator is not strictly considered a size cut (Andersen Instruments, Inc., 1985), it is plotted at a D_{50} diameter 10 μm.

5.1.3 Pulverized Coal Horizontal Probe Tests - Results

Horizontal Probe Tests, Unmodified Coals:
Figure 5.2 shows a summary of tests of Upper Freeport, Kentucky #11, and Illinois #6 raw coals. The mass collected on each stage of the cascade impactor is plotted relative to the D_{50} size cut of that particular stage. Repeatability is very good for this test series.

Test 05069401 was conducted with the auxiliary burner operating near stoichiometric, resulting in a furnace exit temperature of 688 C, which is 50 degrees higher than comparable tests. The elevated temperature does not seem to significantly change the ash size distribution. This change in temperature may be too small to warrant a change in ash formation mechanisms. Kramlich and Newton (1994a) noted in their experiments that ash yield was not significantly effected by moderate changes in combustion temperature.

Differences in total ash yield are expected to be a direct consequence of differences in ash content of the raw fuels. The table associated with Figure 5.2 shows this trend. The average mass of ash collected for a coal is compared to the other two coals, in terms of ash yield normalized to the ash yield of Upper Freeport. The collected ash yield is compared to the ash content of the coal as obtained from ASTM proximate analysis (see Table 5.1). Agreement is reasonably good, considering that material collected in the preseperator is not included, and all ash collected is not expected to be in the form of elemental oxides.

Detailed mass closure for this system is not practical, primarily due to anisokinetic sampling and loss of large particulate minerals at the first bend prior to the horizontal exhaust duct. Losses relating to super-isokinetic sampling is addressed in Appendix C. Approximately 90% of particulate matter with a diameter below 10 μm is expected to be captured. Above 10 μm the capture efficiency drops significantly, resulting in under-representation of the largest residual particles. Since behavior of mineral matter below 10 μm is of more importance in this investigation, failing to fully capture the largest size fraction is not detrimental.

Figure 5.2 also illustrates the inherent difficulties of interpreting cascade impactor data. The amount of ash collected on a particular stage is not only a function of the true particle size distribution, but also a function of cut-off diameter spacing. Hence, if a stage only catches a narrow range of particle diameters, it will capture less material than if the stage covered a wider range of diameters. With this in mind, it is clear that the area under the mass curve is not proportional to the mass over a size range, unless the D_{50} size cuts of the stages happen to be equally spaced on a logarithmic scale. This can be seen more clearly by comparing Figures 5.3 and 5.4, discussed next, where the apparent dip near 4 μm is partly due to close impactor stage spacing.

In Figure 5.3, the ash distribution has been normalized to the total ash collected for each coal, excluding the ash collected in the preseperator. Preseperator ash was not quantified. Note that the overall ash size distribution is very similar between all tests. All tests show an aerosol mode, a 3 μm mode, and a larger residual mode. Upper Freeport shows a reduced aerosol mode, and a proportionately increased large residual mode. As was shown in Figure 5.1, the average mineral inclusion size in the unburned Upper Freeport is greater than the other two coals. Hence, an enhanced residual size fraction is expected.

Test 05049401 deviates from the family of curves in Figure 5.3. This run was conducted without preheating the cascade impactor prior to test, resulting in condensation of combustion water in the impactor. After drying the stages and filter, the ash yield at D_{50}=1.1 μm is low compared to the other tests. Ash yield at D_{50}= 3.3 μm is slightly high. It is possible that condensation on ash particles increased the average aerodynamic diameter of the resulting ash. This phenomenon is exploited in industry by the use of a humidifier prior to a "wet" Electrostatic Precipitator, since the larger, wet particles are more easily charged and captured.

Figure 5.4 shows the same data as Figure 5.3, except replotted as a function of (ΔMass/ΔlogD). Presented in this form, mass over a particular particle diameter range is proportional to the area under the curve, as discussed earlier. Note the presence of a large residual mode and 3 μm mode, similar to Figure 5.3, and the attenuation of the mass distribution dip near 4 μm. The aerosol mode is not so apparent, which is more an artifact of this method of data presentation than lack of aerosol mode. Expressed in log-log form (lower graph in Figure 5.4) the reduced ash yield around 1 μm on test 05049401 is noticeable. As mentioned previously, this is probably a result of condensation in the impactor and subsequent particulate diameter growth.

Upper Freeport Horizontal Probe Tests:
Figure 5.5 shows ash size distribution for as-received Upper Freeport pulverized coal (raw), Upper Freeport cleaned coal, and Upper Freeport coal particles between 37 and 85 μm. As a percentage of total collected ash, the sized fuel shows a significantly enhanced yield of large particles (D_{50} = 9 μm), at the expense of the ≈ 3 μm mode. Test 06019401 (Upper Freeport 37-85 μm) had a dark filter, possibly indicative of incomplete char combustion and/or large particle bounce-through. The aerosol measurement for this test should be viewed with this in mind.

These data from Figure 5.5 are shown in normalized form in Figure 5.6. Normalizing consists of adjusting the total ash yield of each fractionated coal such that the yield is proportional to the ratio of the cleaned (or sized) coal mass to the as-received coal mass:

$$\text{measured ash mass} \times \text{fraction of total coal mass} = \text{scaled ash mass}$$

For example, the percentage of cleaned coal derived from a given mass of raw coal is shown in Table 5.5 to be 75.5%. Hence, the cleaned coal total ash yield was reduced to 75.5% of the measured yield, since cleaning removed 24.5% of the total mass from the parent pulverized fuel, as shown in Figure 5.6. Of course, the cleaning process is designed to remove mineral matter, so ash yield is most likely less than 75.5% of the uncleaned coal. Total mineral matter content by proximate analysis for this cleaned coal is not known, but may be determined in the future.

Scaling the 37 to 85 μm cut to 29.2% of its original ash yield (Figure 5.6), shows that a significant fraction of the residual is probably made up of mineral inclusions that have coalesced, or residual ash unchanged since breakup of the original fuel particle. This ash distribution implies that most of the 3 μm mode must be from smaller (<37 μm) coal size cuts. This will be discussed in more detail for tests performed on all size cuts, with the vertical sampling probe.

Aerosol yield is best presented by a cumulative ash yield plot. Figures 5.7 and 5.8 show ash yield as measured, and scaled proportionate to the fraction of original coal, respectively. Material collected on the aerosol filter for the 37-85 μm Upper Freeport test appeared dark, possibly because of incomplete burnout or particle bounce-though, as mentioned earlier. If this is the case, the aerosol yield will be artificially high. Nonetheless, it should be noted that the sized coal aerosol yield is about the same as the raw coal and cleaned coals. If aerosol yield were proportional to the fraction of sized coal to raw coal, one would expect the aerosol yield to be about one-third the aerosol yield of the raw coal.

One cleaned coal test appears to show a very low aerosol yield. No abnormalities were observed during this test that would lead one to expect a low aerosol yield.

Kentucky #11 Horizontal Probe Tests:

Figure 5.9 shows four Kentucky #11 tests. The sized coal test (06029401) is shown twice, once with the ash yield as measured, and secondly with the ash yield scaled to the ratio of sized coal mass to unsized coal mass. For Kentucky #11, 26.6% of the mass of the raw coal is between 37 and 85 μm in diameter, hence the scaling factor was .266. Like the Upper Freeport, the 37 to 85 μm size cut contributes a significant amount to the large (> 9 μm) particle mode, and very little to the 3 μm mode.

It should be noted that test 06029401 was conducted with the auxiliary burner off, possibly resulting in a lower overall tunnel temperature. The temperature measured near the top of the furnace (43 cm from the coal injection port), and at the bottom of the furnace (185 cm from the coal injection port) were 1060 C and 637 C, respectively, which is typical for this test series. The auxiliary burner had failed unexpectedly just prior to testing, so a change in the furnace temperature profile was probably delayed by the low heat dissipation rate of the refractory walls. Burn-out for this test appeared good.

Ash yields for the Kentucky #11 coals are expressed in terms of cumulative mass in Figure 5.10. Test 05049401 had condensation evident in the cascade impactor, making this test questionable, as was discussed earlier in conjunction with Figure 5.3. As can be seen in Figure 5.10, the 37 - 85 μm Kentucky #11 coal ash produces approximately three times the ash of the whole coal, when measured as a percentage of total ash yield. When the ash yield of the 37 -85 μm coal is scaled as before, the aerosol yield is about the same as the raw coal.

Illinois #6 Horizontal Probe Tests:

Tests performed using the horizontal probe with Illinois #6 coal is shown in Figure 5.11. Test 05319401 is shown "as measured" as well as proportionately scaled. The ratio of 37 to 85 μm coal to unsized coal for Illinois #6 is 0.294. Test 05129401 is highlighted because a significant amount of water was found in the preseperator post-test. The likely source is coolant water from the exhaust duct water atomizer. If the probe tip is angled slightly downward, it is possible that condensed water could run down the outside of the probe to the tip, and be pulled into the impactor. The largest size cut seemed to be most significantly effected, most likely from large particle capture by the standing water in the preseperator.

The ash distribution for the 37 to 85 μm coal is very similar to the ash distribution of the unsized coal. The 3 μm mode is apparent for this coal size cut, unlike the sized cuts of Upper Freeport and Kentucky #11. Re-examining Figure 5.1, it can be seen that the average inclusion size of Illinois #6 coal is significantly less than the average inclusion size of Upper Freeport, and moderately less than Kentucky #11. The implication is that Illinois #6 37 - 85 μm coal has many small inclusions, while Upper Freeport 37-85 μm is probably predominantly larger inclusions, and that these modes ultimately carry over to the ash size distribution.

5.1.4 Pulverized Coal Vertical Probe Tests - Results

With the sampling probe in the vertical position, large particles were more efficiently captured in the preseparator, and an improved method of preseperator material weighing was employed. Preseperator mass measurements are provided as appropriate.

Vertical Probe Tests, Unmodified Coals:
Figure 5.13 shows ash mass collected as a function of the cutoff diameter of the capturing stage for each of the three coals tested at a furnace equivalence ratio of 1.8. Recall that furnace equivalence ratio is set by the natural gas and air flow rates, which is about 500 times the flow rate of the solid fuel. Hence, equivalence ratio is primarily a control of the furnace temperature.

Each mass measurement at a particular diameter in Figure 5.13 corresponds the mass collected from the D_{50} diameter indicated, up to the D_{50} diameter of the previous stage. Test to test repeatability is very good. The two Kentucky #11 tests were slightly overloaded in the larger size cuts, and the aerosol filter had some particle bounce-though. The Upper Freeport coals produced dark ash, which may indicate incomplete combustion. The Illinois #6 appeared to have a good ash distribution and burn-out.

As was the case for the horizontal probe tests, Illinois #6 total ash yield is lower than Upper Freeport and Kentucky #11. This is expected, since ASTM ashing shows Illinois #6 to have about half the ash content of Kentucky #11 or Upper Freeport.

If the mass distribution is expressed as $\Delta Mass\%/\Delta \log D_{50}$ versus the aerodynamic diameter on a logarithmic scale, the area under the curve between two aerodynamic diameters is proportionate to the mass in that size range. This is shown in Figure 5.14 for the three coals tested. All three coals show a similar mass distribution.

Figure 5.15 is the cumulative mass plotted with respect to the cut-off diameter of the capturing stage. Normalized to the total ash collected, including the mass found in the preseperator, the aerosol yield of the Illinois #6 is about 1.5% of the total ash. This contrasts with Kentucky #11 and Upper Freeport, which have less than 0.3% of their ash in the aerosol size range. Tests with the horizontal probe showed only slightly higher aerosol yield for Illinois #6 compared to Upper Freeport and Kentucky #11, as can be seen

in Figure 5.4. Neglecting the mass in the preseperator in the vertical tests does not account for the difference.

Kentucky #11, Vertical Probe Tests with Variable Stoichiometry:
A series of tests using Kentucky #11 with variable air/natural gas stoichiometries were conducted, at air/fuel equivalence ratios of 1.7, 1.8, and 2.0, as shown in Figure 5.16. Maximum furnace temperature measured for each stoichiometry was 1250 C, 1190 C, and 1125 C, as detected by a bare thermocouple at the port closest to the point of solid fuel injection. The bare thermocouple was not a particularly reliable measure of furnace temperature, and accuracy deteriorated with the age of the thermocouple. Thermocouple degradation is documented in the data record sheets of the appropriate tests, but will not be discussed in detail here.

Coal flow rate was maintained at about 1.1 g/minute for all tests, compared to the overall hot gas flow rate of about 515 g/minute, hence the coal flow rate did not significantly influence the overall stoichiometry. The range in stoichiometry resulted in a range of dry O_2 after fuel combustion from 8.6 to 10.9%.

In terms of cumulative mass, the aerosol yield appears to be slightly lower for an equivalence ratio of 1.8, as shown in Figure 5.17. Although this is not the leanest test of this series, Table 5.6 does show that the temperature at the sample port is lower than the temperature for the leaner tests (10079401 and 10119401). One would expect the exit temperature to be cooler for the leaner tests. This may warrant closer scrutiny of the temperature data (*e.g.* reliability of bare thermocouple measurements). It is possible the differences in aerosol yield between these tests are within the error of the data.

Upper Freeport, Vertical Probe Tests:
All vertical probe tests with Upper Freeport coal are shown in Figure 5.18. Two tests (09159401, 09169401) were conducted with the unmodified coal at a stoichiometry of 1.8. These two tests were compared to Kentucky #11 and Illinois #6 in Figure 5.8, with the same stoichiometry. All other tests in Figure 5.18 are at a stoichiometry of 1.7. Tests 10169401, 10219401, and 10259401, are baseline tests, while the remaining tests are the ash distributions for sized fractions of the parent pulverized fuel. It is clear that the size cut of the coal is a factor in the ultimate ash yield. The larger size cuts of coal tend to produce a larger residual ash mode, at the expense of the 3 μm mode, while the smaller sized cut coal

shows a greater 3 μm mode. Note also that the largest size cut of coal produced proportionately the greatest aerosol yield.

Also shown on Figure 5.18 is run 11149401. This is an imperfect test which is included to show the effect of impactor overload. The combination of long sampling time coupled with a possible feeder jam clearing in a single burst, caused an overload of the impactor. The filter was black, most likely from unburned carbon (soot), and stages showed signs of particle blow-by. Blow-by was also a problem with the largest size cut coal. Sampling time was reduced for tests 11289401 and 12029401 to five minutes in order to minimize overload, while tests 12079401 was limited to one minute sampling time.

Figure 5.19 shows the same tests as Figure 5.18, but with a linear independent variable axis. Presented in this way, the area under the curve between two aerodynamic diameters is proportional to the mass between the diameters. As noted before, the smallest size cut is a significant contributor the 3 μm mode.

Aerosol yield is greatest for the coal particles greater than 85 μm, as seen in Figure 5.20. All other size cuts and the raw coal had less than 1% aerosol mass, with the exception of tests 11149401, which was an overloaded test discussed with Figure 5.18.

The ash yield of each size cut was reduced in proportion to the mass of that size cut in the raw (*i.e.* unsized) coal. In this way, the sum of the ash from the sized coals could be compared to the raw coal. The size cut coals, in scaled form, are compared to the raw coal in Figure 5.21. Note that aerosol yield of each sized coal comparable to the aerosol of the unsized coal. Test 11149401, a test with impactor overload, is also shown for comparison. Test 12079401 appears to be moderately inconsistent, compared to other >85 μm tests. This was a one minute test, while the other >85 μm tests were five minute tests.

Figure 5.22 shows the same information as Figure 5.21, but with a linear vertical scale. In this form, it is clear that the residual mode greater than 9 μm is a sum of the size cuts, while the 3 μm mode is mostly from the <18 μm size cut coal.

Summing the fractions of ash from the sized coals produces the ash distribution shown in Figure 5.23. This figure indicates that the residual mass greater than 9 μm is nearly the sum of the large residual mass from the sized coals, but the 3 μm mode is somewhat reduced. Examined in terms of cumulative mass (Figure 5.24), the mass missing from the

3 μm mode appears to be in the aerosol mode. Aerosol yield from the sum of the size-cut coals is about double the aerosol yield of the whole coal. Tests of raw Upper Freeport with the sampling probe in the horizontal position and the vertical position are compared in Figure 5.25. Preseperator mass is not included, since it was not measured for horizontal tests. Mass distributions are very similar. Vertical probe testing shows slightly improved collection of the residual mode, as is expected.

5.1.5 Summary of Pulverized Coal Results

The experiments with pulverized coals support the following observations:

• Experiments with unmodified coals show similar ash size distributions for all three coals tested: A sub-micron aerosol mode, a 3 μm mode, and a >9 μm mode. The aerosol is most likely formed from condensed and coagulated vapors, while the 3 μm and ≥9 μm modes are fragmented and coalesced residual ash.

• The sum of aerosol from individually burned aerodynamically-sized coal fractions is greater than the aerosol yield of the whole coal. This is demonstrated with Upper Freeport coal, in which the aerosol yield was about 0.25% of the total ash for the whole coal, compared to 0.75% of the total ash for the summed coal fractions. This lends support to the conclusion that alkali vapor release is attenuated by close association of mineral inclusions.

• Ash size distribution is not identical for all aerodynamically-sized coal fractions. Sized Upper Freeport of <18 μm contributes as much mass to the 4 μm mode as all other size cuts combined. Ash from size cuts greater than 18 μm are predominantly greater than 9 μm in diameter. The obvious implication is incomplete fragmenting of larger mineral inclusions.

5.2 Pulverized Artificial Char Experiments

The complex composition of natural coal makes investigating fundamental properties of a natural coal very challenging. An artificial char is used in this test series to investigate vaporization and/or capture of sodium in the presence of three common minerals. Artificial

char for the current investigation was produced by Park (1995), and the described experiments were conducted with his cooperation.

5.2.1 Artificial Char Characterization

Artificial char is produced using the sucrose pyrolysis technique, following the procedures of Neville *et al.*(1981). A detailed description of the preparation of the artificial char used in this investigation is available in Park (1995). In summary, high purity sucrose, pulverized carbon black, organic alkali salts and discrete mineral inclusions are combined in distilled water to form a paste. The mixture is placed in an nitrogen purged oven at 600 C until a char is formed, in which the pyrolyzed sucrose acts as a binder. Microporosity of the char is controlled by relative proportions of sucrose to carbon black, with higher microporosity associated with higher carbon black content. During pyrolysis, approximately 50% of the sucrose/carbon black dry weight is lost (Park, 1995). After cooling to room temperature in a nitrogen environment, the residual char is pulverized in a ball mill to approximately 50 to 70 μm.

Table 5.7 summarizes the properties of the components used in artificial char preparation, as well as the compositions of the chars prior to pyrolysis. Pyrite, bentonite, and calcite were selected as representative discrete mineral inclusions. Park (1995) chose the ratio of total mineral mass to char mass to be similar to coals studied by Boni *et al.*(1990). Bentonite, chosen as a representative clay mineral, is source variant, and the exact composition of the bentonite used for this study is not certain. A chemical analysis of the remaining bentonite may be warranted.

Sodium oxalate ($Na_2C_2O_4$, decomposition at 270 C) was used as the source of atomically dispersed sodium. The ratio of sodium to char mass was chosen to be representative of a typical western coal of low rank, which is normally high in sodium compared to other coal types (Park, 1995).

5.2.2 Artificial Char Test Matrix

Table 5.8 is a summary of artificial char experiments performed. These tests were performed in cooperation with Park (1995). Individual tests are detailed in Appendix H. All tests were conducted at a furnace air to fuel ratio near 1.45 in order to assure good

burnout, with the exception of test 02069501. This test was conducted at a leaner stoichiometry, which resulted in incomplete burnout.

The very limited supply of artificial char prevented use of the standard screw-type feeder. Instead, a syringe drive system with a premeasured char load was used, as described in the Technical Approach and Experimental Apparatus chapter. Run to run variations with this char feeder is common, so accurate measurement of the total char feed is not readily available. Most tests were conducted with 18 cc (10.8 g) of char over a 10 to 15 minute test period.

5.2.3 Artificial Char Results

When compared to the experiments conducted with pulverized coal and with sawdust/sanderdust (discussed in other sections), it is clear that run to run variability is much greater for the artificial char tests. This is most likely attributable to the char feed system, and compositional variations of the char itself. Char burnout was not complete for all tests, as will be discussed as appropriate.

Artificial Char with Sodium Doping Only:
Figure 5.26 shows all tests using an artificial char composed of only sucrose, carbon black, and dispersed sodium. The higher microporosity char is Suc50/50, as discussed earlier. Results on this figure are given in terms of mass collected on each stage, which is the most fundamental representation of the collected data. All tests have significant aerosol yield, as is indicated by the mass collected on the Backup Filter, and significant residual yield indicated by the mass retrieved from the preseperator. If sodium vaporization and char burnout were complete, one would expect no large residual mode. Test 03169503 is marked for particularly poor burnout, which was manifest as dark ash in the large size cuts. Poor burnout of this nature was usually accompanied by a artificial char feeder jam that was cleared suddenly. No jam was noted on this test, but that is not assurance that one did not occur.

The furnace temperature, as measured by a bare thermocouple in the hot gas stream 43 cm from the point of solid fuel injection, is labeled on the graph. It should be mentioned that furnace temperature is always measured without pulverized fuel flow. Note that the cooler furnace temperature results in higher residual mode compared to the aerosol mode.

These same tests are shown in Figure 5.27, plotted as cumulative mass as a function of D_{50} diameter of the collecting stage. As mentioned previously, run to run variability seems high for artificial char experiments. Aerosol yield for the Suc50/C50 experiments is about 25% to 35% of the total ash collected. The one Suc50/C50 experiment conducted with a cooler furnace temperature yielded 17% aerosol by mass, indicative of incomplete char burnout. This is also evident in the Suc75/C25 test with dark ash, although it appears to have more particulate in the 4 to 5 μm range.

Artificial Char Aerosol Suppression with Bentonite:
All tests conducted with bentonite and sodium doping are shown in Figure 5.28. Two tests with sodium doping, conducted at identical furnace settings as the bentonite tests, are also presented for comparison. It is immediately clear that the bentonite contributes to the residual mode, both in the largest size cut (the preseperator, roughly 10 μm diameter and larger), and intermediate size cuts prior to the aerosol filter. Thus, it is assumed that the particles captured on stages 0 through 7 are primarily residual bentonite particles and a small amount of residual sodium/char that has not been consumed.

Test 03019501 is called out because the char feeder jammed during testing. In the course of clearing it, a large batch of char was sent through the furnace suddenly. This resulted in incomplete combustion and the distorted ash size distribution for that test as shown.

Figure 5.29 shows the same data in terms of the cumulative ash yield, normalized to the total ash. The general trend of a reduction in aerosol yield as a fraction of total ash mass seems clear. Recognizing that burn-out was not necessarily complete, it is difficult to determine if this correlates with sodium absorption by the bentonite or is an artifact of measurement. In particular, increasing the bentonite content from 3.75 g to 5.00 g results in a slightly greater aerosol yield, when the general trend is a reduction in aerosol percentage as bentonite increases. Appropriate scaling factors such that sodium absorption can be quantified is an area worthy of further study in the future.

Artificial Char Aerosol Suppression with Calcite:
Calcite/sodium doped experiments are summarized in Figure 5.30. Tests with sodium doping alone are also shown for comparison. The calcite inclusions do not appear to have fragmented significantly upon firing. The size distribution after the preseperator (about 10 μm and below) is essentially the same for all tests; the majority of the residual ash is captured in the preseperator for all tests. Interestingly, the char with the lowest calcite

content (0.25g) gave the largest preseperator yield. This mass was associated with one large particle that was found in the preseperator and 3 other slightly smaller particles. The test with Cal 0.50 g also had one large particle. These large particles are unusual in that coalescence of this magnitude is would be very unlikely. The other calcite tests did not have large particles in the preseperator.

Note that aerosol yield is very similar for all tests. This is likely due to two factors. The small surface to volume ratio of the large (15 to 17 μm) calcite particles offer very little surface area for heterogeneous reaction with the available sodium. Secondly, calcite undergoes calcination to CaO at about 900C, which is a crystalline structure. Melting of CaO does not occur until 2580C, well above practical furnace temperatures. In its crystalline form, it is doubtful CaO would be reactive enough to complex sodium, even with additional surface area.

Artificial Char Aerosol Suppression with Pyrite:

The pyrite series is shown in Figure 5.31. Like the bentonite, the addition of mineral matter generally results in an increase in residual ash. The exception in this case is a higher residual ash yield for char doped with 2.78 grams of pyrite compared to char doped with 3.70 grams. It is very likely that the 2.78 gram tests are distorted by an undetected feeder jam/clear, or other anomaly. An indicator is a dark or black backup filter, usually a sign of impactor overloading due to incomplete char combustion.

All tests show an increase in preseperator yield with addition of pyrite, as well as an enhanced yield in the size range between the preseperator and the backup filter (roughly 0.4 μm to 10 μm). This is significant in that it appears the pyrite has fragmented from its original 9 to 10 μm size. Pyrite fragmentation has been observed by other researchers as well (Srinivasachar *et al.*, 1990, Baxter, 1990). This contrasts with the calcite, which did not show significant fragmentation, and compares well with the bentonite series, which has a 1 to 2 μm inclusion size prior to combustion.

Figure 5.32 shows cumulative mass for this series. Although the general trend is for the percentage of aerosol to be lower as pyrite is increased, it is not clear that this is a result of a reduction in aerosol or is solely an increase in residual mass.

5.2.4 Discussion of Artificial Char Results

The artificial char experiments require further interpretation, particularly in determining the true aerosol change as a function of mineral composition. This information is difficult to directly extract from the tests, because of the affects of incomplete burn-out, possible compositional variations in the unburned artificial char, and run-to-run anomalies that can occur with physical experiments. Nonetheless, some observations may be made:

- Aerosol yield generally decreases with increasing bentonite, although the affect of incomplete burnout and experimental uncertainty cannot be ignored. Suppression of aerosol fraction is most likely alkali metal absorption by bentonite inclusions as the surface of the char particle recedes during combustion, as has been noted by other researchers

- Calcite fragmentation is limited, with most mass remaining in the large (>9 μm) particle range. This results in very little surface area for sodium interaction. Sodium and calcite interaction is also probably limited because of the high melting temperature of CaO, which is the favored species above 900 C.

- Pyrite minerals exhibited significant fragmentation, as has been observed by other researchers. Like bentonite, the pyrite generally shows a reduction in aerosol yield with increased mineral content, although it remains to be determined if this is a result of sodium/pyrite interaction or is an experimental artifact.

Table 5.1: Proximate and ultimate analysis of pulverized coals (Adapted from Boni et. al., 1990, Table 3-8(a))

	Upper Freeport	Kentucky #11	Illinois #6
Proximate Analysis (As Recieved, mass %)			
Fixed Carbon	52.27	41.96	42.15
Volatile Matter	23.99	33.24	35.92
Ash	23.23	20.96	8.62
Moisture	0.51	3.84	13.31
Ultimate Analysis (As Recieved, mass %)			
Carbon	64.57	57.73	59.87
Hydrogen	4.07	4.42	4.55
Oxygen	3.92	7.64	8.52
Nitrogen	1.63	1.29	1.37
Sulfur	2.07	4.22	3.76
Ash	23.23	20.96	8.62
Moisture	0.51	3.84	13.31
Heating Value and Sulfur Form (As Recieved)			
HHV, Btu/lb	11395	--	10693
Sulfate S	0%	0%	0%
Pyrite S	1.41%	2.55%	1.11%
Organic S	0.66%	1.67%	2.65%
Acid Soluble Alkalies (ppm, mass)			
Na	360	371	2258
K	2350	3448	2380
Ca	3700	4875	5811
Mg	1200	1009	1766

Table 5.2: Ash chemistry of pulverized coals
(Adapted from Boni et. al., 1990, Table 3-8(b))

	Upper Freeport	Kentucky #11	Illinois #6
Ash Chemistry			
SiO2	50.6	46.7	46.1
Al2O3	24.6	19.4	18.0
TiO2	1.2	0.9	0.9
Fe2O3	13.5	20.0	20.5
CaO	2.2	4.4	5.3
MgO	1.4	0.9	0.6
Na2O	0.3	0.3	1.3
K2O	3.1	2.2	2.1
SO3	2.4	5.0	4.4
P2O5	0.1	0.2	0.1
Ash Fusion Temperatures (ASTM)			
* Reducing (°C):			
Initial Deformation	1192	1256	1238
Softening Temperature (Sph.)	1235	1260	1260
Softening Temperature (Hem.)	1271	1278	1268
Fluid Temperature	1298	1289	1349
Oxidizing (°C):			
Initial Deformation	1321	1261	1238
Softening Temperature (Sph.)	1369	1293	1216
Softening Temperature (Hem.)	1381	1316	1277
Fluid Temperature	1391	1333	1368

* From Gallagher, 1992

Coal Composition by Ohio

Table 5.3: Conventional analysis and ICP metals analysis of aerodynamically sized Upper Freeport pulverized coal

Coal Composites for Dan	Upper Freeport size cuts			
	<18 μm	18 to 37 μm	37 to 85 μm	> 85 μm
Fraction of Unsized fuel	31.0%	26.2%	29.2%	13.7%
Carbon, Volatiles, Ash (Mass %, as recieved basis)				
Total Carbon%	56.01	57.00	56.85	49.41
Total Solids %	98.45	98.51	98.89	98.64
Volatile Solids %	22.70	23.38	24.14	24.65
Ash %	19.74	18.15	17.90	24.58
Dry-Loss %	1.55	1.49	1.11	1.36
***ICP Metals by EPA method 6010** (μg/g as recieved fuel)				
Aluminum	24000	19000	20000	25000
Arsenic	28	14	23	23
Barium	110	77	82	100
Calcium	2300	2300	3500	5300
Cadmium				
Cobalt				
Chromium	24	84	18	22
Copper	13	33	20	33
Iron	9800	13000	17000	35000
Potassium	5400	4200	4000	4700
Lithium	30	30	19	25
Magnesium	1400	880	1000	1300
Manganese	56	66	57	97
Sodium	500	550	400	440
Nickel	21	57	14	29
Phosphorus	170	900	180	190
Lead			15	
Sulfur	7300	10000	14000	28000
Silicon	130000	110000	100000	140000
Strontium	65	59	69	85
Titanium	1200	1000	970	1100
Vanadium	50	41	39	46
Yttrium	6.7	5.4	6.6	6
Zinc	45	51	52	79
Elements below detection limits: Sb <7.3, B <36, Be <2.6, Cd <0.73, Hg <3.6, Mo <3.6, Se <11, Ag <3.6, Sn <7.3, Tl <11 μg/g as recieved fuel				

*Acid digestion of fuel with HNO_3, HCl, HF

Table 5.4: Conventional analysis and ICP metals analysis with weak acid solution of aerodynamically sized Upper Freeport pulverized coal

Coal Composition by Class	Upper Freeport size cuts			
	<18 μm	18 to 37 μm	37 to 85 μm	> 85 μm
Fraction of Unsized fuel	31.0%	26.2%	29.2%	13.7%
Carbon, Volatiles, Ash (Mass %, as recieved basis)				
Total Carbon%	56.01	57.00	56.85	49.41
Total Solids %	98.45	98.51	98.89	98.64
Volatile Solids %	22.70	23.38	24.14	24.65
Ash %	19.74	18.15	17.90	24.58
Dry-Loss %	1.55	1.49	1.11	1.36
***ICP Metals by EPA method 6010** (μg/g as recieved fuel)				
Aluminum	13000	8900	5900	7800
Arsenic	12	14		26
Barium	73	53	46	65
Calcium	2900	3400	4400	6500
Cadmium			1.2	1.6
Cobalt	3.2	3.6	3.5	4.6
Chromium	23	16	9.7	12
Copper	19	19	22	31
Iron	11000	15000	20000	39000
Potassium	3200	2400	1800	2000
Lithium	17	10		16
Magnesium	1200	910	750	950
Manganese	62	58	64	99
Sodium	350	260	< 240	250
Nickel	9.6	12	5.5	22
Phosphorus	170	150	120	120
Lead	17	14		24
Sulfur	10000	13000	18000	34000
Silicon	760	740	610	480
Strontium	64	59	53	68
Titanium	160	120	76	76
Vanadium	30	26	22	22
Yttrium	7.9	6.9	4.9	6.8
Zinc	41	44	58	75
Elements below detection limits: Sb <7.3, B <36, Be <2.6, Cd <0.73, Hg <3.6, Mo <3.6, Se <11, Ag <3.6, Sn <7.3, Tl <11 μg/g as recieved fuel				

*Acid digestion of fuel with 1 part HNO_3, 1 part HCl, as 5% solution

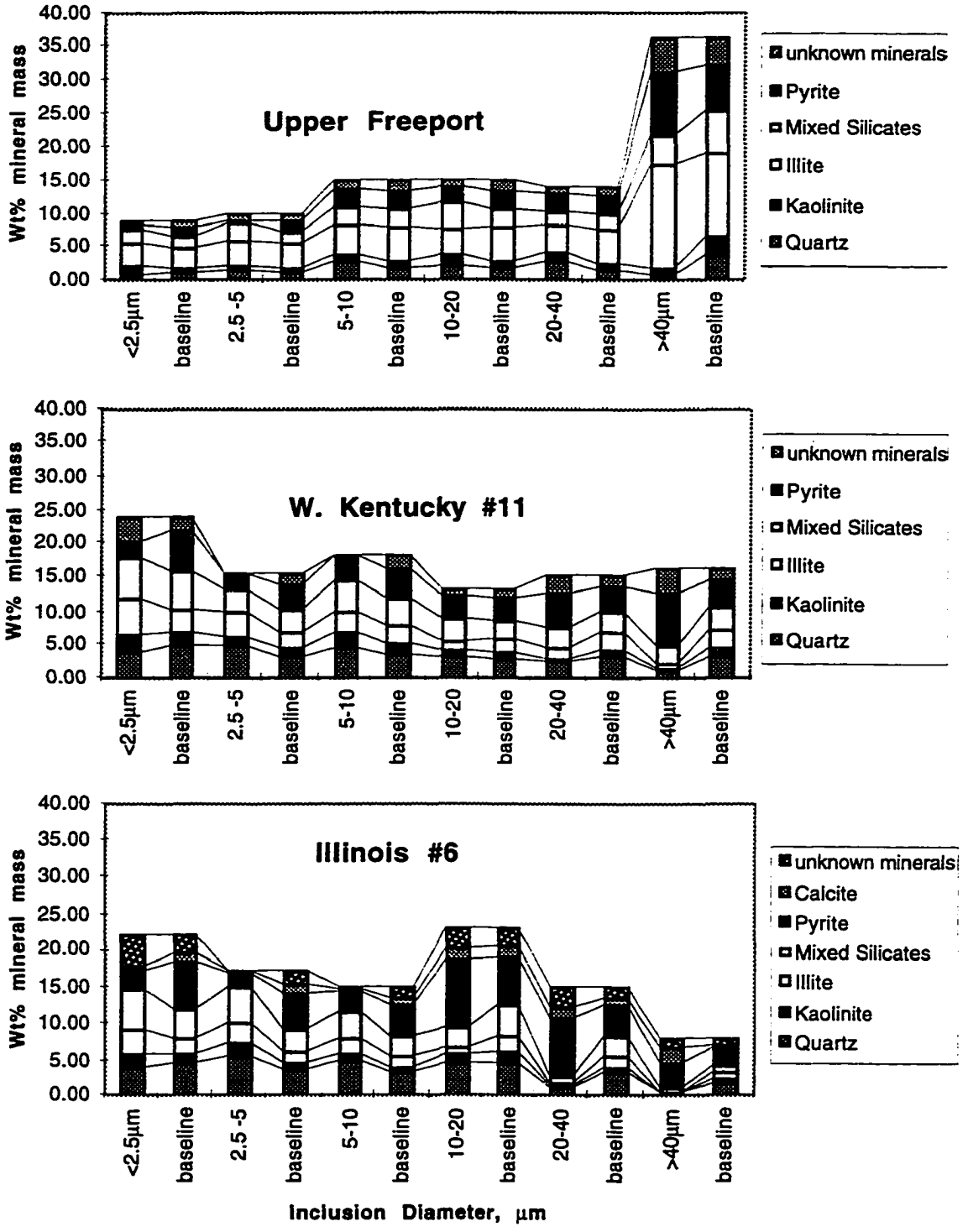


Figure 5.1: Coal mineral composition as a function of discrete mineral inclusion diameter, as measured by CCSEM (Compiled from data in Boni et. al., 1990, Table 4.4)

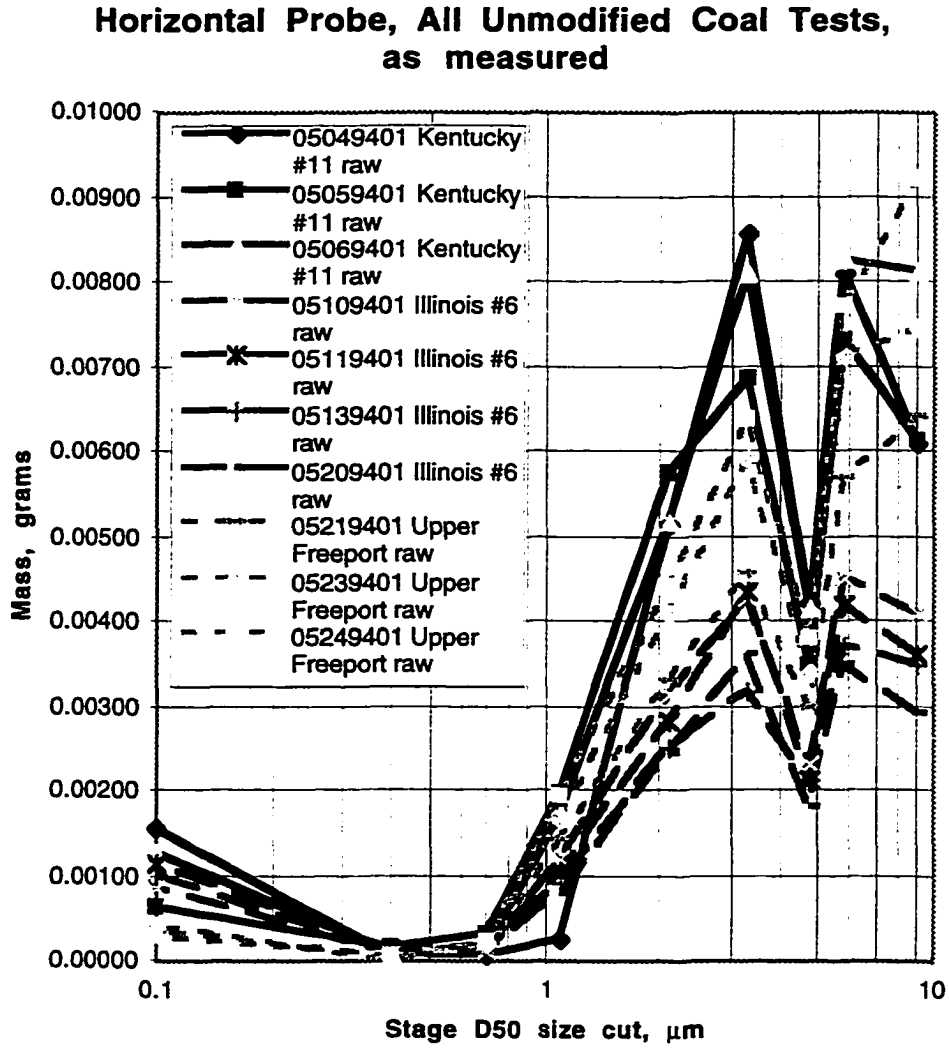
Table 5.5: Upper Freeport froth floatation cleaning

Froth Floatation cleaning results		
Pulverized Fuel, grams	1991.7	100.0%
Cleaner Froth #3, grams	1503.3	75.5%
Cleaner Tailing #3, grams	110.4	5.5%
Cleaner Tailing #2, grams	130.4	6.5%
Cleaner Tailing #1, grams	136.0	6.8%
Rougher Tailing, grams	111.6	5.6%

Table 5.6: Pulverized coal test matrix

Test Number	Fuel	Solid Fuel Modification	Furnace Flowrate, g/m (no solid fuel)	A/F equiv	Upper Aux A/F equiv	Dry O2%, no fuel	Dry O2%, w/fuel	Upper Temp, C	Lower Temp, C	Sample Temp, C	Sample Time, min
Horizontal Probe Tests											
05219401	Upper Freeport	raw	489.0	1.7	1.6	9.2	8.8	1058	621	350	15
05239401	Upper Freeport	raw	492.3	1.7	1.5	9.2	8.8	1057	625	325	15
05249401	Upper Freeport	raw	492.3	1.7	1.5	9.2	8.8	1045	624	325	15
05269401	Upper Freeport	cleaned	492.0	1.7	1.6	9.4	9.0	1063	628	360	15
05269402	Upper Freeport	cleaned	492.0	1.7	1.5	9.4	9.0	1058	623	365	15
05279401	Upper Freeport	cleaned	483.5	1.7	1.6	9.2	8.7	1075	623	350	15
06019401	Upper Freeport	37 - 85 µm	492.1	1.7	1.5	9.3	9.3	1058	642	330	15
05049401	Kentucky #11	raw	494.7	1.7	1.6	9.5	9.1	1060	612	308	15
05059401	Kentucky #11	raw	494.7	1.7	1.6	9.5	9.5	1060	612	308	15
05069401	Kentucky #11	raw	494.7	1.7	1.0	9.5	9.5	1060	688	375	15
06029401	Kentucky #11	37 - 85 µm	492.0	1.7	Off	9.4	9.0	1068	637	350	15
05109401	Illinois #6	raw	488.9	1.7	1.6	9.3	8.9	1058	603	325	15
05119401	Illinois #6	raw	483.0	1.7	1.6	9.2	8.8	1050	634	350	15
05129401	Illinois #6	raw	494.7	1.7	1.6	9.5	9.1	1063	632	350	15
05139401	Illinois #6	raw	488.9	1.7	1.6	9.3	8.9	1050	632	350	15
05209401	Illinois #6	raw	494.8	1.7	1.6	9.4	9.0	1065	623	372	15
05319401	Illinois #6	37 - 85 µm	492.0	1.7	1.5	9.4	9.0	1068	630	330	15
Vertical Probe Tests											
09159401	Upper Freeport	raw	507.6	1.8	1.7	9.8	9.4	1190	575	700	15
09169401	Upper Freeport	raw	516.2	1.8	1.7	10.0	9.6	1180	575	700	15
10169401	Upper Freeport	raw	517.6	1.7	1.7	9.0	8.6	1245	660	813	15
10219401	Upper Freeport	raw	519.2	1.7	1.7	9.1	8.7	1243	662	807	15
10259401	Upper Freeport	raw	519.8	1.7	1.7	9.0	8.6	1245	663	805	15
11149401	Upper Freeport	< 18 µm	518.9	1.7	1.7	9.2	8.8	1246	649	798	15
11149402	Upper Freeport	< 18 µm	518.9	1.7	1.7	9.2	8.8	1246	649	798	15
11169401	Upper Freeport	< 18 µm	519.1	1.7	1.7	9.1	8.7	1238	633	777	5
11219401	Upper Freeport	< 18 µm	519.1	1.7	1.7	9.1	8.7	1244	646	798	5
11079401	Upper Freeport	18 - 37 µm	518.7	1.7	1.7	9.0	8.6	1243	650	798	15
11109401	Upper Freeport	18 - 37 µm	521.7	1.7	1.7	9.1	8.7	1250	656	800	15
11119401	Upper Freeport	18 - 37 µm	519.2	1.7	1.7	9.1	8.7	1239	649	798	15
11039401	Upper Freeport	37 - 85 µm	517.5	1.7	1.7	9.1	8.7	1254	650	800	15
11049401	Upper Freeport	37 - 85 µm	519.2	1.7	1.7	9.0	8.6	1245	661	800	15
11289401	Upper Freeport	> 85 µm	517.6	1.7	1.7	9.0	8.6	1249	646	795	5
12029401	Upper Freeport	> 85 µm	520.5	1.7	1.7	9.0	8.5	1245	647	791	5
12079401	Upper Freeport	> 85 µm	519.3	1.7	1.6	9.0	8.6	1250	648	793	1
10139401	Kentucky #11	raw	519.2	1.7	1.7	9.0	8.6	1249	663	813	15
10149401	Kentucky #11	raw	519.8	1.7	1.7	9.0	8.7	1250	662	817	15
09089401	Kentucky #11	raw	517.8	1.8	1.6	10.1	9.7	1190	560	655	15
09099401	Kentucky #11	raw	516.2	1.8	1.6	10.0	9.6	1180	560	680	15
10079401	Kentucky #11	raw	514.7	2.0	1.7	11.1	10.8	1125	628	759	15
10119401	Kentucky #11	raw	514.5	2.0	1.7	11.2	10.9	1118	623	744	15
09219401	Illinois #6	raw	516.4	1.8	1.7	9.9	9.5	1180	580	700	15
09239401	Illinois #6	raw	516.4	1.8	1.7	9.9	9.5	1185	595	725	15
10069401	Blank	-	512.9	1.9	1.7	10.5	10.5	1173	635	770	15

All tests were conducted with pulverized fuel flow rate of 1.1 g/min



	Upper Freeport	Illinois #6	Kentucky #11
Average Total Ash collected by horizontal probe, grams	0.02972	0.01845	0.03455
Average Total Ash collected normalized to Upper Freeport, %	100	62	116
Ash in raw coal, (grams ash/ grams as received coal), %	23.2	8.6	21.0
Ash in raw coal, normalized to Upper Freeport, %	100	37	90

Figure 5.2: Ash size distributions of Upper Freeport, Kentucky #11 and Illinois #6 coals as measured with the horizontal sampling probe

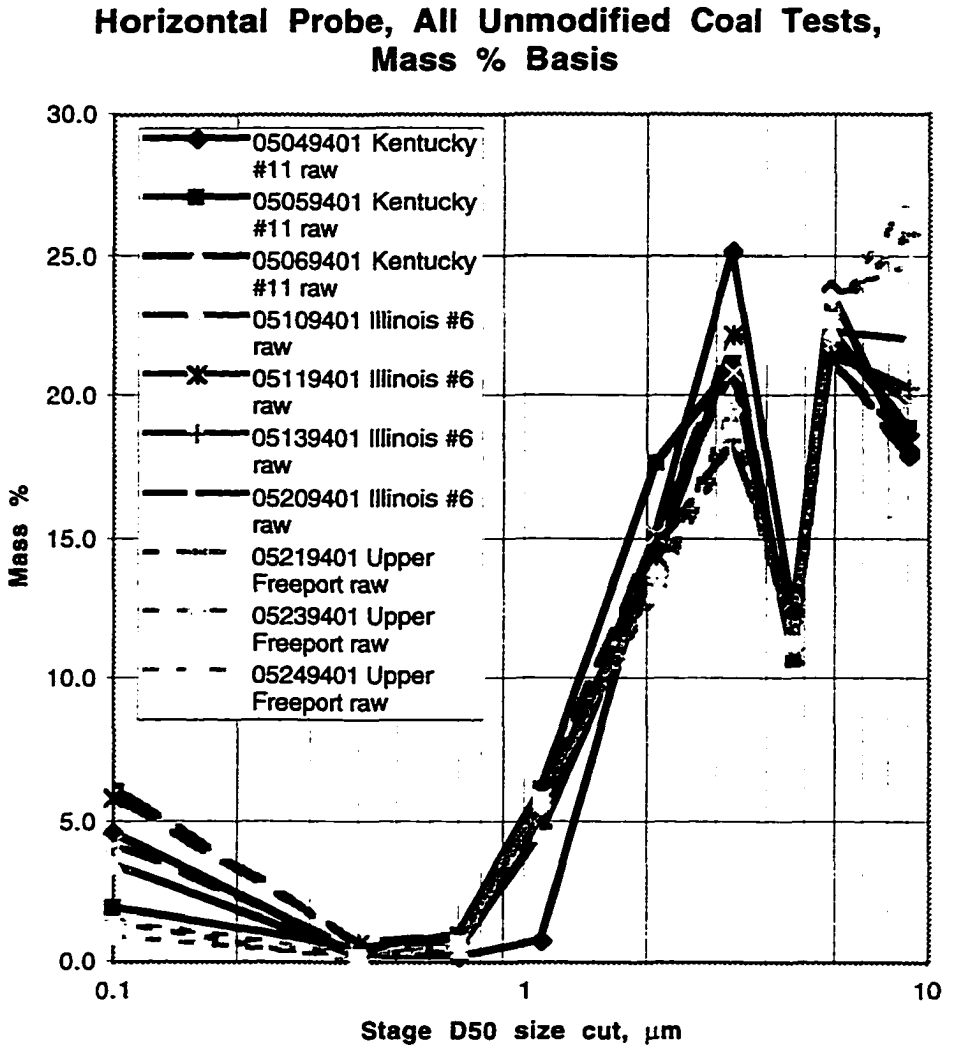


Figure 5.3: Ash size distributions of Upper Freeport, Kentucky #11 and Illinois #6 coals as measured with the horizontal sampling probe, normalized to total mass collected

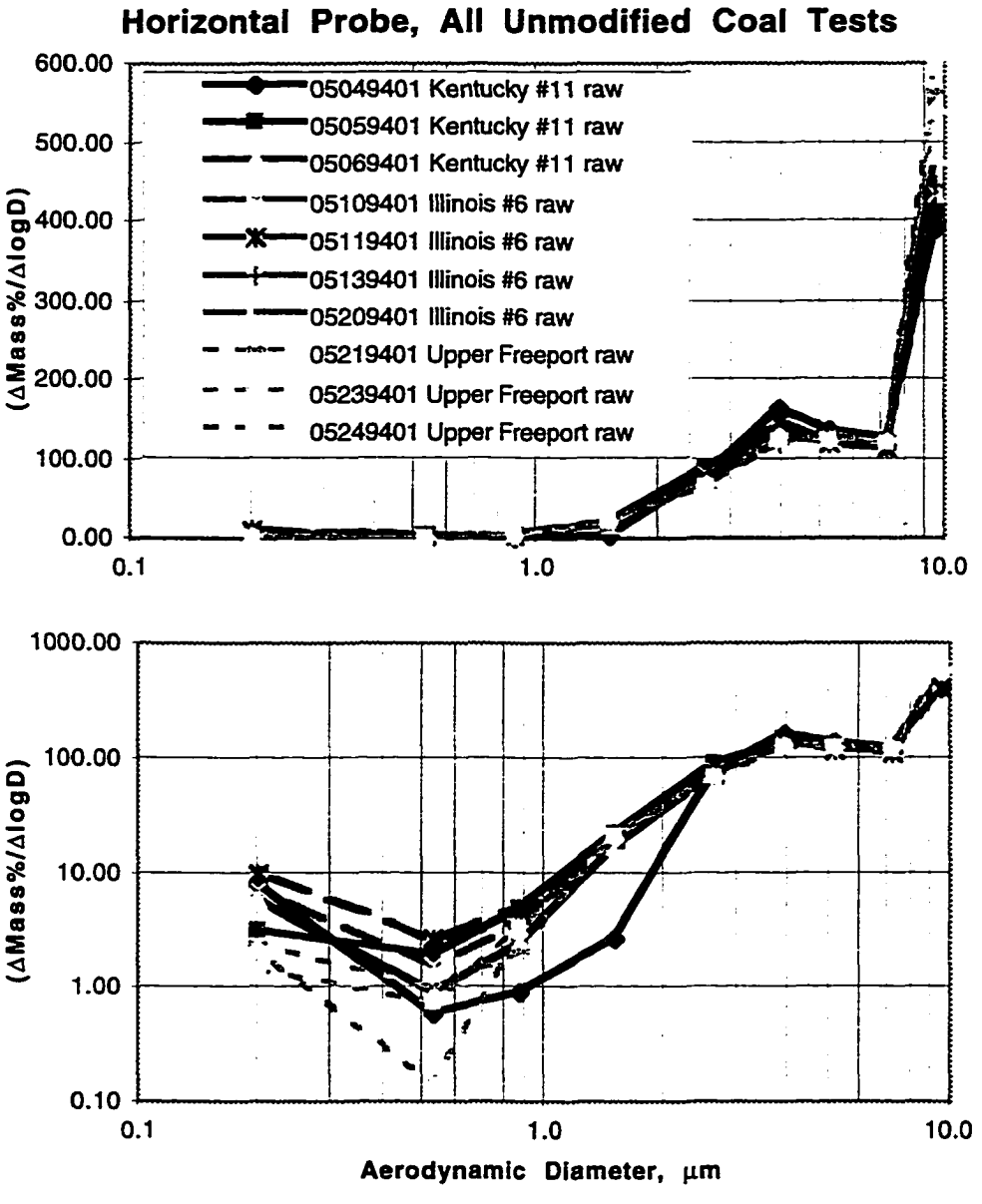


Figure 5.4: Ash size distributions of Upper Freeport, Kentucky #11 and Illinois #6 coals as measured with the horizontal sampling probe, in terms of ΔMass/ΔlogD

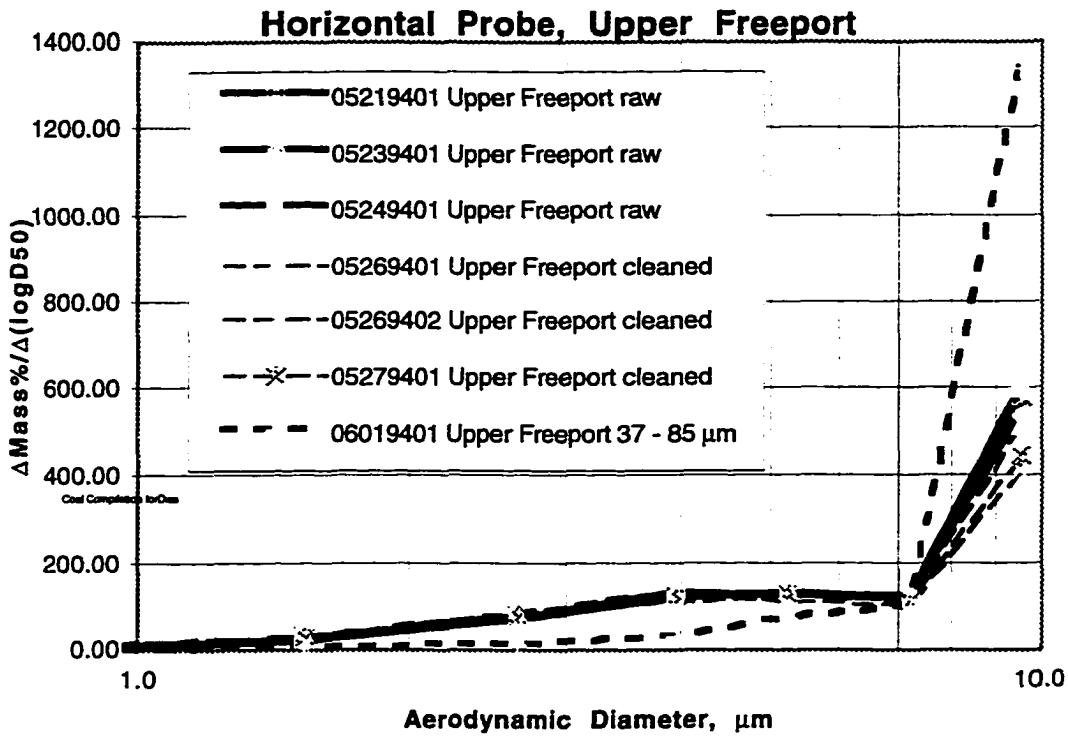


Figure 5.5: Upper Freeport ash size distribution using a horizontal sampling probe, ΔMass/ΔlogD as a function of particle diameter

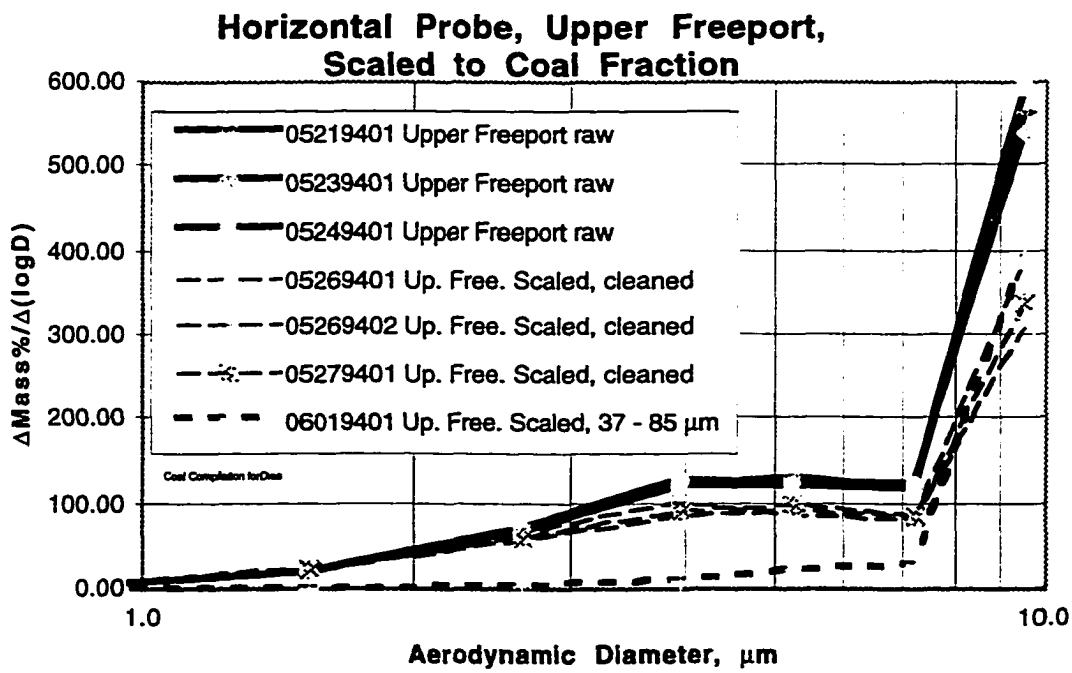


Figure 5.6: Upper Freeport ash size distribution using a horizontal sampling probe, mass percent adjusted for total fraction of original coal

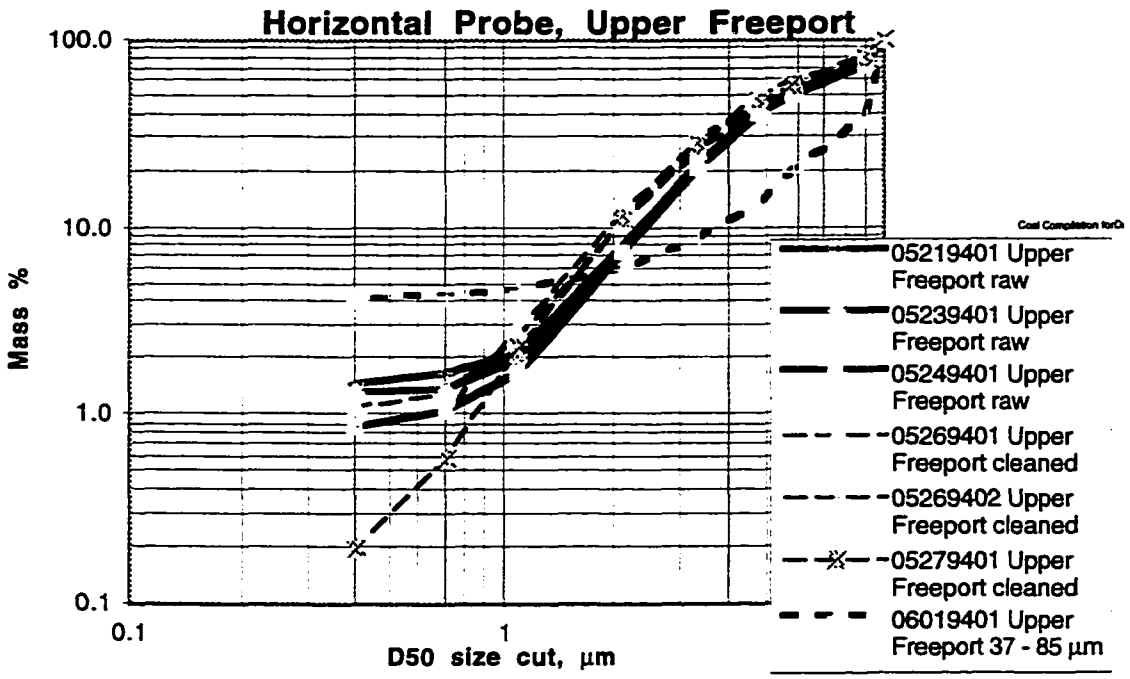


Figure 5.7: Upper Freeport cumlative ash size distribution using a horizontal sampling probe, mass percent as a function of cascade impactor size cut

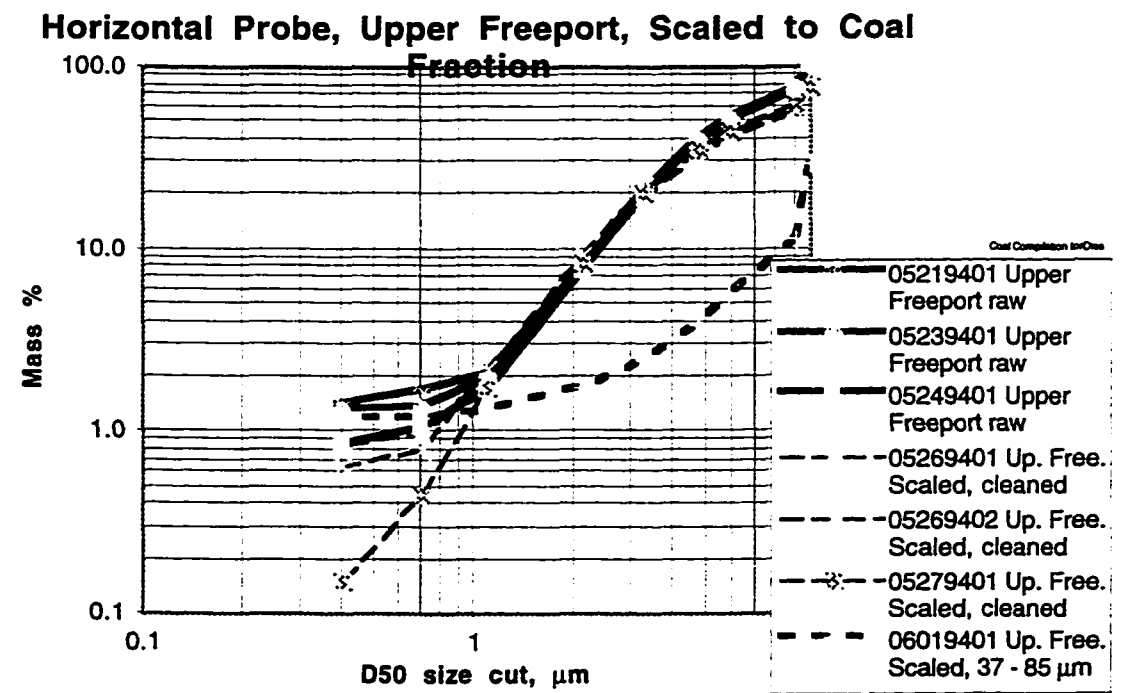


Figure 5.8: Upper Freeport cumulative ash size distribution using a horizontal sampling probe, mass percent adjusted for total fraction of original coal

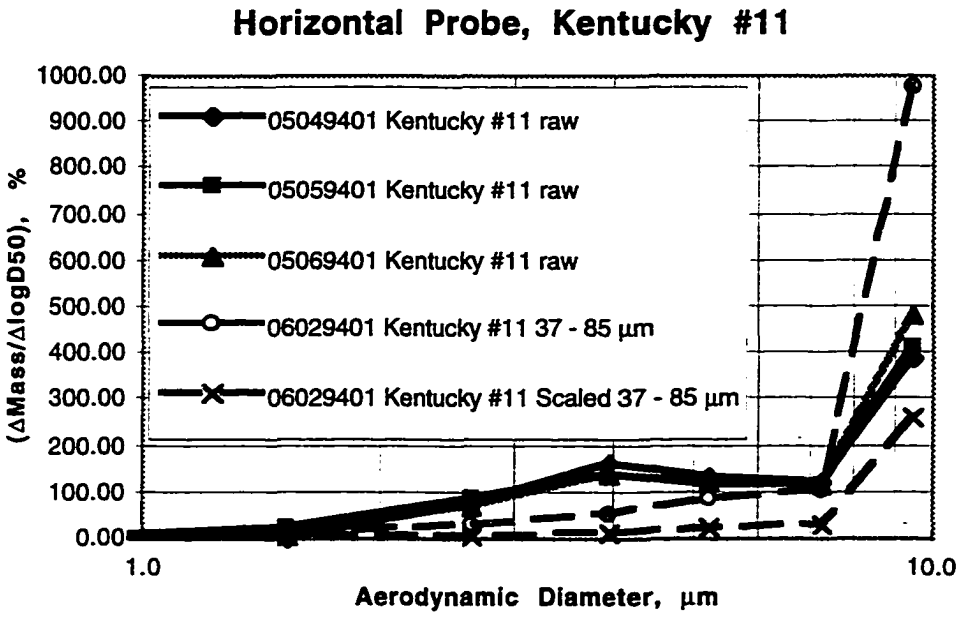


Figure 5.9: Kentucky #11, ash mass distribution using a horizontal sampling probe

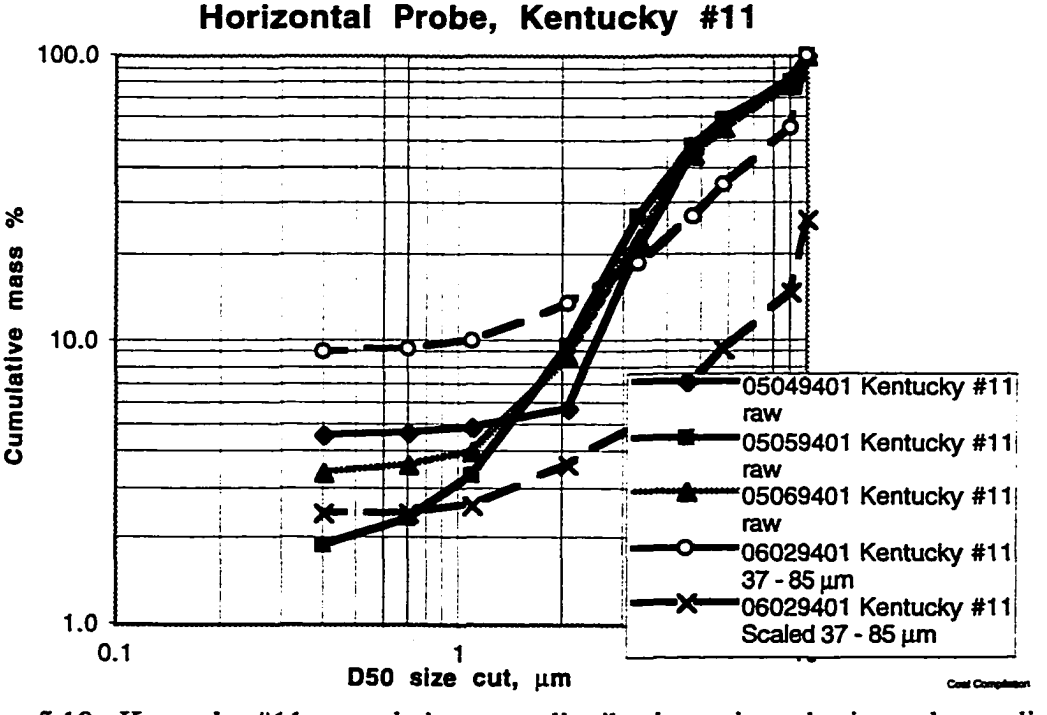


Figure 5.10: Kentucky #11, cumulative mass distribution using a horizontal sampling probe

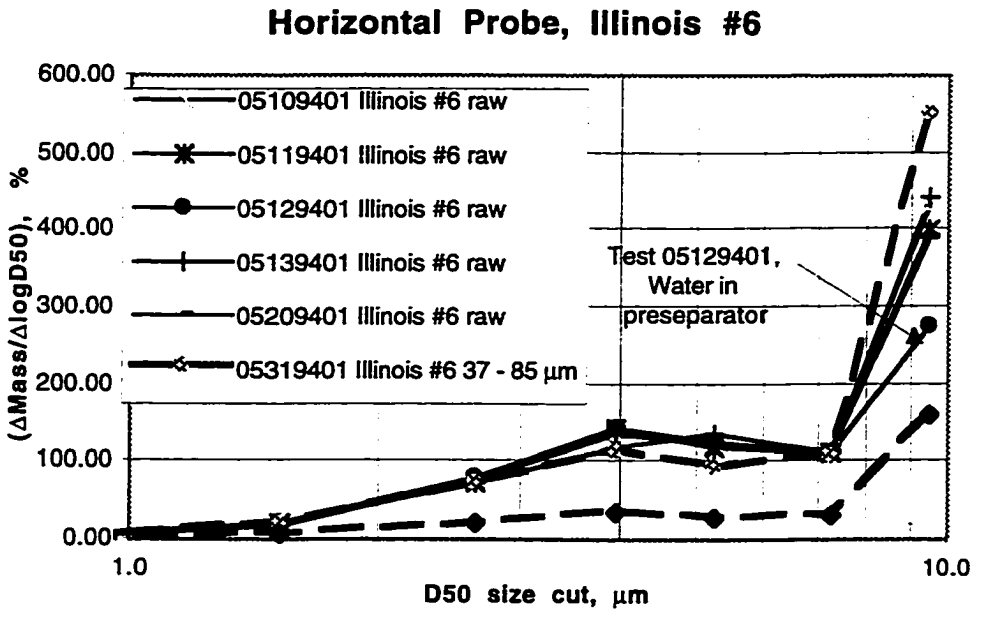


Figure 5.11: Illinois #6, ash size distribution using a horizontal sampling probe

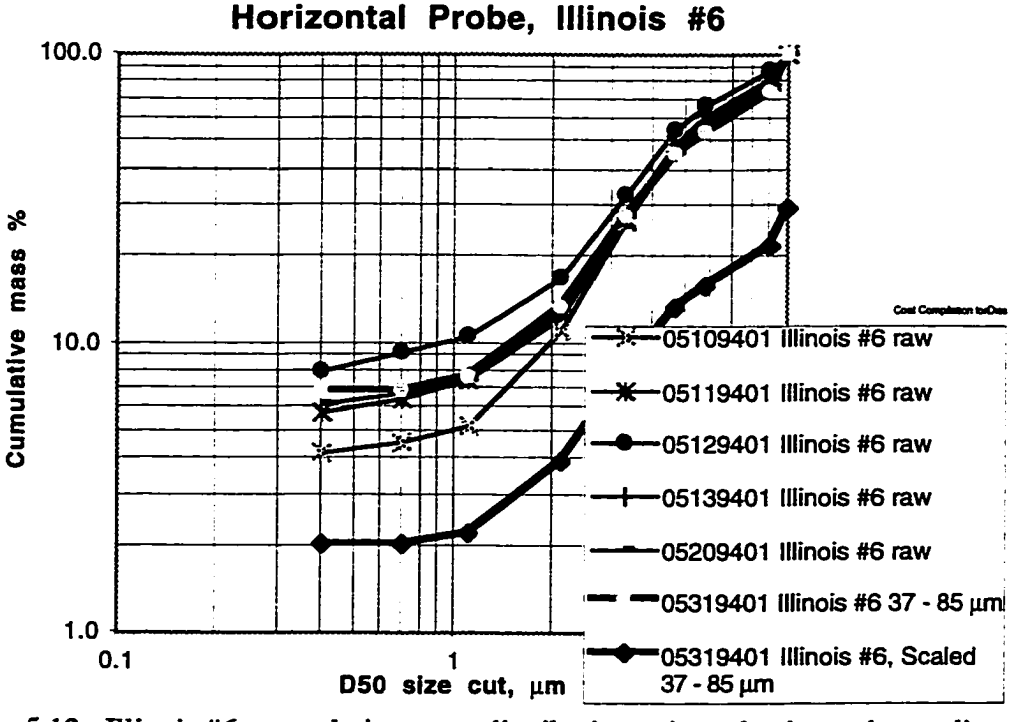


Figure 5.12: Illinois #6, cumulative mass distribution using a horizontal sampling probe

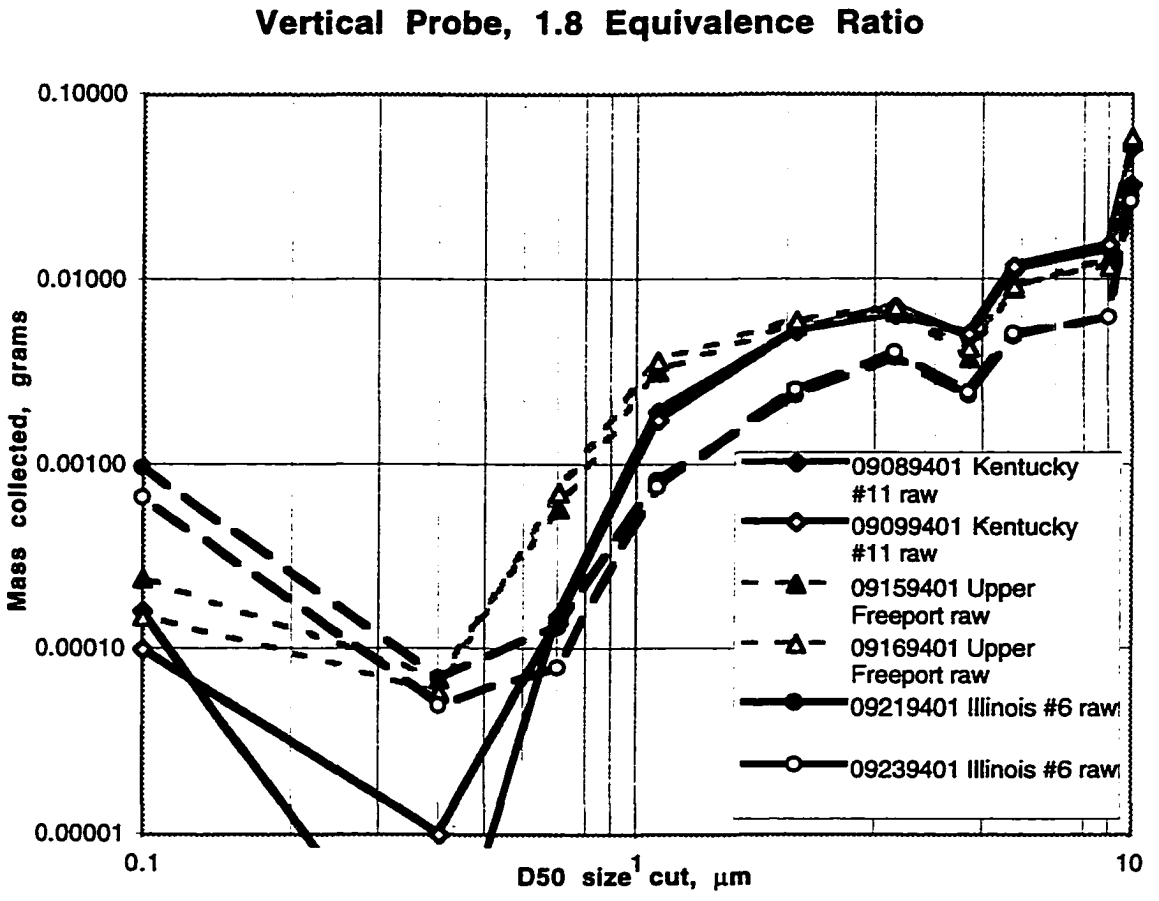


Figure 5.13: Three coals, ash collected as a function of impactor stage for 1.8 furnace equivalence ratio

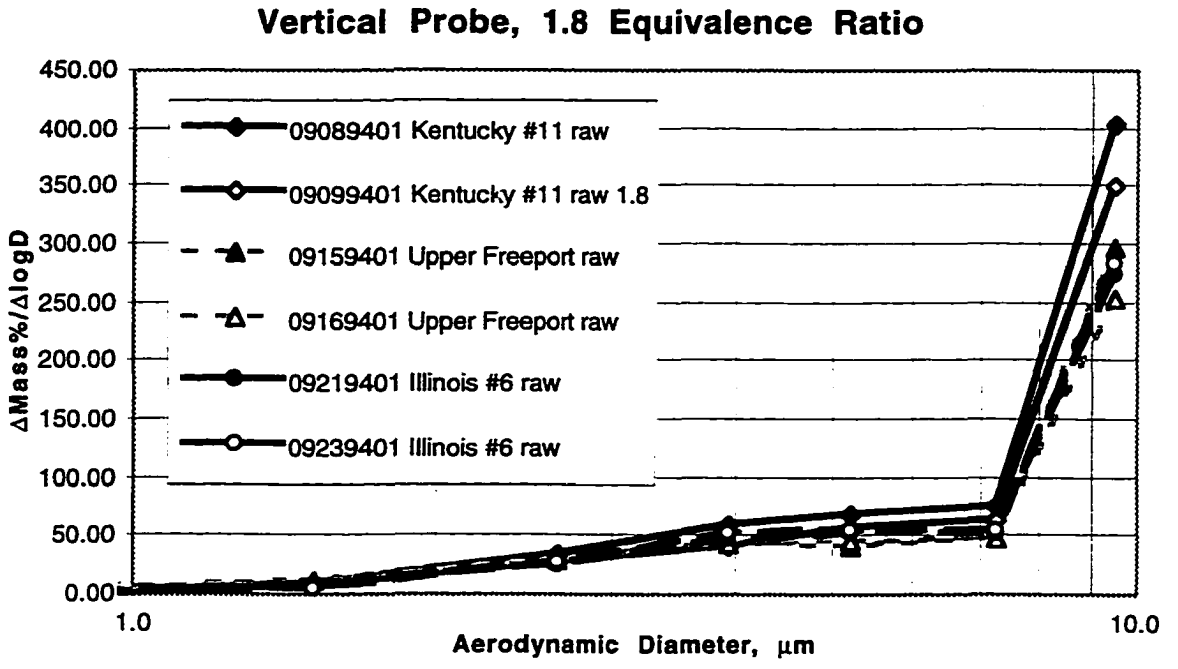


Figure 5.14: Three coals, ash collected expressed as ΔMass%/ΔlogD for 1.8 furnace equivalence ratio

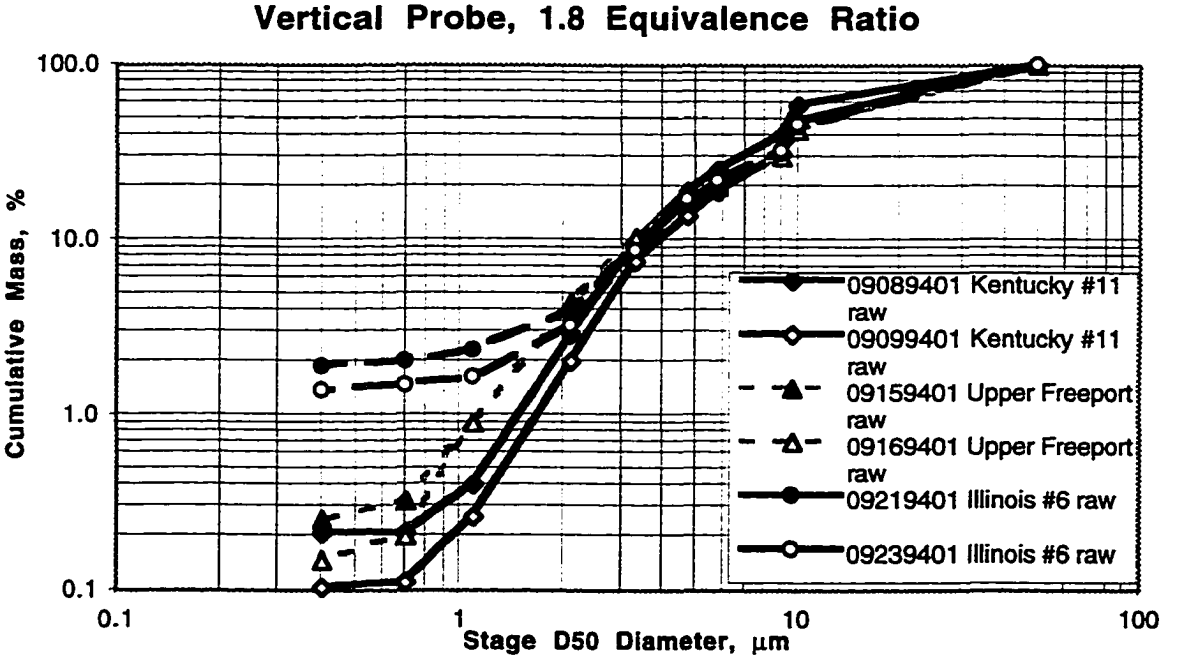


Figure 5.15: Three coals, ash collected expressed as cumulative mass for 1.8 furnace equivalence ratio

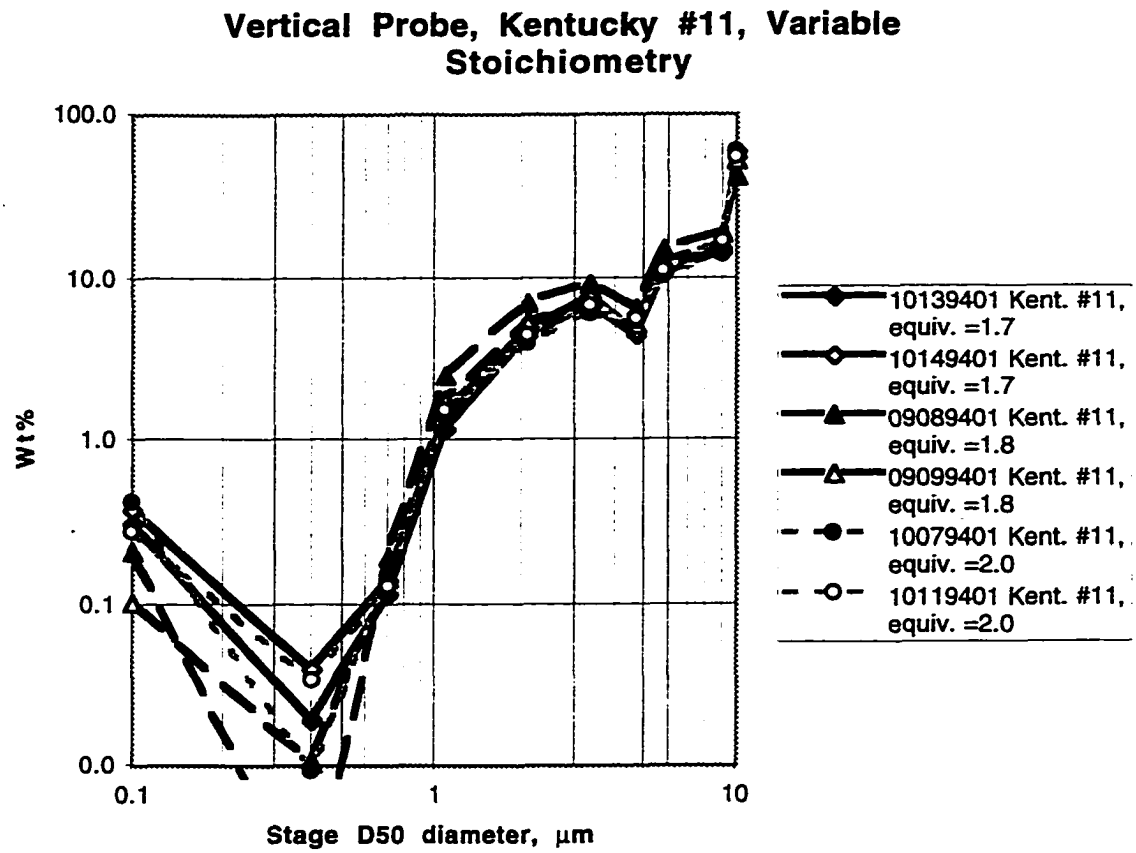


Figure 5.16: Kentucky #11, the effect of furnace stoichiometry on ash yield

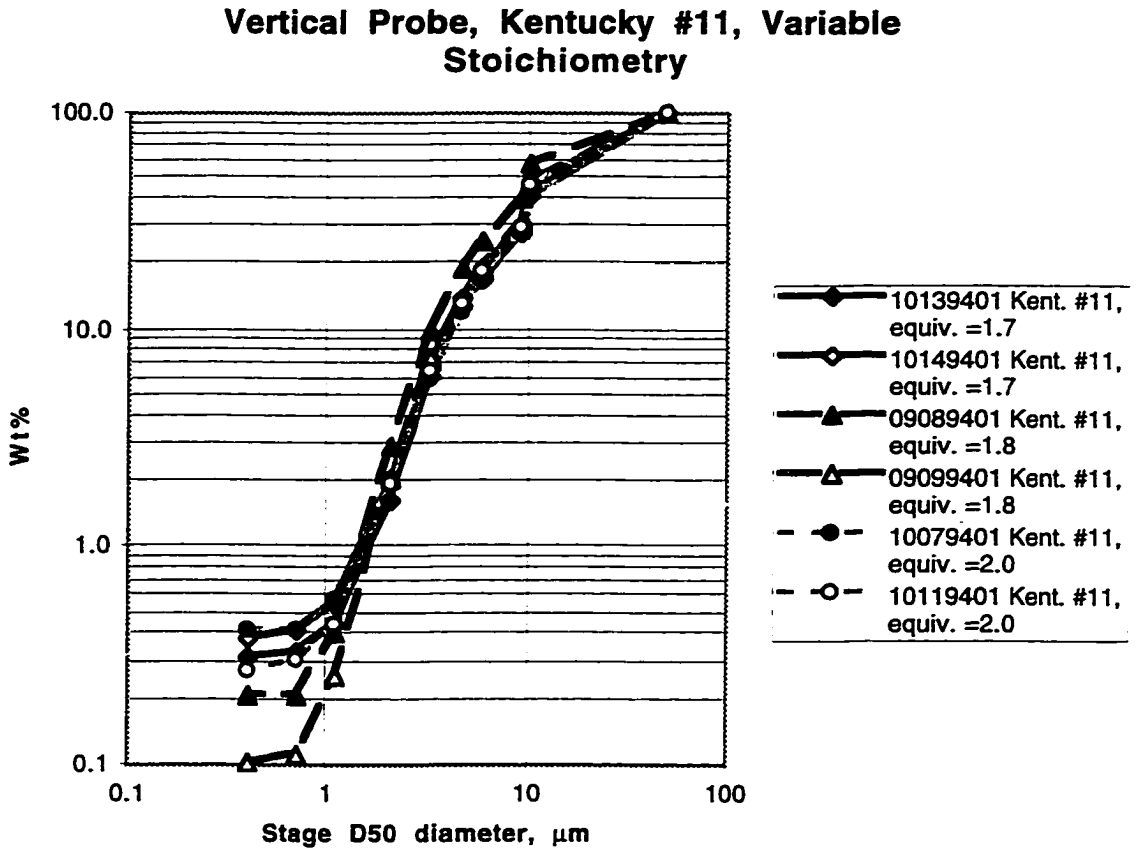


Figure 5.17: Kentucky #11, ash collected expressed as cumulative mass

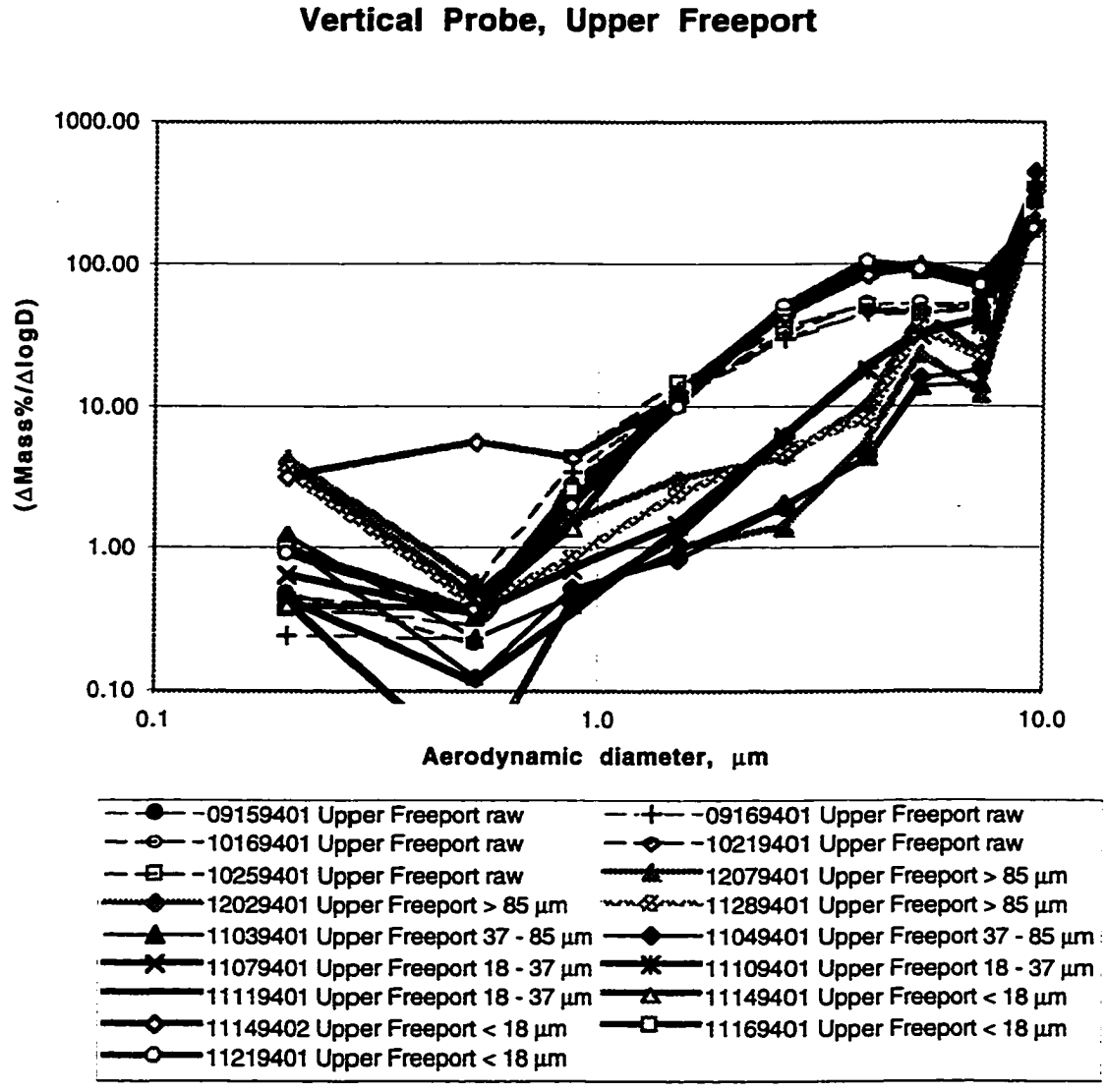


Figure 5.18: All Upper Freeport tests conducted with the vertical probe

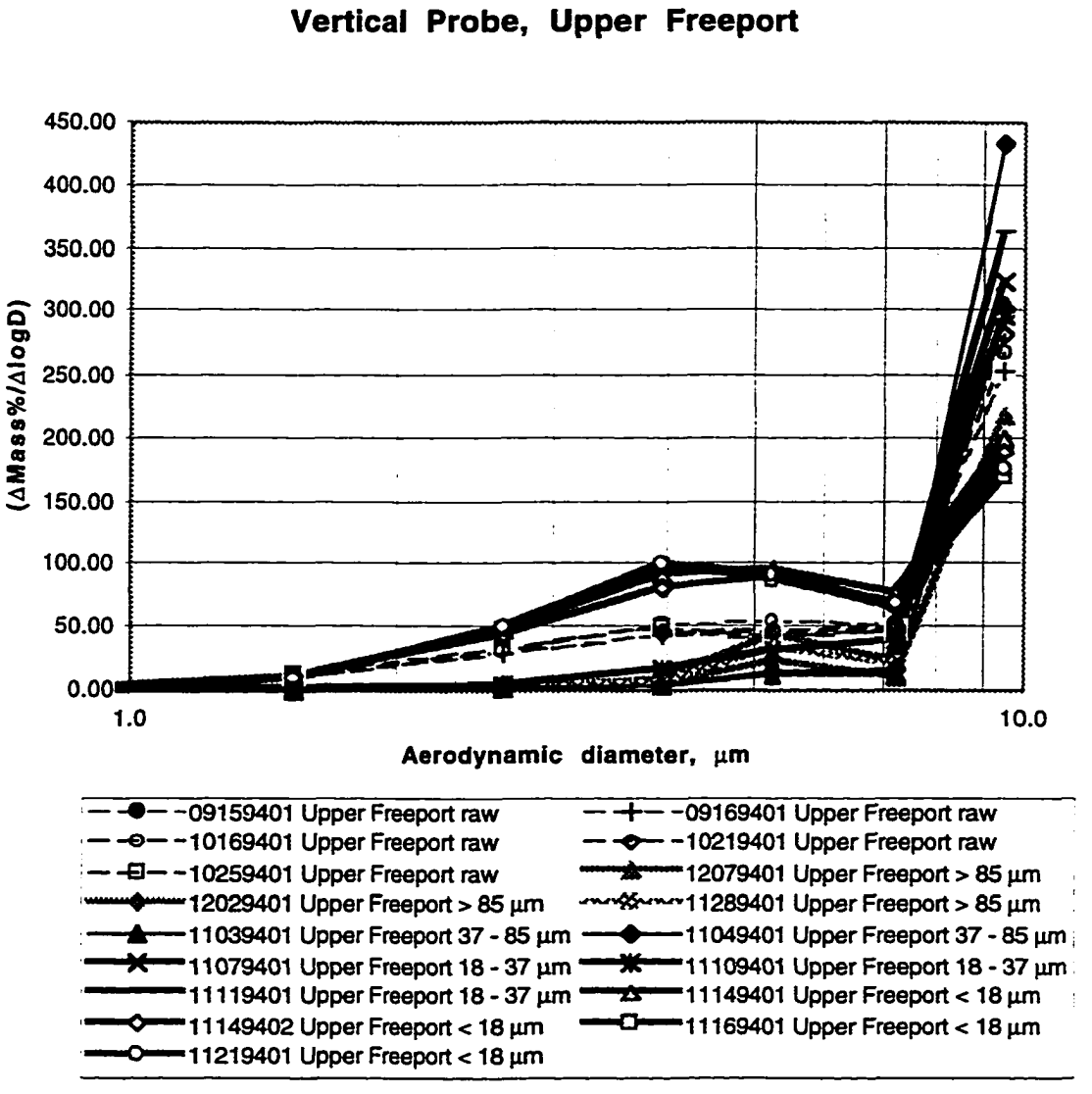


Figure 5.19: All Upper Freeport test with the vertical probe with ash yield expressed as ΔMass%/dlogD

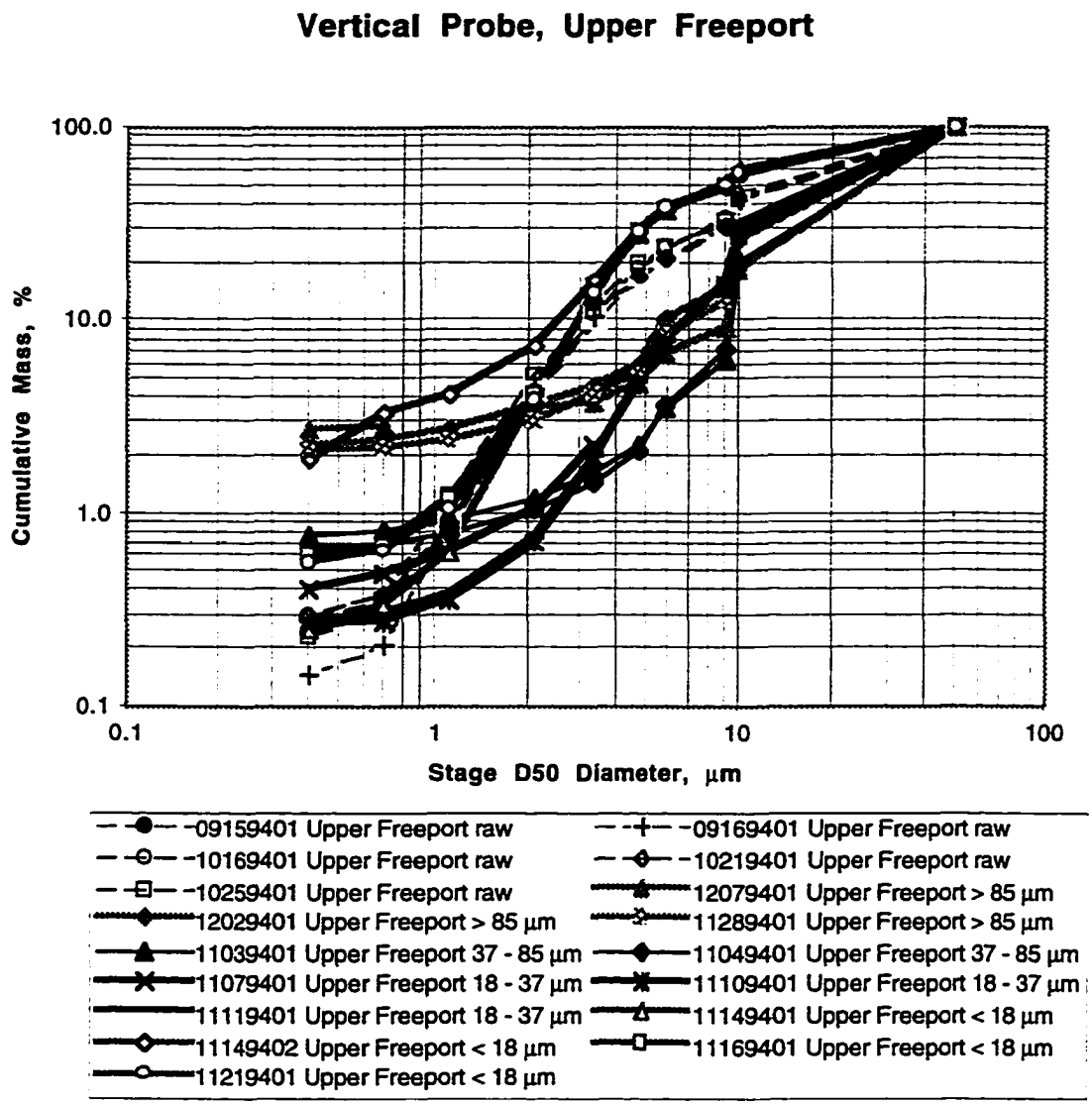


Figure 5.20: All Upper Freeport test with the vertical probe with ash yield expressed as cumulative mass

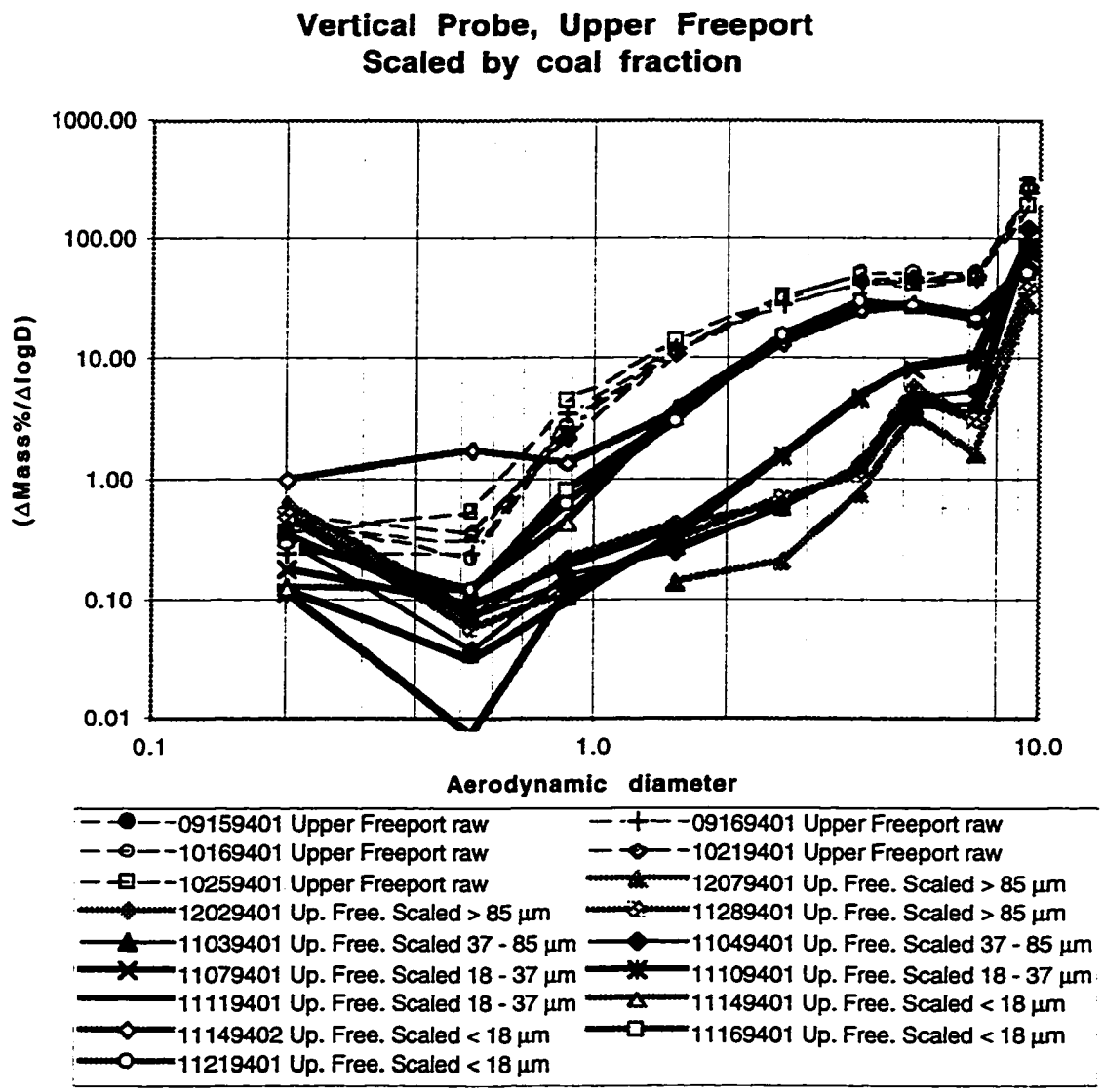


Figure 5.21: Upper Freeport tests scaled by coal fraction, expressed as ΔMass%/dlogD on logarithmic scale

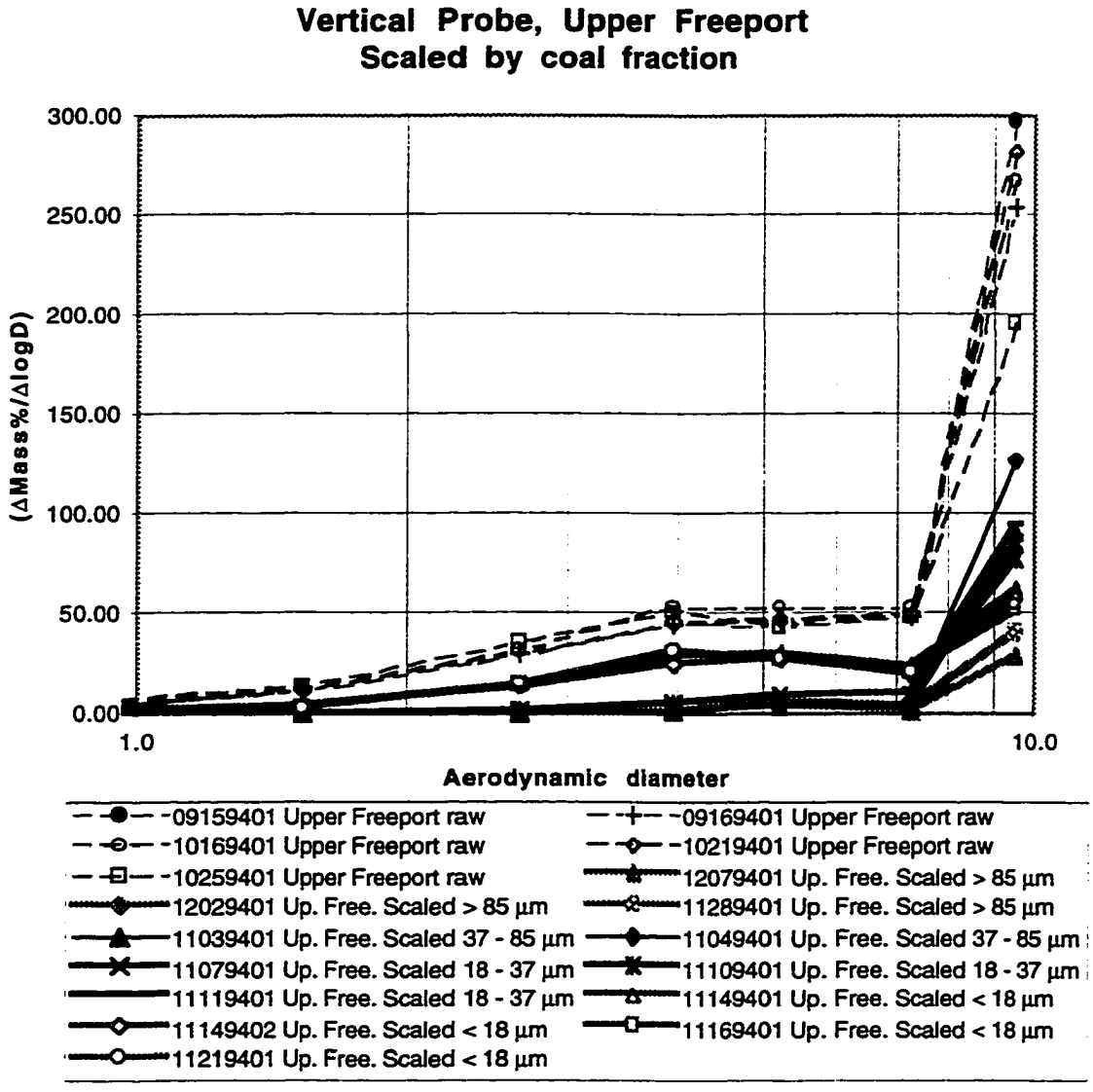


Figure 5.22: Upper Freeport tests scaled by coal fraction, expressed as ΔMass%/dlogD

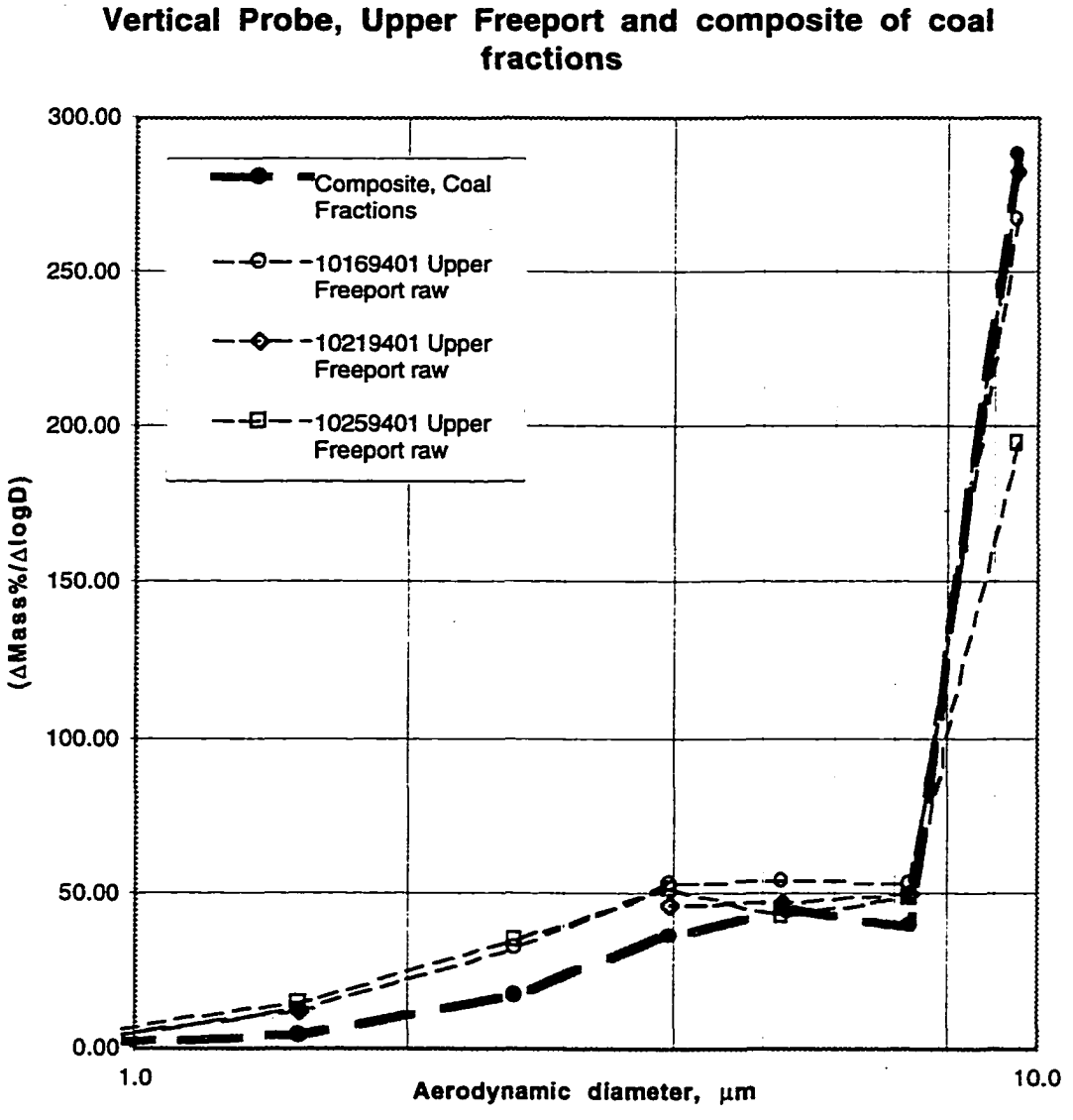


Figure 5.23: Upper Freeport raw coal ash distribution compared to the sum of the sized coal, expressed as ΔMass%/dlogD

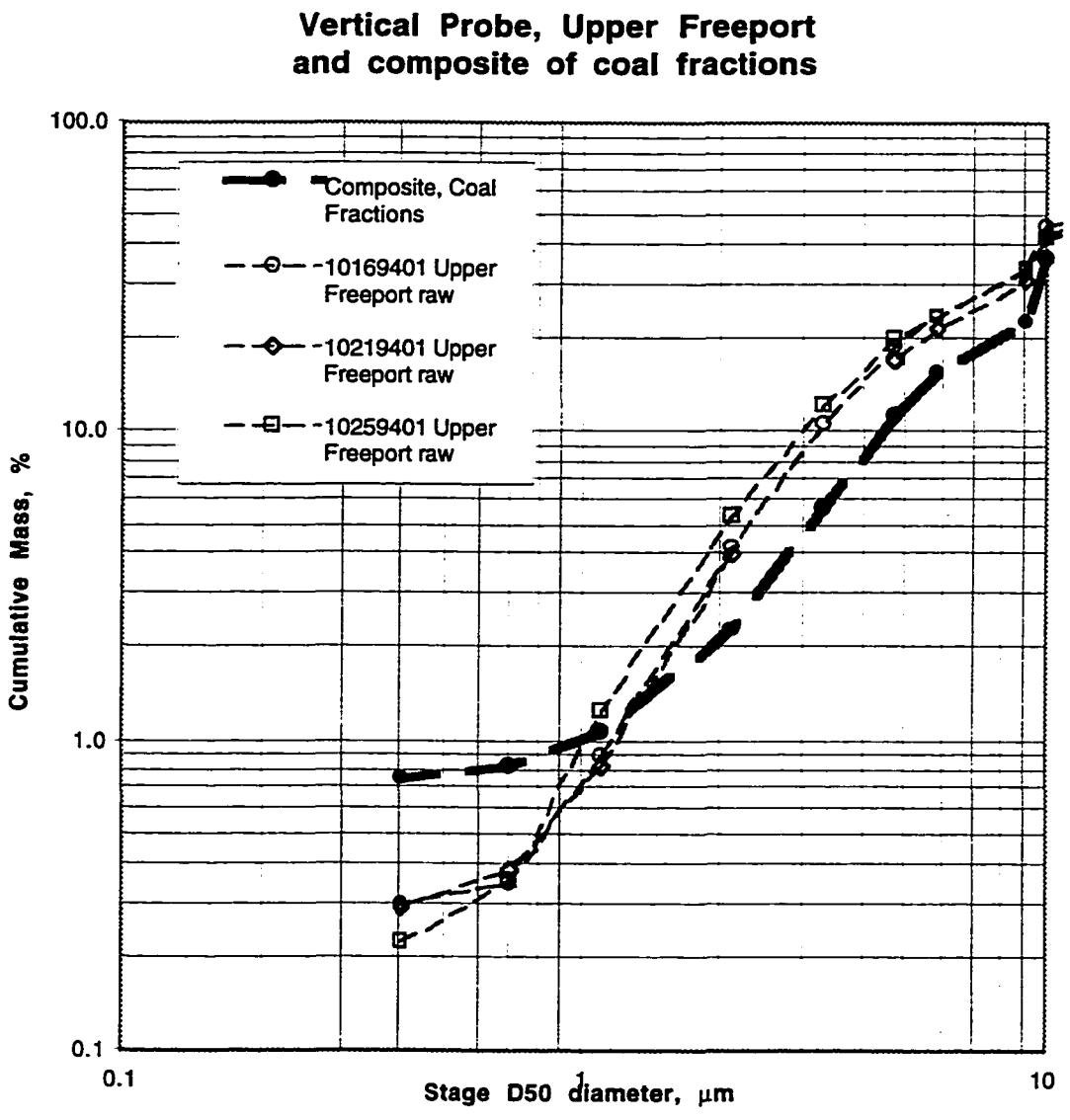


Figure 5.24: Upper Freeport raw coal ash distribution compared to the sum of the sized coal, expressed as cumulative mass

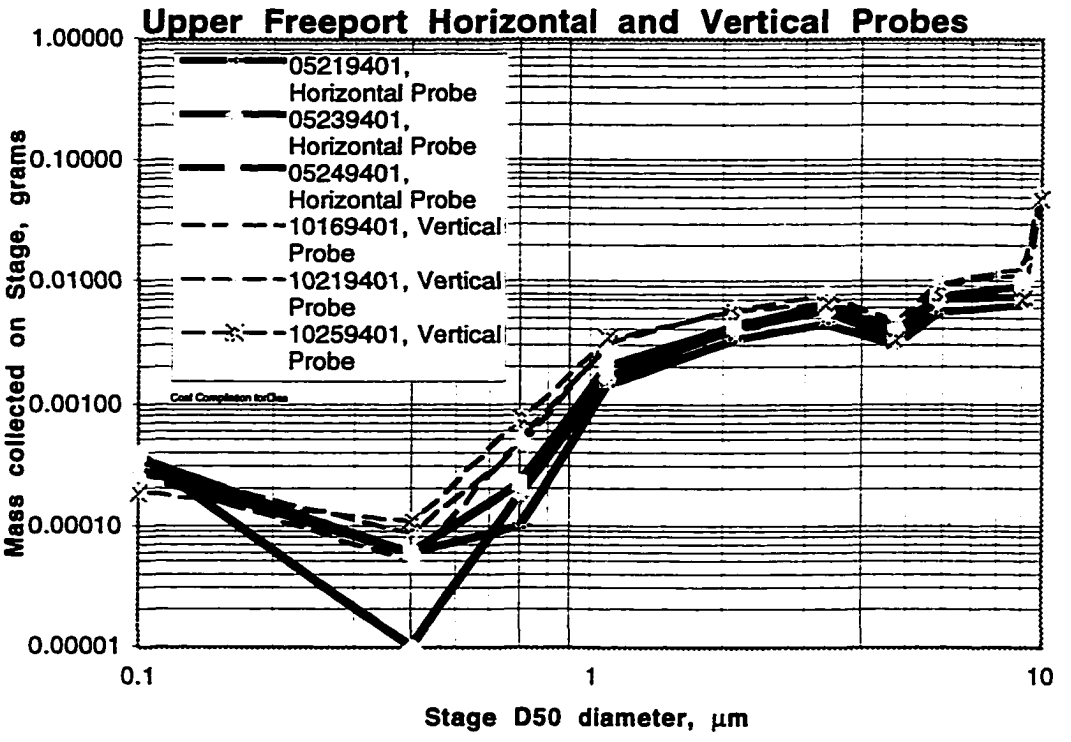


Figure 5.25: Upper Freeport, comparison of ash yields between horizontal and vertical probe tests

Table 5.7: Composition of artificial char

Component:	Sucrose	Carbon Black	Sodium	Pyrite	Bentonite	Calcite
Chemical Formula:	$C_{12}H_{22}O_{11}$	C	$Na_2C_2O_4$	FeS_2	*see note	$CaCO_3$
Average particle diameter, µm :	soluble	0.04 to 0.06 µm	soluble	9 to 10 µm	0.9 to 1 µm	15 to 17 µm
Char Name	grams	grams	grams	grams	grams	grams
Suc50/C50	50	50	0.5			
Suc75/C25	75	25	0.5			
Pyr 0.93 g	50	50	0.5	0.925		
Pyr 1.85 g	50	50	0.5	1.85		
Pyr 2.78 g	50	50	0.5	2.775		
Pyr 3.70 g	50	50	0.5	3.7		
Ben 1.25 g	50	50	0.5		1.25	
Ben 2.50 g	50	50	0.5		2.5	
Ben 3.75 g	50	50	0.5		3.75	
Ben 5.00 g	50	50	0.5		5	
Cal 0.25 g	50	50	0.5			0.25
Cal 0.50 g	50	50	0.5			0.5
Cal 0.75 g	50	50	0.5			0.75
Cal 1.00 g	50	50	0.5			1
* Bentonite is mainly montmorillonite ($(1-x)Al_2O_3 \cdot x(MgO,Na,O)\cdot 4SiO_2\cdot H_2O$)						

Table 5.8: Artificial char test matrix

Test Number	Char Name	A/F Equiv. (w/o char)	Furnace Flow Rate, grams	Dry O2, % (w/o char)
03019501	Ben 1.25 g	1.47	634	7.7
03139501	Ben 1.25 g	1.47	631	7.8
03029501	Ben 2.50 g	1.45	621	7.5
03149501	Ben 2.50 g	1.47	627	7.8
03039501	Ben 3.75 g	1.44	625	7.5
03149502	Ben 3.75 g	1.48	627	7.9
02279501	Ben 5.00 g	1.44	621	7.4
03149503	Ben 5.00 g	1.46	628	7.7
03129501	Cal 0.25 g	1.46	630	7.7
03079502	Cal 0.50 g	1.45	629	7.6
03079501	Cal 0.75 g	1.46	631	7.7
03069502	Cal 1.00 g	1.46	630	7.7
02219501	Pyr 0.93 g	1.44	625	7.5
03179502	Pyr 0.93 g	1.42	617	7.3
03039502	Pyr 1.85 g	1.44	625	7.5
03179501	Pyr 1.85 g	1.46	628	7.7
03069501	Pyr 2.78 g	1.46	630	7.7
03169501	Pyr 2.78 g	1.47	631	7.8
03169504	Pyr 3.70 g	1.47	627	7.8
02239501	Pyr 3.70 g	1.44	622	7.5
02149501	Suc50/C50	1.42	617	7.3
03129502	Suc50/C50	1.43	618	7.4
02069501	Suc50/C50	1.63	521	8.9
02179501	Suc75/C25	1.44	622	7.5
03169503	Suc75/C25	1.45	628	7.6

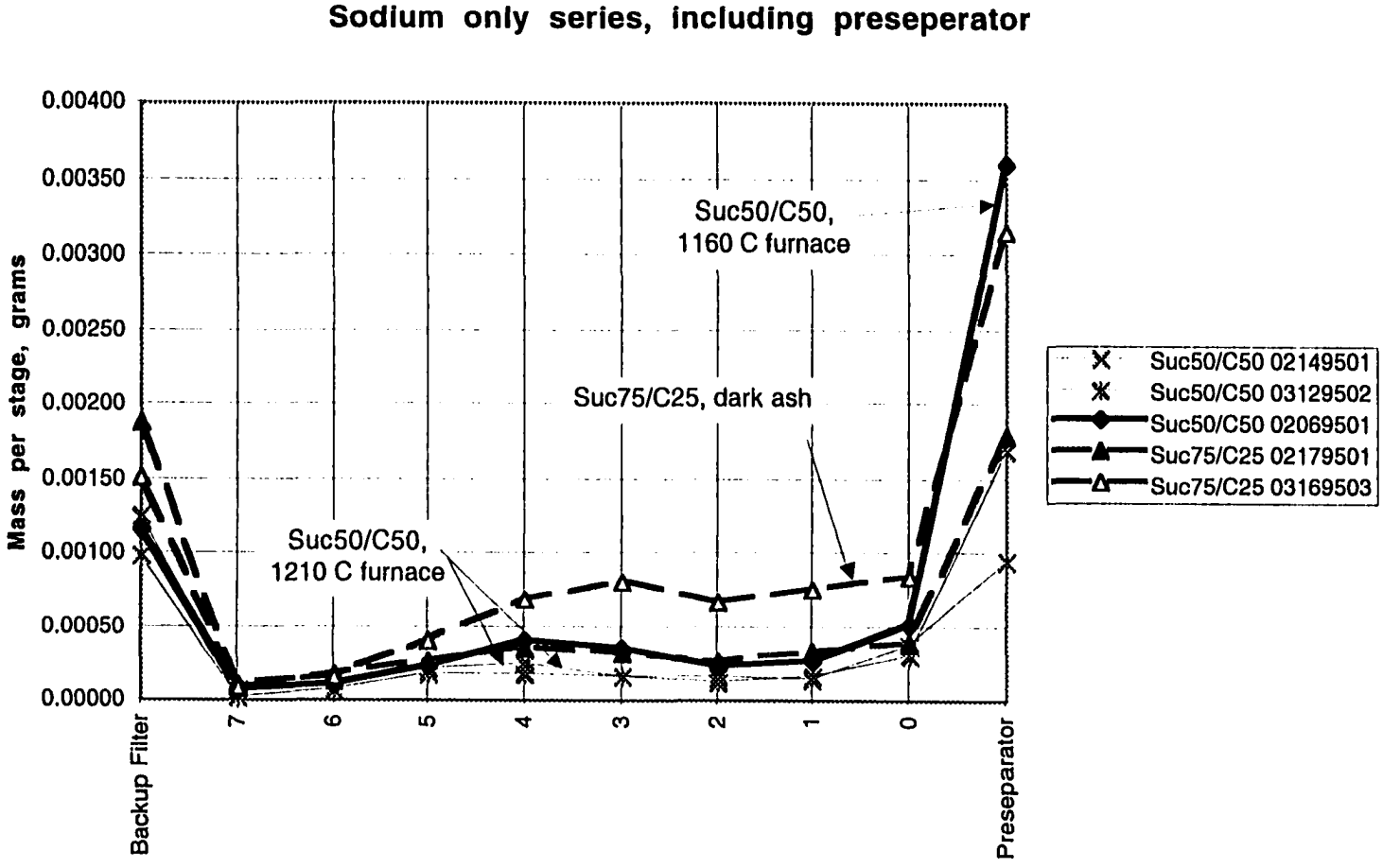


Figure 5.26: Artificial char with sodium doping only, ash mass distribution by cascade impactor stage

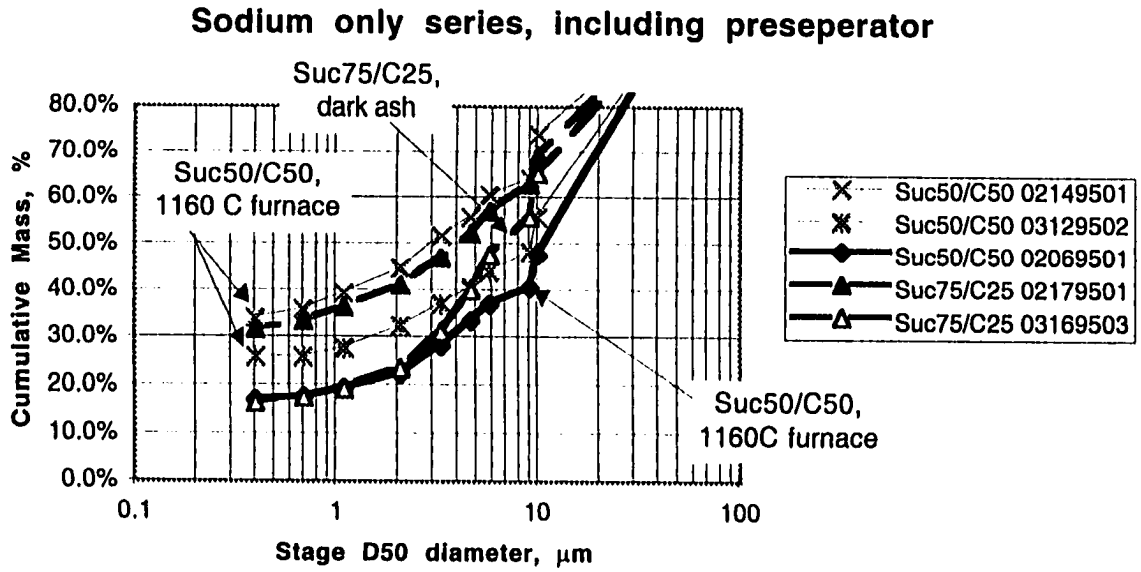


Figure 5.27: Artificial char with sodium doping only, cumulative mass

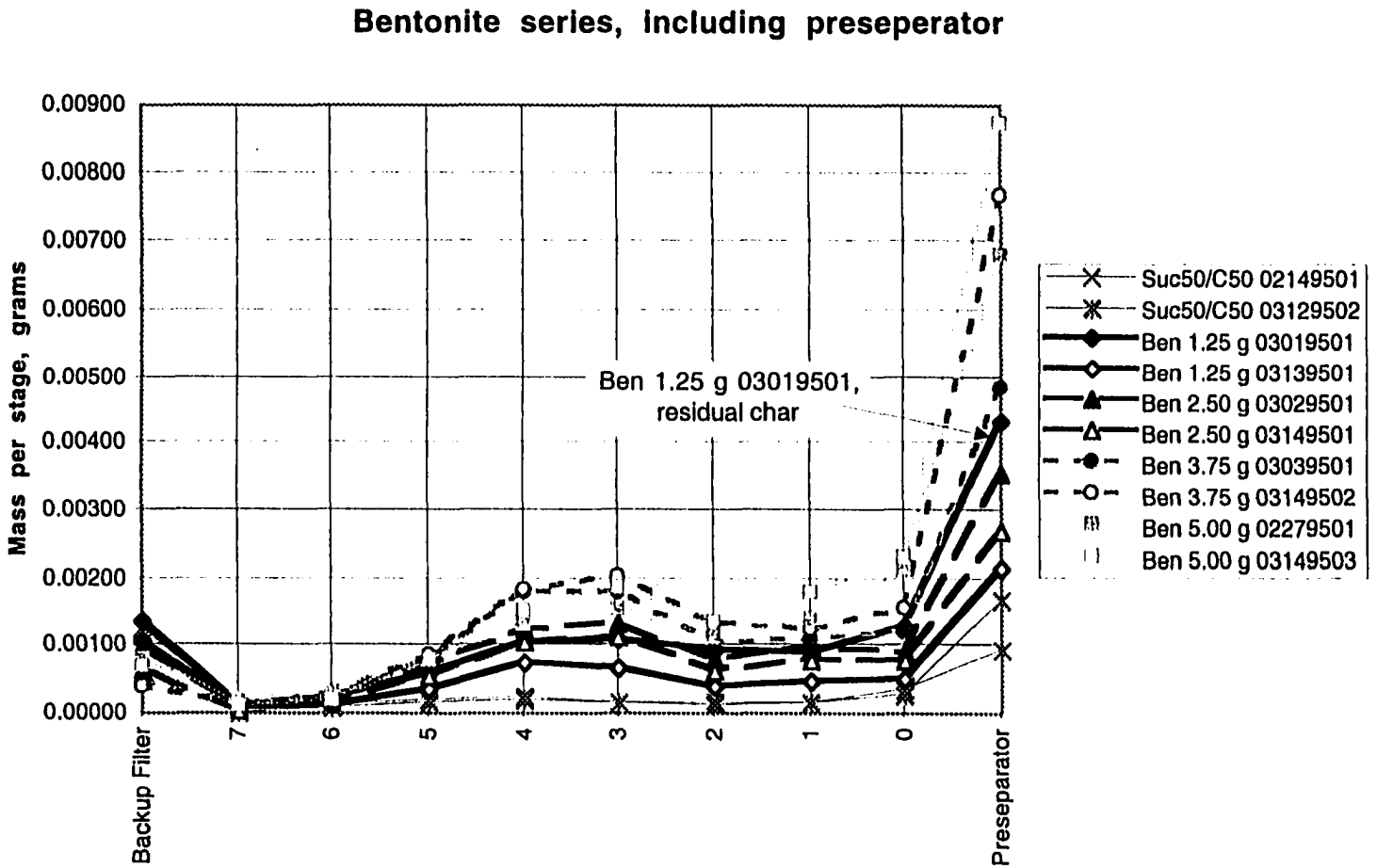


Figure 5.28: Artificial char with bentonite/sodium doping, ash mass distribution by cascade impactor stage

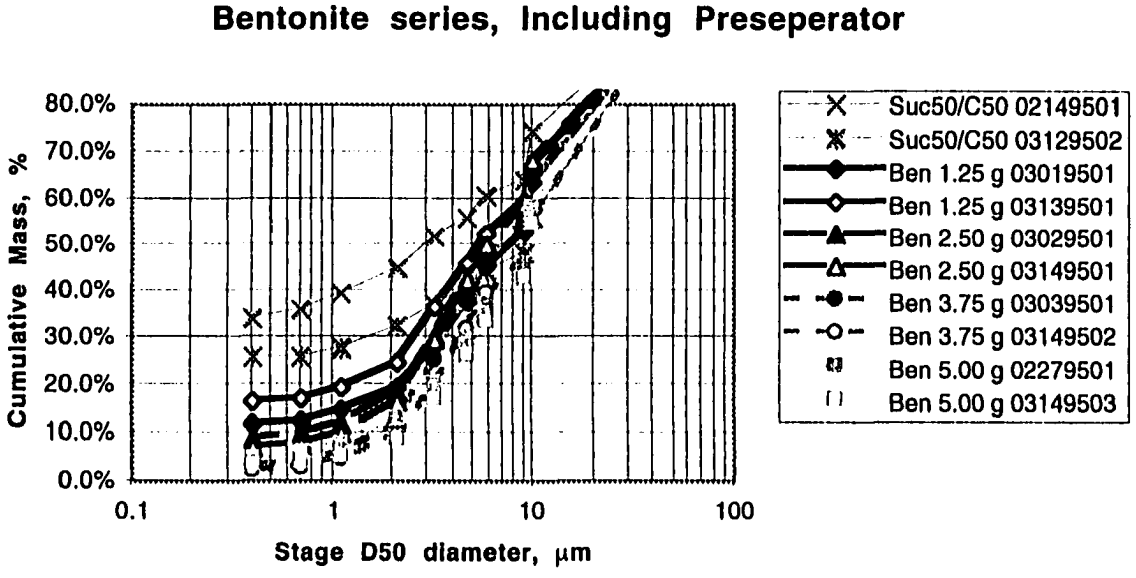


Figure 5.29: Artificial char with bentonite/sodium doping, cumulative mass

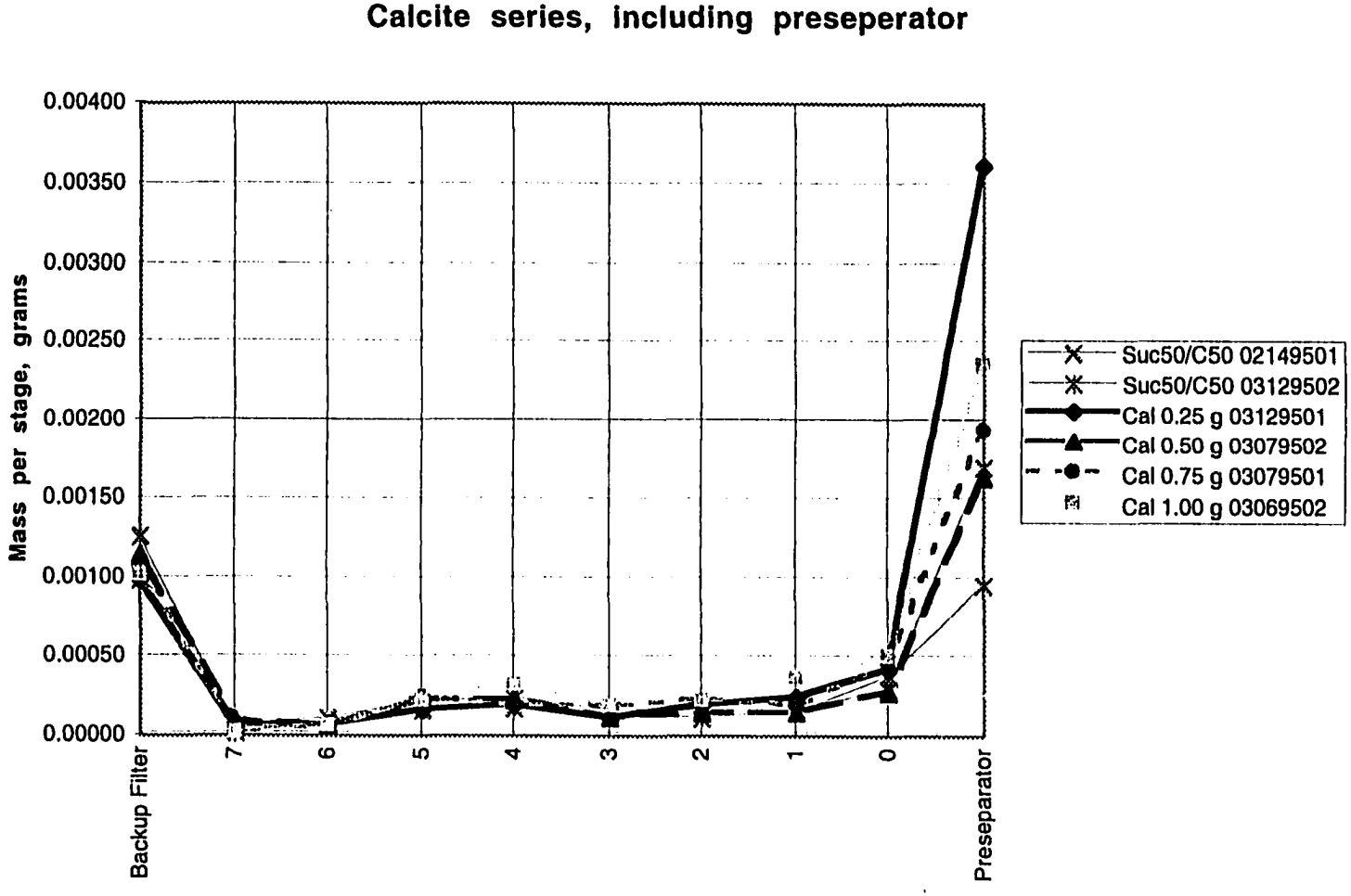


Figure 5.30: Artificial char with calcium/sodium doping, ash mass distribution by cascade impactor stage

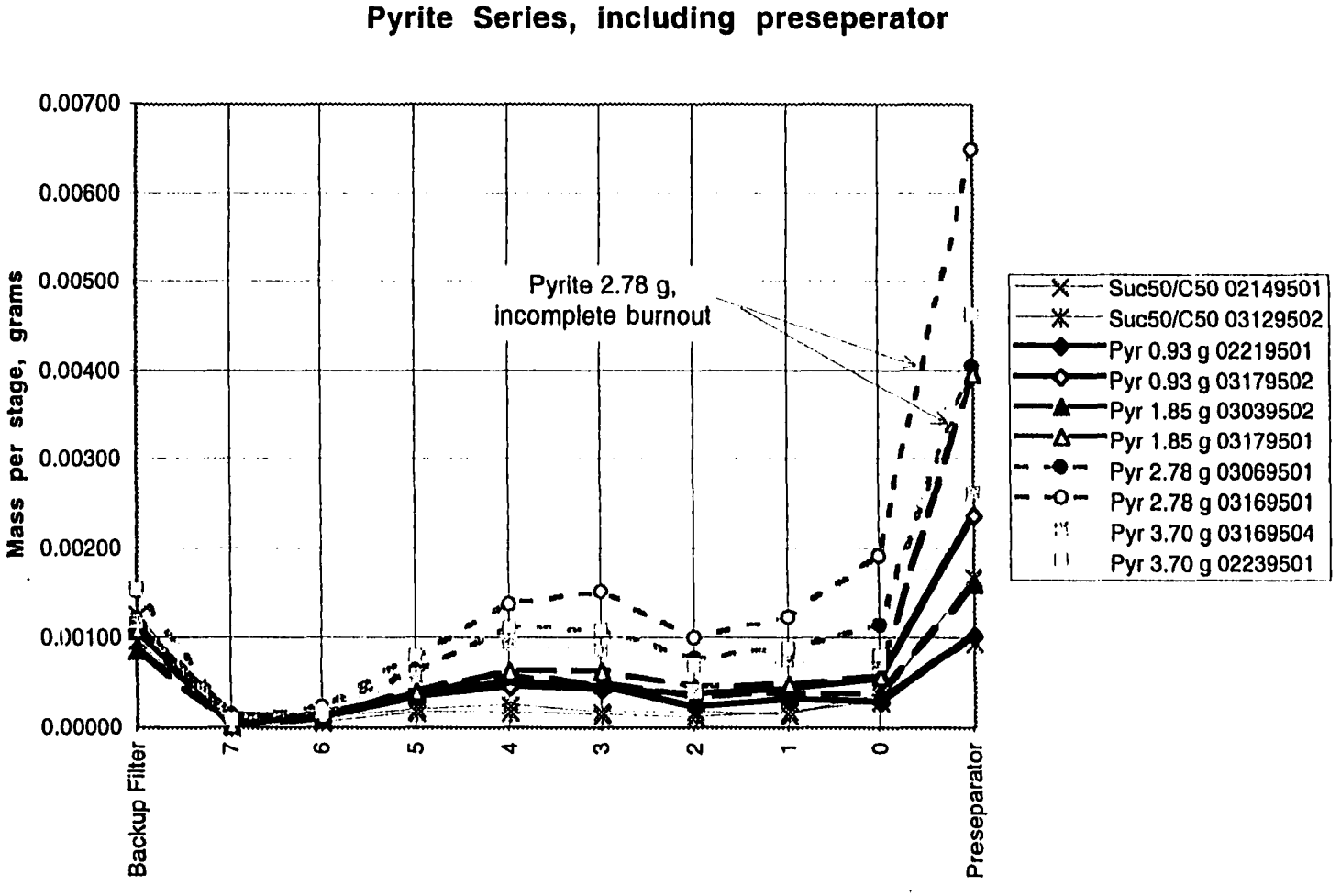


Figure 5.31: Artificial char with pyrite/sodium doping, ash mass distribution by cascade impactor stage

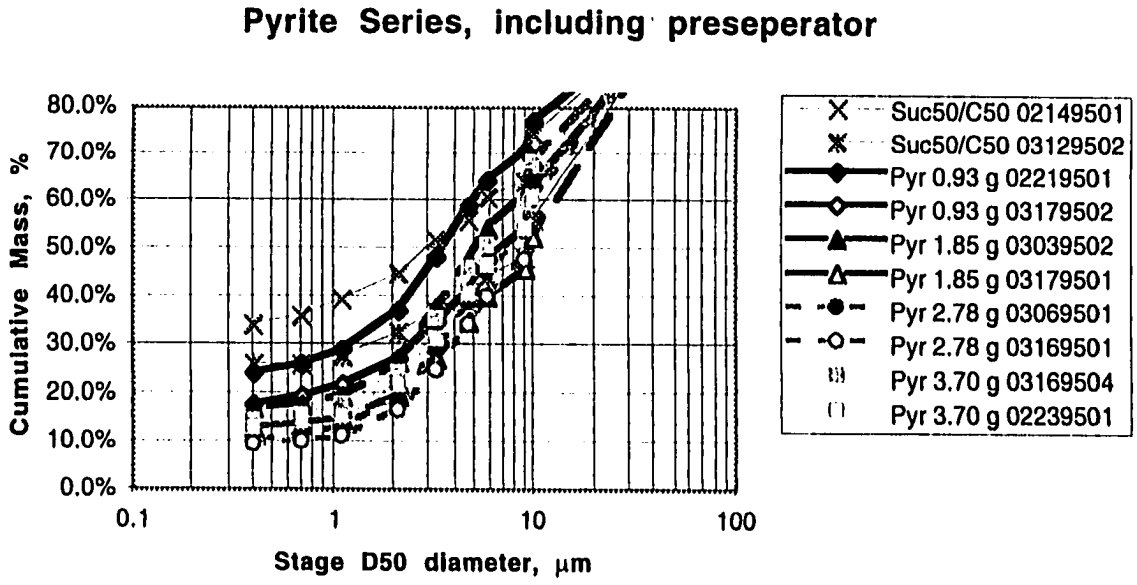


Figure 5.32: Artificial char with pryrite/sodium doping, cumulative mass

MINERAL BEHAVIOR IN SAWDUST/SANDERDUST COMBUSTION

Sawdust and sanderdust are byproducts of particle board and strand board manufacture. Rather than landfill this resource, efficient facilities use this material as fuel for some plant operations, such as chip drying. Unfortunately, experience has shown that the resulting ash plays a role in the fouling of downstream equipment, resulting in high maintainance for particulate matter collection devices (*e.g.* ESPs), and volatile organic compound removal devices (e.g. thermal oxidizers).

In this chapter, we examine the ash size distributions and chemical compositions resulting from the firing of these sawdust and sanderdust fuels in a laboratory scale furnace.

6.1 Fuel Properties and Preparation

6.1.1 Sawdust/sanderdust Characterization

The present research examines four sanderdust/sawdust fuels. Various wood-products manufacturing facilities supplied the samples, which were selected to be representative of typical fuels used in suspension burners at the given facility. Ultimate analyses, mineral elemental analyses via atomic absorption, and total halogens analyses were performed by an independent laboratory and are summarized in Table 6.1. The alkaline earth element calcium and the alkali elements sodium and potassium were the primary metals detected. Note that Fuels 1 and 2 have an order of magnitude larger halogen content than Fuels 3 and 4. Significant differences in nitrogen, alkali and halogen content between the fuels are likely the result of manufacturing additives (*i.e.* urea formaldehyde, phenol formaldehyde, and MDI-isocyanide based binding resins), parent wood variety, and/or other processing sources. Research by Miles (1998, personal communication) has shown that binding resins can contain sufficient alkali to cause ash-related problems in industrial burners.

Analysis of Kentucky #11, a pulverized sub-bituminous coal, is also shown on Table 6.1 for comparison. Note that ash yield is significantly higher for coal. Si, Fe and Al are primary elements present in the coal ash, all of which are not readily vaporized in their original mineral forms. Ash-forming components are shown in Figure 6.1, expressed in

terms of mass. Sulfur content is included because it is capable of joining the ash material in the form of a sulfate, as discussed in detail later.

Brief descriptions of the physical properties of the four fuels tested are given below, including their "As-Received" size distributions. The fuels were size classified using US Standard sieve sizes in a column with manual agitation. A cumulative size distribution for each fuel is shown in Figure 6.2. Figure 6.3 shows the size distribution in the form of Δmass %/Δ(logD) vs. logD. Expressed in this way, the area under the curve between two particle diameters is proportional to the mass in that diameter range.

Fuel 1: This fuel is primarily composed of pine from the southeast United States. The fuel was obtained directly from the sanderdust silo at a particle board production facility. According to the site engineer, it is milled prior to combustion, and is "a mixture of mainly UF (Urea Formaldehyde) resinated sanderdust mixed with other fine waste material from our various pneumatic conveying systems". The sample received was uniformly fine in texture, with an unburned particle size centered at 250 μm and aspect ratios near unity. Sieving of Fuel 1 through standard mesh screens showed that the particle size distribution was log-normal as shown in Figure 6.3. No significant wood chips or slivers were evident. Urea formaldehyde resin, used as a binder in particle board production, is the source of the unusually high nitrogen content (see Table 6.1).

Fuel 2: This fuel was obtained from a sanderdust silo at a medium density fiberboard facility. It is a mixture of sanderdust and other material from pneumatic systems at the facility, all of which contain UF resin. Like Fuel 1 sanderdust, the UF resin is the source of the high nitrogen content. The fuel is not milled prior to pneumatic injection into the burners. It was reported to be "50% hard -oak, hickory, etc. & 50% soft -gum, beech, etc." by the site engineer.

The sample received was a mixture of fine particles and very high aspect ratio fibers. The fibrous nature of this fuel is unique compared to the other fuels tested. Sieving this fuel produced cotton-like material on sieves with a minimum opening of 710 μm and greater, and powdery material on sieves with openings of 180 μm and less. Figure 6.3 indicates that most of the fuel was on the order of 250 μm. A secondary mode near 700 μm was associated with the long fibers.

Fuel 3: This material was mostly sanderdust (phenol formaldehyde and methyl Di-isocyanate resinated) and board trim waste from strand board. It consists of 60% Virginia pine, 30% poplar, and 10% miscellaneous hardwoods. A small amount of wax (parafins) is also added to the board, but is not believed to significantly affect the composition or properties of the sanderdust/board trim fuel.

Visual inspection of the Fuel 3 revealed a moderately coarse texture and a diverse size distribution. Fine particles appeared to be on the order of 250 μm in diameter. Larger particles were on the order of 10 mm in the longest dimension, with high aspect ratios (slivers). Sieving showed a broad size range, with a median size near 400 μm, as shown in Figure 6.3

Fuel 4: This fuel is from a strand board plant, and includes the dryer fines which are sieved out of the raw material before resin is added, and the strand board trim. It is likely low in UF resin or other additives. The environmental engineer on site described the fuel as 65% aspen, 20% mixed hardwoods such as maple, and 15% red or jack pine.

Visual inspection of Fuel 4 showed a generally coarser texture than the bulk of the Fuel 3 sample. Qualitatively, particle aspect ratios were lower than Fuel 3. Figure 6.3 shows a size mode near 1 mm, with a secondary distribution centered near 0.3 mm. Note that the majority of Fuel 4 was of larger particle size than Fuels 1, 2 or 3.

6.1.2 Fuel Preparation for Screened Sawdust/sanderdust Experiments

Removal of oversized fuel particles from the "As Received" sawdust and sanderdust samples was required for smooth, repeatable operation of the fuel injection system. Two layers of 1.6 mm by 1.6 mm screen (opening size), separated by approximately 4 mm, were used to remove large particles. To aid in the removal of high aspect ratio particles, the second screen grid was oriented at 45 degrees to the first screen grid. Sieving with the double screen removed 0% of Fuel 1, 10% of Fuel 2, 18% of Fuel 3, and 31% of Fuel 4, as noted in Table 6.1. Composition of the screened product may, thus, be somewhat different from the total compositional analysis shown in Table 6.1.

6.1.3 Fuel Preparation for Milled Sawdust/sanderdust Experiments

For milled sawdust/sanderdust experiments, Fuels 2, 3 and 4 were processed in a Thomas-Wiley laboratory mill with a 0.5 mm diameter exit screen. Fuel 1 was received in a milled state. Milling allowed complete use of the available fuel, aided in dispersion of the fuel at the tunnel furnace injection point, and promoted complete combustion of char particles. It also allowed a more direct comparison between fuels by allowing their ashing properties to be evaluated on a common-size basis. Figure 6.4 shows the size distributions of the four fuels after milling. Note that Fuel 4 has a slightly higher average particle diameter, which can be traced back to the larger mean size of the unmilled Fuel 4 shown in Figure 6.2.

6.2 Screened Sawdust/sanderdust Experiments

6.2.1 Screened Sawdust/sanderdust Test Matrix and Conditions

The experiments specified in Table 6.2 were performed with the Screened sawdust/ sanderdust samples. In summary, these tests entailed burning the sawdust/ sanderdust in a natural gas-fired tunnel furnace and collecting the resulting ash using a water-cooled sampling probe coupled with a cascade impactor. Detailed experimental procedures are presented in Section 4.4 and individual test summaries are in Appendix E. Additional tests were performed to verify correct operation of the combustion and sampling apparatus.

Operational settings are summarized in Table 6.3. Some of the fuels required a slightly higher air entrainment flow rate for smooth operation of the injection system. This resulted in a slight variation in the total mass flow and dry O_2 content from test-to-test. Note that tests were conducted in a fuel-lean environment, and the wood fuel flow rate did not significantly deplete the free oxygen content.

Residence time is based on the integration of the inverse of the gas velocity, as calculated from the measured temperature gradient in the reactor and the total mass flow rate. The calculated standard deviation of the residence time is based on the variation in mass flow rate between tests.

Temperature profiling was accomplished using the High Velocity Thermocouple (HVTC) described in Section 4.6. Figure 6.5 shows the gas temperature in the reactor as measured via the sample ports distributed down the height of the reactor. Also included is the

temperature measured with a bare type-K thermocouple (not corrected for radiative heat loss) and the reactor wall temperature measured using a Leeds and Northrop optical pyrometer (Cat. No. 8621-C). The upper auxiliary burners were operated near the same stoichiometry as the main burners, resulting in nearly isothermal wall, thermocouple, and HVTC measurement at sample ports 43.2 cm, 58.4 cm and 73.7 cm from the injection port. The cooler wall temperature measured at 88.9 cm was somewhat surprising, since it is very near the auxiliary burner heat zone. Conductive and radiative heat loss to the unheated section directly below the auxiliary burner must be significant.

Figure 6.6 shows a curve fit of the temperature as measured by the HVTC in terms of the residence time rather than distance from the injection point. The furnace quench rate was about 150 K per second.

6.2.2 Screened Sawdust/sanderdust Results

6.2.2.1 Ash Size Distribution and Morphology

Figures 6.7 through 6.10 present size distribution data for the four wood products tested. The following plots are mass size distributions, and are based on these two assumptions: (1) that the particles are solid spheres, and (2) that the particle density is the same as that of $CaCO_3$ (2.7 g/cc). While the results are not strongly sensitive to assumed particle density, the shape and porosity of the particles can significantly influence the stage upon which capture occurs. The mass collected on a given stage is normalized to the total mass collected, including the material deposited in the preseparator.

A simple water-cooled sampling probe was used in this test series. The ratio of probe inlet velocity to the free stream velocity was approximately 7 to 1, which is anisokinetic sampling (*e.g.* Hinds, 1982, page 187). A calculation of sampling efficiency for this configuration showed that particles with diameters of 10 μm or less are captured with 90% or better efficiency, as shown in Appendix C. Essentially all particles below 4 μm were expected to be captured. Above 10 μm, the capture efficiency drops significantly, resulting in an under-representation of the largest residual particles.

Mass closure for Fuel 1 and 2, which exhibited very good burn-out, indicated that the collected ash was 20% to 55% less than expected, based on probe flow rate. This is

similar to the results of Gallagher (1992). The capture efficiency calculations (Appendix C) indicate that this missing ash is in the large size mode. As is discussed in detail in the Modeling chapter, it is clear that particulate matter greater than 10 μm does not play a significant role in alkali capture mechanisms, so its under-representation here is of little consequence.

Figure 6.7 is a plot of mass collected on each stage, as well as the mass collected on the aerosol filter. Mass collected on a particular stage is plotted at the diameter of a particle with 50% probability of capture on that particular stage, commonly referred to as D_{50}. The mass of material collected on the aerosol filter is nominally plotted at 0.1 μm. Although not strictly a plot of d(mass%)/d(logD) vs. logD, which is usually used to show mass distribution, this plot is useful in that stage spacing is approximately proportional to logD for stages between the aerosol filter and the preseparator stage. All four wood-based fuels have three clear modes: An aerosol mode in the sub-micron range, a secondary residual mode at about 1 to 3 μm, and a primary residual mode consisting of the material 8 μm and greater.

The ash size distribution for a typical pulverized coal (Kentucky 11), fired under similar conditions, is also shown in Figure 6.7. Note that all of the wood fuels yield much more aerosol than this typical bituminous coal, no doubt due to the much higher alkali content. Additionally, coal usually has a high clay content (46.7% SiO_2, 19.4% Al_2O_3 in terms of oxides in ash, for Kentucky 11). These aluminosilicate clays tend to compete with alkali vaporization by complexing alkali metals during char combustion (Gallagher, 1992). This further reduces sub-micron aerosol yields.

Figure 6.8 shows cumulative mass relative to D_{50} of each impactor stage. Fuel 1 and 2 have a high conversion of parent fuel to aerosol. Aerosol yield is also significant for Fuels 3 and 4, making up about 6% of the total mass collected.

The filter stage is typically light brown, possibly indicating some soot or organic tar formation from incomplete combustion. Evidence indicates that the *majority* of the mass collected on the filter stage is non-organic in nature. Energy Dispersive X-ray Spectroscopy performed on the filter stages of the four wood products tested show high alkali content. This suggests that the aerosol was produced by vaporized alkalies, which

condense to form sub-micron particulate matter. This is expected, in light of the high alkali content of the parent fuel.

For Fuel 3 and Fuel 4, the bulk of the mass in the preseparator appears to be char particles too large to burn within the available residence time (about one second). A mass closure calculation indicates that 2 to 4 times more material was captured by the impactor than one would expect from complete combustion. Fuels 1 and 2, being much finer fuels, exhibited better burnout and hence left less organic mass in the preseparator. Burnout at size cuts less than about five microns for all fuels appeared excellent, based on ash color.

The unburned carbon appears to be confined to particles 5 microns and above. Thus, Figure 6.9 attempts to remove the effect of the unburned carbon by renormalizing the size distributions by excluding particles above 5 μm. This attenuates the effect of incomplete char combustion for the Fuel 3 and Fuel 4 samples. Note that the representative coal ash aerosol yield remains significantly lower than the high alkali wood ash. Two distinct families of size distributions are evident in the wood ash. Fuel 1 and Fuel 2 show a significantly lower aerosol yield than the Fuel 3 and Fuel 4, as seen in Figure 6.10. as well as a higher 1.5 micron mode, as seen in Figure 6.9. The reason for the different yields is not clear, although the uncertainty associated with the exclusion of the unburned carbon argues against drawing conclusions at this point.

6.2.2.2 Ash Composition as a Function of Ash Size

Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDS) were used to gain insight into the morphology and composition of the ash particles. A flat, smooth specimen is ideal. Since particulate matter is far from an ideal flat surface, the elemental analysis presented should be viewed as semi-quantitative. Other limitations of EDS are (1) it cannot directly detect the form of bonding, (2) it cannot detect elements below atomic number 11, (3) composition can vary from particle to particle, and (4) the method is surface composition sensitive rather than volume composition sensitive. This last limitation is a problem if a composition gradient exists, such as a particle with a condensed species on its surface.

The following figures (Figures 6.11a through 6.23) show typical particulate matter collected on selected impactor stages and on the aerosol filter for the four fuels examined.

Fuel 1:
Figure 6.11a shows a selection of material collected on stage 0 (D_{50} cutoff approximately 8.3 μm) of the cascade impactor. Much of the material is highly porous, suggesting that the particles did not melt. EDS was used to analyze a typical collection of particles on this stage, and is shown in Figure 6.11b. Note that the material analyzed is primarily calcium. Figure 6.11c shows that the majority of material collected in the impactor was collected on stage 0 and the preseparator. Since the melting temperature of pure CaO is high, it is not surprising there is limited evidence of melting.

Figure 6.12a shows the diverse assortment material collected on stage 1 of the cascade impactor. Stage 1 corresponds to a particle cutoff diameter of approximately 5.3 μm. These large size cuts (including stage 0 and the preseparator) tend to show a diverse assortment of material, with the majority of it appearing to be fragmented structures of the unmelted parent minerals. These are likely skeletal mineral structures left by the burnout of the carbon from the char. Also present are spheres, which appear to be minerals that have melted and coalesced. Although calcium is the dominant element on this stage, composition varies from particle to particle. For example, EDS of the particle in the upper right corner of photo is almost pure silicon, as shown in Figure 6.12b. Of the selected stages inspected, the fraction of molten/coalesced particles to unmelted porous structures increases as average size decreases.

Figure 6.12c shows the detail of the lacy, porous structure of material near the center of Figure 6.12a. Elemental analysis (Figure 6.12d) shows this to be about 80% calcium. In the absence of a fluxing agent, CaO is not expected to melt at the furnace temperature.

Figure 6.12e shows the mass contribution of this stage in relation to total mass collected on all stages. Figure 6.12f is the elemental analysis of a typical collection of particles on this stage. This EDS was conducted at 10 kV at 2000x. Composition remains predominantly calcium, as with the previous stage (see Figure 6.11b), but alkaline earth elements, silica, iron and phosphorous are more abundant.

Figure 6.13a shows material that has been collected on stage 4 (D_{50} of 1.7 μm) of the impactor. Note that the fraction of particles that have melted has increased. EDS analysis at 1500x and 10 kV indicates mostly calcium with a balance of alkaline earth elements, silica, iron and phosphorous, as was seen in a larger size cut (D_{50} of 5.3 μm, Figure 6.12f). Alkali elements sodium and potassium are not well represented.

Figure 6.14a shows ash collected on the final stage of the impactor, which is just prior to the borosilicate glass absolute filter. The particles are roughly spherical with low porosity and a D_{50} diameter of 0.4 μm. Closer inspection at higher magnification (Figure 6.14b) shows angularity to some of the particles (*i.e.*, a gravel-like appearance), as well as nodes on otherwise smooth spheres. This is may be indicative of coagulation of aerosol alkali metals, or the sintering of the material rather than full melt. EDS results, shown in Figure 6.14c, indicate an increase in alkali metals potassium and sodium, as well as chlorine, presumably as an anion to the alkali metals. Figure 6.14d shows that this stage collects only a small fraction of the ash produced.

Inspection of the filter shows two remarkably different kinds of particles present. The surface of the filter is coated with particles that appear to be identical to the material collected on the 0.4 μm stage, shown in Figure 6.14a. A low power (250x) SEM photograph of the filter is shown in Figure 6.15a. In some areas, the fibers of the filter are visible through this collection of sub-micron particles. Inspection of the glass fibers themselves reveal (Figure 6.15b) that the fibers are collection surfaces for very fine material that is of the order of 0.05 μm. This suggests that the fine particles collected by the filter are made up of two modes. Scanning Electron Microscope techniques were unable to establish which of the two modes contributes the most mass.

Figure 6.15c shows the results of EDS analysis at low power (250x). This composition measurement requires careful interpretation. The EDS signal includes contributions from both the particles and the underlying borosilicate glass fiber filter. A semi-quantitative method of correction for the background elements composing the filter is presented later in this discussion (page 130). After correction, it appears that the material collected on the aerosol filter is primarily sodium and potassium, with chlorine as the primary anion.

Although the filter analysis is biased by the background composition of the filter itself, background elements are not a significant problem for SEM analysis of cascade impactor stages. Ash collected on the surface of aluminum foil impactor stage substrates was transferred to SEM stubs, which have a simple and known background signal.

Fuel 2:

Figure 6.16a is an elemental scan of a relatively dense collection of particles retained in the preseparator of the cascade impactor during testing of Fuel 2. The scan was performed at 750x and 10kV. Although no photo is available, SEM imaging verified that obvious plant

fiber structures were clearly visible in the preseparator. To illustrate composition diversity, an EDS scan of a char particle with a length scale of about 100 μm is shown in Figure 6.16b. What is particularly interesting about this particle is that it shows an intermediate char conversion extent between complete burnout (100% conversion) and the raw fuel, as discussed below. Analysis of this particle gives a semi-quantitative glimpse of ash morphology as a function of char conversion. Sodium, potassium, and chlorine are depleted compared to the parent fuel (see Figure 6.1, Fuel 2), resulting in an apparent "enrichment" of the lower volatility elements such as calcium, magnesium, silicon, iron. This indicates that alkali release begins early in the char conversion process. Work by Wornat *et al.* (1995) shows similar quantitative results for pine and switchgrass chars.

Figures 6.16d and 6.16e show the spectrum of the two scans shown in Figures 6.16a and 6.16b, respectively. The vertical axis is a count of photoelectrons, while the independent variable is the energy of the photoelectron. The background noise visible across all energies is known as a "carbon hump", and is indicative of a carbon background or matrix. The scan shows evidence of the sputter coating, which is composed of gold and palladium. This is added during the SEM preparation to prevent surface charging. Note that the relative magnitude of gold and palladium to other detected elements is greater for scan 6.16e than for scan 6.16d. The implication is that much of the EDS energy is lost to a carbon background composed of incompletely burned fuel, and the particle analyzed in Figure 6.16b is indeed incompletely burned.

Figure 6.17a is material collected on stage 0 (D_{50} of 8.3 μm). Aggregates, spheres and porous structures are visible in this collection of particles. Composition varies significantly from particle to particle. Figure 6.17b is an EDS analysis of the uncommon 10 μm by 30 μm particle shown in the center of Figure 6.17a. It is predominantly Ca (Figure 6.17b), which is similar in composition to material found in the large size cuts of Fuel 1.

The EDS analysis of a more common structure is shown in Figure 6.17c. It is porous and predominantly calcium as well.

Figure 6.17d shows EDS results for a 1500x 10kV analysis of a collection of particles, considered typical of this stage. A photograph is not available. Note that calcium remains the dominant element.

Figure 6.17e illustrates the diversity of particles on this stage. The particle scanned was not photographed, but appeared to have a smooth surface, was oblong with a major axis of approximately 15 μm and a minor axis of 10 μm, and bulged slightly along the major axis. This particle was very unique in appearance compared to the majority of other material present. The high titanium content is indicative of foreign contamination.

Figure 6.18a and 6.19a show collections of particles on stage 4 (D_{50} of 1.7 μm). Like Fuel 1, stage 4 material is made of diverse particles. The lacy structure in the center of Figure 6.18a is shown in detail in Figure 6.18b, along with a general scan of the particle at 15,000x 10kV in Figure 6.18c. This size cut is part of a secondary mode of the ash size distribution, as shown in Figure 6.18e. A higher powered examination of the lacy particle at 100,000x (Figure 6.18d) indicates that composition not only can vary from particle to particle, but across the surface of the particle as well. The higher faction of potassium and sodium, along with chlorine and sulfur, at the lower power examination tends to suggest that the particle has collected sub-micron aerosol particles during the combustion process, or is a condensation surface for vapor phase compounds. This will be examined in more detail later.

Figure 6.19b, a close-up view of a highlighted particle from Figure 6.19a, appears to be a calcium structure that has undergone some fluxing. Figure 6.19c is a close-up of a sphere also shown in Figure 6.19a. Three elemental analyses were conducted. Figure 6.19e is EDS was conducted at 100,000x 10kV, and included some nodes on the surface. Figure 6.19f was at 43,000x 10 kV, and focused on a single node only. Figure 6.19g focused on a smooth portion of the sphere. Compositional variation does not seem significant, which may indicate that the nodes were present during sphere formation rather than deposited by collision.

The aerosol filter of Fuel 2 was examined and is shown in Figure 6.20a. Material captured on and in the filter makes up about 30% of the total ash yield, as shown in Figure 6.20b. Like material collected on the Fuel 1 filter, the sub-micron particles have a granular appearance. Surface charging by the electron microscope resulted in the distortion line that runs left to right across the figure - *i.e.* it is not a true feature of the aerosol particles. EDS analysis conducted at 4000x and 10 kV (Figure 6.20c) shows significant quantities of chlorine and alkalies, implying that this sub-micron aerosol is primarily condensed salts.

Some large particles, on the order of 10 μm and larger, were also found on the filter. An example is shown in Figure 6.21a. These particles bypassed earlier stages, most likely by bouncing off the collection surfaces. EDS of three different particles (Figures 6.21b, c, and d) show high calcium, as is common for the larger particles, as well as alkalies and chlorine, which is common for smaller particles. This could be background signal from sub-micron particles, or impacted sub-micron particles collected by the large particle while sitting on the filter.

Fuel 3:

Figure 6.22a shows the aerosol filter surface recovered from firing Fuel 3. A significant number of large particles can be seen on the filter, most likely arriving at the filter by bouncing off earlier impactor stages. Figure 6.2 previously showed that unburned Fuel 3 has more oversized particles than unburned Fuel 1 and 2. This results in more large-diameter ash particles in the residual ash mode. The greater population of large ash particles leads to impactor overload and stage bounce, resulting in the appearance of more residual ash on the filter.

Examining Figure 6.22b, it is clear that sub-micron particles have adhered to the filter fibers themselves. This is very similar to the filter deposition mechanism observed for Fuel 1, Figure 6.15b. A notable difference is the lack of particles on the order of 0.4 μm. EDS analysis of the filter at 250x 10kV shows high silicon, calcium, and aluminum signals, part of which must be attributed to the filter material. Also present in significant quantities are potassium, sodium and sulfur which are likely attributable to the collected aerosol, as will be discussed later. Figure 6.22d shows the relative mass of the aerosol compared to the remainder. Although the aerosol yield is much less than the mass attributable to very large particles (8.3 μm D_{50} and greater), it is a significant fraction of the remaining mass.

Fuel 4:

Figure 6.23a is the Fuel 4 aerosol filter, showing that a substantial quantity of large particles bounced through to the aerosol filter. Closer examination of the filter fibers, as seen in Figure 6.23b, shows sub-micron particles adhered to the fibers. Figure 6.23c shows elemental analysis of the filter at low power, which includes large particles. This composition detected is not significantly different from the material analyzed at higher power, shown in Figure 6.23d.

One large (approximately 10 μm in diameter) particle on the surface of the filter was analyzed, as shown in Figure 6.23e, and found to have a higher calcium content than the overall filter surface. The composition of this particle is somewhat similar to the composition of particles found on the larger stage cuts of other fuels (*e.g.* Fuel 1, stage 1, Figure 6.12). Although no large stage cuts were analyzed for this fuel, it is logical to conclude that the composition of particles found there would be somewhat similar to this particle.

Figure 6.23f shows that Fuel 4 aerosol is a significant portion of the overall ash mass, similar in yield to Fuel 3.

Clean and Blank Filters:

The background elements present in the filter interfere with determining the composition of the material collected on the filter. For this reason, elemental analysis of clean (*i.e.* unused) and blank (*i.e.* used in the impactor/furnace, but with no solid fuel flow) filters were conducted. Figures 6.24a and 6.24b show EDS analysis at 15000x and 1000x respectively, which shows that the compositions of the two are essentially identical. The blank filter, Figure 6.24c, shows slightly more sulfur than the clean filter. This is possibly a result of trace amounts of sulfur in the natural gas (see Appendix D), or is band-width noise from the gold/palladium signal (sputter coating) adjacent to sulfur.

Figure 6.24d shows the blank filter at a magnification of 5000x and 10kV. Note that the image is distorted in the horizontal direction, which is caused by charging of the filter surface during scanning. As mentioned before, this is an instrument induced effect, manifest only in the photograph. During real-time observation, the fibers were shown to be of uniform diameter along their lengths, and relatively straight. The non-conductive nature of the blank filter is the primary cause of surface charging. The gold/palladium sputter coating has more difficulty reducing the effect here due to the tortuosity of the surface, which inhibits charge mobility.

6.2.3 Discussion of Screened Sawdust/sanderdust Results

Some general observations about this test series can be made, each worthy of discussion. These trends are illustrated with the aid of the results of Fuel 1 ash composition

measurements shown in Figure 6.25. These compositions are considered to be the most representative of the material collected on the indicated stage or filter. It is observed that:

- The largest size cut (8.3 μm) is almost entirely made of alkaline elements (calcium and magnesium).

- A second residual mode is centered near 2 μm. Particles in this mode are generally very diverse both physically and chemically. They remain primarily calcium and magnesium, like the largest size cut.

- The 0.4 μm size cut is essentially chemically identical to the 2 μm mode with the exception of the appearance of sodium, potassium, chlorine, and sulfur. This size cut is unique in that the particulate matter is physically uniform.

- The aerosol mode is high in alkali metals and anions. It appears to be composed of primarily sub-micron particulate matter that is formed via vaporization followed by nucleation and condensation.

These observations are discussed in detail below.

A clear trend drawn from the data is that calcium is the dominant element for all size cuts above the aerosol filter, as shown in Figure 6.25. Comparing the elemental composition of unburned Fuel 1 to the composition of all residual size fractions, it is clear that calcium and magnesium are enriched and sodium, potassium and chlorine are depleted in the residual ash. As expected, low volatility minerals remain with the residual fraction (the first four columns) while higher volatility alkalies and their anions escape (the right-most column), resulting in an apparent enrichment of the low volatility elements in the large residual mode. This general behavior is predicted by equilibrium calculations discussed in the Modeling chapter. These results are also similar to results seen by Wornat *et al.* (1995), where experiments with southern pine showed 80% of the original calcium and magnesium remained in the char particle after 95% char conversion of the particle to ash, and alkalies were depleted to 30% to 47% of their original content.

Residual Porous Ash:

The large calcium structures are generally very porous and do not appear to have gone through a molten stage. As discussed earlier (Chapter 2), calcium is typically found as a

component of the cell walls of the parent biofuel. It is proposed that the porous structure of these large residual particles is an artifact of the cell walls, resulting from the conversion and collapse of the original cellular structure, as organically bound calcium is converted to oxide form, and eventually carbonate form. Baxter *et al.* (1996), found that the calcium in biofuels they tested (wood/ straw/ shell mixes, paper, and other biofuels) is primarily in the form of ion-exchangeable and acid soluble compounds, and not in water soluble form or in an oxide form. The implication is that the calcium is in an organic form. Simple equilibrium (presented in the Modeling chapter) indicates the favored form of this calcium at elevated temperatures is as an oxide, in combination with silica oxide and/or magnesium oxide, until ultimately forming a carbonate around 1000 K. In the absence of fluxing agents, the melting temperature of oxide mixtures composed of primarily CaO is high, as illustrated in the phase diagram shown in Figure 6.26. Since the original cell walls of the parent wood fuel are calcium rich relative to other inorganics, and these inorganic are essentially atomically dispersed, it can be assumed that these solid phase structures will be formed without entering a melt phase.

Although there is a risk of oversimplifying with a simple two-oxide system as shown in Figure 6.26, it is useful for illustrative purposes for two reasons: 1): Although the addition of alkalies or other elements can lower eutectic temperatures and shift compositions, the basic behavior of the two oxide system is *generally* similar to the more complex system. Secondly, clean biomass fuel is much more likely to have well-dispersed inorganics rather than discrete mineral inclusions, as discussed previously. Therefore, the *locally* well-mixed organically-bound minerals and finely dispersed SiO_2 can form combined solid phases directly, with a melting temperature governed by the *local* composition. Hence, some information can be gained from solid/liquid phase diagrams, as long as kinetic limitations and their simplicity are recognized.

Returning to Figure 6.26, it is clear that a CaO rich system (+60% CaO, for example) will maintain a solid phase at higher temperatures than a system composed of 50% CaO and 50% SiO_2. Therefore a calcium-rich zone, such as a cell wall in the parent wood fuel, can generate porous particulate matter. It would be useful to determine the inorganics concentration by element in the parent wood fuel using SEM and EDS techniques, but that investigation is beyond the scope of the current study.

The highly porous calcium structures do not appear to have crystalline features, but instead appear to have undergone some surface softening. Some possible mechanisms for this phenomena are proposed. First, repeated formation and decomposition of metastable $CaCO_3$, in a CO_2 environment, can result in catalyzed sintering of the CaO structure (Borgwardt *et al.*, 1989: Silcox *et al.*, 1989). This leads to an estimate of 0.25 μm for the minimum radius of curvature maintainable by a given CaO feature, as discussed in Chenevert *et al.* (1998). A second possibility is based on equilibrium and kinetic considerations. Below about 1000 K, simple equilibrium predicts for Fuel 1 that Ca_2SiO_4 (s) will be converted to $CaCO_3$ (s), and the $CaMgO_2$ (s) will be converted to $Ca_3MgSi_2O_8$, as shown in Figure 7.2 of the Modeling chapter. Of course, solid to solid phase reactions are not kinetically favored, so significant exchange of oxide metals is very unlikely. What is more likely is carbonate formation on the surface of existing solid phase calcium-based structures, which is ultimately diffusionally limited by CO_2 penetration into the oxide ash. Acting against the argument for carbonate formation is the fact that sampling for these tests occurred above 1000 K, and quench is fast after sampling.

A third possibility is alkali-catalyzed surface-melting of the existing structure. This is addressed in conjunction with addressing the diversity of composition and morphology in the 2 μm mode.

Residual Two Micron Mode:

The composition of the residual ash generally shows greater diversity, both morphological and chemically, as the particulate matter diameter decreases. This diversity is probably the result of many interacting processes, including inhomogeneity in the unburned fuel (meaning discrete mineral deposits), preferential combination of specific elements to form eutectic melts, fragmentation, and coalescence. These mechanisms are briefly addressed.

Inhomogeneity of the parent fuel is very common in coal, as discussed in the Mechanisms chapter. Discrete mineral inclusions of different composition are very likely to have different size distributions in the unburned fuel. For example, pyrite inclusions in Kentucky #11 unburned pulverized coal are generally 20 to 40 μm and larger, while most of the quartz is in the form of inclusions less than 20 μm (Boni *et al.*, and Figure 5.1). The size distribution of discrete mineral inclusions and extraneous material directly influences the ultimate size distribution and chemical composition of the resulting ash (*e.g.*, Boni *et*

al., 1990; Helble *et al.*, 1990; Kramlich and Newton, 1994b). The Random Coalescence Model presented by Barta *et al.*(1992) uses probability techniques to determine the ultimate size and composition of the residual ash based on the discrete mineral distribution in the parent fuel. Benson *et al.* (1993) presented a slagging/fouling model, also based on the discrete mineral composition of the unburned coal. The coal literature leaves no doubt that one should expect diversity in the residual mode, due to the diversity of the micro-inclusions in pulverized fuels.

Unlike coal, much of the ashing elements in biomass is finely, if not atomically, dispersed in the fuel. An exception is contamination, typically meaning the soil associated with the biomass source, which usually is in form of aluminosilicate clays. The sawdust/ sanderdust fuels used here are low in aluminum and silica, so discrete minerals contamination from soil is not likely. However, these fuels are composed of waste from board-making facilities, so they do contain binding resins with some inorganic components. These resins surely modify the composition. Some fuel particles will likely have a resin coating rather than a uniformly distributed composition.

It is likely that some of the unique particles in the micron size range are the result of preferential combination of inorganic elements. In coal, the combination of alkali and alkaline elements with alumino-silicates is well studied. For example, Zygarlicke *et al.* (1992) performed artificial char experiments with Ca-Si-S and Na-Si-S systems. It was found that organically bound calcium reacted with quartz crystals to form a lower temperature eutectic. As the char particle surface recedes during burning, molten particles form on the char surface and eventually coalesce. Less research has been done with systems deficient in aluminum and silica. In a biomass system, switchgrass charring experiments conducted by Wornat *et al.* (1995) showed the formation of K-Si "beads" for a char conversion of 50%. At 94% conversion, beads on the surface of the char were primarily of Ca-Si. Shedding and fragmentation at the char surface (Helble, 1989) can liberate these non-homogeneous mineral melts. This results in a diverse mineral distribution in the smaller diameter range.

It is hypothesized that a significant factor in the physical and chemical diversity of the 2 μm mode particles is preferential combination of low-volatility elements interacting with alkalies to form melts. These melts are continuously transformed by temperature change, as well as by depletion of their alkali components. Sequestering of otherwise mobile

alkalies occurs when precipitates are formed, governed by phase equilibrium. Migration of molten combinations, catalyzed by alkalies, of otherwise immobile elements explains both the diversity of smaller particles, as well as the softening of some calcium-based structures. This hypothesis is illustrated by example using phase equilibrium of a simplified system as a guide.

As mentioned earlier, simple-system phase diagrams are useful for illustrating the *qualitative* behavior of the actual system. Figure 6.26 shows a phase diagram of a system composed of calcium oxide and silica oxide at one atmosphere. For now, other important inorganic components are not included. An example isopleth at 62% CaO is shown (dashed line). Following this line of constant composition from low temperature to high temperature, one would expect an atomically disperse mixture to form into a two phase system above 1464 C (indicated by point "A"). The solid phase consists of essentially solid Ca_2SiO_4 (point "B") and the liquid phase would consist of the eutectic composition of 55% CaO and 45% SiO_2 (point "C"). If the temperature is increased, more of the residual Ca_2SiO_4 (s) would be lost to form a CaO enriched liquid phase. Ultimately, all the solid phase is converted to the liquid phase (point "D"). For comparison, an isopleth is drawn to indicate the silicon and calcium concentration in Fuel 1 as determined by Atomic Absorption Spectroscopy. This corresponds to 73% CaO and 26% SiO_2 on a mass basis and is labeled "Fuel 1 by AAS".

Summarizing thus far: 1) If the system temperature does not reach the eutectic temperature, a two-phase system does not exist, and no molten minerals are liberated from the char matrix. In this case, the residual ash is porous because of burnout of organics, and spheroidal ash particulate matter is not present. 2) If the system temperature reaches the local eutectic temperature, a two phase system exists in which a fraction of the mineral matter is liquefied to form the eutectic composition. The remaining residual is porous as before, and the cooled ash is a mix of porous structures and spheroidal ash particles. 3) If the system reaches its ultimate melting temperature, all the mineral matter is molten. The residual will be essentially spheroidal.

Of course, the actual elemental distribution is not completely homogenous. Locally (*e.g.* in cell walls), the calcium concentration may be so high that very little of the local mineral matter enters the molten stage. For example, an isopleth at 20% SiO_2 and 80% CaO would

not form a partial melt until 2070 C. As discussed earlier, this is a likely mechanism for the residual porous structures dominating the larger size cuts.

The influence of alkali metals in this system is not trivial. It is generally well known by researchers that alkalies invariably lower the melting temperature of otherwise solid oxides. It is useful to review this phenomena by comparing the phase diagrams of a $CaO\text{-}SiO_2$ system and a $CaO\text{-}SiO_2\text{-}Na_2O$ system. Figure 6.27 is a phase equilibrium diagram for a system composed of $CaOSiO_2$ and Na_2OSiO_2. The left edge of this figure shows the melting temperature of $CaOSiO_2$, which is 1544 C. On Figure 6.26, this same composition and melting temperature can be found in the middle of the figure at a CaO concentration of 48%. Returning to Figure 6.27, assume a local composition of ash that consists of $2Na_2O{\bullet}CaO{\bullet}3SiO_2$ and is 1400 C, which is indicated by a letter "E". Note that above 1200 C, this mixture will be in liquid phase. In Figure 6.26, a mixture of $CaO{\bullet}3SiO_2$ (which corresponds to 23% CaO) is indicated with the letter "E" at 1400 C. This composition is completely in solid form when sodium is not present. Hence, for this simple system it is clear that sodium depresses the melting temperature.

Going one step further, assume a system composed of 67% Na_2OSiO_2 and 23% $CaOSiO_2$ is very quickly lowered from 1400 C to the melting temperature. This is indicated by the line "E" to "F" on Figure 6.27. The solid $Na_2O{\bullet}2CaO{\bullet}3SiO_2$ (s) condenses out as the temperature is lowered. It is important to note that the bulk of the sodium that enters into this solid phase is essentially trapped by diffusional resistance from participating in further equilibrium driven reactions with other elements. Eventually (and ideally), the remaining liquid hits the peritectic temperature of about 1150 C, and completely condenses to $2Na_2O{\bullet}CaO{\bullet}3SiO_2$ (s) by 1050 C. In this ideal system, the sodium in this system is completely captured by the solid phase.

In actuality, some sodium does escape the system. Equilibrium predicts alkalies to escape in the vapor phase at combustion conditions, either as chlorides (when available) or hydroxides, and experimental evidence verifies that most of the alkalies do escape. What is important to note is that a *fraction* of the sodium that does participate in a melt will be captured in the solid condensed phase, with that fraction dictated by phase equilibrium.

The fraction of sodium captured is influenced by the local composition. This is illuminated by the ternary diagram of CaO-SiO_2-Na_2O shown in Figure 6.28. This diagram has been modified with dotted lines indicating constant CaO:SiO_2 ratios. Following a dotted line from left to right is equivalent to a system which is uniformly being depleted of Na_2O while CaO and SiO_2 are held constant. For example, consider a system initially composed of 36% Na_2O, 50% SiO_2, and 14% CaO at a temperature of 1400 C, which is on the line of CaO:SiO_2 = 2:7 g/g. At a temperature above about 1150 C, this combination exists as a liquid. If the temperature is dropped before sodium can escape, the condensate will capture a fraction of the sodium as solid $Na_2O \bullet 2CaO \bullet 3SiO_2$. The amount captured is a function of sodium escape rate and the system temperature. Now assume that sodium is leaving the initial system (36% Na_2O, 50% SiO_2) at a rate such that the system temperature does not drop significantly prior to significant sodium depletion. The liquid will follow the dotted composition line from left to right as the sodium escapes, eventually condensing as Tridymite, a form of SiO_2. In a real system, the sodium will escape at a rate somewhere between these two extremes, resulting in some sodium capture, and some sodium release.

The example phase diagram systems discussed above focus on silica-based interactions. Silica system phase diagrams are relatively abundant because of their importance to the ceramics industry. Of course, other eutectics mixes are likely in the sawdust/sanderdust ash as well. For example, a CaO-Fe_2O_3 system has a eutectic at 1200 C, which is well below the melting point of CaO (2570 C) and pure Fe_2O_3 (about 1580 C). Investigation of all possible combinations is well beyond the scope of the current study, and would obviously include detailed chemical equilibrium in all phases.

Adding to this already complicated picture is the potential for locally reducing or stoichiometric combustion. Elevated temperatures and elimination of some otherwise stable oxide forms (*e.g.* $CaO \rightarrow Ca+O$) can change the composition of the residual as well. This avenue of mineral matter transformation is usually discussed relative to vaporization and aerosol formation, but it is recognized that it may play a role in the residual mode.

Residual 0.4 Micron Mode:

The final residual size cut prior to the aerosol filter is made up of particulate matter with a gravel-like appearance and diverse composition. What makes it unique is its uniformity,

and the presence of alkalies and potential anions. Subsequent discussion in the Modeling chapter will suggest that the chlorine and sulfur are present because they are bonded with sodium and potassium. Thus, these four elements can probably be viewed as resulting from either (1) aerosol captured by the last impactor stage, possibly via coagulation with other particles, or (2) vaporized alkali that condense on the smallest existing particles. If Na, K, Cl, and S are removed from the 0.4 μm stage and the remaining elements are renormalized, the resulting composition is very similar to the 5.3 and 1.6 μm size cuts. This suggests that the 5.3, 1.6, and 0.4 μm materials are all the result of similar mechanisms, with the exception that the 0.4 μm stage is "contaminated" by the presence of alkali (either as aerosol or direct condensate).

The typical diameter of these particles (about .4 μm) is similar to the typical feature size making up the large, residual lacy calcium structures. For example, compare Figure 6.12c to Figure 6.14a. As discussed above, softening of the calcium structure and mobility of eutectic forming minerals is likely. It is proposed that these particles are formed from liberated subdivisions of the larger porous structures. This hypothesis is implicitly supported by the argument of a minimum maintainable radius of curvature of a CaO structure in a CO_2 catalyzed environment (Borgwardt *et al.*, 1986, Silcox et al, 1989). That radius is estimated to be .25 μm for this system (Chenevert *et al.*, 1998). Examining the structure of the large porous particle in Figure 6.12c, it appears that the mode of further transformation of this structure is extensive fragmentation rather than coalescence.

Once liberated from the porous structure, yet still associated with fluxing elements, the sub-micron particles continue to soften. Since the particles remains primarily Ca (presumably CaO), the particles do not achieve full melt, but rather "relax" to its gravel-like appearance. Of course, all arguments for formation of eutectic melts, discussed earlier, apply.

Aerosol ash:

Composition analysis of material on collected by the aerosol filter presents a problem because the instrument signal comes from both the aerosol and the underlying filter substrate. An attempt was made to correct the raw filter concentrations using the blank filter response shown in Figure 6.25. The right-most column in Figure 6.25 presents this corrected composition and the column labeled "Aerosol Filter" is the uncorrected composition. To make the correction, it was assumed that all silicon detected on the Fuel 1 filter was from the filter itself (this is justified because Si is an inconsequential element in

these particular fuels, compared to other elements present). The filter composition based on EDS analysis of a filter used in the cascade impactor, but with no wood flow, is labeled "Blank Filter" in Figure 6.25. Using this as a scaling factor, the proportionate amount of other background elements were removed from the Fuel 1 filter elemental analysis, and the composition was normalized to 100%. Calcium, iron and phosphorous were set to zero, because the correction for these elements yielded slightly negative values.

The compositions shown in Figure 6.29 are the result of applying the normalizing procedure to EDS data for all four fuel aerosol filters. All four fuels show very high alkali content in the aerosol mode. Recalling that up to 30% of the total ash mass was accumulated on the filter stage, a significant portion of the total sodium and potassium must be in the aerosol size range.

Figure 6.29 indicates there is a large amount of chlorine present in the aerosol for Fuels 1 and 2. This is a reflection of the high chlorine content of the unburned fuel (see Table 6.1 and Figure 6.1). The analysis suggests that more than enough chlorine is present on the filter to tie all the sodium and potassium up as NaCl and KCl. Unburned Fuels 3 and 4 are deficient in chlorine on the filter, as seen in Table 6.1 and Figure 6.1, and the aerosol filter analysis reflects the deficiency. It appears that sodium and potassium are primarily bound as sulfates in these fuels.

Although sulfur content is similar in Fuels 1, 2, and 4, it does not appear that sulfate displaces the chloride ion for Fuels 1 and 2. This is obvious in Table 6.4, where the molar ratio of Cl to 2S is shown for the unburned fuels and the material collected on the aerosol filters. (Note that one mole of Cl captures one mole of Na as NaCl, and one mole of S captures two moles of Na as Na_2SO_4, so the ratio Cl:2S is relevant.) It is clear that sulfur is under-represented in the aerosol mode when the parent fuel is rich in chlorine.

Equilibrium calculations, presented in the modeling chapter, indicate that sodium sulfate will form around 1250 K, prior to condensation of vapor phase KCl and NaCl around 900 K. The predominance of chlorine over sulfur indicates that the sulfur is unable to displace chlorine to form sulfate. This indicates that sulfate formation, which is essentially a $SO_2(g)$ - alkali chloride(s) reaction in this system, is kinetically limited.

Potassium escapes the residual mode more effectively than sodium, as is seen in the ratio of Na to K in the fuels and aerosols in Table 6.4. The ratio of sodium to potassium is reduced

by half from the unburned fuel to the aerosol. A phase diagram of a K_2O-Na_2O-SiO_2 system, shown in Figure 6.30, suggests preferential capture of sodium by the residual ash. A dotted line representing a *molar* ratio of Na to K of 2.5 for Fuel 1 is shown as a dotted line in Figure 6.30. Note that the first condensed species along the length of this line is either a pure silicate, or a sodium silicate. Potassium (and some of the sodium) remains in the liquid phase, ultimately escaping, while a fraction of the sodium is bound in the solid form and becomes diffusionally immobile as the system cools. The quantitative fraction of sodium remaining with the residual ash is a function of system temperature history and other factors, as discussed earlier. Qualitatively, this simplified system indicates that the sodium will be preferentially captured over potassium. For comparison, a dotted line representing a Na to K molar ratio of 1:1 is also shown in Figure 6.30. It does overlap into a potassium-silica condensed phase, but only slightly. All for fuels tested lie in a region that favors sodium rather than potassium in the solid form.

Returning to Table 6.4, the cation to anion ratio indicates more than enough anions are available to capture the detected alkalies for Fuels 1, 2 and 3. The excess Cl and/or S may be related to the reduction in available Na due to residual capture. For Fuel 4, the molar ratio indicates that some of the alkali on the aerosol filter may be in the form other than chloride or sulfate, such as a carbonate. Equilibrium, discussed in the Modeling chapter, predicts some alkali carbonate formation for Fuel 4.

6.3 Milled Sawdust/sanderdust Experiments

6.3.1 Milled Sawdust/sanderdust Test Matrix and Conditions

Table 6.5 is a summary of milled sawdust/sanderdust experiments. The experiments were performed following the experimental procedures described in Section 4.5. In brief, the milled fuel was burned in the tunnel furnace and sampled isokinetically using the porous wall dilution probe. This diluted flue gas and particulate matter was passed through a cascade impactor to remove large particles, and then routed through a tank of a preselected volume. The tank volume controled the residence time of the flue/aerosol prior to sizing of the remaining ash with an Electrical Aerosol Analyzer.

Table 6.5 is a summary of the test matrix for this series. The test number and fuel type are shown in the first two columns. Next, the sampling hardware configuration is shown. An

"x" in the Cascade Impactor column indicates that mass measurements of the cascade impactor stages were made. Although a cascade impactor was used for all EAA tests, not all cascade impactor ash collections were of interest. The next column indicates that an Electrical Aerosol Analyzer (EAA) was used for all tests, except for tests which were conducted solely to accurately measure the furnace temperature profile. Temperature profiling tests were performed with a High Velocity Thermocouple as described in Chapter 4.

The size of the delay tank (*i.e.* the residence time) between the cascade impactor and the EAA is a critical factor. Three tanks were used: a plastic tank (200 liters), a steel tank (199 liters), and a Plexiglas tank (21 liters). Some tests were also performed with no delay tank. The milled sawdust/sanderdust flow rate was also varied as shown in the next column in Table 6.5.

The tunnel furnace temperature was set by controlling the natural gas/air stoichiometry. The overall flow rate, the air to fuel ratio of the main burner, and the stoichiometry of the upper auxiliary burner are shown for each test. Also shown is the calculated dry oxygen content of the flue gas, with no solid fuel added. Note that the addition of solid fuel did not dramatically change the free oxygen content, as the wood fuel flow rate was about two orders of magnitude lower than the overall furnace flow rate.

Experiments were performed under three furnace conditions, and are grouped accordingly on Table 6.5. The first grouping are experiments conducted with the tunnel furnace main burner (natural gas fired) operated at the highest temperature. The high temperature furnace setting test was selected to be comparable to the screened sawdust/sanderdust series, and similar to an environment found in an industrial burner. The low temperature test series was performed in order to determine if vapor condensation prior to entering the sample probe affected the ultimate aerosol size distribution. This was a limited series with a lower furnace flow rate (*i.e.* longer furnace residence time) and a leaner stoichiometry. The auxiliary burner was run closer to stoichiometric in an attempt to maintain a constant temperature down the height of the furnace. The third grouping was conducted with a slightly leaner stoichiometry in the main and auxiliary burners, and about half the furnace mass flow rate of the first grouping.

Radial temperature profiles were obtained at every port in the furnace, as shown in Figures 6.31 through 6.33. These measurements were made using the High Velocity Thermocouple (HVTC) described in Chapter 4.

Figure 6.31 shows the radial temperature profile at a series of axial locations for the maximum furnace temperature and flow rate settings. Temperature fluctuations are quantified by the error bars accompanying each sample point. The tunnel furnace expands beginning near the point of fuel injection, and the temperature profiles at the first few ports (43 cm, 58 cm, and 74 cm) reflect the reduced tunnel diameter. From the top of the furnace to near the bottom, the temperature shows good radial uniformity. The obvious exception was at the last port of the furnace, which is located just above the inlet of the vertically positioned sampling probe at 185 cm from the point of fuel injection. The temperature dip noted on centerline was due to a backflow of air up the probe shaft, induced by the draw of furnace exhaust system. In normal operation the probe is independently aspirated and the temperature dip does not occur.

The temperature profiles also show a lower temperature near the furnace walls, which is the left-most point of each profile. Note that the temperature profile is flatter near the upper auxiliary burners where the tunnel is heated, as expected.

Figure 6.32 shows the temperature profiles for a slightly leaner main burner setting, but a richer upper auxiliary burner setting. Note that the temperature profiles in the upper region of the furnace, where the auxiliary burner is located, are tightly grouped. At the lower end of the furnace, the temperature drops more quickly since the lower auxiliary burners are not in use. Again, the influence of room-air entrainment up the sampling probe is seen in the 185 cm profile. The temperature at the 155 cm port and -5 cm from the centerline indicates a very localized temperature dip, which recovers by the 170 cm port. It is likely that a small crack is present in the refractory near this point, allowing a small amount of air from the idle auxiliary burner to enter. It appears to be a relatively small leak, judging from the temperature profile. This temperature series was chronologically the latest of the three milled sawdust/sanderdust temperature profile tests (*i.e.* Figures 6.31 and 6.33), so any leak is relatively new.

Figure 6.33 shows the temperature profiles for the leanest furnace setting. This profile set is very similar profiles describes with Figures 6.31 and 6.32. The temperature was

uniform radially, with the exception of the temperature dip discussed earlier at the lowest station.

Figure 6.34 summaries the three temperature profiles. The axial temperature down the length of the furnace was calculated as the radial average of the temperature measured at each available port. These data are shown in tabular form on the lower portion of the figure. The average temperature measurements taken at the port nearest the inlet of the vertical sampling probe did not include data that were obviously influenced by the probe air entrainment, since it was an artifact of the inactive sampling probe.

The temperature profiles in Figure 6.34 are similar. The moderate temperature test was conducted with the upper auxiliary burners operating hotter than the other two tests, resulting in a flatter temperature profile near the top of the reactor.

The sample system modifications performed for the milled sawdust/ sanderdust experiments significantly changed the post-furnace environment experienced by the sampled flue gas and ash. Milled sawdust/sanderdust tests are characterized by longer furnace residence times (1 second for screened sawdust/sanderdust experiments versus 1.4 and 3.0 seconds for milled experiments), in-probe sample dilution, and a variable delay time prior to ash sizing.

Figure 6.35 shows the temperature/time history of the sampled gas, as well as a measure of the dilution of the sample with time. In the upper figure, three different furnace flow rates are illustrated. The 525 g/minute flow rate corresponds to the temperature profile versus time for the screened sawdust experiments discussed in Section 6.2. The steep temperature gradient near one second residence time is representative of quenching in the sampling probe. Recall that experiments conducted with the screened sawdust/ sanderdust were done with a simple water-cooled sampling probe rather than the dilution probe.

The temperature versus residence time for milled sawdust/sanderdust experiments at 525 g/minute furnace flow rate is indicated on Figure 6.35. The steep temperature gradient at about 1.4 seconds was the result of quenching inside the sampling probe. The dilution for this condition is indicated in the lower figure. Note that dilution in the sampling probe resulted in a significant temperature drop and an order of magnitude reduction in ash flow concentration prior to exiting the sample probe. The dilution ratio for the high temperature tests was about 25 to 1 on a mass basis. Following dilution and passage through the

cascade impactor, the sampled flue entered the delay tank. The delay tank residence time was controlled by tank volume: 239 seconds for a 199 liter tank, 25 seconds for a 21 liter tank, and no delay for no tank. The variable delay time provides an opportunity to observe the influence of "aging" on the aerosol generated by the primary flame.

The temperature profile indicated by a furnace flow rate of 305 g/minute in Figure 6.35 is based on test 112096T. It is typical of the other milled sawdust/ sanderdust experiments conducted. The probe dilution ratio for this furnace flow rate is about 25 parts dilution air to one part flue gas.

6.3.2 Milled Sawdust/sanderdust Results

Figures 6.36 through 6.42 are summaries of all Electrical Aerosol Analyzer (EAA) experiments conducted. Appendix F is a more detailed description of each individual test, with the practical limitations of listing all computer-collected data recognized. These figures are all shown in terms of d(volume)/d(log diameter) versus particle diameter, where volume refers to the ash concentration expressed as μm^3 of aerosol per cm^3 of carrier gas. Like cascade impactor data expressed in this form, the area under the curve between two diameters is proportional to the mass in that diameter range.

A change in measuring procedures was incorporated early in this test series, in which the EAA was switched from hand-recorded measurements to computer controlled bin sizing and data acquisition. This allowed recording of up to 10 cycles through all particle diameter bin sizes (with high precision) in the same amount of time a researcher could record one cycle by hand. The large delay tank was changed from a plastic tank to a steel tank in this same time frame. In Figures 6.36 through 6.42, tests that include the symbol "m" refer to the method of data acquisition (manual) and a plastic delay tank, while tests that are identified with an "e" referring to electronic data acquisition and a steel delay tank.

The upper graph in Figure 6.36 shows those Fuel 1 tests conducted at the highest furnace temperature that used either the large plastic tank or the large steel tank. Both tanks had volumes of about 200 liters, which results in a delay time of 239 seconds. Each curve represents a different sawdust/sanderdust flow rate into the furnace. As one would expect, the aerosol decreases as wood flow rate decreases. In the upper graph of Figure 6.36, the cause of the difference between the 4.6 g/minute test with the steel tank and the two tests

with the plastic tank is not fully resolved, although it is clear there is significant variation associated with the manually collected size distributions.

The middle graph in Figure 6.36 shows all Fuel 1 experiments at the given furnace temperature when a delay tank of 21 liters was used. This is equivalent to a 25 second delay time, which is an order of magnitude shorter delay time than the tests shown in the upper graph. Immediately obvious is that the major aerosol mode peaks below 0.1 μm, while the major mode with the longer delay tank time (above) peaks above 0.1 μm.

Note also that there is now a size mode near 0.025 μm evident at all sanderdust/ sawdust flow rates. As the milled sawdust/ sanderdust flow rate decreases, both modes are attenuated, but the mode near 0.1 μm is decreased disproportionately more than the 0.025 μm mode.

The lower graph in Figure 6.36 shows aerosol size distribution from the Fuel 1 tests, at the same furnace conditions as above, but with no delay tank. The diluted sample was transported from the cascade impactor to the EAA with no delay other than residence time in the sampling line. In this graph, there is no obvious peak at 0.1 μm. Below 0.1 μm, the EAA becomes saturated at the highest flow rates, indicative of particle counts beyond the range of the instrument. Since mass is conserved, regardless of delay tank time, it is logical to conclude most of the mass was in the smaller size mode.

Similar trends for the other three sawdust/ sanderdust fuels are apparent in Figure 6.37 through Figure 6.39. Note that Fuels 3 and 4 appear to have enhanced 0.025 μm modes when compared to Fuels 1 and 2.

Figure 6.40 shows the results of testing at the intermediate furnace settings. Note that both Fuels 1 and 4 have no significant 0.025 μm mode, exhibit a 0.1 μm mode, and appear to show a possibly larger mode.

Figures 6.41 show all EAA tests at the lowest furnace temperature for Fuel 1. Interestingly, the 0.025 μm mode is not readily apparent in this series, except in the lowest sawdust/sanderdust flow rates.

Fuels 2, 3 and 4 test results at this furnace setting are shown in Figure 6.42. These profiles are very similar to results at the slightly hotter furnace settings shown in Figure 6.40.

Cascade impactor data for the milled sawdust/sanderdust is of secondary importance, but is given here for completeness. The cascade impactor was essentially a large particle filtering device for these tests, and as such it was operated above it standard operating volumetric flow rate of one cubic foot per minute. Ash size distributions are shown in Figures 6.43 through 6.45. Merging cascade impactor test data with the EAA data is a challenge, particularly since the cascade impactor is an mechanical integrator by nature (all ash is collected) and therefore includes all transient flow rates, while the EAA makes instantaneous measurements and does not directly measure mass.

6.3.3 Discussion of Milled Sawdust/sanderdust Results

Figure 6.46 shows three EAA tests with the independent variable being delay tank size (*i.e.* delay tank residence time). This particular test was conducted with Fuel 1, but all four fuels show similar behavior. The largest delay time (239 sec) results in the majority of the mass being centered near 0.1 μm. For a delay time of 25 seconds, mass is split between a 0.025 μm mode and 0.1 μm mode.

When testing with no delay time, number densities are beyond the range of the EAA for particle sizes below about 0.04 μm. Since total mass is conserved, regardless of residence time, it is logical to conclude that nearly all of the aerosol is below 0.04 μm for the test with no delay time.

Coagulation rate is the obvious mechanism controlling the size distribution in the size range measured by the EAA. Simple monodisperse coagulation theory, or Smoluchowski coagulation (see Hinds, 1992), argues that coagulation is governed by diffusion when particle diameter is on the order of the mean free path of molecules in the suspending medium. In this regime, large particles are formed by collisions between smaller particles that are under the influence of Brownian motion.

The practical limit of Brownian motion induced coagulation of aerosol particles is about 0.1 μm, and is demonstrated by the 239 second residence time test. The 25 second delay time

test shows that this time is insufficient for complete coagulation to the 0.1 μm mode. The test with no delay time shows that the elapsed time is insufficient for any significant coagulation to the 0.1 μm mode.

Figure 6.47 compares aerosol size distribution for Fuel 1 between a high furnace temperature test and a low furnace temperature test, with a delay time of 239 seconds. Note that the cooler furnace test shows nearly complete depopulation of the 0.025 μm mode, while the hotter furnace test indicates a small residual mode at 0.025 μm. The reason for this behavior is worthy of investigation, since the surface area of the 0.025 μm particles is a significant fraction of the total surface area available for downstream surface chemistry. This is explored in terms of coagulation theory and species equilibrium, as discussed below.

It is suggested that at the higher sampling temperature (*i.e.* hotter furnace) much of the condensation/ coagulation occurs within the dilution probe. Since this occurs under strongly diluted conditions, the coagulation rate is significantly reduced, yielding more fine particles. With the cooler test, the reduced sampling temperature moves the condensation/coagulation events into the undiluted furnace gas. Here, the accelerated coagulation rapidly depopulates the finer particle sizes.

This interpretation is supported by equilibrium calculations discussed in the Modeling chapter. Simple equilibrium shows that Na_2SO_4 is the first alkali species predicted to form a liquid or solid phase. This event is, however, accompanied by a reaction. This suggests that there may be a chemical kinetic barrier to rapid formation of this compound. Alternately, NaCl (s) and KCl (s) are formed directly from identical gas-phase species. This lowers the expected alkali condensation temperature to around 600 C. As mentioned above, this places the condensation event largely within the probe during high-temperature sampling and within the reactor free-stream for low-temperature sampling. Thus, the reduced coagulation rate (when the furnace gas is dilution quenched by high-temperature sampling) is the reason the fine particles remain for the higher temperature test, even with a 239 second delay time.

A qualitative extrapolation to practical systems indicates that while delay times are much less than those used in the present experiments, the initial number density is higher. This suggests that the dilution air location may have a significant influence on the final aerosol

particle size distribution, which in turn will affect both downstream impacts and collectability. Also, the presence of chlorine alters the condensation temperatures predicted at equilibrium. Thus, the behavior of the fuels that contain significant chlorine may be different than those that are chlorine poor.

To summarize:

- Testing with the EAA demonstrated that the size distribution in the sub-micron stage is bimodal, with one mode near 0.1 μm and the other near 0.025 μm. The relative proportion of mass in each size range is a function of the variables that influence coagulation rate. The influence of number density and residence time on size distribution was illustrated, shown that longer residence times led to increased coagulation.

- It is clear that depopulation of the 0.025 μm mode is affected by the composition of the vapor, in that species with high boiling temperatures will preferentially condense to form nucleate first. If the temperature is maintained just below the condensation temperature, and dilution is delayed, coagulation is fast.

Table 6.1: Analysis of As Received sanderdust and sawdust samples

		Fuel 1 sanderdust	Fuel 2 sanderdust	Fuel 3 sanderdust / board trim	Fuel 4, dryer fines/ board trim	Kentucky #11, sub-bit. coal*
Ultimate Analysis (% mass, Oven Dry Basis)	C	47.5	47.7	50.8	49.9	60.1
	N	5.2	3.4	0.19	0.10	1.2
	H	5.5	5.8	5.6	6.4	4.6
	S	.033	.030	.062	.038	4.4
	O by Δ	40.9	42.0	42.6	42.3	7.9
Moisture (% mass, as received)		4.2	4.1	5.2	4.2	3.8
Ash at 750C (% mass, OD Basis)		0.81	1.07	0.66	1.29	21.8
Major Mineral Components, (mg per kg raw fuel)	Ca	1640	2410	1120	3930	6589
	Na	1000	1500	480	870	466
	K	674	1020	454	1160	3827
	Mg	249	281	233	405	1137
	Mn	94	91	112	76	N/A
	Fe	198	43	308	75	29310
	P	65	80	57	118	183
	Si	403	263	241	200	45734
Total Halogens, (mg/kg raw fuel)		1215	2130	82	137	N/A
Mass (%) removed after sieving, doubled 1.6 x 1.6 mm screen		0	10	18	31	N/A

* Analysis of Kentucky #11 adapted from reference PSI. Additional components for Kentucky #11: Al: 21513 mg/kg, S: 4195 mg/kg, Ti: 1130 mg/kg.

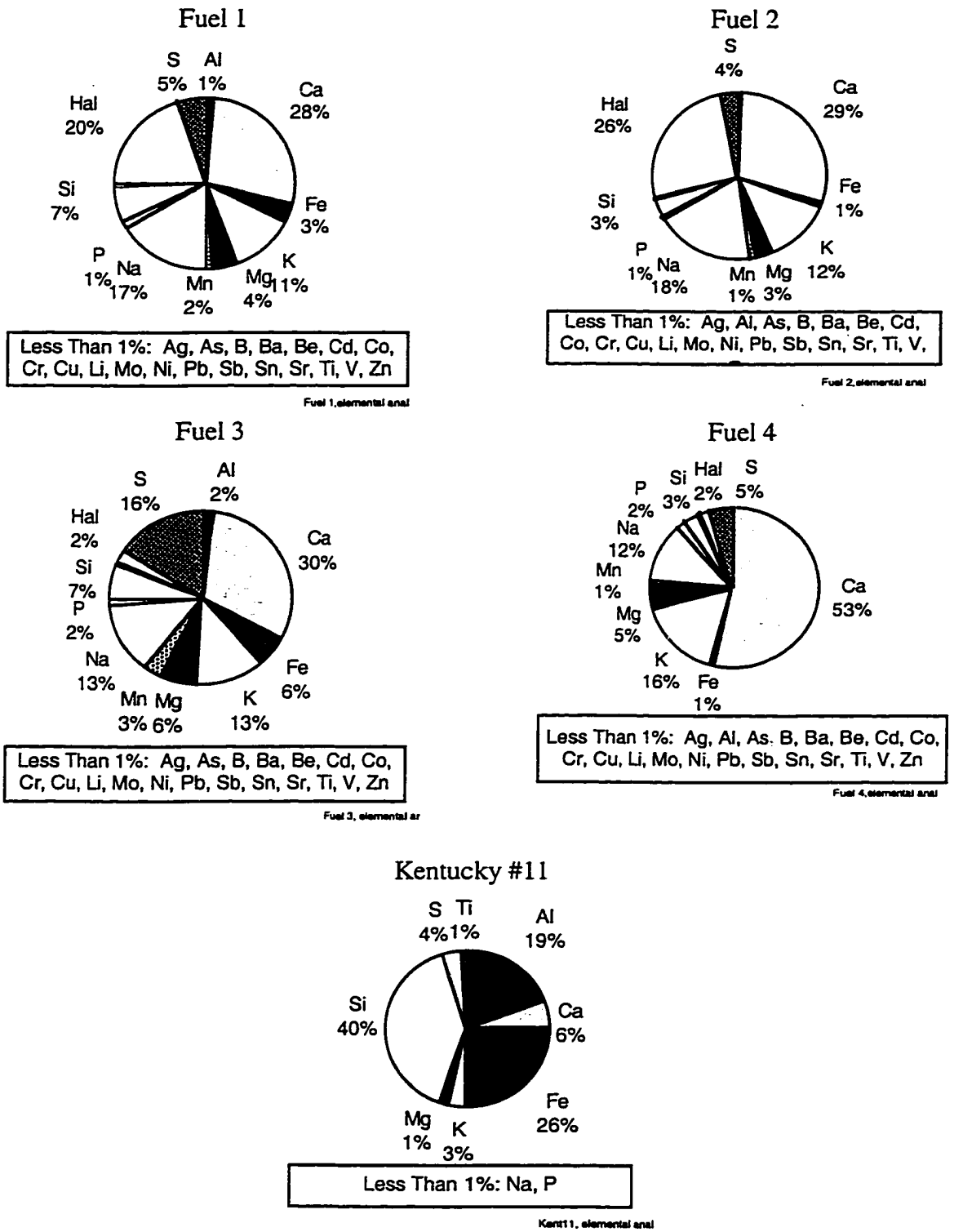


Figure 6.1: Atomic Absorption analysis of As-Received fuels

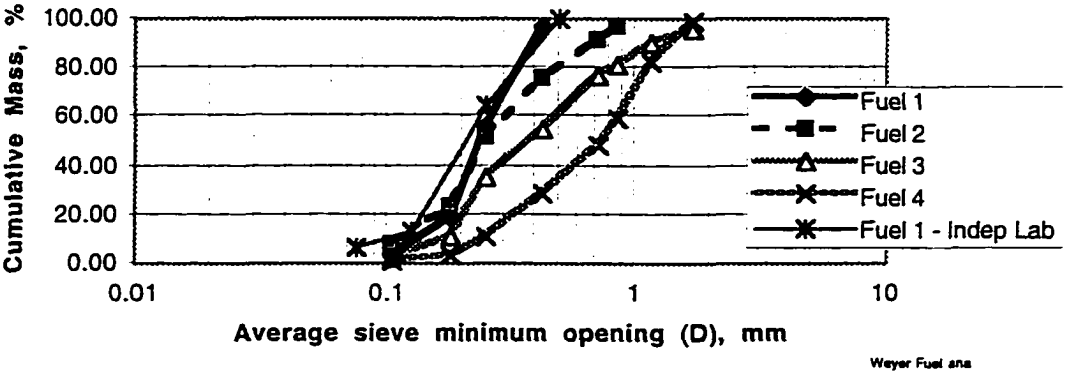


Figure 6.2: As-Received fuels size distribution by cumulative mass

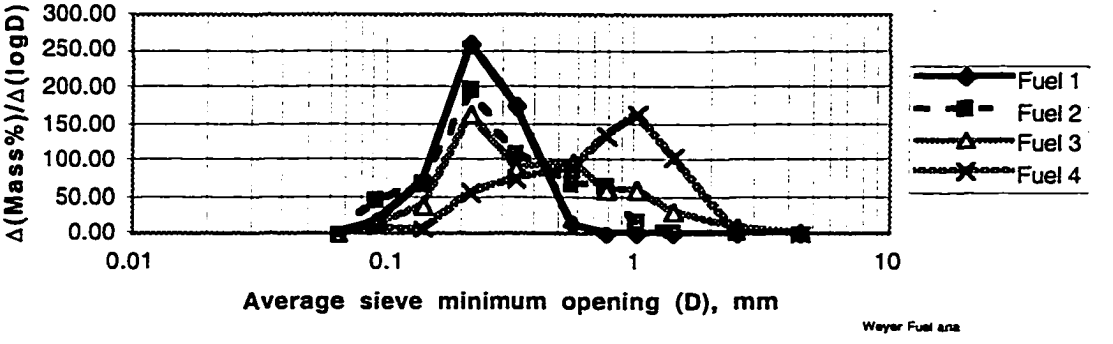


Figure 6.3: As-Received fuels size distribution

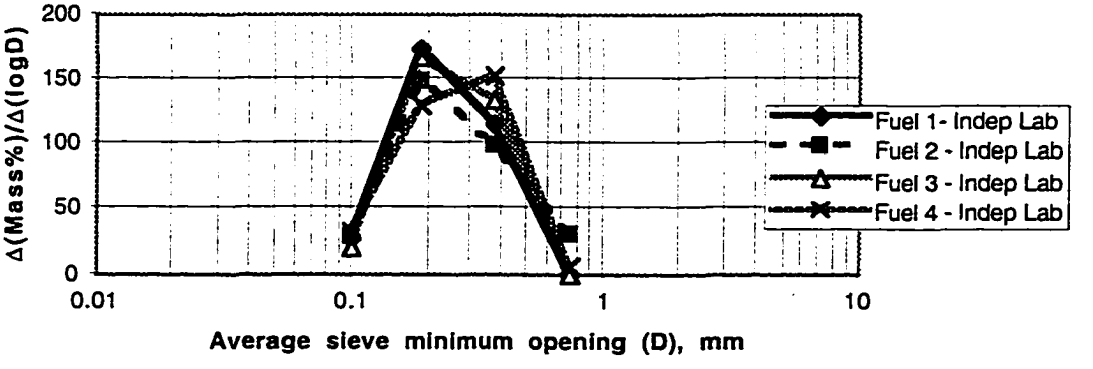


Figure 6.4: Milled fuel size distribution. Fuel 1 As-Received, Fuels 2, 3, and 4 milled to 0.5 mm diameter exit screen

Table 6.2: Screened sawdust/sanderdust test matrix

Test Number	Fuel	Fuel Flow rate, g/min	Sampling Time, min:sec	Total Ash collected, mg
08089501	Fuel 1	6.8	15:00	15.13
08099501	Fuel 1	6.8	5:00	4.34
08169501	Fuel 1	5.0	15:00	11.52
08169502	Fuel 1	5.0	15:00	10.59
08169503	Fuel 1	5.0	15:00	12.62
11099501	Fuel 1	5.1	10:00	N/A
10269501	Fuel 2	5.45	15:00	20.66
10269502	Fuel 2	5.45	10:00	14.75
10139501	Fuel 3	5.0	15:00	47.88
10319501	Fuel 3	5.0	15:00	51.69
11029501	Fuel 3	5.0	10:00	30.38
11079501	Fuel 4	5.22	10:00	63.22
11229501	Fuel 4	5.22	10:00	61.83
10169501	Temperature	0.0	--	--
10069401	Blank	0.0	15:00	0.26

Table 6.3: Test conditions for Screened sawdust/sanderdust experiments

	Average	Standard Deviation
Main Burner A/F Equivalence Ratio	1.57	0.02
Main Burner - Total mass flow including solid fuel entrainment air, g/min	524.1	12.6
Upper Aux Burner A/F Equivalence Ratio	1.65	0.01
Upper Aux Burner Mass Flow, g/min	545.2	3.0
Dry O2 No solid fuel injection, % by vol	9.1	0.4
Dry O2 solid fuel injection, % by vol	7.8	0.5
Residence Time - Solid fuel injection point to sample probe inlet, seconds	1.08	0.03

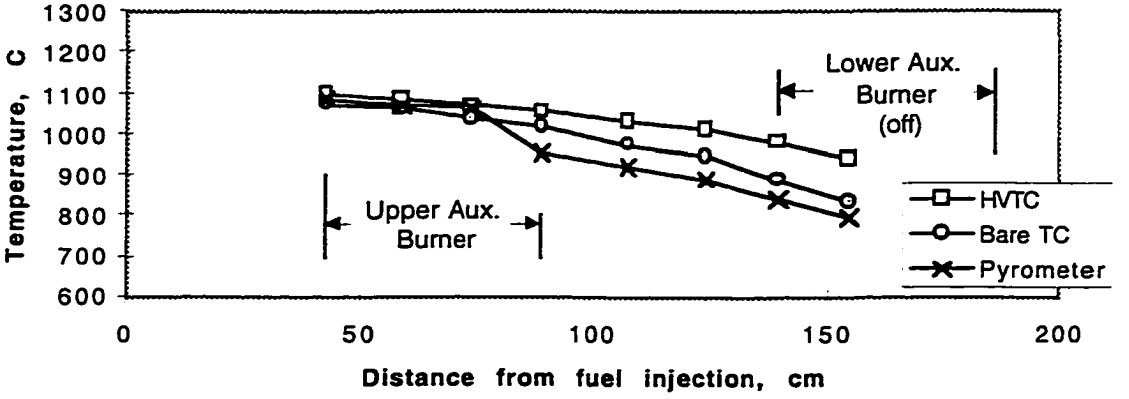


Figure 6.5: Temperature as a function of furnace height

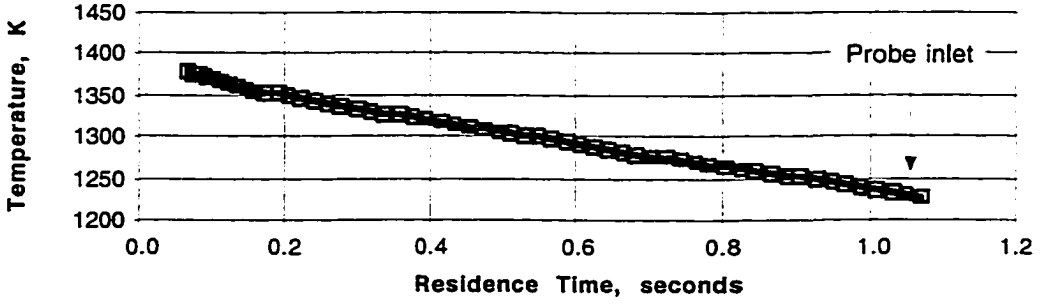


Figure 6.6: Temperature as a function of calculated residence time for Screened sawdust/sanderdust fuels, based on High Velocity Thermocouple measurements

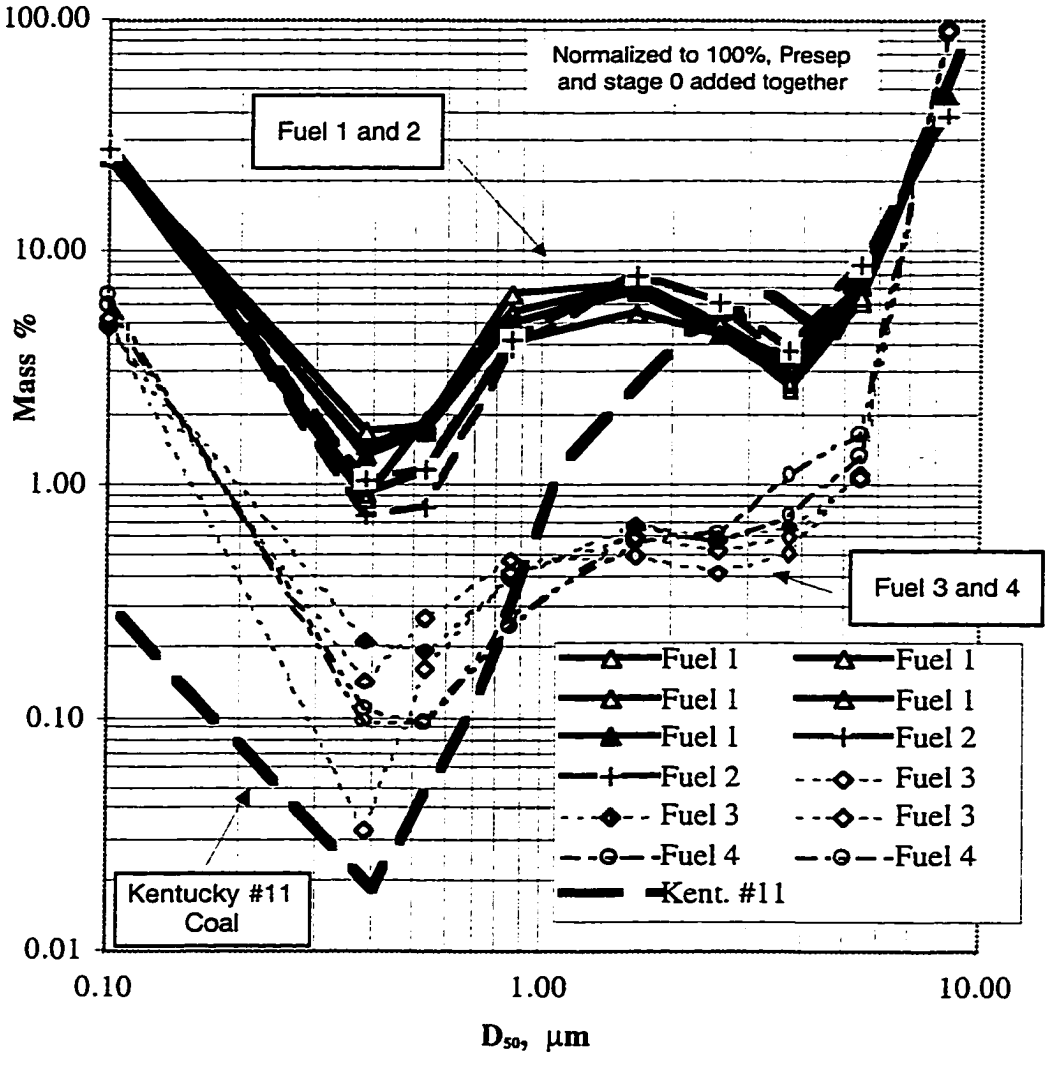


Figure 6.7: Screened sawdust/sanderdust ash size distribution as a function of impactor stage cutoff diameter.

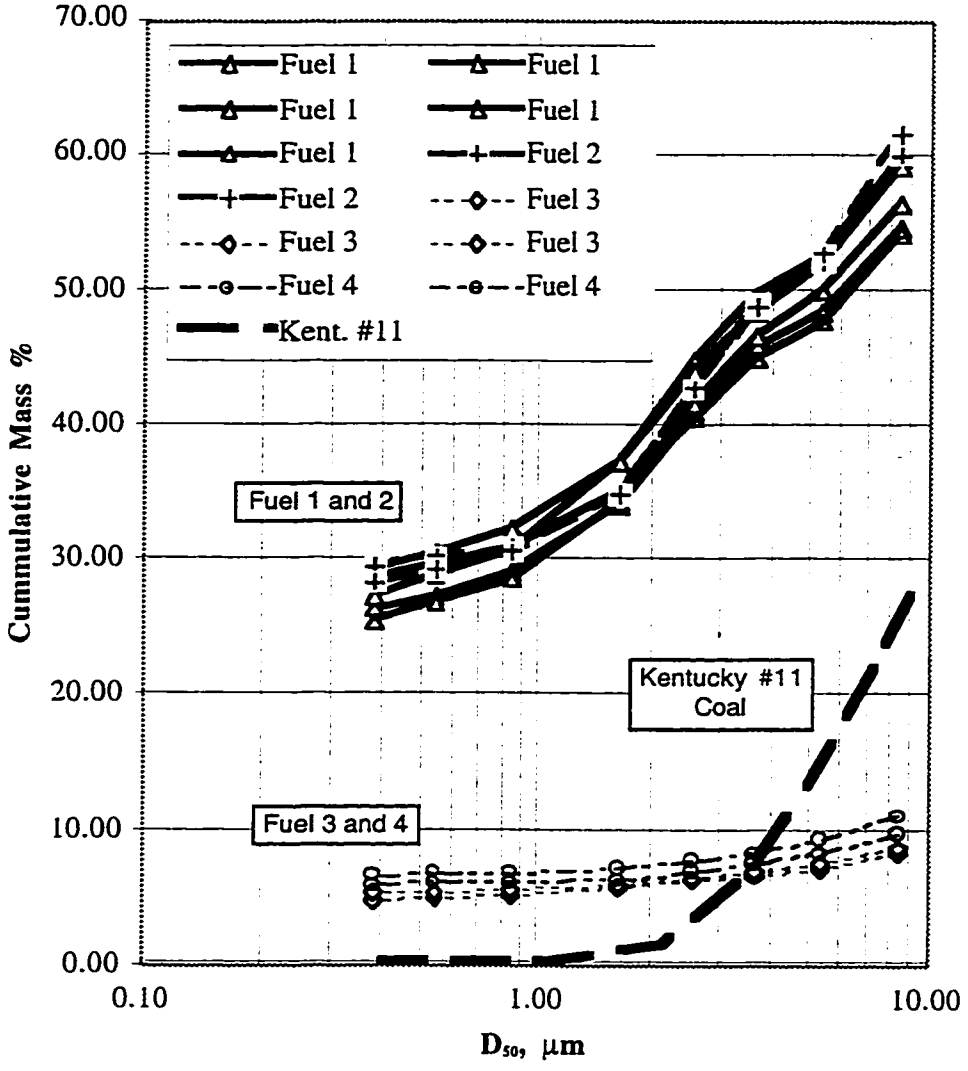


Figure 6.8: Screened sawdust/sanderdust ash size distribution as a function of cumulative mass

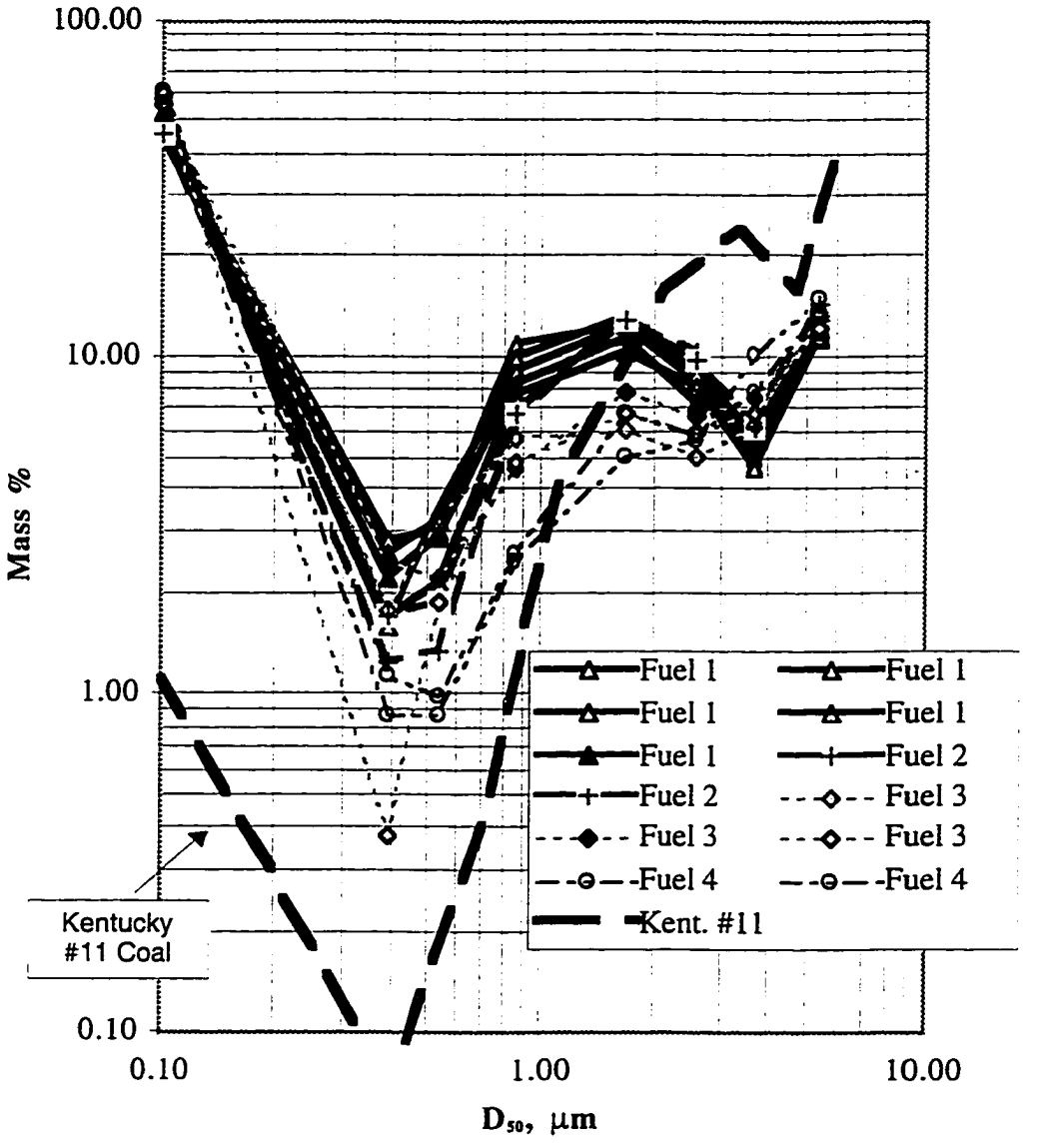


Figure 6.9: Screened sawdust/sanderdust ash size distribution as a function of impactor cutoff diameter, excluding ash of greater than 5 µm

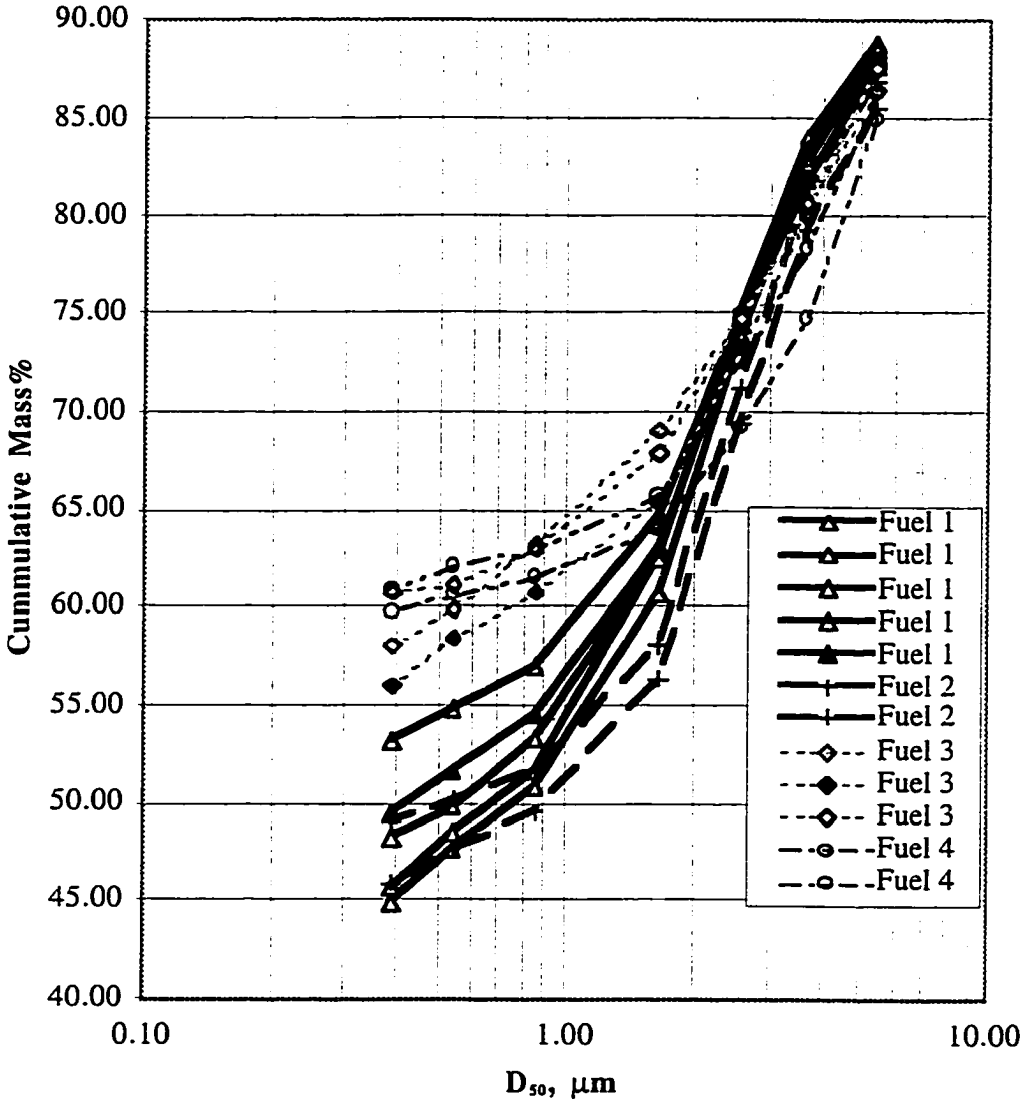
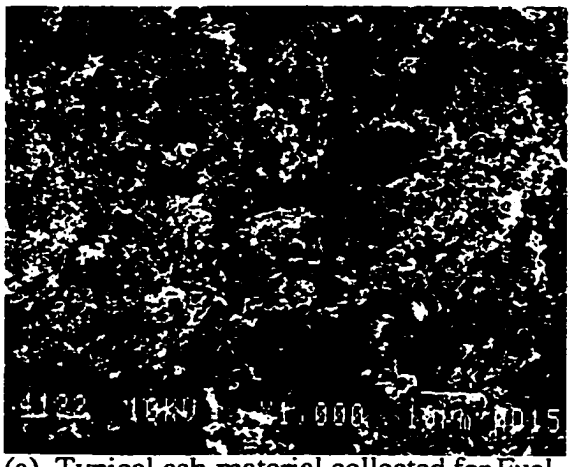
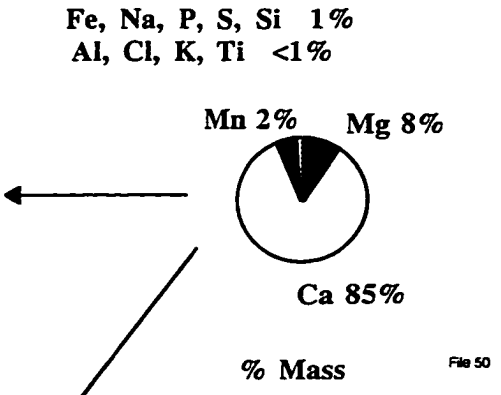


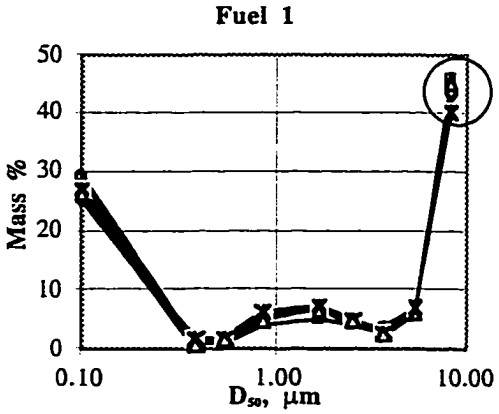
Figure 6.10: Screened sawdust/sanderdust ash size distribution as a function of cumulative mass, excluding particles of greater than 5 μm



(a) Typical ash material collected for Fuel 1, Stage 0



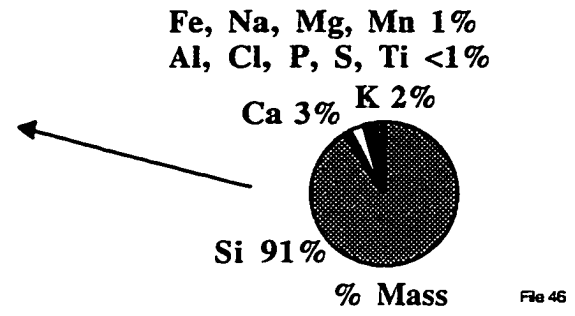
(b) EDS analysis of typical Fuel 1, Stage 0 ash, 1500x



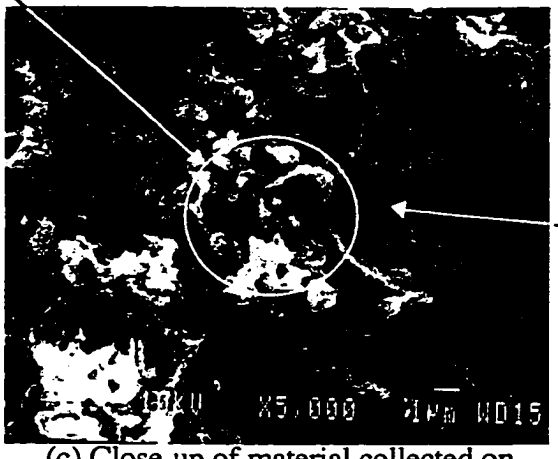
(c) Ash mass distribution with area of interest highlighted

Figure 6.11: Fuel 1, Stage 0 Scanning Electron Microscope results

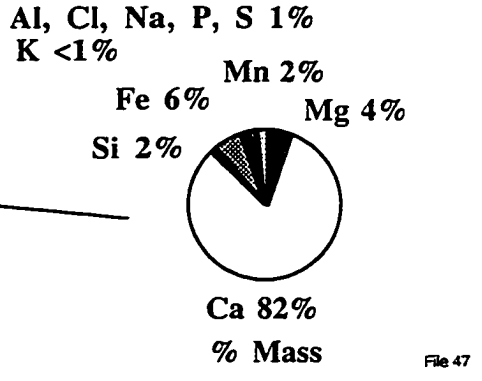
(a) Ash material, Fuel 1, Stage 1



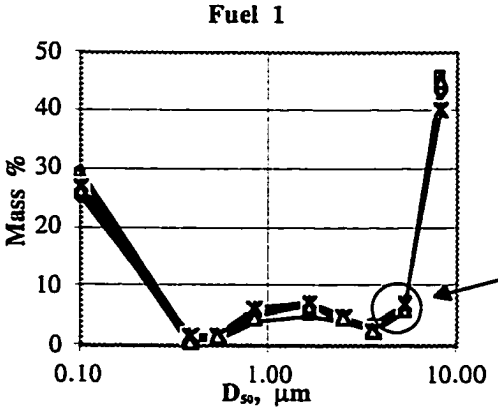
(b) EDS of indicated particle



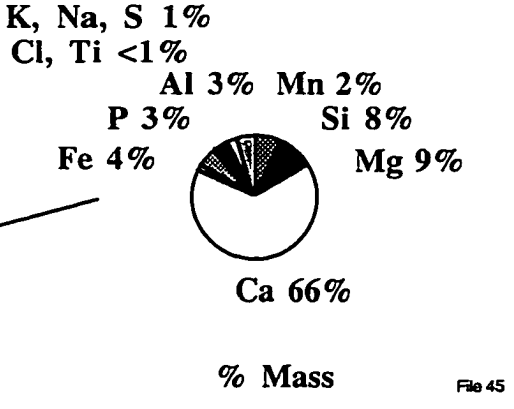
(c) Close-up of material collected on Stage 1



(d) EDS of indicated material

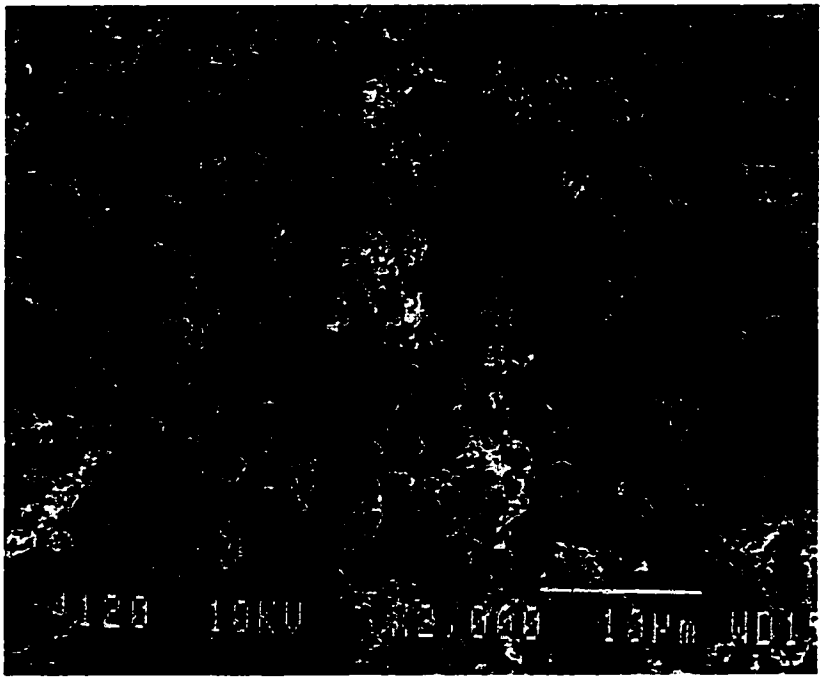


(e) Size distribution

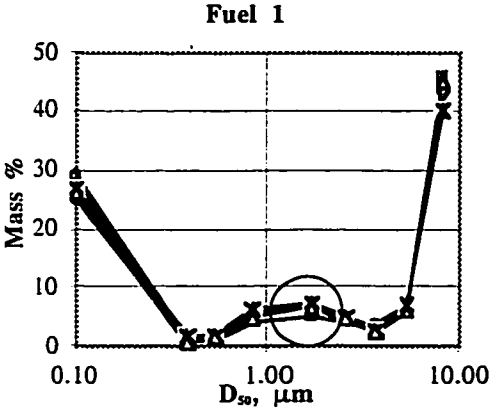


(f) Typical Fuel 1, Stage 1 ash, 2000x

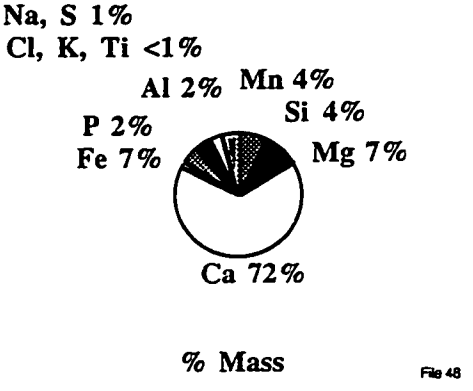
Figure 6.12: Fuel 1 Stage 1 Scanning Electron Microscope results



(a) Ash collected for Fuel 1, Stage 4

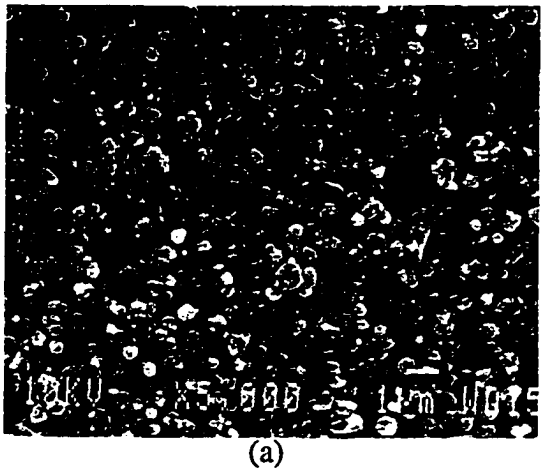


(b)

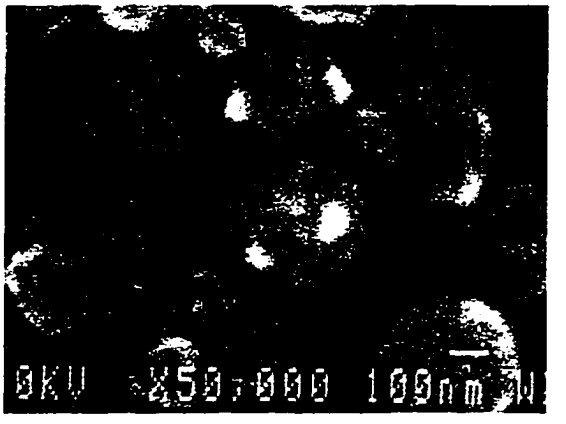


(c) Typical Stage 4 ash, 1500x

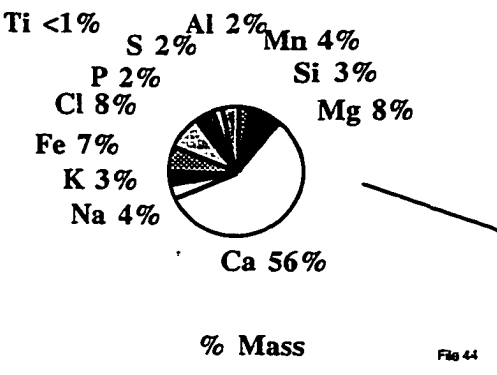
Figure 6.13: Fuel 1 Stage 4 Scanning Electron Microscope results



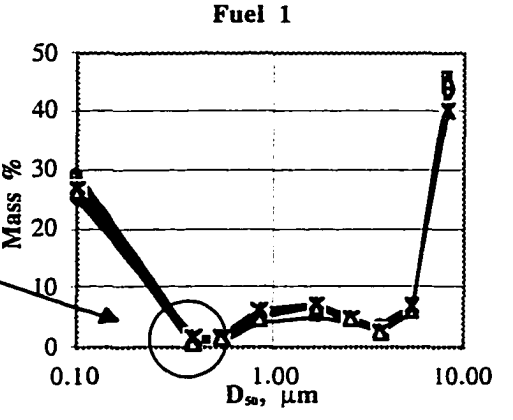
(a)



(b)

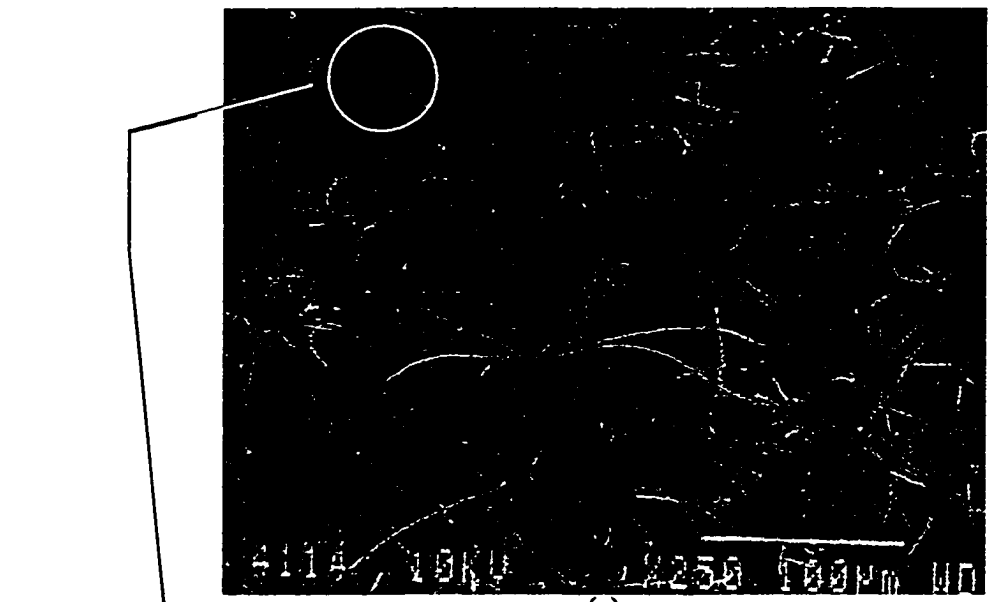


(c)



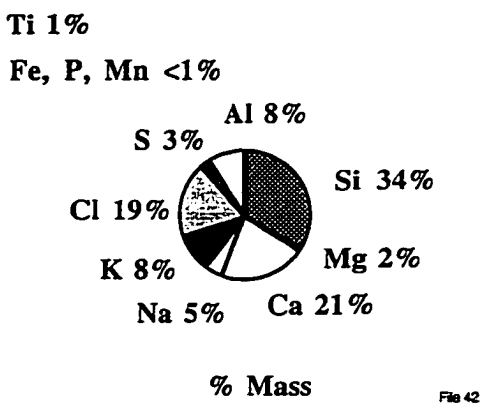
(d)

Figure 6.14: Fuel 1 Stage 7 Scanning Electron Microscope results



(a)

(b)



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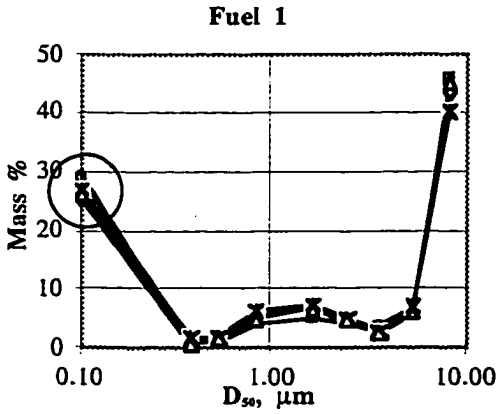
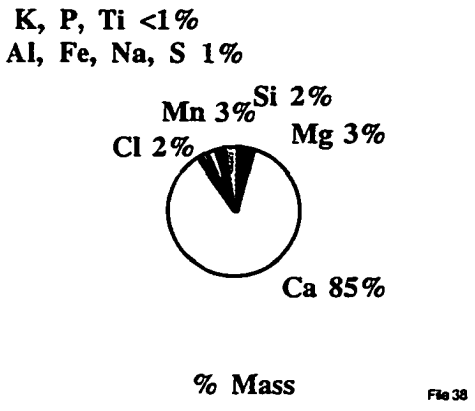
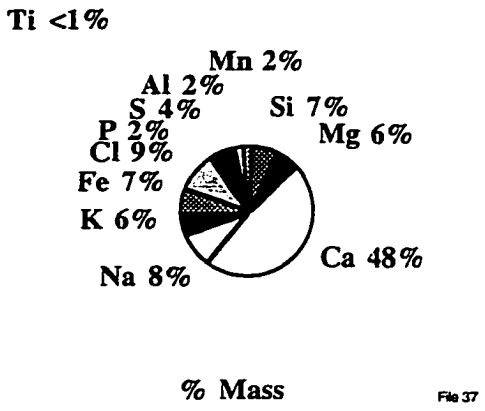


(d)

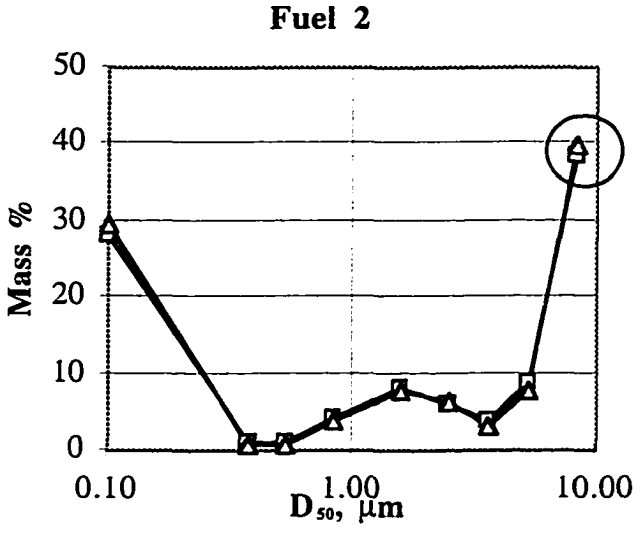
Figure 6.15: Fuel 1 aerosol filter



(a) 750x

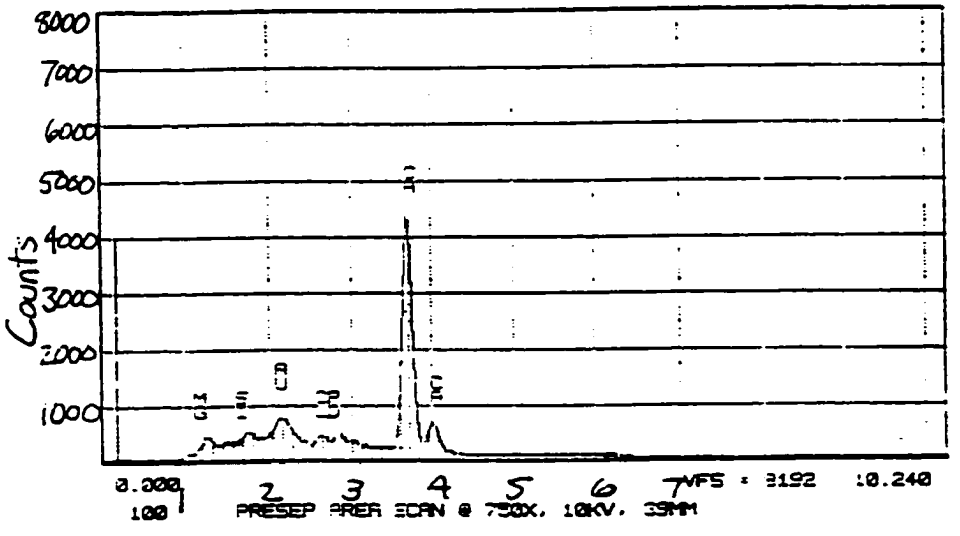


(b) Large particle with carbon background

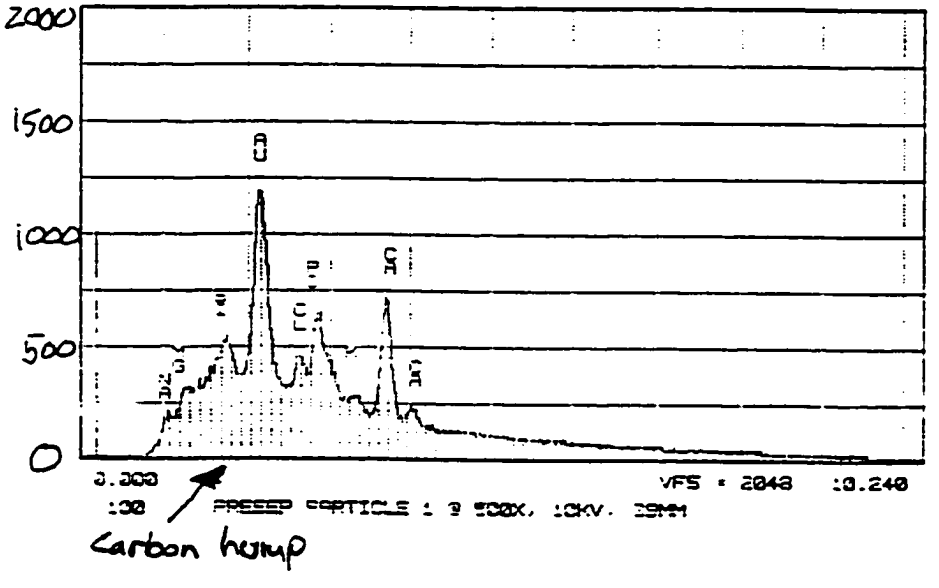


(c)

Figure 6.16: Fuel 2, ash from preseparator

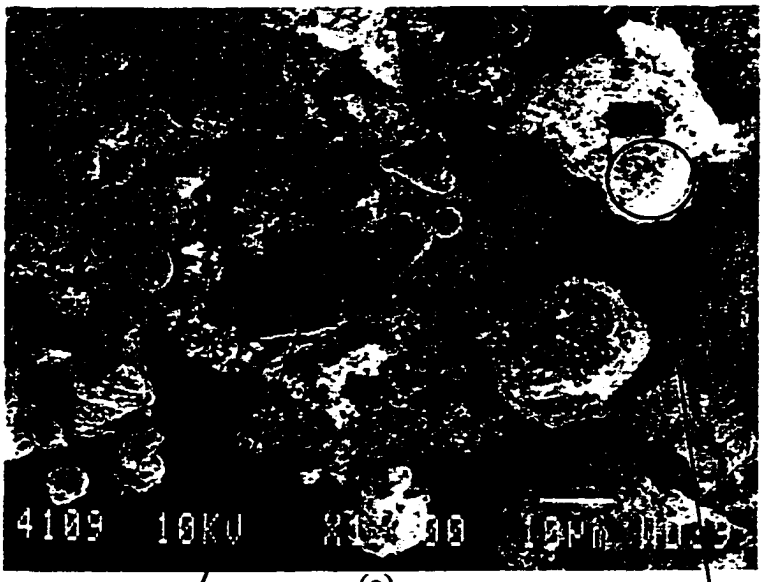


(d) Unprocessed composition signal from EDS for 6.16(a)



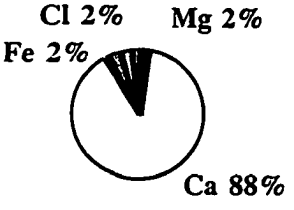
(e) Unprocessed composition signal from EDS for 6.16(b)

Figure 6.16 (continued): Fuel 2. Preseparator



(a)

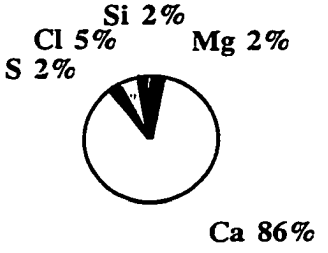
Al, Mn <1%
K, Na, P, S, Si, Ti 1%



% Mass File 35

(b)

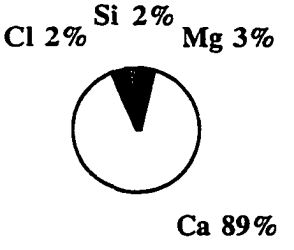
P, Ti <1%
Al, Fe, K, Mn, Na 1%



% Mass File 36

(c)

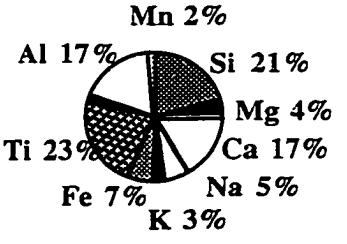
Fe, K <1%
Al, Mn, Na, P, S, Ti 1%



% Mass File 33

(d) 1500x

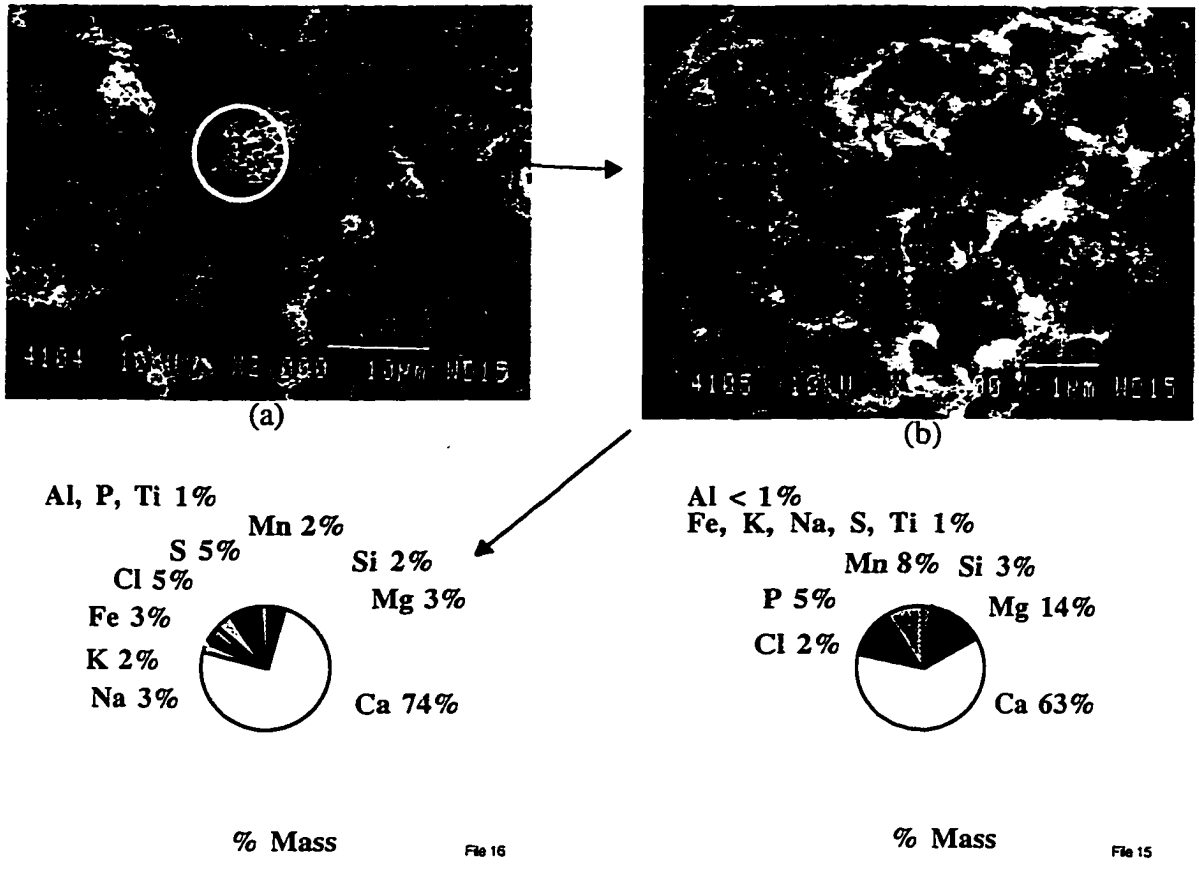
Cl, S <1%
P 1%



% Mass File 34

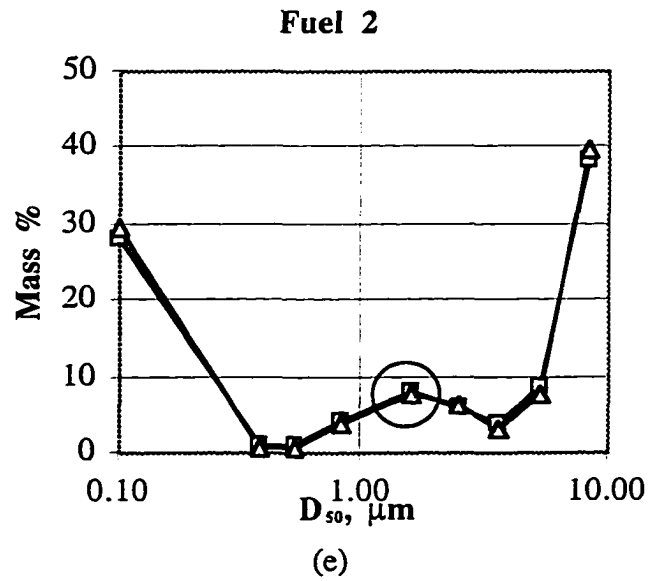
(e)Unique particle, not pictured

Figure 6.17: Fuel 2, Stage 0



(c) EDS of lacy particle, 15K x

(d) Lacy particle wall, 100K x



(e)

Figure 6.18: Fuel 2, Stage 4

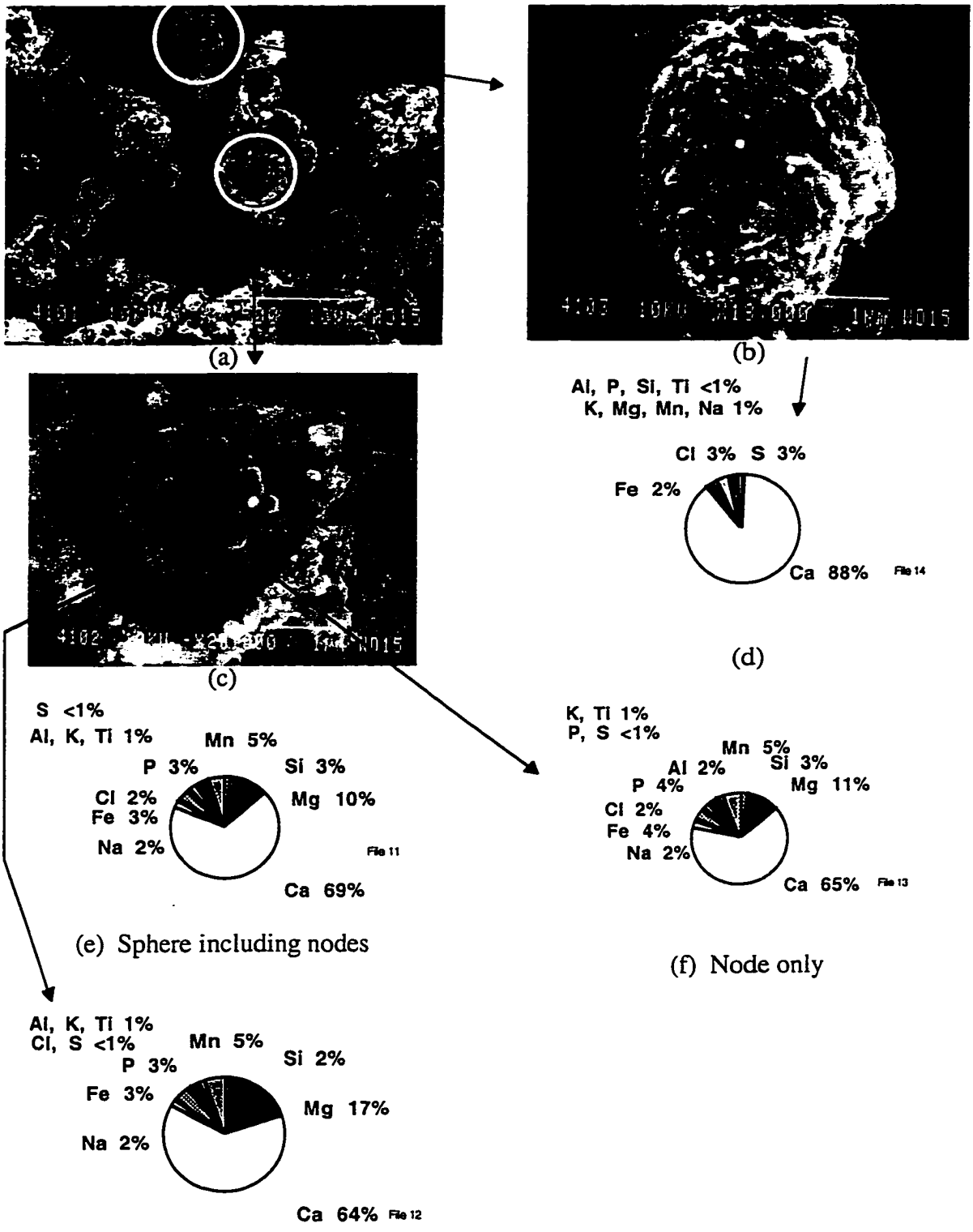
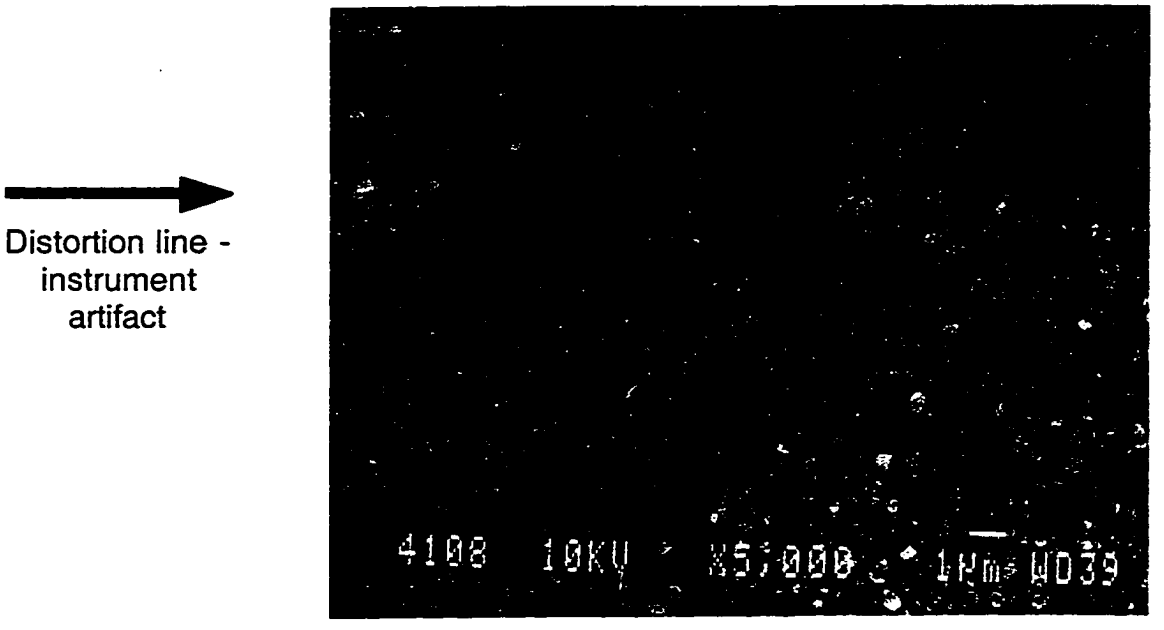
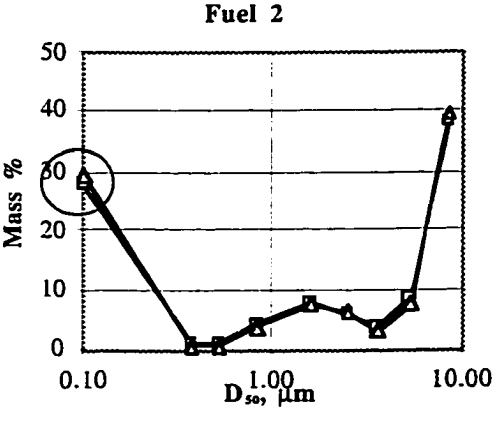


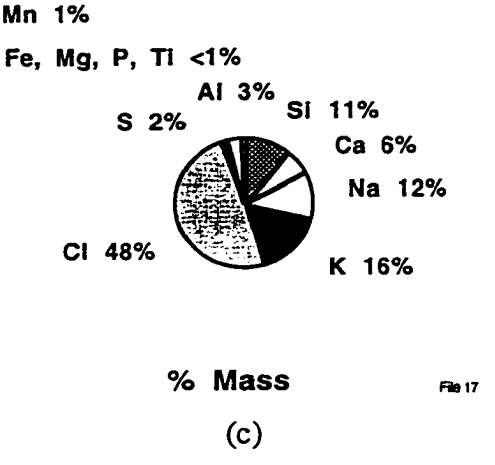
Figure 6.19: Fuel 2, Stage 4



(a)

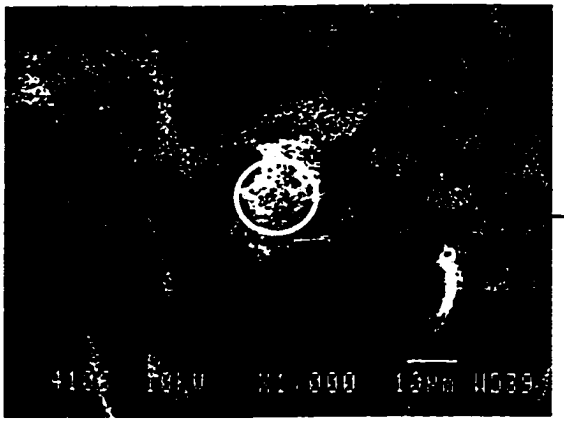


(b)

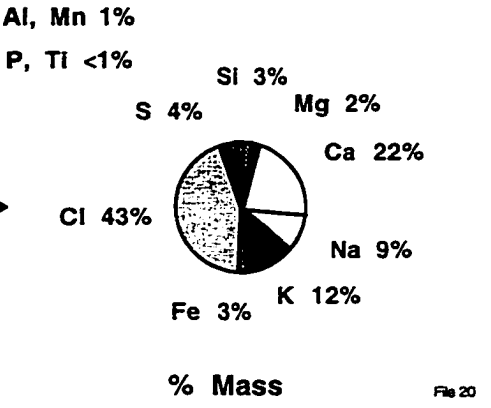


(c)

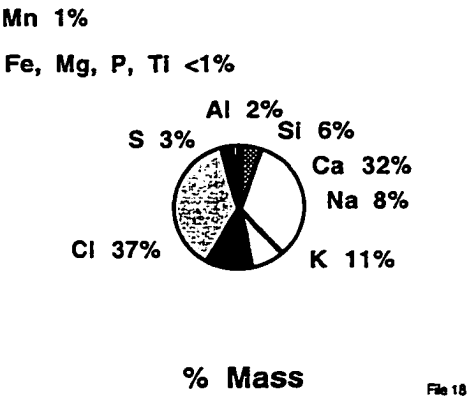
Figure 6.20: Fuel 2, aerosol filter



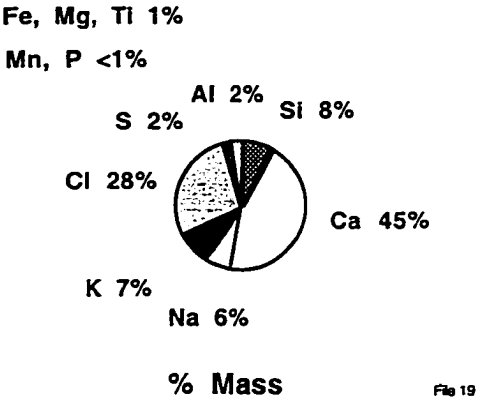
(a)



(b) Large particle on filter

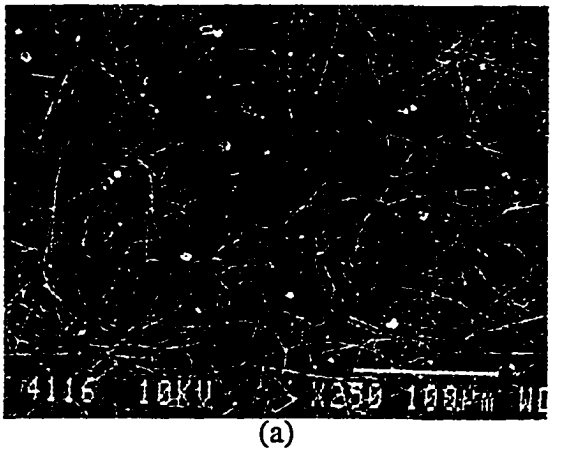


(c) Particle on filter, not pictured

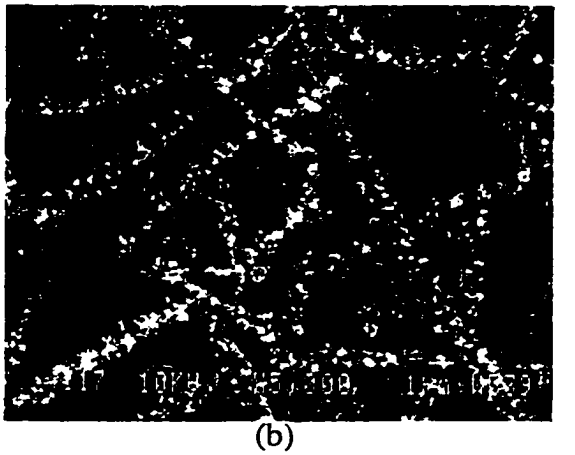


(d) Particle on filter, 10 μm dia, not pictured

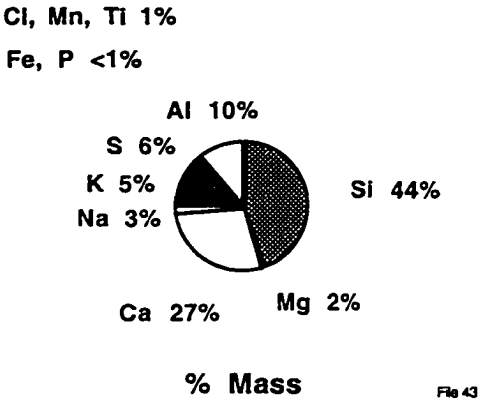
Figure 6.21: Fuel 2 filter, oversize particles



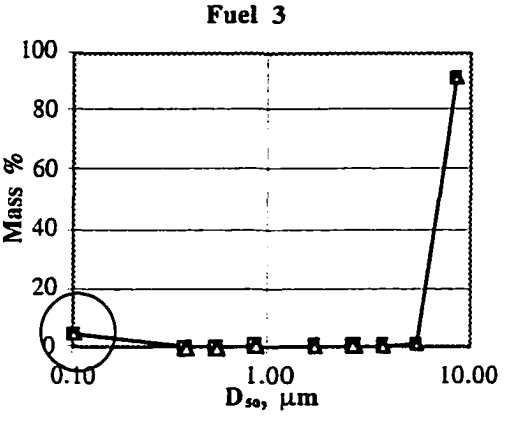
(a)



(b)

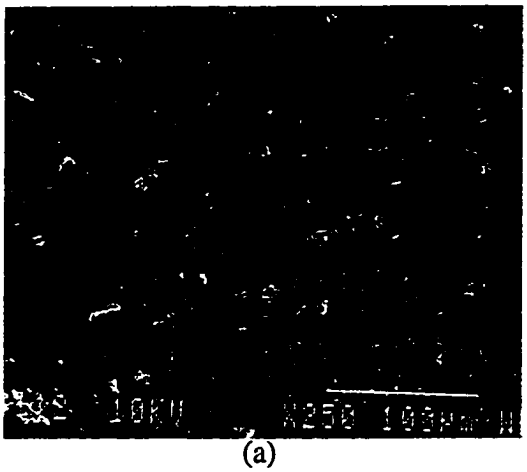


(c)



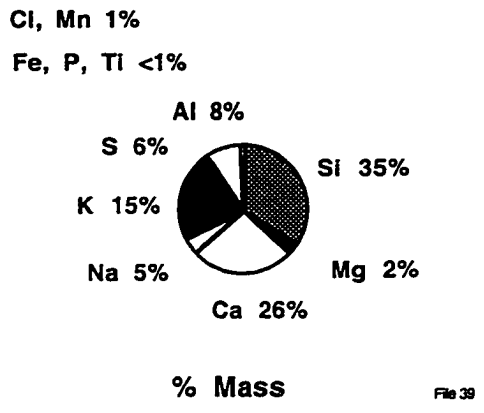
(d)

Figure 6.22: Fuel 3, aerosol filter

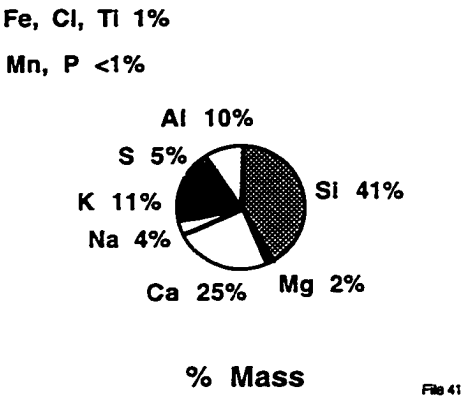


(a)

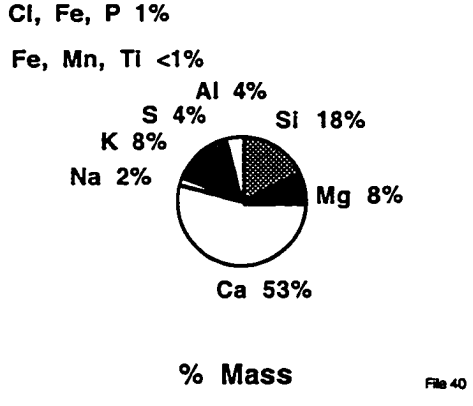
(b)



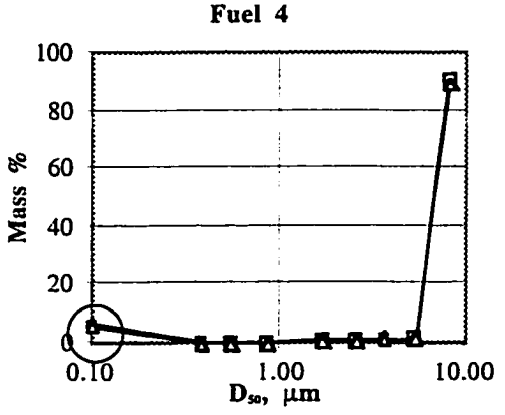
(c) Filter surface, low power (250 x)



(d) Filter surface, high power (5000x)

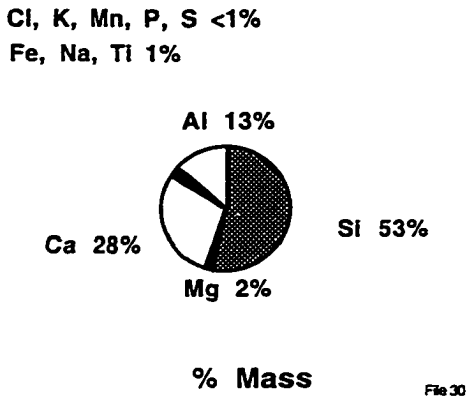


(e) 10 μm particle (not pictured)

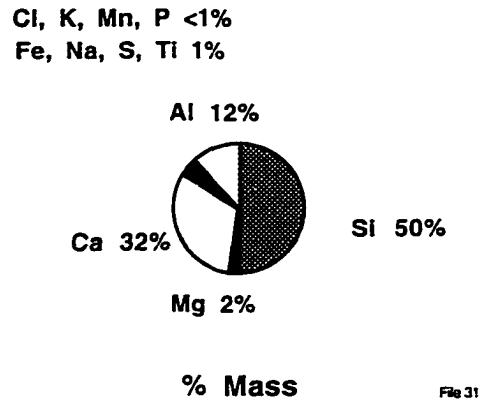


(f)

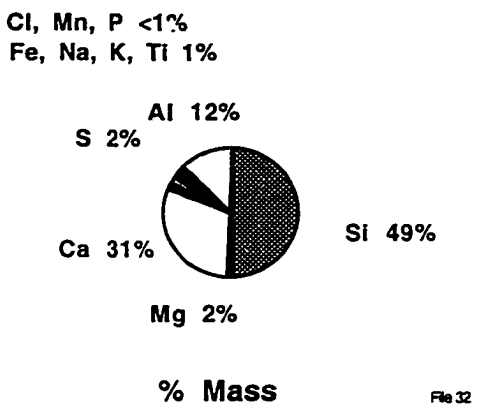
Figure 6.23: Fuel 4, aerosol filter



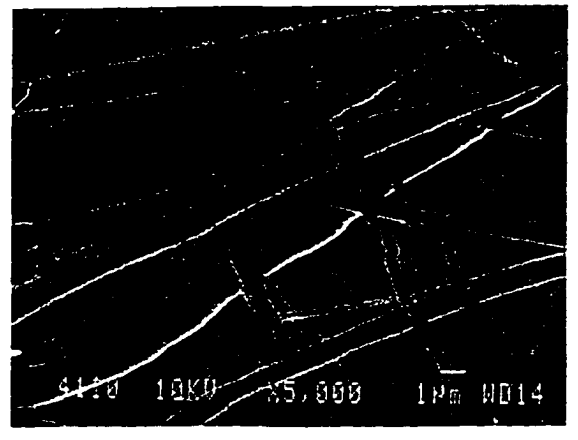
(a) Clean filter, 15000 x



(b) Clean filter, 1000 x



(c) Blank filter, 1000 x



(d) Blank filter, 1000 x, (distortion of image from surface charging)

Figure 6.24: Clean (unused) and blank (used) aerosol filters

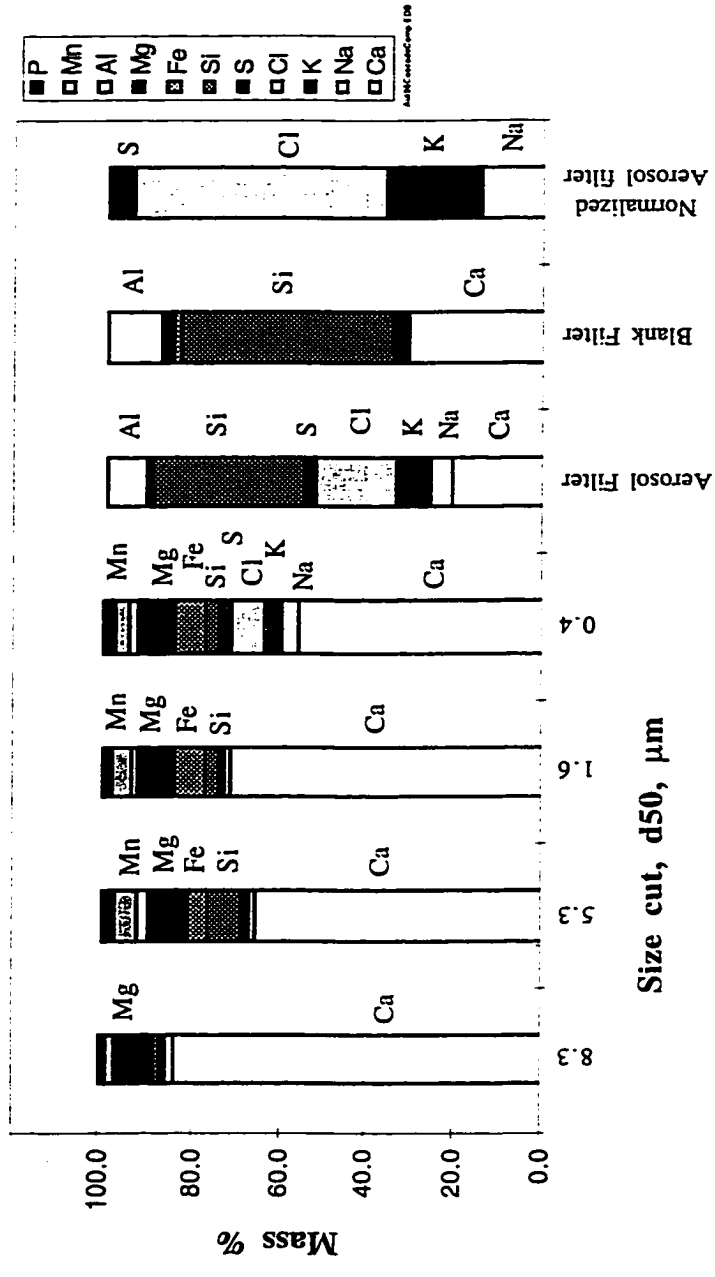


Figure 6.25: Fuel 1 ash elemental analysis by EDS, composition variation with particulate matter size

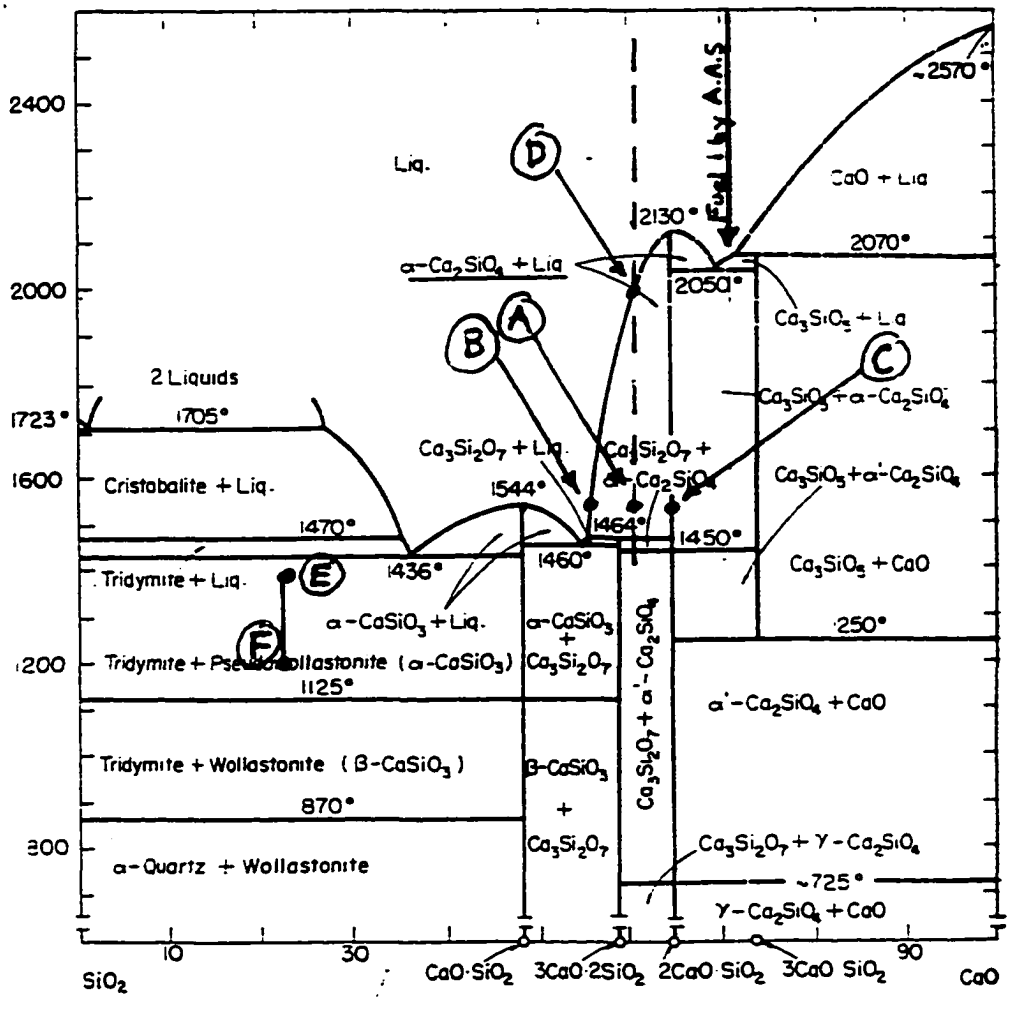


FIG. 237.—System CaO–SiO_2.

Bert Phillips and Arnulf Muan, *J. Am. Ceram. Soc.*, 42 [9] 414 (1959).

Based mainly on data of G. A. Rankin and F. E. Wright, *Am. J. Sci.* [4], 39, 5 (1915) and J. W. Greig, *Am. J. Sci.*, [5], 13, 1–44; [74] 133–54 (1927). Changes with respect to stability relations of tricalcium and dicalcium silicates based on data of D. M. Roy, *J. Am. Ceram. Soc.*, 41 [8] 293–99 (1958) and J. H. Welch and W. Gutt, *J. Am. Ceram. Soc.*, 42 [1] 11–15 (1959).

Figure 6.26: Phase diagram for CaO- SiO_2 system (American Ceramic Society, 1964)

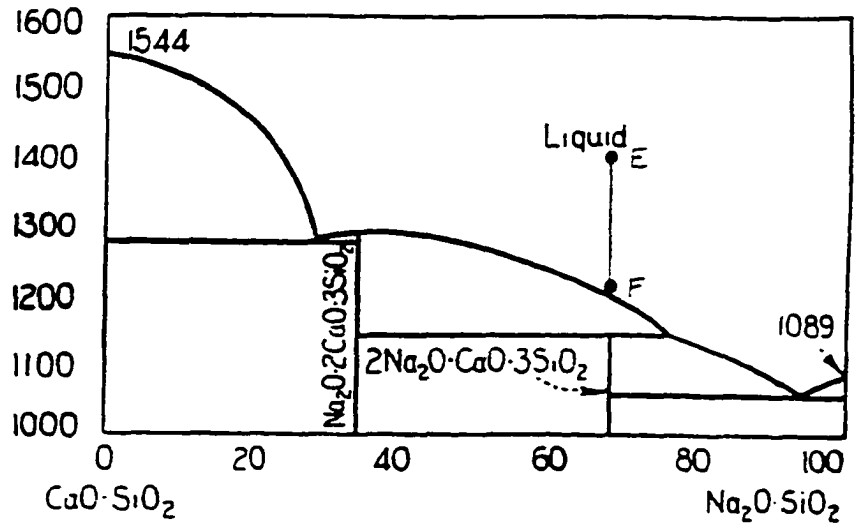


FIG. 484.—System $Na_2O \cdot SiO_2$–$CaO \cdot SiO_2$.

G. W. Morey and N. L. Bowen, *J. Soc. Glass Technol.*, 9, 248 (1925); see also J. Spivak, *J. Geol.*, 52, 29 (1944).

Figure 6.27: Phase diagram for $CaOSiO_2$- Na_2OSiO_2 system (American Ceramic Society, 1964)

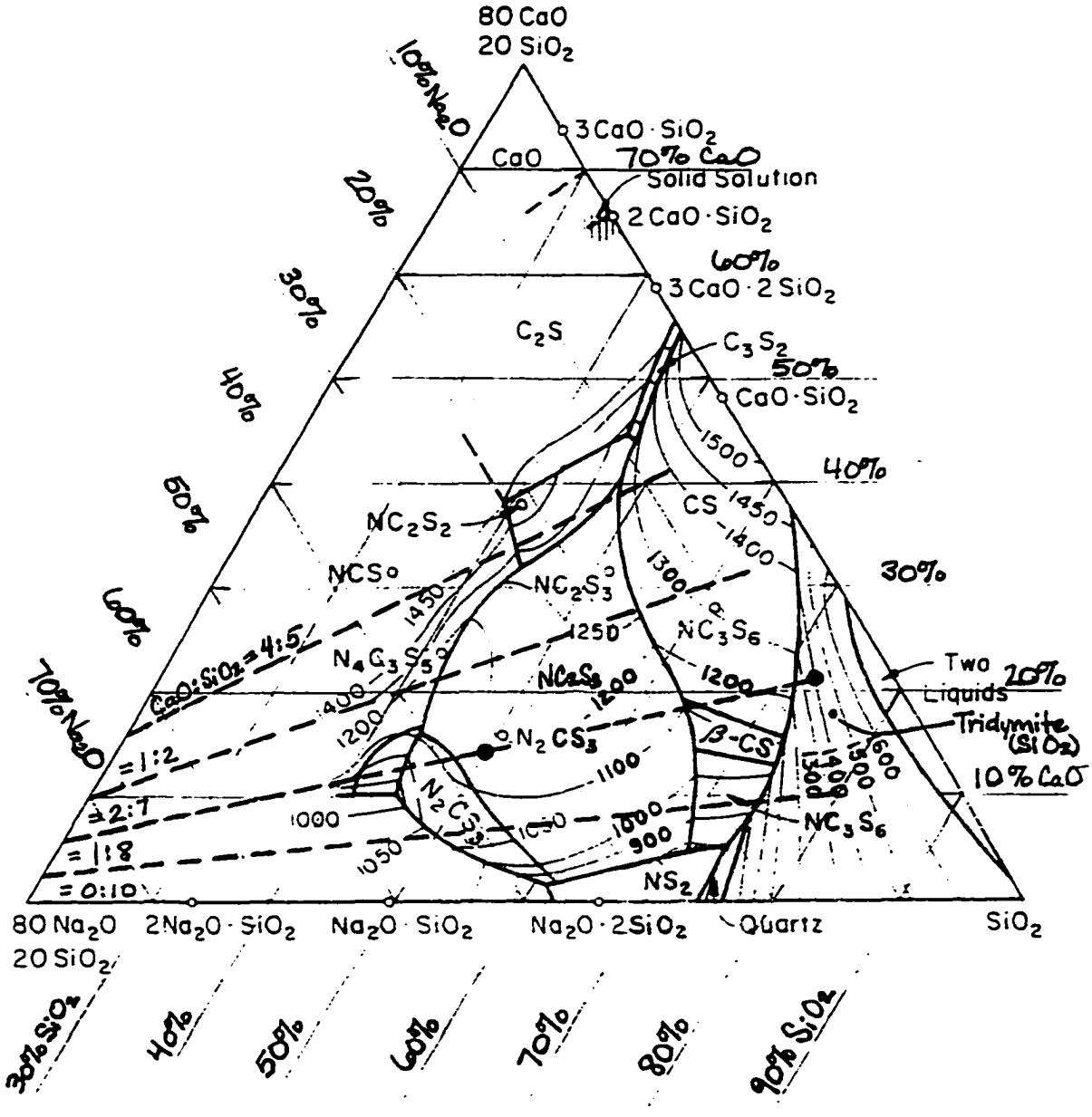


FIG. 481.—System Na_2O–CaO–SiO_2. N = Na_2O; C = CaO; S = SiO_2

The area NS-CS-SiO_2 after Morey and Bowen, Fig 482.
E. R. Segnit, *Am. J. Sci.*, **251** [8] 590 (1953).

Figure 6.28: Ternary diagram for the high silica end of CaO- Na2O - SiO2 system (American Ceramic Society, 1964)

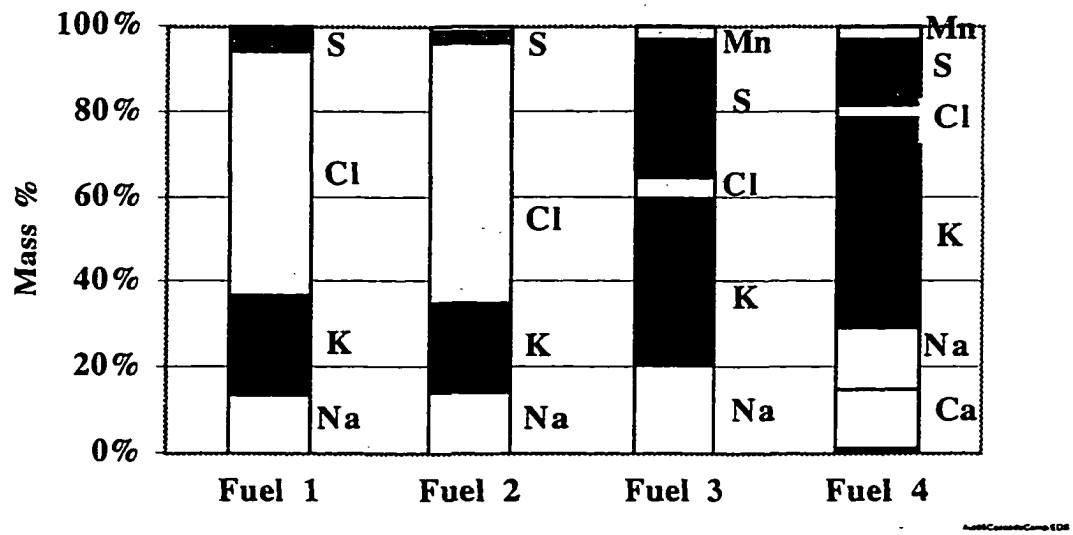


Figure 6.29: Composition of aerosol collected filters, determined by correcting EDS results for background signal from the filter substrate

Table 6.4: Comparision of alkali content to potential anion content in unburned fuels and aerosol ash

	Fuel 1		Fuel 2		Fuel3		Fuel4	
Molar Ratio	Unburned	Aerosol Filter Ash	Unburned	Aerosol Filter Ash	Unburned	Aerosol Filter Ash	Unburned	Aerosol Filter Ash
CL:2S, moles	1.7	6.0	3.3	14.2	0.1	0.1	0.2	0.1
Na:K, moles	2.5	1.1	2.5	1.2	1.8	0.9	1.3	0.5
Na+K:Cl+2S	1.1	0.6	1.2	0.6	0.8	0.9	2.5	1.8

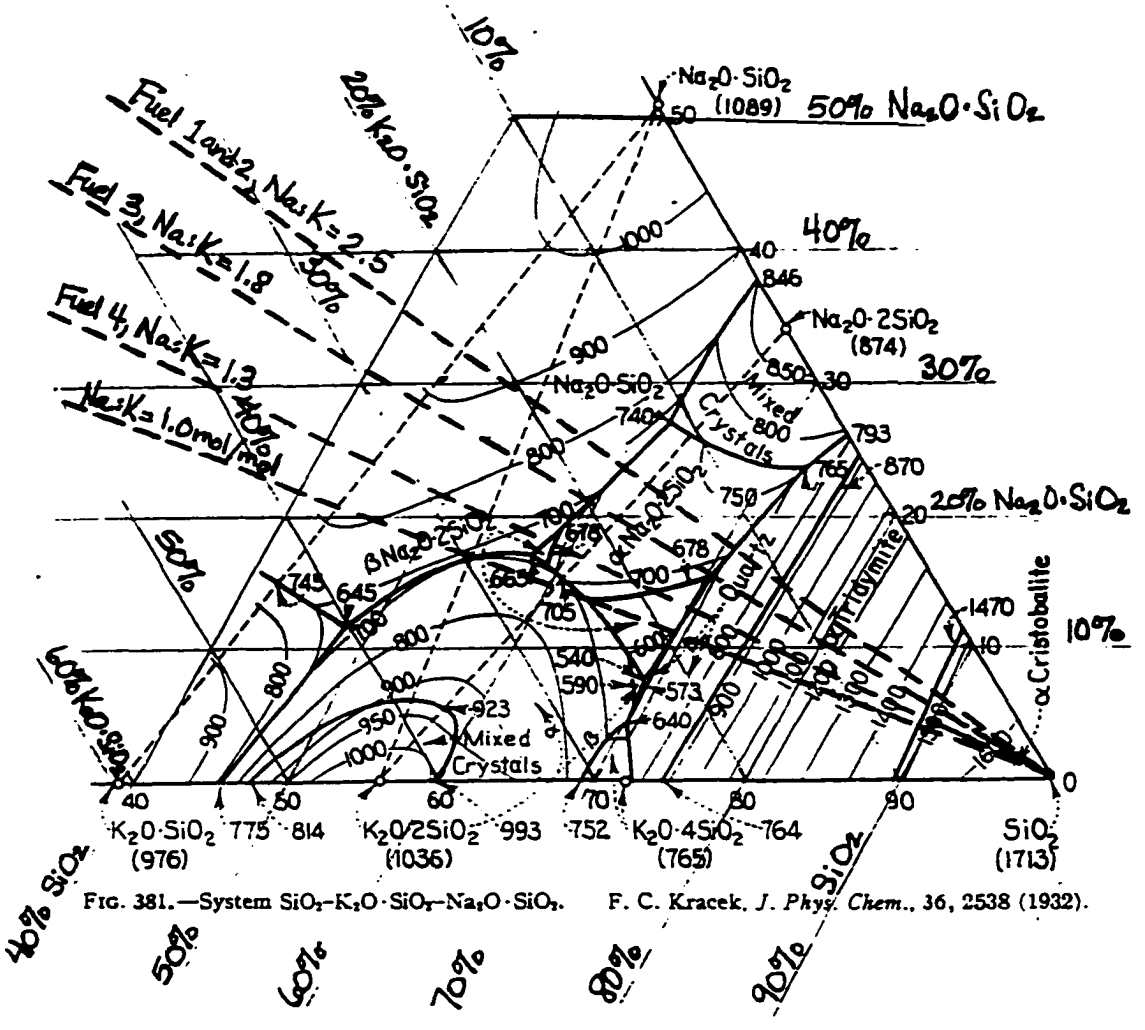


FIG. 381.—System SiO_2-K_2O·SiO_2-Na_2O·SiO_2. F. C. Kracek, *J. Phys. Chem.*, 36, 2538 (1932).

Figure 6.30: Ternary diagram for the high silica end of K_2O- Na_2O - SiO_2 system (American Ceramic Society, 1964)

Table 6.5: Milled sawdust/sanderdust test matrix

Test Number	Fuel	Cascade Impactor	EAA	Temperature	Plastic Tank (200 liter)	Steel Tank (199 liter)	Plexiglass Tank (21 liter)	No Tank	Solid fuel flow rate, g/m					Furnace Flowrate, g/m (no solid fuel)	A/F , incl entrainment air, no solid fuel	Upper Aux A/F equiv	Dry O2, no fuel, % vol	Dry O2 w/fuel, % vol
101796T				x										544.6	28.8	2.0	9.0	
10149601	Fuel 1	x	x		x				4.6					547.1	29.3	2.0	9.3	8.2
10179602	Fuel 1	x	x		x				4.6					544.6	28.8	2.0	9.0	8.0
10219601	Fuel 1	x	x		x				4.6					543.0	28.7	2.1	9.0	7.9
11079601	Fuel 1		x			x			4.6	2.6	1.7	1.1		544.0	28.7	2.0	9.0	
11079602	Fuel 1		x				x		4.6	2.6	1.7	1.1	0.7	544.0	28.7	2.0	9.0	
11079603	Fuel 1		x					x	4.6	2.6	1.7	1.1	0.7	544.0	28.7	2.0	9.0	
11149601	Fuel 2	x	x			x			3.8					548.0	28.9	1.9	9.1	8.3
11149602	Fuel 2	x	x			x			3.8					548.7	29.1	2.0	9.2	8.3
11159601	Fuel 2		x			x			3.8	2.2	1.4	0.9	0.6	548.1	29.2	1.9	9.2	
11159602	Fuel 2		x				x		3.8	2.2	1.4	0.9	0.6	548.1	29.2	1.9	9.2	
11159603	Fuel 2		x					x	3.8	2.2	1.4	0.9	0.6	548.1	29.2	1.9	9.2	
11169601	Fuel 3	x	x			x			4.4					538.7	28.6	2.0	9.0	7.9
11169602	Fuel 3	x	x			x			4.4					545.9	29.1	1.9	9.2	8.1
11179601	Fuel 3		x			x			4.4	2.7	1.7	1.1	0.7	545.9	29.1	2.0	9.2	
11179602	Fuel 3		x				x		4.4	2.7	1.7	1.1	0.7	545.9	29.1	2.0	9.2	
11179603	Fuel 3		x					x	4.4	2.7	1.7	1.1	0.7	545.9	29.1	2.0	9.2	
11129601	Fuel 4	x	x			x			3.4					546.5	28.9	2.0	9.1	8.2
10249601	Fuel 4	x	x		x				3.4					544.6	28.8	2.0	9.0	8.2
11139601	Fuel 4		x			x			3.4	2.0	1.3	0.8	0.5	548.0	28.9	2.0	9.1	
11139602	Fuel 4		x				x		3.4	2.0	1.3	0.8	0.5	548.0	28.9	2.0	9.1	
11139603	Fuel 4		x					x	3.4	2.0	1.3			548.0	28.9	2.0	9.1	
Average:														**545.9**	**28.9**	**2.0**	**9.1**	
112596T				x										304.9	31.6	1.3	10.2	
11269601	Fuel 1	x	x			x			4.6					307.1	31.2	1.3	10.0	8.2
11279601	Fuel 1	x	x			x			4.6					305.3	30.9	1.3	9.9	8.0
11279602	Fuel 4	x	x			x			3.4					305.9	31.0	1.3	10.0	8.5
11279603	Fuel 4	x	x			x			3.4					302.8	30.7	1.3	9.9	8.3
Average:														**305.3**	**31.0**	**1.3**	**9.9**	
112096T				x										305.3	32.4	2.1	10.4	
11219601	Fuel 1	x	x			x			4.6					303.1	32.2	2.0	10.4	8.5
11219602	Fuel 1	x	x			x			4.6					302.9	31.9	2.0	10.3	8.4
11219603	Fuel 1		x			x			4.6	2.6	1.7	1.1	0.7	302.3	32.0	2.0	10.3	
11219604	Fuel 1		x				x		4.6	2.6	1.7	1.1	0.7	302.3	32.0	2.0	10.3	
11219605	Fuel 1		x					x	4.6	2.6	1.7	1.1	0.7	302.3	32.0	2.0	10.3	
11239602	Fuel 2	x	x			x			3.8					303.7	32.6	1.9	10.5	9.0
11239603	Fuel 2	x	x			x			3.8					303.3	32.7	2.0	10.6	9.0
11229601	Fuel 3	x	x			x			4.4					302.8	32.1	2.0	10.4	8.5
11229602	Fuel 3	x	x			x			4.4					307.7	32.6	2.0	10.5	8.7
11229603	Fuel 4	x	x			x			3.4					302.9	31.9	2.0	10.3	8.8
11239601	Fuel 4	x	x			x			3.4					303.5	32.5	2.0	10.5	9.0
11219606	Blank	x	x											302.8	32.0	2.0	10.3	
Average:														**303.5**	**32.2**	**2.0**	**10.4**	

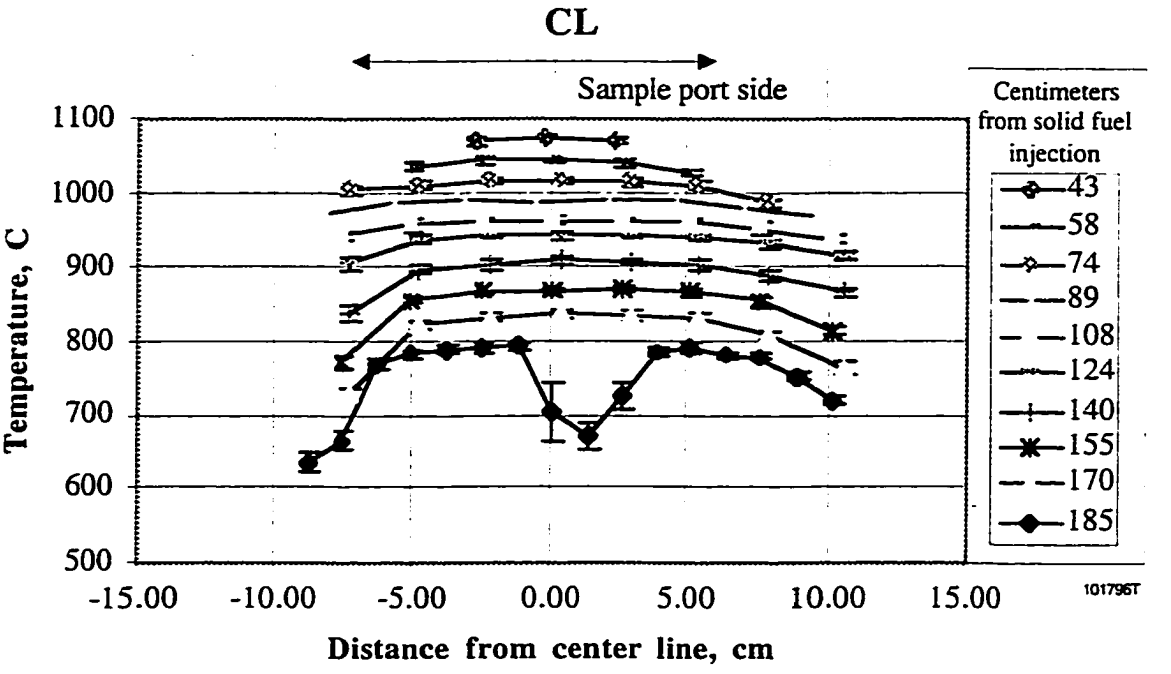


Figure 6.31: Transverse temperature profile by High Velocity Thermocouple at maximum temperature/flow rate settings, test number 101796T

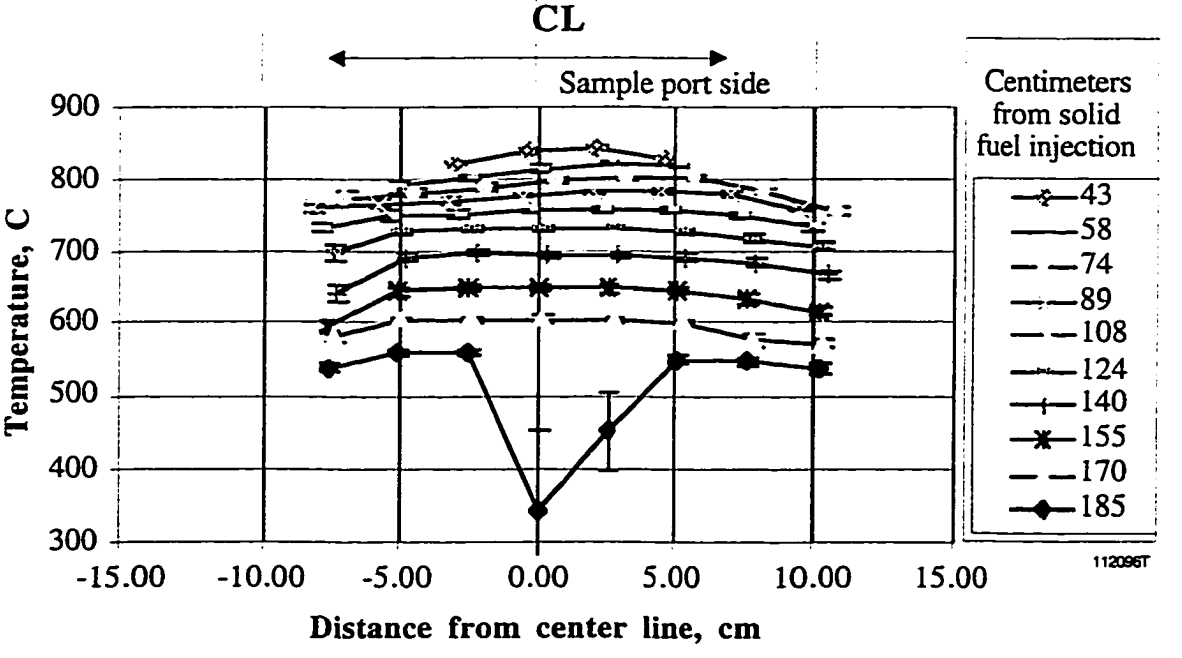


Figure 6.32: Transverse temperature profile by High Velocity Thermocouple at moderate temperature/flow rate settings, test number 112596T

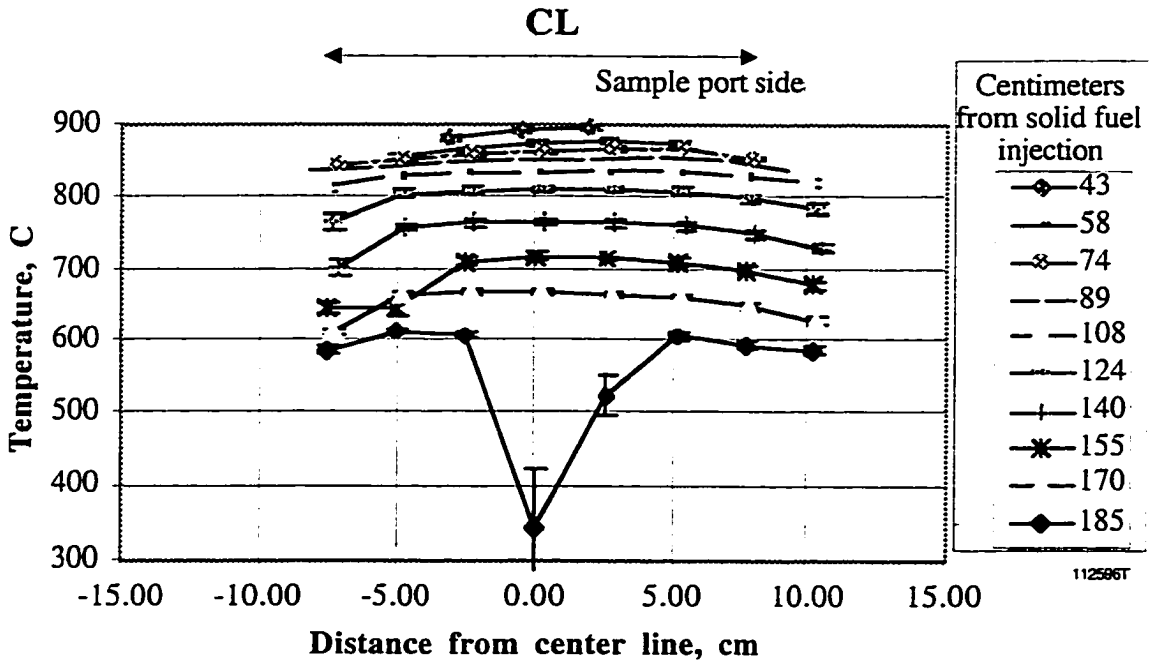
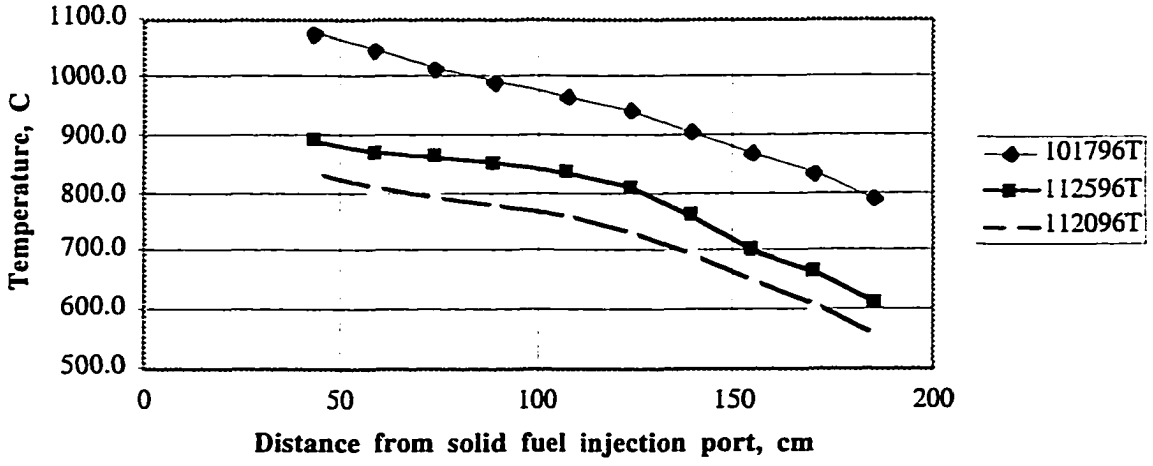


Figure 6.33: Transverse temperature profile by High Velocity Thermocouple at minimum temperature/flow rate settings, test number 112096T



	101796T	101796T	101796T	112596T	112596T	112096T	112096T
Port	cm from solid fuel injection	Average temperature, degC	Average dev. ,+/- K	Average temperature, degC	Average dev. ,+/- K	Average temperature, degC	Average dev. ,+/- K
k*	185	791.0	5.6	611.	4.6	559.	4.1
j	170	832.2	5.6	667.	3.7	609.	3.8
i	155	867.8	3.9	701.	5.8	650.	4.0
h	140	905.0	5.0	764.	4.6	696.	3.9
g	124	941.7	4.4	808.	4.7	733.	3.2
f	108	964.4	4.4	835.	3.3	758.	3.5
e	89	989.9	4.9	853.	3.1	780.	3.5
d	74	1013.3	4.4	862.	2.6	793.	4.4
c	58	1045.2	4.6	873.	3.3	815.	3.5
b	43	1073.0	3.7	889.	3.3	838.	3.3
Average temperature taken from -5 cm to +5 cm, relative to CL							
*Port K measurements from 0 to +2.5 cm disgarded							

Figure 6.34: Temperature profile as a function of distance from pulverized fuel injection for three different furnace settings

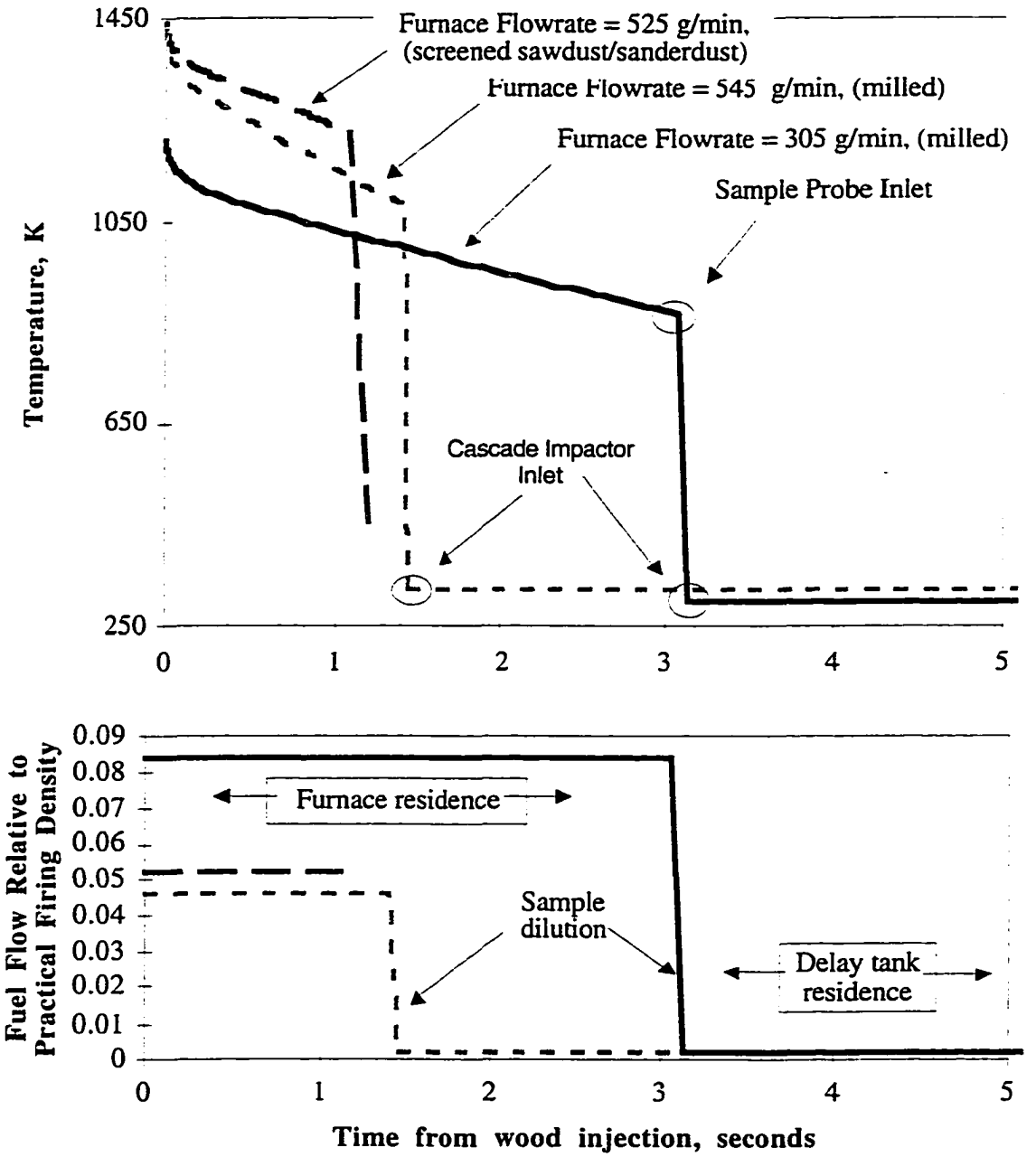


Figure 6.35: Temperature and dilution profiles for sawdust/sanderdust experiments

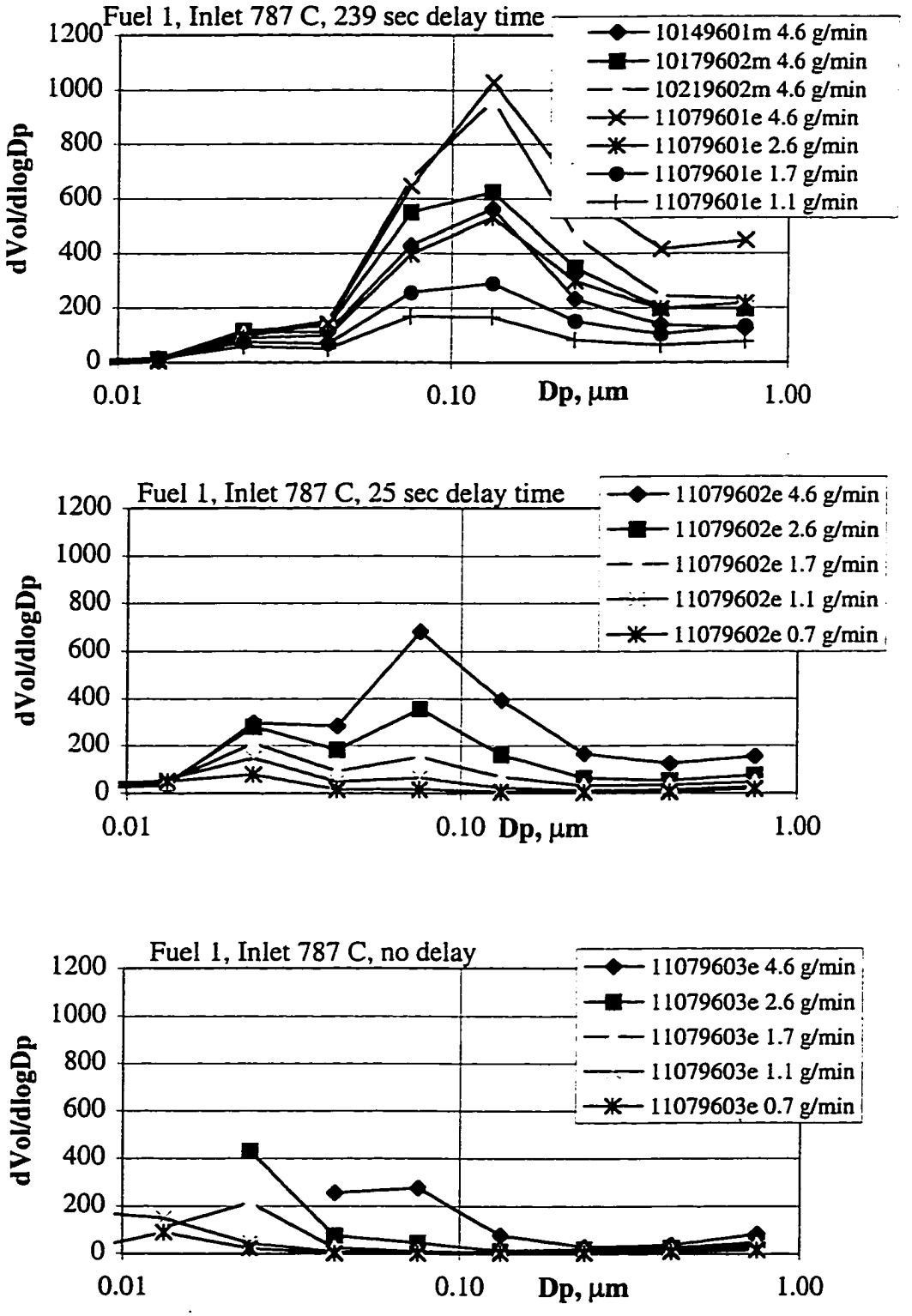


Figure 6.36: Fuel 1 EAA experiments at highest furnace temperature

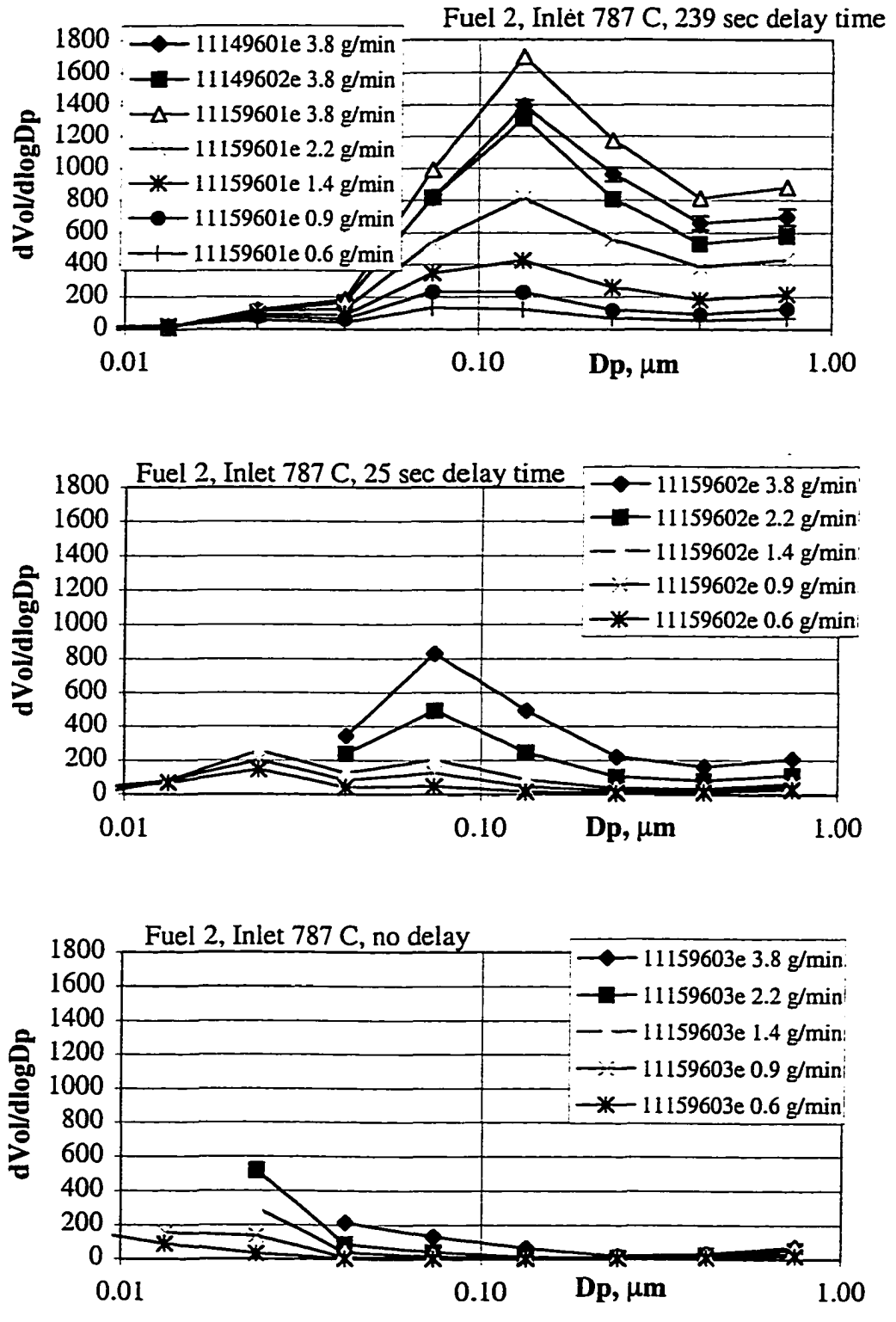
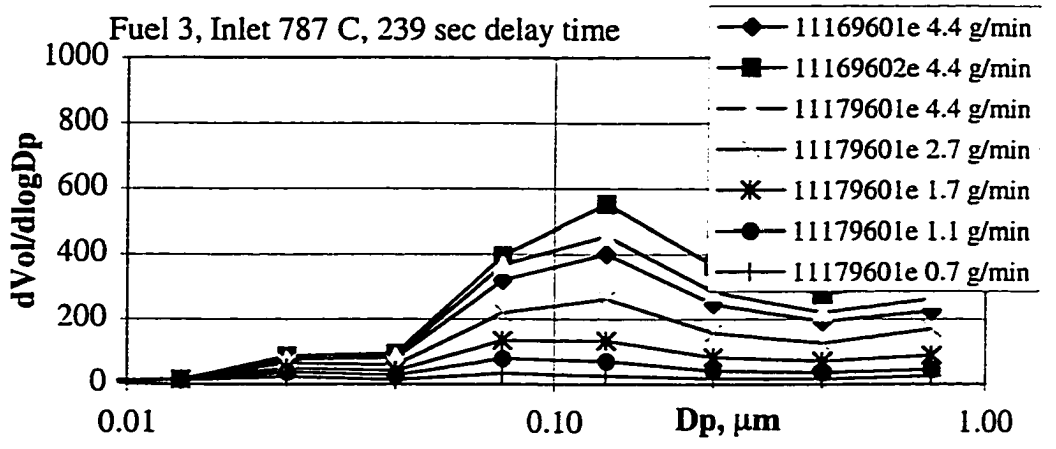
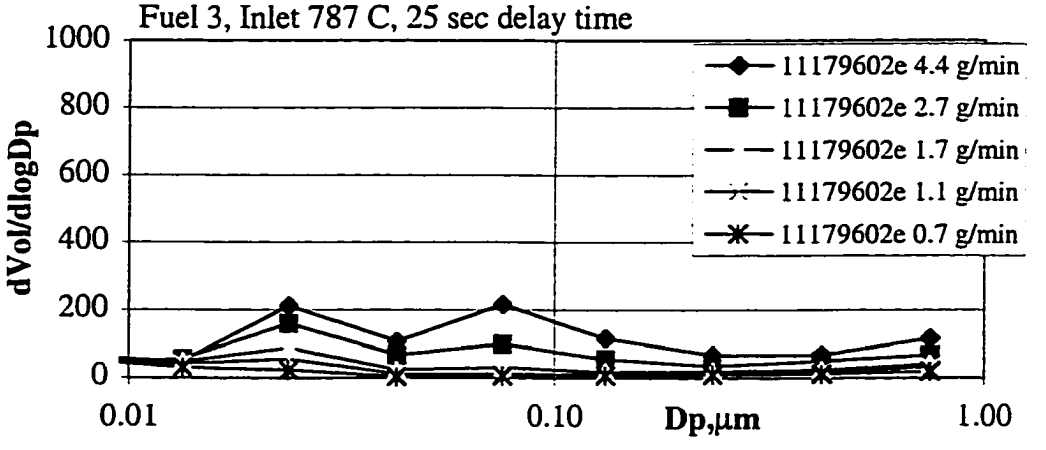


Figure 6.37: Fuel 2 EAA experiments at highest furnace temperature





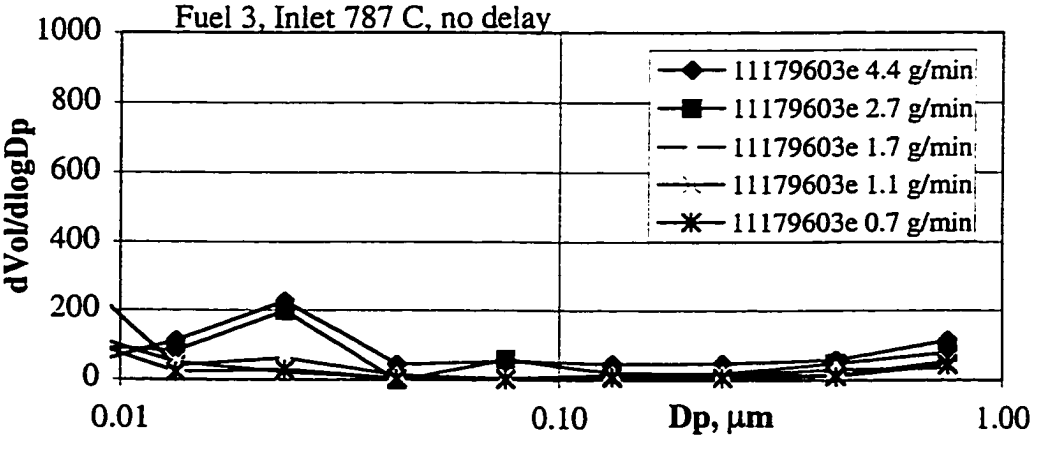


Figure 6.38: Fuel 3 EAA experiments at highest furnace temperature

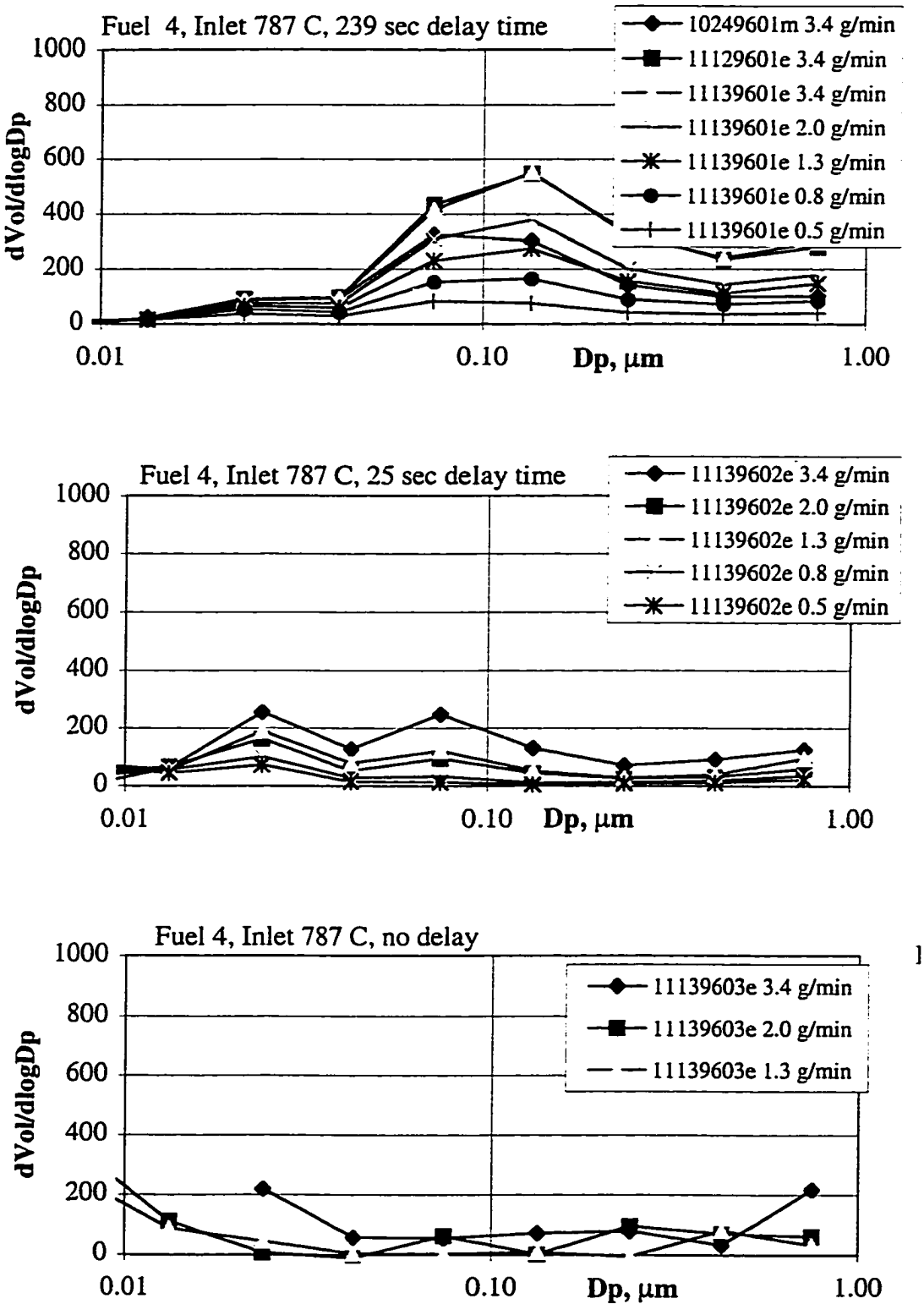


Figure 6.39: Fuel 4 EAA experiments at highest furnace temperature

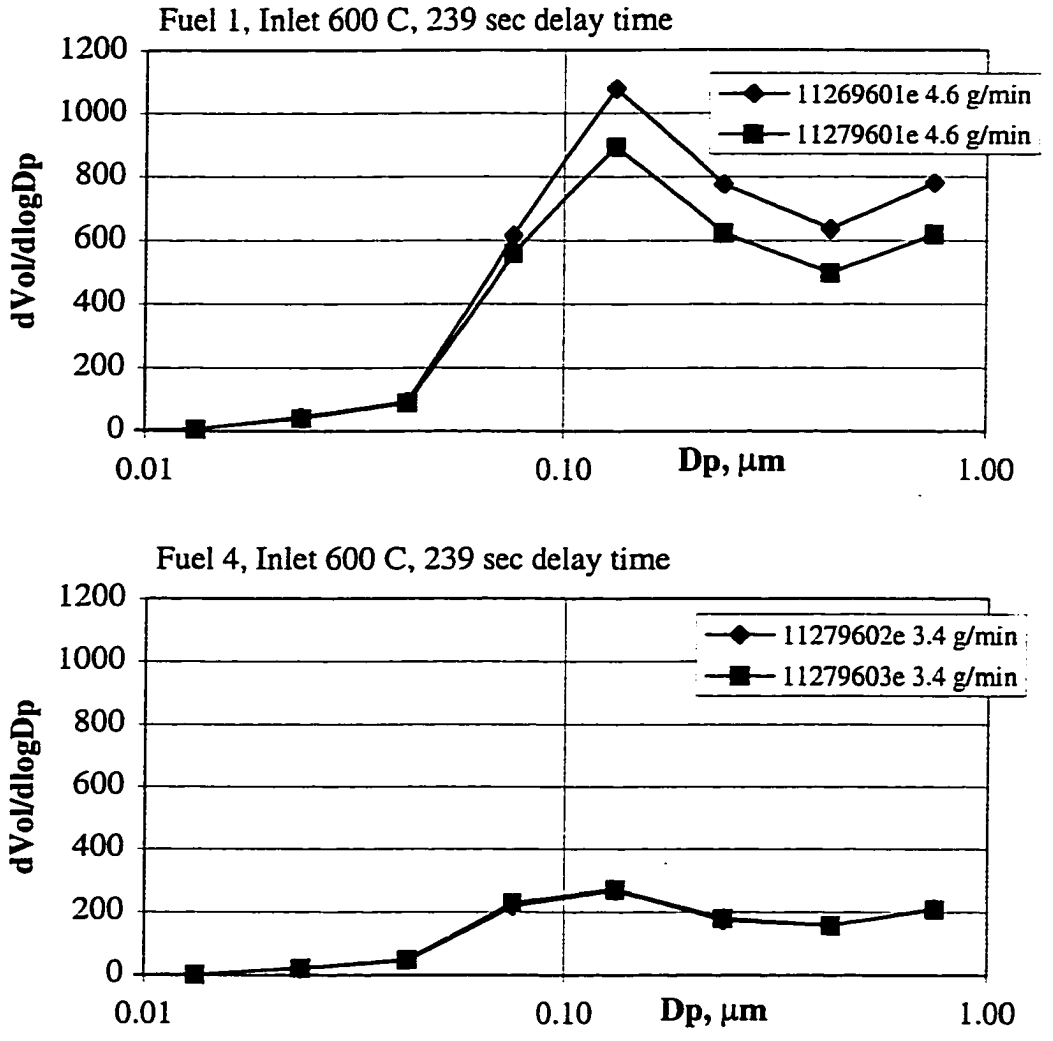
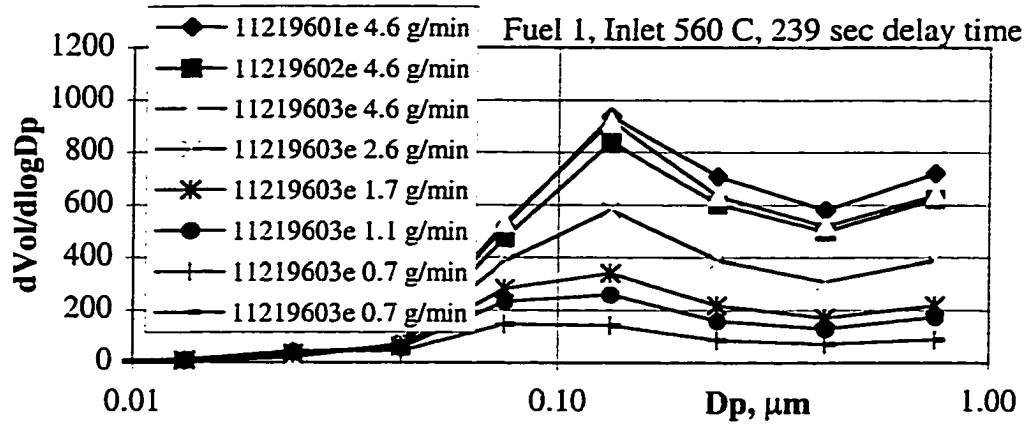
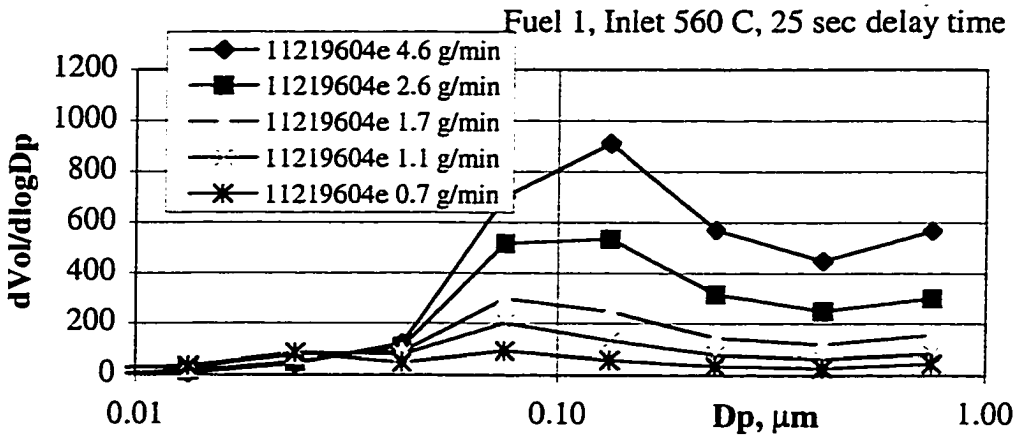


Figure 6.40: Fuel 1 and 4 EAA experiments at moderate temperature





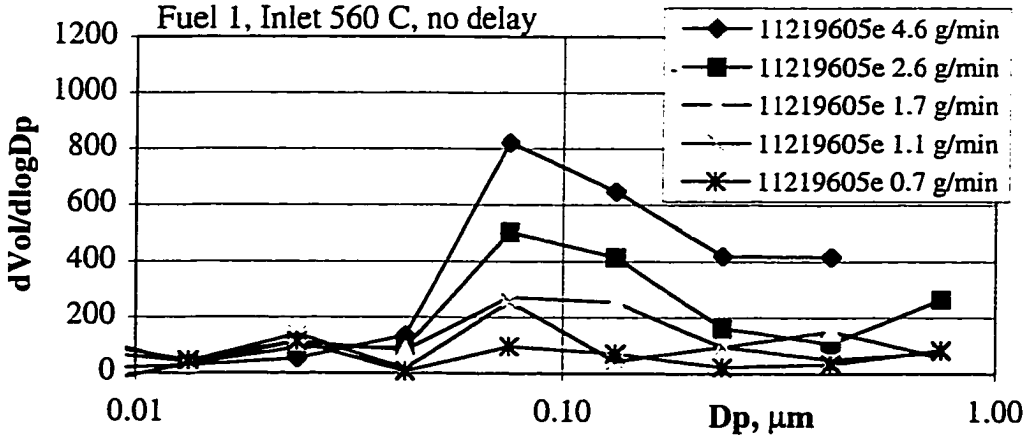


Figure 6.41: Fuel 1 EAA experiments at low furnace temperature

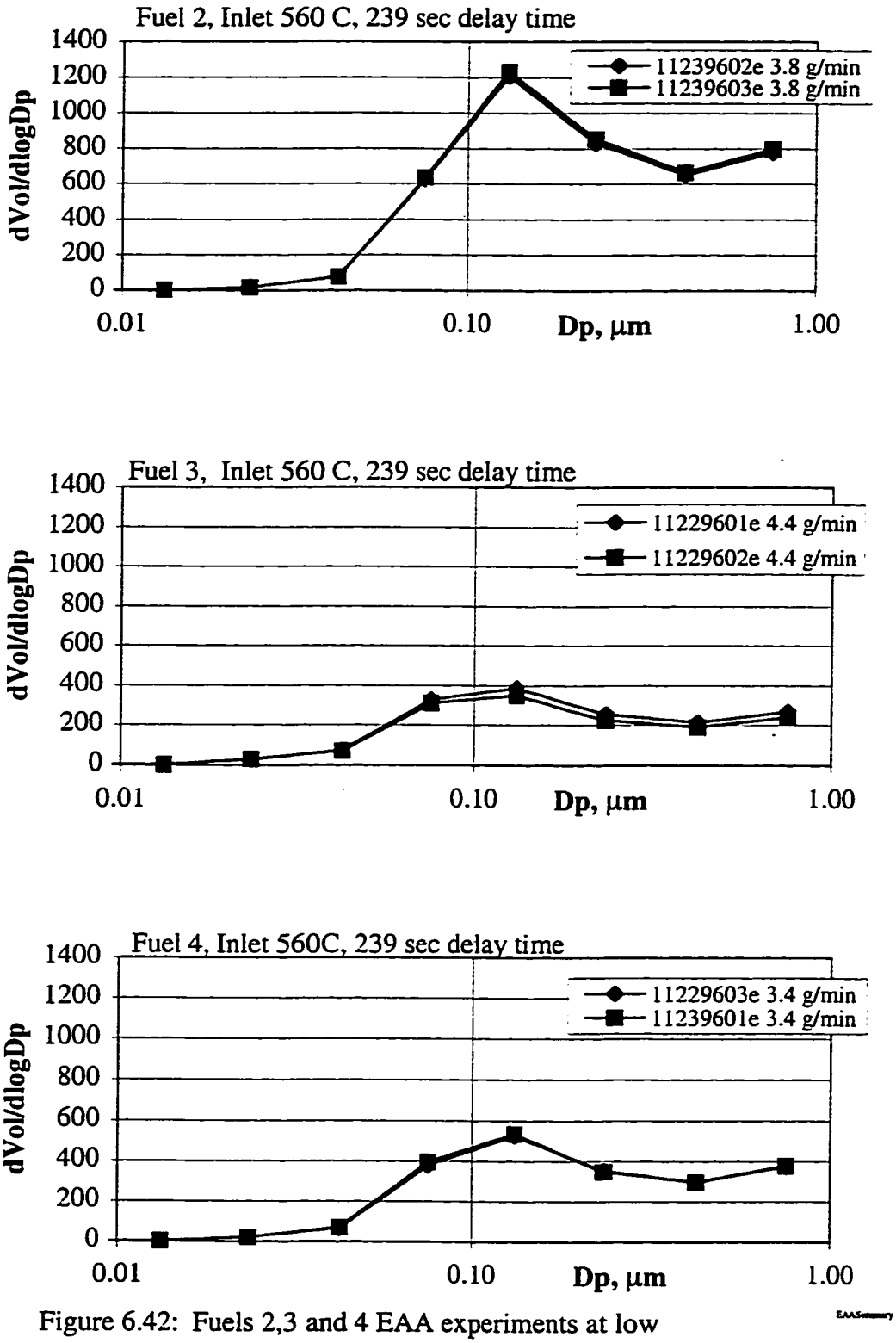


Figure 6.42: Fuels 2,3 and 4 EAA experiments at low furnace temperature

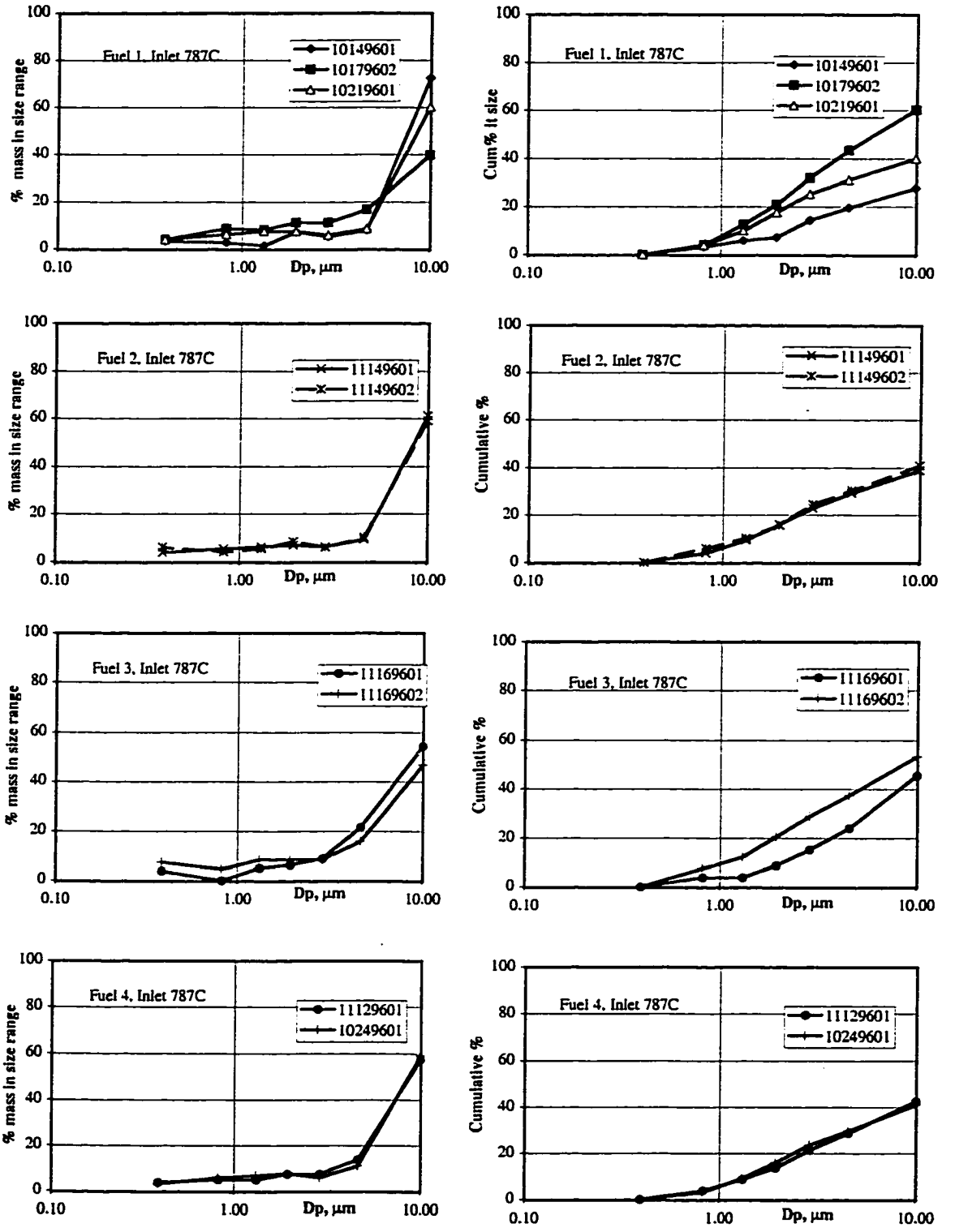


Figure 6.43: Fuels 1, 2, 3 and 4 cascade impactor data at highest furnace temperature

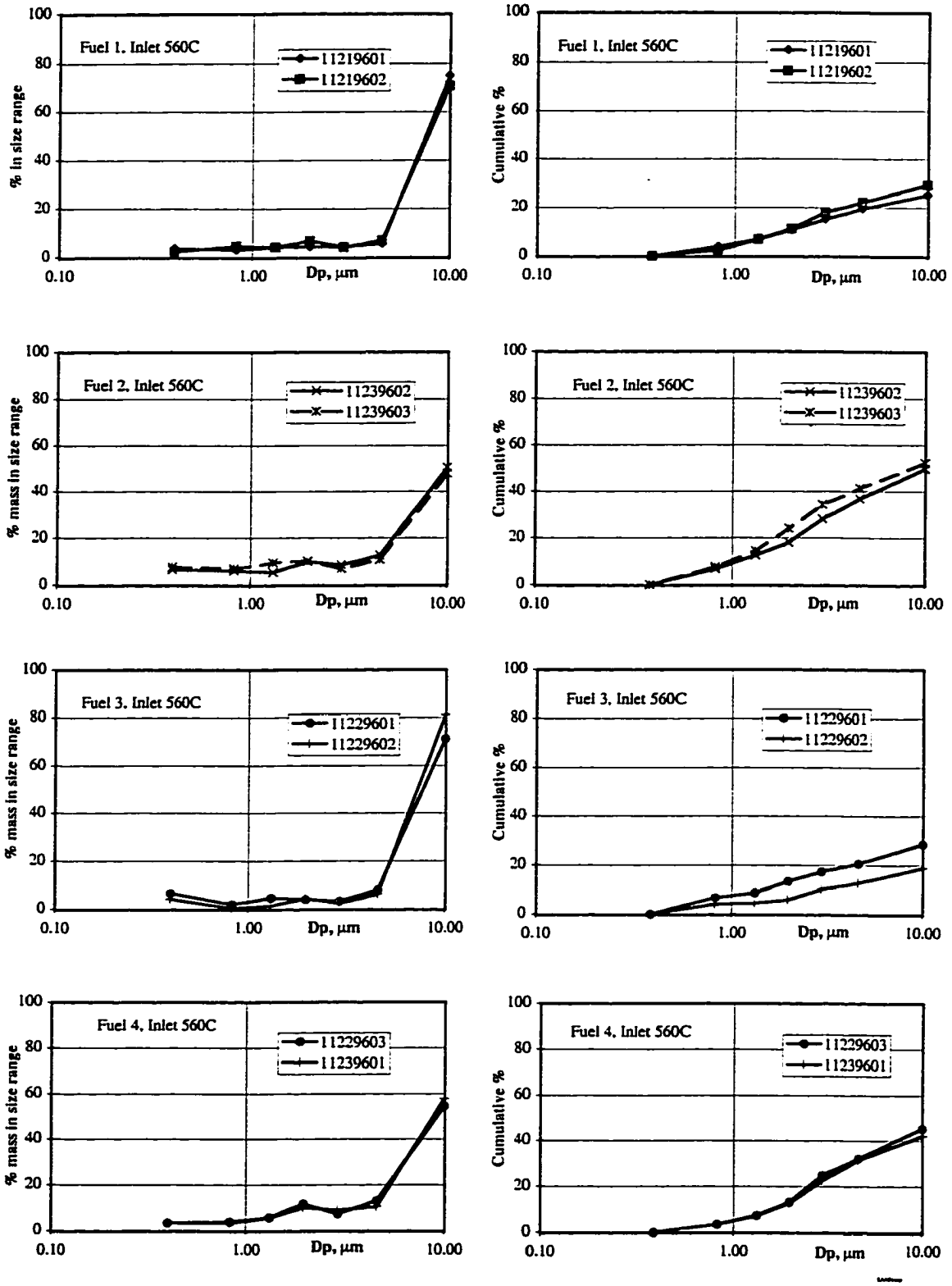


Figure 6.45: Fuels 1, 2, 3 and 4 cascade impactor data at low furnace temperature

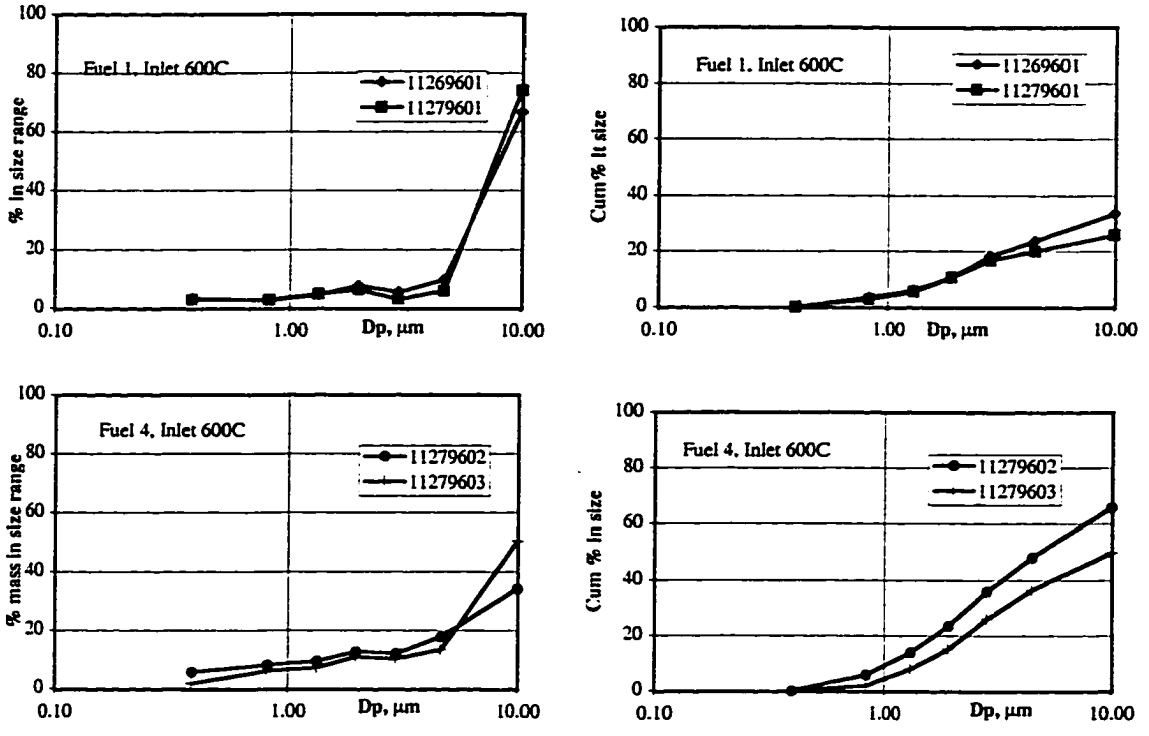


Figure 6.44: Fuels 1 and 4 cascade impactor data at moderate furnace temperature

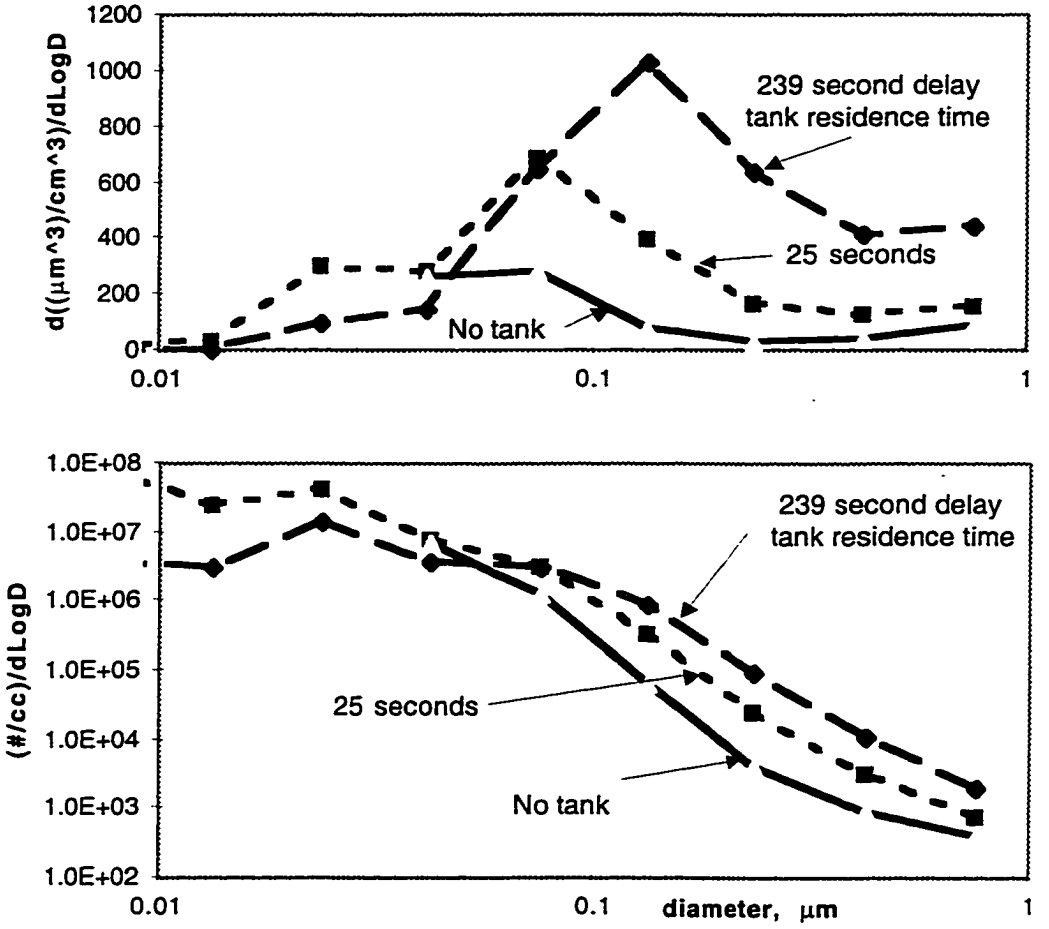


Figure 6.46: Fuel 1 tests with variable delay tank residence times

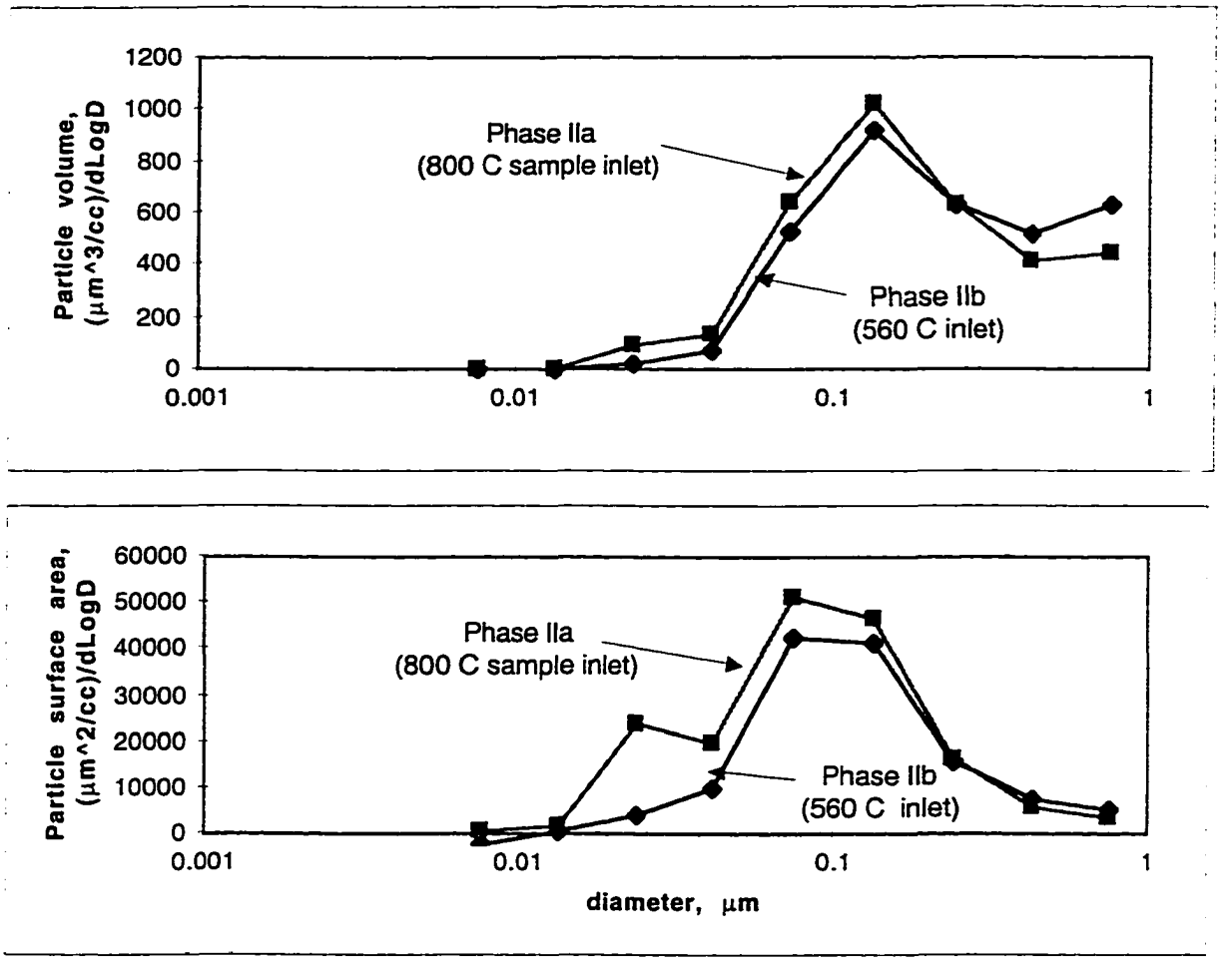


Figure 6.47: Fuel 1 EAA experiments showing the effect of sample inlet temperature on size distribution

MODELING

Modeling is used to examine the critical mechanisms that control ash transformations in the sub-micron particle size range. Although some industrial parameters can be duplicated at laboratory scale, it is clear that modeling plays an important role in bridging the gap between these conditions. The experimental results discussed earlier are used to anchor the model. The ultimate goal is to understand how the size distribution is developed, and how the mineral elements are partitioned into the various size classes.

7.1 Modeling Parameters

Modeling consists of three components: First, gas-phase and condensed phase mineral species favored by equilibrium are determined. Relatively high furnace temperatures and residence times suggest that equilibrium is a good model for gas-phase mineral transformations. Second, the fate of condensing mineral species is investigated by modeling the competition between *condensation* of vapor-phase mineral matter on existing particles, versus *homogeneous nucleation.* Third, the ultimate size distribution of condensed species is investigated by application of a coagulation model.

Modeling is investigated relative to the industrial application shown in schematic form in Figure 7.1. Sawdust/sanderdust is pneumatically injected tangential into the cylindrical primary combustor from a single port. Primary air is added tangential down the length of the burner through sized tuyures, which results in a variable mixture ratio. Overall, the primary combustion zone is operated with an excess air flow rate of 80% to 125%. Secondary air is added in the volume linking the suspension burner to the blend chamber. Blend air is added as required to obtain the desired mass flow rate and to limit the maximum dryer inlet temperature to 866K.

Table 7.1 compares typical combustion conditions in the laboratory tunnel furnace to conditions found in an industrial suspension burner fired with Fuel 4. The table shows that industrial furnace is operated in an overall lean mode, like the laboratory furnace. Facility engineers estimate a primary combustion zone temperature of 1750K to 1475K when operating with Fuel 4 and 80% to 125% excess air. If the primary combustion zone were perfectly premixed, this fuel to air ratio range would result in an adiabatic flame temperature

of 1452K to 1265K, based on the lower heating value of Fuel 4. The high temperature observed in the field is undoubtedly driven by the variable mixture ratio in the primary burner, in which air is added incrementally down the length of the burner.

Table 7.1 also shows the laboratory burner operates at an order of magnitude lower wood-fuel-flowrate-to-total-flowrate ratio than the industrial burner, although the dry oxygen content and exhaust gas temperature is similar. Recall that the laboratory tunnel furnace conditions are maintained with a natural gas and air flame, with sawdust/sanderdust added after primary combustion, while the industrial furnace is operated solely on sawdust and sanderdust. (Note that it was not the goal of the laboratory furnace experiments to match the industrial conditions. Instead, the goal of the dilute suspension firing was to maintain a known, controllable environment around each burning particle.)

The combustion zone residence time is based on plug flow estimates for both the laboratory and industrial systems. The highly-stirred nature of the suspension burner probably results in a variable particulate matter residence time. Incompletely burned sawdust/sanderdust particles have been observed entering the blend chamber from the secondary volume. Incomplete combustion is partly due to oversize fuel particles but is also due to the short residence time.

Table 7.2 shows a summary of idealized residual ash particle size distributions used for modeling alkali condensation onto existing residual particles. A idealized residual size distribution is used in modeling for two reasons: First, simplifying the input residual size distribution allows the user to analyze vapor capture by isolating a discrete particle diameter, rather than grouping vapor capture rates over a range of particle diameters. Secondly, residual ash size distributions are typically not characterized well enough to justify incorporating a detailed residual size input.

Appendix A details the method used for converting the discrete size distributions obtained from the experimental data set into the size distributions shown in Table 7.2. In summary, the residual particles are assumed to form two discrete modes, which are expressed as a Geometric Mass Mean Diameter and a Geometric Standard Deviation. For the heterogeneous vapor capture model, this is further simplified to a single particle size for each mode. It is assumed that these modes are made of a particulate matter with a solid

density of 3.25 g/cc (CaO). The particle number density for that mode is calculated assuming mass is conserved in that mode.

Since it was clear from the experimental results that Fuel 1 and Fuel 2 have similar experimental residual size distributions, their idealized size distributions are taken to be identical. Likewise, Fuel 3 and Fuel 4 idealized size distributions are taken to be identical.

7.2 Equilibrium

Equilibrium conditions were investigated using a derivative of the NASA chemical equilibrium code CET89 (Eddings). This code is very useful in particulate matter investigations because it includes metallic and alkali species in its equilibrium database and predicts equilibrium species in both the gas and condensed phase. Although the code considers condensed species, it does not treat interactions between these species (*e.g.*, the formation of solid solutions or eutectics). In other words, each condensed species is treated as an individual solid or liquid, in contact with the gas but not in contact with each other. For example, the code would not predict a suppression of sodium vapor pressure due to the complexing of the sodium with an aluminosilicate.

The products of combustion from the main burner (*i.e.* methane and air), and air used for pulverized fuel entrainment were included in the calculations. In general, elemental species considered are C, H, O, N, S, Al, Ca, Fe, Mg, Na, P, Si, and Cl. Concentrations of abundant common species (*e.g.*, H_2O, N_2, O_2, CO_2) and species not relevant to ash formation (*e.g.* CO, NO) are not presented here.

7.2.1 Fuel 1 Equilibrium at Laboratory Conditions

Figure 7.2 shows equilibrium conditions in the tunnel furnace for Fuel 1. Input composition is based on 4.64 grams/minute Fuel 1, 18.3 grams/minute natural gas, and 525 grams/minute air.

Equilibrium suggests that non-alkali solid phase minerals are favored at all reasonable flame temperatures of the reactor. It further suggests that solid phase chemistry will result in transformation into other solid species at lower temperatures (*e.g.*, the transformation of $CaMgO_2$ to $Ca_3MgSi_2O_8$ at 1000K). Of course, solid-to-solid transformation is not

kinetically favored on any reasonable time scale. It is more likely that solid mineral phases will evolve in a complex way, driven by very localized char composition and the local combustion environment. Mineral species already in close association or in a fuel rich environment may form preferentially over the global equilibrium species. In the absence of other mineral species, oxides are favored for non-alkali metals.

It is immediately clear in Figure 7.2 that vapor phase NaCl and KCl are stable at combustion temperatures. These are precursors to the condensed species formation. NaCl and KCl condense near 870K and 860K.

Sodium sulfate is expected by equilibrium to begin forming as a liquid near 1250K. This process is surely kinetically limited in a practical environment, since vapor-phase Na_2SO_4 is not a preferred species. At equilibrium, the formation mechanism is likely a NaOH reaction with SO_2, but under kinetically controlled conditions it is more likely formed by sulfation of a condensed phase alkali. Formation of Na_2CO_3 begins at about 1050K, at the expense of the remaining vapor phase NaOH and some NaCl. However, a rapid quench rate may result in direct condensation of NaOH, without conversion to a carbonate. Although sodium carbonate is not a preferred vapor phase species, its formation may be assisted by the abundance of carbon species in the flue gas. HCl is formed during the conversion, but is converted back to alkali salts at a lower temperature. Kinetics probably favor direct condensation of the alkali salts without the HCl intermediary.

Figure 7.3 shows equilibrium conditions for only the alkali species in the laboratory furnace. Non-alkali solid phase minerals equilibrium values at 870K under these conditions are also shown for reference. Note that a rapid quench event through the condensation temperature will likely result in direct formation of solid phase from vapor phase NaCl and KCl. Although this fuel is much higher in chlorine than Fuels 3 and 4, it is an insufficient amount for complete capture of all alkali species. As discussed earlier (see Figure 7.2) Na_2SO_4 and Na_2CO_3 are probably not kinetically favored over condensed NaOH, in a rapid quench environment.

7.2.2 Fuel 1 Equilibrium at Industrial Conditions

Figure 7.4 shows equilibrium calculations for conditions in a commercial suspension burner operated at 80% excess air. The commercial burner is ideally fired with only air and

wood fuel, while the laboratory furnace hot gas environment is maintained by natural gas and air combustion. This results in an order of magnitude increase in ash concentration (per mole of combustion products) between the laboratory furnace and the commercial burner. The higher partial pressure of the mineral species drives the equilibrium condensation temperatures up. This is of little consequence for most non-alkali mineral species, since their condensation temperatures are higher than the commercial burner operating range of 1750 K to 1475K.

Sodium sulfate is formed at about 1400 K (compared to 1250 K for the laboratory furnace), but conversion is probably kinetically limited because vapor phase Na_2SO_4 does not exist, as stated earlier. Sodium carbonate is favored at about 1130 K (vs. 1080 K for the laboratory furnace), NaCl condenses from the vapor phase near 960K (vs. 880 K), and KCl condenses near 940 K (vs. 860 K). Higher condensation/formation temperatures promotes large particle formation via coagulation of the highly mobile sub-micron aerosol earlier in the time/temperature history of the combustion gases.

The preferential vapor-phase sodium species shifts from NaOH to NaCl near 1700 K, versus 1300 K for the laboratory furnace. This may result in a higher fraction of NaCl conversion to NaCl (s), and less conversion of NaOH to NaOH (l) in a rapid quench environment.

The calculated adiabatic temperature drops from 1630K to 1298K when combustion gases from the suspension burner mix with the air added in the secondary volume. It is possible that Na_2SO_4 can overcome the kinetic barrier and form in the secondary volume. This conversion is assumed to be negligible compared to other conversions events occurring downstream. In addition, dilution with secondary air lowers the partial pressure of all fuel-generated species. This results in a shift of solid and liquid-phase mineral formation toward slightly cooler temperatures, which is a detriment to Na_2SO_4 formation.

Figure 7.5 shows equilibrium calculations for the blend chamber. About five times the amount of air used during primary combustion is added in the blend chamber to reduce the dryer inlet temperature, as shown in Figure 7.1. This results in a significant dilution of the vapor phase species, and a drop in NaCl condensation temperature from about 950 K to 910K, and a drop in KCl from about 940K to 880K. Sodium sulfate and sodium carbonate equilibrium formation temperatures drop by about 60 K and 70K, respectively.

Equilibrium in the blend chamber was recalculated with sulfur and carbon excluded, with the purpose of excluding alkali species whose formation is most likely kinetically limited (*i.e.* Na_2CO_3 and Na_2SO_4). The major carbon species CO_2 was replaced with N_2 to preserve relative molar concentrations. The result is shown in the lower graph of Figure 7.5. Potassium has priority in chlorine capture over sodium, with the remaining sodium condensing to liquid NaOH.

Although the condensation scenario shown in the lower graph of Figure 7.5 is probably closer to the results expected from an industrial system, one obvious kinetic barrier exists. KOH in the vapor phase is predicted by equilibrium to capture chlorine from NaCl in order to completely convert to KCl (s). In reasonably rapid quench, NaCl, NaOH, and existing vapor phase KCl will likely homogeneously condense before this ion exchange is complete. Figure 7.6 gives insight to the fate of KOH, in the absence of S, C and Cl. Liquid phase KOH forms at a low temperature compared to other condensed alkalis. The high mobility of nucleated particulate (*e.g.* NaCl (s)) will probably aid in the conversion of KOH vapor to KCl (s) as a surface reaction. The large surface to volume ratio of these condensed species are a critical factor.

7.2.3 Fuel 2 Equilibrium

Fuel 2 is the highest in chlorine of the four fuels tested. Like Fuel 1, the chlorine combines with potassium and sodium to form salts in the vapor phase, as shown in Figure 7.7. Vapor phase NaCl and KCl eventually become condensed NaCl and KCl as the gas temperature is lowered. Sodium sulfate is favored by equilibrium starting at 1230 K, but its formation is limited by diffusion transport and residence time. Sulfation of NaCl(s) and $NaCO_3$(s) will probably continue after exiting the primary and secondary combustion zones.

Interestingly, KCl (s) and Na_2SO_4 (s) exchange anions below 600 K. Although this solid-to-solid ion exchange will surely be rare in a practical combustion environment, surface sulfation of KCl particles by uncombined SO_2 seems reasonable.

Note that CaO (s) is directly formed at temperatures above 1070 K. This species is probably not kinetically limited as compared to more complex multi-metal species. The abundance of free oxygen surely favors direct oxidation of Ca. Further, direct oxidation of

other free minerals is more likely than formation of multi component minerals, unless these minerals are closely associated in the parent material prior to combustion. Carbon dioxide combining with CaO(s) beginning at 1100 K will likely be a surface reaction, limited by diffusion of CO_2 through the $CaCO_3$ product layer that grows on each CaO surface.

Figure 7.8 shows equilibrium results for the laboratory burner operated with Fuel 2 at 3.78 g/min. This is essentially a dilution limit case for the industrial burner, similar to conditions found in the blend chamber prior to entry into the dryer. The fuel-to-total-flow rate ratio is an order of magnitude lower than conditions found in the industrial primary combustion chamber. For reference, the predicted adiabatic temperatures through the industrial system is shown. Condensed NaCl and KCl are formed below about 900 K and 880 K, resulting in nucleated particles forming in the blend chamber. This is about 100 degrees cooler than NaCl and KCl condensation temperatures for the undiluted system shown in Figure 7.7.

7.2.4 Fuel 3 Equilibrium

Figure 7.9 shows Fuel 3 equilibrium for conditions in the industrial primary combustor. Fuel 3 is unique in that it contains nearly twice the sulfur of other fuels, and very low chlorine. Computational limitations of the equilibrium program require the removal of Ca Mg, and Si species at 1600K. All species containing these elements are predicted to be in solid phase by this temperature, such that any additional transformation is probably limited by diffusion into the solid particle. Note that NaOH and KOH are the dominant forms of vapor phase alkalis above 1400K. In a rapid quench environment, it is reasonable to expect these vapors to homogeneously condense at a faster rate than diffusion transport allows Na_2SO_4 (s) and K_2SO_4 to form. Note that equilibrium predicts sulfated alkalis over KCl or NaCl when sulfur is present in excess.

Equilibrium calculations for the laboratory burner conditions, which is somewhat more dilute than conditions for the same fuel in the industrial burner blend chamber (*i.e.* a limit case), is shown in Figure 7.10. Sulfur is ideally tied up by Ca beginning at about 1270, and by sodium below 1260K. Since calcium is in the condensed phase prior to sulfation, $CaSO_4$ production is probably kinetically limited. Again, Na_2SO_4 is likely to be kinetically limited as well because of its lack of vapor phase. From a purely equilibrium standpoint, in

which excess sulfur is captured by $CaSO_4$, potassium is expected to exchange ions to form KCl (s) around 650K.

When equilibrium is determined for Fuel 3 with sulfur and non-participating minerals excluded, alkali species (NaOH and KOH) form carbonates beginning around 1000 K. Condensation of NaOH and KOH is expected to occur near 975 K and 775 K, respectively, if only homogeneous nucleation and condensation are considered.

7.2.5 Fuel 4 Equilibrium

Figure 7.11 shows equilibrium for Fuel 4 at 80% excess air, which is a realistic condition for a commercial suspension burner. Calcium content is two to three times higher than the other three fuels. It is clear that significant amounts of CaO and $CaCO_3$ can be expected from this fuel.

Like Fuel 3, this fuel is an order of magnitude lower in chlorine than Fuels 1 and 2, and has about half the sulfur of Fuel 3. This low anion availability (Cl and sulfate) results in an interesting transition from Na_2SO_4 to K_2SO_4 around 1200 K under equilibrium conditions. This transition is kinetically unlikely. Formation of sodium carbonate is also indicated around 1200 K. Condensation of NaOH, followed by a CO_2 gas and NaOH(l) surface reaction may be more likely. This will be limited by CO_2 diffusion.

Figure 7.12 shows equilibrium for the limit case of laboratory burner conditions. This is similar to the fuel-to-total flow rate of the industrial configuration inside the Blend Chamber. The mineral KCl is the preferred chloride species above 820 K, and condensed species below 820K. Note that the quench rate in the temperature range of 1200K to 1000K plays an important role in the composition of the solid particulate matter. A very slow quench would allow alkali-sulfate formation, while a rapid quench favors direct condensation of alkali hydroxides followed by surface reactions.

7.2.6 Summary of Equilibrium Findings

RESIDUAL PARTICLES:

- Non-alkali metals and silicon form residual solids that are not expected to vaporize in at standard industrial furnace temperatures. Equilibrium predicts they will form complex

species that can recombine to form new species at cooler temperatures. In the absence of other mineral species, oxides are generally the favored form of non-alkali metals (*e.g.* MgO (s)). In practice, the composition is most likely driven by the very localized composition of the char particle and local combustion conditions (*i.e.* formation of eutectic mixtures, and reducing vs. oxidizing environment). Recombination of solids to form new solid species at lower temperatures is surely a phenomena limited to surface reactions between colliding residual particles.

- Equilibrium predicts formation of $CaCO_3$ and $CaSO_4$ through a solid/gas interaction. Sulfation of residual particles or combination with CO_2 is likely limited to surface interactions, assuming complete char burn-out. The kinetic limitation is SO_2 and CO_2 diffusion into the existing particle.

AEROSOL PARTICLES:

Figure 7.13 compares equilibrium results (at 700 K) to the material collected on the aerosol ash filters for the four sawdust/sanderdusts tested. For this comparison, the equilibrium column shows only species expected to form from gas phase species (*i.e.* no residual ash). These are alkali metals sodium and potassium, and potential anions chlorine and sulfur (as SO_4). Carbon and oxygen are not detectable by the method used to analyze the aerosol filter (EDS), so the anion CO_3 is not included in this system. However, the *alkali* associated with carbonate is included, since it is detectable by EDS. The elemental composition of the raw fuel as determined by Atomic Absorption is also shown.

In Figure 7.13, the raw fuel composition and the predicted equilibrium composition are essentially the same, reflecting the fact that sulfur and chlorine preferentially combine with the alkalies rather than with the residual ash. For Fuel 3, a small fraction of the available sulfur combines with calcium, so this sulfur is assumed to be part of the residual modes rather than the aerosol mode. Also, the chlorine in Fuel 3 remains in the vapor phase as HCl until about 650 K (Figure 7.11), so it is not included in the equilibrium balance at 700 K.

Immediately clear is that sodium is under-represented on all four aerosol filters in Figure 7.13. It is possible that sodium is preferentially captured over potassium by the residual ash prior to entering the gas phase, and therefore never enters the vapor phase. This is discussed at length in Chapter 6.

Figure 7.14 shows an under-representation of sulfur relative to chlorine on the aerosol filter for Fuels 1 and 2. This suggests there is resistance to sulfation when chlorine is present, even though sulfate formation is favored. If little chlorine is present (Fuels 3 and 4), then sulfate is formed. It is not clear when the sulfate is formed in Fuels 3 and 4. Neither equilibrium nor the experiments conducted can offer a definitive answer to this kinetics problem.

In summary, equilibrium relative to aerosol shows:

- Both potassium and sodium are predicted by equilibrium to escape the residual/char and enter the vapor phase. The preferred form of vapor phase sodium is chloride and hydroxide, in the range of typical combustion temperatures (about 1800K to 1400K). Vapor phase HCl is converted to NaCl and KCl as the combustion temperature is lowered, well above the condensation temperatures of NaCl and KCl. The vapor phase is exclusively hydroxide if chlorine is absent.

- Formation of Na_2SO_4 (liquid) from vapor phase sodium species (primarily NaOH) and SO_2 is predicted by equilibrium to occur near the adiabatic temperature of the Secondary Volume in the industrial burner. This formation is most likely kinetically limited in a practical quench environment, since this is a gas/gas interaction rather than a condensation event. Sulfation is will most likely occur in a practical combustor as a SO_2 gas reaction with condensed NaOH.

- Sulfur in excess of stoichiometic Na_2SO_4 and K_2SO_4 will prevent formation of solid phase NaCl and KCl, at equilibrium conditions. In a practical rapid quench environment, solid phase NaCl and KCl and liquid phase NaOH and KOH would likely be precursors to gas/particle sulfation.

- In a chlorine deficient environment, chlorine is preferentially complexed to solid form by potassium rather than sodium, until all chlorine is in solid phase. Since vapor phase NaCl condenses at a higher temperature than KCl, a rapid quench will likely lead to a significant NaCl formation.

7.3 Homogeneous and Heterogeneous Condensation Modeling

Equilibrium calculations indicate that alkali metals are vaporized during combustion. The metals enter a condensed state due to quench (by heat transfer from the system, addition of dilution air) or by chemical complexing. Neglecting vapor-phase chemical change (*e.g.* alkali sulfate formation), the super-saturated vapor will either self-nucleate and form homogeneous particles or it will diffuse to existing particles and condense (heterogeneous condensation). In a practical system, the condensation pathway will be a mixture of these two modes. The goal of the work described in this section is to resolve the relative importance of these two paths under the various experimental and practical conditions.

7.3.1 Homogeneous and Heterogeneous Modeling Method

Limit cases of homogeneous and heterogeneous condensation are illustrated in Figure 7.14. Homogeneous condensation tends to produce coagulated particles typically less than 0.1 μm in diameter with high number densities. Efficient filtering or electrical precipitation is usually required to remove these highly mobile homogeneous particles from industrial flue gas. In contrast, heterogeneous condensation on existing particles does not change the particle number density in the flue-gas. This typically means orders of magnitude lower number density and larger particle diameters. A significant fraction of these heterogeneous particles may be removed by centrifugal separators and/or cloth filtering.

Determining the ultimate fate of vapor phase alkalis requires resolving the relative contributions via these two different pathways. To that end, the critical controlling mechanisms are presented below and incorporated into a computational model. The model is applied to data from laboratory and industrial sources.

Kelvin Effect

Condensation on a flat material surface occurs when the vapor pressure of the material exceeds the saturation pressure. If the material surface is curved, molecules are less tightly bound at the surface because there are less adjacent molecules sharing Van der Waal forces. Hence, the saturation pressure of material in equilibrium with its curved surface is greater than the saturation pressure over a flat surface of the same material. This relationship between the plane-surface saturation pressure, p_{sat} , and the saturation pressure over a curved surface, p_d , is given by:

$$\ln\left(\frac{p_d}{p_{sat}}\right) = \frac{4\bar{v}\sigma}{d_p \tilde{R}T} \qquad \text{(eq 7.1)}$$

and is known as the Kelvin effect (for example, see Hinds, 1982). The Kelvin relationship dictates that a supersaturated ($s=p_{vap}/p_{sat} > 1$) condition will result in a condensation event only if the system contains condensation nuclei with diameters greater than a critical diameter. In a system lacking foreign nuclei, homogeneous condensation occurs when the saturation ratio is high enough for molecular clusters to initiate nucleation. In a system with foreign particles present (*i.e.* larger diameter nuclei), the supersaturation will be partially or fully relieved by heterogeneous condensation on the foreign particles, as summarized in Table 7.3. The remainder of this section presents relations to quantify s_{het} and s_{crit}, and explores the rate of condensation for these two modes as a function of known variables.

Homogeneous nucleation and condensation
Friedlander (1977) derived a relationship for the rate of droplet formation as a function of saturation ratio, based on homogeneous nucleation initiated by molecular clusters.

$$I = \left[\frac{p_1}{(2\pi mkT)^{1/2}}\right] * (n_1 v_m^{2/3}) * \left[\frac{\sigma v_m^{2/3}}{kT}\right]^{1/2} \exp\left[-\frac{16\pi\sigma^3 v_m^2}{3(kT)^3(\ln S)^2}\right] \qquad \text{(eq. 7.2)}$$

Friedlander defines the critical saturation ratio (S_{crit}) as the ratio at which droplets are formed at a rate of one drop/cm^3/sec, which is considered a formation rate that can be conveniently observed experimentally.

For modeling, it is assumed that reaching the critical saturation ratio will result in rapid relief of the supersaturation by homogeneous condensation. This is a reasonable assumption for three reasons: The high surface-area-to-volume ratio of the newly formed nuclei represent a significant increase in available condensation surface area. Secondly, the high number density of the nucleii limits gas transport resistance for NaCl (v) to the particle surface. Third, as the newly-formed particles grow, the Kelvin effect relaxes. Hence, all remaining vapor is assumed to be converted to homogeneously condensed particulate matter.

Heterogeneous Condensation

Within the heterogeneous condensation regime, the rate of vapor deposition on the particle surface is strongly driven by the particle diameter relative to the mean free path in the carrier gas. For a particle with a diameter much greater than the gas mean free path (Knudsen number, $Kn=\lambda/d \ll 1$) in an infinite medium, continuum gas dynamics applies. It can be shown that diffusion results in a growth law (dmolecules/dtime) proportional to particle diameter (Friedlander, 1977).

$$\frac{d\#}{dt} = \frac{2\pi D d_p (p_i - p_d)}{kT} \qquad \text{for } Kn \ll 1 \qquad \text{(eq. 7.3)}$$

For particles with diameters much smaller than the gas mean free path ($Kn \gg 1$), molecular bombardment is the governing conversion mode and particle growth rate is proportional to the particle diameter squared (Friedlander, 1997).

$$\frac{d\#}{dt} = \frac{\alpha\pi d_p^{\,2} (p_i - p_d)}{(2\pi mkT)^{1/2}} \qquad \text{for } Kn \gg 1 \qquad \text{(eq. 7.4)}$$

For the modeling approach, the transition region of $Kn \approx 1$ is of particular interest. Experimental size distributions of the residual ash showed that a foreign particle diameter in the range of .3 μm to 10 μm is likely, which is near the mean free path of the combustion gas (about 0.3 μm at 1000 K). Hence, the approximate interpolation formula proposed by Fuchs and Stutugin (1971) is used:

$$\frac{d\#}{dt} = \frac{2\pi D d_p (p_i - p_d)}{kT} * \left\{ \frac{1 + Kn}{1 + 1.71Kn + 1.333Kn^2} \right\} \qquad \text{for all Kn} \qquad \text{(eq 7.5)}$$

The Fuchs/Stutugin equation reduces to equation 7.3 for $Kn \ll 1$, and about 1.2 times the value of equation 7.4 for $Kn \gg 1$ (Friedlander, 1977).

Modeling Approach

Some assumptions are made for modeling the condensation rate of vapor on existing particle surfaces. They are:

- No spacial temperature gradient. The particle is at the same temperature as the freestream fluid. The heat of vaporization (endothermic condensation) is dissipated quickly compared to the condensation rate on the particle.

- No convective mass transfer to the particle surface. The particle travels with the fluid.

- The density gradient to the particle surface is negligible (no diffusion induced secondary convection term).

- Surface wetting properties of the nucleate are identical to the condensing material.

- The mineral NaCl is the vaporized/condensing species. When present in a fuel, it is favored in the vapor phase at combustion temperatures, and is predicted to condense to solid phase by equilibrium. Kinetic arguments also favor its formation in a rapid quench environment. It is in high abundance in two of the four sawdust/sanderdusts investigated, and it is expected to closely match the behavior of KCl under similar conditions. Under rapid quench conditions that are present in an industrial dryer, this model is likely to simulate NaOH or KOH condensation mechanisms as well.

The computer code is written using Mathematica, and is described in detail in Appendix I. In summary, the model is composed of the following steps:

1. The properties of the vapor phase species and hot gas are calculated.

2. Condensation rate equations are defined. For heterogeneous particulate matter formation, the equation of Fuchs and Stutugin (1971) is used, as described above. The relation for critical saturation ratio defines the region dominated by homogeneous condensation.

3. The foreign particle number density, foreign particle diameter, initial vapor phase partial pressure and quench rate are supplied. The model allows two foreign particle diameters and corresponding particle number densities.

4. The temperature at which heterogeneous condensation is initiated is calculated, based on the Kelvin effect and vapor properties. The temperature at which homogeneous

condensation (in the absence of foreign particles) occurs is calculated, based on the input conditions and critical saturation ratio.

5. Beginning at the temperature of heterogeneous condensation initiation, the vapor collection rate on the surface of heterogeneous nuclei is calculated.

6. The time step is incremented. The mass of vapor captured over the incremental time step is calculated.

7. The partial pressure and saturation ratio of the free vapor is recalculated. This is done with respect to the vapor captured by the heterogeneous particulate matter and the system temperature at the end of the incremental time step.

8. The critical saturation ratio for homogeneous nucleation is calculated.

9. If the new saturation ratio calculated in step 7 is greater than the critical saturation ratio calculated in step 8, then homogeneous nucleation occurs and the remaining vapor phase is assumed to form homogeneous condensate. If the saturation ratio is less than the critical saturation ratio, steps 6 through 8 are repeated until all vapor is captured heterogeneously, or homogeneous nucleation occurs.

7.3.2 Homogeneous and Heterogeneous Condensation Model Results

Figure 7.15 shows predicted condensation regimes for a combustor with an initial NaCl vapor pressure of 14 Pa. This approximately corresponds to the partial pressure of all alkali species (mainly NaCl and KCl, and NaOH and KOH) present in an industrial suspension burner operated on Fuel 1 with 80% excess air. Three heterogeneous particle sizes are also assumed to be present, as an example. As the flue gas temperature is decreased with time (*i.e.* a Lagrangian coordinate system), the gas volume will go through three condensation regimes. Between 1030 K and 1022 K, the system saturation ratio ($S = P_{vapor}/P_{sat}$) is less than one, which dictates that only vapor phase alkali species are present. At 1022 K, the radius of curvature of a particle with a diameter of 7.16 μm is adequate for condensation of vapor phase, and the vapor phase will begin to be depleted by condensation on particles of this size and larger. Note that this saturation ratio is very close to unity, which is indicative that the Kelvin effect is of little consequence for a particle of relatively large diameter.

The second largest particle in the hypothetical system becomes a collection surface around 1014 K. Although this particle is 3 orders of magnitude smaller (in terms of mass) than the largest particle, the two condensation temperatures are separated by only 8 K.

As the temperature is reduced further, and assuming the system has not been appreciably depleted of vapor phase alkali, the cross-over of point at which individual molecular clusters act as nuclei is reached around 994 K. This corresponds to a particle diameter of about .00222 μm in this system. Below this temperature, the supersaturation is quickly relieved by condensation on these particles.

Note that the condensation temperature becomes very sensitive to the particle diameter between .00222 μm and .00669 μm - diameters which are only separated by a factor of 3. This is a manifestation of the Kelvin effect. Examining equation 7.5, for condensation to occur:

$$(p_i - p_d) > 0 \qquad \text{(eq. 7.6).}$$

Substituting in Kelvin's relation for p_d yields;

$$\left(p_i - p_{sat} * e^{\left[\frac{4\bar{v}\sigma}{d_p \bar{R}T}\right]} \right) > 0 \qquad \text{(eq. 7.7).}$$

From this relation, it is clear that the exponential term is near unity for large values of dp, and rapidly increases for very small values of dp. Note that this relationship also implies that pure particles with diameters below a critical size (for a given temperature and partial pressure) have a negative condensation rate, and will vaporize.

The following modeling results focus primarily on Fuel 1. The residual size distribution for Fuel 2 is essentially identical to Fuel 1, as discussed relative to Table 7.2, such that presentation of Fuel 2 modeling is redundant.

Figure 7.16 demonstrates the effect of quench rate assuming a system composed of Fuel 1 in an 80% excess air environment. The initial vapor pressure shown here is the sum of the NaCl and KCl vapor predicted by equilibrium prior to condensation. Condensation on heterogeneous particles, with diameters of 7.16 μm and .669 μm , begins at 1008 K. These particle diameters are large enough that the Kelvin effect is relatively small and the

temperature at which heterogeneous condensation commences is essentially the flat-surface condensation temperature.

The topmost curve shows the depletion of alkali vapor pressure a very rapid quench rate of 10,000 K/sec. Less than 3% of the available alkali vapor is captured by the heterogeneous particles by the time the point of homogeneous nucleation is reached, at 974 K. Recall that reaching the homogeneous nucleation state results in a rapid depletion of the system via condensation on the newly-formed high surface area to volume nucleates. Hence, the remaining 97% of the NaCl is depleted homogeneously. For a very slow quench, vapor capture by heterogeneous particles will be much greater, as is illustrated by the 400 K/sec curve in Figure 7.16. The heterogeneous particles are able to deplete the vapor reservoir at a rate fast enough for the saturation ratio to remain below the critical pressure ratio for homogeneous nucleation, until 818 K. All of the vapor is collected by the heterogeneous particles, leaving none for conversion to homogeneous particles.

The lower graph in Figure 7.16 shows some practical limitations of aerosol control through quench rate. As the vapor concentration is reduced, the rate of vapor capture decreases, as can be seen in the flattening of the 400 K/sec quench curve with residence time. Note also that a high quench rate correlates to a faster capture rate, which can be seen by comparing the slope of the 400 K/sec curve the 700 K/sec curve around 0.1 seconds. It is clear that the capture rate is faster for the 700 K/sec quench, but the duration of the 400 K/sec quench ultimately results in greater heterogeneous capture.

Figure 7.17 shows a series of graphs for six different quench rates. Each graph shows eleven separate initial vapor pressures separated by increments of 1.5 Pascal. Examining the upper left graph as an example, the temperature at which heterogeneous condensation is initiated can be very low for a low initial concentration. As the initial concentration is increased, the temperature for heterogeneous condensation becomes less sensitive to initial concentration. The practical implication is that a system with a high initial concentration of NaCl requires a slow quench at a higher temperature for conversion to hetero-particles. A slow quench beginning below the critical saturation temperature for that partial pressure is of no value.

The partial pressures at the bottom of Figure 7.18 give an indication of the alkali-species vapor pressure for Fuel 1 combusted in an industrial suspension burner. The first vapor

pressure is based on the NaCl content of Fuel 1. The second combines the NaCl and KCl of Fuel 1 and approximates it as all NaCl. The third combines the NaCl, KCl, NaOH, and KOH in Fuel 1 and approximates it as all NaCl. This is meant to give an idea of condensable vapor available in a high alkali fuel. Note that for a given quench rate, the absolute mass captured by heterogeneous particles increases as partial pressure increases. Regardless of initial concentration, the fraction of vapor converted to heterogeneous particulate is about the same.

The top plot in Figure 7.18 shows NaCl vapor pressure as predicted in an industrial blend chamber, in which the industrial burner hot gas illustrated in Figure 7.17 has been diluted by a factor of 5.4. Note that the conversion to heterogeneous particles is very low, even for an extremely slow quench rate of 200 K/sec. It is clear that quenching after dilution results in poor vapor capture. The mechanism for this is primarily a reduction in the total hetero-particle surface area per volume of hot gas. Dilution greatly increases the gas volume, but, of course, leaves total hetero-particle surface area unchanged.

The lower plot in Figure 7.18 shows NaCl vapor pressure for the laboratory furnace configuration. Condensation on the heterogeneous particles is very low, regardless of quench rate. Almost all of the NaCl and KCl present in the fuel was found on the aerosol filter, which is indicative of homogeneous condensation. The quench rate in the undiluted sampling probe is calculated to be about 5400 K/sec, based on measured probe inlet temperature and estimated exit temperature.

The modeling results for Fuel 1 are summarized in Figure 7.19. The mass fraction captured by heterogeneous condensation relative to the initial NaCl in the system is shown, as a function of quench rate. The "Industrial Burner" grouping shows the conversion for eleven initial vapor pressures. It is clear that the initial vapor pressure only weakly drives the conversion efficiency, while the quench rate is critical. This observation is the same for the grouping labeled "Industrial Blend Chamber" and the "Laboratory Furnace" grouping.

Comparing the groupings in Figure 7.19, it is obvious that the change in quench rate for a given capture efficiency is directly proportional to the dilution ratio. Diluting the industrial burner hot gas by a factor of ten requires a reduction in a quench rate (for the same conversion efficiency) by a factor of ten, which is essentially shown by the laboratory

furnace data. This is intuitively reasonable, since dilution by an order of magnitude reduces the heterogeneous particle number density by an order of magnitude in the system.

If heterogeneous capture of the vapor is desirable, as one would expect in an industrial application, quenching prior to dilution is critical. For example, a quench rate of 1000 K/sec will convert about 40% of the alkali vapor to heterogeneous particulate in the industrial burner, but only about 5% will be converted for the same quench rate after the hot gas has been diluted by a factor of 5.4 in the blend chamber.

It was found in Fuel 1 modeling that less than 3% of the heterogeneously captured vapor was deposited in the large particle mode. Although the capture rate for a single 7.16 μm particle is approximately an order of magnitude greater than the capture rate of a .669 μm particle, the small particle number density is three orders of magnitude greater than the large particle mode. Hence, the heterogeneous capture process is dominated by the smaller diameter particles. Fuel 3 and Fuel 4 have residual modes composed primarily of large (8 μm) particles, as was shown in Table 7.2. It is clear that only a very small fraction of vapor will be captured at any reasonable quench rate for Fuel 3 and Fuel 4.

7.3.3 Summary of Homogeneous and Heterogeneous Modeling Findings

- The critical temperature range for condensing alkali vapor onto existing residual particles is dictated by the diameter of the existing residual particles (upper bound), and the vapor pressure of the condensable alkali vapor (lower bound). The time/temperature history of the flue gas outside of this temperature range does not effect the conversion efficiency.

- The conversion efficiency of vapor phase alkali to heterogeneous particles is a logarithmic function of the quench rate between the temperature at which heterogeneous condensation starts, and the temperature at which homogeneous nucleation starts. Therefore conversion efficiency can be modified significantly with small changes in quench rate, in a slow quench environment.

- For a fixed quench rate, the initial vapor pressure of the condensing species does significantly change the conversion efficiency.

- Dilution of a condensing system requires a directly proportional increase in quench rate in order to achieve the same conversion efficiency. Dilution of the flue gas reduces the conversion efficiency primarily through reduction of the foreign particle number density.

- In order to obtain the highest conversion efficiency in an industrial dryer application, the undiluted flue gas should be quenched through the temperature range of conversion prior to dilution. This may be best accomplished by staged dilution in an industrial application, in which only enough dilution air is added to lower the system temperature into the heterogeneous condensation temperature range. Additional dilution air may be added downstream of an insulated volume (*i.e.* a slow quench zone), in order to obtain the desired dryer inlet temperature and volumetric flow rate.

7.4 Coagulation Modeling

The MAEROS2 code (Gelbard, 1996) is used to determine the influence of coagulation on the ultimate aerosol size distribution. The code is a numerical method based on resolving the diameter distribution into discrete bins and enforcing conservation of mass for each component (Gelbard, 1996). Coagulation rate can be calculated with Brownian motion, gravity and turbulence terms. For the purposes of this work, only Brownian motion is considered.

The program calculates the size distribution of aerosol as a function of time for an enclosed volume (*i.e.* Eulerian coordinate system). By coordinate transformation, the code also applies to a moving volume (*i.e.* Lagrangian coordinate system). The input parameters are initial mass concentration with a mean particle diameter and geometric standard deviation, condensable vapor source rate, aerosol source rate, volume, temperature, and system pressure.

7.4.1 Coagulation Modeling for Fuel 1 Ash

It is clear that the ultimate size distribution is a function of many variables. A major factor with a condensing aerosol species is the initial particle size, number concentration, and residence time for coagulation. This is investigated by modeling the expected conditions in

an industrial suspension burner used for drying of wood chips. Some assumptions are necessary in order to examine the fundamental coagulation process:

- Non-alkali minerals form particles with an initial size distribution similar to the residual particle size distribution found during laboratory-scale experiments. This is approximated as two log-normal size distributions, which are described by a geometric mean diameter and geometric standard deviation. Calculation of these parameters are described in Appendix A. It is assumed that all non-alkali species are part of this size distribution.

- Alkali species condense as chlorides when chlorine is available, and hydroxides otherwise. The initial mass of self-nucleated particulate matter is therefore set by the alkali content of the as-received fuel. The initial diameter of the nucleated particulate matter is assumed to be the critical diameter of nucleation for NaCl in the reactor. The calculation for initial aerosol mass and diameter is shown in Appendix A.

- Turbulence is not included, although it surely increases the coagulation rate. Incorporating fluid dynamic effects into this phase of the modeling is beyond the scope of the current investigation.

- Every collision results in a larger particle.

- A uniform particulate matter density is required for all input size distributions. The appropriate density for each example is noted as necessary.

Figures 7.20 through 7.23 show coagulation results for Fuel 1 in for an idealized industrial burner shown in Figure 7.1. For this series, it was assumed that three initial size distributions were present: 1) An aerosol mode composed of all the aerosol-forming material, assuming to have a diameter of $1.9*10^{-3}$ μm, 2) a residual mode (labeled Zone 2), corresponding to a residual mode with a geometric mean diameter of 1.7 μm, and 3) A residual mode (labeled Zone 3), corresponding to the largest residual mode with a geometric mean diameter of 7.8 μm. (Note that a geometric mean diameters are required by MAEROS2 rather than count mean diameters.) The ash concentration is based on the expected concentration in the blend chamber shown in Figure 7.1, with an initial combustion conditions of 80% excess air. The temperature in the blend chamber is

approximated to be 800 K, for modeling purposes. All particulate matter is assumed to have a uniform density of 2.7 g/cc.

These three initial modes are shown in Figure 7.20. A sum of the modes is also shown by the curve-fit line. In Figure 7.21 and 7.22 the aerosol mode very quickly coagulates through Brownian motion and marches toward the larger size distributions. The advance slows as the as the mean diameter increases, as shown in Figure 7.23 It is clear from Figure 7.24 that the residual modes do not significantly participate at any reasonable time scale because of low mobility. Note that the aerosol mode is predicted to eventually stabilize at about 0.05 μm.

Figure 7.25 compares two conditions - "aging" of initial aerosol in a plug flow condition and aging in a perfectly mixed chamber. In the perfectly mixed condition (taken as the estimated volume of an industrial-scale blend chamber), freshly nucleated particulate matter interacts with older aerosol to form a wider size distribution. The plug flow condition is the limit case of the industrial blend chamber with no mixing. No fresh nucleated particulate matter is available, hence the size distribution is determined by the coagulation of the initial aerosol, and the peak is narrower.

Figure 7.26 are MAEROS2 results for a conditions similar to coagulation conditions in the delay tanks used for the milled sawdust/sanderdust experiments. For this comparison, the density of the aerosol was assumed to be 1 g/cc. Hence, the axis is the aerodynamic diameter of the particulate, which is equivalent to the diameter as determined by the EAA.

Comparing Figure 7.26 to experimental results shown in Figure 7.27, the fundamental behavior of the coagulating aerosol is clear: The mean diameter is driven by the coagulation of the nucleated aerosol. In the experimental results, a secondary mode is present, possibly related to unaccounted pre-existing modes. This is possibly an artifact of non-uniform nucleation, for example NaCl, and KCl do have condensation temperatures higher than NaOH and KOH. Other possible nucleate sources can include (but are not limited to) reduction/oxidation-formed aerosols of CaO, 0.4 μm range aerosol not captured by the impactor, or soot.

7.4.2 Summary of Coagulation Modeling

- Coagulation modeling of the industrial burner blend chamber demonstrated that coagulation changes the ash size distribution only below 1 μm range. The coagulating aerosol is expected to converge to about .05 μm under typical conditions for an industrial burner. Residual modes above 1 μm are not expected to change, due to low Brownian mobility.

- Coagulation modeling suggests that the *major* mode diameter of sub-micron aerosol may be reasonably predicted by assuming the aerosol is composed of the alkali components of the parent fuel, in the form of alkali chlorides and alkali hydroxides. More extensive characterization of initial aerosol components is required to model detailed coagulation.

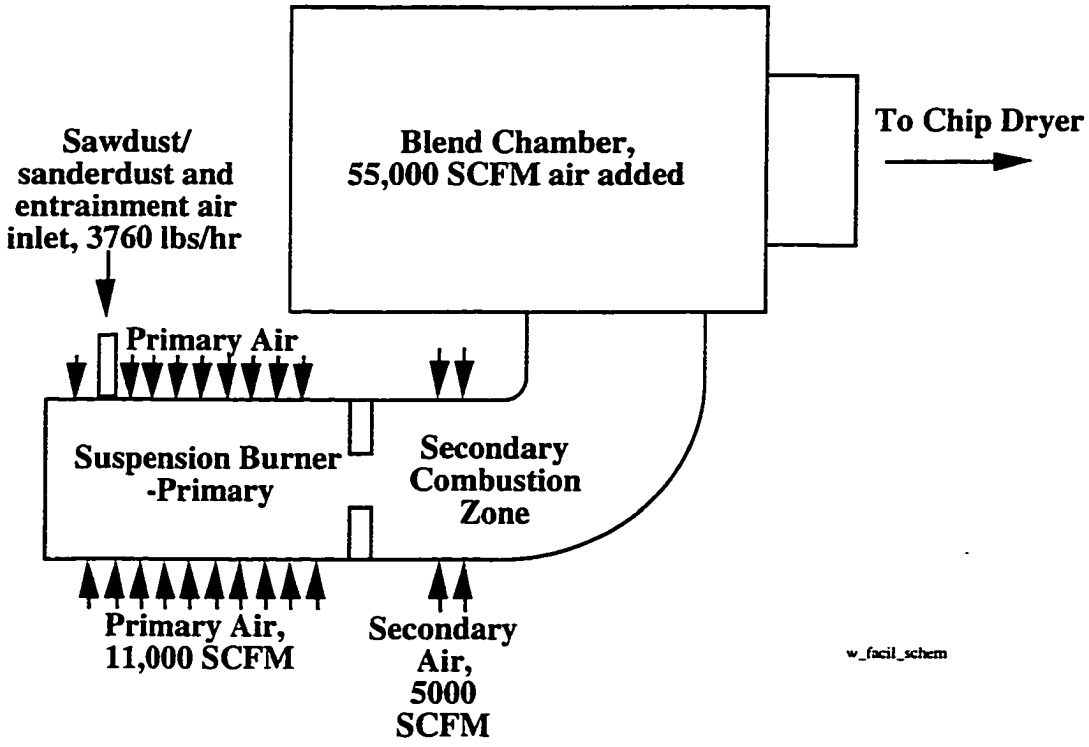


Figure 7.1: Example configuration of a sawdust/sanderdust burner used for wood chip drying in a strand board production facility

Table 7.1 Comparison of typical laboratory conditions to typical industrial burner conditions

Parameter	Laboratory Tunnel Furnace	Industrial Suspension Burner*
Dry Oxygen Post-Combustion, Percent by Volume	7.3% to 9.0%	9.4% to 11.7% (primary)
Typical Maximum Operating Temperature	1450K	1750K to 1475K
Wood Fuel Flowrate over Total Flowrate, kg/kg	.006 to .009 (main) .00024 to .00032 (in dilution probe)	.07 to .09 (primary) .05 to .06 (secondary) .012 to .016 (blend)
Combustion Zone Residence Time	1.0 to 1.3 seconds	.08 seconds primary .16 seconds secondary

*Industrial conditions estimated for Fuel 4, based on information supplied by site engineers

Table 7.2: Simplified residual particle size distributions used for modeling

	Hetero-particle Diameter 1, μm	Diameter 1, number density, #/(kg Fuel)	Hetero-particle Diameter 2, μm	Diameter 2, number density, #/(kg Fuel)
Fuel 1 and 2	7.16	$4.74*10^{9}$	.669	$2.64*10^{12}$
Fuel 3 and 4	8.21	$7.43*10^{9}$	.689	$3.35*10^{11}$

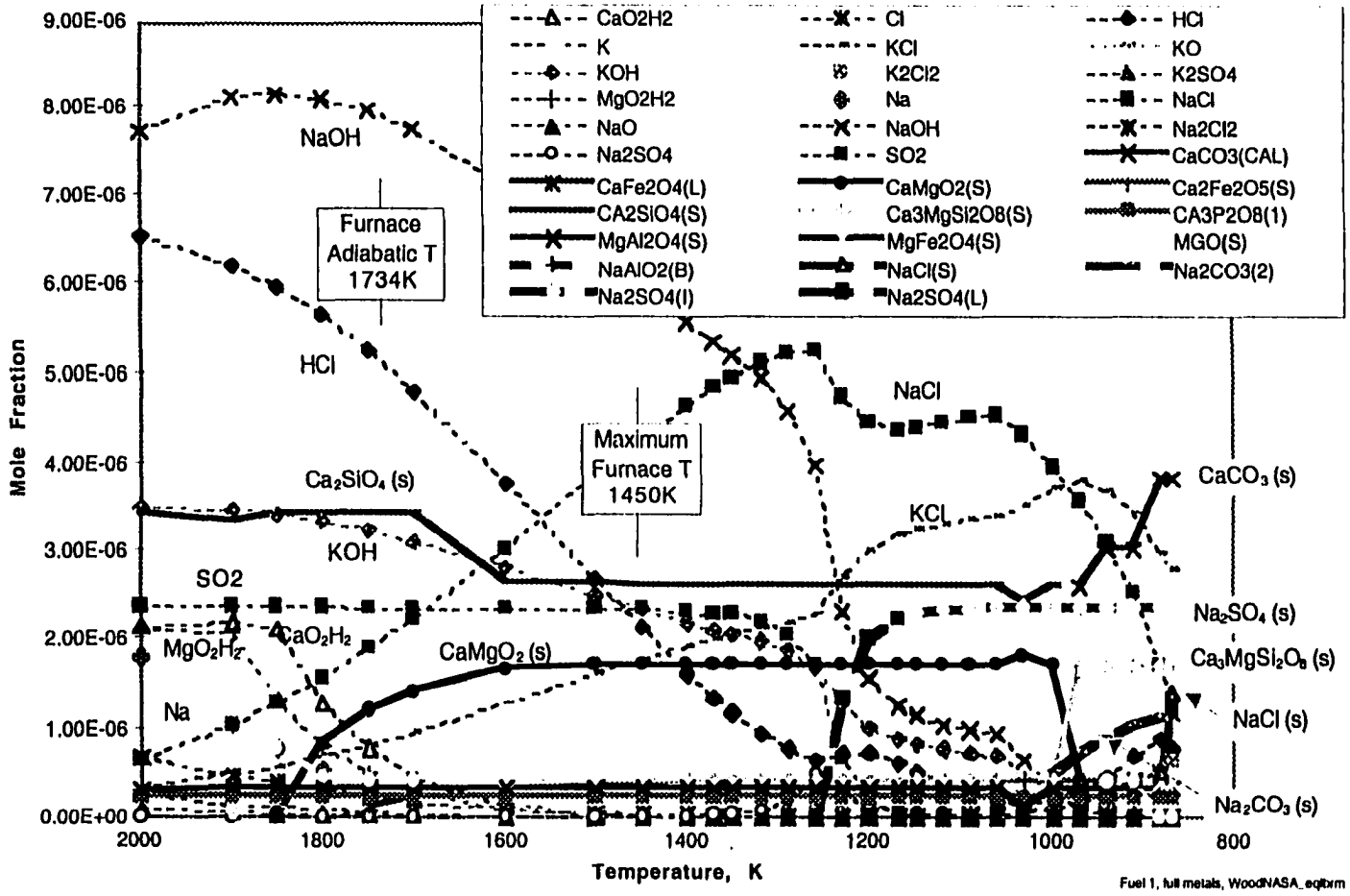


Figure 7.2: Fuel 1 equilibrium calculations for tunnel furnace conditions. Excess oxygen is 7.9% by dry volume, (Fuel 1 flowrate)/(Total flowrate) = 0.0085.

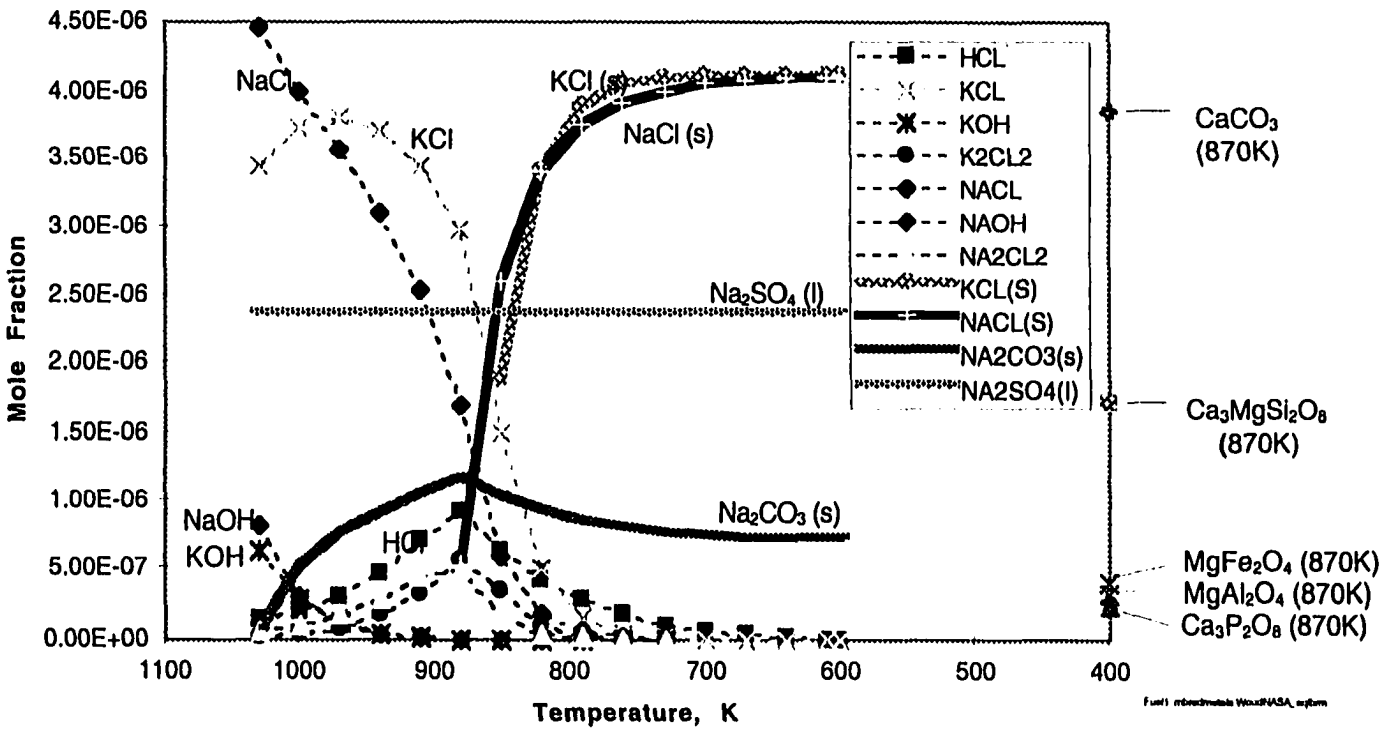


Figure 7.3: Fuel 1 equilibrium calculations for tunnel furnace conditions, alkali species only. Excess oxygen is 7.9% by dry volume, (Fuel 1 flowrate)/(Total flowrate) = 0.0085.

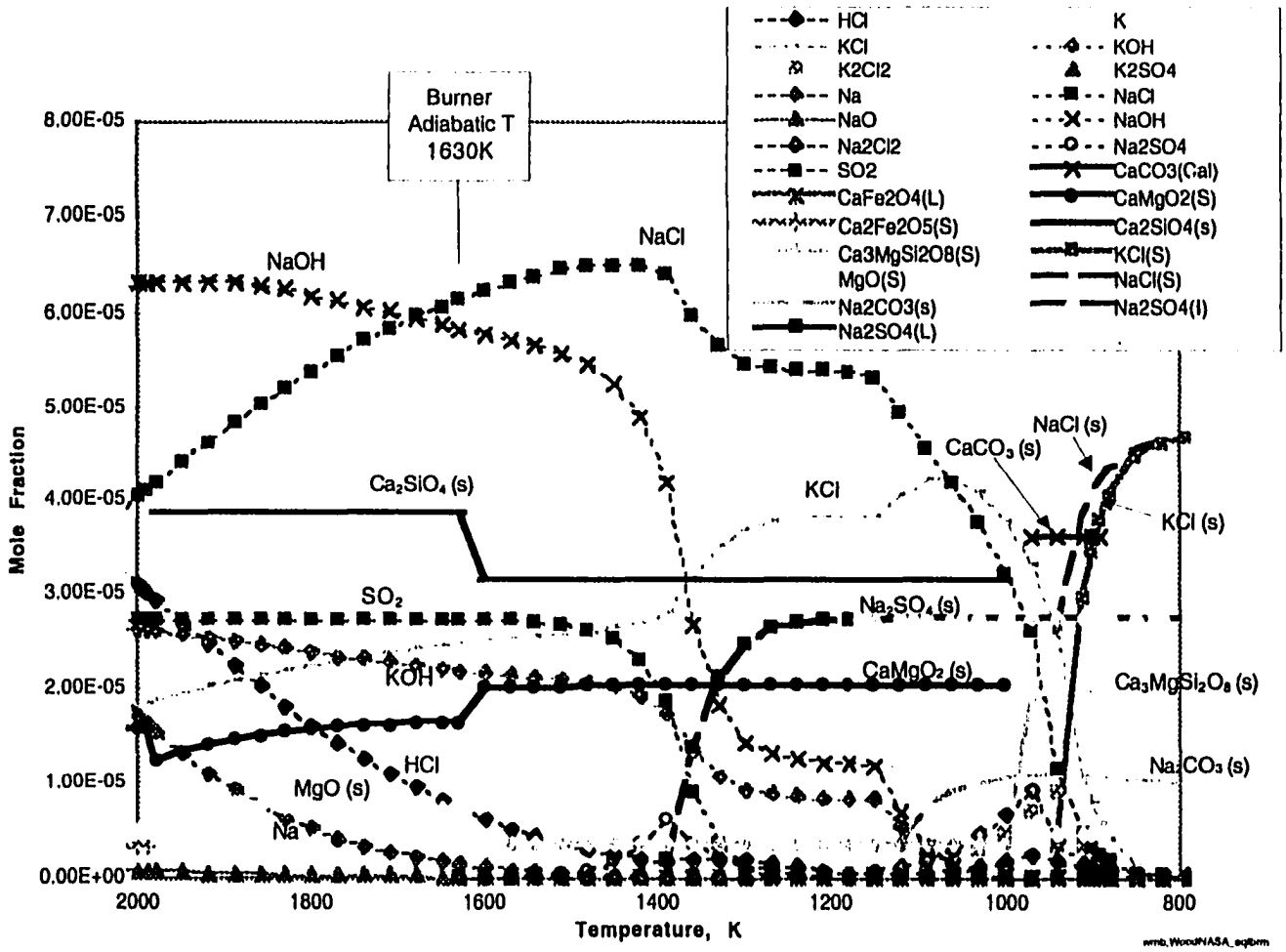


Figure 7.4: Fuel 1 equilibrium calculations for industrial burner conditions. Excess oxygen is 9.3% by dry volume, (Fuel 1 flowrate)/(Total flowrate) = 0.094

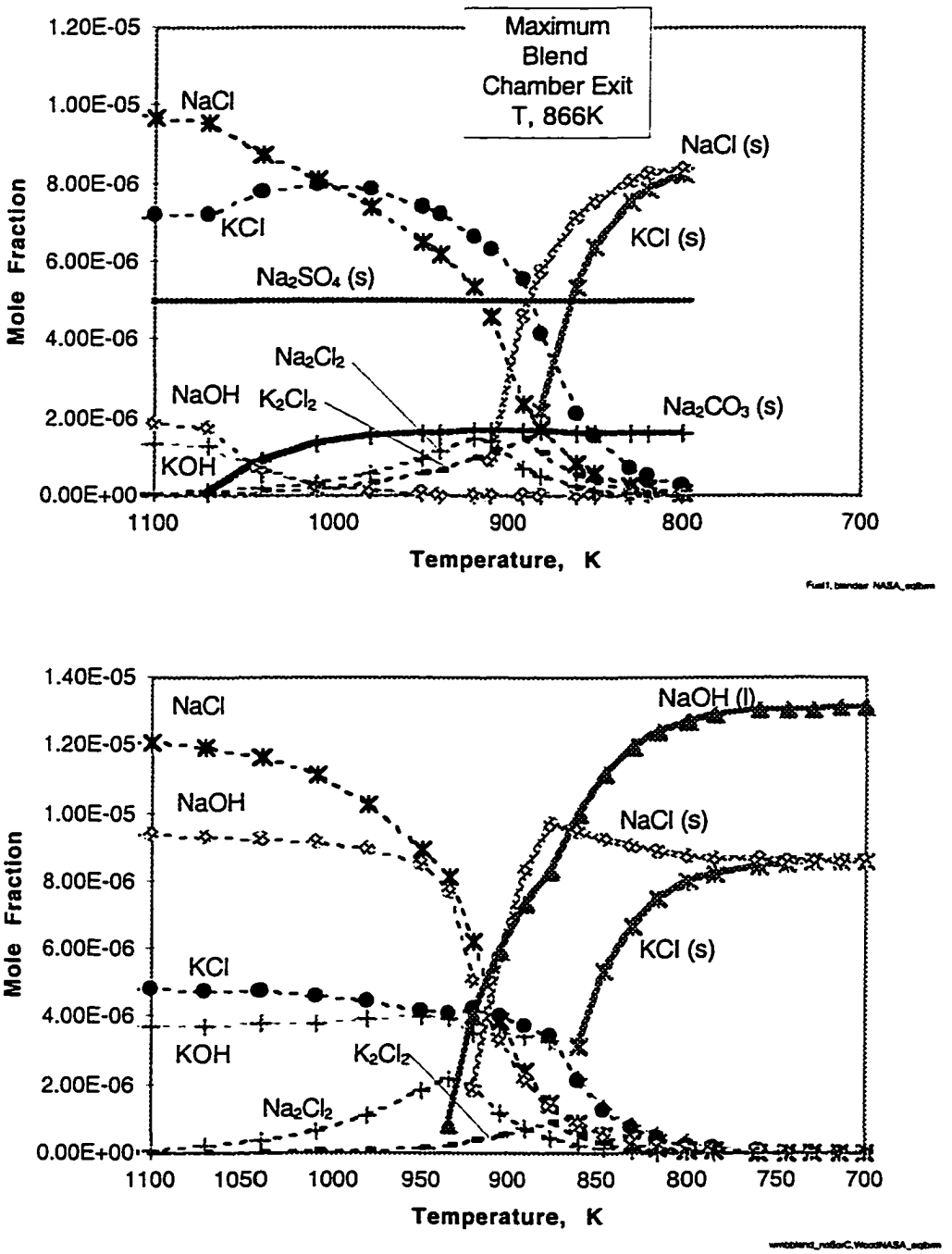


Figure 7.5: Fuel 1 equilibrium calculations for industrial burner conditions in Blend Chamber, with sulfur and carbon included, and with sulfur and carbon not included, (Fuel 1 flowrate)/(Total flowrate) = 0.017

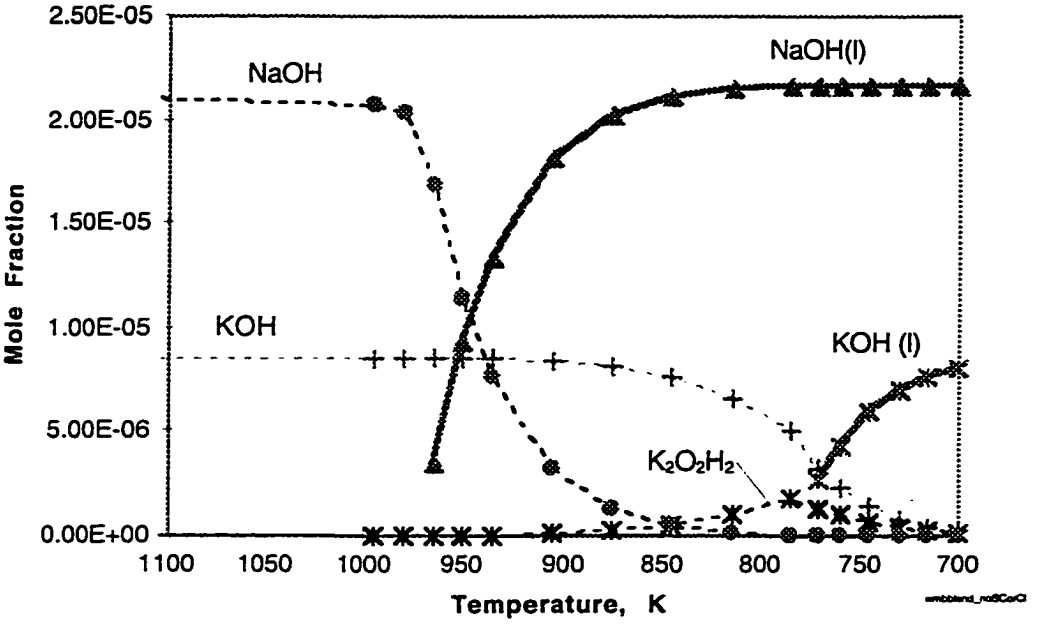


Figure 7.6: Fuel 1 equilibrium calculations for industrial burner conditions in Blend Chamber; sulfur, carbon and chlorine not included, (Fuel 1 flowrate)/(Total flowrate) = 0.017

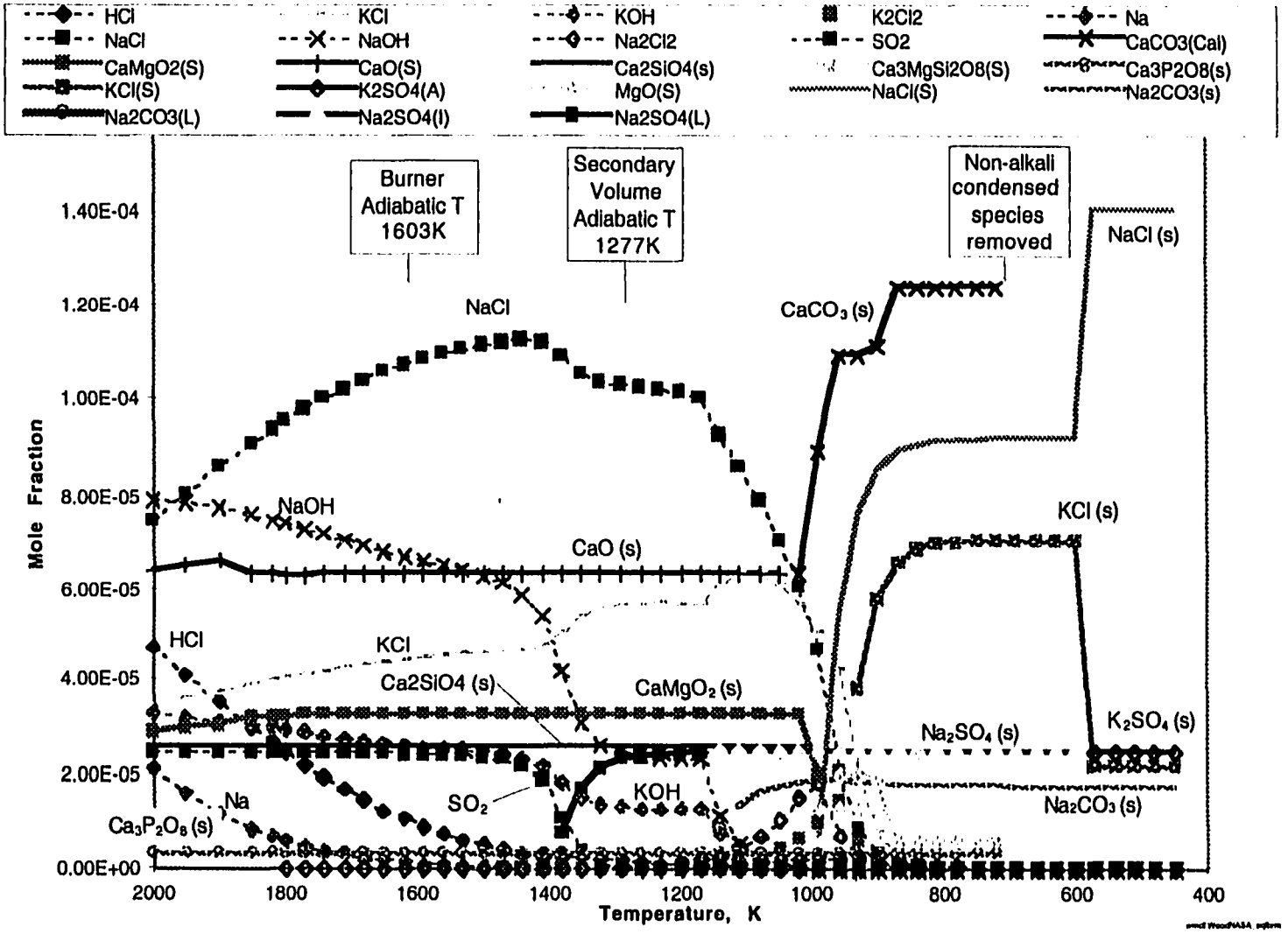


Figure 7.7: Fuel 2 equilibrium calculations for industrial burner conditions, (Fuel 2 flowrate)/(Total flowrate) = 0.093

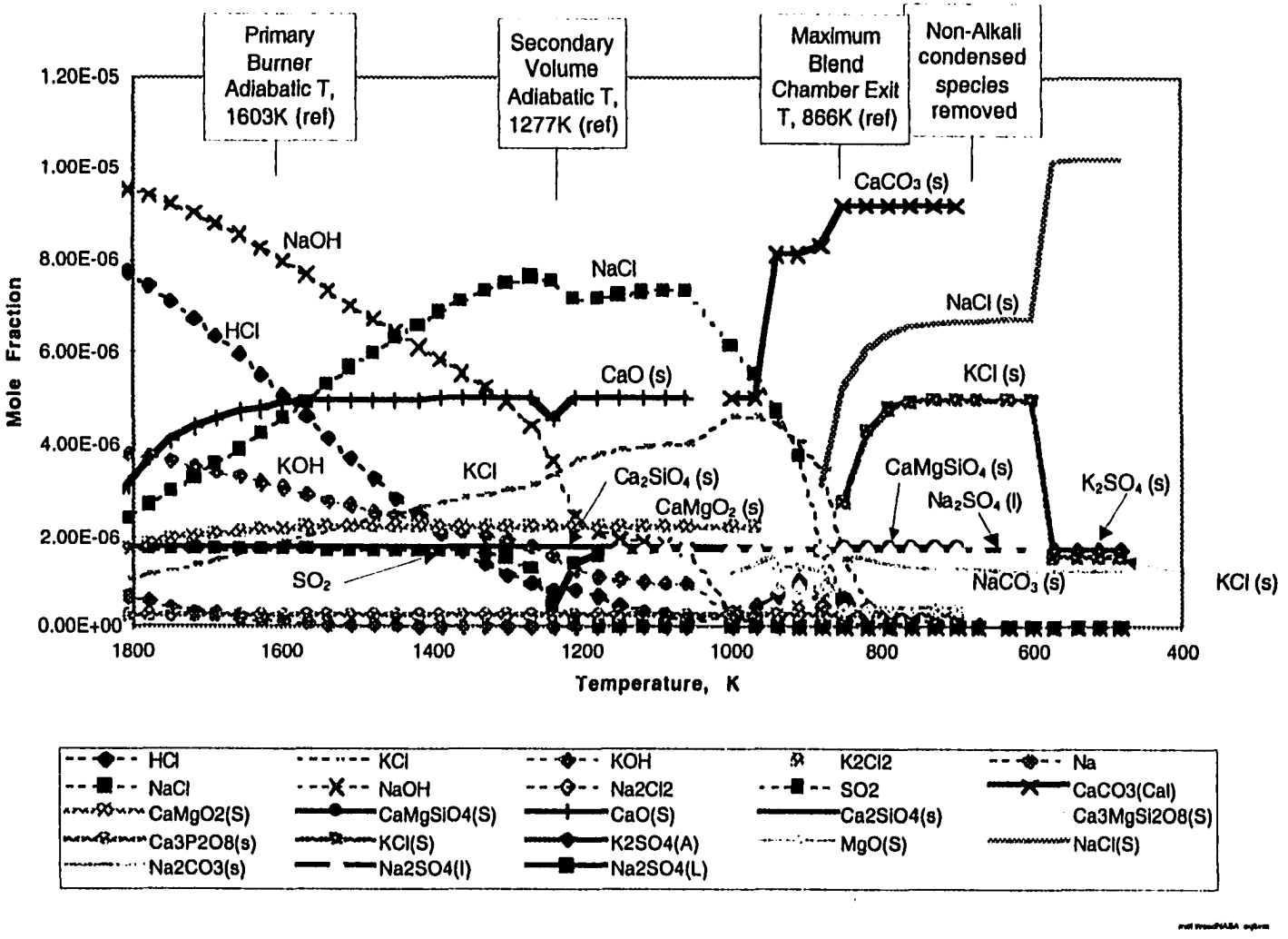


Figure 7.8: Fuel 2 equilibrium calculations for laboratory burner conditions, (Fuel 2 flowrate)/(Total flowrate) = 0.0068

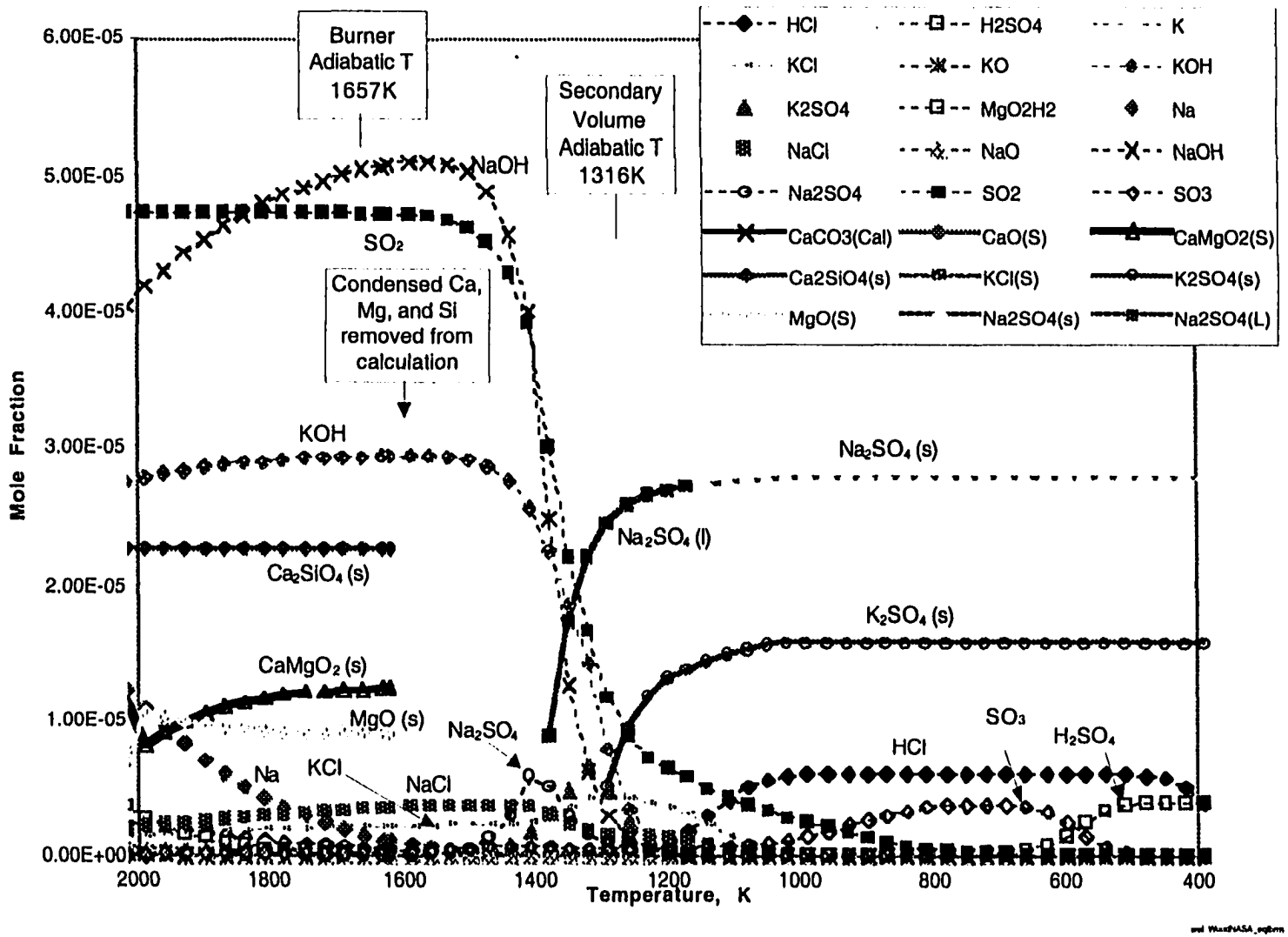


Figure 7.9: Fuel 3 equilibrium calculations for industrial burner conditions, (Fuel 3 flowrate)/(Total flowrate) = 0.090

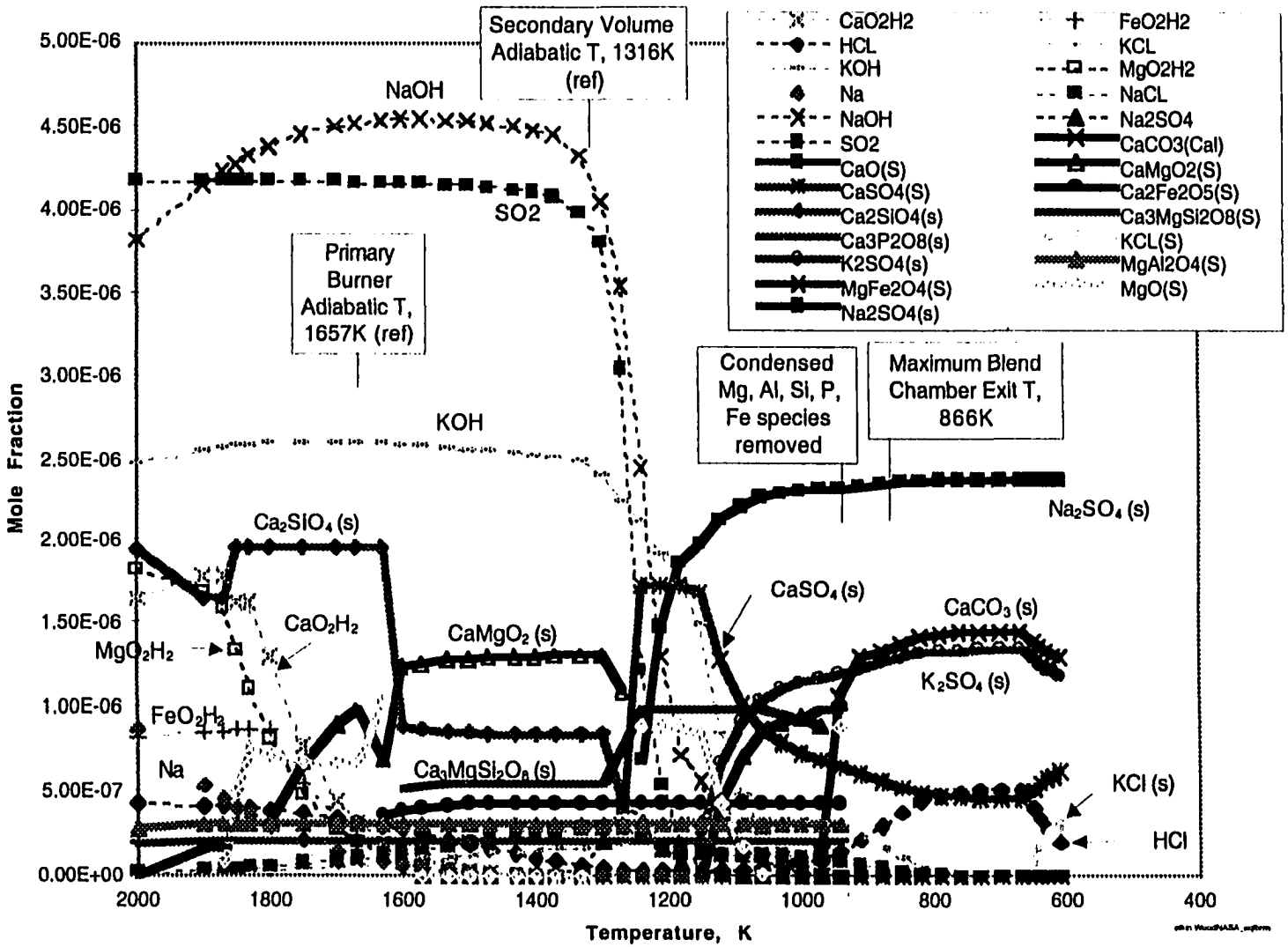


Figure 7.10: Fuel 3 equilibrium calculations for laboratory burner conditions, (Fuel 3 flowrate)/(Total flowrate) = 0.0081

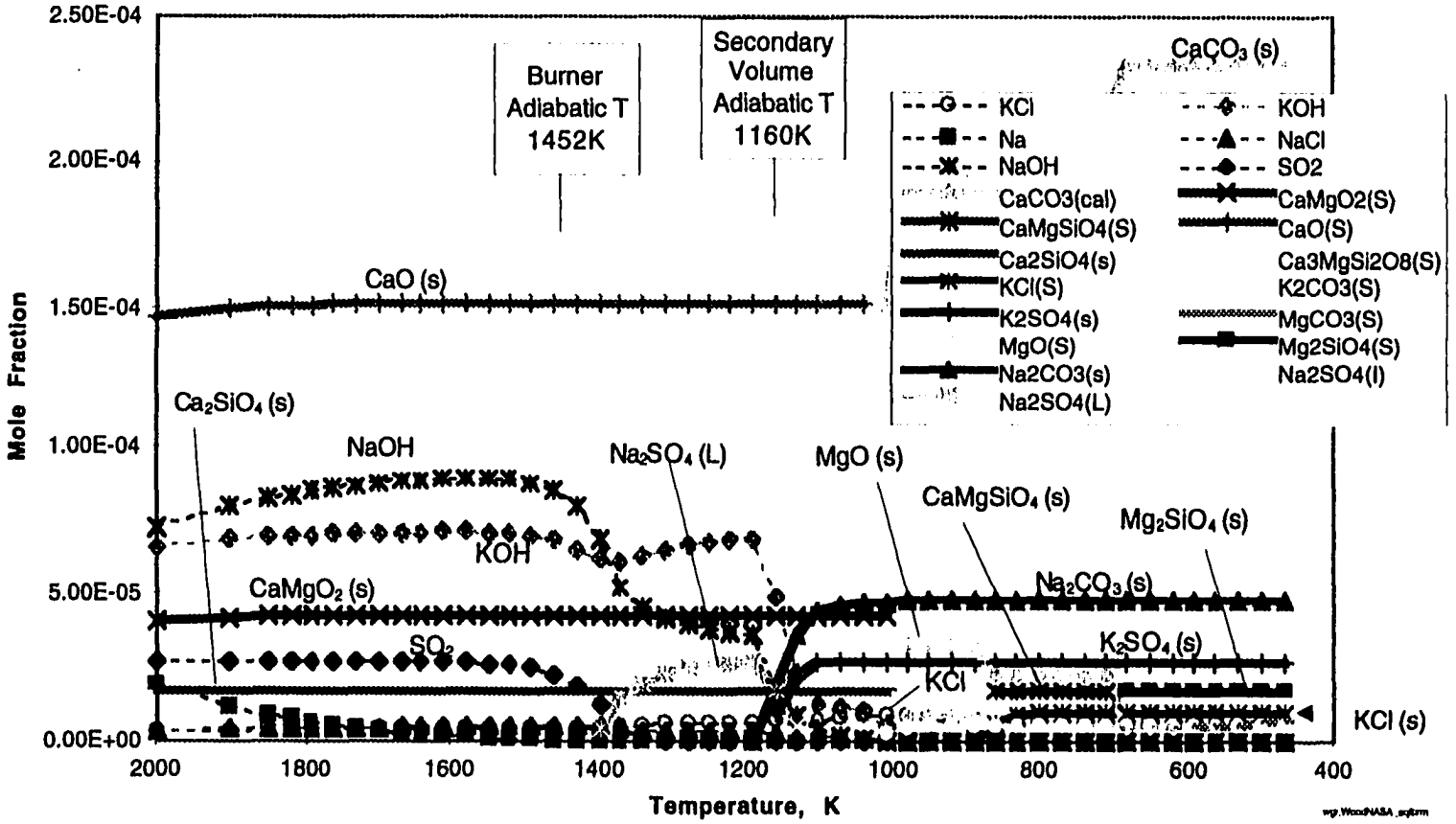


Figure 7.11: Fuel 4 equilibrium calculations for industrial burner conditions, (Fuel 4 flowrate)/(Total flowrate) = 0.087

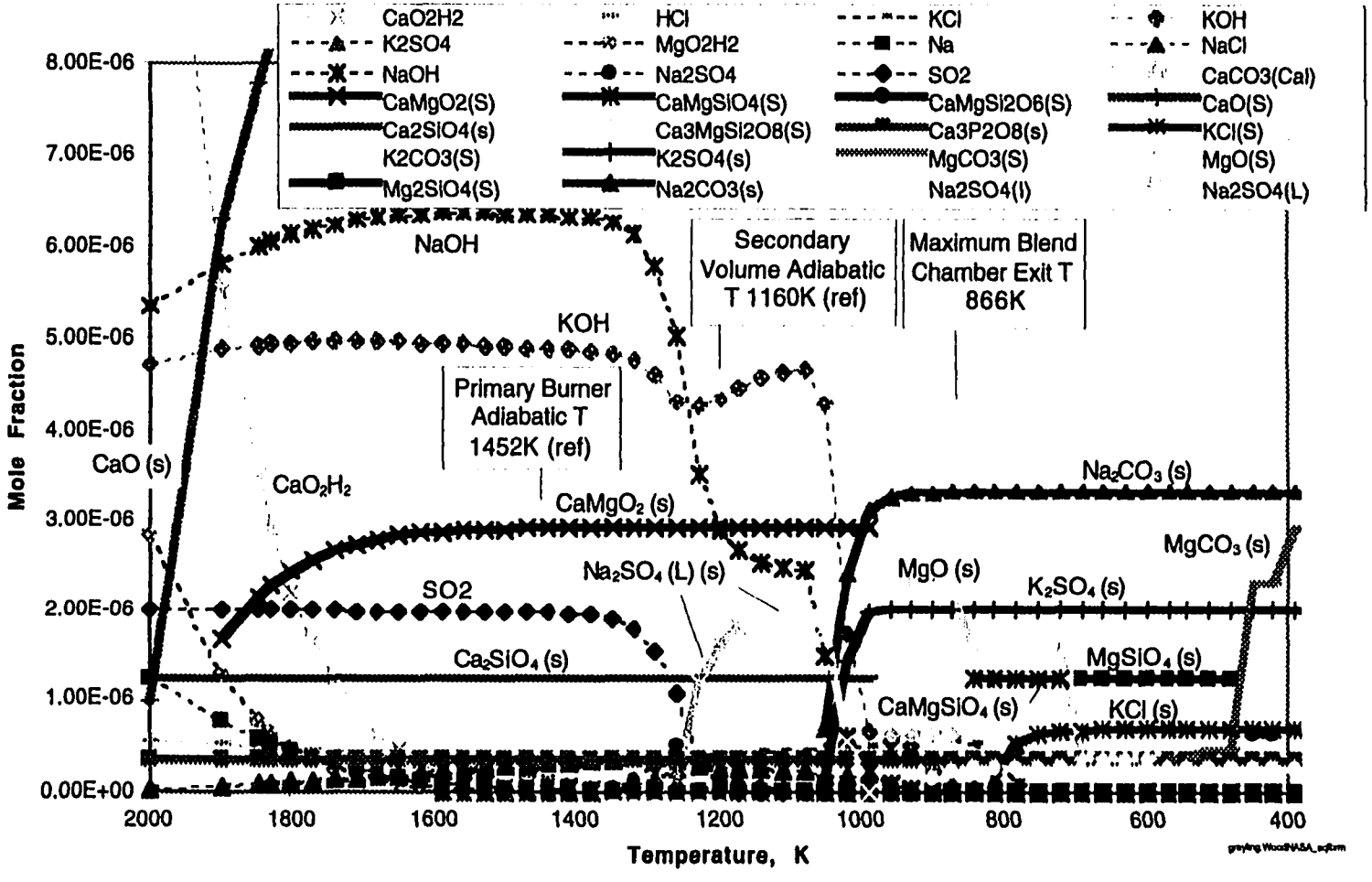


Figure 7.12: Fuel 4 equilibrium calculations for laboratory burner conditions, (Fuel 4 flowrate)/(Total flowrate) = 0.0062

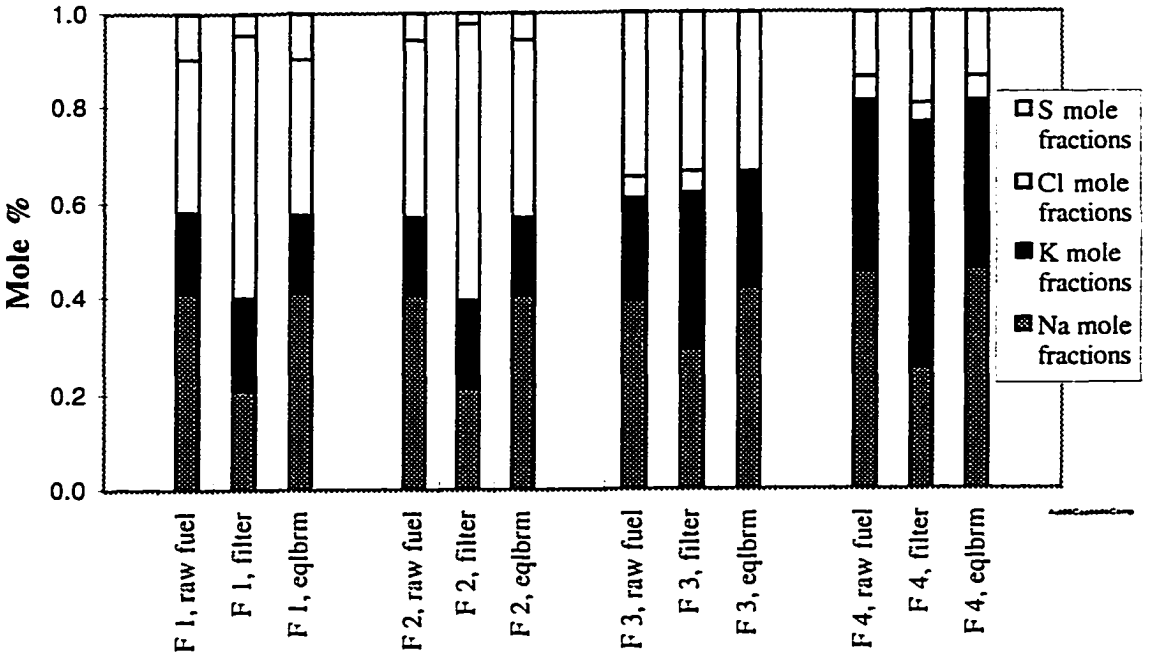


Figure 7.13: Predicted aerosol composition vs. measured aerosol composition. A comparision based on raw fuel composition, aerosol ash composition and equilibrium composition.

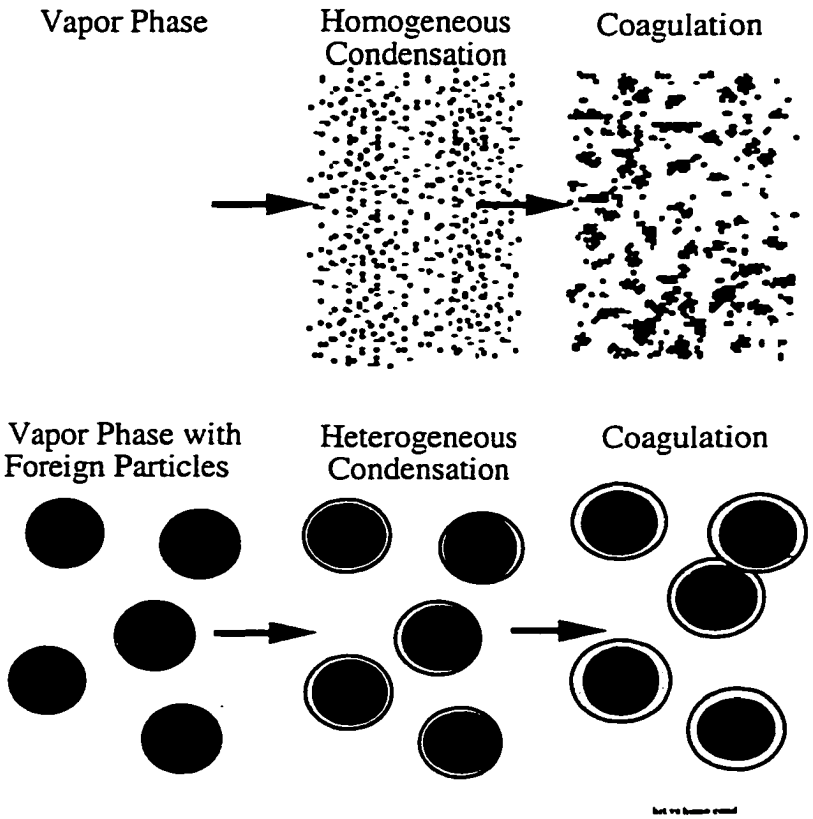


Figure 7.14: Limit cases of homogeneous condensation and heterogeneous condensation in a super saturated environment.

Table 7.3: Saturation Ratio (S=Pvap/Psat) condensation regimes for systems containing only vapor phase, and systems containing foreign particles.

Saturation Ratio S_{crit} = homogeneous condensation S_{het} = heterogeneous condensation	**Vapor Phase with no Foreign Particles**	**Vapor Phase with Foreign Particles**
$S<1$	No Condensation	No Condensation
$S_{het}<S<S_{crit}$	No Condensation	Heterogeneous Condensation only
$S_{het}<S_{crit}<S$	Homogeneous Condensation	Homogeneous and Heterogeneous Condensation Competition

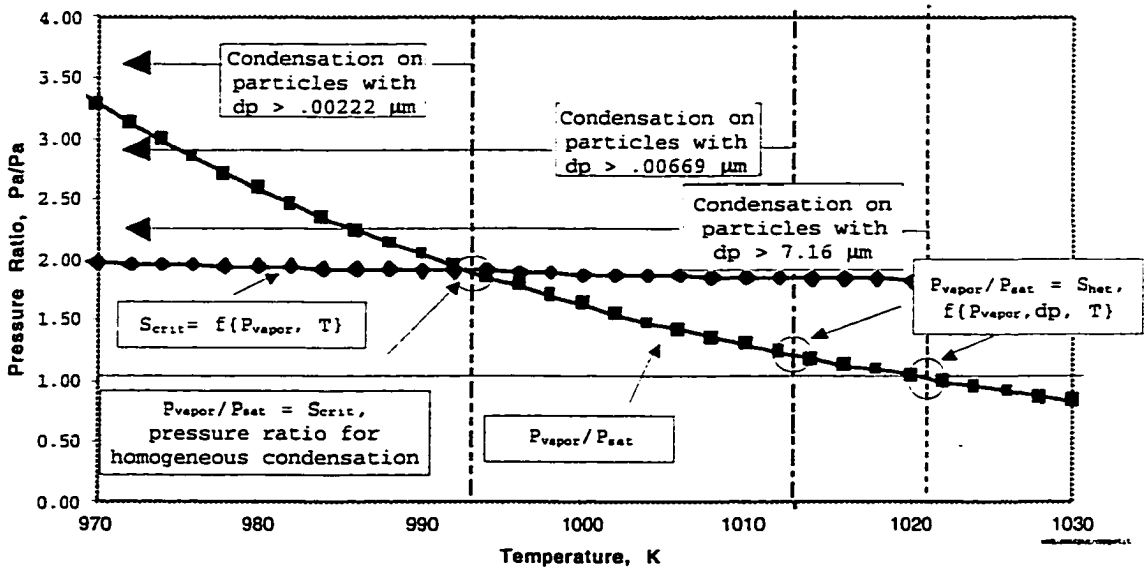


Figure 7.15: Condensation regimes for a system containing NaCl vapor at 14 Pa partial pressure.

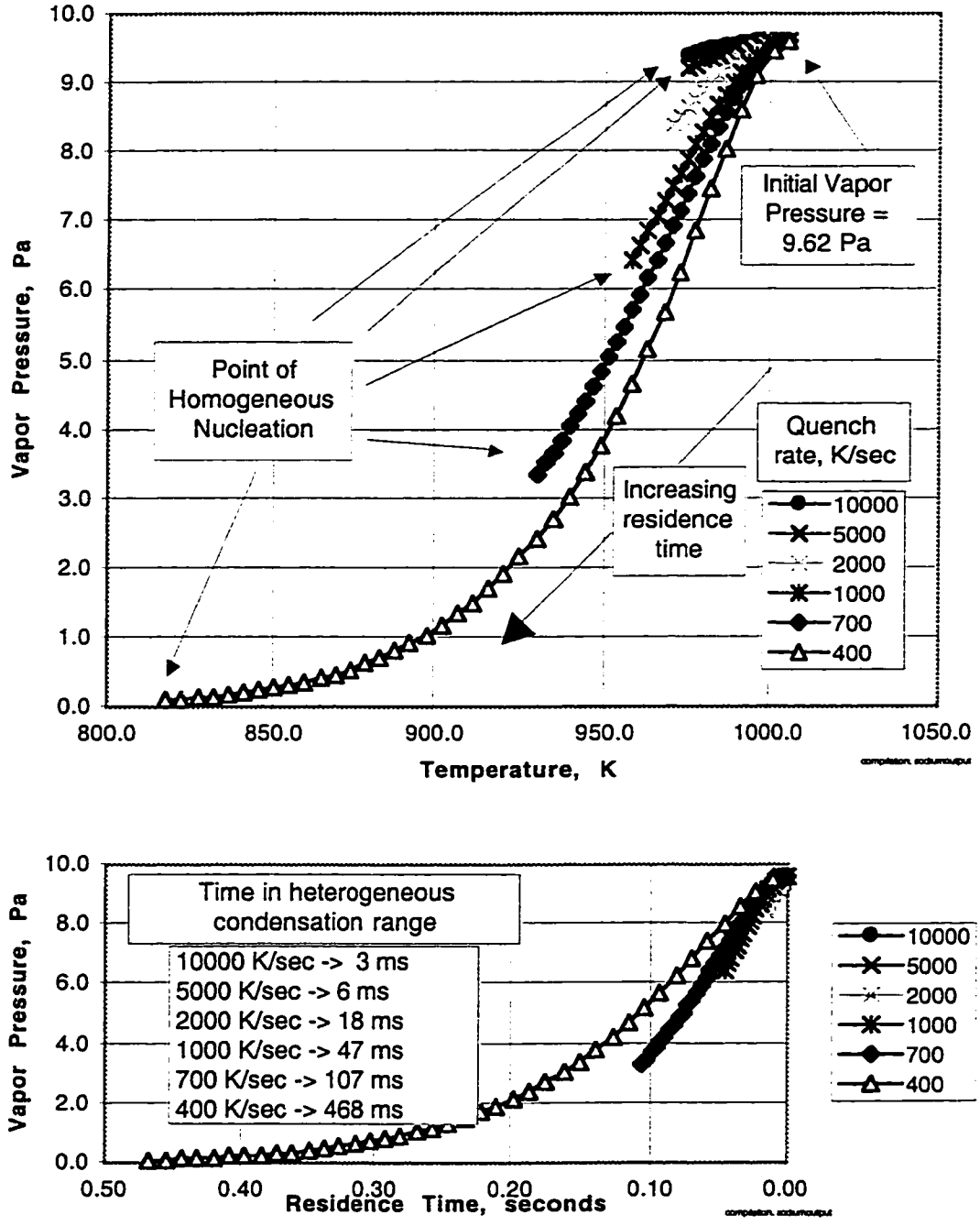


Figure 7.16: Alkali vapor capture by heterogeneous particles as a function of system quench rate for an initial vapor pressure of 9.62 Pa, Fuel/Total Mass = .094. Heterogeneous particle size and number densities: dp1 = 7.16 μm, 4.74e9 #/kgFuel; dp2 =.669 μm, 2.64e12 #/kgFuel

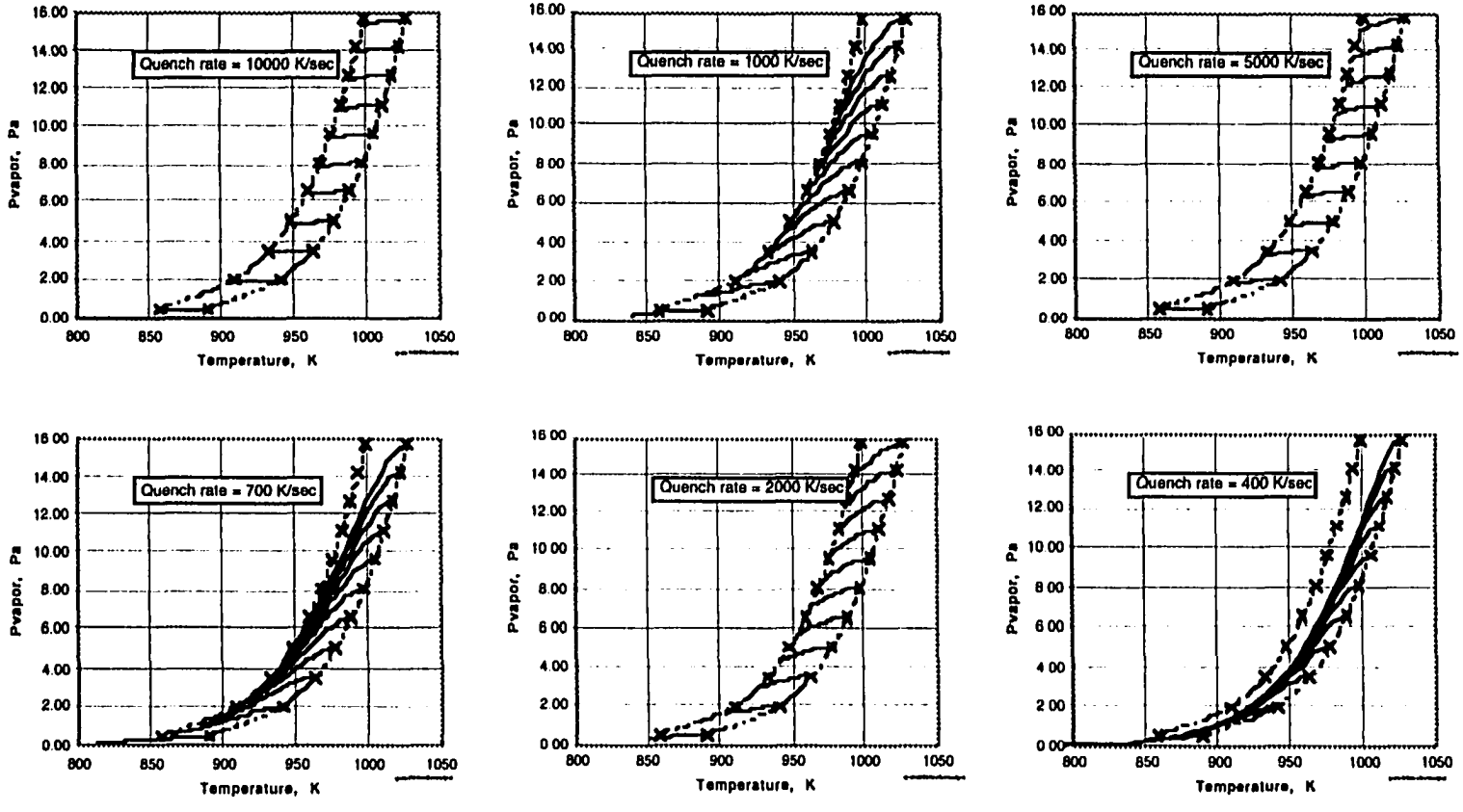
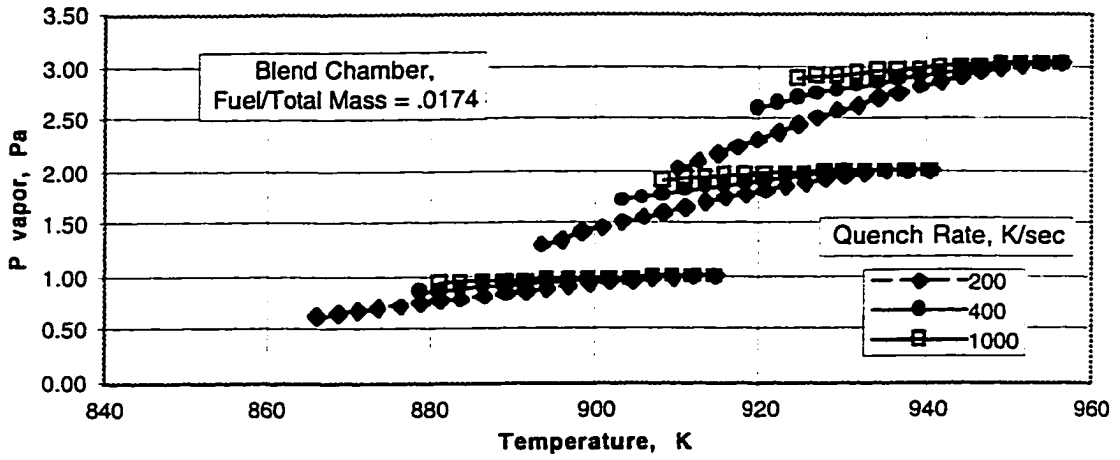
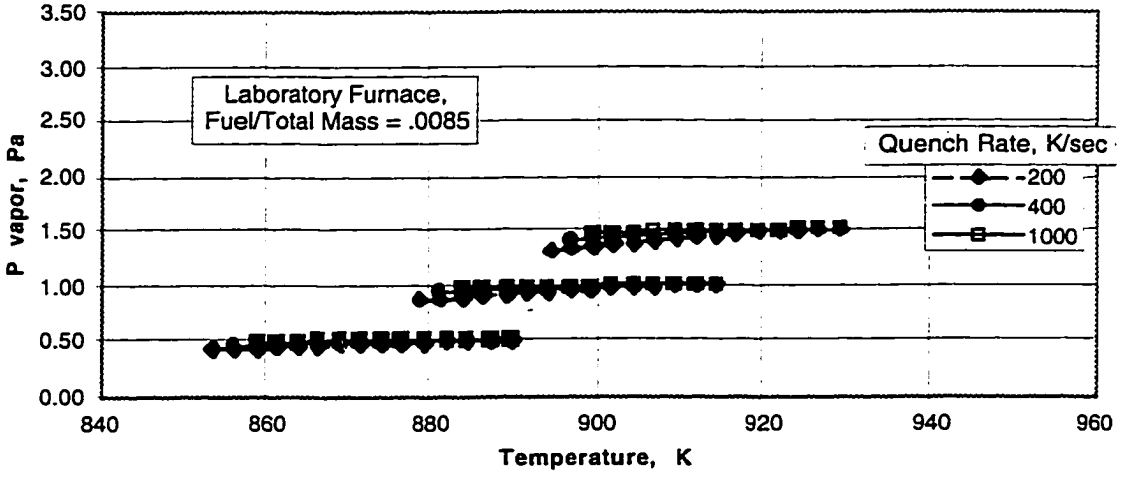


Figure 7.17: Vapor capture by heterogeneous particles as a function of quench rate for Fuel 1, Fuel/Total Mass = .094. Heterogeneous particle size and number densities: dp1 = 7.16 μm, 4.74e9 #/kgFuel; dp2 =.669 μm, 2.64e12 #/kgFuel.





Example Alkali Loading	Industrial Burner Blend Chamber	Laboratory Burner
Fuel 1 NaCl	1.1 Pa	0.5 Pa
Fuel 1 NaCl x 1.4	1.7 Pa	0.7 Pa
Fuel 1 NaCl x 2.4	2.7 Pa	1.3 Pa

Figure 7.18: Change in Alkali vapor pressure with quench rate, for Fuel 1 in Industrial Blend Chamber and Laboratory Furnace. Heterogeneous particle size and number densities: dp1 = 7.16 μm, 4.74e9 #/kgFuel; dp2 =.669 μm, 2.64e12 #/kgFuel.

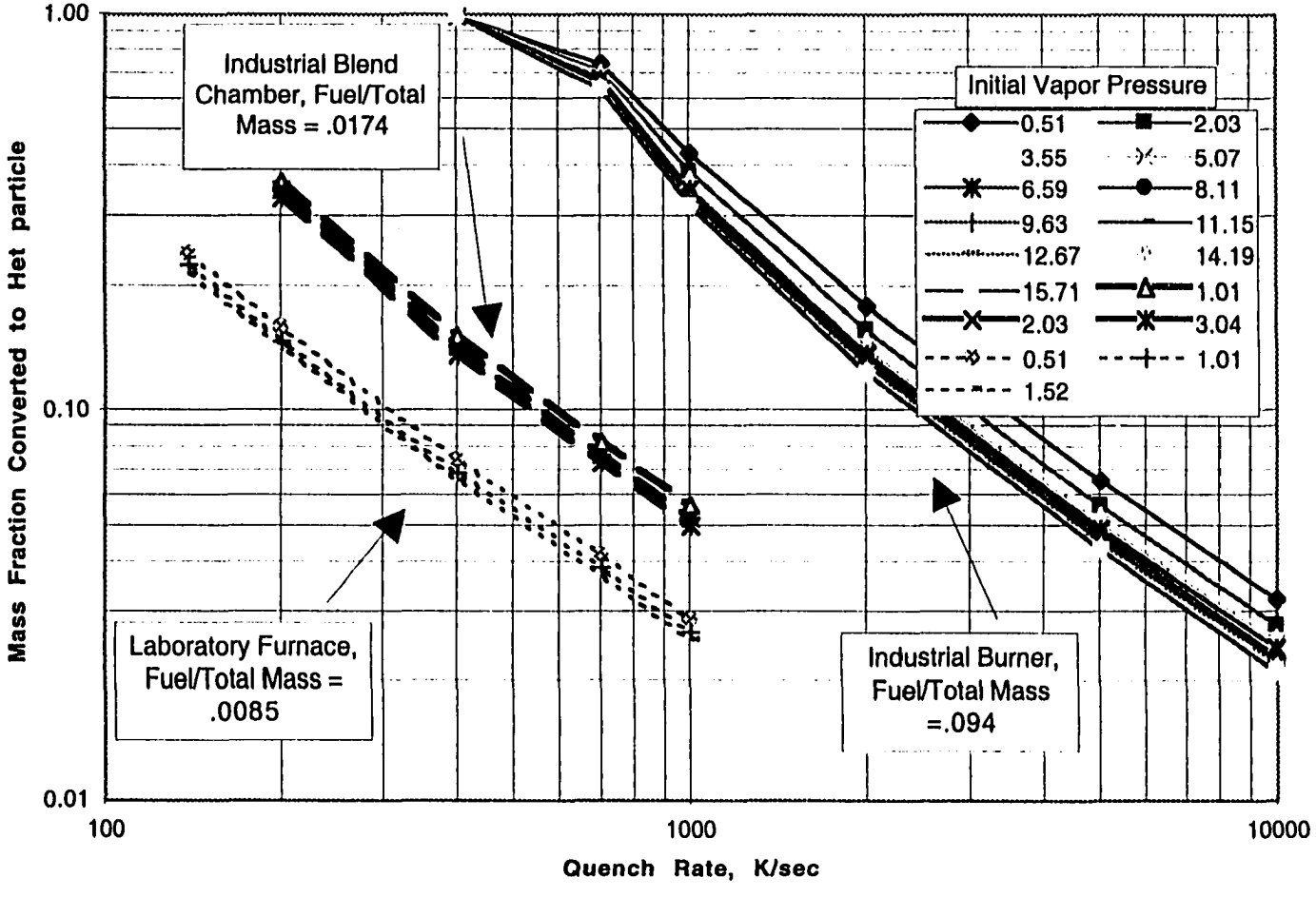


Figure 7.19: Comparision of heterogeneous collection efficiency as a function of Quench Rate and dilution ratio for Fuel 1. Heterogeneous particle size and number densities: dp1 = 7.16 μm, 4.74e9 #/kgFuel; dp2 =.669 μm, 2.64e12 #/kgFuel.

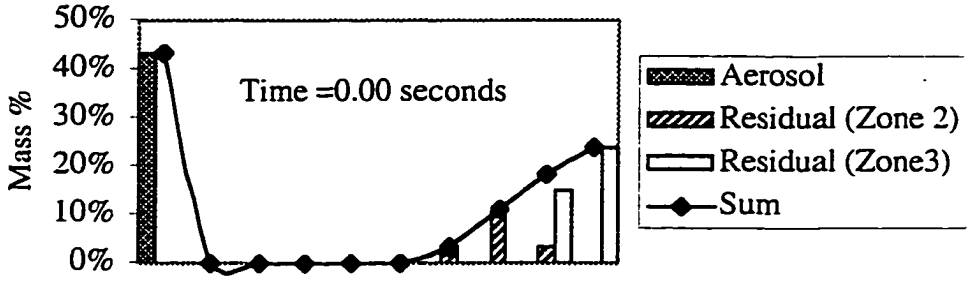


Figure 7.20: Fuel 1 aerosol coagulation in industrial blend chamber at initial conditions

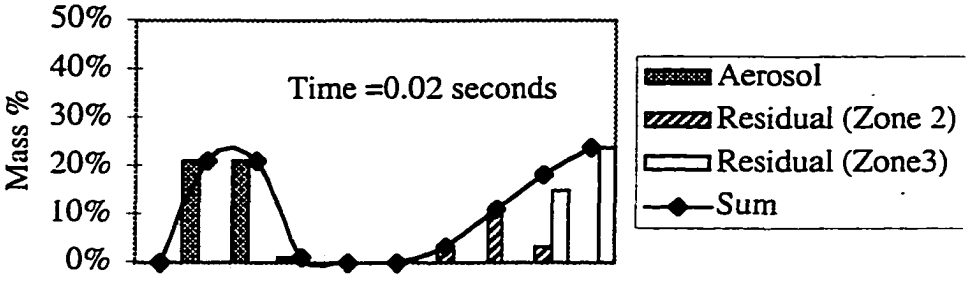


Figure 7.21: Fuel 1 aerosol coagulation in industrial blend chamber at 0.02 seconds

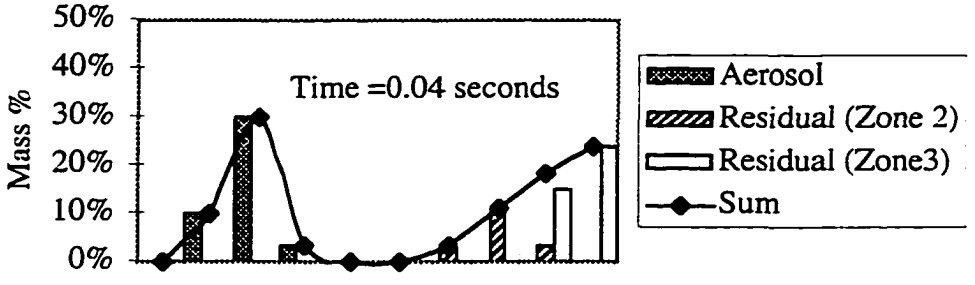


Figure 7.22: Fuel 1 aerosol coagulation in industrial blend chamber at 0.04 seconds

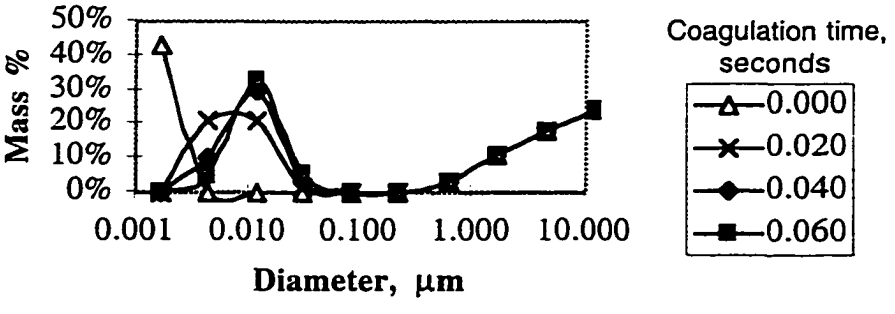


Figure 7.23: Fuel 1 aerosol coagulation in industrial blend chamber as a function of time

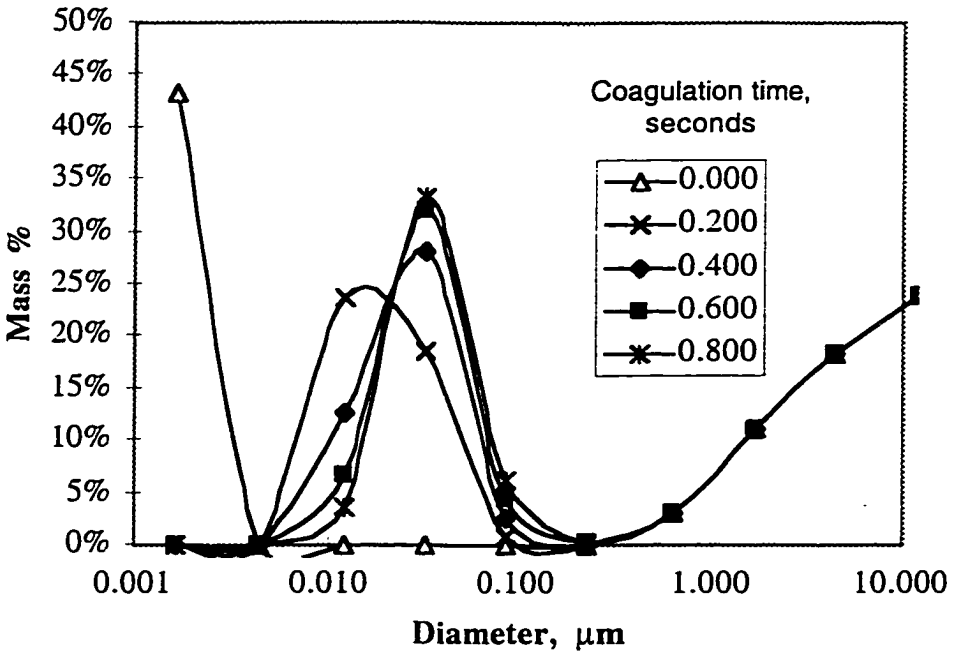


Figure 7.24: Fuel 1 aerosol coagulation in industrial blend chamber for long residence

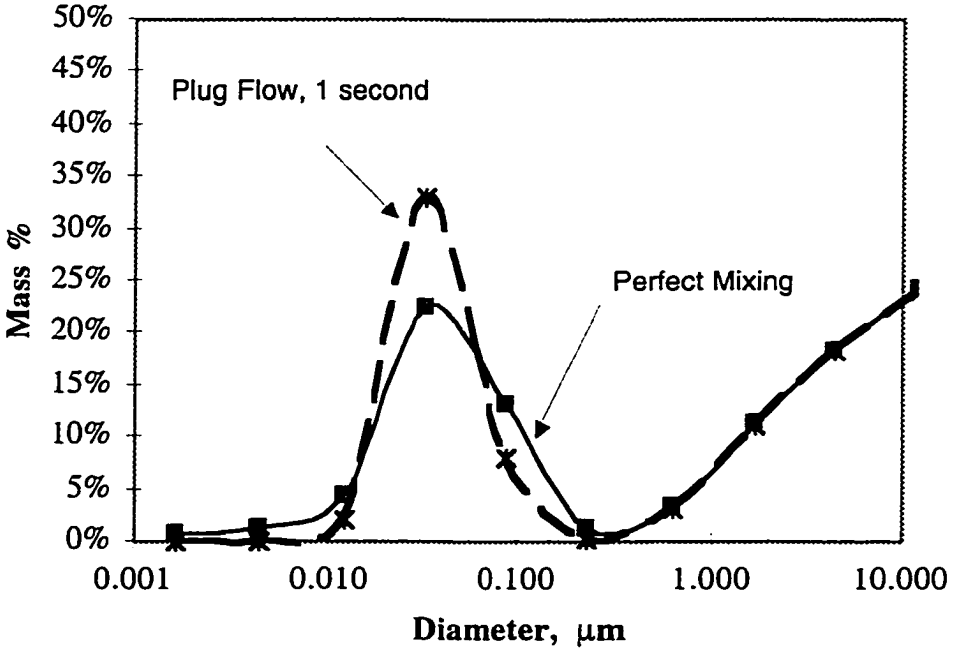


Figure 7.25: Fuel 1 aerosol coagulation in industrial blend chamber, comparing limit cases of plug flow versus perfect mixing

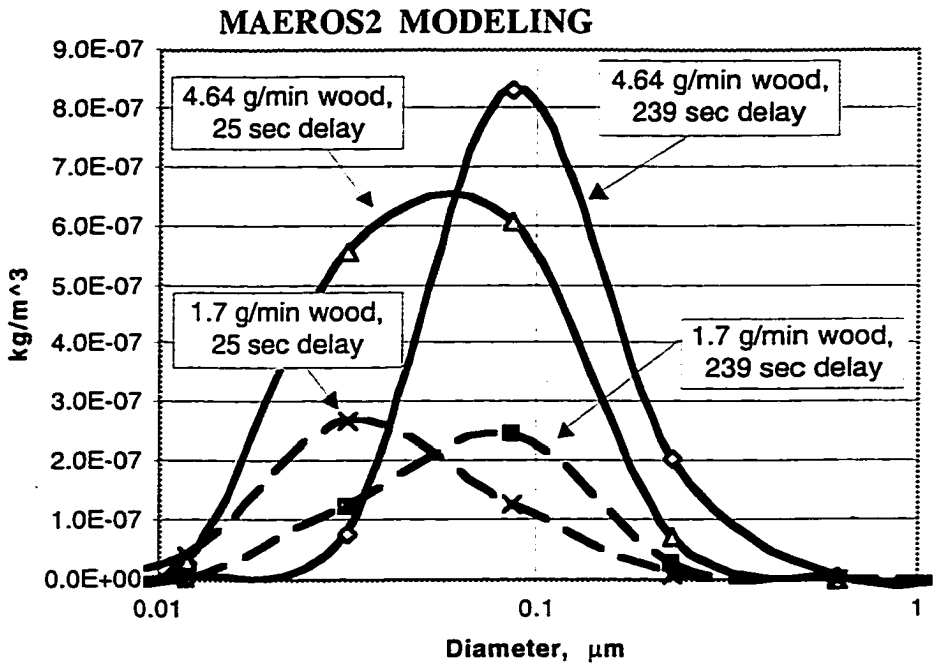


Figure 7.26: Fuel 1 aerosol coagulation in the EAA delay tank as calculated by MAEROS2

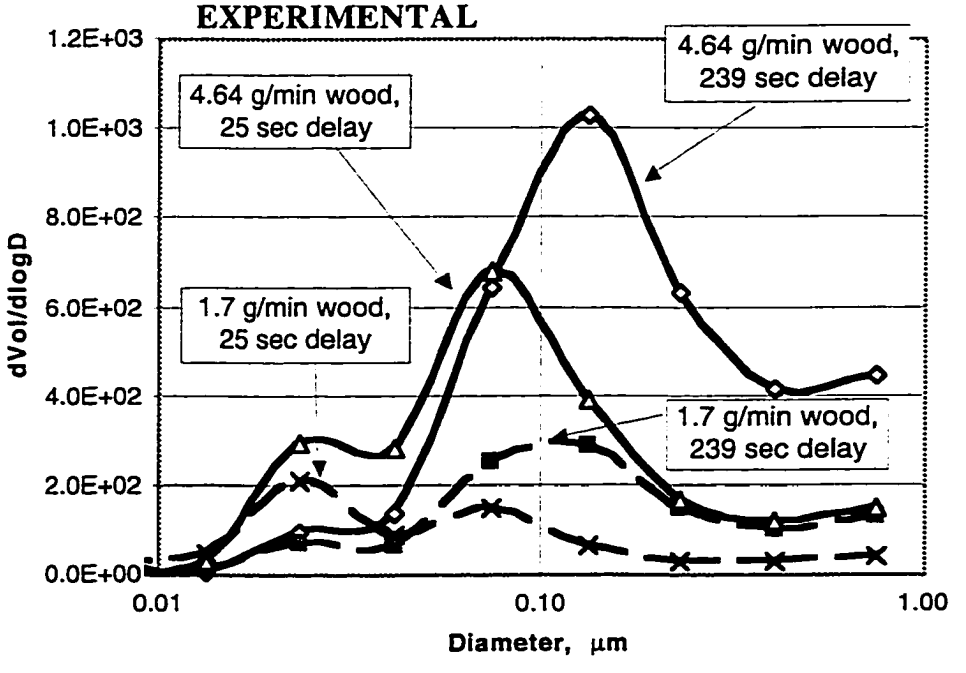


Figure 7.27 Fuel 1 aerosol coagulation in the EAA delay tank as measured experimentally

CONCLUSIONS AND SUMMARY

Understanding and predicting residual and aerosol ash properties of biomass and coal fuels is of paramount importance to the industrial community. Potential for excessive slagging, fouling, corrosion, and/or aerosol escape continues to separate viable fuel sources from unusable fuel sources. Development of reliable prediction methods and libraries of ashing characteristics for pulverized fuels significantly aids in the design of cost effective industrial facilities.

The body of work presented here is an investigation into the ash characteristics of industrially significant sawdust/sanderdust fuels. The two primary objectives are: 1) Accurately characterize the morphology and composition of the residual and aerosol ash, and 2) Develop a modeling methodology useful for predicting the characteristics of the ash formed by sawdust/sanderdust combustion, with particular focus on the aerosol mode.

Like many clean biomass-derived fuels, the fuels tested are high in alkali and low in clay minerals compared to coal. High alkali fuels have presented challenges to industry. They typically generate highly mobile sub-micron aerosol ash via a vaporization/condensation mechanism. This sub-micron particulate matter often leads to fouling in the convective pass of industrial boilers. Sub-micron ash that is not retained by the furnace must be efficiently cleaned from the flue gas for health and environmental reasons, reasons which are enforced with federal regulations. Generally, efficient aerosol capture requires expensive pollution control equipment. Alkalies can also combine with clay minerals to form low melting eutectics. These are capable of forming glass-like slags, as well as producing "sticky" surfaces for accelerated fouling. Hence, the study of these high alkali fuels is an important step in cataloging behavior and developing useful predictive models.

A secondary objective of this work is to present an investigation of ash morphology for a well-characterized set of research coals and artificial chars. This database serves as a source of comparison for the sawdust/sanderdust experiments and explores variables affecting coal aerosol yield.

Sawdust/sanderdust Results

Ash size distributions as determined by the cascade impactor showed three mass modes. Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDS) were used to investigate these distinct modes. In brief, the modes can be described as:

- *A residual mode composed of large particulate matter, on the order of 8 μm and larger.* This mode contains the bulk of residual ash and is dominated by calcium-based porous structures. It is hypothesized that the porous nature of these structures is related to the distribution of calcium in the cell walls of the parent fuel. Organically bound calcium is converted to oxide or carbonate as the cell walls collapse, with little fluxing. Magnesium, the other alkaline earth element in the fuel, is also present. All other elements are less well represented.

  EDS showed little complexing or surface deposition of alkali metals in the large residual mode. Low mobility of the large residual mode and low fluxing due to high Ca concentrations is the likely reason for the lack of alkali metals.

- *A secondary residual mode near 2 μm.* This mode is more chemically and morphologically diverse than the large residual mode. Both spherical particles (indicating full melting) and porous structures are present. It is suggested that the melts are evidence of eutectic formation, with alkali metals being the active fluxing agents. These eutectic melts are mobile compared to unmelted structures, and therefore are susceptible to separation from the parent ash particle. The average size of a single melt particle is governed by the *local* combustion conditions and the *local* mineral matter composition. Hence, the magnitude and the location of this size mode may be the result of natural segregation of the eutectic material.

  The high volatility of the alkali allows most of the alkali to escape, but a fraction is captured by solidifying melts as they enter a two-phase region. Smaller particles near 0.4 μm show more alkali content and a very uniform size. Fluxing appears to be driven by alkalies here as well, but deposition via condensation is also likely.

- *An aerosol mode near 0.1 μm.* This mode is composed primarily of alkali chlorides when chlorine is available, and sulfates when chlorine is not available. These conclusions are based on EDS measurements modified to remove the background signal of the filter substrate. Although simple equilibrium predicts condensed sulfate to form prior to condensation of vapor phase alkali chlorides, sulfur does not appear to displace chlorine on the aerosol particles. Sodium appears to be under-represented in the aerosol mode relative to potassium. Preferential complexing of sodium with the limited amount of silicates available is suggested.

Cascade Impactor and SEM work suggests that the aerosol may be composed of particulate matter of more than one size mode. Determination of the magnitudes of these individual modes was investigated with an isokinetic sampling probe, a delay tank to control coagulation time, and an Electrical Aerosol Analyzer. It was found that the aerosol size distribution is a function of the variables that influence coagulation, specifically the initial aerosol density (mass/volume) and time.

Tests with no delay tank, a 25 second delay tank, and a 239 second delay tank demonstrated that the 0.1 μm peak is formed over time by coagulation of much smaller particulate matter. The maximum mode diameter migrates from less than 0.01 μm to about 0.1 μm as coagulation time increases. Long coagulation times (239 seconds) leads to an aerosol peak near 0.1 μm for all sawdust/sanderdust fuels.

Sampling vapor-phase alkalies and quenching by dilution results in a low initial number density of nucleated alkalies. This low initial number density results in slow coagulation. Sampling and diluting *after* initial nucleation results in high number densities and very fast coagulation prior to entering the probe. After entering the probe, coagulation continues as before, but much of the coagulation process is already accomplished.

It is concluded from the EAA tests that aerosol is formed via homogeneous nucleation/condensation. This particulate matter is initially less than 0.01 μm in diameter but quickly coagulates to a larger diameter. The ultimate diameter of the particulate matter can be modified, with dilution and coagulation time being the control variables.

Modeling Results

Modeling was approached in a modular form. By splitting the process into three elements, the role and importance of each modeling element is isolated. These elements are: 1) Equilibrium calculations to investigate the preferred species of alkali metals and the residual elements, 2) Condensation modeling to determine the partitioning of alkali metal vapor between homogenous particulate formation (self-nucleation) and deposition on existing residual particles, and 3) Coagulation modeling to determine the ultimate diameter of nucleated aerosol particulate matter.

Equilibrium:
A simple equilibrium model, which includes condensed phase species but does not incorporate eutectic formation, predicts an aerosol mode driven by alkali vaporization and condensation. Alkalies are expected to vaporize to form alkali chlorides, when chlorine is present, as well as hydroxides. No significant alkali sulfates in vapor phase are expected. As the gases cool, sulfates are favored by equilibrium to form a condensed phase, followed by condensation of vapor phase alkali chlorides. However, it is clear from the present experiments that sulfate formation is limited relative to the rapid condensation of vapor phase chlorides. This illustrates the limitations on conclusions drawn from equilibrium predictions. In particular, condensation events accompanied by a change in composition requires a reaction. This imposes a kinetic limitation that might not be overcome in reality. The data show this for Fuels 1 and 2. Here, the predominant aerosol anion is chlorine, even though sulfates are the favored equilibrium product and sulfur is present in abundance. It is clear that the sulfur cannot displace the chorine as an anion. Whether this is due to a pure chemical kinetic constraint, or a transport limitation (*e.g.*, the resistance of a thin product layer of sulfate on alkali chloride particles to the diffusion of sulfur to the chloride substrate) is not known.

Complexing of the alkali species with silicates is also not predicted, since this is a eutectic formation process that is beyond the capabilities of the NASA CET89 program. Additionally, this complexing is a *local* mineral matter concentration phenomena rather than an *overall* composition phenomena, so system equilibrium calculations are not appropriate tools to investigate this. Low mobility of liquid and solid phases to form equilibrium compounds is an obvious limitation.

Equilibrium shows that non-alkali metals and silicon form residual solids that are not expected to vaporize at standard industrial furnace temperatures. Equilibrium predicts they will form complex species that can recombine to form new species at cooler temperatures. In the absence of other mineral species, oxides are generally the favored form of non-alkali metals (*e.g.* MgO (s)). Recombination of solids to form new solid species at lower temperatures is surely a phenomena limited to very minor surface reactions between colliding residual particles.

Condensation Modeling:
A modeling program was written to determine the fate of alkali chlorides that enter the vapor phase. One pathway is self-nucleation (at the critical saturation ratio) to form highly mobile particles, which ultimately coagulate. The other pathway is heterogeneous condensation on particles in the residual mode, which results in a low number density and little coagulation. This model is based on diffusion-driven vapor transport (both continuum and free molecule modes considered) for heterogeneous condensation, and the critical saturation ratio (*i.e.* diameter) for homogeneous condensation. The Kelvin effect, accounting for the influence of particle curvature on vapor pressure, is also included.

This model showed that the critical temperature range for condensing alkali vapor onto existing residual particles is dictated by the diameter of the existing residual particles (upper bound), and the vapor pressure of the condensable alkali vapor (lower bound). For a given heterogeneous particle diameter and alkali vapor pressure, there exists a temperature at which condensation on the particle surface will occur. Maintaining a temperature below this temperature, yet above the self-nucleation temperature, promotes heterogeneous condensation.

The conversion efficiency of vapor phase alkali to heterogeneous particles is a logarithmic function of the quench rate between the temperature at which heterogeneous condensation starts, and the temperature at which homogeneous nucleation starts. Therefore, conversion efficiency can be modified significantly with small changes in quench rate, as long as the quench environment is relatively gentle.

A finding of practical significance is that dilution ratio is an important control parameter. In order to obtain the highest conversion efficiency to the larger, more easily removed heterogeneous particles in an industrial dryer application, the undiluted flue gas should be quenched through the temperature range of conversion prior to dilution. This may be best

accomplished by staged dilution. Additional dilution air may be added downstream of an insulated volume (*i.e.* a slow quench zone), in order to obtain the desired dryer inlet temperature and volumetric flow rate.

Coagulation Modeling:
Coagulation modeling of the industrial burner blend chamber demonstrated that coagulation changes the ash size distribution only below ≈ 1 μm. The coagulating aerosol is expected to converge to about .05 μm under typical conditions for an industrial burner. Residual modes above 1 μm are not expected to change, due to low Brownian mobility. Results suggests that the *major* mode diameter of sub-micron aerosol may be reasonably predicted by assuming the aerosol is composed of the alkali components of the parent fuel, in the form of alkali chlorides and alkali hydroxides.

Pulverized Coal and Artificial Char Results

Investigations with these fuels was limited to mass distribution measurements obtained using the tunnel furnace, water-cooled probe, and cascade impactor.

Experiments with unmodified coals show similar ash size distributions for all three coals tested: A sub-micron aerosol mode, a 3 μm mode, and a > 9 μm mode. The aerosol is most likely formed from condensed and coagulated vapors, while the 3 μm and ≥ 9 μm modes are fragmented and coalesced residual ash.

The sum of aerosol from individually burned aerodynamically-sized coal fractions is greater than the aerosol yield of the whole coal. This is demonstrated with Upper Freeport coal, in which the aerosol yield was about 0.25% of the total ash for the whole coal, compared to 0.75% of the total ash for the summed coal fractions. This lends support to the conclusion that alkali vapor release is attenuated by close association of mineral inclusions, since this close association is disturbed by the aerodynamic sizing process.

The ash size distribution is not identical for all aerodynamically-sized coal fractions. Sized Upper Freeport of < 18 μm contributes as much mass to the 4 μm mode as all other size cuts combined. Ash from size cuts greater than 18 μm are predominantly greater than 9 μm in diameter. If the 4 μm mode is assumed to be formed by the surface shedding of fine

particles during char combustion, then the finer coal cut should have a higher yield since it exposes the most surface area per unit mass.

The experiments with bentonite-doped artificial char show that aerosol yield generally decreases with increasing bentonite, although the affect of incomplete burnout and experimental uncertainty cannot be ignored. Suppression of aerosol fraction is most likely alkali metal absorption by bentonite inclusions as the surface of the char particle recedes during combustion, as has been noted by other researchers

Experiments with calcite chars show that calcite fragmentation is limited, with most mass remaining in the large (>9 μm) particle range. This results in very little surface area for sodium interaction. Sodium and calcite interaction is also probably limited because of the high melting temperature of CaO, which is the favored species above 900 C. This limits the opportunity for chemical interaction between sodium and calcium.

Pyrite minerals exhibited significant fragmentation, as has been observed by other researchers. Like bentonite, the pyrite generally shows a reduction in aerosol yield with increased mineral content, although it remains to be determined if this is a result of sodium/pyrite interaction, or is too small observe relative to the experimental uncertainty.

Suggested Future Investigations

Past investigations by other researchers into the mechanisms of ash transformations have always left room future research. The complexity of ash formation mechanisms dictate that the current investigation is no exception. Hence, this research may be the starting point for the following future investigations:

- Benefication of coal to reduce mineral content has shown some success, but potentially increases the sub-micron aerosol yield. An area worthy of further investigation is benefication of high-alkali fuels by leaching. Some work has been done in this area with naturally leached rice straw (Jenkins *et al.*, 1997). Modifying the current sawdust/ sawdust samples by a simple water leach process may yield results of practical significance to the industrial community.

- Doping of the current fuel with finely dispersed clays might also be of interest. This may be done concurrently with the leaching process mentioned above, by leaching the fuel with clay in a water suspension as a final rinse. Ideally, surface tension would hold the suspended clay onto the fuel particles during evaporative drying. The clay would act as an alkali sink as vapor attempted to leave the particle during combustion, and as a deposition surface during the condensation phase. Critical parameters are uniform distribution of the char surface, and clay particle size, respectively. Of course, potential for slagging must be recognized.

- A unified model of aerosol and residual ash transformations would be useful to the biomass combustion industry. The evolution of the current investigation verified that this is no simple matter. It is obvious that a unified model requires incorporation of discrete mineral sizes and dispersions in the parent fuel, temperature/time histories in the combustor and flue, accurate determination of local stoichiometry, incorporation of fluid dynamics, and more. This type of aggressive modeling (Barta, *et al.*, 1992) and experimental research (Boni, *et al.*, 1990) has been initiated by coal investigators. The growing importance of biomass combustion in industry warrants its inclusion in this important work.

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APPENDIX A: SIMPLIFIED RESIDUAL SIZE DISTRIBUTION

Calculation of simplified residual size distribution for Fuel 1 and Fuel 2, and Fuel 3 and 4:

Residual size distributions for Fuel 1 and Fuel 2 are very similar, as are distributions for Fuel 3 and 4. Hence, a simplified size distribution is made based on an average of Fuel 1 and 2, and another simplified size distribution is made with Fuel 3 and 4. These consist of two modes per residual size distribution, with a corresponding Geometric Mass Mean Diameter and a Geometric Standard Deviation. Some parameters are more appropriately estimated without averaging, such as chemical composition. In this case, Fuel 1 is considered the primary fuel when Fuel 1 and 2 are not averaged. Fuel 4 is considered the primary fuel when Fuel 3 and 4 are not averaged.

Assume an industrial burner wood flow rate of 3760 lbs/hr, per site information from Fuel 4 facility.

3760 lbs/hr * .4536 kg/lb * 1hr/3600 sec = .47376 kg/sec

Assume 80% excess air. This assumption based on the maximum firing rate of the Fuel 4 facility.

According to equilibrium calculations, and assuming complete combustion, the air to fuel ratio and adiabatic flame temperature is:

Fuel 1 and 2:
9.60 (kg Air)/(kg Fuel 1), T adiabatic = 1630 K.
Fuel 3 and 4:
10.49 (kgAir)/kg Fuel 4), T adiabatic = 1452 K

This adiabatic temperature is lower than the estimated temperature for the Fuel 4 combustion in the industrial facility, as provided by facility personnel (they estimate 1755 K). This is probably a result of variable stoichiometry in the main burner under non-ideal conditions.

NASA equilibrium predicts non-alkali species existing as solids for temperatures of 1600K and below. Primary species are:

Fuel 1:
Ca_2SiO_4 (s) -> 3.14e-5 moles/(moles total)
$CaMgO_2$ (s) -> 2.01e-5 moles/(moles total)
Ca_3MgSiO_8 (s) -> 3.60e-6 moles/(moles total)

Fuel 4:
CaO (s) -> 1.51e-4 moles/(moles total)
$CaMgO_2$ (s) -> 4.31e-5 moles/(moles total)
Ca_2SiO_4 (s) -> 1.80e-5 moles/(moles total)

All non-alkali minerals go to an oxide form. These may recombine to form complex species as above, but they are essentially (and by formula) oxides. So, it is assumed these form the residual size distribution. Based on the ICP analysis of Fuel 1and Fuel 4 conducted by an independent industrial laboratory, the mass of the ash in oxide form is (as calculated by spread sheet WoodNASA_ eqlbrm/ RawFuel atomic spec):

Fuel 1 = 4308.9 (mg ash)/(kg as-received wood), not including K, Cl, Na, or S
Fuel 4 = 7177.5 (mg ash)/(kg as-received wood), not including K, Cl, Na, or S

Assuming this is all ash that is residually formed (i.e. never enters a vapor phase), the size distribution of residual ash found during laboratory scale testing is assumed to be reasonably accurate.

In the primary industrial combustor, alkali species are expected to be in vapor phase, based on NASA equilibrium calculations. Species are: NaOH, NaCl, KOH, KCl, HCl. In the secondary chamber, the temperature (adiabatic T = 1298K for Fuel 1) is cool enough for Na_2SO_4 formation, but is probably not kinetically favored. KCl and NaCl are the primary vapor phase alkalis. It is assumed that aerosol coagulation begins in the blend chamber in such a way that NaOH and KCl form nucleated particles in tandem with NaCl. Therefore, NaCl KCl and NaOH form nucleated particles simultaneously, and the initial size distribution of these particles is similar to self-nucleated NaCl at the partial pressure of the sum of NaCl, KCl and NaOH. Na_2SO_4 is assumed not to be formed as an initial species.

If all the alkalies form chlorides or hydroxides from the vapor phase, an estimate of the initial aerosol size distribution can be determined.

Fuel 1 = 3277.3 (mg aerosol ash)/(kg as-received wood), with K and Na as hyroxides and chlorides
Fuel 4 =3121.7 (mg ash)/(kg as-received wood), with K and Na as hyroxides and chlorides

In order to use this information, the laboratory-determined size distribution was broken down into 3 zones, as shown in the figures at the end of this section:

Zone 1: Particles .4 μm and smaller. It is assumed that all ash in this zone is from the vaporization/nucleation/condensation formation mechanism. This is stage 7 (.39 μm) and the filter (~.1 μm).

Zone 2: A residual mode formed by breakup of the parent particles, assumed to be stages 2 (3.66 μm) to stage 6 (.54 μm).

Zone 3: A residual mode formed by conglomerated and unfragmented particles. Stages 0 (8.33 μm) and 1 (5.33 μm) and the preseperator. The ash in the preseperator was assumed to be 8.33 μm like stage 0.

The average mass on each stage is shown in Table A.1. In terms of zones, this yields:

Fuel 1&2 Zone 1 = 29.22% ash
Fuel 1&2 Zone 2 = 22.06% ash
Fuel 1&2 Zone 3 = 48.73% ash

Fuel 3&4 Zone 1 = 5.74% ash
Fuel 3&4 Zone 2 = 2.43% ash
Fuel 3&4 Zone 3 = 91.83% ash

Calculating the mass and average initial diameter of the aerosol requires assumptions. It should be recognized that the aerosol mass as collected on the aerosol filter may under represent amount of aerosol-forming material in the fuel. Incomplete combustion of the fuel may have left some alkali in the fuel, and much of it may be complexed with the residual. Additionally, some coagulation/deposition into the larger size modes may have occurred prior to size sorting in the impactor. For modeling purposes, it seems more reasonable to estimate that the mass in the aerosol mode based on the total alkali as chlorides and hydroxides. Using this approximation, the mass of aerosol relative to the mass of residual is:

For Fuel 1, this is:

$$\frac{\text{Alkali as chlorides/hydroxides}}{\text{Alkali as chlorides/hydroxides} * \text{metals as oxides}} = \frac{3277.3}{3277.3 * 4308.9} = 43\% \text{ aerosol}$$

This compared to 48.73% based on experimental results. Hence, this assumption is of little consequence.

For Fuel 4, this is:

$$\frac{\text{Alkali as chlorides/hydroxides}}{\text{Alkali as chlorides/hydroxides} * \text{metals as oxides}} = \frac{3121.7}{3121.7 * 7177.5} = 30\% \text{ aerosol}$$

This compared to 5.7% based on experimental results. The reason this aerosol estimate is higher than experimental results is probably related to incomple burnout of the residual ash. For modeling purposes, using the 30% aerosol seems to be a more appropriate value to use.

It is assumed that the *residual* modes will be formed with mass proportional to the ash collected in each residual zone (i.e. zones 2 and 3), as discussed above. Based on this assumption, our three-zone ash distribution is:
For Fuels 1 and 2, the mass divided between Zones 2 and 3 is:

Zone 2 -> 22.06% / (22.06% + 48.73%) = 31.2%
Percent mass of ash in Zone 2, relative to the total ash in Zones 2 and 3.

Zone 3 -> 48.73% / (48.73% + 22.06%) = 68.8%
Percent mass of ash in Zone 3, relative to the total ash in Zones 2 and 3.

For Fuels 3 and 4, the mass divided between Zones 2 and 3 is:

Zone 2 -> 2.43% / (2.43% + 91.83%) =2.58%
Percent mass of ash in Zone 2, relative to the total ash in Zones 2 and 3.

Zone 3 -> 91.83% / (2.43% + 91.83%) = 97.4%
Percent mass of ash in Zone 3, relative to the total ash in Zones 2 and 3.

Calculate the ash per second in each zone:
Fuel 1&2:

Zone 3: .688 * .004309 (kg oxide ash/kgFuel) * .47376 (kgFuel/sec) = .001404 kgAsh/sec

Zone 2: .312 * .004309 (kg oxide ash/ kgFuel) * .47376 (kgFuel/sec) = .0006369 kgAsh/sec

Zone 1: .003277 (kg aerosol ash/kgFuel) * .47376 (kgFuel/sec) = .0015525 kgAsh/sec

Fuel 3&4:

Zone 3: .974 * .007178 (kg oxide ash/ kgFuel) * .47376 (kgFuel/sec) = .003312 kgAsh/sec

Zone 2: .026 * .007178 (kg oxide ash/ kgFuel) * .47376 (kgFuel/sec) = .00008842 kgAsh/sec

Zone 1: .003122 (kg aerosol ash/kgFuel) * .47376 (kgFuel/sec) = .001479 kgAsh/sec

Assuming that each zone forms a log-normal distribution, the zone Geometric Mass Mean Diameter and Geometric Standard Deviation is calculated. The GMMD and GSD are calculated on a separate spreadsheet (Aut95CascadeComp/Compilation). This was facilitated by assuming that all mass on a stage is made of particles of the stage cut-off diameter. The preseperator was assumed to be all 8.33 μm particles, like stage 0.

Fuel 1&2
Zone 3:
GMMD: 7.77 μm
GSD: 1.18
Mass Fraction: 68.8%

Fuel 3&4
Zone 3:
GMMD: 8.27 μm
GSD: 1.05
Mass Fraction: 97.4%

Fuel 1&2
Zone 2:
GMMD: 1.68 μm
GSD: 1.74
Mass Fraction: 31.2%

Fuel 3&4
Zone 2:
GMMD: 1.98 μm
GSD: 1.81
Mass Fraction: 2.6%

These distributions are shown in Figures A.1 and Figure A.2. An aerosol mode is also shown, based on the *experimental* size distribution. As discussed earlier, this distribution

is misleading if one is attempting coagulation calculations. The initial aerosol distribution used for modeling is discussed next.

For the aerosol, the initial particulate diameter is estimated based on the critical saturation ratio (discussed in the modeling chapter) for a system composed of NaCl with an initial vapor pressure of .8 Pa. This results in a critical diameter of:

All Fuels:
Zone 1: Initial diameter: $1.9 * 10^{-9}$ meters

This is also the calculated critical diameter for a system with an initial vapor pressure from 1.22 Pa to 0.4 Pa, within 2 %.
Note that for modeling purposes (in particular, the MAEROS2 code), a uniform material density must be assumed for the residual and aerosol modes. For convenience, this density is chosen to be 2733 kg/m^3, which is the density of $CaCO_3$. This is more than NaCl, KCl, NaOH, and KOH (1980 to 2170 kg/m^3), but less than the oxide CaO (3300 kg/m^3). It is a compromise between the estimated aerosol density and residual density.

Surface Area Estimate:
Estimate the particulate surface area, assuming a density of CaO (3.25 g/cc):
(3.25 gCaO/cc) * (10^3 (cm^3)/(m^3)) * (1kg/1000g) = 3250 kg/m^3

Fuel 1&2:
Volume of Zone 3 ash:
((1/3250) m^3/kg) * (.001404 kgAsh/sec) = 4.32e-7 m^3/sec

Volume of Zone 2 ash:
((1/3250) m^3/kg) * (.0006369 kgAsh/sec) = 1.9596e-7 m^3/sec

Fuel 3&4:
Volume of Zone 3 ash:
((1/3250) m^3/kg) * (.003312 kgAsh/sec) = 1.020e-6 m^3/sec

Volume of Zone 2 ash:
((1/3250) m^3/kg) * (.00008842 kgAsh/sec) = 2.72e-8m^3/sec

To solve for the number density, it is assumed that the Count Mean Diameter is the critical parameter rather than the Geometric Mass Mean Diameter. Since the absolute mass collected from the vapor phase is a strong function of available surface area, it is assumed that conserving the residual particle surface area (for a fixed mass) is important. Hence, the GMMD is converted to CMD:
Fuel 1&2:
Zone 3: CMD = GMMD/(Exp(3ln^{2}GSD) = 7.16 μm
Zone 2: CMD = GMMD/(Exp(3ln^{2}GSD) = .669 μm

Fuel 3&4:
Zone 3: CMD = GMMD/(Exp(3ln^{2}GSD) = 8.21 μm
Zone 2: CMD = GMMD/(Exp(3ln^{2}GSD) = .689 μm

Note that the CMD is somewhat smaller than the GMMD, especially for Zone 2. Using the CMD, the significant surface area of the smaller size particles is included.

Converting the particle diameter and ash volumes to particle number densities:

$N*(4/3)*pi* r^3$= volume/time
Solving for N, particles per sec:

Fuel 1&2:

For Zone 3: N = $((3*8)/(4*pi*(7.16e-6)^3) *(4.32e-7)$ = 2.248e9 particles/sec
For Zone 2: N = $((3*8)/(4*pi*(.669e-6)^3) *(1.96e-7)$ = 1.25e12 particles/sec
Zone 2 surface area over Zone 3 surface area = 4.8

Fuel 3&4:

For Zone 3: N = $((3*8)/(4*pi*(8.21e-6)^3) *(1.02e-6)$ = 3.520e9 particles/sec
For Zone 2: N = $((3*8)/(4*pi*(.689e-6)^3) *(2.72e-8)$ = 1.588e11 particles/sec
Zone 2 surface area over Zone 3 surface area =1.8e-4

Note that very little of the surface area is in Zone 2 for Fuel 3 and 4, since the particle count is very low compared to all other zones.

It is informative to also calculate the total surface area in a volume of hot gas in the blend chamber for Fuel 1, as provided by the hetero- particles. Assuming the density in the blend chamber is the density of the hot gas system at 800K, equilibrium shows the hot gas density to be .441 kg/m^3 for Fuel 1. The total flow rate for this system is 27.18 kg/sec, for a wood flowrate of .47376 kg/sec and air to fuel ratio of 56.37 kgAir/kgFuel1.

Volumetric flowrate at 800K for Fuel 1 is (1/.441)(m^3/kg)*27.18 kg/sec = 61.63 m^3/sec. This seems very high, but is probably reasonably accurate based on the scale of an industrial-size wood chip dryer.

The particle number density and surface-area/volume for Fuel 1 and 2 in Zone 3 is:
(2.248e9 particles/sec) /(61.63 kg/m^3) = 3.6346e7 particles/m^3 at 800K in Blend Chamber

(.3260m^2/sec)/ (61.63 kg/m^3) = 5.874e-3 m^2/m^3 at 800K in Blend Chamber, which is a very small surface area for condensation

The particle number density and surface-area/volume for Fuel 1 and 2 Zone 2 is:
(1.2496e12 particles/sec) /(61.63 kg/m^3) = 2.028e10 particles/m^3 at 800K in Blend Chamber

(1.757m^2/sec)/ (61.63 kg/m^3) = .02851 m^2/m^3 at 800K in Blend Chamber, which is a very small surface area for condensation.

Table A.1: Averages of mass collected on stages for screened sawdust/sanderdust experiments

Stage number	Dia, μm	Fuel 1 and 2 mass % on stage (averages)	Fuel 3 and 4 mass % on stage (averages)
Presep and 0	8.32	41.19	90.54
1	5.33	7.54	1.29
2	3.66	3.27	.77
3	2.53	5.42	.55
4	1.64	7.39	.60
5	.85	4.65	.35
6	.54	1.33	.15
7	.39	1.08	.12
Filter	.10	28.14	5.62

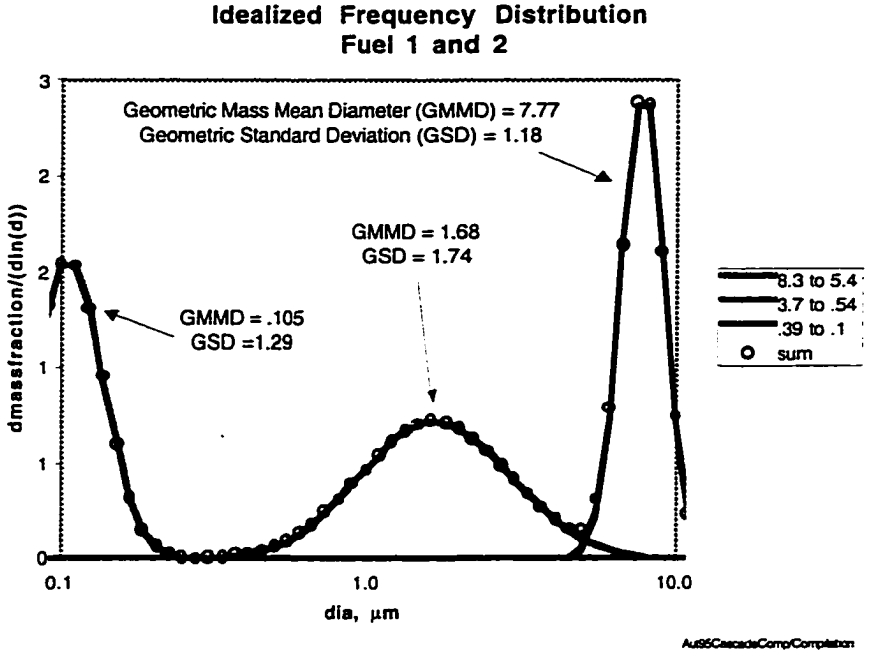


Figure A.1: Approximated mass/size distribution of Fuel 1 and Fuel 2 based on experimentally determined size distributons

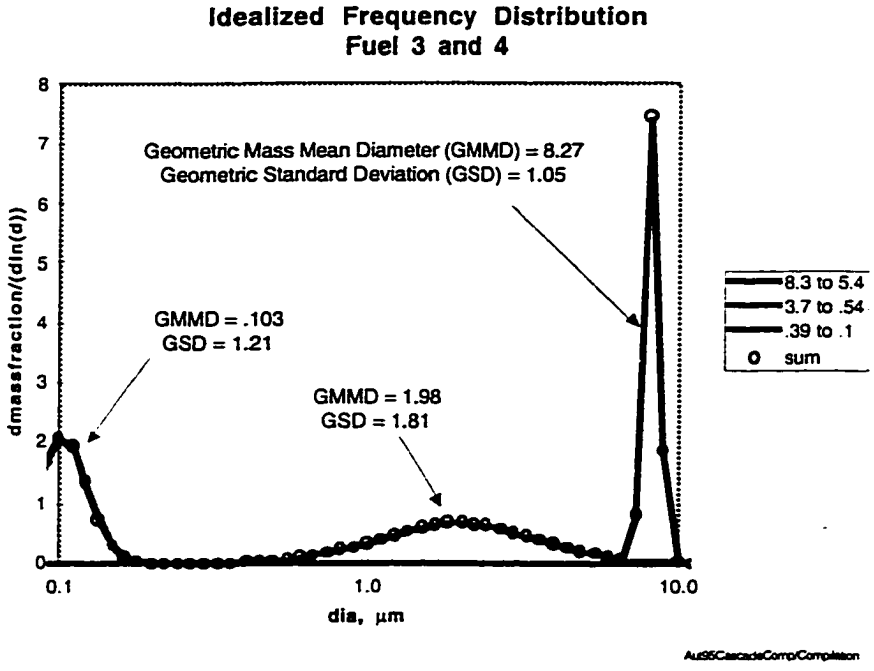


Figure A.2: Approximated mass/size distribution of Fuel 3 and Fuel 4 based on experimentally determined size distributons

APPENDIX B: AIR, WATER AND NATURAL GAS SCHEMATICS, AND SUMMARY OF LABORATORY MODIFICATIONS

During experimental testing, extensive modifications were made to the furnace and laboratory. Significant modifications included:

- Addition of two high volume exhaust systems to aid in laboratory cooling (laboratory ambient temperature was known to reach 95 F in summer months).
- Redesign of the main burner mounting system to greatly improve heat transfer to the gas stream. Casting of main burner interface. Plugs for inactive main ports were also cast. Modification of flame detector mounts to prevent heat damage, and condensation buildup.
- Backfire burner modifications to prevent sooting.
- Replumbing of the air supply system to decouple valving. An additional air source was also added to supply air for ancillary equipment
- Replumbing of the water supply system, including adding an additional source, and filtration and settling traps.
- Extensive exhaust system modifications, including water atomizer redesign, a dilution control, and condensate drain systems. Eventual corrosion of the existing stainless steel exhaust ducting required a major redesign and rebuild of the exhaust system. This included modification to the upper backfire burners exit ports.
- Addition of internal and external exhaust duct coolant coils.
- Redesign and construction of the pulverized fuel feed system, including redesign of the water cooled injector spike.
- Exhaust duct insulation to rooms B6 and G4.
- Redesign and construction of horizontal sample port mount, vertical sample port mount, pulverized fuel injector mount and furnace packing.

Figures B-1, B-2, and B-3 show configurations of the air, natural gas, and water supply systems for the tunnel furnace and ancillary devices.

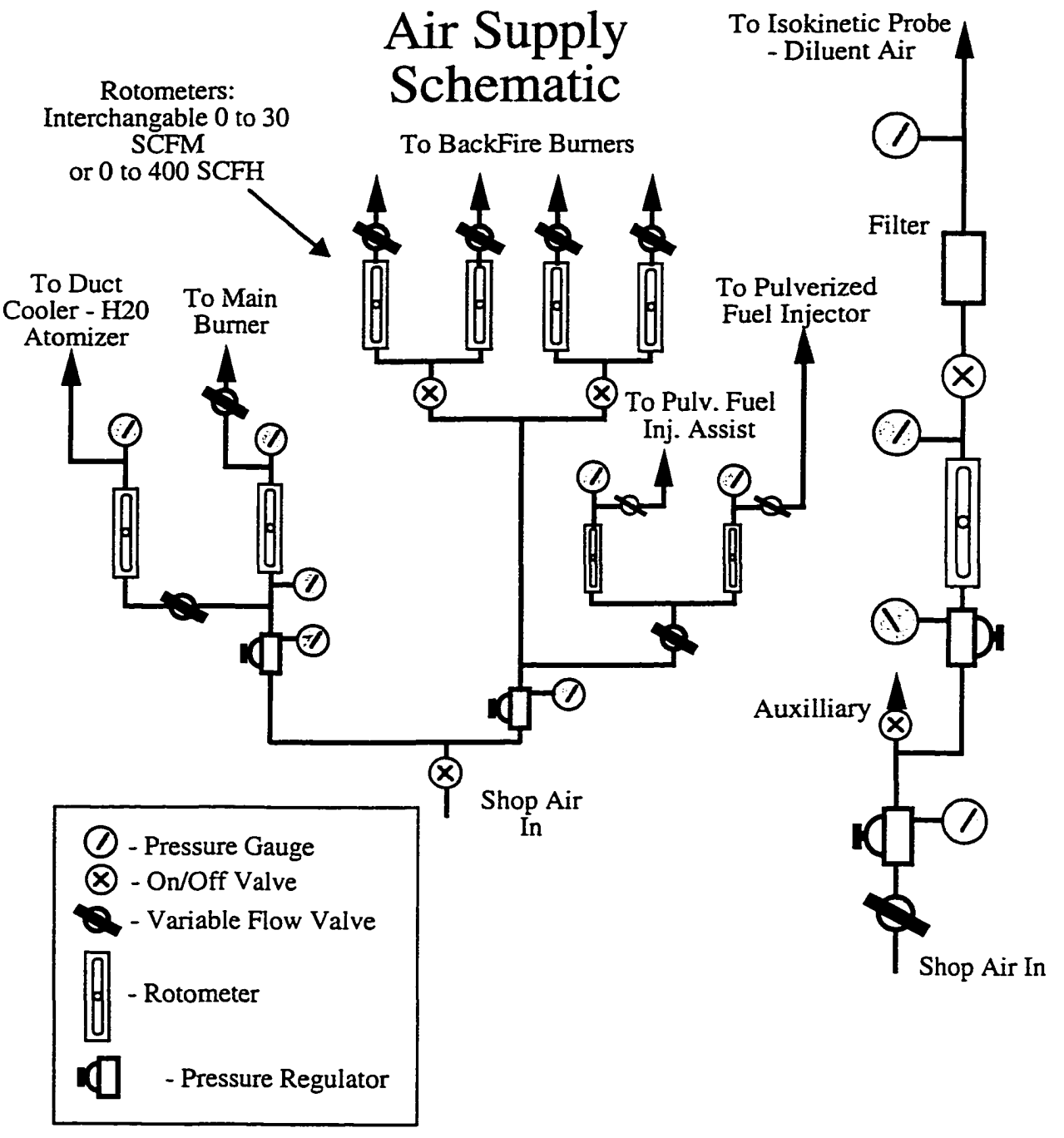


Figure B-1: Air Supply Schematic

Natural Gas Supply Schematic

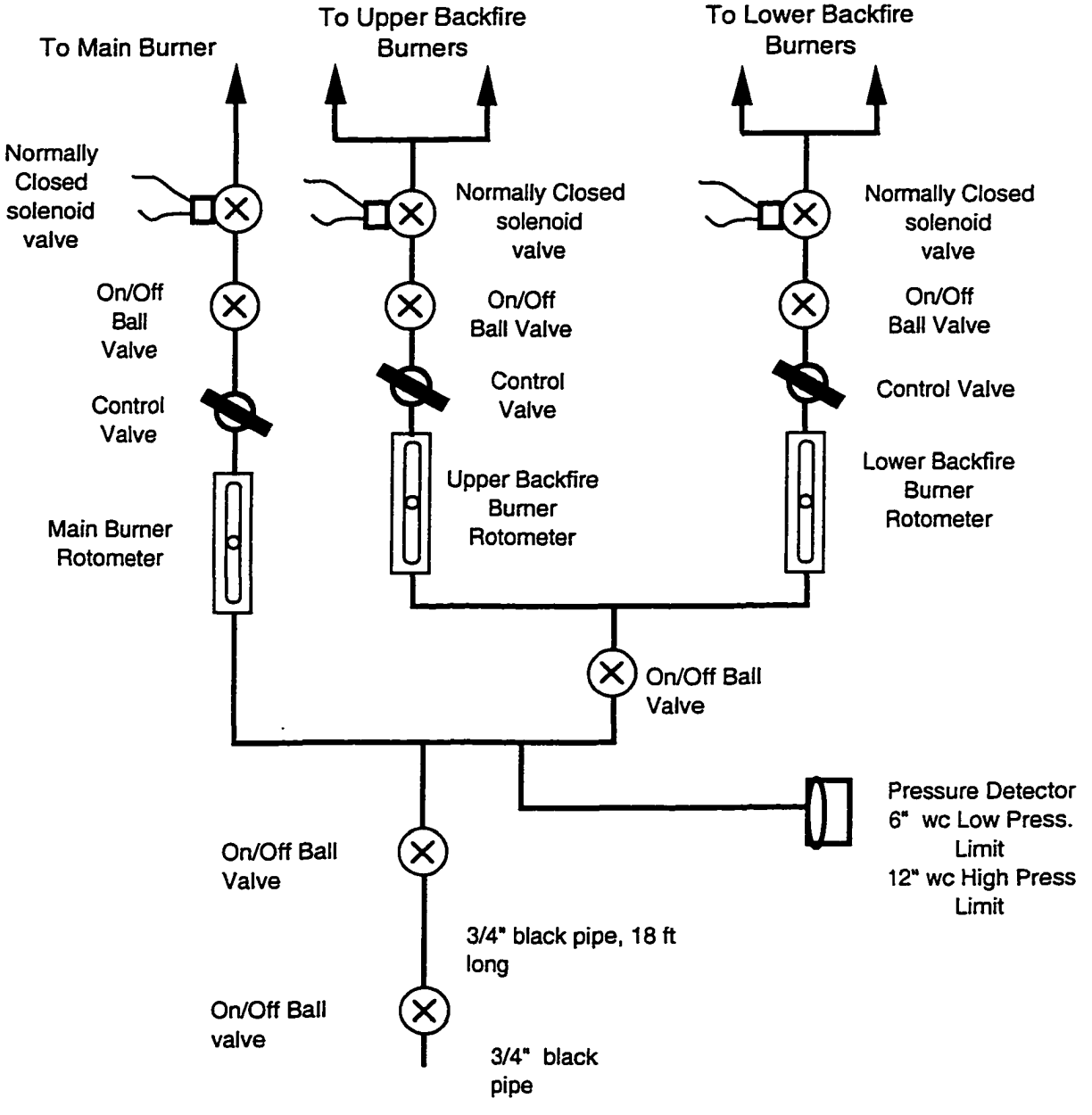


Figure B-2: Natural Gas Supply Schematic

Water Supply Schematic

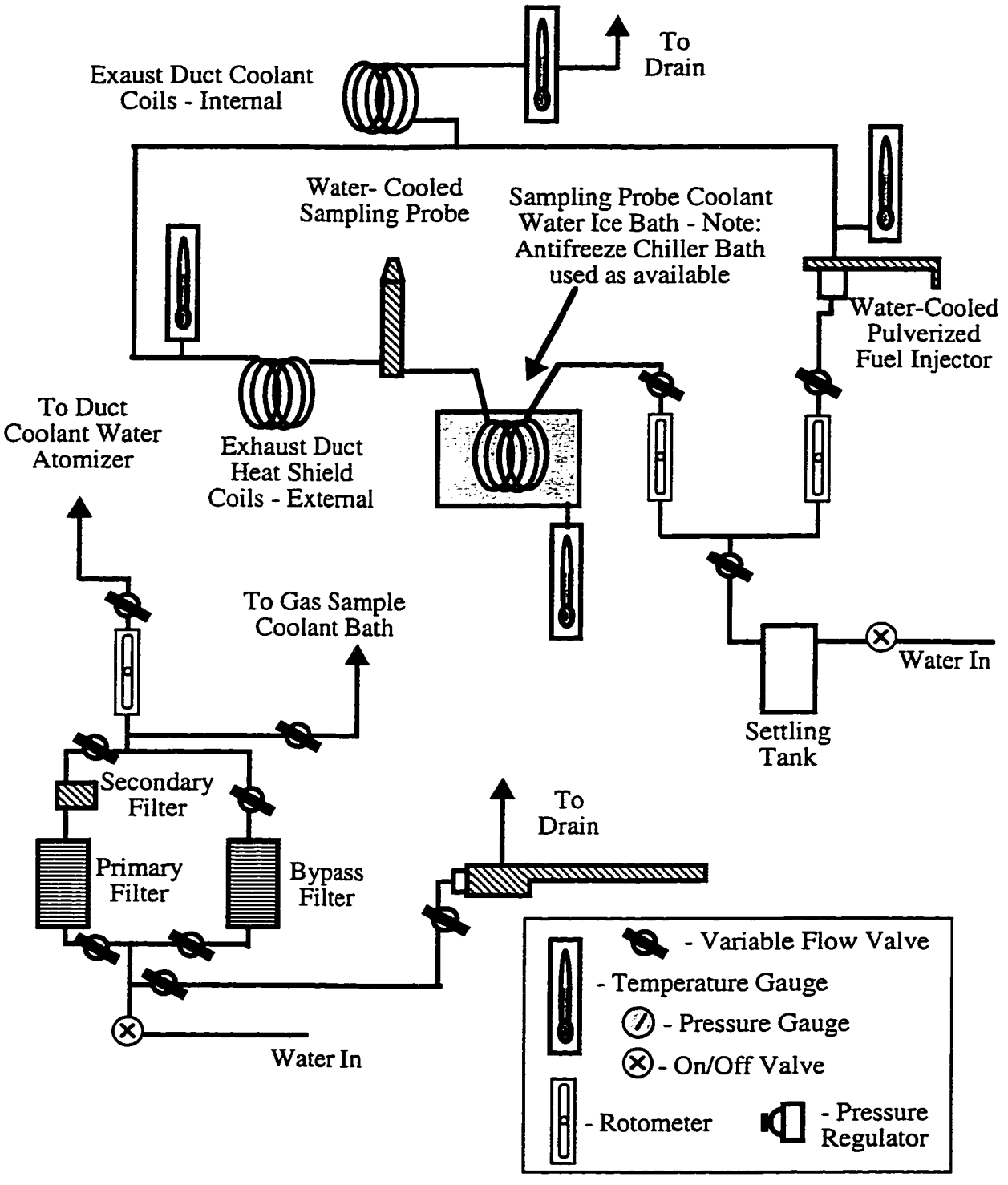


Figure B-3: Water Supply Schematic

APPENDIX C: SAMPLING EFFICIENCY USING A SIMPLE WATER-COOLED PROBE AT NON-ISOKINETIC CONDITIONS

Practical constraints on the maximum inner diameter of the simple water cooled sampling probe required that sampling be conducted at non-isokinetic conditions. This was remedied when the porous-walled isokinetic sampling probe was designed and constructed. Since the research presented here is primarily concerned with particulate matter in the micron and sub-micron range (i.e. low stokes number). and sampling velocity mismatch is less of a factor as stokes number decreases, this sampling bias was determined to be acceptable. What follows is an estimate of sampling error, based on the general procedure presented by Brockman (1993), and also Hinds (1982). Corrections for probe misalignment and inlet wall thickness are considered to be negligible.

Sampling a particle-laden gas stream at a faster flow rate than the bulk velocity of the gas stream is termed super-isokinetic sampling. Large particles that have sufficient momentum will deviate from the gas flow lines, resulting in a fraction of these particles missing the probe inlet. Hence, the large particulate will be under-represented in the captured flue gas. A numerical correlation determined by Liu, Zhang, and Kuehn (1989) and Zhang and Lui (1989) is recommended by Brockman (1993) to estimate the sampling efficiency:

$$\eta_{asp} = 1 + \frac{\left(\frac{U_o}{U} - 1\right)}{\left[1 + \left(0.506\left(\frac{U_o}{U}\right)^{.5}\right) \Big/ Stk\right]}$$

$$0.01 \le Stk \le 100$$

$$0.1 \le \frac{U_o}{U} \le 1$$

where:

$Stk = \frac{\tau * U_o}{d}$, Stokes number

$\tau = \frac{\rho_p * d_p^{\,2} * C_c}{18 * \eta}$, relaxation time, sec

$\rho_p =$ particle density, kg/m^3

d_p = particle diameter, m

C_c = Cunningham Slip Coefficient

η = dynamic gas viscosity, Pa * sec

U_o = freestream velocity, m/sec

U = probe inlet velocity, m/sec

d = probe diameter, m

Cunningham Slip Coefficient is based on an empirical fit derived from air data (Allen and Raabe, 1985) as interpreted by Brockman (1993):

$$C_o = 1 + Kn\left[\alpha + \beta * e^{\frac{-\gamma}{Kn}}\right]$$

$\alpha = 1.142$

$\beta = 0.558$

$\gamma = 0.999$

The dynamic gas viscosity is calculated by (Brockman, 1993):

$$\eta = \eta_{ref}\left(\frac{T_{ref} + S}{T + S}\right)\left(\frac{T}{T_{ref}}\right)^{1.5}$$

η_{ref} = reference viscosity, $18.203 * 10^{-6}$ Pa * s

S = Sutherland Interpolation constant for air, 110.4 K

T_{ref} = reference temperature, 293.15 K

T = hot gas temperature, K

Calculation of the Knudsen number at elevated temperatures is based on the mean free path calculation by Willeke (1976):

$$Kn = \frac{2\lambda}{d_p}$$

$$\lambda = \lambda_{ref}\left(\frac{P_{ref}}{P}\right)\left(\frac{T}{T_{ref}}\right)\left(\frac{1+\frac{S}{T_{ref}}}{1+\frac{S}{T}}\right)$$

λ_{ref} = reference gas mean free path, $= .0665 * 10^{-6}$ meters

P_{ref} = reference pressure, = 101325 Pa

An estimate of sampling efficiency for a representative Screened sawdust/ sanderdust test (08169501) is shown in Figure C-1. Relevant input data is:

Gas inlet temperature = 1114.15 K
Probe inlet diameter = .01427 m (9/16 inch)
Freestream velocity = .85 m/s
Probe inlet velocity = 6.01 m/s
Particle density = 2700 kg/m^3 (calcium carbonate density)

Below 10 μm the sampling efficiency is 90% or greater. The size distribution below this diameter is not strongly biased by non-isokinetic conditions. Above 10 μm, the capture efficiency begins to asymptote to the oversampling ratio, meaning that only the particles with straight trajectories into the probe inlet will enter, as expected. The absolute magnitude of the particulate matter above 10 μm is of little consequence to this study.

The sampling efficiency for the isokinetic probe is also estimated. Isokinetic conditions are maintained to the tolerance of the sampling system. Errors may be introduced by calibration drift of the CO_2 meter, rotometer errors, or other measurement errors. Assuming that flow velocities are inadvertently mismatched by 20%, the sampling efficiency is calculated. Input variables are:

Gas inlet temperature = 1061 K
Probe inlet diameter = .01427 m (9/16 inch)
Freestream velocity = .874 m/s
Probe inlet velocity = (.874 *1.2) m/s
Particle density = 2700 kg/m^3 (calcium carbonate density)

The results are shown in Figure C-2. It is clear that worst-case sampling error for the isokinetic probe is negligible over the range of particle diameters of interest.

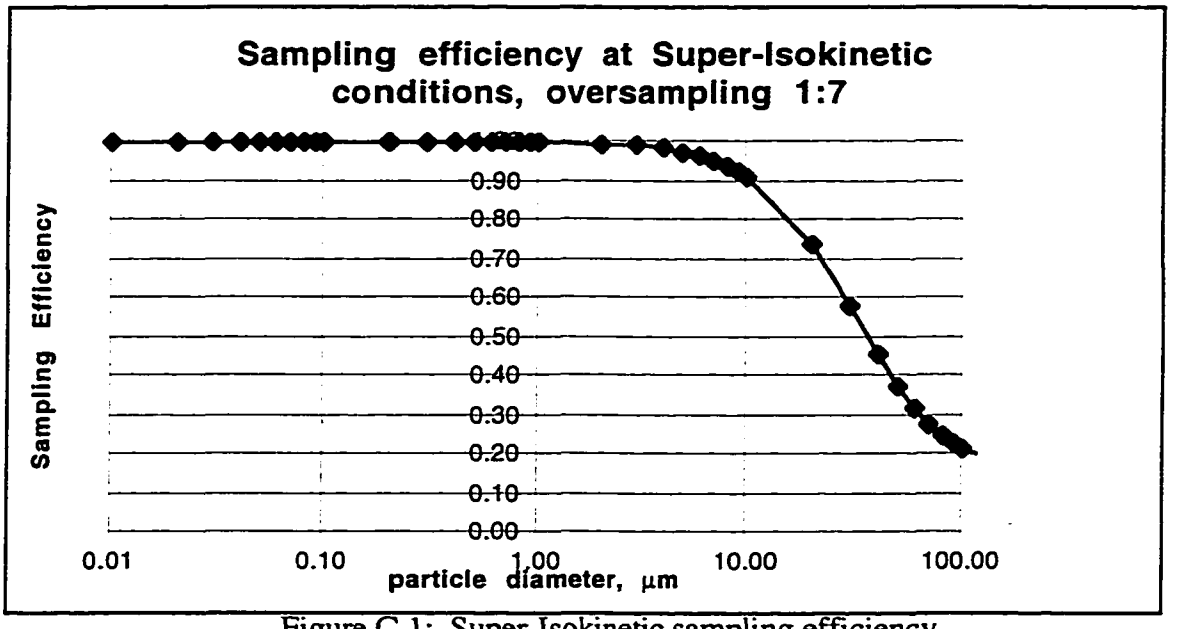


Figure C.1: Super-Isokinetic sampling efficiency

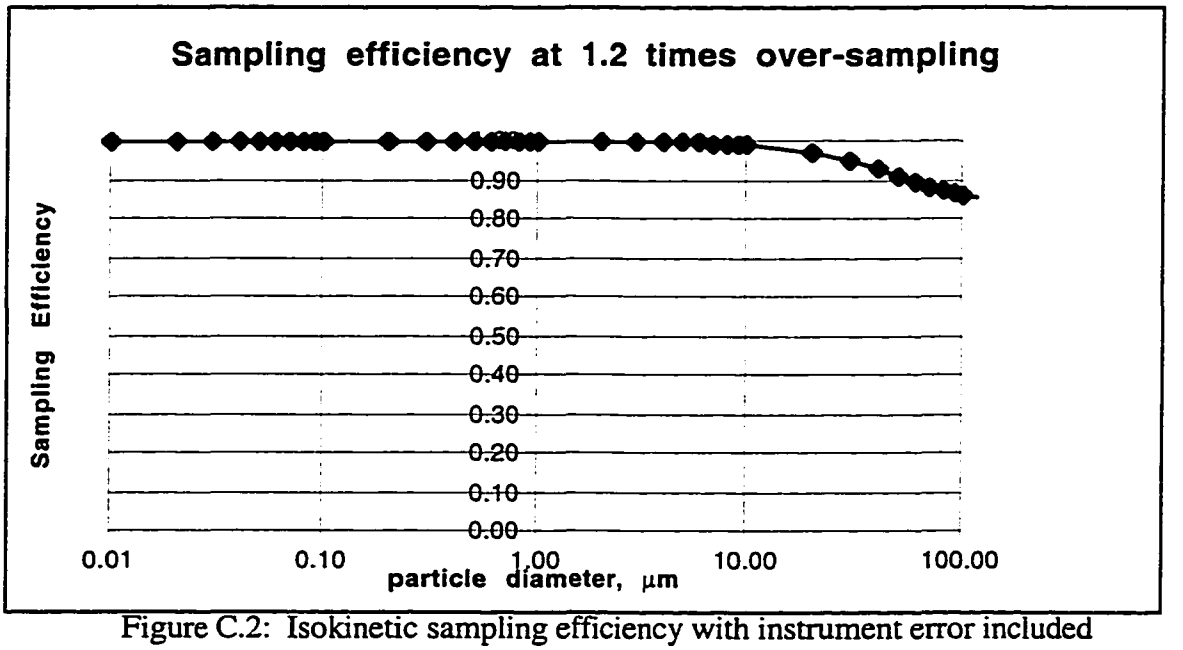


Figure C.2: Isokinetic sampling efficiency with instrument error included

APPENDIX D: NATURAL GAS COMPOSITION

Personal Communication with Paul Riley, Process Lead, Gas Measurement, Washington Natural Gas, 206-224-2369

Average Gas Composition for January 1996 to December 1996:

Species	Formula	Btu/ft^3	Mass %
Methane	CH_4	1012.0	95.66%
Ethane	C_2H_6	1773.7	02.74%
Propane	C_3H_8	2522.1	00.56%
N Butane	C_4H_{10}	3270.1	00.07%
I Butane	C_4H_{10}	3260.5	00.11%
Pentane	C_5H_{12}	4014.6	00.02%
Hexane	C_6H_{14}	5141.2	00.01%
Carbon Dioxide	CO_2	0000.0	00.11%
Nitrogen	N_2	0000.0	00.70%
Average Btu/ft^3		1041.0	

Avg Specific Gravity = .5811
WNG Sulphur System Average = 0.02987 Grains H_2S / 100 ft^3
Average H_2O Content = 0.2 gallons / Mmcf
End of Personal Communication with Paul Riley

Calculation of sulphur fraction from furnace operation in a typical pulverized wood test:

.02987 grains of H_2S per 100 ft^3 of Natural Gas =1.9355 mg H_2S/100ft^3

Mass of S in H_2S = 32.066/ (32.066 +2*1.0079) = .94008 S/H_2S

Density of methane = 101325 Pa/((8314.4 J/kmol*K)*300K)/16kmol/kg CH4) = .64 kg/m^3

Mass flowrate of NG during typical test = 18 grams/minute

Mass flowrate of S during typical test:
(1.9355 mg H_2S/100ft^3) * .94008 S/H_2S *35.314 ft^3/m^3 * (1/.64995)*(m^3/kg) *.018 kg/min = .0178 mg S per minute from natural gas.

Mass flowrate of S from pulverized wood during typical test:
Fuel 1 at 4.64 grams/minute => S = 4.6 *10^{-5}
moles/minute = 1.475 mg/minute from wood fuel

About 80 times more sulphur comes from the wood fuel than from the natural gas. Coal contains an order of magnitude more S than the wood fuels used. Hence, S from natural gas is not of concern in this system.

APPENDIX E: SCREENED SAWDUST/SANDERDUST CASCADE IMPACTOR TEST SUMMARIES

The spreadsheets that follow summarize the detailed measurements and calculations required to determine the size distribution of ash for four pulverized wood fuels. These experiments were conducted with a natural-gas fired furnace. Ash samples were collected with a simple water cooled sampling probe and size-sorted with a Mark II cascade impactor.

Table E.1: Test 08089501

Table E.2: Test 08099501

Date:	8/9/95	mo/day/yr	Main NG:	62.0	%		Probe clnt T:	135	F										
Coal:	Fuel 1	source	Main Air:	35.0	%		Prbe clnt flw:	lopped	mm										
		process		43.0	psig		Comb prg p:	off	psig										
test no:	08099501	m/d/ymum	BF1NG:	44.0	%		Coal feed:	50	units	Imp Init diam	9/16	inches		MAIN BURNER					
test dur:	5.00	minutes	BF1Air:	4.0	units,front		Coal feed conv	6.8	g/m	Mainduct rad	4	inches							
Coal Properties: (Rel. only)				4.0	units, back		Vacuum Rate:	33.0	%	Main Gas Rate	0.62	fraction		mdot CH4	17.458	g/min			
			BF2NG:		%		Vacuum Rate:	3.0	in hg	Main Air Rate	0.35	fraction		mdot Main Air	466.845	g/min			
grams	atoms/100g	Ult. Ana.	BF2Air:		units,front		atomizer air:	full	units	Main Air Rate	43.0	psig		phi	1.556	Air/ Fuel by mass			
45.1178	3.76	Carbon			units, back		atomizer air:	full	psig	Inj. Air Rate	20	%		mdotA/mdotF	29.742	g/g			
5.8682	5.97	Hydrogen	Inj. Rate:	20	%		atomizer H2O		120	mm	Inj Air Rate	48	psig		CO2	1.091	moles/min	CH4&Air only	
39.3459	2.46	Oxygen	Inj. Rate:	48	psig		exit duct T:		105	F					H20	2.182	moles/min	CH4&Air only	
5.0986	0.36	Nitrogen					over furn T:		112	F					N2	12.787	moles/min	CH4&Air only	
0.02886	0.00	Sulfur	Imp in temp:	298	C (est)		entr bypass		0	"scfm"	Fuel comp on Elemental level				O2	1.218	moles/min	CH4&Air only	
0.8177	0.82	Ash	Imp temp based on:		08079501		inj exit T			F	Carbon (monatomic)	3.76E-02	moles/g		mdot air inj	22.941	g/min		
3.8	0.21	Moisture	Imp x temp	50	C (est)						Hydrogen (monatomic)	5.97E-02	moles/g		O2	0.187	moles/min	inj Air only	
100.07896		Total	ep, gr, ash	2.7	units (est)						Oxygen (monatomic)	2.46E-02	moles/g		N2	0.629	moles/min	inj Air only	
											Nitrogen (monatomic)	3.64E-03	moles/g		Dry O2 w/inj	8.719	vol%	total w/o solid fuel	
											Sulfur (monatomic)	9.02E-06	moles/g		DryO2w/o inj	8.971	vol%	total w/o solid fuel and inj	
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % lt. size rge	D50 calc.	Size Range micrometers (default)	T/C Port	Temp, C	Ash	8.18E-03	g ash/g fuel							
										H2O	2.11E-03	moles/g		CO2	1.347	moles/min	total		
										mdot solid fuel	6.8	g/min		H20	2.396	moles/min	total		
Presepartor	0.32565	0.32730	0.00165	38.02	61.98	10.00	10.0 & up	B		Sample probe inlet Temp	841	degC		N2	13.427	moles/min	total		
0	0.29059	0.29093	0.00034	7.83	54.15	8.30	9.0 -10.0	C		Impactor Inlet T	298	degC (est. T)		SO2	0.000	moles/min	total		
1	0.30126	0.30154	0.00028	6.45	47.70	5.32	6.8 - 9.0	D		Impactor Exit T				O2	1.114	moles/min	total		
2	0.32676	0.32688	0.00012	2.76	44.93	3.65	4.7 - 5.8	E		Vacuum Rate	3	in Hg		Dry O2	7.010	vol%	total		
3	0.32524	0.32543	0.00019	4.38	40.55	2.53	3.3 - 4.7	F		Vacuum Rate T	23	degC (est. T)		H20 wt	0.084	mass fraction			
4	0.32678	0.32700	0.00024	5.53	35.02	1.64	2.1 - 3.3	G		Vacuum Rate	33	CFH							
5	0.32962	0.32980	0.00018	4.15	30.88	0.85	1.1 - 2.1	H		coal flow time	5	min		mol wt wet	28.112	g/mol			
6	0.32573	0.32578	0.00006	1.15	29.72	0.54	0.7 - 1.1	I	841					dens @ inlet	307.534	g/m^3	Sample probe inlet		
7	0.32608	0.32612	0.00004	0.92	28.80	0.38	0.4 - 0.7	J						mdot duct	513.988	g/min	Ash flow neglected		
Backup Filter	0.32808	0.32931	0.00125	28.80	0.00	0.10	0 -0.4	K						vduct	51.537	meters/min	v=mdot/(rho*A)		
										BACKFIRE BURNERS				vduct	2.818	ft/sec			
		total mass:	0.00434											dens @ imp inl	610.682	g/m^3	rho=P/(R*T)		
										mdotBF1 CH4	18.360647								
										mdotBF1 Air	528.17795			mol wt dry	29.637	g/mol			
										phi	1.677	Air/ Fuel by mass		dens @ rota	1097.929	g/m^3	rho=P/(R*T)		
										mdotA/mdotF	28.782525			volflowraterota	1.49E-02	m^3/min	Dwyer flowmeter		
Notes:	*) Ran impactor for 5 minutes pretest to heat it up a bit.													volflowraterota	5.24E-01	ft^3/min			
	*) Bumped impactor while removing from furnace									mdotBF1 CH4	0								
	*) Stage 0 - fiberous material on stage 0. Loose, not in plee									mdotBF1 Air	0			mdotrota	16.342	g/min			
	*) Refilled the bin pretest. It was pretty low									phi	#DIV/0!	Air/ Fuel by mass		mdotimp	17.839	g/min	mdotrota/(1-H20f/act)		
	*) Feed was very smooth									mdotA/mdotF	#DIV/0!			volflwimp	0.029	m^3/min	mdotimp/dens @ imp inlet		
														volflwimp	1.032	ft^3/min			
														vinlet	361.800	m/min	Sample probe inlet		
														vinlet	19.783	ft/sec			
										actual ash:	0.00434	g		mdot ash	1.93E-03	g/min	mdot ash to impactor		
														expected ash	9.65E-03	g	total ash expected in impactor		
														volume ratio	0.035	vol in/vol tot	gas vol collected/ total in duct		
														velocity ratio	7.020	Vinlet/Vduct	Vel. at probe inlet/Vel. in duct		
														%Diff ash	-122.328	%	based on actual		

Table E.3: Test 08169501

Date:	8/16/95	mo/day/yr	Main NG:	62.0	%		Probe clnt T:	142	F										
Coal:	Fuel 1	source	Main Air:	35.0	%		Prbe clnt flw:	102	mm										
		process		42.0	psig		Comb prg p:		psig										
test no:	08169501	m/d/ymum	BF1NG:	44.0	%		Coal feed:	25	units	Imp Init diam	9/16	inches		MAIN BURNER					
test dur:	15.00	minutes	BF1Air:	4.0	units,front		Coal feed conv	5	g/m	Mainduct rad	4	inches							
Coal Properties: (Ref. only)				4.0	units, back		Vacuum Rate:	33.0	%	Main Gas Rate	0.62	fraction		mdot CH4	17.458	g/min			
			BF2NG:		%		Vacuum Rate:	3.0	in hg	Main Air Rate	0.35	fraction		mdot Main Air	462.782	g/min			
grams	atoms#/100g	Ult. Ana.	BF2Air:		units,front		atomizer air:		units	Main Air Rate	42.0	psig		phi	1.545	Air/ Fuel by mass			
45.1178	3.76	Carbon			units, back		atomizer air:		psig	Inj Air Rate	20	%		mdotA/mdotF	26.509	g/g			
5.8682	5.87	Hydrogen	Inj. Rate:	20	%		atomizer H2O	90	mm	Inj Air Rate	48	psig		CO2	1.091	moles/min	CH4&Air only		
39.3458	2.46	Oxygen	Inj. Rate:	48	psig		exit duct T:	113	F					H20	2.182	moles/min	CH4&Air only		
5.0996	0.36	Nitrogen					over furn T:	101	F	Fuel comp on Elemental level				N2	12.675	moles/min	CH4&Air only		
0.02896	0.00	Sulfur	Imp in temp:	288	C (est)		entr bypass	0	*scfm*	Carbon (monatomic)	3.76E-02	moles/g		O2	1.189	moles/min	CH4&Air only		
0.8177	0.82	Ash	Imp temp based on:		08079501		inj exit T		F	Hydrogen (monatomic)	5.87E-02	moles/g		mdot air inj	22.941	g/min			
3.8	0.21	Moisture	Imp x temp	50	C (est)					Oxygen (monatomic)	2.46E-02	moles/g		O2	0.197	moles/min	Inj Air only		
100.07996		Total	sp. gr. ash	2.7	units (est)					Nitrogen (monatomic)	3.64E-03	moles/g		N2	0.928	moles/min	Inj Air only		
										Sulfur (monatomic)	9.02E-06	moles/g		Dry O2 w/inj	8.609	vol%	total w/o solid fuel		
										Ash	8.18E-03	g ash/g fuel		DryO2w/o inj	7.950	vol%	total w/o solid fuel and inj		
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % lt. size rnge	D50 calc.	Size Range micrometers (default)	T/C Port	Temp, C.	H2O	2.11E-03	moles/g							
										mdot solid fuel	5	g/min		CO2	1.279	moles/min	total		
Preseparator	0.32392	0.32824	0.00432	37.49	62.51	10.00	10.0 & up	B	1119	Sample probe inlet Temp	841	degC		H20	2.339	moles/min	total		
0	0.29736	0.29809	0.00071	6.16	56.35	8.31	9.0 -10.0	C	1069	Impactor inlet T	288	degC (est. T)		N2	13.313	moles/min	total		
1	0.29799	0.29873	0.00074	6.42	49.93	5.33	5.8 - 9.0	D	1064	Impactor Exit T				SO2	0.000	moles/min	total		
2	0.32379	0.32417	0.00038	3.30	46.64	3.65	4.7 - 5.8	E	1038	Vacuum Rate	3	in Hg		O2	1.156	moles/min	total		
3	0.32532	0.32590	0.00058	5.03	41.60	2.53	3.3 - 4.7	F	996	Vacuum Rate T	23	degC (est. T)		Dry O2	7.341	vol%	total		
4	0.32548	0.32631	0.00085	7.41	34.19	1.64	2.1 - 3.3	G	958	Vacuum Rate	33	CFH		H20 wt	0.083	mass fraction			
5	0.32481	0.32545	0.00064	5.55	28.63	0.85	1.1 - 2.1	H	900	coal flow time	15	min							
6	0.32409	0.32430	0.00021	1.82	26.81	0.54	0.7 - 1.1	I	841					mol wt wet	28.094	g/mol			
7	0.32467	0.32484	0.00017	1.48	25.34	0.39	0.4 - 0.7	J	780					dens @ inlet	307.337	g/m^3	Sample probe inlet		
Backup Filter	0.33084	0.33380	0.00292	25.34	0.00	0.19	0 -0.4	K	721					mdot duct	508.139	g/min	Ash flow neglected		
										BACKFIRE BURNERS				vduct	50.984	meters/min	u=mdot/(rho*A)		
		total mass:	0.01152											vduct	2.788	ft/sec			
														dens @ imp inl	610.291	g/m^3	rho=P/(R*T)		
										mdotBF1 CH4	18.350647								
										mdotBF1 Air	523.58102			mol wt dry	29.593	g/mol			
										phi	1.663	Air/ Fuel by mass		dens @ rota	1096.318	g/m^3	rho=P/(R*T)		
										mdotA/mdotF	28.53202			volflowrateIp	1.49E-02	m^3/min	Dwyer flowmeter		
Notes:														volflowrateIp	5.25E-01	ft^3/min			
	*) adjusted mass for dots rubbed out by glove prior to weighing - multiplied the net mass by the inverse of the									mdotBF1 CH4	0								
	fraction of dots remaining -should be 365 dots, but only 374 remain									mdotBF1 Air	0			mdotrota	18.306	g/min			
	*) Preheated impactor to 120degC (typically heat to 110C), but it was too hot to handle. Backed back down to									phi	#DIV/0!	Air/ Fuel by mass		mdotimp	17.779	g/min	mdotrota/(1-H20fract)		
	110 degC after putting foils and filter in.									mdotA/mdotF	#DIV/0!			volflwimp	0.029	m^3/min	mdotimp/dens @ imp inlet		
	*) No pretest impactor inlet temp measurement taken. Assumed 282degC inlet, as previous tests.													volflwimp	1.029	ft^3/min			
	*) Ran the impactor hooked up for 5 minutes pretest (before wood flow) to preheat													vinlet	360.829	m/min	Sample probe inlet		
	*) Rubbed a bunch of dots off stage 4. Plan to compensate by adjusting the measured weight (see 1st note)													vinlet	19.730	ft/sec			
	*) The balance room was being disassembled at the time of weighings, so there was alot of bouncing around.																		
	*) The slow feed rate has really smoothed at the injection surges. The feed line used to bounce, but now is													mdot ash	1.43E-03	g/min	mdot ash to impactor		
	pretty stable.									actual ash:	0.0115244	g		expected ash	2.16E-02	g	total ash expected in impactor		
														volume ratio	0.035	vol in/vol tot	gas vol collected/ total in duct		
														velocity ratio	7.077	Vinlet/Vduct	Vel. at probe inlet/Vel. in duct		
														%Diff ash	86.196	%	based on actual		

Table E.4: Test 08169502

Date:	8/16/95	mo/day/yr	Main NG:	61.5	%			Probe ctrl T:	154	F									
Coal:	Fuel 1	source	Main Air:	35.0	%			Probe ctrl fltr:	97	mm									
		process		42.0	psig			Comb prg p:		psig									
test no:	08169502	m/d/ymum	BF1NG:	44.0	%			Coal feed:	25	units	Imp inlt diam	9/16	inches		MAIN BURNER				
test dur:	15.00	minutes	BF1Air:	4.0	units,front			Coal feed conv	6	g/m	Mainduct rad	4	inches						
Coal Properties: (Ref. only)				4.0	units, back			Vacuum Roto:	33.0	%	Main Gas Roto	0.615	fraction		mdot CH4	17.317	g/min		
			BF2NG:		%			Vacuum Roto:	3.0	in hg	Main Air Roto	0.35	fraction		mdot Main Air	462.792	g/min		
grams	atoms/100g	Ult. Ana.	BF2Air:		units,front			atomizer air:		units	Main Air Roto	42.0	psig		phi	1.557	Air/ Fuel by mass		
45.1178	3.76	Carbon			units, back			atomizer air:		psig	Inj Air Roto	20	%		mdotA/mdotF	29.724	g/g		
6.8682	6.87	Hydrogen	Inj. Roto:	20	%			atomizer H2O	97	mm	Inj Air Roto	48	psig		CO2	1.092	moles/min	CH4&Air only	
39.3458	2.46	Oxygen	Inj. Roto:	48	psig			exit duct T:	114	F					H20	2.165	moles/min	CH4&Air only	
5.0096	0.36	Nitrogen						over furn T:	106	F	Fuel comp on Elemental level				N2	12.675	moles/min	CH4&Air only	
0.02886	0.00	Sulfur	Imp in temp:	288	C (est)			entr bypass		"scfm"	Carbon (monatomic)	3.76E-02	moles/g		O2	1.206	moles/min	CH4&Air only	
0.8177	0.82	Ash	Imp temp based on:		09079501			inj exit T		F	Hydrogen (monatomic)	6.87E-02	moles/g		mdot air inj	22.941	g/min		
3.8	0.21	Moisture	Imp x temp	50	C (est)			Feeder p	3.25	psig	Oxygen (monatomic)	2.46E-02	moles/g		O2	0.107	moles/min	Inj Air only	
100.07696		Total	sp. gr. ash	2.7	units (est)						Nitrogen (monatomic)	3.64E-03	moles/g		N2	0.628	moles/min	Inj Air only	
											Sulfur (monatomic)	9.02E-06	moles/g		Dry O2 w/inj	8.716	vol%	total w/o solid fuel	
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % lt. size mge		D50 calc.	Size Range micrometers (default)	T/C Port	Temp, C	Ash	6.16E-03	g ash/g fuel		DryO2w/o inj	8.063	vol%	total w/o solid fuel and inj	
											H2O	2.11E-03	moles/g						
											mdot solid fuel	9	g/min		CO2	1.270	moles/min	total	
Preseparator	0.32186	0.32544	0.00358	33.81		66.19	10.00	10.0 & up	B		Sample probe inlet Temp	841	degC		H20	2.322	moles/min	total	
0	0.29621	0.29690	0.00069	6.52		59.66	9.32	9.0 -10.0	C		Impactor inlet T	288	degC (est. T)		N2	13.313	moles/min	total	
1	0.29753	0.29828	0.00075	7.08		52.60	5.33	6.8 - 9.0	D		Impactor Exit T				SO2	0.000	moles/min	total	
2	0.31843	0.31873	0.00030	2.83		49.78	3.66	4.7 - 6.8	E		Vacuum Roto	3	in Hg		O2	1.174	moles/min	total	
3	0.32316	0.32371	0.00053	5.00		44.76	2.53	3.3 - 4.7	F		Vacuum Roto T	23	degC (est. T)		Dry O2	7.449	vol%	total	
4	0.32511	0.32590	0.00079	7.46		37.30	1.64	2.1 - 3.3	G		Vacuum Roto	33	CFH		H20 wt	0.082	mass fraction		
5	0.32410	0.32479	0.00069	6.52		30.78	0.85	1.1 - 2.1	H		coal flow time	15	min						
6	0.32250	0.32269	0.00019	1.79		28.99	0.54	0.7 - 1.1	I	841					mol wt wet	28.190	g/mol		
7	0.32078	0.32094	0.00016	1.70		27.29	0.39	0.4 - 0.7	J						dens @ inlet	307.401	g/m^3	Sample probe inlet	
Backup Filter	0.33129	0.33418	0.00289	27.29		0.00	0.19	0 -0.4	K						mdot duct	507.999	g/min	Ash flow neglected	
															vduct	50.959	meters/min	u=mdot/(rho*A)	
		total mass:	0.01059								BACKFIRE BURNERS				vduct	2.786	ft/sec		
															dens @ imp inl	610.418	g/m^3	rho=P/(R*T)	
											mdotBF1 CH4	18.350647							
											mdotBF1 Air	523.58102			mol wt dry	29.588	g/mol		
											phi	1.563	Air/ Fuel by mass		dens @ ratp	1096.120	g/m^3	rho=P/(R*T)	
											mdotA/mdotF	28.53202			volflwrateratp	1.49E-02	m^3/min	Dwyer flowmeter	
Notes:															volflwrateratp	5.25E-01	ft^3/min		
	*) 5 minute pretest warmup without wood										mdotBF1 CH4	0							
	*) Some very large, loose particles on stage 0, with very very little piling. (Typical of these Moncure MB runs, le last test)										mdotBF1 Air	0			mdotratp	18.301	g/min		
	*) Stage 2 was tilted. Ash reading no good										phi	#DIV/0!	Air/ Fuel by mass		mdotimp	17.763	g/min	mdotratp(1-H2Ofract)	
	*) Stage 3 effected by stage 2 tilt. Looks good, but includes some stage 2.										mdotA/mdotF	#DIV/0!			volflwimp	0.029	m^3/min	mdotimp/dens @ imp inlet	
	*) Stage 4 was tilted.														volflwimp	1.028	ft^3/min		
	*) Stage 5 looks like stage 3														vinlet	360.417	m/min	Sample probe inlet	
	*) Filter looks clean!!!														vinlet	19.706	ft/sec		
															mdot ash	1.43E-03	g/min	mdot ash to impactor	
											actual ash:	0.01059	g		expected ash	2.14E-02	g	total ash expected in impactor	
															volume ratio	0.035	vol in/vol tot	gas vol collected/ total in duct	
															velocity ratio	7.073	Vinlet/Vduct	Vel. at probe inlet/Vel. in duct	
															%Diff ash	-102.493	%	based on actual	

Table E.5: 08169503

Date:	8/16/96	mo/day/yr	Main NG:	61.5	%		Probe clnt T:	155	F
Coal:	Fuel 1	source	Main Air:	35.0	%		Prbe clnt flw:	98	mm
	MB	process		43.0	psig		Comb prg p:		psig
test no:	08169503	m/d/ynum	BF1NG:	44.0	%		Coal feed:	25	units
test dur:	15.00	minutes	BF1Air:	4.0	units,front		Coal feed conv	5	g/m
Coal Properties: (Ref. only)				4.0	units, back		Vacuum Roto:	33.0	%
			BF2NG:		%		Vacuum Roto:	3.0	in hg
grams	atomwt/100g	Ult. Ana.	BF2Air:		units,front		atomizer air:		units
45.1178	3.76	Carbon			units, back		atomizer air:		psig
5.8682	5.87	Hydrogen	Inj. Roto:	20	%		atomizer H2O	138	mm
39.3458	2.46	Oxygen	Inj. Roto:	48	psig		exit duct T:	98	F
5.0986	0.36	Nitrogen					over furn T:	101	F
0.02886	0.00	Sulfur	Imp in temp:	288	C (est)		entr bypass	0	'scfm'
0.8177	0.82	Ash	Imp temp based on:		08079501		inj exit T		F
3.8	0.21	Moisture	Imp x temp	50	C (est)				
100.07896		Total	sp. gr. ash	2.7	units (est)				
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % lt. size rnge	D50 calc	Size Range micrometers (default)	T/C Port	Temp, C.
Preseparator	0.32744	0.33250	0.00506	40.10	59.90	10.00	10.0 & up	B	
0	0.29758	0.29826	0.00068	5.39	54.52	8.32	9.0 - 10.0	C	
1	0.29787	0.29864	0.00077	6.10	48.42	5.34	5.8 - 9.0	D	
2	0.32667	0.32700	0.00033	2.61	45.80	3.66	4.7 - 5.8	E	
3	0.32726	0.32787	0.00061	4.83	40.97	2.54	3.3 - 4.7	F	
4	0.32686	0.32773	0.00087	6.89	34.07	1.65	2.1 - 3.3	G	
5	0.32686	0.32749	0.00063	4.99	29.08	0.85	1.1 - 2.1	H	
6	0.32695	0.32719	0.00024	1.90	27.18	0.54	0.7 - 1.1	I	841
7	0.32515	0.32526	0.00011	0.87	26.31	0.39	0.4 - 0.7	J	
Backup Filter	0.33161	0.33493	0.00332	26.31	0.00	0.10	0 - 0.4	K	
		total mass:	0.01262						
Notes:	*) 5 minute warmup of impinger pretest								
	*) All stages looked typical, except the last stage came out dirty!!!								
	*) I did notice that the feeder, for some reason, was feeding much more clumpy than the previous two tests								
	(08169501 &2) Surges were noticable because the teflon feed line would bounce as a surge passed through.								
	*) The preseperator seems to have more material in it than tests 08169501 &2. It appears to be slightly								
	fiberous, like dust on furniture. Some particles are rather large, up to about 1/32nd inch. It appears mostly shades								
	of gray with some black flecks.								
	*) BUMPED STAGE 2 during loading. Ashing looked pretty light to begin with.								

imp inlt diam	9/16	inches	MAIN BURNER			
Meinduct rad	4	inches				
Main Gas Roto	0.615	fraction	mdot CH4	17.317	g/min	
Main Air Roto	0.35	fraction	mdot Main Air	466.845	g/min	
Main Air Roto	43.0	psig	phi	1.571	Air/ Fuel by mass	
Inj. Air Roto	20	%	mdotA/mdotF	26.959	g/g	
Inj Air Roto	48	psig	CO2	1.082	moles/min	CH4&Air only
			H20	2.165	moles/min	CH4&Air only
Fuel comp on Elemental level			N2	12.787	moles/min	CH4&Air only
Carbon (monatomic)	3.76E-02	moles/g	O2	1.236	moles/min	CH4&Air only
Hydrogen (monatomic)	5.87E-02	moles/g	mdot air inj	22.941	g/min	
Oxygen (monatomic)	2.46E-02	moles/g	O2	0.167	moles/min	Inj Air only
Nitrogen (monatomic)	3.64E-03	moles/g	N2	0.628	moles/min	Inj Air only
Sulfur (monatomic)	9.02E-06	moles/g	Dry O2 w/inj	8.825	vol%	total w/o solid fuel
Ash	8.18E-03	g ash/g fuel	DryO2w/o inj	8.183	vol%	total w/o solid fuel and inj
H2O	2.11E-03	moles/g				
			CO2	1.270	moles/min	total
mdot solid fuel	5	g/min	H20	2.322	moles/min	total
Sample probe inlet Temp	841	degC	N2	13.424	moles/min	total
Impactor Inlet T	288	degC (est. T)	SO2	0.000	moles/min	total
Impactor Exit T			O2	1.203	moles/min	total
Vacuum Roto	3	in Hg	Dry O2	7.569	vol%	total
Vacuum Roto T	23	degC (est. T)	H20 wt	0.082	mass fraction	
Vacuum Roto	33	CFH				
coal flow time	15	min	mol wt wet	28.105	g/mol	
			dens@inlet	307.484	g/m^3	Sample probe inlet
			mdot duct	512.062	g/min	Ash flow neglected
			vduct	51.356	meters/min	u=mdot/(rho*A)
BACKFIRE BURNERS			vduct	2.808	ft/sec	
			dens@imp inlt	610.543	g/m^3	rho=P/(R*T)
mdotBF1 CH4	18.350647					
mdotBF1 Air	528.17795		mol wt dry	29.581	g/mol	
phi	1.677	Air/ Fuel by mass	dens@roto	1095.874	g/m^3	rho=P/(R*T)
mdotA/mdotF	28.782526		volflwrateroto	1.49E-02	m^3/min	Dwyer flowmeter
			volflwrateroto	5.25E-01	ft^3/min	
mdotBF1 CH4	0					
mdotBF1 Air	0		mdotroto	18.296	g/min	
phi	#DIV/0!	Air/ Fuel by mass	mdotimp	17.744	g/min	mdotroto/(1-H20fract)
mdotA/mdotF	#DIV/0!		volflwimp	0.029	m^3/min	mdotimp/dens@imp inlet
			volflwimp	1.026	ft^3/min	
			vinlet	359.956	m/min	Sample probe inlet
			vinlet	19.683	ft/sec	
			mdot ash	1.42E-03	g/min	mdot ash to impactor
actual ash:	0.01262	g	expected ash	2.13E-02	g	total ash expected in impactor
			volume ratio	0.036	vol in/vol tot	gas vol collected/ total in duct
			velocity ratio	7.009	Vinlet/Vduct	Vel. at probe inlet/Vel. in duct
			%Diff ash	-68.396	%	based on actual

Table E.6: Test 10139501

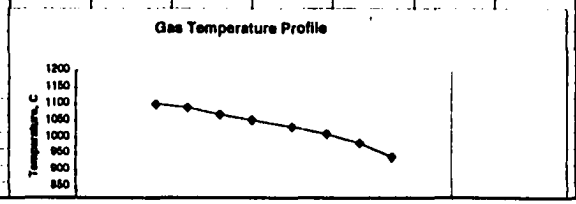
Date:	10/13/95	mo/day/yr	Main NG:	60.5	%		Probe cint T:	169	F
Coal:	Fuel 3	source	Main Air:	34.5	%		Prbe cint flw:	105	mm
	single sieve	process		43.0	psig		Comb prg p:	off	psig
test no:	10139501	m/d/ynum	BF1NG:	45.0	%		Coal feed:	350	units
test dur:	15.00	minutes	BF1Air:	4.0	units,front		Coal feed conv	5	g/m
Coal Properties:	(Ref. only)			4.0	units, back		Vacuum Roto:	33.5	%
			BF2NG:		%		Vacuum Roto:	3.3	in hg
grams	atoms/100g	Ult. Ana.	BF2Air:		units,front		atomizer air:	full	units
47.7225	3.98	Carbon			units, back		atomizer air:	full	psig
6.237	6.24	Hydrogen	Inj. Roto:	40	%		atomizer H2O	115	mm
39.69	2.48	Oxygen	Inj. Roto:	48	psig		exit duct T:	96	F
0.38745	0.03	Nitrogen					over furn T:	96	F
0	0.00	Sulfur	Imp in temp:	288	C (est)		entr bypass	0.18	"scfm"
0.5481	0.55	Ash	Imp temp based on:		08079501		inj exit T	114	F
5.5	0.31	Moisture	Imp x temp	50	C (est)				
100.08505		Total	sp. gr. ash	2.7	units (est)				
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % lt. size rnge	D50 calc.	Size Range micrometers (default)	T/C Port	Temp, C.
Preseparator	0.32594	0.36844	0.04250	88.764	11.24	10.00	10.0 & up	B	
0	0.28789	0.28933	0.00144	3.008	8.23	8.34	9.0 - 10.0	C	
1	0.28553	0.28606	0.00053	1.107	7.12	5.35	5.8 - 9.0	D	
2	0.32565	0.32590	0.00025	0.522	6.60	3.67	4.7 - 5.8	E	
3	0.32573	0.32593	0.00020	0.418	6.18	2.54	3.3 - 4.7	F	
4	0.32511	0.32535	0.00024	0.501	5.68	1.65	2.1 - 3.3	G	
5	0.32302	0.32325	0.00023	0.480	5.20	0.85	1.1 - 2.1	H	
6	0.32460	0.32473	0.00013	0.272	4.93	0.54	0.7 - 1.1	I	938
7	0.32521	0.32528	0.00007	0.146	4.78	0.39	0.4 - 0.7	J	
Backup Filter	0.32818	0.33047	0.00229	4.78	0.00	0.10	0 -0.4	K	
		total mass:	0.04788						
Notes:	*)Plenty of way oversize particles in the presep, on the 0 and 1 orifice plate, and stage 0 and 1. Stage 2 as well to a lesser exent. Stage 3 looksrelatively normal.								
	*)Washed stage 0 and 1 overflows (on orifice plate into the presep wash. there is a lot of crap in this impactor. Large, partially charred slivers								
	*)There are many loose particles on the 0 stage. Some fell into the petri dish <1%.								
	*)There aren't neat piles of ash on stage 0, 1, 2. More of a loose distribution. Stage 2 looks like its piling, but there is still plenty of dispersion.								
	*)Temp at port I is based on test 10169501, taken with a High Velocity TC								

imp inlt diam	9/16	inches
Mainduct rad	4	inches
Main Gas Roto	0.605	fraction
Main Air Roto	0.345	fraction
Main Air Roto	43	psig
Inj. Air Roto	40	%
Inj Air Roto	48	psig
Fuel comp.on Elemental level		
Carbon (monatomic)	3.98E-02	moles/g
Hydrogen (monatomic)	6.24E-02	moles/g
Oxygen (monatomic)	2.48E-02	moles/g
Nitrogen (monatomic)	2.77E-04	moles/g
Sulfur (monatomic)	0.00E+00	moles/g
Ash	5.48E-03	g ash/g fuel
H2O	3.06E-03	moles/g
mdot solid fuel	5	g/min
Sample probe inlet Temp	938	degC
Impactor Inlet T	288	degC (est. T)
Impactor Exit T		
Vacuum Roto	3.25	in Hg
Vacuum Roto T	23	degC (est. T)
Vacuum Roto	33.5	CFH
coal flow time	15	min
BACKFIRE BURNERS		
mdotBF1 CH4	18.787707	
mdotBF1 Air	528.17795	
phi	1.640	Air/ Fuel by mass
mdotA/mdotF	28.142913	
mdotBF1 CH4	0	
mdotBF1 Air	0	
phi	#DIV/0!	Air/ Fuel by mass
mdotA/mdotF	#DIV/0!	
actual ash:	0.04788	g

MAIN BURNER			
mdot CH4	17.035	g/min	
mdot Main Air	460.175	g/min	
phi	1.574	Air/ Fuel by mass	
mdotA/mdotF	27.013	g/g	
CO2	1.065	moles/min	CH4&Air only
H2O	2.129	moles/min	CH4&Air only
N2	12.604	moles/min	CH4&Air only
O2	1.223	moles/min	CH4&Air only
mdot air inj.	45.882	g/min	
O2	0.334	moles/min	Inj Air only
N2	1.257	moles/min	Inj Air only
Dry O2 w/inj	9.446	vol%	total w/o solid fuel
DryO2w/o inj	8.211	vol%	total w/o solid fuel and inj
CO2	1.264	moles/min	total
H2O	2.301	moles/min	total
N2	13.861	moles/min	total
SO2	0.000	moles/min	total
O2	1.342	moles/min	total
Dry O2	8.150	vol%	total
H2O wt	0.078	mass fraction	
mol wt wet	28.137	g/mol	
dens @ inlet	283.158	g/m^3	Sample probe inlet
mdot duct	528.068	g/min	Ash flow neglected
vduct	57.507	meters/min	u=mdot/(rho*A)
vduct	3.145	ft/sec	
dens @ imp inl	611.238	g/m^3	rho=P/(R*T)
mol wt dry	29.564	g/mol	
dens @ roto	1084.692	g/m^3	rho=P/(R*T)
volflwrateroto	1.50E-02	m^3/min	Dwyer flowmeter
volflwrateroto	5.30E-01	ft^3/min	
mdotroto	16.290	g/min	
mdotimp	17.677	g/min	mdotroto/(1-H2Ofract)
volflwimp	0.029	m^3/min	mdotimp/dens @ imp inlet
volflwimp	1.021	ft^3/min	
vinlet	389.373	m/min	Sample probe inlet
vinlet	21.291	ft/sec	
mdot ash	9.17E-04	g/min	mdot ash to impactor
expected ash	1.38E-02	g	total ash expected in impactor
volume ratio	0.033	vol in/vol tot	gas vol collected/ total in duct
velocity ratio	6.771	Vinlet/Vduct	Vel. at probe inlet/Vel. in duct
%Diff ash	71.261	%	based on actual

Table E.7: Test 10169501T

Date:	10/16/95	mo/day/yr	Main NG:	60.0	%		Probe clnt T:	167	F														
Coal:	None	source	Main Air:	34.0	%		Prbe clnt flw:	110	mm														
		process		43.0	psig		Comb prg p:		psig														
test no:	10169501	m/d/ymum	BF1NG:	45.0	%		Coal feed:		units	inp inlt diam	9/16	inches		MAIN BURNER									
test dur:		minutes	BF1Air:	4.0	units,front		Coal feed conv		g/m	Mainduct rad	4	inches											
Coal Properties: (Ref. only)				4.0	units, back		Vacuum Roto:		%	Main Gas Rot	0.6	fraction		mdot CH4	16.894	g/min							
			BF2NG:		%		Vacuum Roto:		in hg	Main Air Roto	0.34	fraction		mdot Main Air	453.506	g/min							
grams	atom#/100g	Ult. Ana.	BF2Air:		units,front		atomizer air:		units	Main Air Roto	43.0	psig		phi	1.564	Air/ Fuel by mass							
		Carbon			units, back		atomizer air:		psig	Inj. Air Roto	40	%		mdotA/mdotF	26.844	g/g							
		Hydrogen	Inj. Roto:	40	%		atomizer H2O	112	mm	Inj Air Roto	48	psig		CO2	1.056	moles/min	CH4&Air only						
		Oxygen	Inj. Roto:	48	psig		exit duct T:	99	F					H20	2.112	moles/min	CH4&Air only						
		Nitrogen					over furn T:	112	F	Fuel comp on Elemental level				N2	12.421	moles/min	CH4&Air only						
		Sulfur	Inp in temp:	288	C (est)		entr bypass	0	"actm"	Carbon (mona	0.00E+00	moles/g		O2	1.192	moles/min	CH4&Air only						
		Ash	Inp temp based on:		08079501		inj exit T	119	F	Hydrogen (mo	0.00E+00	moles/g		mdot air inj	45.882	g/min							
		Moisture	Inp z temp	50	C (est)					Oxygen (mon	0.00E+00	moles/g		O2	0.334	moles/min	Inj Air only						
		Total	sp. gr. ash	2.7	units (est)					Nitrogen (mon	0.00E+00	moles/g		N2	1.257	moles/min	Inj Air only						
										Sulfur (monat	0.00E+00	moles/g		Dry O2 w/inj	9.385	vol%	total w/o solid						
										Ash	0.00E+00	g ash/g fuel		DryO2w/o inj	8.124	vol%	total w/o solid						
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % lt. size rnge	D50 calc.	Size Range micrometers (default)	T/C Port	Temp, C.	H2O	0.00E+00	moles/g											
														CO2	1.056	moles/min	total						
Preseparator			0.00000				10.0 & up	B		mdot solid fue	0	g/min		H20	2.112	moles/min	total						
0			0.00000				9.0 - 10.0	C		Sample probe	841	degC		N2	13.678	moles/min	total						
1			0.00000				5.8 - 9.0	D		Impactor inlet	288	degC (est. T)		SO2	0.000	moles/min	total						
2			0.00000				4.7 - 5.8	E		Impactor Exit T				O2	1.529	moles/min	total						
3			0.00000				3.3 - 4.7	F		Vacuum Roto	0	in Hg		Dry O2	9.385	vol%	total						
4			0.00000				2.1 - 3.3	G		Vacuum Roto	23	degC (est. T)		H20 wt	0.074	mass fraction							
5			0.00000				1.1 - 2.1	H		Vacuum Roto	0	CFH											
6			0.00000				0.7 - 1.1	I	841	coal flow time	0	min		mol wt wet	28.102	g/mol							
7			0.00000				0.4 - 0.7	J						dens@inlet	307.430	g/m^3	Sample probe						
Backup Filter			0.00000				0 -0.4	K						mdot duct	616.283	g/min	Ash flow neg						
										BACKFIRE BURNER				vduct	51.785	meters/min	u=mdot/(rho*A						
		total mass:	0.00000											vduct	2.832	ft/sec							
										mdotBF1 CH4	16.7677071			dens@inp inl	610.476	g/m^3	rho=P/(R*T)						
										mdotBF1 Air	529.177964			mol wt dry	29.414	g/mol							
										phi	1.640	Air/ Fuel by mass		dens@roto	1211.037	g/m^3	rho=P/(R*T)						
Notes:										mdotA/mdotF	26.1429133			volflwrateroto	0.00E+00	m^3/min	Dwyer flowm						
														volflwrateroto	0.00E+00	ft^3/min							
										mdotBF1 CH4	0												
Temp measurement with High velocity TC										mdotBF1 Air	0			mdotrote	0.000	g/min							
										phi	#DIV/0!	Air/ Fuel by mass		mdotimp	0.000	g/min	mdotrotor[1-H						
Procedure:										mdotA/mdotF	#DIV/0!			volflwimp	0.000	m^3/min	mdotimp/dens						
Started at port H., went through up to B, then did "I" last. Water valves full open, shop air on, full closed sample valve. Inserted HVTC to center line. Let warm up about 15 seconds. Slowly opened suction valve until at 15 in Hg. Let set for about 30 seconds for temp stabilization. Closed suction valve. Slowly removed HVTC and inserted in next port ASAP. Open ports as needed. Didn't leave open during sampling.														volflwimp	0.000	ft^3/min							
														vinlet	0.000	m/min	Sample probe						
														vinlet	0.000	ft/sec							
														mdot ash	0.00E+00	g/min	mdot ash to in						
										actual ash:	0	g		expected ash	0.00E+00	g	total ash expe						
														volume ratio	0.000	vol in/vol tot	gas vol collec						
														velocity ratio	0.000	Vinlet/Vduct	Vel. at probe						
														%Diff ash	#DIV/0!	%	based on actu						
Test 10169501 -Main NG@ 60%, Main Air @ 34%/43psig, BF1@ 45% and 4/4 units, inj air at 40%/48psig																							
Port	Dist. from inj.	Dist from thrp	Pyrometer	Bare TC	HVTC		dT/dtime	268.128	quench rate														
b	43.18	15	1085	1075	1098																		
c	58.42	21	1068	1058	1068																		
d	73.66	27	1063	1037	1067																		
e	88.9	33	950	1018	1052																		
f	107.95	40.5	918	978	1032																		
g	124.46	47	891	945	1010																		
h	139.7	53	837	887	980																		
i	154.94	59	796	832	938																		
j		65																					
k		71																					



mperature, c

Table E.8: Test 10269501

Date:	10/26/95	mo/day/yr	Main NG:	62.5	%		Probe ctrl T:	158	F								
Coal:	Fuel 2	source	Main Air:	35.0	%		Prbe ctrl flw:	97	mm								
	solved	process		43.0	psig		Comb prg p:		psig								
test no:	10269501	m/d/ymum	BF1NG:	45.0	%		Coal feed:	450	units	Imp Init diam	9/16	inches		MAIN BURNER			
test dur:	15.00	minutes	BF1Air:	4.0	units,front		Coal feed conv	5.45	g/m	Mainduct rad	4	inches					
Coal Properties: (Ref. only)				4.0	units, back		Vacuum Rate	33.5	%	Main Gas Rate	0.825	fraction		mdot CH4	17.598	g/min	
			BF2NG:		%		Vacuum Rate	9.3	in hg	Main Air Rate	0.35	fraction		mdot Main Air	466.845	g/min	
grams	atoms/100g	Ult. Ana.	BF2Air:		units,front		atomizer air:		units	Main Air Rate	43.0	psig		phi	1.546	Air/ Fuel by mass	
43.948	3.65	Carbon			units, back		atomizer air:		psig	Inj Air Rate	40	%		mdotA/mdotF	26.529	g/g	
5.959	5.86	Hydrogen	Inj. Rate:	40	%		atomizer H2O	100	mm	Inj Air Rate	48	psig		CO2	1.100	moles/min	CH4&Air only
40.448	2.53	Oxygen	Inj. Rate:	48	psig		exit duct T:	99	F					H20	2.200	moles/min	CH4&Air only
3.213	0.23	Nitrogen					over furn T:	94	F					N2	12.787	moles/min	CH4&Air only
0.027405	0.00	Sulfur	Imp in temp:	288	C (est)		entr bypass	0.17	"scfm"	Fuel comp on Elemental level				O2	1.201	moles/min	CH4&Air only
1.0584	1.06	Ash	Imp temp based on:		09079501		inj exit T	116	F	Carbon (monatomic)	3.65E-02	moles/g		mdot air inj	45.882	g/min	
5.5	0.31	Moisture	Imp x temp	50	C (est)					Hydrogen (monatomic)	5.86E-02	moles/g		O2	0.334	moles/min	Inj Air only
99.951905		Total	ep. gr. ash	2.7	units (est)					Oxygen (monatomic)	2.53E-02	moles/g		N2	1.257	moles/min	Inj Air only
										Nitrogen (monatomic)	2.30E-03	moles/g		Dry O2 w/inj	9.204	vol%	total w/o solid fuel
										Sulfur (monatomic)	8.56E-06	moles/g		DryO2w/o inj	7.960	vol%	total w/o solid fuel and inj
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % lt. size mge	D50 calc.	Size Range micrometers (default)	T/C Port	Temp, C	Ash	1.06E-02	g ash/g fuel					
										H2O	3.06E-03	moles/g					
														CO2	1.299	moles/min	total
										mdot solid fuel	5.45	g/min		H20	2.378	moles/min	total
Preseparator	0.32688	0.33309	0.00621	30.06	69.94	10.00	10.0 & up	B		Sample probe inlet Temp	938	degC		N2	14.049	moles/min	total
0	0.28934	0.29108	0.00172	8.33	61.62	8.33	9.0 - 10.0	C		Impactor inlet T	288	degC (est. T)		SO2	0.000	moles/min	total
1	0.29015	0.29200	0.00185	8.95	52.66	5.34	5.8 - 9.0	D		Impactor Exit T				O2	1.325	moles/min	total
2	0.32668	0.32747	0.00079	3.82	48.84	3.66	4.7 - 5.8	E		Vacuum Rate	3.25	in Hg		Dry O2	7.947	vol%	total
3	0.32629	0.32754	0.00125	6.05	42.79	2.54	3.3 - 4.7	F		Vacuum Rate T	23	degC (est. T)		H20 wt	0.080	mass fraction	
4	0.32602	0.32768	0.00166	8.03	34.75	1.65	2.1 - 3.3	G		Vacuum Rate	33.6	CFH					
5	0.32622	0.32709	0.00087	4.21	30.54	0.85	1.1 - 2.1	H		coal flow time	15	min		mol wt wet	28.122	g/mol	
6	0.32666	0.32690	0.00024	1.16	29.38	0.54	0.7 - 1.1	I	938					dens @ inlet	293.003	g/m^3	Sample probe inlet
7	0.32478	0.32500	0.00022	1.06	28.32	0.39	0.4 - 0.7	J						mdot duct	535.718	g/min	Ash flow neglected
Backup Filter	0.33022	0.33607	0.00585	28.32	0.00	0.10	0 -0.4	K						vduct	58.372	meters/min	u=mdot/(rho*A)
										BACKFIRE BURNERS				vduct	3.192	ft/sec	
		total mass:	0.02066											dens @ imp inl	610.904	g/m^3	rho=P/(R*T)
										mdotBF1 CH4	18.767707						
										mdotBF1 Air	528.17795			mol wt dry	29.565	g/mol	
										phi	1.640	Air/ Fuel by mass		dens @ rota	1085.068	g/m^3	rho=P/(R*T)
										mdotA/mdotF	28.142913			volflwrotarota	1.50E-02	m^3/min	Dryer flowmeter
														volflwrotarota	5.30E-01	ft^3/min	
Notes:										mdotBF1 CH4	0						
*) Presep is very clean - some particulates, but not the usual large chunks (i.e. Elkin)										mdotBF1 Air	0			mdotrota	18.299	g/min	
*) A few large particles on the 0 orifice plate - not a lot - 3 very large, (mil?)										phi	#DIV/0!	Air/ Fuel by mass		mdotimp	17.713	g/min	mdotrotor(1-H20frac)
*) Stage 0 is very loaded. Ash is very light brown/tan color. Nice piling.										mdotA/mdotF	#DIV/0!			volflwimp	0.029	m^3/min	mdotimp/dens @ imp inlet
*) This run was textbook! Every stage looked great. Ash load is very significant on all stages, but doesn't appear overloaded.														volflwimp	1.024	ft^3/min	
*) The Filter is WHITE														vinlet	390.400	m/min	Sample probe inlet
*) Bumped stage 6 post weighing														vinlet	21.347	ft/sec	
														mdot ash	1.91E-03	g/min	mdot ash to impactor
										actual ash:	0.02066	g		expected ash	2.84E-02	g	total ash expected in impactor
														volume ratio	0.933	vol in/vol tot	gas vol collected/ total in duct
														velocity ratio	0.898	Vinlet/Vduct	Vel. at probe inlet/Vel. in duct
														%Diff ash	-38.476	%	based on actual

Table E.9: Test 10269502

Date:	10/26/95	mo/day/yr	Main NG:	62.5	%			Probe clnt T:	116	F									
Coal:	Fuel 2	source	Main Air:	35.2	%			Prbe clnt flw:	93	mm									
	sieved	process		43.0	psig			Comb prg p:		psig									
test no:	10269502	m/d/ynum	BF1NG:	45.0	%			Coal feed:	450	units	Imp Inlt diam	9/16	inches		MAIN BURNER				
test dur:	10.00	minutes	BF1Air:	4.0	units,front			Coal feed conv	5.45	g/m	Mainduct rad	4	inches						
Coal Properies:	(Ref. only)			4.0	units, back			Vacuum Rota:	34.0	%	Main Gas Rota	0.625	fraction		mdot CH4	17.598	g/min		
			BF2NG:		%			Vacuum Rota:	3.4	in hg	Main Air Rota	0.352	fraction		mdot Main Air	469.512	g/min		
grams	atom wt/100g	Ult. Ana.	BF2Air:		units,front			atomizer air:		units	Main Air Rota	43.0	psig		phi	1.565	Air/ Fuel by mass		
43.848	3.65	Carbon			units, back			atomizer air:		psig	Inj. Air Rota	40	%		mdotA/mdotF	26.679	g/g		
5.859	5.86	Hydrogen	Inj. Rota:	40	%			atomizer H2O	99	mm	Inj Air Rota	48	psig		CO2	1.100	moles/min	CH4&Air only	
40.446	2.53	Oxygen	Inj. Rota:	48	psig			exit duct T:	105	F					H20	2.200	moles/min	CH4&Air only	
3.213	0.23	Nitrogen						over furn T:	95	F	Fuel comp on Elemental level				N2	12.860	moles/min	CH4&Air only	
0.027405	0.00	Sulfur	Imp in temp:	288	C (est)			entr bypass	0.17	"acfm"	Carbon (monatomic)	3.65E-02	moles/g		O2	1.220	moles/min	CH4&Air only	
1.0584	1.06	Ash	Imp temp based on:		08079501			Inj exit T	168	F	Hydrogen (monatomic)	5.86E-02	moles/g		mdot air inj	45.882	g/min		
5.5	0.31	Moisture	Imp x temp	50	C (est)						Oxygen (monatomic)	2.53E-02	moles/g		O2	0.334	moles/min	Inj Air only	
99.951805		Total	sp. gr. ash	2.7	units (est)						Nitrogen (monatomic)	2.30E-03	moles/g		N2	1.257	moles/min	Inj Air only	
											Sulfur (monatomic)	8.56E-06	moles/g		Dry O2 w/inj	9.269	vol%	total w/o solid fuel	
											Ash	1.06E-02	g ash/g fuel		DryO2w/o inj	8.039	vol%	total w/o solid fuel and inj	
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % ft. size mge		D50 calc.	Size Range micrometers (default)	T/C Port	Temp, C.	H2O	3.06E-03	moles/g						
Preseparator	0.32619	0.33102	0.00483	32.75	67.25		10.00	10.0 & up	B		mdot solid fuel	5.45	g/min		CO2	1.299	moles/min	total	
0	0.28822	0.28928	0.00106	7.19	60.07		8.31	9.0 - 10.0	C		Sample probe inlet Temp	936	degC		H20	2.376	moles/min	total	
1	0.28859	0.28975	0.00116	7.86	52.20		5.33	5.0 - 9.0	D		Impactor Inlet T	288	degC (est. T)		N2	14.123	moles/min	total	
2	0.32627	0.32675	0.00048	3.25	48.96		3.85	4.7 - 5.0	E		Impactor Exit T				SO2	0.000	moles/min	total	
3	0.32488	0.32579	0.00091	6.17	42.78		2.53	3.3 - 4.7	F		Vacuum Rota	3.4	in Hg		O2	1.344	moles/min	total	
4	0.32636	0.32752	0.00116	7.86	34.92		1.64	2.1 - 3.3	G		Vacuum Rota T	23	degC (est. T)		Dry O2	8.019	vol%	total	
5	0.32467	0.32525	0.00058	3.93	30.98		0.85	1.1 - 2.1	H		Vacuum Rota	34	CFH		H20 wt	0.079	mass fraction		
6	0.32661	0.32673	0.00012	0.81	30.17		0.54	0.7 - 1.1	I	938	coal flow time	10	min		mol wt wet	28.125	g/mol		
7	0.32549	0.32559	0.00011	0.75	29.42		0.39	0.4 - 0.7	J						dens @ inlet	283.036	g/m^3	Sample probe inlet	
Backup Filter	0.33053	0.33487	0.00434	29.42	0.00		0.10	0 -0.4	K						mdot duct	538.385	g/min	Ash flow neglected	
															vduct	58.654	meters/min	u=mdot/(rho*A)	
		total mass:	0.01475								BACKFIRE BURNERS				vduct	3.207	ft/sec		
															dens @ imp inlt	610.980	g/m^3	rho=P/(R*T)	
											mdotBF1 CH4	18.787707							
											mdotBF1 Air	529.17795			mol wt dry	29.581	g/mol		
											phi	1.640	Air/ Fuel by mass		dens @ rota	1078.844	g/m^3	rho=P/(R*T)	
											mdotA/mdotF	28.142913			volflwrotarota	1.52E-02	m^3/min	Dwyer flowmeter	
Notes:	*) Presep is pretty lightly loaded again (as last test)														volflwrotarota	5.37E-01	ft^3/min		
	*) Stages looked good										mdotBF1 CH4	0							
											mdotBF1 Air	0			mdotrota	18.400	g/min		
											phi	#DIV/0!	Air/ Fuel by mass		mdotimp	17.815	g/min	mdotrota/(1-H20fract)	
											mdotA/mdotF	#DIV/0!			volflwimp	0.029	m^3/min	mdotimp/dens @ imp inlet	
															volflwimp	1.030	ft^3/min		
															vinlet	392.594	m/min	Sample probe inlet	
															vinlet	21.487	ft/sec		
															mdot ash	1.91E-03	g/min	mdot ash to impactor	
											actual ash:	0.01475	g		expected ash	1.91E-02	g	total ash expected in impactor	
															volume ratio	0.033	vol in/vol tot	gas vol collected/ total in duct	
															velocity ratio	6.693	Vinlet/Vduct	Vel at probe inlet/Vel. in duct	
															%Diff ash	-29.406	%	based on actual	

Table E.10: Test 10319501

Date:	10/31/95	mo/day/yr	Main NG:	60.5	%		Probe cint T:	172	F								
Coal:	Fuel 3	source	Main Air:	35.0	%		Probe cint thr:	90	mm								
	double seive	process		43.0	psig		Comb prg p:		psig								
test no:	10319501	m/d/ynum	BF1NG:	45.0	%		Coal feed:	350	units	Imp inj diam	9/16	inches	MAIN BURNER			
test dur:	15.00	minutes	BF1Air:	4.0	units,front		Coal feed conv	5	g/m	Mainduct rad	4	inches				
Coal Properties: (Ref. only)				4.0	units, back		Vacuum Rate:	33.0	%	Main Gas Rate	0.605	fraction	mdot CH4	17.036	g/min	
			BF2NG:		%		Vacuum Rate:	3.0	in hg	Main Air Rate	0.35	fraction	mdot Main Air	466.845	g/min	
grams	atomw/100g	Ult. Ana.	BF2Air:		units,front		atomizer air:	fullopen	units	Main Air Rate	43.0	psig	phi	1.597	Air/ Fuel by mass	
47.7225	3.98	Carbon			units, back		atomizer air:		psig	Inj Air Rate	40	%	mdotA/mdotF	27.405	g/g	
6.237	6.24	Hydrogen	Inj. Rate:	40	%		atomizer H2O	105	mm	Inj Air Rate	48	psig	CO2	1.065	moles/min	CH4&Air only
39.69	2.48	Oxygen	Inj. Rate:	48	psig		exit duct T:	106	F				H20	2.129	moles/min	CH4&Air only
0.38745	0.03	Nitrogen					over furn T:	107	F				N2	12.787	moles/min	CH4&Air only
0	0.00	Sulfur	Imp in temp:	288	C (est)		anti bypass	0.15	"actm"	Fuel comp on Elemental level			O2	1.271	moles/min	CH4&Air only
0.5481	0.55	Ash	Imp temp based on:		08079501		Inj exit T	118	F	Carbon (monatomic)	3.98E-02	moles/g	mdot air inj	45.982	g/min	
5.5	0.31	Moisture	Imp x temp	50	C (est)					Hydrogen (monatomic)	6.24E-02	moles/g	O2	0.334	moles/min	inj Air only
100.08505		Total	sp. gr. ash	2.7	units (est)					Oxygen (monatomic)	2.48E-02	moles/g	N2	1.251	moles/min	inj Air only
										Nitrogen (monatomic)	2.77E-04	moles/g	Dry O2 w/inj	9.609	vol%	total w/o solid fuel
										Sulfur (monatomic)	0.00E+00	moles/g	DryO2w/o inj	8.406	vol%	total w/o solid fuel and inj
										Ash	5.48E-03	g ash/g fuel				
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % & size mge	D50 calc.	Size Range micrometers (default)	T/C Port	Temp, C.	H2O	3.06E-03	moles/g	CO2	1.264	moles/min	total
										mdot solid fuel	5	g/min	H20	2.301	moles/min	total
Preseperator	0.32150	0.36626	0.04476	86.59	13.41	10.00	10.0 & up	B		Sample probe Inlet Temp	938	degC	N2	14.044	moles/min	total
0	0.29280	0.29527	0.00247	4.78	8.63	8.35	9.0 - 10.0	C		Impactor Inlet T	288	degC (est. T)	SO2	0.000	moles/min	total
1	0.29443	0.29497	0.00055	1.06	7.56	5.38	5.0 - 9.0	D		Impactor Exit T			O2	1.391	moles/min	total
2	0.32578	0.32610	0.00034	0.66	6.91	3.67	4.7 - 5.0	E		Vacuum Rate	5	in Hg	Dry O2	8.328	vol%	total
3	0.32383	0.32413	0.00030	0.58	6.33	2.55	3.3 - 4.7	F		Vacuum Rate T	23	degC (est. T)	H20 wt	0.077	mass fraction	
4	0.32614	0.32649	0.00035	0.68	5.65	1.65	2.1 - 3.3	G		Vacuum Rate	33	CFH				
5	0.32314	0.32335	0.00021	0.41	5.24	0.85	1.1 - 2.1	H		coal flow time	15	min	mol wt wet	28.149	g/mol	
6	0.32311	0.32321	0.00010	0.19	5.05	0.54	0.7 - 1.1	I	938				dens @ inlet	283.244	g/m^3	Sample probe inlet
7	0.32465	0.32476	0.00011	0.21	4.84	0.39	0.4 - 0.7	J					mdot duct	534.735	g/min	Ash flow neglected
Backup Filter	0.32997	0.33247	0.00250	4.84	0.00	0.10	0 -0.4	K					vduct	58.218	meters/min	u=mdot/(rho*A)
													vduct	3.183	ft/sec	
		total mass:	0.05169							BACKFIRE BURNERS			dens @ imp inl	611.424	g/m^3	rho=P/(R*T)
										mdotBF1 CH4	18.797707		mol wt dry	29.644	g/mol	
										mdotBF1 Air	528.17796		dens @ rota	1094.486	g/m^3	rho=P/(R*T)
										phi	1.640	Air/ Fuel by mass	volflowrate/rota	1.49E-02	m^3/min	Dwyer flowmeter
										mdotA/mdotF	28.142913		volflowrate/rota	5.25E-01	ft^3/min	
Notes:																
*)Plenty of large, barely burned wood particles in the preseperator.										mdotBF1 CH4	0					
*)0 orifice plate has large char particles										mdotBF1 Air	0		mdotrota	18.265	g/min	
*)0 stage has large unburned particles										phi	#DIV/0!	Air/ Fuel by mass	mdotimp	17.630	g/min	mdotrota*(1-H20frac)
*)1orifice plate and 1 stage have large unburned particles										mdotA/mdotF	#DIV/0!		volflwimp	0.029	m^3/min	mdotimp/dens @ imp inlet
*)2 stage doesn't have good piles, and has some large particles													volflwimp	1.018	ft^3/min	
*)Stage 3 looks pretty close to normal													vinlet	388.236	m/min	Sample probe inlet
*)Stages 4 to 7 look normal													vinlet	21.229	ft/sec	
*)Filter is orange, as in other efficiency tests.																
													mdot ash	9.04E-04	g/min	mdot ash to impactor
DOUBLE SEIVED										actual ash:	0.05169	g	expected ash	1.36E-02	g	total ash expected in impactor
													volume ratio	0.033	vol in/vol tot	gas vol collected/ total in duct
													velocity ratio	0.669	Vinlet/Vduct	Vel. at probe inlet/Vel. in duct
													%Diff ash	73.780	%	based on actual

Table E.11: Test 11029501

Date:	11/2/96	mol/dmYr	Main NO:	60.5	%		Probe ctrl T:	175	F										
Coal:	Fuel 3	source	Main Air:	35.0	%		Pths ctrl (hr:	195	mm										
	single sieve	process		43.0	psig		Comb prg P:		psig										
test no:	11029501	mr/dy/mm	BF1NO:	45.0	%		Coal feed:	350	units	Imp Inl diam		8/16	inches		MAIN BURNER				
test dur:	10.00	minutes	BF1Air:	4.0	units, front		Coal feed conv	5	g/m	Manifold (pd		4	inches						
Coal Properties:	(Rel. ash)			4.0	units, back		Vacuum Ratio:	33.0	%	Main Gas Ratio		0.605	fraction		mdot CH4	17.035	g/min		
		BF2NO:			%		Vacuum Ratio:	33.0	in hg	Main Air Ratio		0.35	fraction		mdot Main Air	466.946	g/min		
		BF2Air:			units, front			full open	units	Main Air Ratio		43.0	psig		pH	1.697	Air Fuel by mass		
grams	atomm/100g	Ult. Ana.			atomizer air,				psig	Inj Air Ratio		40	%		mdotA/mdotF	27.495	g/g		
	47.7225	Carbon			units, back				psig	Inj Air Ratio		40	psig		CO2	1.065	moles/min	CH4&Air only	
	3.98	Hydrogen	Inj. Ratio:	40	%		atomizer H2O	110	mm			40	psig		H2O	2.129	moles/min	CH4&Air only	
	9.24	Oxygen	Inj. Ratio:	40	psig		ash duct T:	100	F						N2	12.787	moles/min	CH4&Air only	
	2.48	Nitrogen					cmd turn T:	110	F	Fuel comp.on Elemental basi					O2	1.271	moles/min	CH4&Air only	
	0.03	Sulfur	Imp in temp.	288	C (est)		inst bypass	0.17	'actm'	Carbon (monatomic)		3.99E-02	moles/g		O2	46.882	g/min		
	0.00	Sulfur	06070501					115	F	Hydrogen (monatomic)		8.24E-02	moles/g		mdot air inj		g/min	Inj Air only	
	0	Ash	Imp temp based on:				Inj exit T			Oxygen (monatomic)		2.48E-02	moles/g		O2	0.334	moles/min	Inj Air only	
	0.5481	Ash	Imp x temp	50	C (est)					Nitrogen (monatomic)		2.77E-04	moles/g		N2	1.257	moles/min	Inj Air only	
	5.5	Moisture	sp. gr. ash	2.7	units (est)					Sulfur (monatomic)		0.00E+00	moles/g		Dry O2 wrt inj	9.606	vol%	total w/o added fuel	
	100.00505	Total								Ash		5.48E-03	g ash/g fuel		Dry O2 w/o inj	9.499	vol%	total w/o added fuel and inj	
										H2O		9.06E-03	moles/g						
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % lt. size mpe	D50 calc.	Size Range micrometers (default)	T/C Port	Temp, C						CO2	1.254	moles/min	total	
										mdot solid fuel		5	g/min		H2O	2.301	moles/min	total	
Presepartor	0.32145	0.24820	0.02875	88.06	11.96	10.00	10.0 & up	B		Sample probe inlet Temp		638	degC		N2	14.044	moles/min	total	
0	0.29418	0.29518	0.00099	3.23	8.72	9.55	9.0 : 10.0	C		Impactor Inlet T		288	degC (est. T)		SO2	0.000	moles/min	total	
1	0.29692	0.29829	0.00033	1.09	7.64	5.36	6.8 : 9.0	D		Impactor Exit T					O2	1.391	moles/min	total	
2	0.32600	0.32818	0.00018	0.59	7.04	3.67	4.7 : 6.8	E		Vacuum Ratio		3	in Hg		Dry O2	8.328	vol%	total	
3	0.32516	0.32532	0.00016	0.53	6.52	2.55	3.3 : 4.7	F		Vacuum Rate T		22	degC (est. T)		H2O lnl.	0.977	mass fraction	total	
4	0.32739	0.32757	0.00018	0.59	5.92	1.65	2.1 : 3.3	G		Vacuum Ratio		33	CFH						
5	0.32283	0.32296	0.00013	0.43	5.50	0.85	1.1 : 2.1	H		coal flow rate		10	min		mol wt wet	28.146	g/mol		
6	0.32181	0.32195	0.00005	0.16	5.33	0.54	0.7 : 1.1	I	638						dens @ Inlet	283.244	g/m^3	Sample probe inlet	
7	0.32432	0.32453	0.00021	0.69	5.30	0.39	0.4 : 0.7	J							mdot dust	634.736	g/min	Ash flow neglected	
Backup Filter	0.32927	0.33098	0.00181	5.90	0.00	0.19	0.0 : 0.4	K							velocity	58.218	meters/min	u=mdot/(rho*A)	
										BACKFIRE BURNERS						3.183	ft/sec		
	total mass:	0.03038													dens @ Imp Inl	811.424	g/m^3	rho=P/(R*T)	
												18.767707							
										mdotBF1 CH4		628.17795			mol wt dry	29.944	g/mol		
										mdotBF1 Air		1.640	Air Fuel by mass		dens @ nzle	1994.466	g/m^3	rho=P/(R*T)	
										pH		28.142813			velocity/area	1.49E-02	m^3/min	Dwyer flowmeter	
										mdotA/mdotF					vel/flow/area	6.26E-01	ft^3/min		
Notes:												0							
	1)The scale was very temperamental on the initial weighings. It would go to -.00005 instead of zero at the end									mdotBF1 CH4		#DIV/0!	Air Fuel by mass		mdot nzle	18.266	g/min		
	of weighings.									mdotBF1 Air		#DIV/0!			mdot/area	17.630	g/min	mdot/area(1):H20(sec)	
	*)Large shape wood chunks in the presepartor.									pH					vel/flow/area	0.929	m^3/min	mdot/area/dens@ imp inlet	
	*)0 orifice plate has particles									mdotA/mdotF		#DIV/0!			vel/flow/area	1.018	m^3/min		
	*)0 stage - very loose. Large particles, some fall into the subsequent during removal, so I shook them back on by stage														vel/vel	588.238	m/min	Sample probe inlet	
	*)Stage 0 through 2 have some large particles. Stage 3 is very loose. Stage 4 looks pretty normal														vel/vel	21.229	ft/sec		
	*)This ten minute run looked pretty light weight. This also is hard not burning out.																		
															mdot ash	9.04E-04	g/min	mdot ash to impactor	
	*)Stage change on stage 0 is pretty large - lost some particles during transfer to scale.									actual ash:		0.03038	g		entrained ash	9.04E-03	g	total ash presented to impactor	
															volume ratio	0.033	vol in/vol out	gas vol collected/ total in duct	
															velocity ratio	6.669	Vnlet/Vduct	Vel. at probe inlet/Vel. in duct	
															%ash ash	70.258	%	based on actual	

Table E.12: Test 11079501

Date:	11/7/95	mo/day/yr	Main NG:	60.5	%		Probe clnt T:	170	F										
Coal:	Fuel 4	source	Main Air:	35.0	%		Prbe clnt flw:	97	mm										
	Double Sieved	process		43.0	psig		Comb prg p:		psig										
test no:	11079501	m/d/ynum	BF1NG:	45.0	%		Coal feed	350	units	Imp init diam	9/16	inches		MAIN BURNER					
test dur:	10.00	minutes	BF1Air:	4.0	units,front		Coal feed conv	5.22	g/m	Mainduct rad	4	inches							
Coal Properties: (Rel. only)				4.0	units, back		Vacuum Rate:	33.0	%	Main Gas Rate	0.605	fraction		mdot CH4	17.035	g/min			
			BF2NG:	0.0	%		Vacuum Rate:	3.0	in hg	Main Air Rate	0.35	fraction		mdot Main Air	466.845	g/min			
grams	atomwt/100g	Ult. Ana.	BF2Air:	0.0	units,front		atomizer air:		units	Main Air Rate	43	psig		phi	1.597	Air/ Fuel by mass			
46.752	3.90	Carbon		0.0	units, back		atomizer air:		psig	Inj Air Rate	40	%		mdotA/mdotF	27.405	g/g			
5.664	5.66	Hydrogen	Inj. Rate:	40	%		atomizer H2O	113	mm	Inj Air Rate	48	psig		CO2	1.065	moles/min	CH4&Air only		
41.184	2.57	Oxygen	Inj. Rate:	48	psig		exit duct T:	90	F					H20	2.129	moles/min	CH4&Air only		
0.4128	0.03	Nitrogen					over furn T:	100	F	Fuel comp on Elemental level				N2	12.787	moles/min	CH4&Air only		
0	0.00	Sulfur	Imp in temp:	288	C (est)		entr bypass	107	"scfm"	Carbon (monatomic)	3.90E-02	moles/g		O2	1.271	moles/min	CH4&Air only		
2.0352	2.04	Ash	Imp temp based on:		09079501		inj exit T		F	Hydrogen (monatomic)	5.66E-02	moles/g		mdot air inj	45.862	g/min			
4	0.22	Moisture	Imp x temp	50	C (est)					Oxygen (monatomic)	2.57E-02	moles/g		O2	0.334	moles/min	inj Air only		
100.048		Total	sp. gr. ash	2.7	units (est)					Nitrogen (monatomic)	2.95E-04	moles/g		N2	1.257	moles/min	inj Air only		
										Sulfur (monatomic)	0.00E+00	moles/g		Dry O2 w/inj	9.606	vol%	total w/o solid fuel		
										Ash	2.04E-02	g ash/g fuel		DryO2w/o inj	8.406	vol%	total w/o solid fuel and inj		
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % ft. size mpe	D50 calc.	Size Range micrometers (default)	T/C Port	Temp, C	H2O	2.22E-03	moles/g							
										mdot solid fuel	5.22	g/min		CO2	1.268	moles/min	total		
Preseperator	0.32132	0.37495	0.05363	84.83	15.17	10.00	10.0 & up	B		Sample probe inlet Temp	938	degC		H20	2.280	moles/min	total		
0	0.29323	0.29670	0.00347	5.49	9.68	8.36	9.0 - 10.0	C		Impactor Inlet T	288	degC (est. T)		N2	14.044	moles/min	total		
1	0.29409	0.29493	0.00084	1.33	8.35	5.36	5.8 - 9.0	D		Impactor Exit T				SO2	0.000	moles/min	total		
2	0.31771	0.31819	0.00048	0.76	7.59	3.97	4.7 - 5.8	E		Vacuum Rate	3	in Hg		O2	1.395	moles/min	total		
3	0.31999	0.32035	0.00036	0.57	7.02	2.55	3.3 - 4.7	F		Vacuum Rate T	23	degC (est. T)		Dry O2	9.352	vol%	total		
4	0.32395	0.32437	0.00042	0.66	6.35	1.65	2.1 - 3.3	G		Vacuum Rate	33	CFH		H20 wt	0.077	mass fraction			
5	0.32169	0.32185	0.00016	0.25	6.10	0.85	1.1 - 2.1	H		coal flow time	10	min							
6	0.32549	0.32555	0.00006	0.09	6.01	0.54	0.7 - 1.1	I	938					mol wt wet	28.157	g/mol			
7	0.32400	0.32407	0.00007	0.11	5.90	0.39	0.4 - 0.7	J						dens @ inlet	293.355	g/m^3	Sample probe inlet		
Backup Filter	0.33133	0.33506	0.00373	5.90	0.00	0.19	0 -0.4	K						mdot duct	534.876	g/min	Ash flow neglected		
														vduct	58.209	meters/min	u=mdot/(rho*A)		
		total mass:	0.06322							BACKFIRE BURNERS				vduct	3.183	ft/sec			
														dens @ imp init	611.663	g/m^3	rho=P/(R*T)		
										mdotBF1 CH4	18.787707								
										mdotBF1 Air	528.17795			mol wt dry	29.548	g/mol			
										phi	1.640	Air Fuel by mass		dens @ rota	1094.656	g/m^3	rho=P/(R*T)		
										mdotA/mdotF	28.142913			volflwrateroto	1.49E-02	m^3/min	Dwyer flowmeter		
														volflwrateroto	5.25E-01	ft^3/min			
										mdotBF1 CH4	0								
										mdotBF1 Air	0			mdotroto	16.289	g/min			
										phi	#DIV/0!	Air Fuel by mass		mdotimp	17.627	g/min	mdotroto/(1-H20frac)		
										mdotA/mdotF	#DIV/0!			volflwimp	0.029	m^3/min	mdotimp/dens @ imp inlet		
														volflwimp	1.018	ft^3/min			
														vinlet	388.002	m/min	Sample probe inlet		
														vinlet	21.219	ft/sec			
														mdot ash	3.50E-03	g/min	mdot ash to impactor		
										actual ash:	0.063217	g		expected ash	3.50E-02	g	total ash expected in impactor		
														volume ratio	0.033	vol in/vol tot	gas vol collected/ total in duct		
														velocity ratio	0.666	Vinlet/Vduct	Vel. at probe inlet/Vel. in duct		
														%Diff ash	44.619	%	based on actual		

Notes:

*)Some ash was left in the petri dish of stages 0 and 1. Mostly light, porous (feathery) structures, but some large char particles in stage 0

*)A mixture of large unburned particles and white ash is in the preseperator. Predominately large particles by weight

*)Stage 0 is very overloaded - some fell off during transfer.

*) Stage 1 orifice plate has overload from 0 stage in it.

*)Stage 1 is overloaded with mostly ash colored

*)Stage 2 is overloaded., but mostly burned out. About 30 particles are obviously too big to be on the stage

*) Stage 3 looks good, except for one large particle

*) The overflow in the preseperator, 0, 1 has a low dunsity component that is feathery and white/gray. Some escaped in the air during transfer to the petri dish.

Table E.13: Test 11229501

Date:	11/22/95	mo/day/yr	Main NG:	60.6	%		Probe ctrl T:		F								
Coal:	Fuel 4	source	Main Air:	35.0	%		Prbe ctrl flw:		mm								
	Double Filter	process		43.0	psig*		Comb prg p:		psig								
test no:	11229501	m/d/ymum	BF1NG:	45.0	%*		Coal feed	350	units	Imp Init diam	9/16	inches		MAIN BURNER			
test dur:	10.00	minutes	BF1Air:	4.0	units,front *		Coal feed conv	5.22	g/m	Meinduct rad	4	inches					
Coal Properties:	(Rel. only)			4.0	units, back*		Vacuum Roto:	35.0	%	Main Gas Roto	0.605	fraction		mdot CH4	17.035	g/min	
			BF2NG:		%		Vacuum Roto:	3.5	in hg	Main Air Roto	0.35	fraction		mdot Main Air	466.845	g/min	
grams	atomw/100g	Ult. Ana.	BF2Air:		units,front		atomizer air		units	Main Air Roto	43.0	psig		phi	1.597	Air/ Fuel by mass	
46.752	3.90	Carbon			units, back		atomizer air		psig	Inj. Air Roto	40	%		mdotA/mdotF	27.405	g/g	
5.664	5.66	Hydrogen	Inj. Roto:	40	%*		atomizer air		mm	Inj Air Roto	48	psig		CO2	1.085	moles/min	CH4&Air only
41.184	2.57	Oxygen	Inj. Roto:	48	psig*		atomizer H2O		mm					H2O	2.129	moles/min	CH4&Air only
0.4128	0.03	Nitrogen					exit duct T:		F					N2	12.787	moles/min	CH4&Air only
0	0.00	Sulfur	Imp in temp:	288	C (est)		over furn T:		F	Fuel comp on Elemental level				O2	1.271	moles/min	CH4&Air only
2.0352	2.04	Ash	Imp temp based on:		09079501		entr bypass	0.17	*scfm*	Carbon (monatomic)	3.90E-02	moles/g		mdot air inj	45.982	g/min	
4	0.22	Moisture	Imp x temp	50	C (est)		inj exit T		F	Hydrogen (monatomic)	5.66E-02	moles/g		O2	0.334	moles/min	Inj Air only
100.048		Total	sp. gr. ash	2.7	units (est)					Oxygen (monatomic)	2.57E-02	moles/g		N2	1.267	moles/min	Inj Air only
										Nitrogen (monatomic)	2.95E-04	moles/g		Dry O2 w/inj	9.606	vol%	total w/o solid fuel
										Sulfur (monatomic)	0.00E+00	moles/g		DryO2w/o inj	8.406	vol%	total w/o solid fuel and inj
										Ash	2.04E-02	g ash/g fuel					
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % & size rnge	D50 calc.	Size Range micrometers (default)	T/C Port	Temp, C	H2O	2.22E-03	moles/g		CO2	1.248	moles/min	total
										mdot solid fuel	5.22	g/min		H2O	2.289	moles/min	total
Preseperator	0.31337	0.36548	0.05211	84.29	15.72	10.00	10.0 & up	B		Sample probe inlet Temp	938	degC		N2	14.044	moles/min	total
0	0.29402	0.29687	0.00285	4.61	11.11	8.23	9.0 - 10.0	C		Impactor Inlet T	288	degC (est. T)		SO2	0.000	moles/min	total
1	0.29392	0.29495	0.00103	1.67	9.45	5.28	5.8 - 9.0	D		Impactor Exit T				O2	1.395	moles/min	total
2	0.32468	0.32558	0.00070	1.13	8.31	3.62	4.7 - 5.8	E		Vacuum Roto	3.5	in Hg		Dry O2	9.352	vol%	total
3	0.32144	0.32183	0.00039	0.63	7.68	2.51	3.3 - 4.7	F		Vacuum Roto T	23	degC (est. T)		H20 wt	0.077	mass fraction	
4	0.32328	0.32363	0.00035	0.57	7.12	1.63	2.1 - 3.3	G		Vacuum Roto	35	CFH					
5	0.32198	0.32215	0.00017	0.27	6.84	0.84	1.1 - 2.1	H		coal flow time	10	min		mol wt wet	28.157	g/mol	
6	0.32573	0.32579	0.00006	0.10	6.74	0.53	0.7 - 1.1	I	938					dens@inlet	283.356	g/m^3	Sample probe inlet
7	0.32528	0.32534	0.00006	0.10	6.65	0.38	0.4 - 0.7	J						mdot duct	534.979	g/min	Ash flow neglected
Backup Filter	0.33299	0.33710	0.00411	6.65	0.00	0.10	0 -0.4	K						vduct	98.208	meter/min	u=mdot/(rho*A)
										BACKFIRE BURNERS				vduct	3.183	ft/sec	
		total mass:	0.06183											dens@imp inl	911.663	g/m^3	rho=P/(R*T)
										mdotBF1 CH4	18.787707						
										mdotBF1 Air	529.17795			mol wt dry	29.648	g/mol	
										phi	1.640	Air/ Fuel by mass		dens@roto	1074.339	g/m^3	rho=P/(R*T)
										mdotA/mdotF	28.142915			volflwrateroto	1.56E-02	m^3/min	Dwyer flowmeter
														volflwrateroto	5.51E-01	ft^3/min	
Notes:	*) Stages 0, 1, and 2 overloaded, and with large particles (up to 1/16")									mdotBF1 CH4	0						
	*) Stage 3 has about 10 particles that are obviously too large. Otherwise, good plate.									mdotBF1 Air	0			mdotroto	18.777	g/min	
	*) Orange filter, stages 4 through 7 look very good.									phi	#DIV/0!	Air/ Fuel by mass		mdotimp	18.177	g/min	mdotroto(1-H20fract)
	*) Plenty of loose particle got loose in the box with static charge.									mdotA/mdotF	#DIV/0!			volflwimp	0.030	m^3/min	mdotimp/dens@imp inlet
	*) Settings with * were not recorded during the test. The furnace was at the standard weyerhaeuser													volflwimp	1.049	ft^3/min	
	settings, as indicated.													vinlet	400.114	m/min	Sample probe inlet
														vinlet	21.978	ft/sec	
														mdot ash	3.81E-03	g/min	mdot ash to impactor
										actual ash:	0.06183	g		expected ash	3.81E-02	g	total ash expected in impactor
														volume ratio	0.034	vol in/vol tot	gas vol collected/ total in duct
														velocity ratio	0.974	Vinlet/Vduct	Vel at probe inlet/Vel. in duct
														%Diff ash	41.610	%	based on actual

APPENDIX F: MILLED SAWDUST/SANDERDUST ELECTRICAL AEROSOL ANALYZER TEST SUMMARIES

The spreadsheets that follow summarize the detailed measurements and calculations required to determine the size distribution in the sub-micron range of ash for four pulverized wood fuels. These experiments were conducted with a natural-gas fired furnace. Ash samples were collected with an isokinetic, water-cooled, sampling probe. Particulate matter approximately 0.4 μm and larger were removed with a Mark II cascade impactor, and the remaining aerosol size distribution was determined with an Electrical Aerosol Analyzer (EAA). Coagulation time at ambient conditions for the aerosol was controlled by the size of delay tank between the cascade impactor and the EAA. EAA data was collected electronically, and is presented in graphical form in the body of the dissertation. Furnace operating conditions, sampling conditions and test notes are summarized here.

Table F.1: Test Log for Milled Sawdust/sanderdust Experiments

Master Set#	Test Number	Fuel	Fuel no.	Spread sheet shared with?	1=calc 2= EAA 3=Temp 4=pmkl	4=Pad 1=Steel Bung 2=Pedgless 3=No	600 Tank	400 Tank	200	100	50	10	Wood Flow Rate	Main NO, g/min	Main air, g/min	Total flow, incl entrainment air, no fuel	Main air, incl entrainment air, g/min	A/F, incl entrainment air, no fuel	Upper Aux A/F equiv	Upper Aux air, g/m	Upper Aux NO, g/m	Dry O2, no fuel, by vol	Dry O2 w/fuel, % vol	Dry O2, no fuel, by vol	Sample Inlet Temp. (est.)
1	09012900		0.00		0	4							0.00	17.6	466.8	506.6	22.1	27.0	1.23	106.3	6.0	9.6		9.6	0.0
2	09060901	Fuel 1		1	0	4							0.00	17.6	466.8	528.9	22.1	28.0	1.20	103.2	6.0	9.1		9.1	0.0
3	09129901		0.00		0	4			2.6				0.00	17.7	466.8	528.1	43.5	28.0	1.20	103.2	6.0	9.0		9.0	0.0
4	09149901	Fuel 1		1	0	4			2.6				0.00	17.7	466.8	528.1	43.5	28.0	1.97	169.1	6.0	9.1		9.1	0.0
5	09039901	Fuel 1		1	0	4		4.6					0.00	17.7	466.8	545.7	90.2	29.5	2.16	185.9	4.6	9.4		9.4	600.0
6	09069901	Fuel 1		1	0	4		4.6					0.00	17.7	466.8	544.9	90.2	29.5	1.97	169.6	6.0	9.3		9.3	0.0
7	10089901	Fuel 1		1	0	4	4						4.64	17.7	484.1	545.5	63.6	29.8	2.03	174.4	6.0	9.5		9.5	787.8
8	10149901	Fuel 1		1	0	4	4						4.64	18.1	488.8	547.1	63.6	29.8	2.03	174.5	6.0	9.3		9.3	787.8
9	10179901	Temperature			3								0.00	18.3	484.1	544.6	63.1	29.8	2.00	172.1	6.0	9.2		9.2	787.8
10	10179902	Fuel 1		1	0	4	4						4.64	18.3	484.1	544.6	63.1	29.8	2.00	172.1	6.0	9.0		9.0	787.8
11	10219901	Fuel 1		1	0	4	4						4.64	18.3	484.1	544.6	63.1	29.8	2.00	172.1	6.0	9.0		9.0	787.8
12	10229901	Fuel 4		4	0	4	4	4.6					4.64	18.3	484.1	544.6	63.1	29.8	2.00	172.1	6.0	9.0		9.0	787.8
13	10249901	Fuel 4		4	0	4	4	3.4					3.41	18.3	484.1	544.6	63.1	29.8	2.01	173.0	6.0	9.0		9.0	787.8
14	10269901				1924901	4	4							18.3	484.1	544.6	63.1	29.8	2.01	173.0	6.0	9.0		9.0	787.8
15	10319901				1924901	4	4							18.3	484.1	544.6	63.1	29.8	2.01	173.0	6.0	9.0		9.0	787.8
16	11019901				1924901	4	4							18.3	484.1	544.6	63.1	29.8	2.01	173.0	6.0	9.0		9.0	787.8
17	11069901				1924901	4	4							18.3	484.1	544.6	63.1	29.8	2.01	173.0	6.0	9.0		9.0	787.8
18	11079901	Fuel 1		1	0	4	4						4.64	18.3	484.1	544.6	63.1	29.8	2.01	173.0	6.0	9.0		9.0	787.8
19	11079902	Fuel 1		1	0	4	4	4.6	2.6	1.7	1.1	0.7	0.00	18.3	484.8	543.0	58.9	28.7	2.03	174.1	6.0	9.0		9.0	787.8
20	11079903	Fuel 1		1	1107901	2	2	4.6	2.6	1.7	1.1	0.7	0.00	18.3	484.8	544.0	58.9	28.7	2.03	174.5	6.0	9.0		9.0	787.8
21	11129901	Fuel 1		1	1107901	2	3	4.6	2.6	1.7	1.1	0.7	0.00	18.3	484.8	544.0	58.9	28.7	2.03	174.5	6.0	9.0		9.0	787.8
22	11129902	Fuel 4		4	0	1	1	3.4	2.0	1.3	0.9	0.6	3.41	18.3	484.8	544.0	58.9	28.7	2.03	174.5	6.0	9.0		9.0	787.8
23	11139901	Fuel 4		4	1139901	2	2	3.4	2.0	1.3	0.9	0.6	3.41	18.3	484.8	544.0	58.9	28.7	2.03	174.5	6.0	9.0		9.0	787.8
24	11139903	Fuel 4		4	1139901	2	3	3.4	2.0	1.3			3.41	18.3	484.8	544.0	58.9	28.7	2.03	174.5	6.0	9.0		9.0	787.8
25	11149901	Fuel 2		2	0	1	1	3.8					3.77	18.3	484.8	544.0	58.9	28.9	1.93	166.0	6.0	9.1		9.1	787.8
26	11149902	Fuel 2		2	0	1	1	3.8					3.77	18.2	484.8	544.7	59.0	29.1	1.97	169.2	6.0	9.3		9.3	787.8
27	11159901	Fuel 2		2	0	1	1	3.8	2.2	1.4	0.9	0.6	0.00	18.2	484.8	544.1	59.0	29.2	1.93	166.0	6.0	9.2		9.2	787.8
28	11159902	Fuel 2		2	1159901	2	2	3.8	2.2	1.4	0.9	0.6	0.00	18.2	484.8	544.1	59.0	29.2	1.93	166.0	6.0	9.2		9.2	787.8
29	11159903	Fuel 2		2	1159901	2	3	3.8	2.2	1.4	0.9	0.6	0.00	18.2	484.8	544.1	59.0	29.2	1.93	166.0	6.0	9.2		9.2	787.8
30	11169901	Fuel 3		3	0	1	1	4.4					4.42	18.2	484.8	545.9	63.6	29.1	1.97	169.2	6.0	9.2		9.2	787.8
31	11169902	Fuel 3		3	0	1	1	4.4					4.42	18.2	484.8	545.9	63.6	29.1	1.97	169.2	6.0	9.2		9.2	787.8
32	11179901	Fuel 3		3	0	2	1	4.4		1.7	1.1	0.7	0.00	18.2	484.8	545.9	63.6	29.1	1.97	169.2	6.0	9.2		9.2	787.8
33	11179902	Fuel 3		3	1117901	2	2	4.4	2.7	1.7	1.1	0.7	0.00	18.2	484.8	545.9	63.6	29.1	1.97	169.2	6.0	9.2		9.2	787.8
34	11179903	Fuel 3		3	1117901	2	3	4.4	2.7	1.7	1.1	0.7	0.00	18.2	484.8	545.9	63.6	29.1	1.97	169.2	6.0	9.2		9.2	787.8
	Averages of all Non-preliminary tests													18.2	545.8			29.9	2.0	170.2	5.9	9.1			
35	11209901	Temperature			0	3							0.00	9.2	231.4	306.3	64.7	32.4	2.07	170.9	4.6	10.4		10.4	0.0
36	11219901	Fuel 1		1	0	1		4.6					4.64	9.1	230.1	303.1	64.0	32.2	1.98	167.0	4.6	10.4		10.4	600.0
37	11219902	Fuel 1		1	0	1		4.6					4.64	9.2	230.1	302.9	63.6	31.9	2.00	171.5	6.0	10.3		10.3	600.0
38	11219903	Fuel 1		1	0	2	1	4.6	2.6	1.7	1.1	0.7	0.00	9.2	230.1	302.3	63.1	32.0	1.97	169.2	6.0	10.3		10.3	600.0
39	11219904	Fuel 1		1	1121903	2	2	4.6	2.6	1.7	1.1	0.7	0.00	9.2	230.1	302.3	63.1	32.0	1.97	169.2	6.0	10.3		10.3	600.0
40	11219905	Fuel 1		1	1121903	2	3	4.6	2.6	1.7	1.1	0.7	0.00	9.2	230.1	302.3	63.1	32.0	1.97	169.2	6.0	10.3		10.3	600.0
41	11219906	Blank			0	1							0.00	9.2	230.1	302.8	63.6	32.0	1.95	167.7	6.0	10.3		10.3	600.0
42	11229901	Fuel 3		3	0	1	1	4.4					4.42	9.2	230.1	302.8	63.6	32.1	1.99	171.0	6.0	10.4		10.4	600.0
43	11229902	Fuel 3		3	0	1	1	4.4					4.42	9.2	230.1	302.7	63.6	32.1	1.96	167.7	6.0	10.5		10.5	600.0
44	11229903	Fuel 4		4	0	1	1	3.4					3.41	9.2	235.4	302.9	63.1	31.9	1.96	170.7	5.9	10.3		10.3	600.0
45	11239901	Fuel 4		4	0	1	1	3.4					3.41	9.2	231.4	302.9	63.1	32.3	1.98	168.5	6.0	10.5		10.5	600.0
46	11239902	Fuel 2		2	0	1	1	3.8					3.77	9.1	231.0	303.5	63.1	32.4	1.94	167.0	6.0	10.5		10.5	600.0
47	11239903	Fuel 2		2	0	1	1	3.8					3.77	9.0	230.6	303.3	63.6	32.7	1.97	169.2	6.0	10.6		10.6	600.0
	Averages of all Non-preliminary tests													9.1	230.8			32.2	2.0	169.0	6.0	10.3			
48	11259901	Temperature			0	3							0.00	9.3	228.4	304.9	63.1	31.6	1.31	169.5	7.6	10.2		10.2	0.0
49	11259902	Fuel 1		1	0	1	1	4.6					4.64	9.1	233.7	307.1	63.9	31.2	1.31	173.0	7.7	9.8		9.8	600.0
50	11279901	Fuel 1		1	0	1	1	4.6					4.64	9.0	232.7	306.3	63.0	30.8	1.29	170.7	7.7	9.9		9.9	600.0
51	11279902	Fuel 4		4	0	1	1	3.4					3.41	9.0	234.0	306.9	64.3	31.0	1.31	170.7	7.6	10.0		10.0	600.0
52	11219903	Fuel 4		4	0	1	1	3.4					3.41	9.2	232.8	306.8	61.3	30.7	1.33	170.7	7.6	9.8		9.8	600.0
	Averages of all Non-preliminary tests													9.0	233.0		63.1	31.1	1.3	170.7	7.6	10.0			

Table F.2: Test 0819601

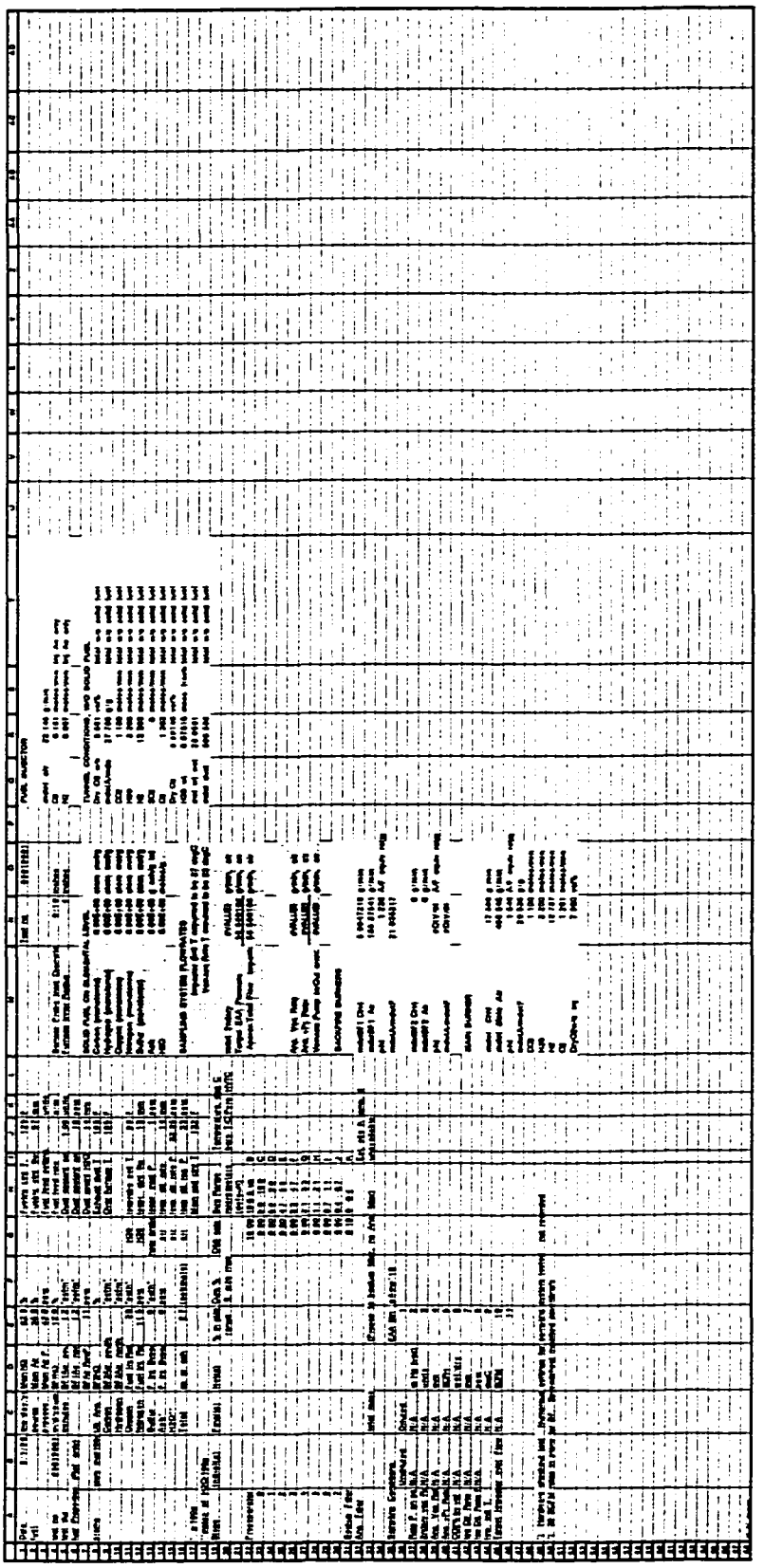


Table F.3: Test 08069601

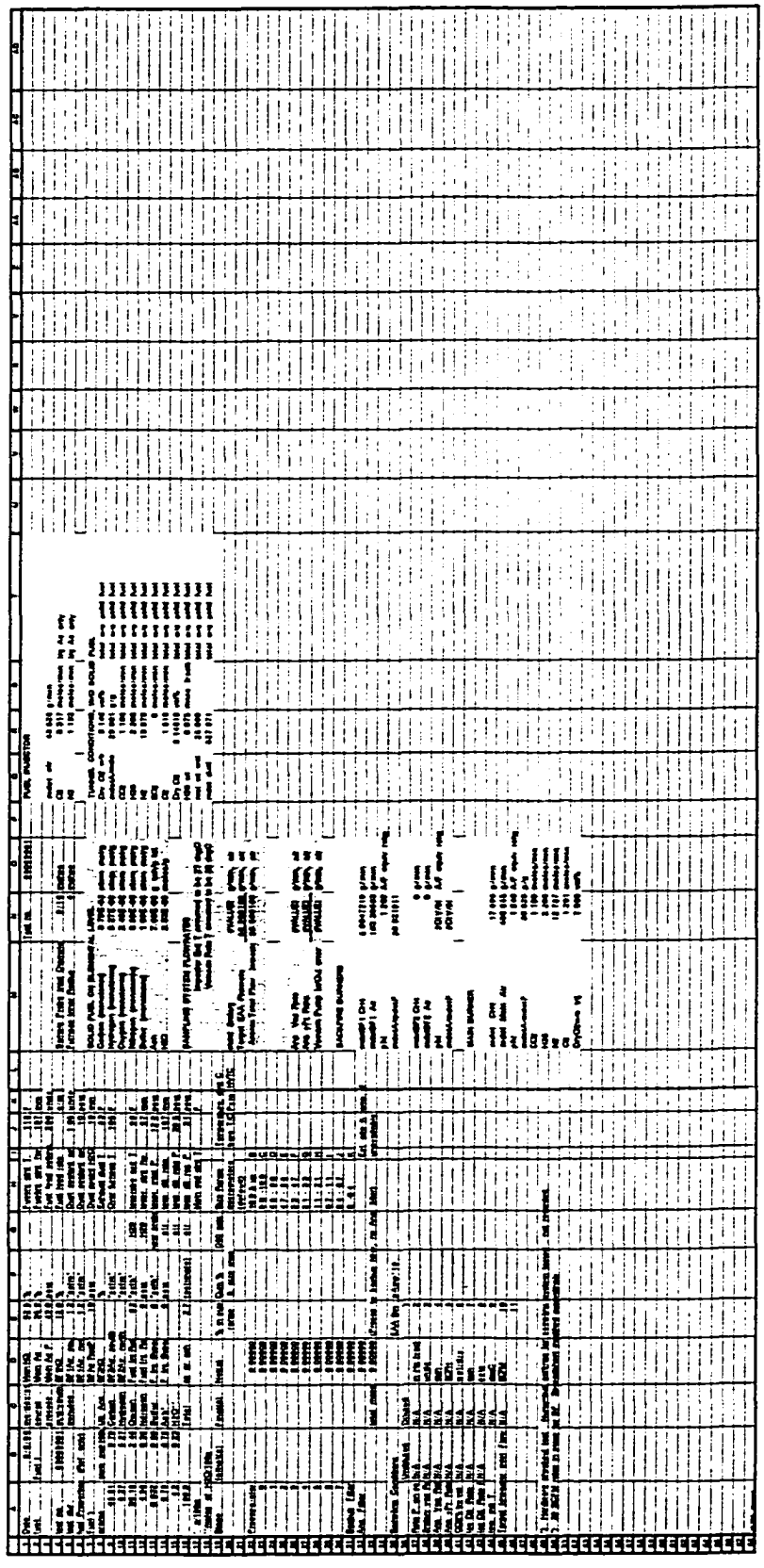


Table F.4: Test 08129601

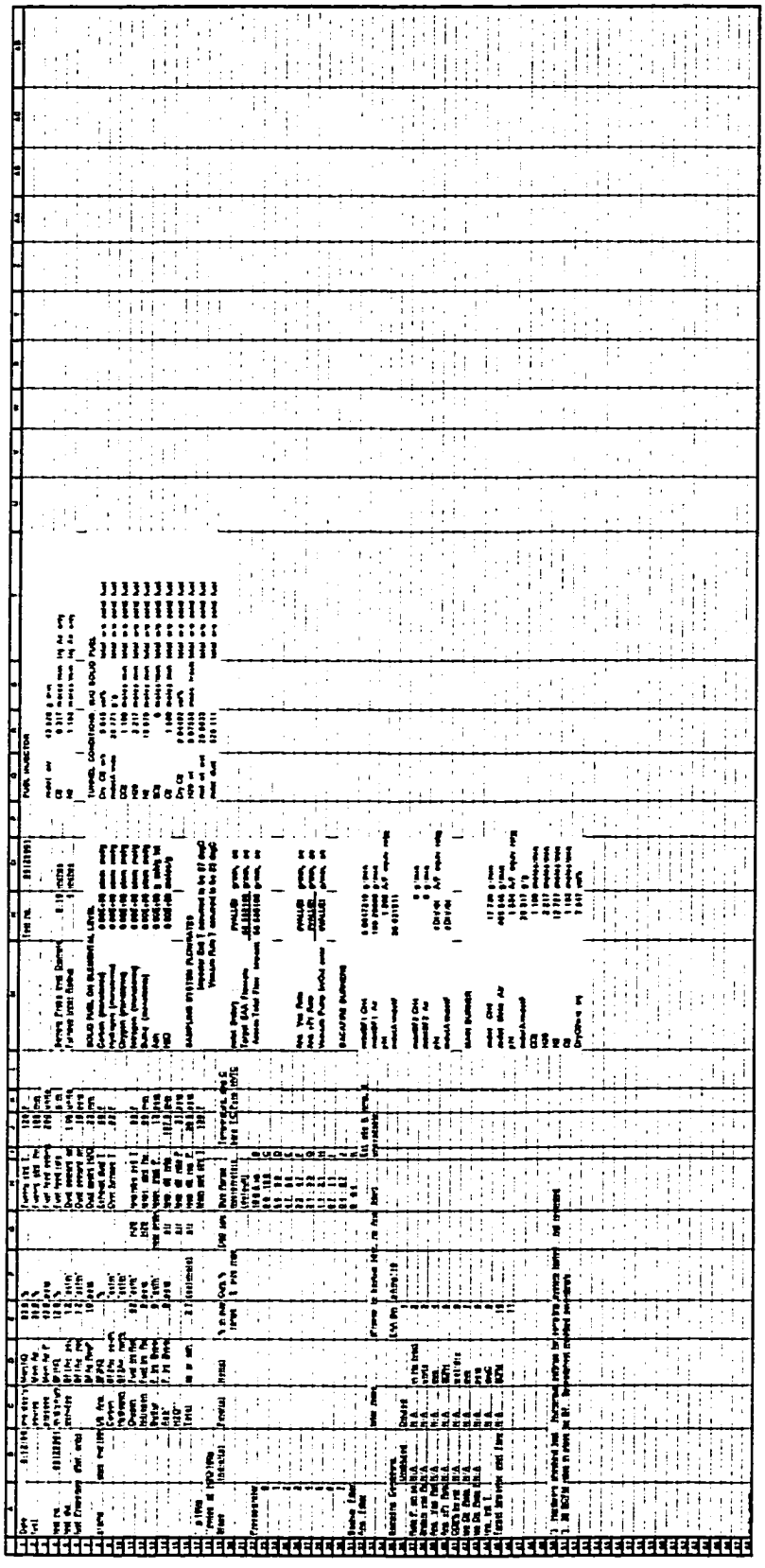


Table F.5: Test 08149601

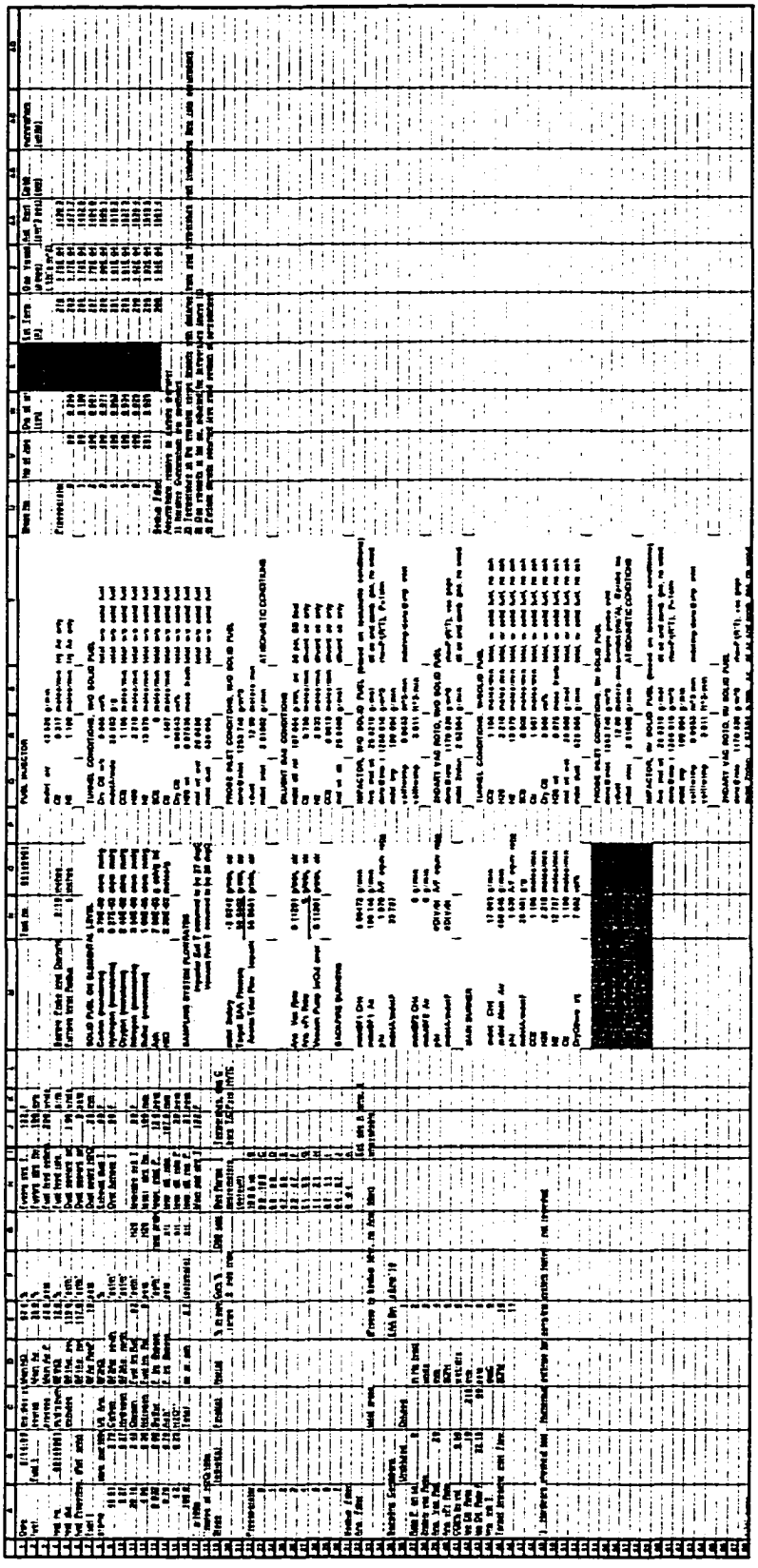


Table F.6: Test 09039601

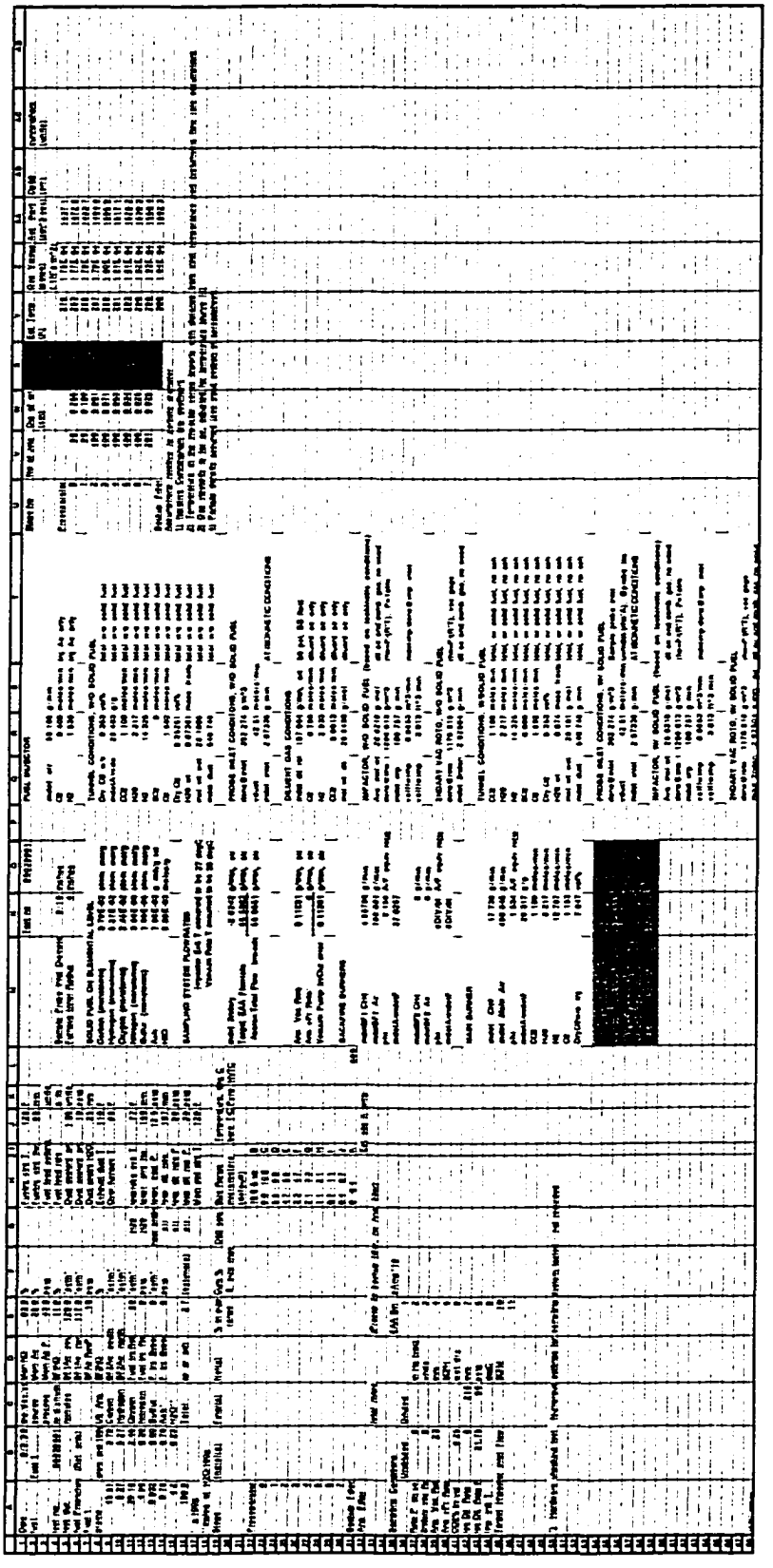


Table F.7: Test 09099601

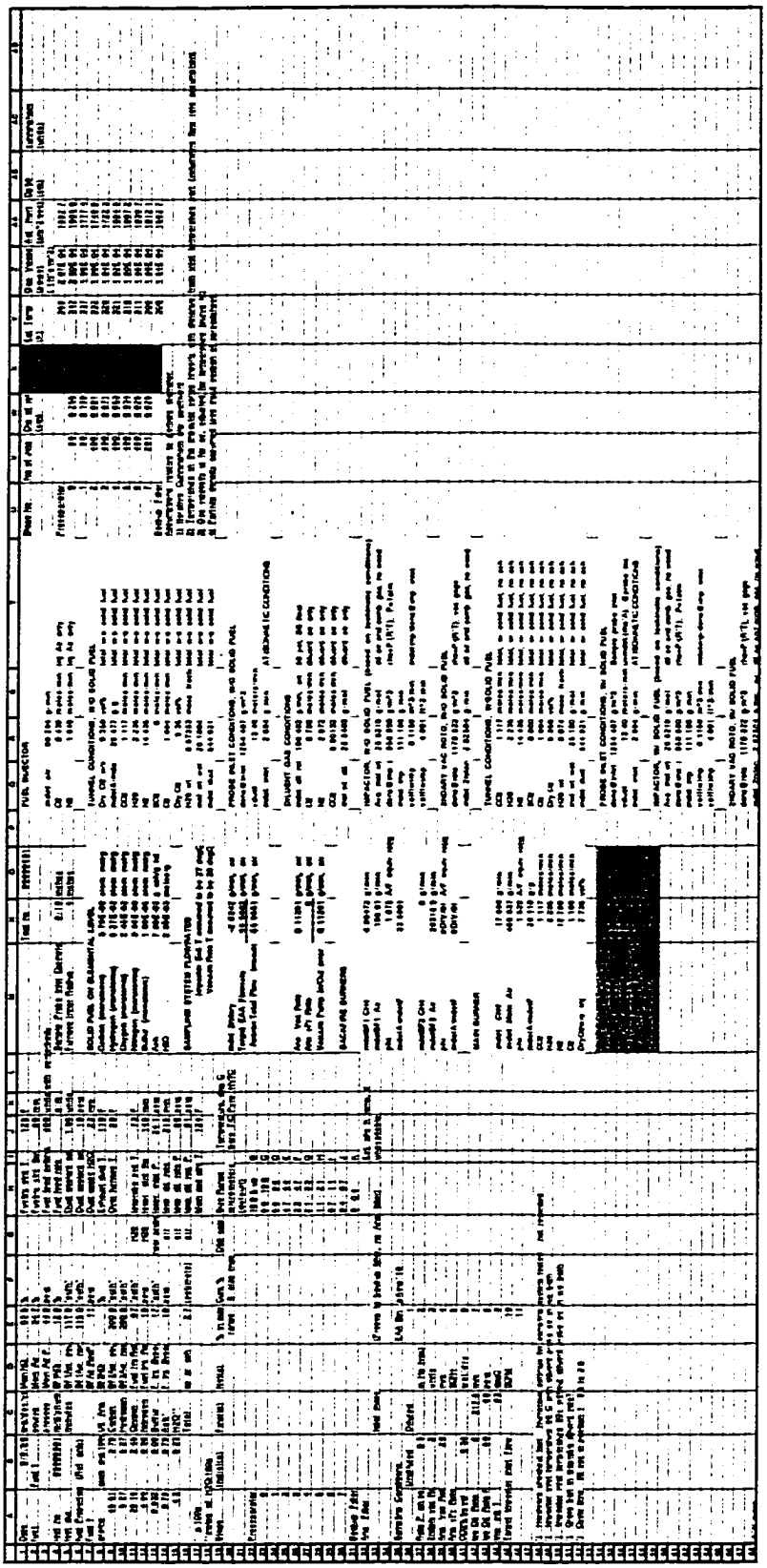


Table F.8: Test 10089601

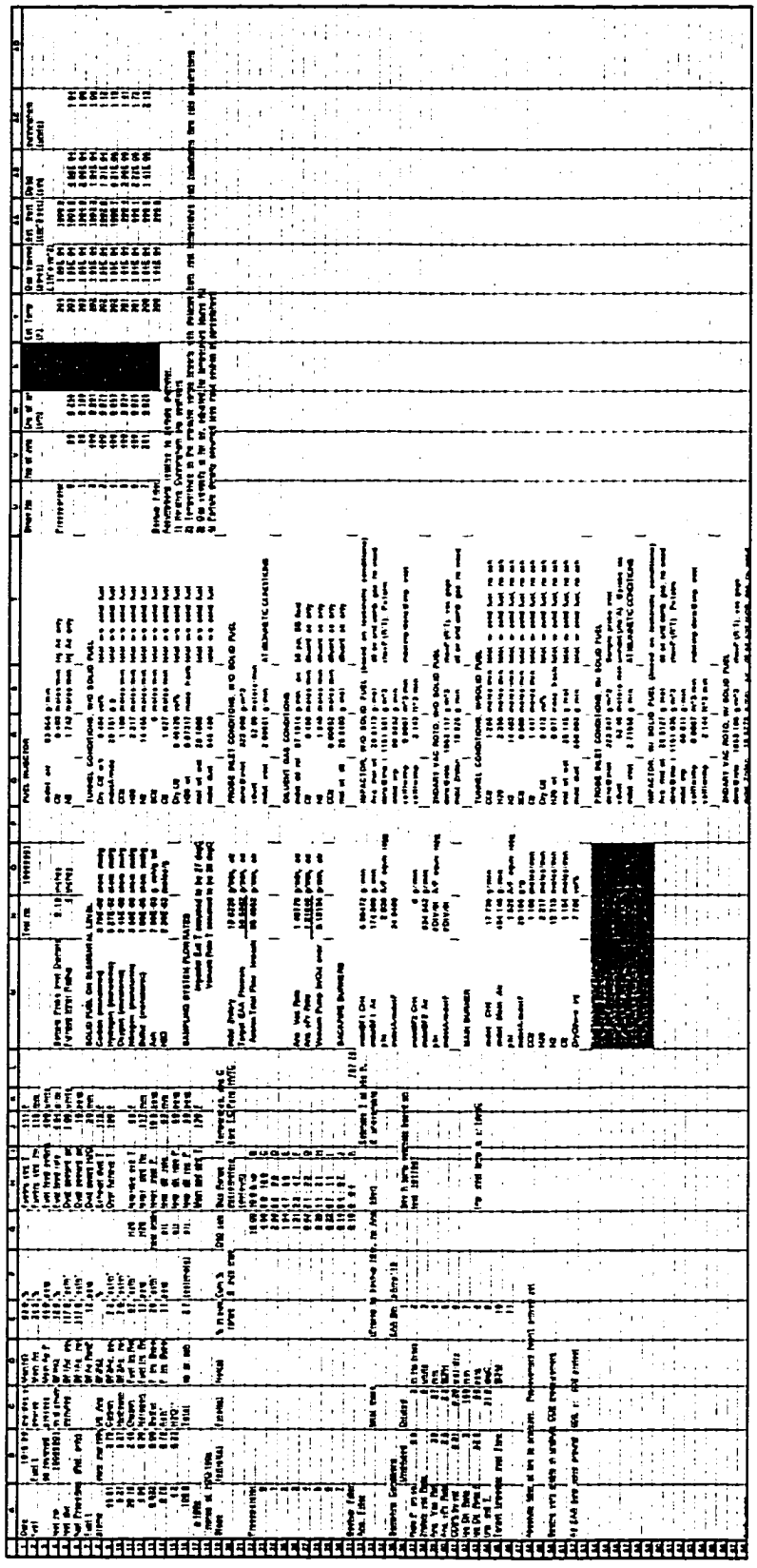


Table F.9: Test 10149601

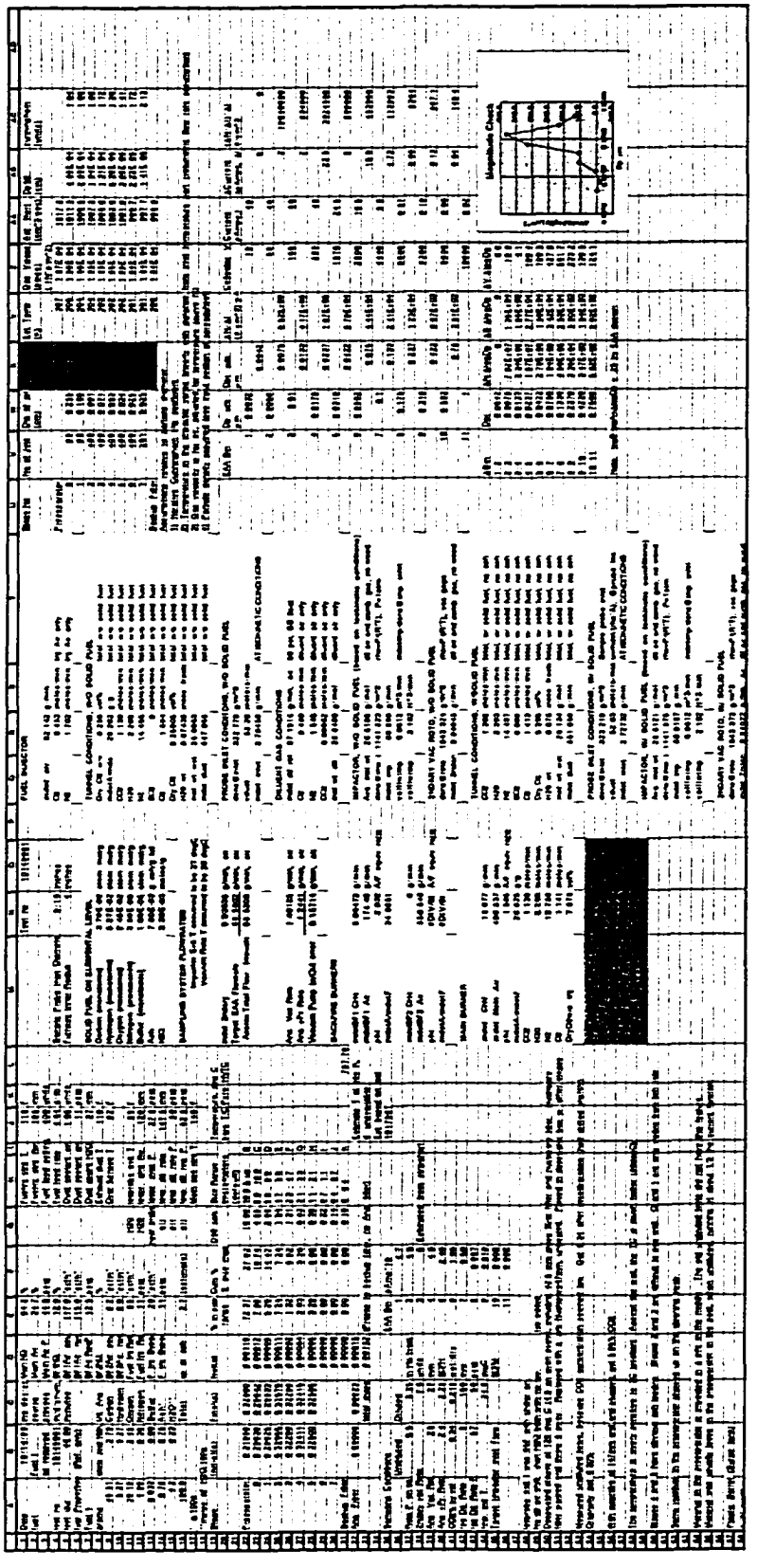


Table F.10: Test 101796T

	A	B	C	D	E	F	G	H	I	J	K	L
1	Date:	10/17/96	mo/day/yr	Main NG:	85.0	%		Fuelinj cint T:		118	F	
2	fuel:	Temperature	source	Main Air:	94.5	%		Fuelinj cint thk:		98	mm	
3			process	Main Air P:	44.0	psig		Fuel feed settings:			units	
4	test no:	101796T	m/d/yr/num	BF1NG:	12.0	%		Fuel feed rate:			g/m	
5	test dur:		minutes	BF1Air: apx	117.0	"scfh"		Duct coolant air		1.00	units	
6	fuel Properties: (Rel. only)			BF1Air: no	114.0	"scfh"		Duct coolant air		11	psig	
7	fuel name here - copy data		rem pg 4>	BFAir RegP	12	psig		Duct coolnt H2O		38	mm	
8	grams	atom mol/100g	UB, Ana.	BF2NG:		%		Exhaust duct T:		108	F	
9			Carbon	BF2Air: apx	9.2	"scfm"		Over furnace T:		89	F	
10			Hydrogen	BF2Air: no	6.0	"scfm"						
11			Oxygen	Fuel Inj Reg	85	"scfh"	H20	Isoprobe ext T:		93	F	
12			Nitrogen	Fuel Inj Rg	11	psig	H20	Isopr. cint thk:		116	mm	
13			Sulfur	F. Inj. Bypa	20	"scfh"	near probe	Isopr. inlet P:		2	psig	
14			Ash*	F. Inj. Bypa	11	psig	air	Isop. dil. rate:		4	mm	
15			H2O**				air	Isop. dil. rate P		58	psig	
16			Total	sp. gr. ash	2.7	(estimate)	air	Isop. dil. reg. P:		68	psig	
17	* g/100g							Main sset cint T:		128	F	
18	**moles of H2O/100g											
19	Stage	(initial(g)	Final(g)	Net(g)	% in size range	Cum % fr. size indx	D50 calc.	Size Range micrometers (default)		Temperature, deg C bare T/C	Pyro	HVTC
20												
21												
22	Presseparator			0.00000				10.0 & up	G			
23	0			0.00000				8.0 - 10.0	C			
24	1			0.00000				5.8 - 8.0	D			
25	2			0.00000				4.7 - 5.8	E			
26	3			0.00000				3.3 - 4.7	F			
27	4			0.00000				2.1 - 3.3	G			
28	5			0.00000				1.1 - 2.1	H			
29	6			0.00000				0.7 - 1.1	I			
30	7			0.00000				0.4 - 0.7	J			
31	Backup Filter			0.00000				0 - 0.4	K			
32	Ana. Filter			0.00000						Est. ave K temp.		
33			total mass	0.00000	(Presep to backup filter, no Ana filter)					unavailable		
34												
35	Sampling Conditions:				EAA Bin	pAmp*10						
36		Undiluted	Diluted		1							
37	Rota P. on sett:			in Hg (vac)	2							
38	2ndary vac Rota:			units	3							
39	Ana. Vac. Rota:			mm	4							
40	Ana. +Pr. Rota:			SCFH	5							
41	CO2% by vol			wet/dry	6							
42	Iso Dil. Rota:			mm	7							
43	Iso Dil. Rota P:			psig	8							
44	Imp. Inlt T:			deaC	9							
45	Target Impactor Inlet Flow:			SCFM	10							
46					11							

	M	N	O
		Test no:	101796T
	Sample Probe Inlet Diamete	9/16	inches
	Furnace Inner Radius	4	inches
	SOLID FUEL ON ELEMENTAL LEVEL		
	Carbon (monatomic)	0.00E+00	atom mol/g
	Hydrogen (monatomic)	0.00E+00	atom mol/g
	Oxygen (monatomic)	0.00E+00	atom mol/g
	Nitrogen (monatomic)	0.00E+00	atom mol/g
	Sulfur (monatomic)	0.00E+00	atom mol/g
	Ash	0.00E+00	g ash/g tot
	H2O	0.00E+00	moles/g
	SAMPLING SYSTEM FLOWRATES		
	Impactor Exit T assumed to be 27 degC		
	Vacuum Rota T assumed to be 23 degC		
	mdot 2ndary	-2.6242	g/min, air
	Target EAA Flowrate	58.5802	g/min, air
	Approx.Total Flow Impactc	55.9356	g/min, air
	Ana. Vac. Rota	0.11291	g/min, air
	Ana. +Pr. Rota:	0	g/min, air
	Vacuum Pump In/Out error:	0.11291	g/min, air
	BACKFIRE BURNERS		
	mdotBF1 CH4	5.00472	g/min
	mdotBF1 Air	172.134	g/min
	phi	2.004	A/F equiv ratio
	mdotA/mdotF	34.3842	
	mdotBF2 CH4	0	g/min
	mdotBF2 Air	545.462	g/min
	phi	#DIV/0!	A/F equiv ratio
	mdotA/mdotF	#DIV/0!	
	MAIN BURNER		
	mdot CH4	18.302	g/min
	mdot Main Air	464.148	g/min
	phi	1.478	A/F equiv ratio
	mdotA/mdotF	25.360	g/g
	CO2	1.144	moles/min
	H20	2.288	moles/min
	N2	12.713	moles/min
	O2	1.093	moles/min
	DryO2w/o Inj	7.313	vol%

	O	R	S	T
	FUEL INJECTOR			
	mdot air h	62.142	g/min	
	O2	0.453	moles/min	in) Air only
	N2	1.702	moles/min	in) Air only
	TUNNEL CONDITIONS, W/O SOLID FUEL			
	Dry O2 w/i	9.038	vol%	total w/o solid fuel
	mdotA/mdot	28.765	g/g	total w/o solid fuel
	CO2	1.144	moles/min	total w/o solid fuel
	H20	2.288	moles/min	total w/o solid fuel
	N2	14.415	moles/min	total w/o solid fuel
	SO2	0	moles/min	total w/o solid fuel
	O2	1.546	moles/min	total w/o solid fuel
	Dry O2	9.03797	vol%	total w/o solid fuel
	H20 wt	0.07562	mass fractn	total w/o solid fuel
	mol wt wet	28.0829		total w/o solid fuel
	mdot duct	544.590		total w/o solid fuel
	PROBE INLET CONDITONS, W/O SOLID FUEL			
	dens@inlet	1253.627	g/m^3	
	vduct	13.40	meters/min	
	mdot inlet	2.69237	g/min	AT ISOKINETIC CONDITIONS
	DILUENT GAS CONDITIONS			
	mdot dil rot	1.86202	g/min, air	50 psi, 55 flow
	O2	0.014	moles/min	diluent air only
	N2	0.054	moles/min	diluent air only
	CO2	2.4E-05	moles/min	diluent air only
	mol wt dil.	28.8403	g/mol	diluent air only
	IMPACTOR, W/O SOLID FUEL (based on isokinetic conditions)			
	Avg. mol wt	28.3873	g/mol	dil air and comb. gas, no wood
	dens@imp k	1267.661	g/m^3	rho=P/(R*T), P=1atm
	mdot imp	4.65439	g/min	
	volf/wimp	0.0037	m^3/min	mdotimp/dens@imp inlet
	volf/wimp	0.130	f^3/min	
	2NDARY VAC ROTO, W/O SOLID FUEL			
	dens@roto	1153.572	g/m^3	rho=P/(R*T), vac gage
	mdot 2ndar	-2.6446	g/min	dil air and comb. gas, no wood
	TUNNEL CONDITIONS, W/SOLID FUEL			
	CO2	1.144	moles/min	total, w/ solid fuel, no ash
	H20	2.288	moles/min	total, w/ solid fuel, no ash
	N2	14.415	moles/min	total, w/ solid fuel, no ash
	SO2	0.000	moles/min	total, w/ solid fuel, no ash
	O2	1.546	moles/min	total, w/ solid fuel, no ash
	Dry O2	9.038	vol%	total, w/ solid fuel, no ash
	H20 wt	0.076	mass fractn	total, w/ solid fuel, no ash
	mol wt wet	28.083	g/mol	total, w/ solid fuel, no ash
	mdot duct	544.590	g/min	total, w/ solid fuel, no ash
	PROBE INLET CONDITIONS, W/ SOLID FUEL			
	dens@inlet	1253.627	g/m^3	Sample probe inlet
	vduct	13.40	meters/min	u=mdot/(rho*A), @probe loc.
	mdot inlet	2.69237	g/min	AT ISOKINETIC CONDITIONS
	IMPACTOR, W/ SOLID FUEL (based on isokinetic conditions)			
	Avg. mol wt	28.3873	g/mol	dil air and comb. gas, no wood
	dens@imp k	1267.661	g/m^3	rho=P/(R*T), P=1atm
	mdot imp	4.65439	g/min	
	volf/wimp	0.0037	m^3/min	mdotimp/dens@imp inlet
	volf/wimp	0.130	f^3/min	
	2NDARY VAC ROTO, W/ SOLID FUEL			
	dens@roto	1153.572	g/m^3	rho=P/(R*T), vac gage
	mdot 2ndar	-2.6446	g/min, air	dil air and comb. gas, no wood

Table F.10(cont.): Test 101796T

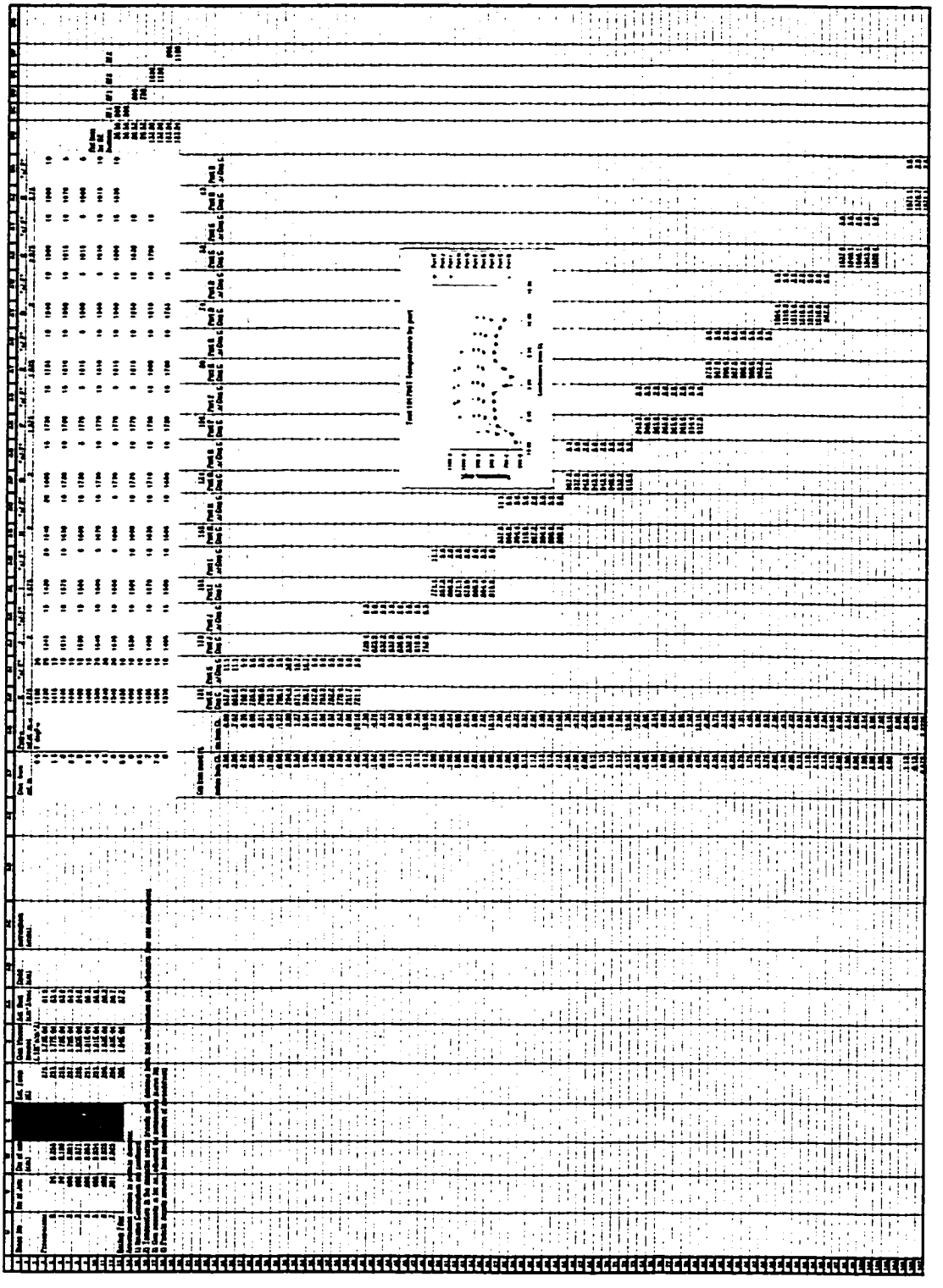


Table F.11: Test 10179602

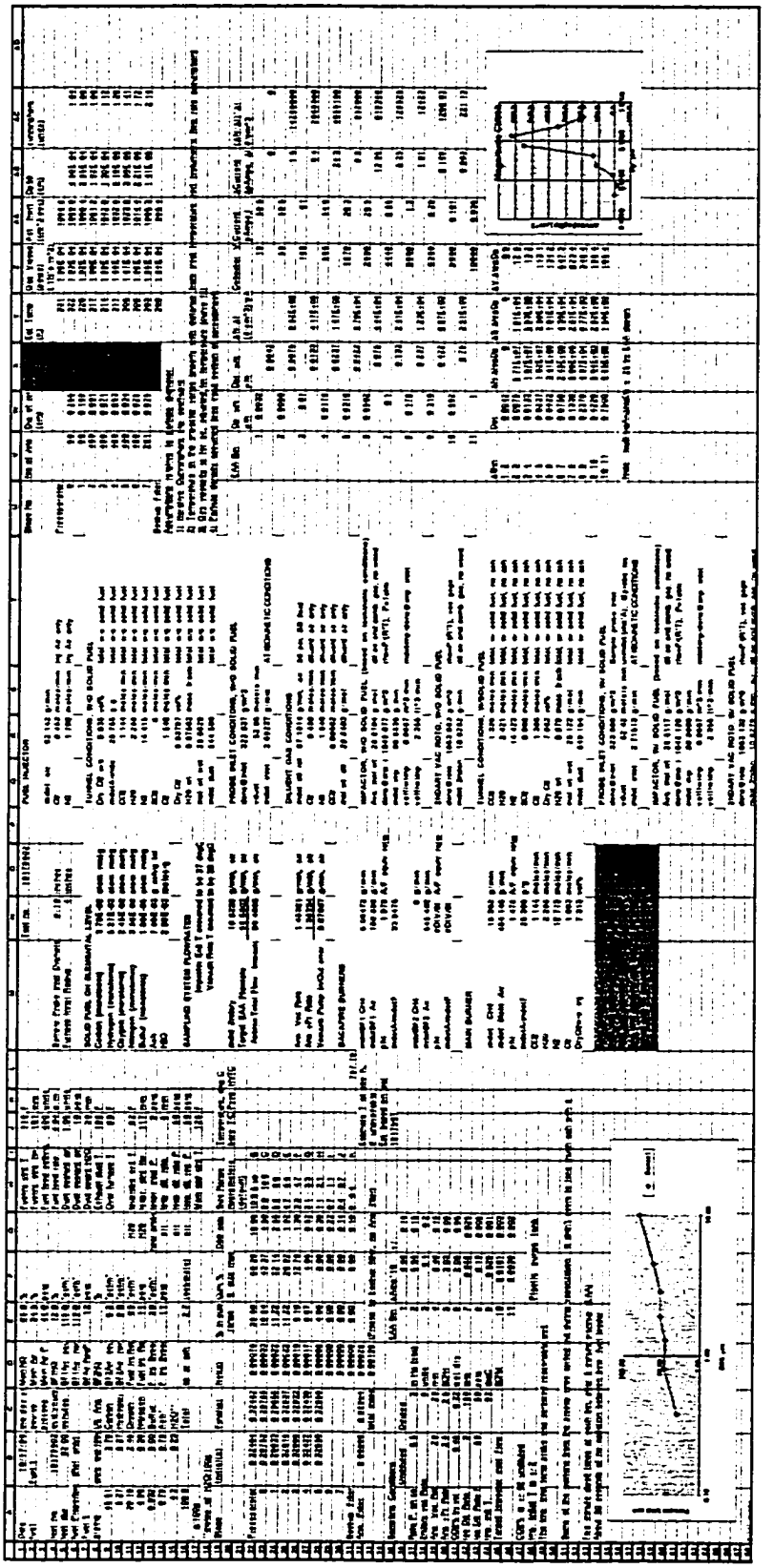


Table F.12: Test 10219601

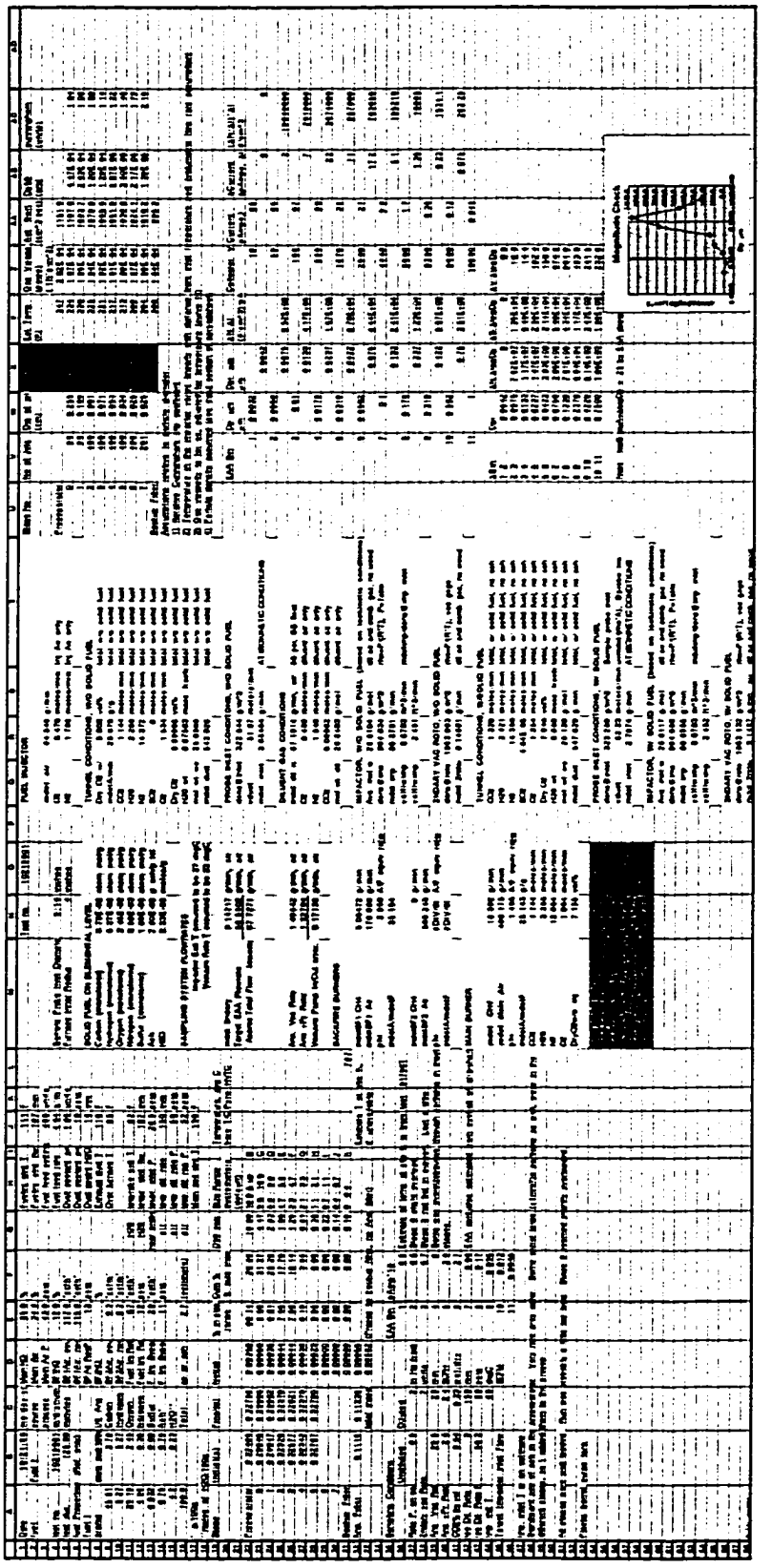


Table F.13: Test 10229601

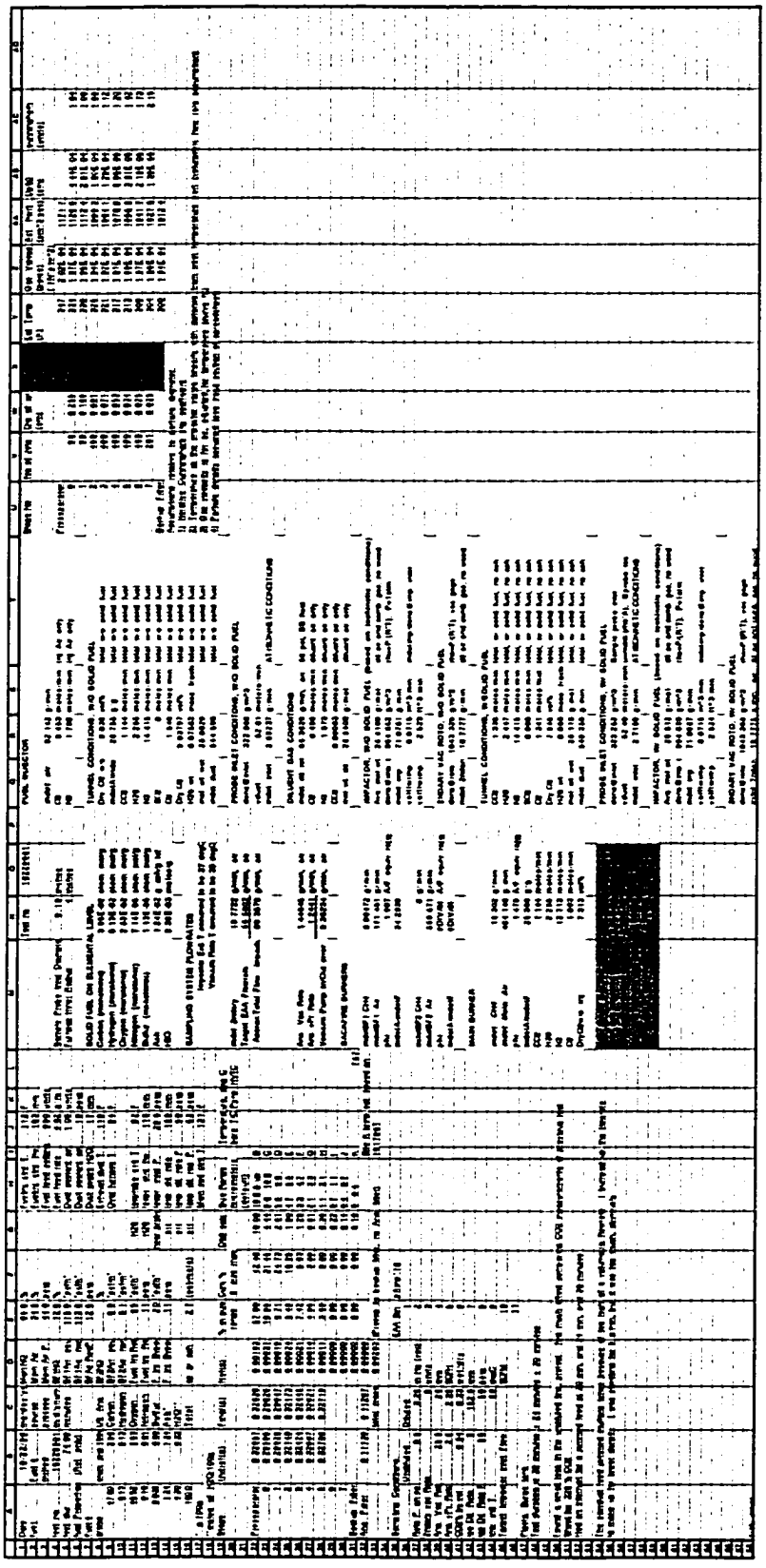


Table F.14: Test 10249601

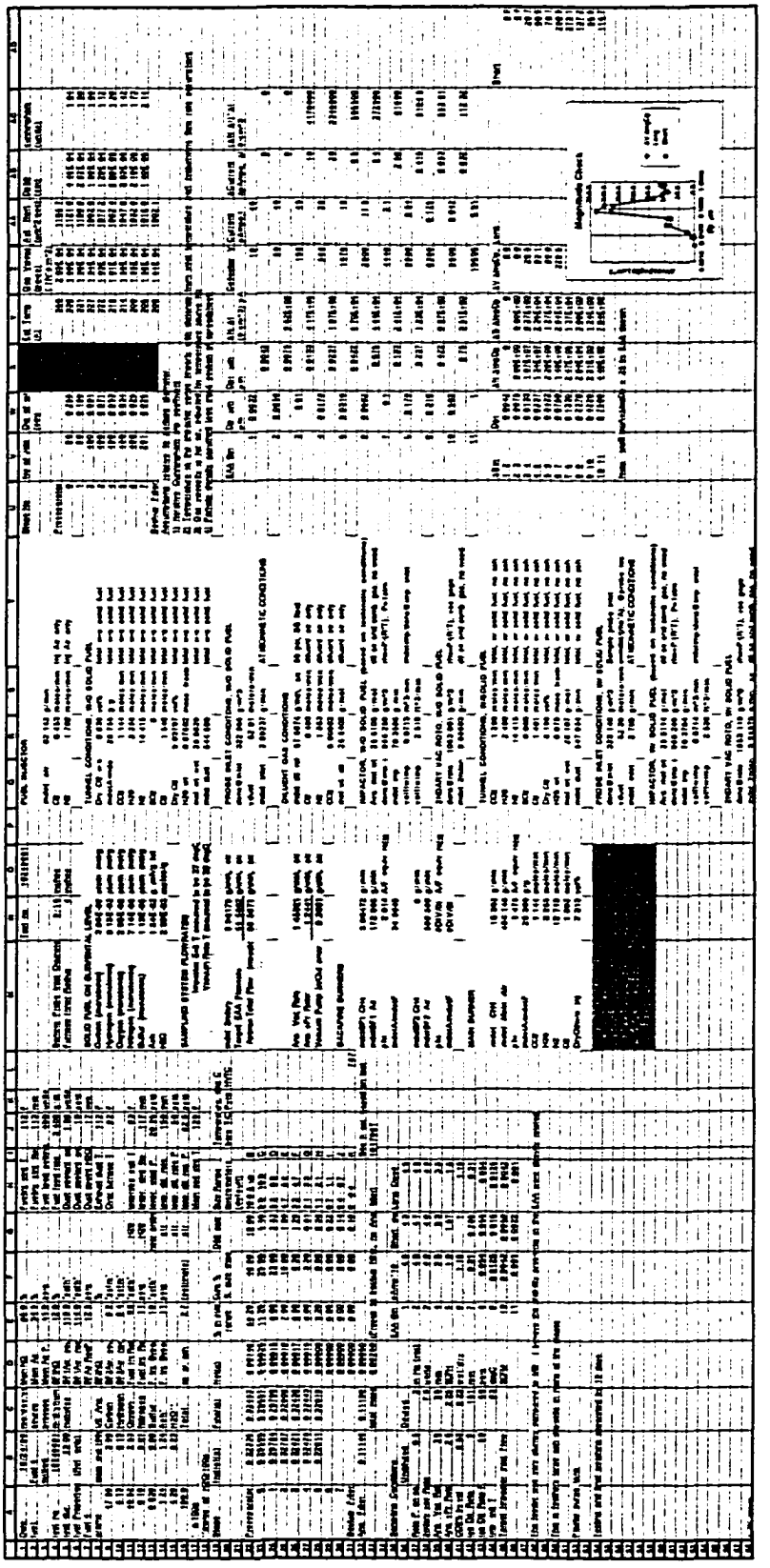


Table F.15: Test 11079601

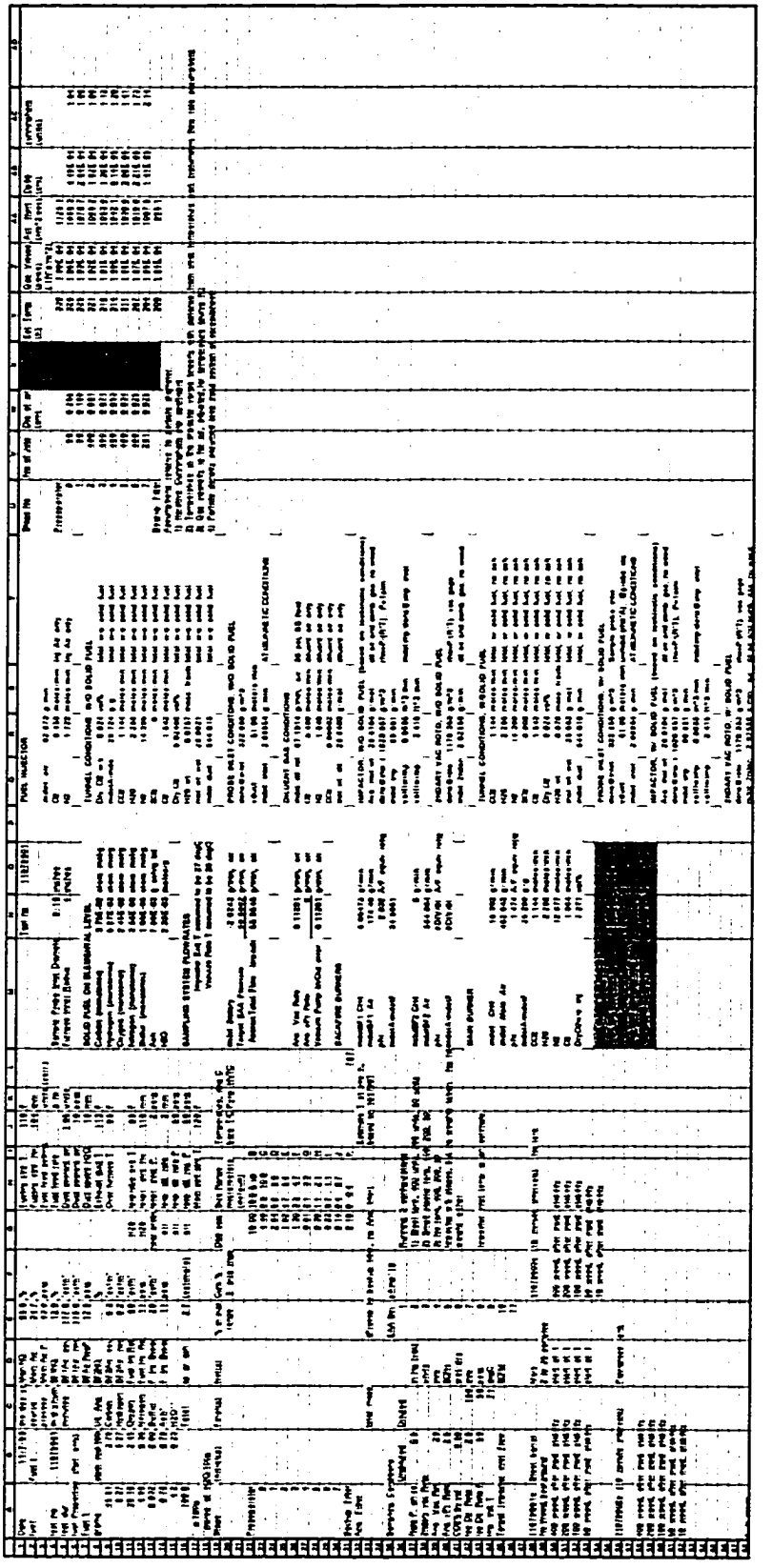


Table F.16: Test 11129601

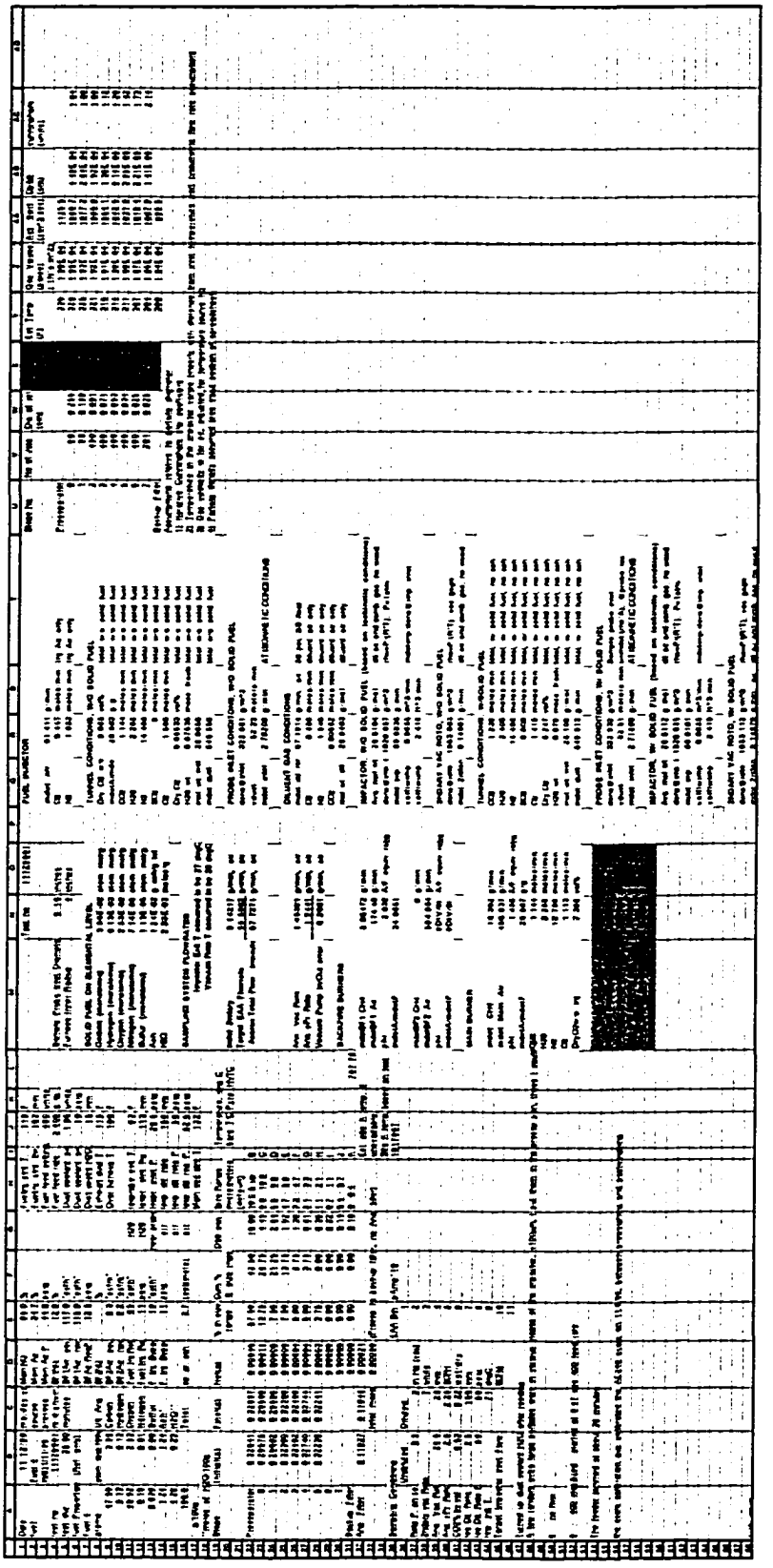


Table F.17: Test 11139601

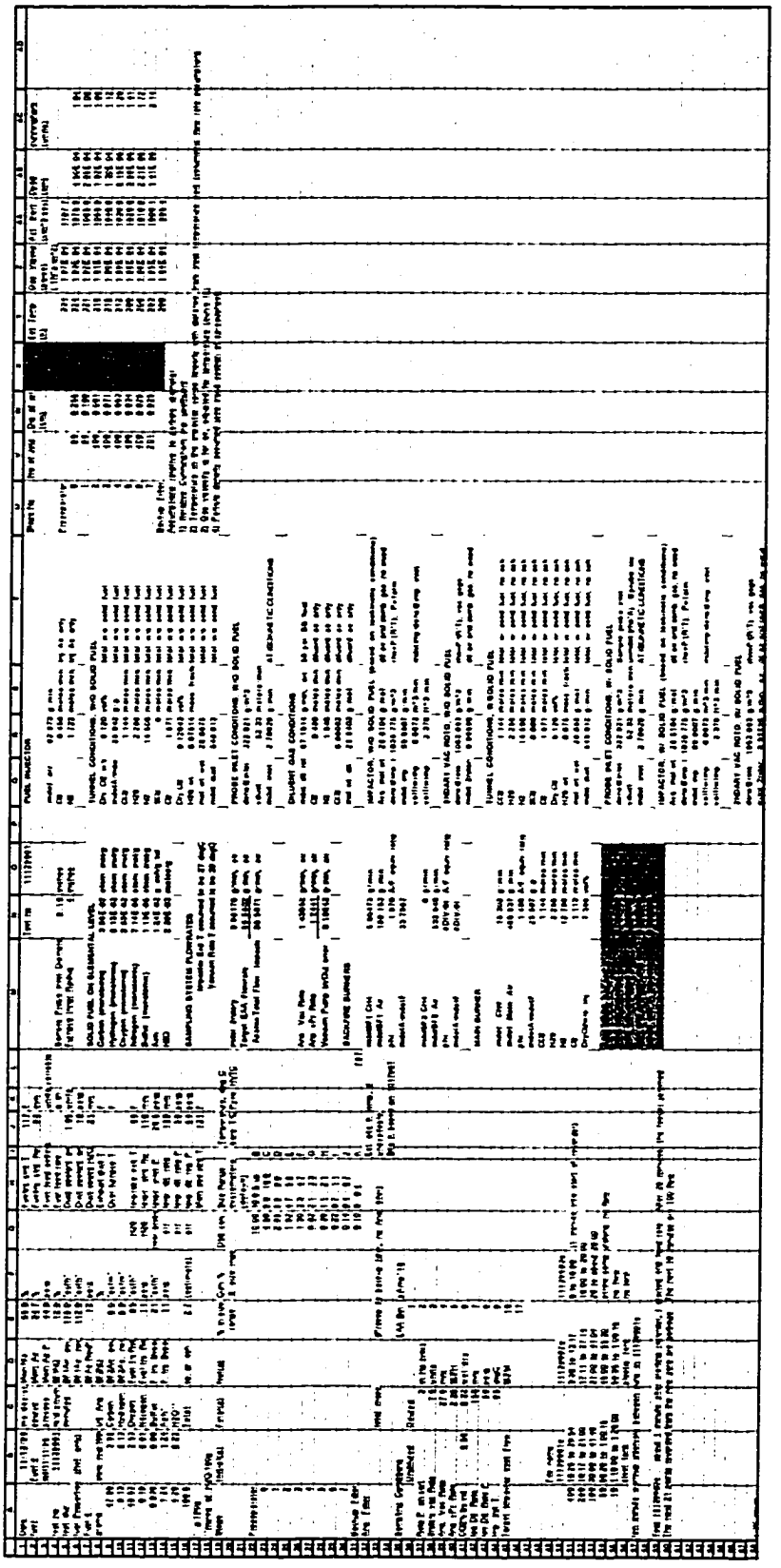


Table F.18: Test 11149601

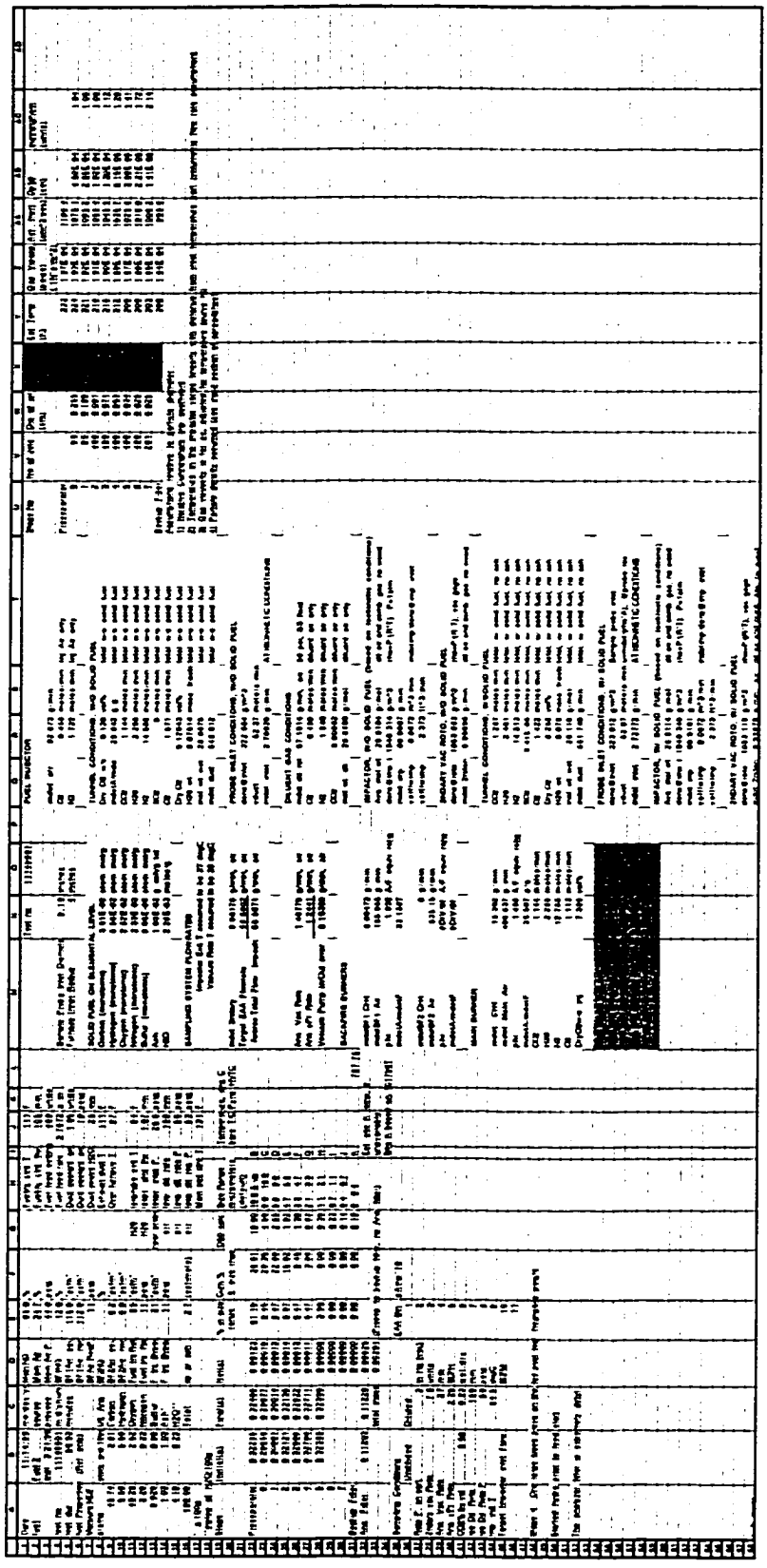


Table F.19: Test 11149602

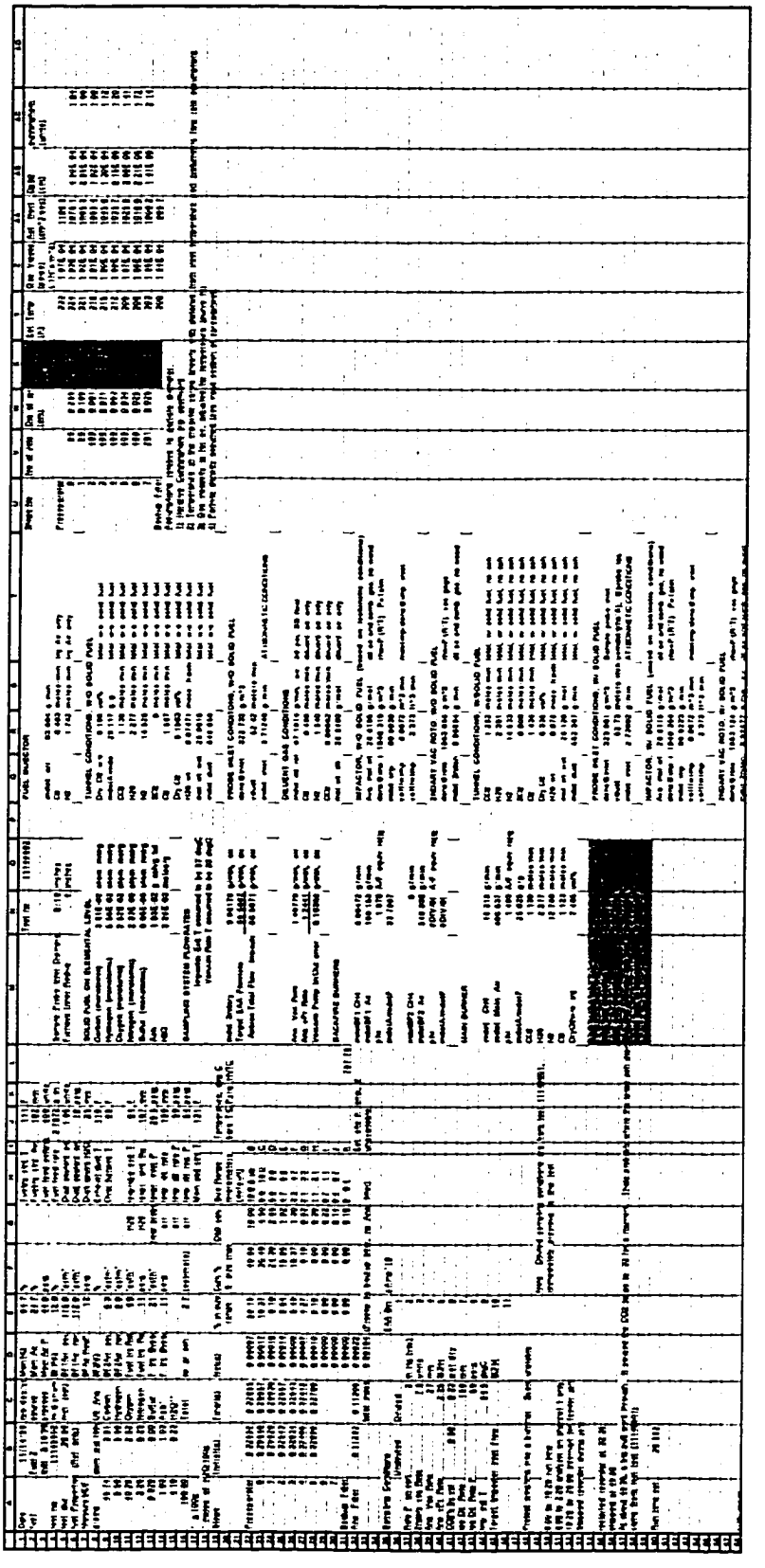


Table F.20: Test 11159601

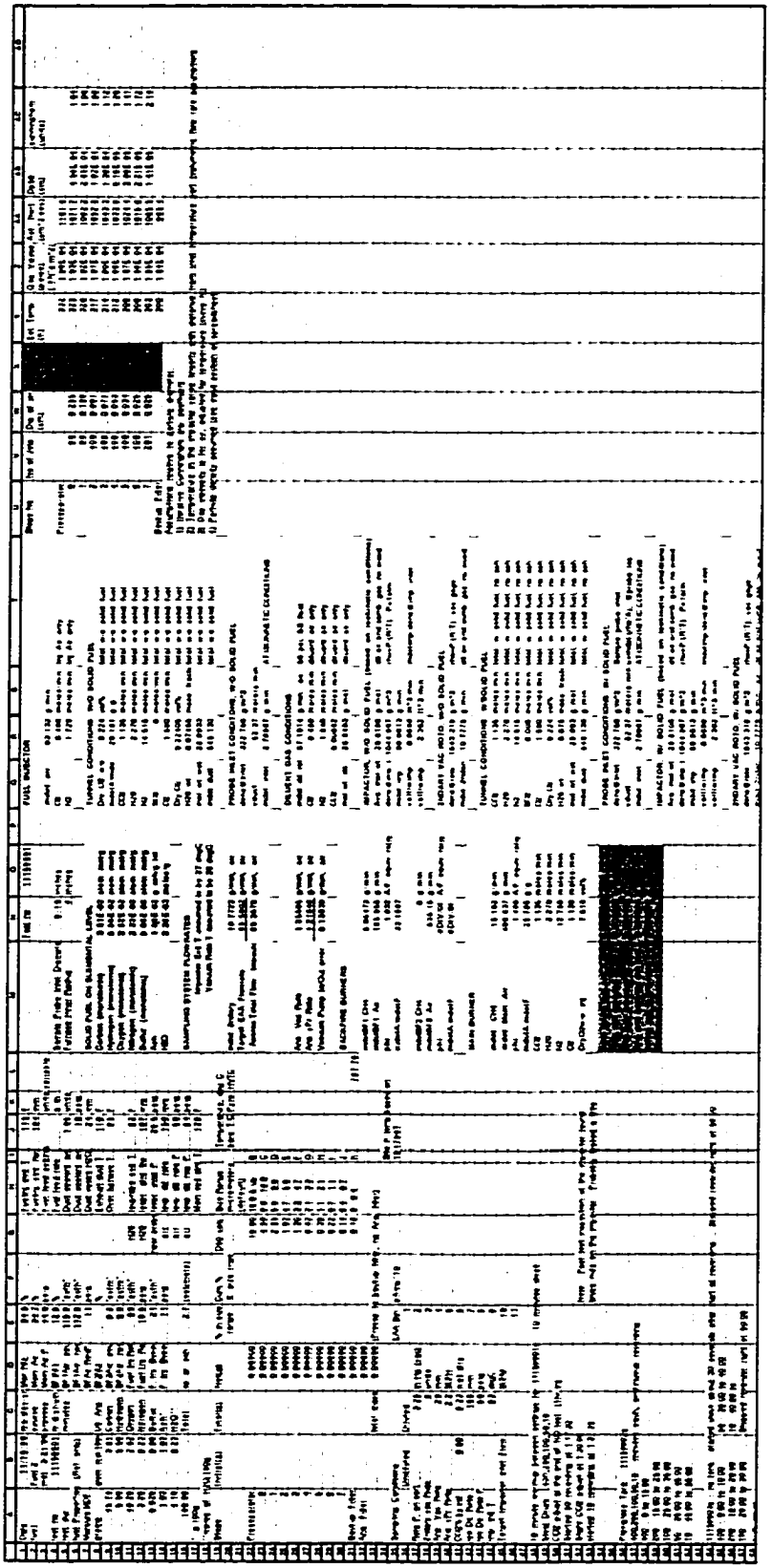


Table F.21: Test 11169601

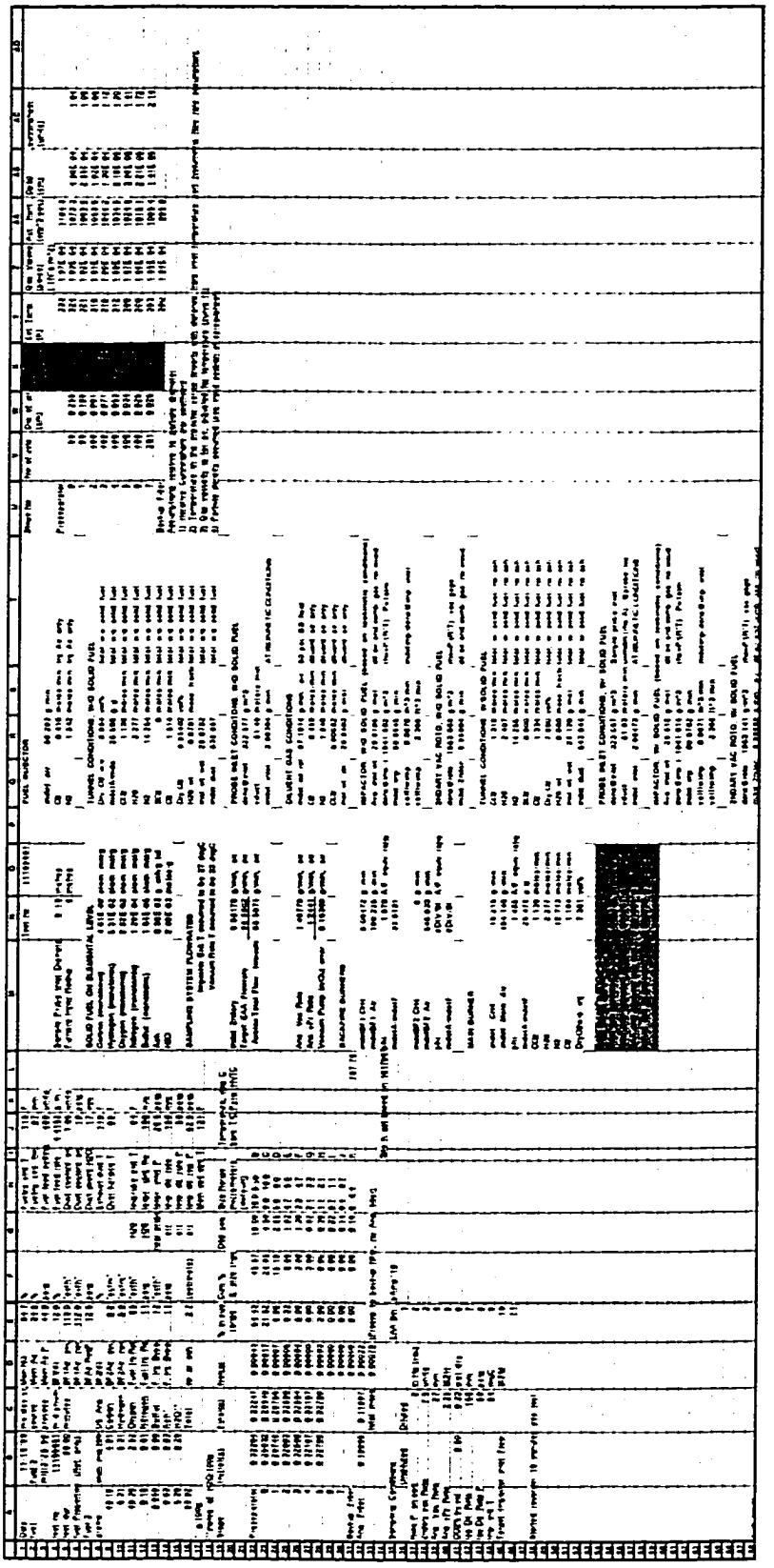


Table F.22: Test 11169602

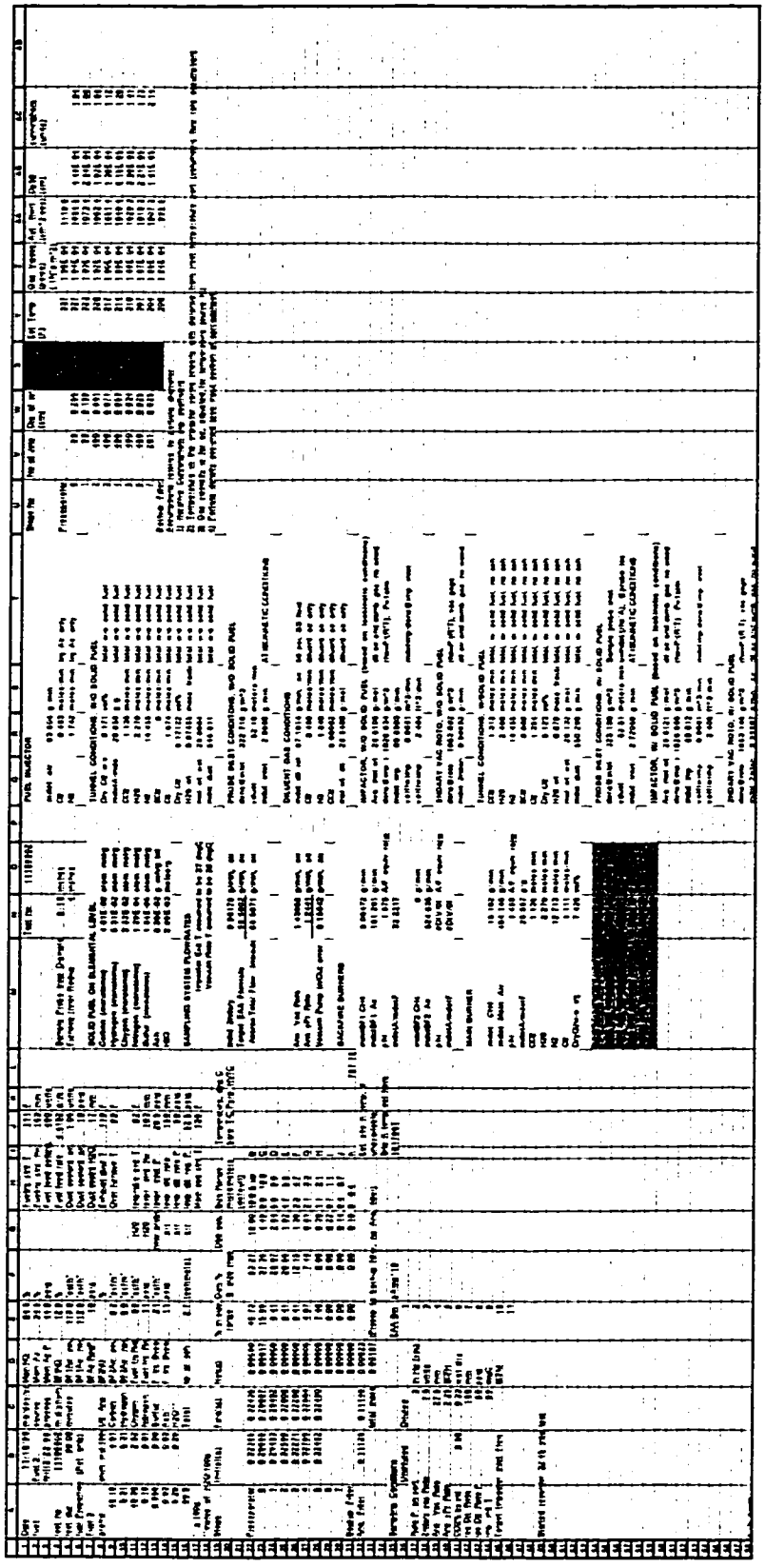


Table F.23: Test 11179601

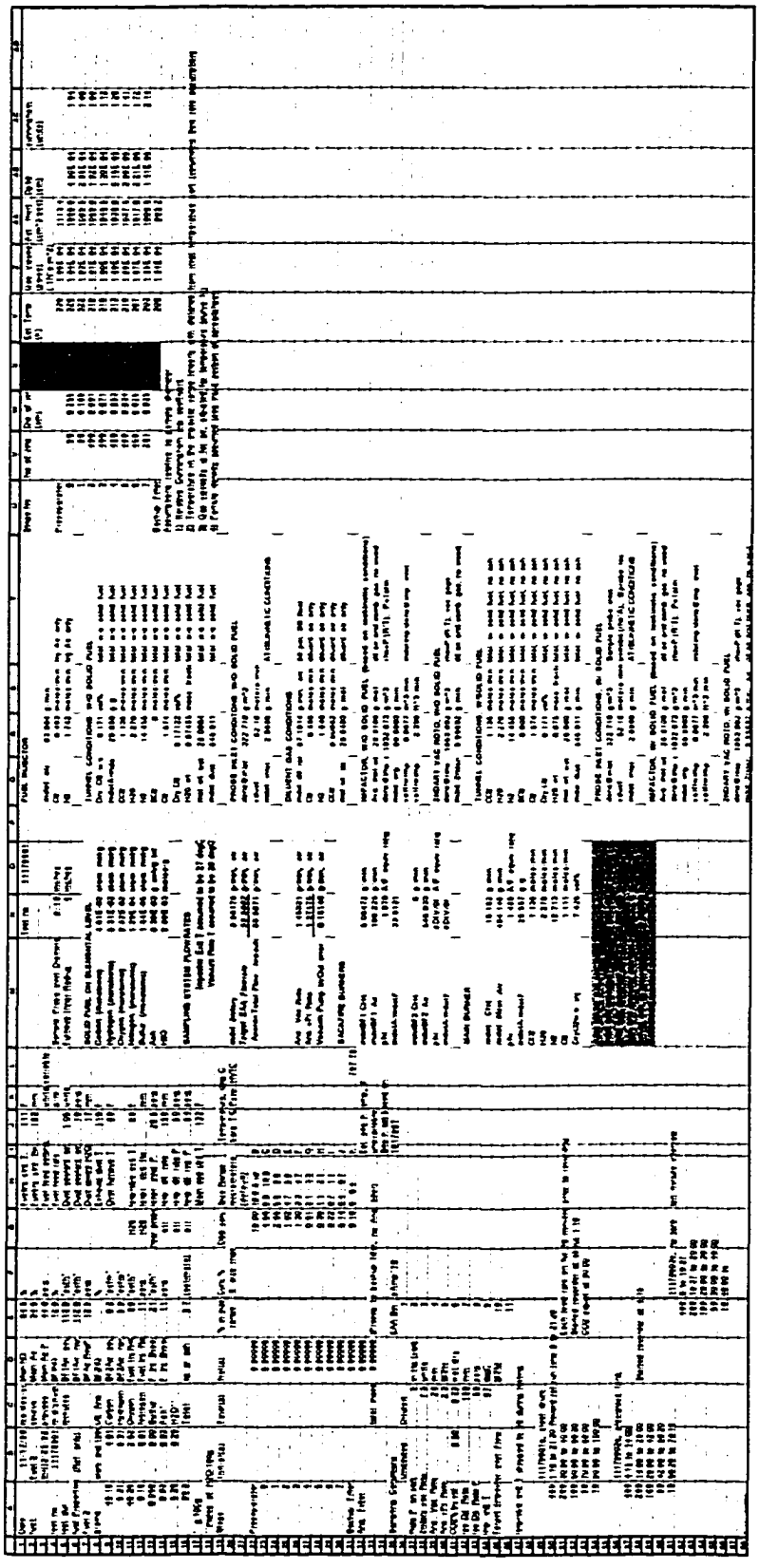


Table F.24: Test 112096T

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	Date:	11/20/96	mr/dav/y	Main NG:	92.5	%		Fuelnj stnl T:		97	F			Test no:	112096T		FUEL INJECTOR			
2	fuel:	Temperature	source	Main Air:	17.2	%		Fuelnj stnl thk		97.5	mm									
3			process	Main Air P:	44.0	psig		Fuel feed setting:			units						mdot air inj	64.701	g/min	
4	test no:	112096T	m/d/yr/v/m	BF1NG:	11.5	%		Fuel feed rate:			g/m		Sample Probe Inlet Diamete	9/16	inches		O2	0.471	moles/min	Inj Air only
5	test dur:		minutes	BF1Air: sov	113.0	"scfh"		Duct coolant air		1.98	units		Furnace Inner Radius	4	inches		N2	1.772	moles/min	Inj Air only
6	fuel Properties: (Ref. only)			BF1Air: no	113.0	"scfh"		Duct coolant air		10	psig									
7	<fuel name here : copy data		from pg 4>	BFAir Reg P	12.5	psig		Duct coolnt H2O		4	mm		SOLID FUEL ON ELEMENTAL LEVEL				TUNNEL CONDITIONS, W/O SOLID FUEL			
8	grams	atomwt/100g	VB. Ana.	BF2NG:		%		Exhaust duct T:		103	F		Carbon (monatomic)	0.00E+00	atom mol/g		Dry O2 w/i	10.449	vol%	total w/o solid fuel
9			Carbon	BF2Air: sov	6.3	"scfm"		Dyer furnace T:		82	F		Hydrogen (monatomic)	0.00E+00	atom mol/g		mdotA/mdot	32.357	g/g	total w/o solid fuel
10			Hydrogen	BF2Air: no	9.1	"scfm"							Oxygen (monatomic)	0.00E+00	atom mol/g		CO2	0.572	moles/min	total w/o solid fuel
11			Oxygen	Fuel Inj Rot	97	"scfh"	H20	Isoprobe exit T:		72	F		Nitrogen (monatomic)	0.00E+00	atom mol/g		H20	1.144	moles/min	total w/o solid fuel
12			Nitrogen	Fuel Inj Reg	11	psig	H20	Isopr. stnl thk:		110	mm		Sulfur (monatomic)	0.00E+00	atom mol/g		N2	8.110	moles/min	total w/o solid fuel
13			Sulfur	F. Inj. Pyrex	21.5	"scfh"	near probe	Isopr. inlet P:		1.25	psig		Ash	0.00E+00	g ash/g tot		SO2	0	moles/min	total w/o solid fuel
14			Ash	F. Inj. Pyrex	11	psig	air	Isop. dil rate:		4	mm		H2O	0.00E+00	moles/g		O2	1.013	moles/min	total w/o solid fuel
15			Moisture				air	Isop. dil. rate P.		98	psig						Dry O2	10.4489	vol%	total w/o solid fuel
16			Total	sp. gr. ash	2.7	(estimate)	air	Isop. dil. reg P.		98	psig		SAMPLING SYSTEM FLOWRATES				H20 wt	0.06745	mass fractn	total w/o solid fuel
17								Main coil stnl T:		100	F		Impactor Exit T assumed to be 27 degC				mol wt wet	28.1626		total w/o solid fuel
18													Vacuum Rota T assumed to be 23 degC				mdot duct	305.252		total w/o solid fuel
19	Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % in size rnge	D50 calc.	Size Range micrometers (default)		Temperature, deg C bare T/C	Pyrex	HYTG								
20													mdot 2ndary	-2.6242	g/min, air		PROBE INLET CONDITIONS, W/O SOLID FUEL			
21													Target EAA Flowrate	58.5802	g/min, air		dens@inlet	1257.192	g/m^3	
22	Preseparator							100 & up	B				Approx.Total Flow Impactc	55.9423	g/min, air		vduct	7.49	meters/min	
23	0							80 -100	C								mdot inlet	1.50912	g/min	AT ISOKINETIC CONDITIONS
24	1							66 - 80	D											
25	2							47 - 66	E								DILUENT GAS CONDITIONS			
26	3							33 - 47	F				Ana. Vac. Rota	0.11291	g/min, air		mdot dil rot	1.98202	g/min, air	50 psi, SS tiost
27	4							21 - 33	G				Ana. +Pr. Rota:	0	g/min, air		O2	0.014	moles/min	diluent air only
28	5							11 - 21	H				Vacuum Pump In/Out error:	0.11291	g/min, air		N2	0.054	moles/min	diluent air only
29	6							07 - 11	I								CO2	2.4E-05	moles/min	diluent air only
30	7							04 - 07	J				BACKFIRE BURNERS				mol wt dil.	28.8403	g/mol	diluent air only
31	Backup Filter							0 -04	K											
32										Estimate T at ste K.			mdotBF1 CH4	4.79619	g/min		IMPACTOR, W/O SOLID FUEL (based on isokinetic conditions)			
33			total mass							if unavaeable			mdotBF1 Air	169.977	g/min		Avg. mol wt	28.5418	g/mol	dil air and comb. gas, no wood
34										(temp by bare	T/C only)		phi	2.085	A/F equiv ratio		dens@imp i	1274.112	g/m^3	rho=P/(R*T), P=1atm
35	Sampling Conditions:				EAA Bin	pAmp*10							mdotA/mdotF	35.44			mdot imp	3.47114	g/min	
36	Undivided	Divided			1												volflwimp	0.0027	m^3/min	mdotimp/dens@imp inlet
37	Rota P. on cell:		in Hg (vac)		2								mdotBF2 CH4	0	g/min		volflwimp	0.096	ft^3/min	
38	2ndary vac Rota:		units		3								mdotBF2 Air	559.571	g/min					
39	Ana. Vac. Rota:		mm		4								phi	#DIV/0!	A/F equiv ratio		2NDARY VAC ROTO, W/O SOLID FUEL			
40	Ana. +Pr. Rota:		SCFH		5								mdotA/mdotF	#DIV/0!			dens@roto	1159.441	g/m^3	rho=P/(R*T), vac gage
41	CO2% by vol		wet/dry		6												mdot 2ndar	-2.6378	g/min	dil air and comb. gas, no wood
42	Iso Dil. Rota:		mm		7								MAIN BURNER							
43	Iso Dil. Rota P:		psig		8												TUNNEL CONDITIONS, W/SOLID FUEL			
44	Imp. Init T:		degC		9								mdot CH4	9.151	g/min		CO2	0.572	moles/min	total, w/ solid fuel, no ash
45	Target Impactor Inlet Flow:		SCFM		10								mdot Main Air	231.400	g/min		H20	1.144	moles/min	total, w/ solid fuel, no ash
46					11								phi	1.474	A/F equiv ratio		N2	8.110	moles/min	total, w/ solid fuel, no ash
47													mdotA/mdotF	25.286	g/g		SO2	0.000	moles/min	total, w/ solid fuel, no ash
48													CO2	0.572	moles/min		O2	1.013	moles/min	total, w/ solid fuel, no ash
49	foil around port and probe to reduce air flow												H20	1.144	moles/min		Dry O2	10.449	vol%	total, w/ solid fuel, no ash
50													N2	8.338	moles/min		H20 wt	0.067	mass fractn	total, w/ solid fuel, no ash
51	Noted on 11/22/96												O2	0.542	moles/min		mol wt wet	28.163	g/mol	total, w/ solid fuel, no ash
52	The flame can be seen flickering yellow in the main burner. Probably getting some soot formation. This												Dry O2w/o in)	7.270	vol%		mdot duct	305.252	g/min	total, w/ solid fuel, no ash
53	might explain the background size distribution (EAA) with this temp setting																			
54																	PROBE INLET CONDITIONS, W/ SOLID FUEL			
55																	dens@inlet	1257.192	g/m^3	Sample probe inlet
56																	vduct	7.49	meters/min	u=mdot/(rho*A), @probe loc
57																	mdot inlet	1.50912	g/min	AT ISOKINETIC CONDITIONS
58																				
59																	IMPACTOR, W/ SOLID FUEL (based on isokinetic conditions)			
60																	Avg. mol wt	28.5418	g/mol	dil air and comb. gas, no wood
61																	dens@imp i	1274.112	g/m^3	rho=P/(R*T), P=1atm
62																	mdot imp	3.47114	g/min	
63																	volflwimp	0.0027	m^3/min	mdotimp/dens@imp inlet
64																	volflwimp	0.096	ft^3/min	
65																				
66																	2NDARY VAC ROTO, W/ SOLID FUEL			
67																	dens@roto	1159.441	g/m^3	rho=P/(R*T), vac gage
68	9/17/97 template																mdot 2ndar	-2.6378	g/min, air	dil air and comb. gas, no wood

Table F.24(cont.): Test 112096T

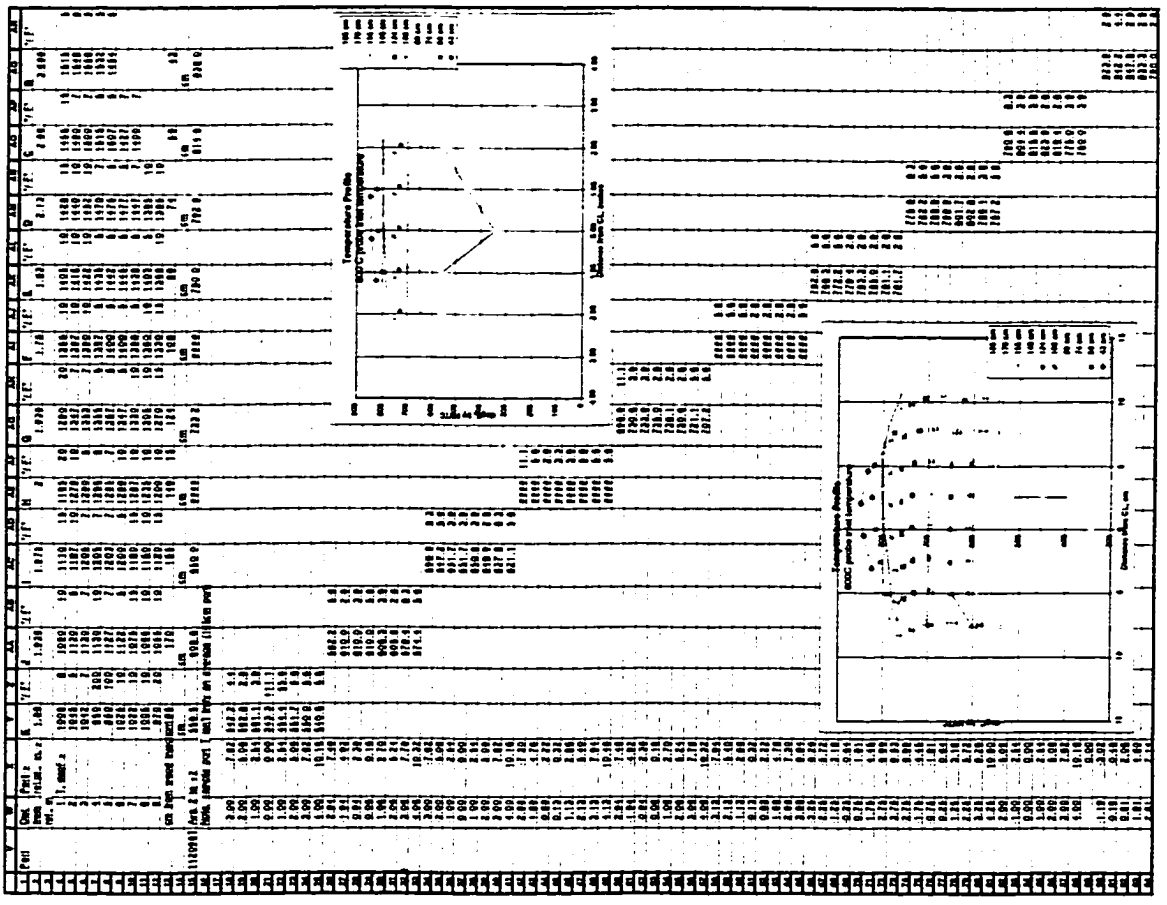


Table F.25: Test 11219601

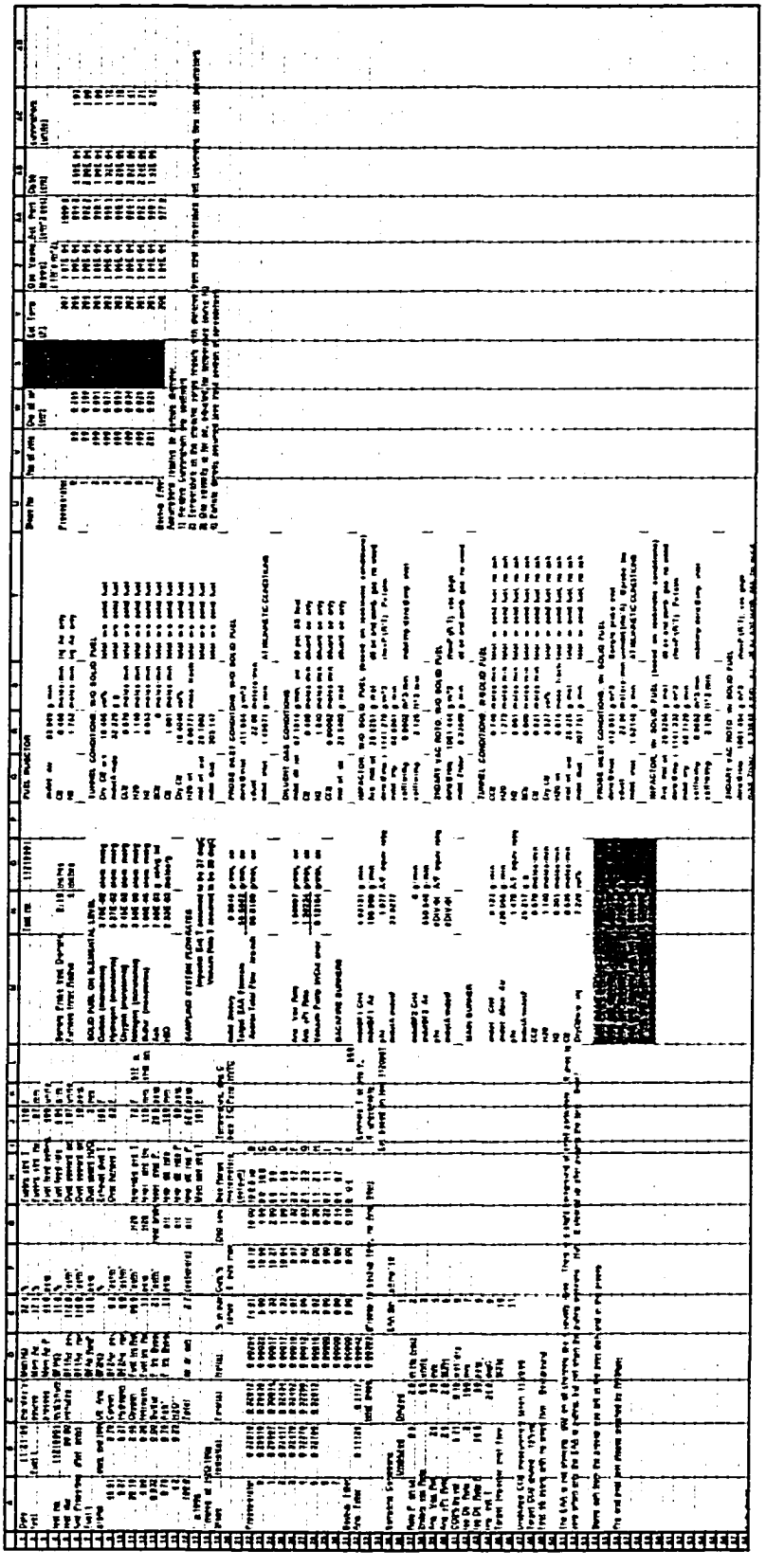


Table F.26: Test 11219602

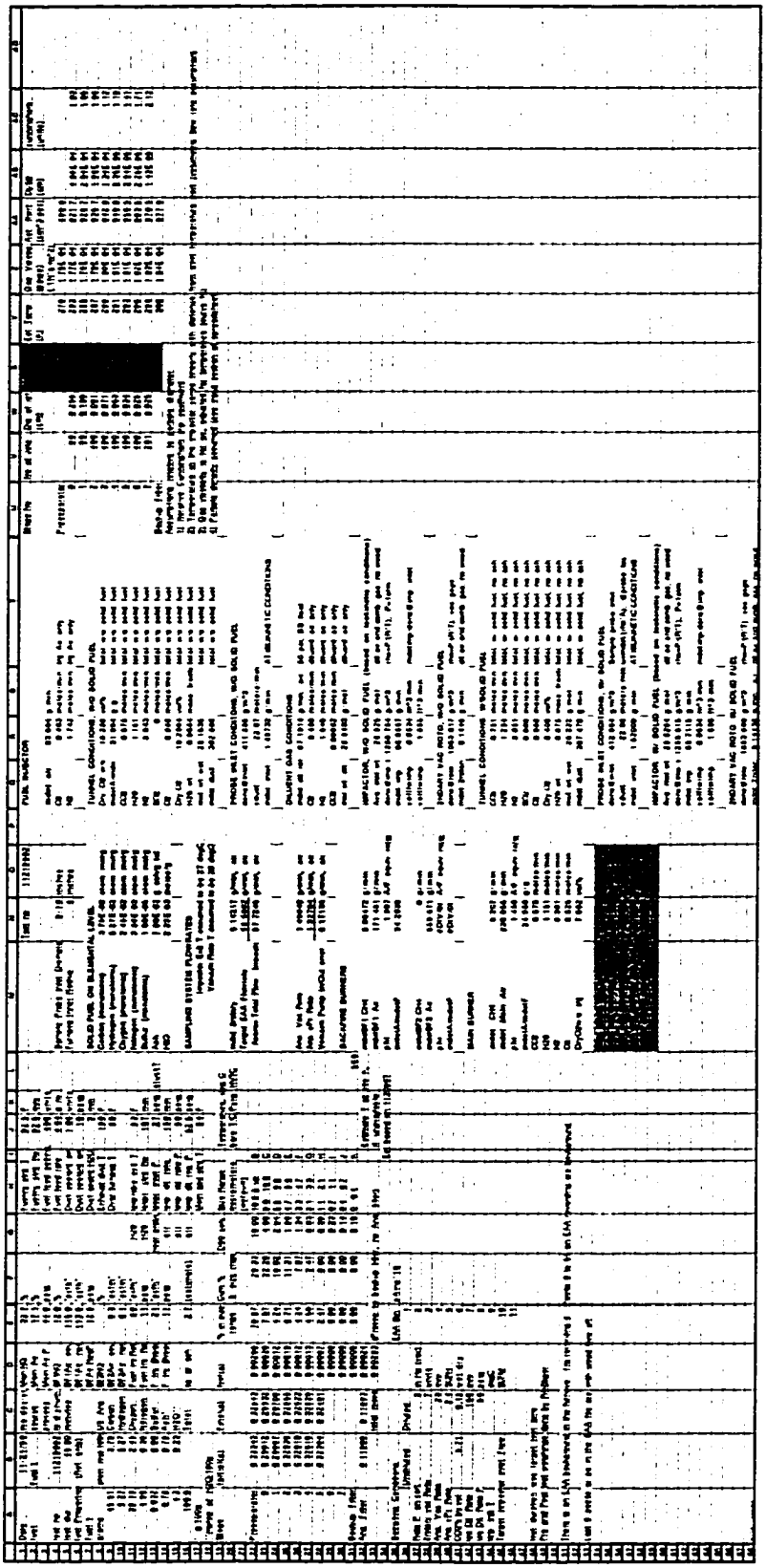


Table F.27: Test 11219603

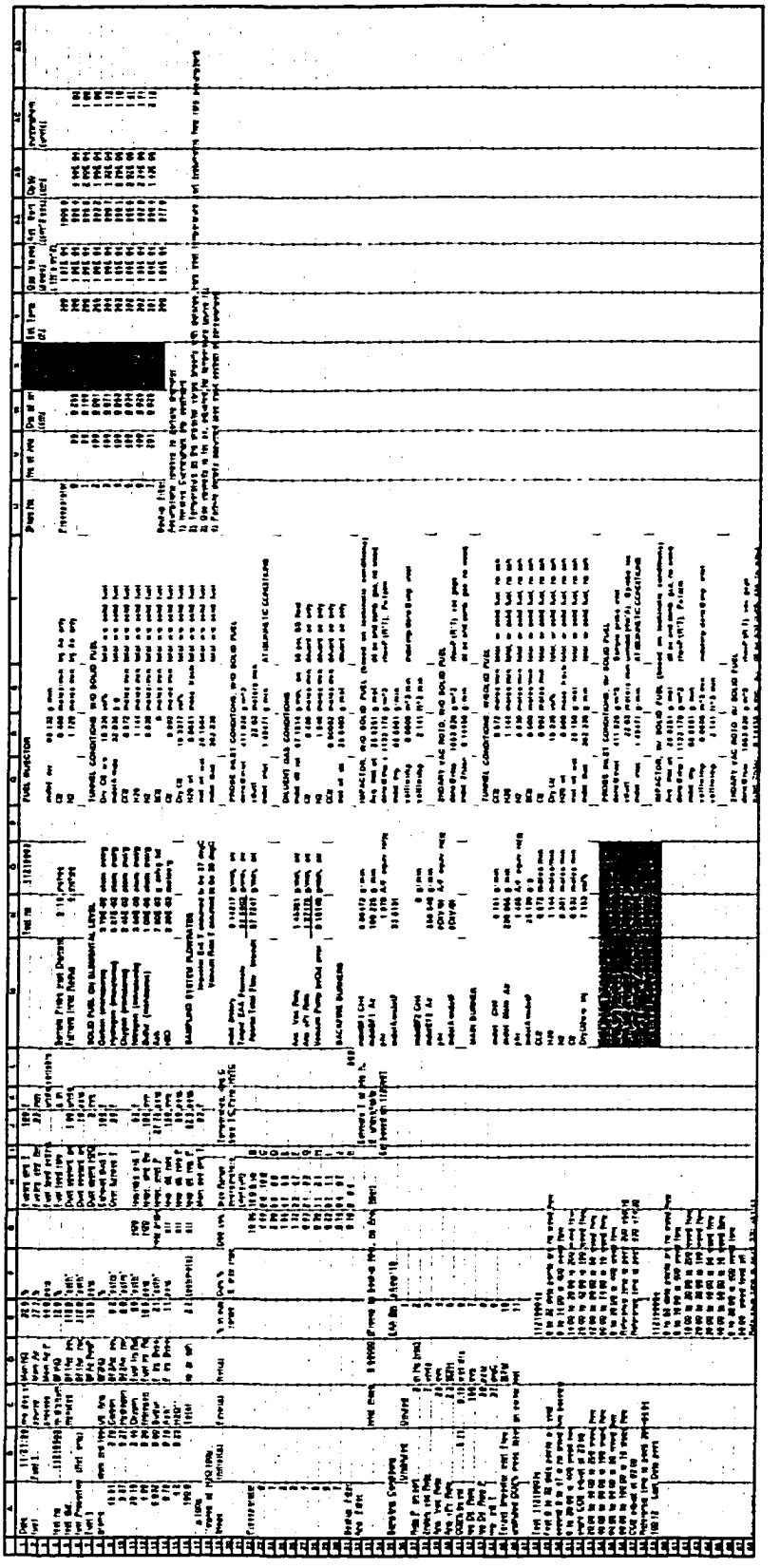


Table F.28: Test 11219606

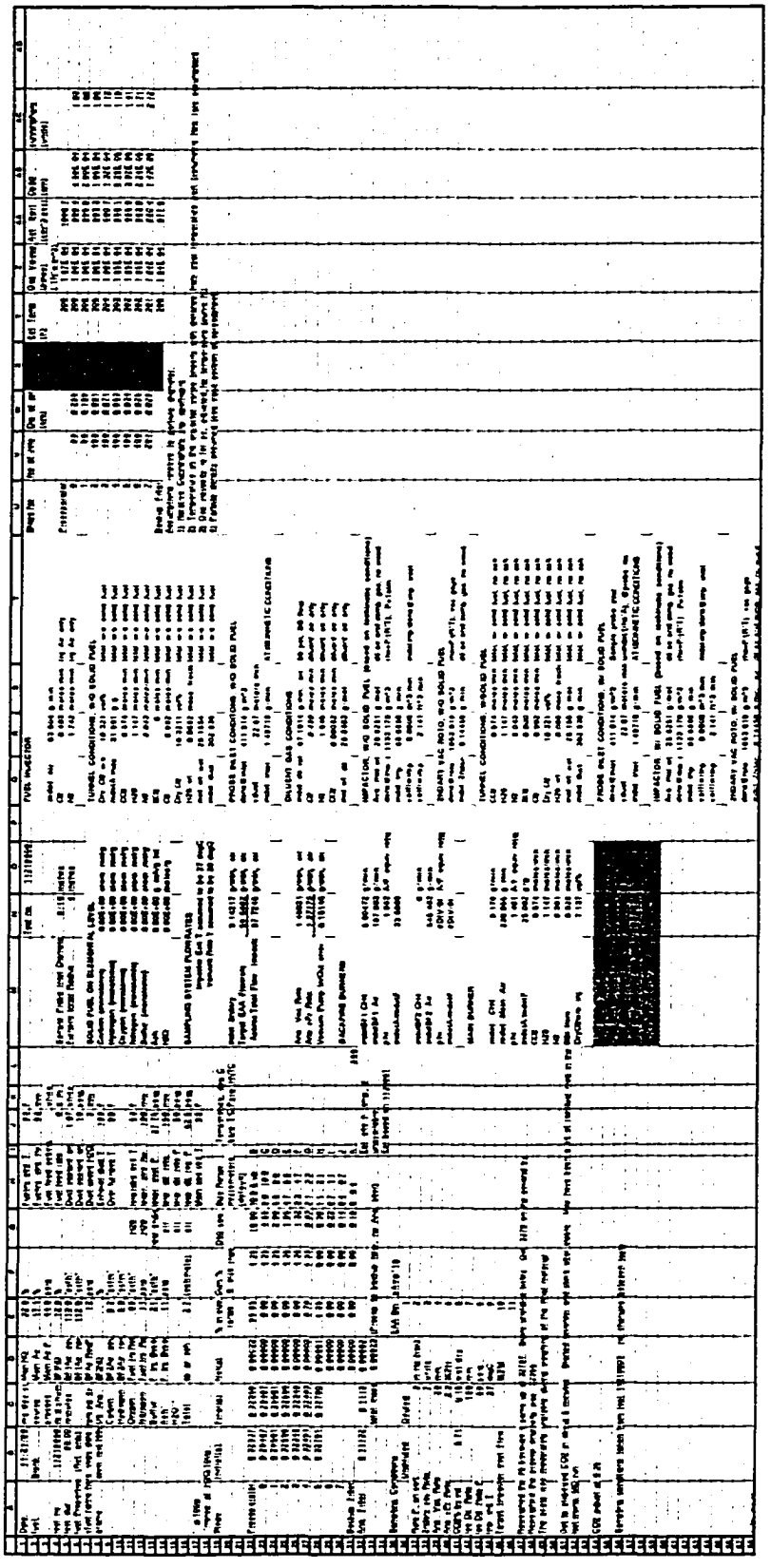


Table F.29: Test 11229601

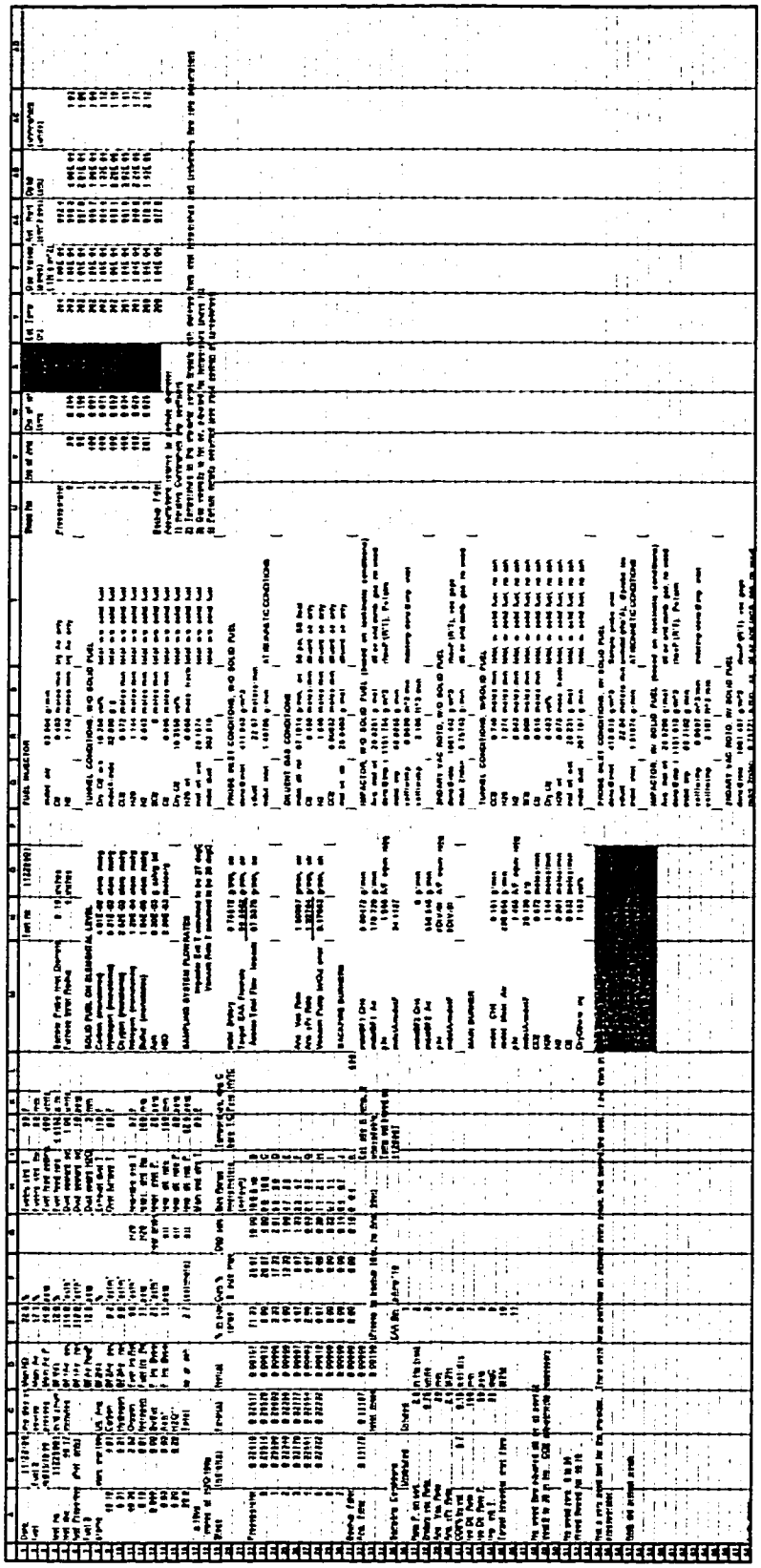


Table F.30: Test 11229602

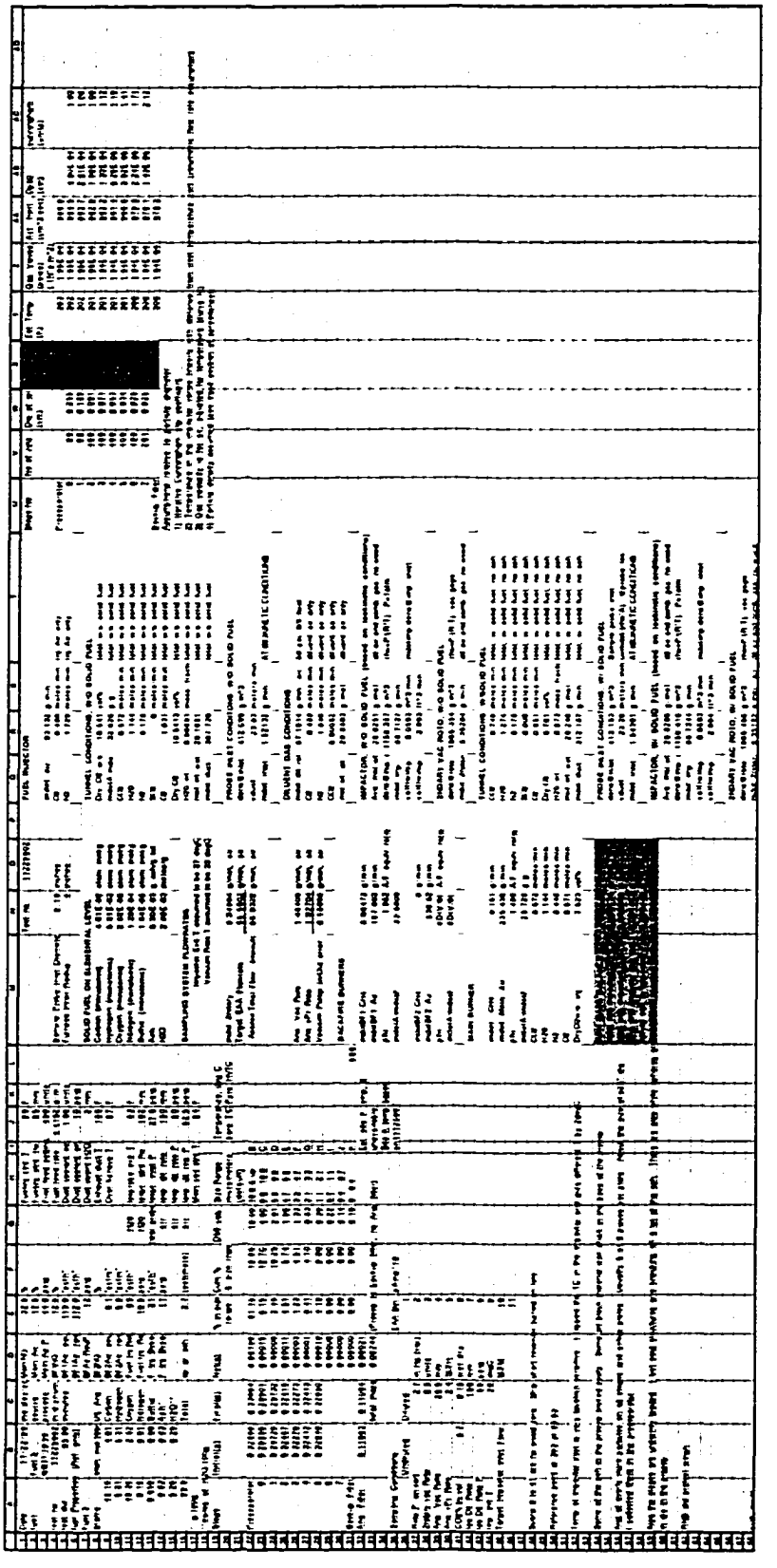


Table F.31: Test 11229603

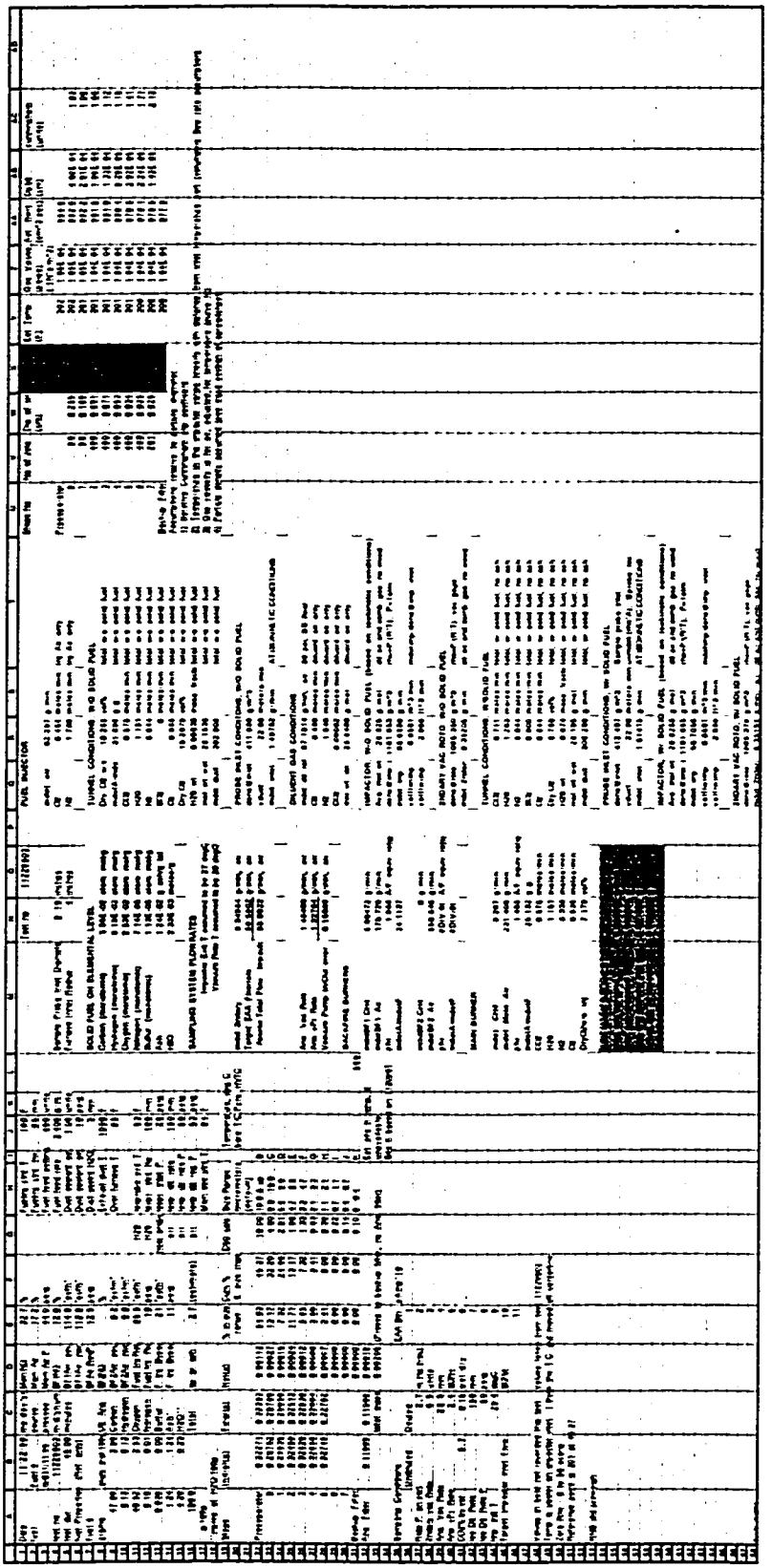


Table F.32: Test 11239601

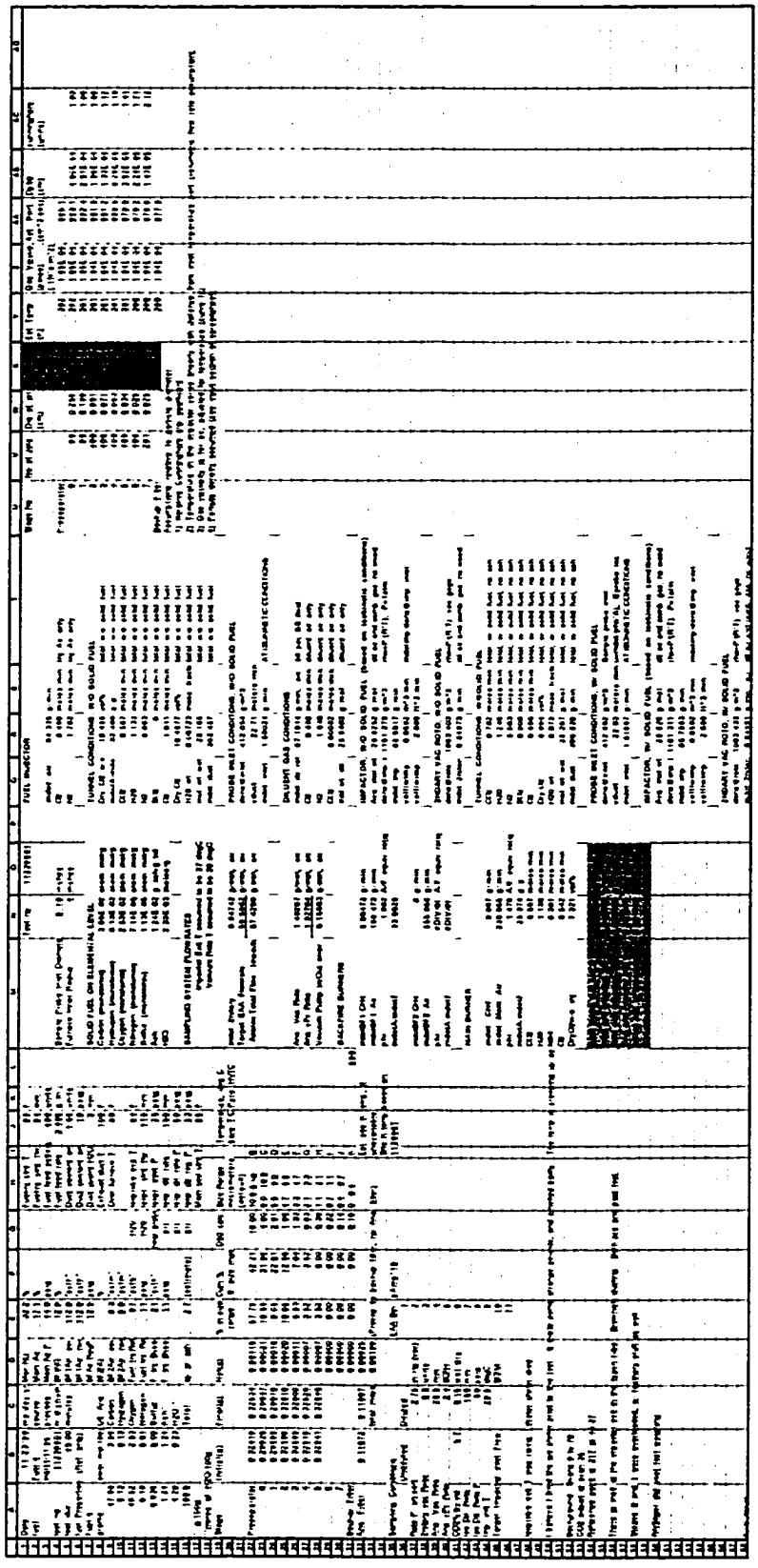


Table F.33: Test 11239602

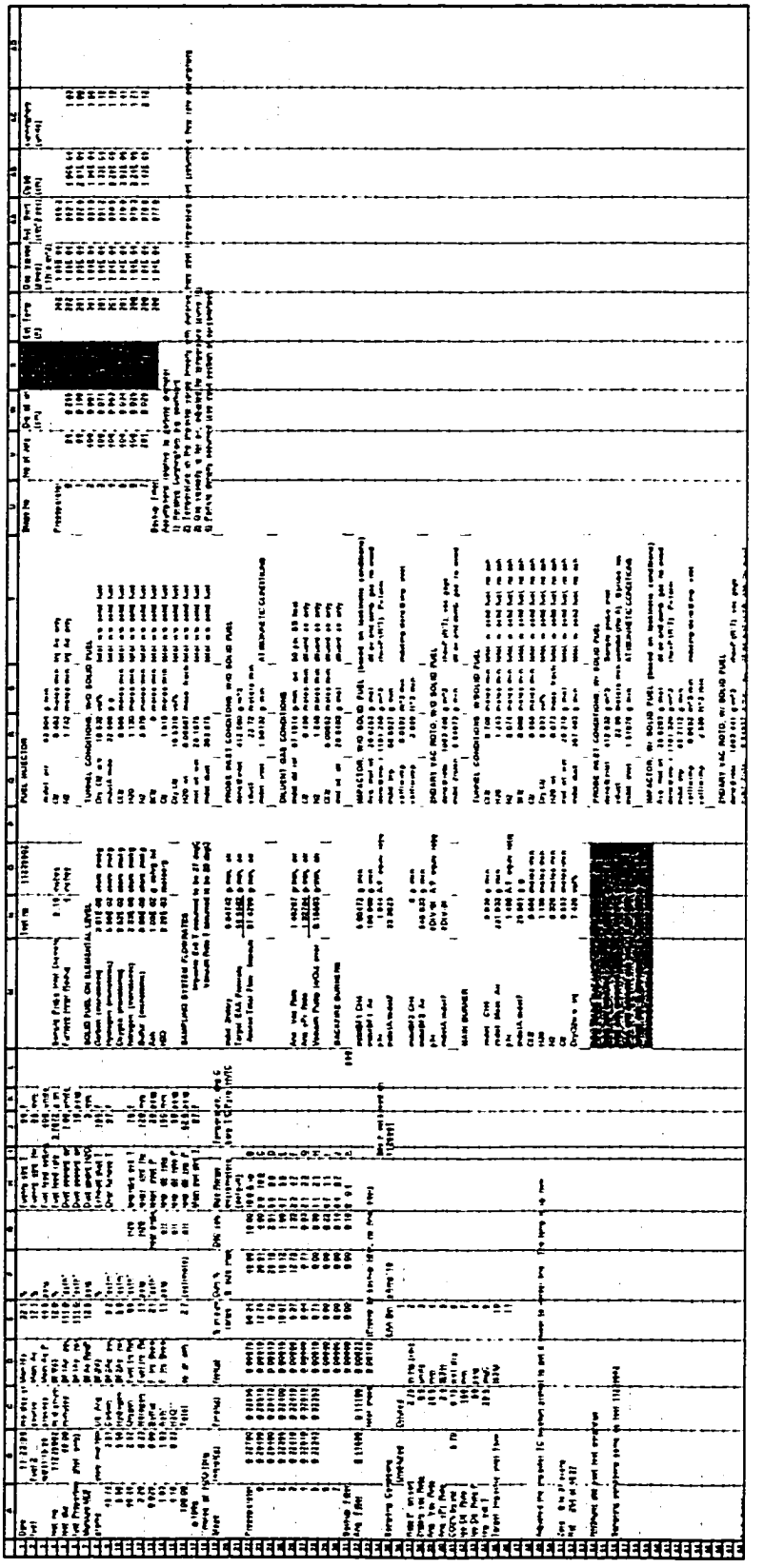


Table F.34: Test 11239603

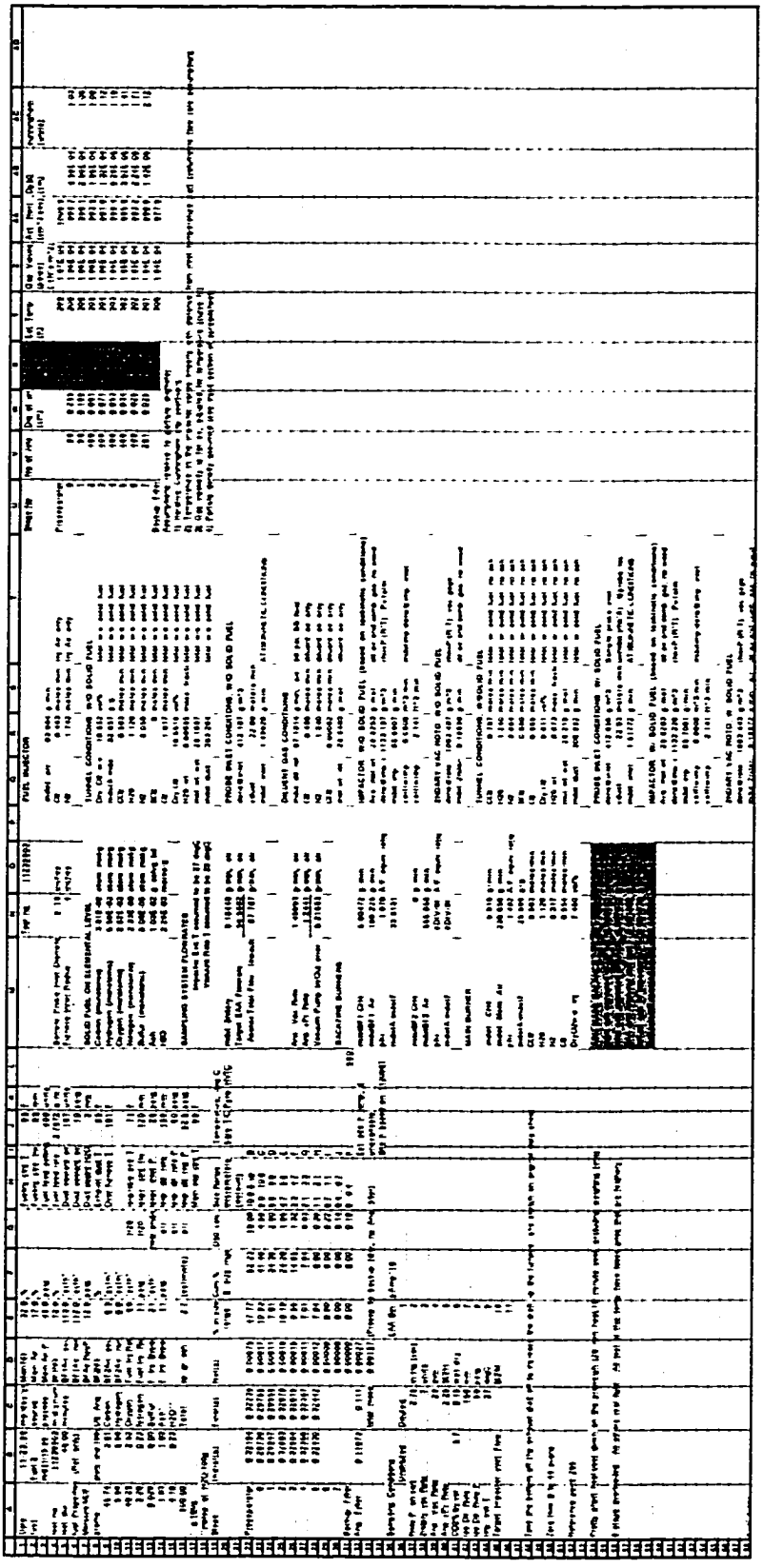


Table F.35: Test 112596T

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	Date:	11/25/99	mo/day/yr	Main NG:	33.2	%		Fuelinj clnt T:		100	F			Test no:	112599T		FUEL INJECTOR			
2	fuel:	Temperature	source	Main Air:	17.2	%		Fuelinj clnt flw:		94	mm									
3			process	Main Air P:	44.5	psig		Fuel feed setting:			units						*mdot air inj*	63.132	g/min	
4	test no:	112599T	mi/d/ynum	BFING:	19.0	%		Fuel feed rate:			g/m		Sample Probe Inlet Diamete	9/16	inches		O2	0.460	moles/min	inj Air only
5	test dur:		minutes	BF1Air: so	112.0	"scfh"		Duct coolant air		1.08	units		Furnace Inner Radius	4	inches		N2	1.729	moles/min	inj Air only
6	fuel Properties: (Ref. only)			BF1Air: no	112.0	"scfh"		Duct coolant air		10	psig									
7	<fuel name here -copy data		rom pg 4>	BFAir RegP	12.5	psig		Duct coolnt H2O		4.5	mm		SOLID FUEL ON ELEMENTAL LEVEL				TUNNEL CONDITIONS, W/O SOLID FUEL			
8	grams	atom mol/100g	UN, Ana	BF2NG		%		Exhaust duct T:		107	F		Carbon (monatomic)	0.00E+00	atom mol/g		Dry O2 w/i	10.185	vol%	total w/o solid fuel
9			Carbon	BF2Air: so	9.2	"scfm"		Oven (unused T:		99	F		Hydrogen (monatomic)	0.00E+00	atom mol/g		mdotA/mdot	31.612	g/g	total w/o solid fuel
10			Hydrogen	BF2Air: no	9.9	"scfm"							Oxygen (monatomic)	0.00E+00	atom mol/g		CO2	0.584	moles/min	total w/o solid fuel
11			Oxygen	Fuel Inj Rot	68	"scfh"	H20	Isoprobe exit T:		70	F		Nitrogen (monatomic)	0.00E+00	atom mol/g		H20	1.169	moles/min	total w/o solid fuel
12			Nitrogen	Fuel Inj. Re	10.5	psig	H20	Isopr. clnt flw:		113	mm		Sulfur (monatomic)	0.00E+00	atom mol/g		N2	8.094	moles/min	total w/o solid fuel
13			Sulfur	F. Inj Bype	21	"scfh"	near probe	Isopr. inlet P:		2	psig		Ash	0.00E+00	g ash/g tot		SO2	0	moles/min	total w/o solid fuel
14			Ash*	F. Inj. Bype	11	psig	air	Isop. dil. rate:		3	mm		H2O	0.00E+00	moles/g		O2	0.984	moles/min	total w/o solid fuel
15			H2O**				air	Isop. dil. rate P		59	psig						Dry O2	10.1851	vol%	total w/o solid fuel
16			Total	sp. gr. ash	2.7	(estimate)	air	Isop. dil reg P:		69	psig		SAMPLING SYSTEM FLOWRATES				H20 wt	0.06869	mass fractk	total w/o solid fuel
17	* g/100g							Main coil clnt T:		100	F		Impactor Exit T assumed to be 27 degC				mol wt wet	28.1477		total w/o solid fuel
18	**moles of H2O/100g												Vacuum Roto T assumed to be 23 degC				mdot duct	304.864		total w/o solid fuel
19	Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum % ft. size inge	D50 calc	Size Range micrometers (default)		Temperature, deg C bare T/C	Pyro	HVTC								
20																	PROBE INLET CONDITONS, W/O SOLID FUEL			
21																	dens@inlet	1256.518	g/m^3	
22	Preseperator						10.00	10.0 & up	B				mdot 2ndary	-2.6242	g/min, air		vduct	7.48	meters/min	
23	0						0.00	9.0 - 10.0	C				Target EAA Flowrate	58.5802	g/min, air		mdot inlet	1.5072	g/min	AT ISOKINETIC CONDITIONS
24	1						0.00	8.0 - 9.0	D				Approx.Total Flow Impactr	55.942	g/min, air					
25	2						0.00	4.7 - 8.0	E								DILUENT GAS CONDITIONS			
26	3						0.00	3.3 - 4.7	F								mdot dil rot	1.96202	g/min, air	50 psi, SS float
27	4						0.00	2.1 - 3.3	G				Ana. Vac. Roto	0.11291	g/min, air		O2	0.014	moles/min	diluent air only
28	5						0.00	1.1 - 2.1	H				Ana. sPr. Roto:	0	g/min, air		N2	0.054	moles/min	diluent air only
29	6						0.00	0.7 - 1.1	I				Vacuum Pump In/Out error:	0.11291	g/min, air		CO2	2.4E-05	moles/min	diluent air only
30	7						0.00	0.4 - 0.7	J								mol wt. dil.	28.9403	g/mol	diluent air only
31	Backup Filter						0.10	0 - 0.4	K				BACKFIRE BURNERS							
32	Ana. Filter									Est. stg K temp. if unavailable							IMPACTOR, W/O SOLID FUEL (based on isokinetic conditions)			
33			total mass		(Presep to backup filter, no Ana filter)								mdotBF1 CH4	7.50706	g/min		Avg. mol wt	28.5353	g/mol	dil air and comb gas, no wood
34													mdotBF1 Air	168.473	g/min		dens@imp s	1273.820	g/m^3	rho=P/(R*T), P=1atm
35	Sampling Conditions,				EAA Bin	pAmp*10							phi	1.308	A/F equiv ratio		mdot imp	3.46922	g/min	
36	Undiluted		Diluted		1								mdotA/mdotF	22.4419			volflwimp	0.0027	m^3/min	mdotimp/dens@imp inlet
37	Roto P, en cert.			in Hg (vac)	2												volflwimp	0.096	ft^3/min	
38	2ndary vac Roto:			units	3								mdotBF2 CH4	0	g/min					
39	Ana. Vac. Roto:			mm	4								mdotBF2 Air	550.546	g/min		2NDARY VAC ROTO, W/O SOLID FUEL			
40	Ana. sPr. Roto:			SCFH	5								phi	#DIV/0!	A/F equiv ratio		dens@roto	1159.176	g/m^3	rho=P/(R*T), vac gage
41	CO2% by vol			wet/dry	6								mdotA/mdotF	#DIV/0!			mdot 2ndar	-2.6382	g/min	dil air and comb. gas, no wood
42	Iso Dil. Roto:			mm	7															
43	Iso Dil. Rote P:			psig	8								MAIN BURNER				TUNNEL CONDITIONS, W/SOLID FUEL			
44	Imp. Inl T:			degC	9												CO2	0.584	moles/min	total, w/ solid fuel, no ash
45	Target Impactor Inlet Flow:			SCFM	10								*mdot CH4*	9.348	g/min		H20	1.169	moles/min	total, w/ solid fuel, no ash
46					11								*mdot Main Air*	232.384	g/min		N2	8.094	moles/min	total, w/ solid fuel, no ash
47													phi	1.449	A/F equiv ratio		SO2	0.000	moles/min	total, w/ solid fuel, no ash
48													mdotA/mdotF	24.859	g/g		O2	0.984	moles/min	total, w/ solid fuel, no ash
49	Turned up BFING to 18% at 1:00pm on 11/24/99, from 17%												CO2	0.584	moles/min		Dry O2	10.185	vol%	total, w/ solid fuel, no ash
50													H20	1.169	moles/min		H20 wt	0.069	mass fractk	total, w/ solid fuel, no ash
51													N2	8.365	moles/min		mol wt wet	28.148	g/mol	total, w/ solid fuel, no ash
52													O2	0.524	moles/min		mdot duct	304.864	g/min	total, w/ solid fuel, no ash
53													DryO2w/o inj	7.015	vol%					
54													[redacted]				PROBE INLET CONDITIONS, W/ SOLID FUEL			
55																	dens@inlet	1256.518	g/m^3	Sample probe inlet
56																	vduct	7.48	meters/min	u=mdot/(rho*A), @probe loc.
57																	mdot inlet	1.5072	g/min	AT ISOKINETIC CONDITIONS
58																				
59																	IMPACTOR, W/ SOLID FUEL (based on isokinetic conditions)			
60																	Avg. mol wt	28.5353	g/mol	dil air and comb. gas, no wood
61																	dens@imp s	1273.820	g/m^3	rho=P/(R*T), P=1atm
62																	mdot imp	3.46922	g/min	
63																	volflwimp	0.0027	m^3/min	mdotimp/dens@imp inlet
64																	volflwimp	0.096	ft^3/min	
65																				
66																	2NDARY VAC ROTO, W/ SOLID FUEL			
67																	dens@roto	1159.176	g/m^3	rho=P/(R*T), vac gage
68	total mass																mdot 2ndar	-2.6382	g/min, air	dil air and comb. gas, no wood
69																				

Table F.35(cont.): Test 112596T

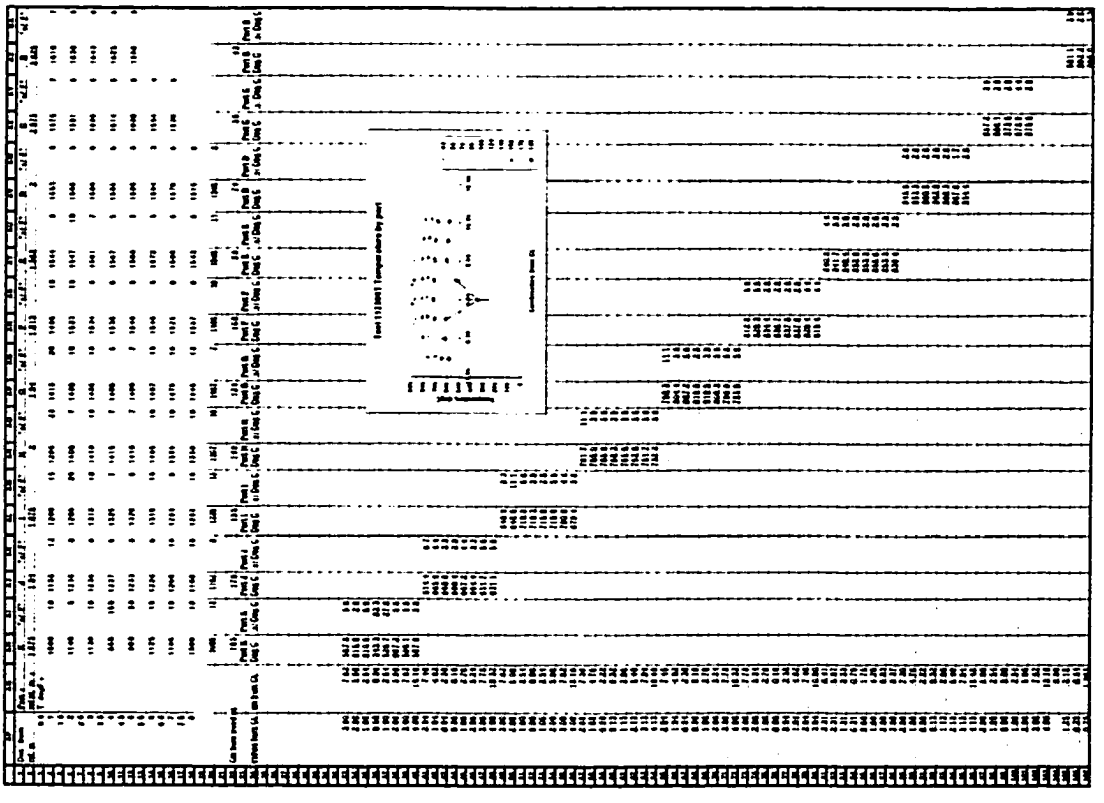


Table F.36: Test 11269601

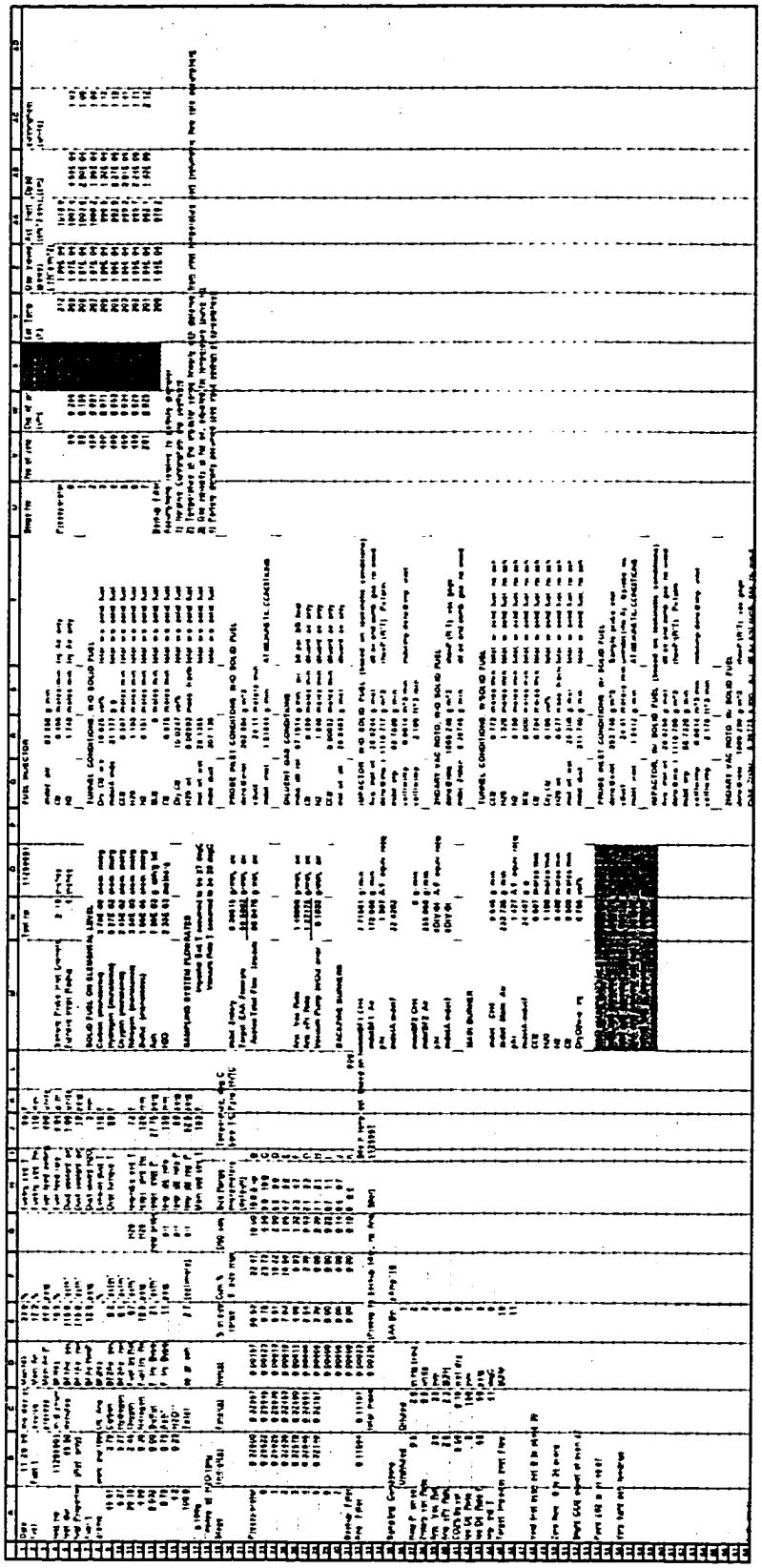


Table F.37: Test 11279601

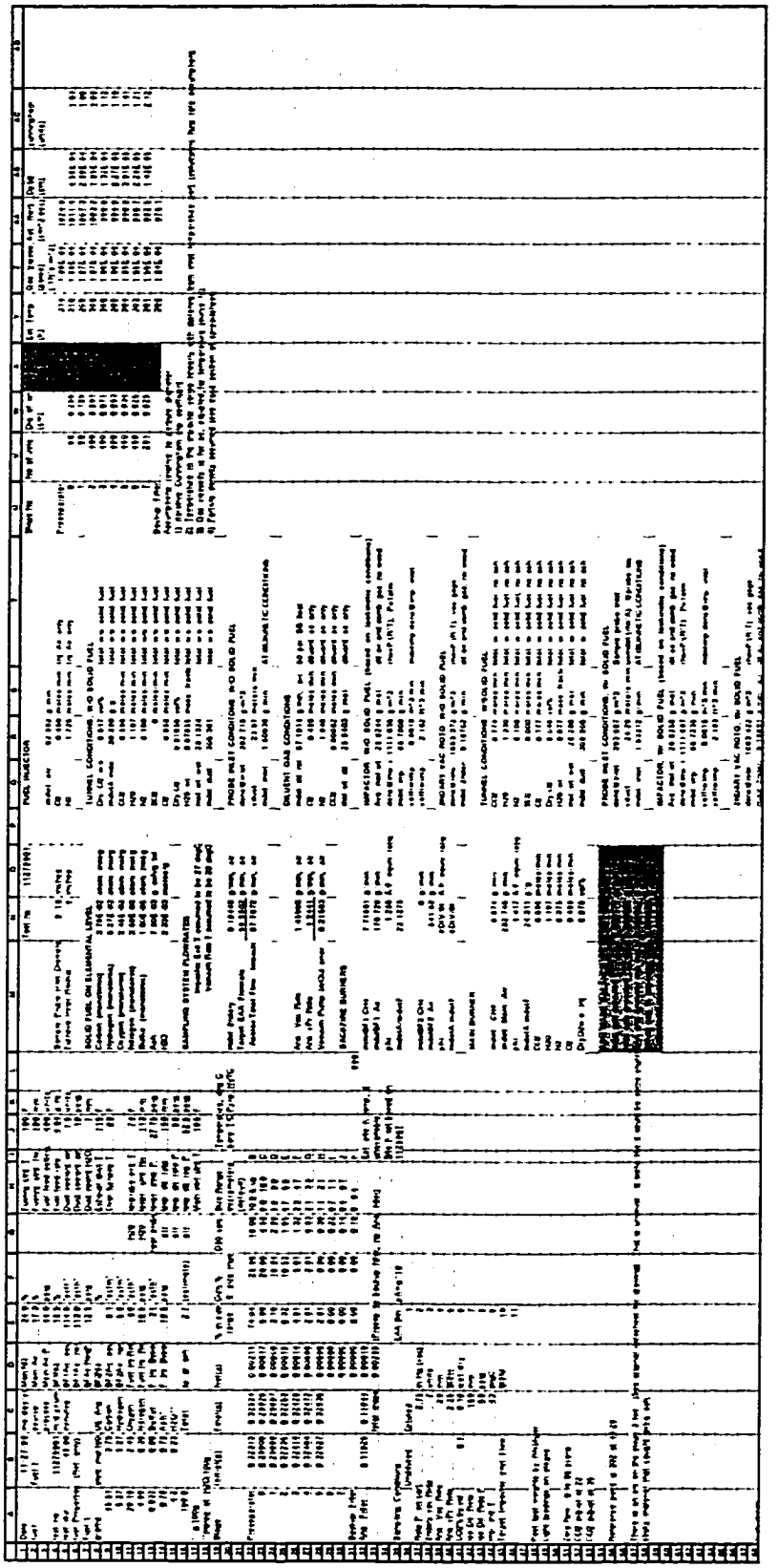


Table F.38: Test 11279602

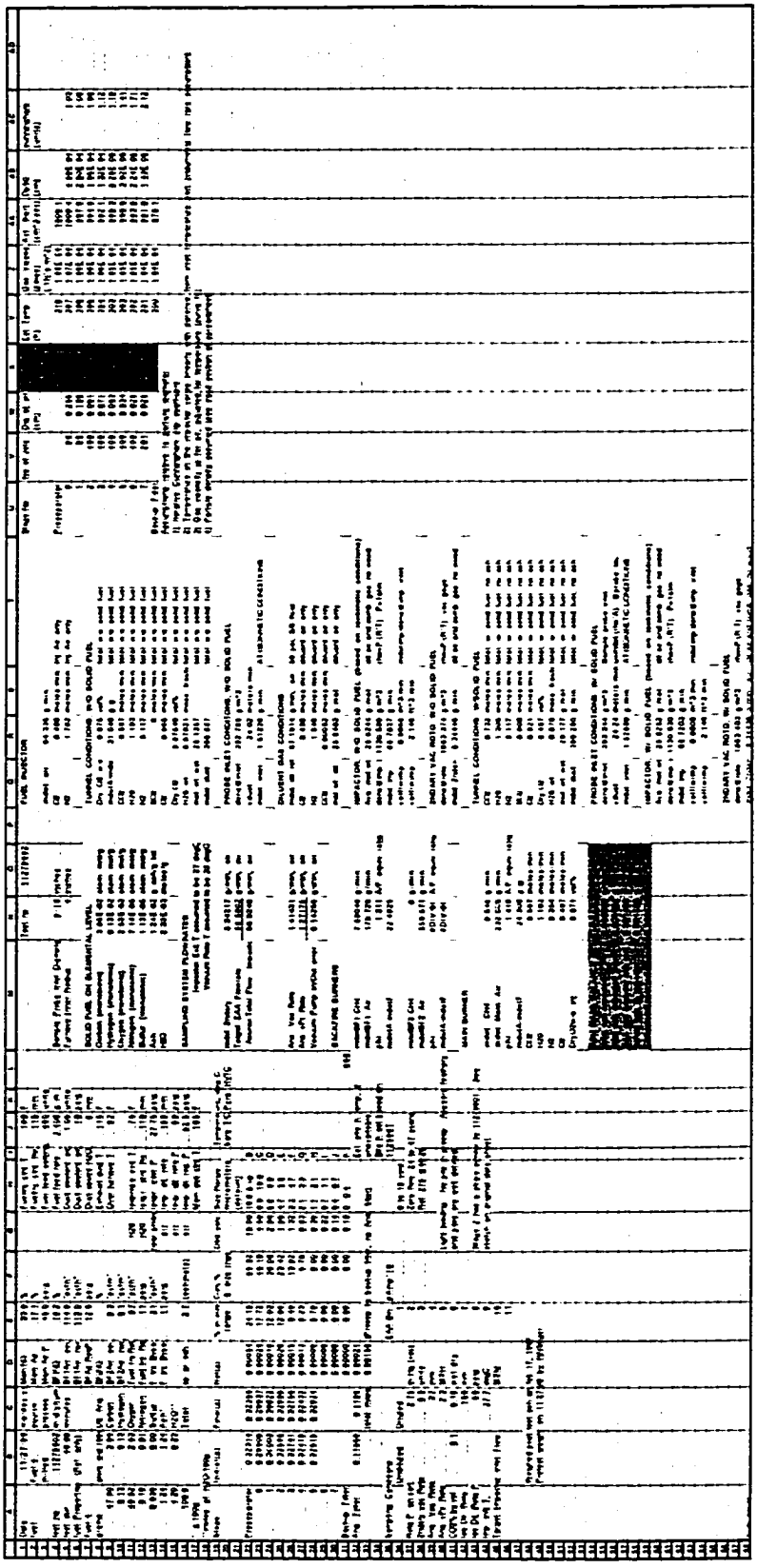
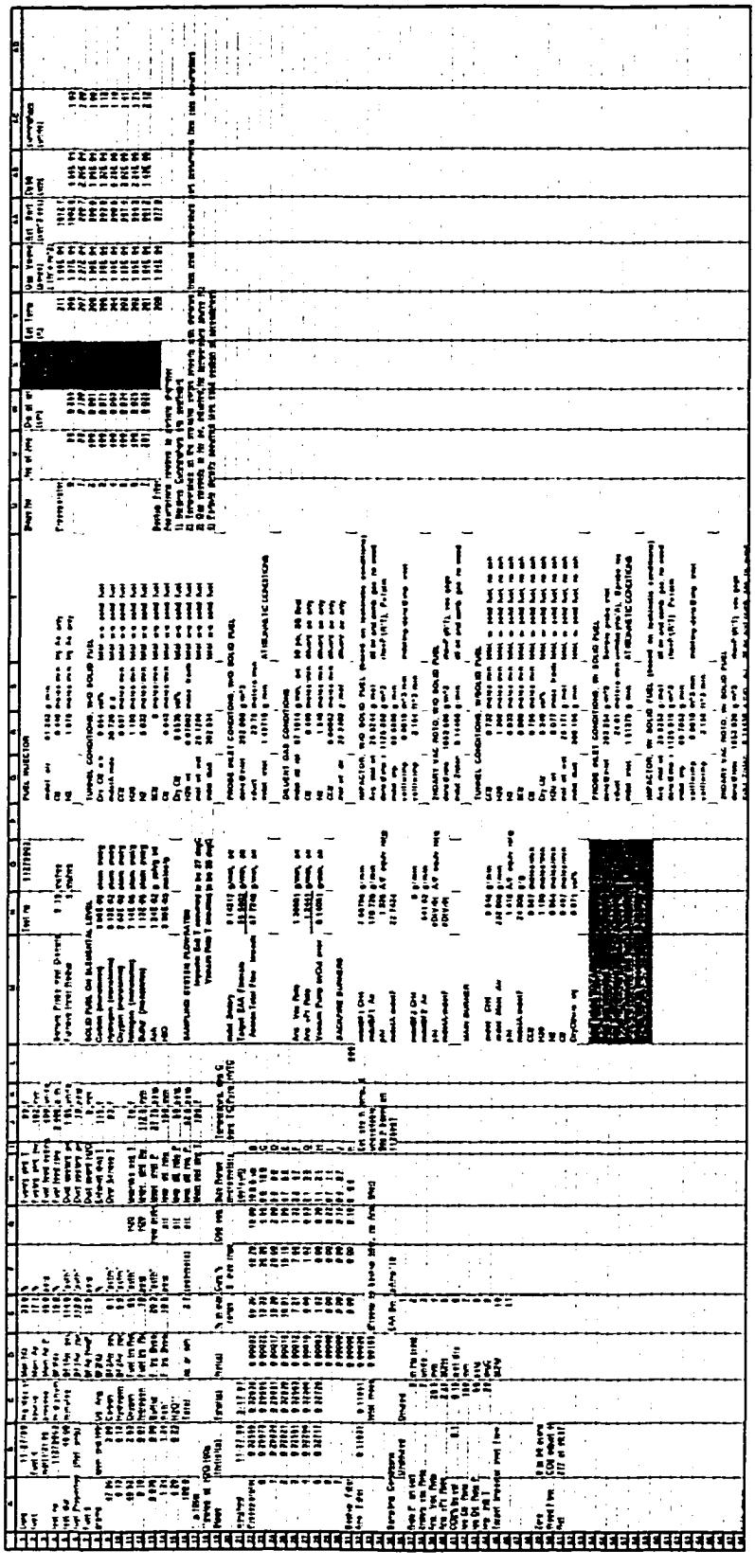


Table F.39: Test 11279603



APPENDIX G: PULVERIZED COAL CASCADE IMPACTOR TEST SUMMARIES

The spreadsheets that follow summarize the detailed measurements and calculations required to determine the size distribution of ash for pulverized coal fuels. These experiments were conducted with a natural-gas fired furnace. Ash samples were collected with a simple water cooled sampling probe and size-sorted with a Mark II cascade impactor.

Table G.1: Test log for pulverized coal experiments

Test Number	Fuel	Solid Fuel Modification	Furnace Flowrate, g/m (no solid fuel)	A/F equiv	Upper Aux A/F equiv	Dry O2%, no fuel	Dry O2%, w/fuel	Upper Temp, C	Lower Temp, C	Sample Temp, C	Sample Time, min
Horizontal Probe Tests											
05219401	Upper Freeport	raw	489.0	1.7	1.6	9.2	8.8	1058	621	350	15
05239401	Upper Freeport	raw	492.3	1.7	1.5	9.2	8.8	1057	625	325	15
05249401	Upper Freeport	raw	492.3	1.7	1.5	9.2	8.8	1045	624	325	15
05269401	Upper Freeport	cleaned	492.0	1.7	1.6	9.4	9.0	1063	628	360	15
05269402	Upper Freeport	cleaned	492.0	1.7	1.5	9.4	9.0	1058	623	365	15
05279401	Upper Freeport	cleaned	483.5	1.7	1.6	9.2	8.7	1075	623	350	15
06019401	Upper Freeport	37 - 85 μm	492.1	1.7	1.5	9.3	9.3	1058	642	330	15
05049401	Kentucky #11	raw	494.7	1.7	1.6	9.5	9.1	1060	612	308	15
05059401	Kentucky #11	raw	494.7	1.7	1.6	9.5	9.5	1060	612	308	15
05069401	Kentucky #11	raw	494.7	1.7	1.0	9.5	9.5	1060	688	375	15
06029401	Kentucky #11	37 - 85 μm	492.0	1.7	Off	9.4	9.0	1068	637	350	15
05109401	Illinois #6	raw	488.9	1.7	1.6	9.3	8.9	1058	603	325	15
05119401	Illinois #6	raw	483.0	1.7	1.6	9.2	8.8	1050	634	350	15
05129401	Illinois #6	raw	494.7	1.7	1.6	9.5	9.1	1063	632	350	15
05139401	Illinois #6	raw	488.9	1.7	1.6	9.3	8.9	1050	632	350	15
05209401	Illinois #6	raw	494.8	1.7	1.6	9.4	9.0	1065	623	372	15
05319401	Illinois #6	37 - 85 μm	492.0	1.7	1.5	9.4	9.0	1068	630	330	15
Vertical Probe Tests											
09159401	Upper Freeport	raw	507.6	1.8	1.7	9.8	9.4	1190	575	700	15
09169401	Upper Freeport	raw	516.2	1.8	1.7	10.0	9.6	1180	575	700	15
10169401	Upper Freeport	raw	517.6	1.7	1.7	9.0	8.6	1245	660	813	15
10219401	Upper Freeport	raw	519.2	1.7	1.7	9.1	8.7	1243	662	807	15
10259401	Upper Freeport	raw	519.8	1.7	1.7	9.0	8.6	1245	663	805	15
11149401	Upper Freeport	< 18 μm	518.9	1.7	1.7	9.2	8.8	1246	649	798	15
11149402	Upper Freeport	< 18 μm	518.9	1.7	1.7	9.2	8.8	1246	649	798	15
11169401	Upper Freeport	< 18 μm	519.1	1.7	1.7	9.1	8.7	1238	633	777	5
11219401	Upper Freeport	< 18 μm	519.1	1.7	1.7	9.1	8.7	1244	646	798	5
11079401	Upper Freeport	18 - 37 μm	518.7	1.7	1.7	9.0	8.6	1243	650	798	15
11109401	Upper Freeport	18 - 37 μm	521.7	1.7	1.7	9.1	8.7	1250	656	800	15
11119401	Upper Freeport	18 - 37 μm	519.2	1.7	1.7	9.1	8.7	1239	649	798	15
11039401	Upper Freeport	37 - 85 μm	517.5	1.7	1.7	9.1	8.7	1254	650	800	15
11049401	Upper Freeport	37 - 85 μm	519.2	1.7	1.7	9.0	8.6	1245	661	800	15
11289401	Upper Freeport	> 85 μm	517.6	1.7	1.7	9.0	8.6	1249	646	795	5
12029401	Upper Freeport	> 85 μm	520.5	1.7	1.7	9.0	8.5	1245	647	791	5
12079401	Upper Freeport	> 85 μm	519.3	1.7	1.6	9.0	8.6	1250	648	793	1
10139401	Kentucky #11	raw	519.2	1.7	1.7	9.0	8.6	1249	663	813	15
10149401	Kentucky #11	raw	519.8	1.7	1.7	9.0	8.7	1250	662	817	15
09089401	Kentucky #11	raw	517.8	1.8	1.6	10.1	9.7	1190	560	655	15
09099401	Kentucky #11	raw	516.2	1.8	1.6	10.0	9.6	1180	560	680	15
10079401	Kentucky #11	raw	514.7	2.0	1.7	11.1	10.8	1125	628	759	15
10119401	Kentucky #11	raw	514.5	2.0	1.7	11.2	10.9	1118	623	744	15
09219401	Illinois #6	raw	516.4	1.8	1.7	9.9	9.5	1180	580	700	15
09239401	Illinois #6	raw	516.4	1.8	1.7	9.9	9.5	1185	595	725	15
10069401	Blank	-	512.9	1.9	1.7	10.5	10.5	1173	635	770	15

Table G.2: Test 05049401

Date	5/4/94	mo/day/yr	Main NG	57.0	%	Upper T	1060	o									
Coal	Kentucky #11	source	Main Air	41.0	%	Sample T	308	o									
	raw	process		29.5	psig	Lower T	912	o									
test no	05049401	m/d/ynum	BF1NG	44.0	%	Coal feed	820	units	imp init diam	0.5625	inches						
test dur	15.00	minutes	BF1Air	4.5	units,front	Coal feed cor	1.1	g/m	Mainduct rad	4	inches						
Coal Properties	(Ref. only)			4.5	units, back	Vacuum Rdg		%	Main Gas Rdg	0.57	fraction	mdot CH4	18.050	g/min			
Kentucky #11			BF2NG		%	Vacuum Rdg		in hg	Main Air Rdg	0.41	fraction	mdot Main A	478.643	g/min			
grams	atomwt/100g		BF2Air		units,front	atomizer air		units	Main Air Rdg	29.5	psig	phi	1.738	units			
57.73	4.81				units, back	atomizer air		psig	Inj. Air Rdg	0	%	mole fract	1.003				
4.42	4.42		Inj. Rdg		%	atomizer H2O		mm	Inj Air Rdg	0	psig	CO2	1.003	moles/min	CH4&Air only		
7.64	0.48		Inj. Rdg		psig	exit duct T		F				H20	2.006	moles/min	CH4&Air only		
1.29	0.09					over furn T		F	Coal Composition on Elemental level			N2	13.110	moles/min	CH4&Air only		
4.22	0.13								Carbon(mon	4.81	moles/100g	O2	1.460	moles/min	CH4&Air only		
20.96	20.96								Hydrogen (r	4.42	moles/100g	mdot air inj	0.000	g/min			
3.84	0.21								Oxygen (mo	0.48	moles/100g	O2	0.000	moles/min	inj Air only		
100.1									Nitrogen (m	0.09	moles/100g	N2	0.000	moles/min	inj Air only		
									Sulfur(mon)	0.13	moles/100g	Dry O2 w/in	9.494	vol%	tot w/o coal		
									Ash	20.96	g/100g	DryO2w/o ir	9.494	vol%	t w/o coal&inj		
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum % fr size rnge	Size Range micrometers	ECD micro m		H2O	0.21	moles/100g	Coal Fractio	0.011	mdotcoal/100g			
												CO2	1.058	moles/min	total		
									mdot coal	1.1	g/min	H20	2.033	moles/min	total		
Preseparator	0.00000	0	0.00000	0.00	100.00	100 & up	10		Probe inlet T	308	deg/C	N2	13.110	moles/min	total		
0	0.29083	0.29091	0.00008	17.86	82.14	90 -100	9		Impactor Inl	100	deg/C (est. T	SO2	0.0015	moles/min	total		
1	0.21159	0.21968	0.00809	23.77	58.37	58 - 90	5.8		Vacuum Rdg	0	in Hg	O2	1.417	moles/min	total		
2	0.30958	0.31381	0.00423	12.43	45.95	47 - 58	4.7		Vacuum Rdg	23	deg/C (est. T	Dry O2	9.089	vol%			
3	0.31057	0.31913	0.00856	25.15	20.80	33 - 47	3.3		Vacuum Rdg	0	CFH	H20 wt	0.074	mass fraction			
4	0.30861	0.31375	0.00514	15.10	5.70	21 - 33	2.1		coal flow lim	15	min	Equiv. Ratio	1.738	w/inj, no solid fuel			
5	0.31074	0.311	0.00026	0.76	4.94	11 - 21	1.1					mol wt wet	28.130	g/mol			
6	0.30934	0.3094	0.00006	0.18	4.76	07 - 11	0.7					dens@inlet	890.030	g/m^3			
7	0.31110	0.31115	0.00005	0.15	4.61	04 - 07	0.4					mdot duct	495.562	g/min	minus ash		
Backup Filter	0.66383	0.6654	0.00157	4.61	0.00	0 -04	0					vduct	25.899	meters/min			
												vduct	1.413	l/sec			
		total mass	0.03404						dens@STP	1202.10	g/m^3	dens@Imp	919.069	g/m^3			
									BACKFIRE BURNERS			mol wt dry	29.451	g/mol			
												dens@rota	1212.548	g/m^3			
Notes	1) Moisture in the cascader starting at stage 3 and going all the way to the								mdotBF1 CH4	18.350647	g/min	volflowrotame	0.000	m^3/min			
	filter								mdotBF1 Air	517.729344	g/min	volflowrotame	0.000	l/^3/min			
	2) Ash was brownish gray								phi	1.644	A/F equiv ratio						
	3) BF1 was running at a low firing rate (about 25,000 BTUs)								mdotA/mdotF	28.2131365		mdotimp	0.000	g/min			
	4) Ran with 2 filters stuck together: oops											mdotimp	0.000	g/min			
									mdotBF2 CH4	0	g/min	volflowimp	0.000	m^3/min			
									mdotBF2 Air	0	g/min	volflowimp	0.000	l/^3/min			
									phi	#DIV/0!	A/F equiv rati	vinlet	0.000	m/min			
									mdotA/mdotF	#DIV/0!		vinlet	0.000	l/sec			
												mdotcoal	0.00000	g/min			
									actual ash	0.03404	g	expected ash	0.0000	g			
												%Diff ash	100.000	%	based on actual		

Table G.3: Test 05059401

Date	5/5/94	mo/day/yr	Main NG	57 0	%	Upper T.	1060	c									
Coal	Kentucky #11	source	Main Air	41 0	%	Sample T.	306	C (est)									
	raw	process		29 5	psig	Lower T.	912	C (est)									
test no	05059401	m/d/ynum	BF1NG	44 0	%	Coal feed	820	units	inj inlt diam	0 5625	inches						
test dur	15 00	minutes	BF1Air	4 5	units,front	Coal feed corr	1 1	g/m	Mainduct rad	4	inches						
Coal Properties	(Ret only)			4 5	units, back	Vacuum Rota		%	Main Gas Ro	0 57	fraction	mdot CH4	16 050	g/min			
			BF2NG		%	Vacuum Rota		in hg	Main Air Rot	0 41	fraction	mdot Main A	478 643	g/min			
grams	moles/100g		BF2Air		units,front	atomizer air		units	Main Air Rot	29 5	psig	phi	1 738	units			
					units, back	atomizer air		psig	Inj Air Rota	0	%	mole fract	1 003				
			Inj Rota		%	atomizer H2O		mm	Inj Air Rota	0	psig	O02	1 003	moles/min	CH4&Air only		
			Inj Rota		psig	exit duct T		F				H20	2 006	moles/min	CH4&Air only		
						over furn T		F	Coal Composition on Elemental level			N2	13 110	moles/min	CH4&Air only		
									Carbon(mon	0 00	moles/100g	O2	1 480	moles/min	CH4&Air only		
									Hydrogen (n	0 00	moles/100g	mdot air inj	0 000	g/min			
									Oxygen (mo	0 00	moles/100g	O2	0 000	moles/min	Inj Air only		
									Nitrogen (m	0 00	moles/100g	N2	0 000	moles/min	Inj Air only		
									Sulfur(mon)	0 00	moles/100g	Dry O2 w/in	9 494	vol%	tot w/o coal		
Stage	Initial(g)	Final(g)	Net(g)	% in size	Cum %	Size Range	ECD		Ash	0 00	g/100g	DryO2w/o ir	9 494	vol%	t w/o coal&inj		
				range	fl size mpe	micrometers	micro m		H2O	0 00	moles/100g	Coal Fractio	0 011	mdotcoal/100g			
												O02	1 003	moles/min	total		
Presepartor	0 00000	0	0 00000	0 00	100 00	10 0 & up	10		mdot coal	1 1	g/min	H20	2 006	moles/min	total		
0	0 28470	0 29084	0 00614	18 84	81 16	9 0 -10 0	9		Probe inlet T	308	degC	N2	13 110	moles/min	total		
1	0 29736	0 29465	0 00729	22 37	58 79	5 8 - 9 0	5 8		Impactor Inl	100	degC (est	SO2	0 0000	moles/min	total		
2	0 30704	0 31053	0 00349	10 71	48 08	4 7 - 5 8	4 7		Vacuum Rot	0	in Hg	O2	1 480	moles/min	total		
3	0 31071	0 31758	0 00687	21 08	27 00	3 3 - 4 7	3 3		Vacuum Rot	23	degC (est	Dry O2	9 494	vol%			
4	0 30950	0 31524	0 00574	17 61	9 39	2 1 - 3 3	2 1		Vacuum Rot	0	CFH	H20 wt	0 073	mass fraction			
5	0 30872	0 3107	0 00198	6 08	3 31	1 1 - 2 1	1 1		coal flow rat	15	min	Equiv. Ratio	1 738	w/in, no solid fuel			
6	0 30758	0 30789	0 00031	0 95	2 36	0 7 - 1 1	0 7					mol wt wet	28 108	g/mol			
7	0 30891	0 30906	0 00015	0 46	1 90	0 4 - 0 7	0 4					dens@inlet	589 590	g/m^3			
Backup Filter	0 33439	0 33501	0 00062	1 90	0 00	0 -0 4	0					mdot duct	495 792	g/min	minus ash		
												vduct	25 931	meters/min			
		total mass	0 03259									vduct	1 415	l!/sec			
									dens@STP	1202 10	g/m^3	dens@inp	918 369	g/m^3			
									BACKFIRE BURNERS			mol wt dry	29 409	g/mol			
												dens@inlet	1210 815	g/m^3			
Notes	1) No moisture in any stages - cascader system was preheated to 100 C								mdotBF1 CH4	16 350647	g/min	vol!!meter	0 000	m^3/min			
!!=thousands	2) Ash was brownish gray								mdotBF1 Air	517 729344	g/min	vol!!meter	0 000	l!^3/min			
	3) BF1 was running at a low firing rate (about 25,000 BTU's)								phi	1 644	A/F equiv ratio						
	4) Only took T at top of reactor - same settings as May 4 test, so T should be same								mdotAirmdotF	29 2131305		mdotrota	0 000	g/min			
												mdotimp	0 000	g/min			
									mdotBF2 CH4	0	g/min	vol!!vimp	0 000	m^3/min			
									mdotBF2 Air	0	g/min	vol!!vimp	0 000	l!^3/min			
									phi	#DIV/0!	A/F equiv rati	vinlet	0 000	m/min			
									mdotAirmdotF	#DIV/0!		vinlet	0 000	l!/sec			
												mdotcoal	0 00000	g/min			
									actual ash	0 03259	g	expected as	0 0000	g			
												%Diff ash	100 000	%	based on actual		

Table G.4: Test 05069401

Date	5/6/94	mo/day/yr	Main NG	57 0	%	Upper T	1060	c									
Coal	Kentucky #11	source	Main Air	41 0	%	Sample T	375	c									
	raw	process		29 5	psig	Lower T	698	c									
test no	05069401	m/d/ynum	BF1NG	75 0	%	Coal feed	820	units	inp inlt diam	0 5625	inches						
test dur.	15 00	minutes	BF1Air	4 5	units,(front	Coal feed cor	1 1	g/m	Maindvct rad	4	inches						
Coal Properties	(Ref. only)			4 5	units, back	Vacuum Rota		%	Main Gas Ro	0 57	fraction	mdot CH4	16 050	g/min			
			BF2NG		%	Vacuum Rota		in hg	Main Air Rot	0 41	fraction	mdot Main A	478 643	g/min			
grams	moles/100g		BF2Air		units,(front	atomizer air		units	Main Air Rot	29 5	psig	phi	1 736	units			
					units, back	atomizer air		psig	Inj Air Rota	0	%	mole fract	1 003				
			Inj Rota		%	atomizer H2O		mm	Inj Air Rota	0	psig	CO2	1 003	moles/min	CH4&Air only		
			Inj Rota		psig	exit duct T		F				H20	2 006	moles/min	CH4&Air only		
						over furn T		F	Coal Composition on Elemental level			N2	13 110	moles/min	CH4&Air only		
									Carbon(mon	0 00	moles/100g	O2	1 480	moles/min	CH4&Air only		
									Hydrogen (n	0 00	moles/100g	mdot air inj	0 000	g/min			
									Oxygen (mo	0 00	moles/100g	O2	0 000	moles/min	Inj Air only		
									Nitrogen (m	0 00	moles/100g	N2	0 000	moles/min	Inj Air only		
									Sulfur(mon	0 00	moles/100g	Dry O2 w/in	9 494	vol%	tot w/o coal		
									Ash	0 00	g/100g	DryO2w/o Ir	9 494	vol%	t w/o coal&Inj		
Stage	Initial(g)	Final(g)	Net(g)	% in size	Cum %	Size Range	ECD		H2O	0 00	moles/100g	Coal Fractio	0 011	mdotcoal/100g			
				range	ft size mge	micrometers	micro m					CO2	1 003	moles/min	total		
Presepersior	0 00000	0	0 00000	0 00	100 00	10 0 & up	10		mdot coal	1 1	g/min	H20	2 006	moles/min	total		
0	0 28537	0 27935	0 00813	21 97	78 03	9 0 -10 0	9		Probe inlet T	375	degC	N2	13 110	moles/min	total		
1	0 29026	0 29951	0 00625	22 29	55 74	5 8 - 9 0	5 8		Impactor Int	100	degC (est. T	SO2	0 0000	moles/min	total		
2	0 30238	0 30654	0 00416	11 24	44 50	4 7 - 5 8	4 7		Vacuum Rot	0	in Hg	O2	1 480	moles/min	total		
3	0 30149	0 30957	0 00808	21 83	22 67	3 3 - 4 7	3 3		Vacuum Rot	23	degC (est. T	Dry O2	9 494	vol%			
4	0 30225	0 30743	0 00518	14 00	8 67	2 1 - 3 3	2 1		Vacuum Rot	0	OFF	H20 wt	0 075	mass fraction			
5	0 30166	0 30336	0 00170	4 59	4 08	1 1 - 2 1	1 1		coal flow tim	15	min	Equiv Ratio	1 736	w/in, no solid fuel			
6	0 30321	0 30338	0 00017	0 46	3 62	0 7 - 1 1	0 7					mol wt wet	28 108	g/mol			
7	0 30513	0 30521	0 00008	0 22	3 40	0 4 - 0 7	0 4					dens@inlet	628 629	g/m^3			
Backup Filter	0 33322	0 33448	0 00126	3 40	0 00	0 -0 4	0					mdot duct	495 792	g/min	minus ash		
												vduct	26 921	meters/min			
		total mass	0 03701									vduct	1 578	ft/sec			
									dens@STP	1202 10	g/m^3	dens@inp	818 369	g/m^3			
									BACKFIRE BURNERS			mol wt dry	29 409	g/mol			
												dens@roto	1210 815	g/m^3			
Notes	1) No moisture in any stages - cascader system was preheated to 100 C								mdotBF1 CH4	31 2795119	g/min	volflwratero	0 000	m^3/min			
	2) Ash was brownish gray								mdotBF1 Air	517 729344	g/min	volflwratero	0 000	ft^3/min			
	3) BF1 exit duct is red hot through the kaowool -Pyro says 989 C								phi	0 966	A/F equiv ratio						
	4) Pyro at lower T port - 830 C								mdotAirmdotF	16 5517079		mdotroto	0 000	g/min			
	5) Pyro at upper T port - 905 C											mdotimp	0 000	g/min			
	6) Pump tested for 1 ACFM at room temp and press								mdotBF2 CH4	0	g/min	volflwimp	0 000	m^3/min			
									mdotBF2 Air	0	g/min	volflwimp	0 000	ft^3/min			
									phi	#DIV/0!	A/F equiv rati	viniet	0 000	m/min			
									mdotAirmdotF	#DIV/0!		viniet	0 000	ft/sec			
												mdotcoal	0 00000	g/min			
									actual ash	0 03701	g	expected as	0 0000	g			
												%Diff ash	100 000	%	based on actual		

Table G.5: Test 05109401

Date:	5/10/94	mo/day/y	Main NG	57.0	%	Upper T	1057.5	c								
Coal:	Illinois #6	source	Main Air	40.5	%	Sample T	325	c								
	raw	process		29.5	psig	Lower T:	603	c								
test no	05109401	m/d/ynum	BF1NG	45.0	%	Coal feed	820	units		imp inlt dian	0.5625	inches				
test dur:	15.00	minutes	BF1Air:	4.4	units,front	Coal feed con	1.1	g/m		Mainduct rad	4	inches				
Coal Properties (Ref only)				4.4	units, back	Vacuum Roto		%		Main Gas Ro	0.57	fraction	mdot CH4	16.050	g/min	
Illinois #6			BF2NG		%	Vacuum Roto		in hg		Main Air Rot	0.405	fraction	mdot Main A	472.606	g/min	
grams	atomwt/100g		BF2Air		units,front	atomizer air		units		Main Air Rot	29.5	psig	phi	1.717	units	
59.87	4.99				units, back	atomizer air		psig		Inj Air Roto	0	%	mole fract	1.003		
4.55	4.55		Inj Roto		%	atomizer H2O		mm		Inj Air Roto	0	psig	CO2	1.003	moles/min	CH4&Air only
8.52	0.53		Inj Roto		psig	exit duct T:		F					H2O	2.006	moles/min	CH4&Air only
1.37	0.10					over furn T:		F		Coal Composition on Elemental level			N2	12.950	moles/min	CH4&Air only
3.76	0.12									Carbon(mon	4.99	moles/100g	O2	1.438	moles/min	CH4&Air only
8.62	8.62									Hydrogen (m	4.55	moles/100g	mdot air inj	0.000	g/min	
13.31	0.74									Oxygen (mor	0.53	moles/100g	O2	0.000	moles/min	Inj Air only
100										Nitrogen (mo	0.10	moles/100g	N2	0.000	moles/min	Inj Air only
										Sulfur(mon)	0.12	moles/100g	Dry O2 w/	9.342	vol%	tot w/o coal
										Ash	8.62	g/100g	DryO2w/o	9.342	vol%	t w/o coal&inj
Stage	Initial(g)	Final(g)	Net(g)	% in size	Cum %	Size Range	ECD			H2O	0.74	moles/100g	Coal Fractio	0.011	mdotcoal/100g	
				range	ft size rnge	micrometers	micro m						CO2	1.058	moles/min	total
										mdot coal	1.1	g/min	H2O	2.039	moles/min	total
Preseparator		0	0.00000	0.00	100.00	10.0 & up	10			Probe inlet T	325	degC	N2	12.950	moles/min	total
0	0.28716	0.29124	0.00408	19.80	80.20	9.0 - 10.0	9			Impactor inl	100	degC (est T	SO2	0.0013	moles/min	total
1	0.28665	0.29115	0.00450	21.83	58.37	5.8 - 9.0	5.8			Vacuum Rot	0	in Hg	O2	1.372	moles/min	total
2	0.30925	0.31158	0.00233	11.31	47.06	4.7 - 5.8	4.7			Vacuum Rot	23	degC (est T	Dry O2	8.920	vol%	
3	0.31382	0.31811	0.00429	20.82	26.25	3.3 - 4.7	3.3			Vacuum Rot	0	CFH	H2O wt	0.075	mass fraction	
4	0.30994	0.31307	0.00313	15.19	11.06	2.1 - 3.3	2.1			coal flow tin	15	min	Equiv Ratio	1.717	w/inj, no solid fuel	
5	0.30965	0.31085	0.00120	5.82	5.24	1.1 - 2.1	1.1						mol wt wet	28.119	g/mol	
6	0.31288	0.31302	0.00014	0.68	4.56	0.7 - 1.1	0.7						dens@inlet	573.039	g/m^3	
7	0.30757	0.30765	0.00008	0.39	4.17	0.4 - 0.7	0.4						mdot duct	489.880	g/min	minus ash
Backup Filter	0.33492	0.33578	0.00086	4.17	0.00	0 - 0.4	0						vduct	26.360	meters/min	
													vduct	1.438	ft/sec	
		total mass	0.02061							dens@STP	1202.10	g/m^3	dens@imp	918.706	g/m^3	
										BACKFIRE BURNERS			mol wt dry	29.460	g/mol	
													dens@roto	1212.928	g/m^3	
										mdotBF1 CH4	18.76770712	g/min	volflwraterd	0.000	m^3/min	
Notes	1)	Presep-	0.47864	0.488	0.00836					mdotBF1 Air	506.2242477	g/min	volflwraterd	0.000	ft^3/min	
[illegible]	2)	connector-	0.47276	0.479	0.00624					phi	1.572	A/F equiv ratio				
	3)	Preseparator not added into main spreadsheet, for ease of comparision								mdotA/mdotF	26.97315364		mdotroto	0.000	g/min	
		to tests w/o preseparator data											mdotimp	0.000	g/min	
	4)	Post test check of ambient air flow through cascader (60F) - 60.5								mdotBF2 CH4	0	g/min	volflwimp	0.000	m^3/min	
		SCFH								mdotBF2 Air	0	g/min	volflwimp	0.000	ft^3/min	
										phi	#DIV/0!	A/F equiv ratio	vinlet	0.000	m/min	
										mdotA/mdotF	#DIV/0!		vinlet	0.000	ft/sec	
													mdotcoal	0.00000	g/min	
											0.02061	g	expected ash	0.0000	g	
													%Diff ash	100.000	%	based on actual

Table G.6: Test 05119401

Date	5/11/94	mo/day/yr	Main NG	57 0	%	Upper T	1050	c									
Coal	Illinois #6	source	Main Air	40 0	%	Sample T	350	c									
	raw	process		29 5	psig	Lower T	934	c									
test no	05119401	m/d/ynum	BF1NG	45 0	%	Coal feed	820	units	Imp Init diam	0 5625	inches						
test dur	15 00	minutes	BF1Air	4 4	units,front	Coal feed con	1 1	g/m	Mainduct rad	4	inches						
Coal Properties	(Rel only)			4 4	units, back	Vacuum Roto		%	Main Gas Ro	0 57	fraction	mdot CH4	16 050	g/min			
Illinois #6			BF2NG		%	Vacuum Roto		in hg	Main Air Rot	0 4	fraction	mdot Main A	466 868	g/min			
grams	atomwt/100g		BF2Air		units,front	atomizer air		units	Main Air Rot	29 5	psig	phi	1 696	units			
59 87	4 99				units, back	atomizer air		psig	Inj Air Roto	0	%	mole fract	1 003				
4 55	4 55		Inj Roto		%	atomizer H2O		mm	Inj Air Roto	0	psig	O02	1 003	moles/min	CH4&Air only		
8 52	0 53		Inj Roto		psig	exit duct T		F				H20	2 006	moles/min	CH4&Air only		
1 37	0 10					over furn T		F	Coal Composition on Elemental level			N2	12 790	moles/min	CH4&Air only		
3 76	0 12								Carbon(mon	4 99	moles/100g	O2	1 395	moles/min	CH4&Air only		
8 62	8 62								Hydrogen (m	4 55	moles/100g	mdot air inj	0 000	g/min			
13 31	0 74								Oxygen (mor	0 53	moles/100g	O2	0 000	moles/min	Inj Air only		
100									Nitrogen (mo	0 10	moles/100g	N2	0 000	moles/min	Inj Air only		
									Sulfur(mon)	0 12	moles/100g	Dry O2 w/o	9 187	vol%	tot w/o coal		
									Ash	8 62	g/100g	DryO2w/o I	9 187	vol%	t w/o coal&Inj		
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum % R size mgs	Size Range micrometers	ECD micro m		H2O	0 74	moles/100g	Coal Fractio	0 011	mdot/coal/100g			
												O02	1 058	moles/min	total		
									mdot coal	1 1	g/min	H20	2 039	moles/min	total		
Preseparator			0 00000	0 00	100 00	100 & up	10		Probe inlet T	350	degC	N2	12 790	moles/min	total		
0	0 28457	0 28818	0 00361	18 42	81 58	90 -100	9		Impactor Init	100	degC (est T	SO2	0 0013	moles/min	total		
1	0 29107	0 29525	0 00418	21 33	60 26	58 - 90	5 8		Vacuum Roto	0	in Hg	O2	1 330	moles/min	total		
2	0 31184	0 31387	0 00203	10 67	49 39	47 - 58	4 7		Vacuum Roto	23	degC (est T	Dry O2	8 759	vol%			
3	0 31161	0 31596	0 00435	22 18	27 19	33 - 47	3 3		Vacuum Roto	0	CFH	H20 wt	0 076	mass fraction			
4	0 31178	0 31457	0 00281	14 34	12 86	21 - 33	2 1		coal flow tin	15	min	Equiv Ratio	1 696	w/inj, no solid fuel			
5	0 31330	0 31436	0 00106	5 41	7 45	11 - 21	1 1					mol wt wet	28 110	g/mol			
6	0 31209	0 31228	0 00019	0 97	6 48	07 - 11	0 7					dens@inlet	549 878	g/m^3			
7	0 30856	0 30869	0 00013	0 66	5 82	04 - 07	0 4					mdot duct	484 023	g/min	minus ash		
Backup Filter	0 33149	0 33263	0 00114	5 82	0 00	0 -04	0					vduct	27 143	meters/min			
												vduct	1 491	ft/sec			
		total mass	0 01960						dens@STP	1292 10	g/m^3	dens@imp	918 428	g/m^3			
									BACKFIRE BURNER8			mol wt dry	28 469	g/mol			
												dens@roto	1213 269	g m^3			
									mdotBF1 CH4	18 787707 12	g/min	vol/liwaterc	0 000	m ^3/min			
Notes	1)	Not much in the preseparator- Not enough to get a good weight							mdotBF1 Air	506 2242477	g/min	vol/liwaterc	0 000	ft^3/min			
[illegible]		measurement using tissue							phi	1 572	A/F equiv ratio						
									mdotA/mdotF	26 97315364		mdot/roto	0 000	g/min			
												mdot/imp	0 000	g/min			
									mdotBF2 CH4	0	g/min	vol/liwimp	0 000	m^3/min			
									mdotBF2 Air	0	g/min	vol/liwimp	0 000	ft^3/min			
									phi	#DIV/0!	A/F equiv rati	v/inlet	0 000	m/min			
									mdotA/mdotF	#DIV/0!		v/inlet	0 000	ft/sec			
												mdot/coal	0 00000	g/min			
									actual ash	0 0186	g	espected ash	0 0000	g			
												%Diff ash	100 000	%	based on actual		

Table G.7: Test 05129401

Date	5/12/94	mo/day/yr	Main NG	57 0	%	Upper T	1092 5	c									
Coal	Illinois #6	source	Main Air	41 0	%	Sample T	350	C (est)									
	raw	process		29 5	psig	Lower T	832	c									
test no	05129401	m/d/ynum	BF1NG	45 0	%	Coal feed	820	units	imp inlt diam	0 5625	inches						
test dur	15 00	minutes	BF1Air	4 4	units,front	Coal feed pos	1 1	g/m	Mainduct rad	4	inches						
Coal Properties (Raf only)				4 4	units, back	Vacuum Reto		%	Main Gas Flo	0 57	fraction	mdot CH4	16 050	g/min			
Illinois #6			BF2NG		%	Vacuum Reto		in hg	Main Air Rot	0 41	fraction	mdot Main A	478 643	g/min			
grams	atomwt/100g		BF2Air		units,front	atomizer air		units	Main Air Rot	29 5	psig	phi	1 738	units			
59 87	4 99				units, back	atomizer air		psig	Inj Air Reto	0	%	mole fract	1 003				
4 55	4 55		Inj Reto		%	atomizer H2O		mm	Inj Air Reto	0	psig	CO2	1 003	moles/min	CH4&Air only		
8 52	0 53		Inj Reto		psig	exit duct T		F				H20	2 006	moles/min	CH4&Air only		
1 37	0 10					over turn T		F	Coal Composition on Elemental level			N2	13 110	moles/min	CH4&Air only		
3 76	0 12								Carbon(mon	4 99	moles/100g	O2	1 480	moles/min	CH4&Air only		
8 62	8 62								Hydrogen (n	4 55	moles/100g	mdot air inj	0 000	g/min			
13 31	0 74								Oxygen (mo	0 93	moles/100g	O2	0 000	moles/min	inj Air only		
100									Nitrogen (m	0 10	moles/100g	N2	0 000	moles/min	inj Air only		
									Sulfur(mon	0 12	moles/100g	Dry O2 w/in	9 494	vol%	tot w/o coal		
									Ash	8 62	g/100g	DryO2w/o a	9 494	vol%	t w/o coal&inj		
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum % lt size rng	Size Range micrometers	ECD micro m		H2O	0 74	moles/100g	Coal Fractio	0 011	mdotcoal/100g			
												CO2	1 058	moles/min	total		
									mdot coal	1 1	g/min	H20	2 039	moles/min	total		
Presseparator			0 00000	0 00	100 00	100 & up	10		Probe inlet T	350	degC	N2	13 110	moles/min	total		
0	0 29293	0 2945	0 00157	12 59	87 41	90 -100	9		Impactor Inlt	100	degC (est T	SO2	0 0013	moles/min	total		
1	0 28955	0 29217	0 00262	21 01	66 40	66 - 90	6 6		Vacuum Rot	0	in Hg	O2	1 415	moles/min	total		
2	0 31350	0 31493	0 00143	11 47	54 93	47 - 66	4 7		Vacuum Rot	23	degC (est T	Dry O2	9 077	vol%			
3	0 31468	0 31744	0 00276	22 13	32 80	33 - 47	3 3		Vacuum Rot	0	CFH	H20 wt	0 074	mass fraction			
4	0 31666	0 32066	0 00198	15 88	16 92	21 - 33	2 1		coal flow tim	15	min	Equiv. Ratio	1 738	w/inj, no solid fuel			
5	0 31094	0 31173	0 00079	6 34	10 59	11 - 21	1 1					mol wt wet	28 127	g/mol			
6	0 30952	0 30969	0 00017	1 36	9 22	07 - 11	0 7					dens@inlet	850 206	g/m^3			
7	0 30942	0 30956	0 00016	1 28	7 94	04 - 07	0 4					mdot duct	495 698	g/min	minus ash		
Backup Filter	0 33113	0 33212	0 00099	7 94	0 00	0 -04	0					vduct	27 791	meters/min			
												vduct	1 516	ft/sec			
		total mass	0 01247						dens@STP	1292 10	g/m^3	dens@imp	818 978	g/m^3			
									BACKFIRE BURNERS			mol wt dry	29 452	g/mol			
												dens@reto	1212 597	g/m^3			
									mdotBF1 CH4	18 7977071	g/min	volflwretero	0 000	m^3/min			
Notes	1)	1/16" WATER IN THE PRESEPARATOR - TEST LIKELY INVALID							mdotBF1 Air	508 224248	g/min	volflwretero	0 000	ft^3/min			
[illegible]	2)	Plenty of water coming out of pump (1 drop per 10 sec) - Good							phi	1 572	A/F equiv ratio						
		indicator of water in cascader, in the future (?)							mdotAir/mdotF	29 9731539		mdotreto	0 000	g/min			
												mdotimp	0 000	g/min			
									mdotBF2 CH4	0	g/min	volflwimp	0 000	m^3/min			
									mdotBF2 Air	0	g/min	volflwimp	0 000	ft^3/min			
									phi	#DIV/0!	A/F equiv rati	vinlet	0 000	m/min			
									mdotAir/mdotF	#DIV/0!		vinlet	0 000	ft/sec			
												mdotcoal	0 00000	g/min			
									actual ash	0 01247	g	expected as	0 0000	g			
												%Diff ash	100 000	%	based on actual		

Table G.8: Test 05139401

Table G.9: Test 05209401

Date	5/20/94	mo/day/yr	Main NG	57.5	%	Upper T	1065	c									
Coal	Illinois #6	source	Main Air	41.0	%	Sample T	372	c									
	raw	process		29.5	psig	Lower T	623	c									
test no	05209401	m/d/ynum	BF1NG	45.0	%	Coal feed	820	units	emp init diam	0.5625	inches						
test dur	15.00	minutes	BF1Air	4.4	units,front	Coal feed corr	1.1	g/m	Meinduct rec	4	inches						
Coal Properties (Ref. only)				4.4	units, back	Vacuum Roto		%	Main Gas Ro	0.575	fraction	mdot CH4	16.191	g/min			
Illinois #6			BF2NG		%	Vacuum Roto		in hg	Main Air Rot	0.41	fraction	mdot Main A	478.643	g/min			
grams	atomwt/100g		BF2Air		units,front	atomizer air		units	Main Air Rot	29.5	psig	phi	1.723	units			
59.87	4.99				units, back	atomizer air		psig	Inj Air Roto	0	%	mole fract	1.012				
4.55	4.55		Inj Roto		%	atomizer H2O	250	mm	Inj Air Roto	0	psig	CO2	1.012	moles/min	CH4&Air only		
8.52	0.53		Inj Roto		psig	exit duct T		F				H2O	2.024	moles/min	CH4&Air only		
1.37	0.10					over fum T		F				N2	13.110	moles/min	CH4&Air only		
3.76	0.12								Coal Composition on Elemental level			O2	1.483	moles/min	CH4&Air only		
8.62	8.62								Carbon(mon	4.99	moles/100g	mdot air inj	0.000	g/min			
13.31	0.74								Hydrogen (m	4.55	moles/100g	O2	0.000	moles/min	Inj Air only		
100									Oxygen (mo	0.53	moles/100g	N2	0.000	moles/min	Inj Air only		
									Nitrogen (m	0.10	moles/100g	Dry O2 w/in	9.386	vol%	tot w/o coal		
									Sulfur(mon)	0.12	moles/100g	DryO2w/o ir	9.386	vol%	t w/o coal&Inj		
Stage	Initial(g)	Final(g)	Net(g)	% in size	Cum %	Size Range	ECD		Ash	8.62	g/100g						
				range	R. size mpe	micrometers	micro m		H2O	0.74	moles/100g	Coal Fractio	0.011	mdotcoal/100g			
												CO2	1.067	moles/min	total		
Preseparator			0.00000	0.00	100.00	100 & up	10		mdot coal	1.1	g/min	H20	2.057	moles/min	total		
0	0.27967	0.2826	0.00293	17.94	82.06	90 -100	9		Probe inlet T	372	degC	N2	13.110	moles/min	total		
1	0.27904	0.28254	0.00350	21.43	60.62	58 - 90	58		Impactor Inl	100	degC (est. T	SO2	0.0013	moles/min	total		
2	0.30540	0.30722	0.00182	11.15	49.48	47 - 58	47		Vacuum Rot	0	in Hg	O2	1.397	moles/min	total		
3	0.30454	0.30815	0.00361	22.11	27.37	33 - 47	33		Vacuum Rot	23	degC (est. T	Dry O2	8.970	vol%			
4	0.30570	0.30816	0.00246	15.06	12.31	21 - 33	21		Vacuum Rot	0	CFH	H20 wt	0.075	mass fraction			
5	0.30730	0.30808	0.00078	4.78	7.53	11 - 21	11		coal flow in	19	min	Equiv. Ratio	1.723	w/in, no solid fuel			
6	0.30726	0.30738	0.00012	0.73	6.80	07 - 11	07					mol wt wet	28.121	g/mol			
7	0.30788	0.30798	0.00010	0.61	6.18	04 - 07	04					dens@inlet	531.325	g/m^3			
Backup Filter	0.33302	0.33403	0.00101	6.18	0.00	0 -04	0					mdot duct	495.638	g/min	minus ash		
												vduct	28.777	meters/min			
		total mass	0.01633									vduct	1.670	ll/sec			
									dens@STP	1202.10	g/m^3	dens@tmp	918.779	g/m^3			
									BACKFIRE BURNERS			mol wt dry	29.456	g/mol			
												dens@rota	1212.817	g/m^3			
		Impactor flowrate 60 SCFM							mdotBF1 CH4	16.7677071	g/min	volflwrotam	0.000	m^3/min			
Notes	1)	presep	0.9972	0.913	net	0.0058			mdotBF1 Air	508.224248	g/min	volflwrotam	0.000	ll^3/min			
	2)	see attached raw notes							phi	1.572	A/F equiv ratio						
	3)								mdotAirmdotF	29.9731536		mdotrota	0.000	g/min			
	4)											mdotimp	0.000	g/min			
	5)								mdotBF2 CH4	0	g/min	volflwimp	0.000	m^3/min			
	6)								mdotBF2 Air	0	g/min	volflwimp	0.000	ll^3/min			
									phi	#DIV/0!	A/F equiv rati	vinlet	0.000	m/min			
									mdotAirmdotF	#DIV/0!		vinlet	0.000	ll/sec			
												mdotcoal	0.00000	g/min			
									actual ash	0.01633	g	expected as	0.0000	g			
												%Diff ash	100.000	%	based on actual		

Table G.10: Test 05219401

Date	5/21/94	mo/day/yr	Main NG	57.5	%	Upper T	1057.5	c											
Coal	Upper Freepo	source	Main Air	40.5	%	Sample T	350	C(est)											
	raw	process		29.5	psig	Lower T	821	c											
test no	05219401	m/d/y=num	BF1NG	45.0	%	Coal feed	820	units	Inj inlt diam	0.5625	inches								
test dur	15.00	minutes	BF1Air	4.4	units,front	Coal feed con	1.1	g/m	Maindyct rad	4	inches								
Coal Properties (Ref only)				4.4	units, back	Vacuum Roto		%	Main Gas Rot	0.575	fraction		mdot CH4	16.191	g/min				
Upper Freepor			BF2NG		%	Vacuum Roto		in hg	Main Air Rot	0.405	fraction		mdot Main A	472.806	g/min				
grams	moles/100g		BF2Air		units,front	atomizer air		units	Main Air Rot	29.5	psig		phi	1.702	units				
84.57	5.38				units, back	atomizer air		psig	Inj Air Roto	0	%		mole fract	1.012					
4.07	4.07		Inj Roto		%	atomizer H2O	250.0	mm	Inj Air Roto	0	psig		CO2	1.012	moles/min	CH4&Air only			
5.92	0.25		Inj Roto		psig	exit duct T		F					H20	2.024	moles/min	CH4&Air only			
1.83	0.12					over furn T		F	Coal Composition on Elemental level				N2	12.950	moles/min	CH4&Air only			
2.07	0.06								Carbon(mon	5.38	moles/100g		O2	1.420	moles/min	CH4&Air only			
23.23	23.23								Hydrogen (n	4.07	moles/100g		mdot air inj	0.000	g/min				
0.51	0.03								Oxygen (mo	0.25	moles/100g		O2	0.000	moles/min	inj Air only			
100									Nitrogen (m	0.12	moles/100g		N2	0.000	moles/min	inj Air only			
									Sulfur(mon)	0.06	moles/100g		Dry O2 w/in	9.233	vol%	tot w/o coal			
									Ash	23.23	g/100g		DryO2w/o ir	9.233	vol%	t w/o coal&inj			
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % lt size mpe	Size Range micrometers	ECD micro m		H2O	0.03	moles/100g		Coal Fractio	0.011	mdotcoal/100g				
													CO2	1.071	moles/min	total			
									mdot coal	1.1	g/min		H20	2.047	moles/min	total			
Presepartor			0.00000	0.00	100.00	10.0 & up	10		Probe inlet T	350	degC		N2	12.950	moles/min	total			
0	0.27687	0.28328	0.00641	25.73	74.27	9.0 -10.0	9		Impactor Inlt	100	degC (est. T		SO2	0.0007	moles/min	total			
1	0.27879	0.28247	0.00368	22.80	51.47	5.8 - 9.0	5.8		Vacuum Rot	0	in Hg		O2	1.351	moles/min	total			
2	0.30591	0.3089	0.00299	12.00	39.48	4.7 - 5.8	4.7		Vacuum Rot	23	degC (est. T		Dry O2	8.795	vol%				
3	0.30465	0.30923	0.00458	18.39	21.08	3.3 - 4.7	3.3		Vacuum Rot	0	CFH		H20 wt	0.075	mass fraction				
4	0.30151	0.30481	0.00330	13.25	7.83	2.1 - 3.3	2.1		coal flow lim	15	min		Equiv. Ratio	1.702	w/inj. no solid fuel				
5	0.30228	0.30371	0.00143	5.74	2.09	1.1 - 2.1	1.1						mol wt wet	28.121	g/mol				
6	0.30301	0.30311	0.00010	0.40	1.69	0.7 - 1.1	0.7						dens@inlet	550.079	g/m^3				
7	0.30136	0.30142	0.00006	0.24	1.45	0.4 - 0.7	0.4						mdot duct	488.841	g/min	minus ash			
Backup Filter	0.33373	0.33409	0.00036	1.45	0.00	0 -0.4	0						vduct	27.460	meters/min				
													vduct	1.498	lt/sec				
		total mass	0.02491						dens@STP	1202.10	g/m^3		dens@Inj	818.764	g/m^3				
									BACKFIRE BURNERS				mol wt dry	28.499	g/mol				
													dens@roto	1213.238	g/m^3				
Notes:			Init.	final	net				mdotBF1 CH4	16.7977071	g/min		volt/meter	0.000	m^3/min				
	1.)	presep	12.523	12.5584	0.0354				mdotBF1 Air	506.224248	g/min		volt/meter	0.000	lt^3/min				
	2.)	connect	11.7825	11.8031	0.0206				phi	1.572	A/F equiv ratio								
	3.)	probe	12.5	12.516	0.016				mdotAir/mdotF	29.9731536			mdotroto	0.000	g/min				
	4.)	additional notes on original data sheet											mdotimp	0.000	g/min				
	5.)								mdotBF2 CH4	0	g/min		volt/wimp	0.000	m^3/min				
	6.)								mdotBF2 Air	0	g/min		volt/wimp	0.000	lt^3/min				
									phi	#DIV/0!	A/F equiv rati		vinlet	0.000	m/min				
									mdotAir/mdotF	#DIV/0!			vinlet	0.000	lt/sec				
	Gross ash mass in system	0.07																	
													mdotcoal	0.00000	g/min				
									actual ash	0.02491	g		expected as	0.0000	g				
													%Diff ash	100.000	%	based on actual			

Table G.11: Test 05239401

Date	5/23/94	mo/day/yr	Main NG	58 0	%	Upper T	1058 5	c									
Coal	Upper Freepo	source	Main Air	41 0	%	Sample T	325	c									
	raw	process		29 0	psig	Lower T	625	c									
test no	05239401	m/d/ynum	BF1NG	46 0	%	Coal feed	820	units	imp inlt dian	0 5825	inches						
test dur	15 00	minutes	BF1Air	4 4	units,front	Coal feed con	1 1	g/m	Mainduct rac	4	inches						
Coal Properties (Ref only)				4 4	units, back	Vacuum Roto		%	Main Gas Ro	0 58	fraction	mdot CH4	16 331	g/min			
Upper Freepor			BF2NG		%	Vacuum Roto		in hg	Main Air Rot	0 41	fraction	mdot Main A	475 828	g/min			
grams	moles/100g		BF2Air		units,front	atomizer air		units	Main Air Rot	29	psig	phi	1 698	units			
64 57	5 38				units, back	atomizer air		psig	Inl Air Roto	0	%	mole fract	1 021				
4 07	4 07		Inl Roto		%	atomizer H2O	250+	mm	Inl Air Roto	0	psig	CO2	1 021	moles/min	CH4&Air only		
3 92	0 25		Inl Roto		psig	exit duct T:		F				H20	2 041	moles/min	CH4&Air only		
1 63	0 12					over turn T		F	Coal Composition on Elemental level			N2	13 035	moles/min	CH4&Air only		
2 07	0 06								Carbon(mon	5 38	moles/100g	O2	1 425	moles/min	CH4&Air only		
23 23	23 23								Hydrogen (m	4 07	moles/100g	mdot air inj	0 000	g/min			
0 61	0 03								Oxygen (mon	0 25	moles/100g	O2	0 000	moles/min	Inj Air only		
100									Nitrogen (mo	0 12	moles/100g	N2	0 000	moles/min	Inj Air only		
									Sulfur(mon)	0 00	moles/100g	Dry O2 w/o	9 207	vol%	tot w/o coal		
									Ash	23 23	g/100g	DryO2w/o I	9 207	vol%	t w/o coal&inj		
Stage	Initial(g)	Final(g)	Net(g)	% in size	Cum %	Size Range	EQD		H2O	0 03	moles/100g	Coal Fractio	0 011	mdotcoal/100g			
				range	lt size rnge	micrometers	micro m					CO2	1 080	moles/min	total		
									mdot coal	1 1	g/min	H20	2 084	moles/min	total		
Preseparator			0 00000	0 00	100 00	100 & up	10		Probe inlet T	325	degC	N2	13 036	moles/min	total		
0	0 27857	0 28403	0 00746	24 69	75 31	90 -100	9		Impactor Inl	100	degC (est. T	SO2	0 0007	moles/min	total		
1	0 27656	0 28368	0 00712	23 56	51 75	58 - 90	5 8		Vacuum Roto	0	in Hg	O2	1 356	moles/min	total		
2	0 30196	0 30536	0 00340	11 25	40 50	47 - 58	4 7		Vacuum Rot	23	degC (est. T	Dry O2	9 762	vol%			
3	0 30242	0 30832	0 00590	19 52	20 98	33 - 47	3 3		Vacuum Rot	0	CFH	H20 wt	0 075	mass fraction			
4	0 30284	0 30693	0 00409	13 53	7 45	21 - 33	2 1		coal flow in	15	min	Equiv Ratio	1 698	w/inj, no solid fuel			
5	0 30662	0 30828	0 00166	5 49	1 95	11 - 21	1 1					mol wt wet	28 119	g/mol			
6	0 31961	0 31979	0 00018	0 60	1 36	07 - 11	0 7					dens@inlet	573 042	g/m^3			
7	0 30199	0 302	0 00001	0 03	1 32	04 - 07	0 4					mdot duct	493 103	g/min	minus ash		
Backup Filter	0 33300	0 3334	0 00040	1 32	0 00	0 -04	0					vduct	26 535	meters/min			
												vduct	1 448	fl/sec			
		total mass	0 03022						dens@STP	1202 10	g/m^3	dens@imp	818 711	g/m^3			
									BACKFIRE BURNERS			mol wt dry	29 469	g/mol			
												dens@roto	1213 279	g/m^3			
		Before	After						mdotBF1 CH4	19 18476726	g/min	vol/liwrater	0 000	m^3/min			
Notes	Presep A	12 55668	12 54520						mdotBF1 Air	503 3529448	g/min	vol/liwrater	0 000	l/^3/min			
[illegible]	Connect B	11 78673	11 81451						phi	1 529	A/F equiv ratio						
	Probe C	11 8322	11 84480						mdotA/mdotF	29 23710978		mdot/roto	0 000	g/min			
												mdot/imp	0 000	g/min			
									mdotBF2 CH4	0	g/min	vol/liwimp	0 000	m^3/min			
									mdotBF2 Air	0	g/min	vol/liwimp	0 000	l/^3/min			
									phi	#DIV/0!	A/F equiv rati	vinlet	0 000	m/min			
									mdotA/mdotF	#DIV/0!		vinlet	0 000	fl/sec			
												mdotcoal	0 00000	g/min			
									actual ash	0 03022	g	expected ash	0 0000	g			
												%Dif ash	100 000	%	based on actual		

Table G.12: Test 05249401

Date	5/24/94	mo/day/yr	Main NG	58.0	%	Upper T	1045	o									
Coal	Upper Freepo	source	Main Air	41.0	%	Sample T	325	C (est)									
	raw	process		29.0	psig	Lower T	624	C (at center)									
test no	05249401	m/d/ynum	BF1NG	46.0	%	Coal feed	820	units	imp init diam	0.5625	inches						
test dur.	15.00	minutes	BF1Air	4.4	units,(roti	Coal feed cor	1.1	g/m	Mainduct rad	4	inches						
Coal Properies (Raf only)				4.4	units, back	Vacuum Rota		%	Main Gas Ro	0.58	(raction	mdot CH4	16.331	g/min			
Upper Freeport			BF2NG		%	Vacuum Rota		in hg	Main Air Rot	0.41	(raction	mdot Main A	475.928	g/min			
grams	moles/100g		BF2Air		units,(roti	atomizer air		units	Main Air Rot	29	psig	phi	1.598	units			
64.57	5.38				units, back	atomizer air		psig	Inj. Air Rota	0	%	mole fract	1.021				
4.07	4.07		Inj. Rota		%	atomizer H2O	250±	mm	Inj Air Rota	0	psig	CO2	1.021	moles/min	CH4&Air only		
3.92	0.25		Inj. Rota		psig	exit duct T		F				H2O	2.041	moles/min	CH4&Air only		
1.63	0.12					over fum T		F	Coal Composition on Elemental level			N2	13.035	moles/min	CH4&Air only		
2.07	0.08								Carbon(mon	5.38	moles/100g	O2	1.425	moles/min	CH4&Air only		
23.23	23.23								Hydrogen (r	4.07	moles/100g	mdot air inj	0.000	g/min			
0.51	0.03								Oxygen (mo	0.25	moles/100g	O2	0.000	moles/min	Inj Air only		
100									Nitrogen (m	0.12	moles/100g	N2	0.000	moles/min	Inj Air only		
									Sulfur(mon)	0.08	moles/100g	Dry O2 w/in	9.207	vol%	tot w/o coal		
									Ash	23.23	g/100g	DryO2w/o i	9.207	vol%	t w/o coal&inj		
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum % R size rnge	Size Range micrometers	ECD micro m		H2O	0.03	moles/100g	Coal Fractio	0.011	mdotcoal/100g			
												CO2	1.080	moles/min	total		
									mdot coal	1.1	g/min	H20	2.064	moles/min	total		
Presepartor			0.00000	0.00	100.00	10.0 & up	10		Probe inlet T	325	degC	N2	13.035	moles/min	total		
0	0.27742	0.28663	0.00921	27.07	72.93	9.0 -10.0	9		Impactor Inl	100	degC (est. T	SO2	0.0007	moles/min	total		
1	0.27889	0.2846	0.00771	22.66	50.26	5.8 - 9.0	5.8		Vacuum Rot	0	in Hg	O2	1.356	moles/min	total		
2	0.30435	0.30816	0.00381	11.20	39.07	4.7 - 5.8	4.7		Vacuum Rot	23	degC (est. T	Dry O2	9.782	vol%			
3	0.30349	0.30986	0.00637	18.72	20.34	3.3 - 4.7	3.3		Vacuum Rot	0	CFH	H20 wt	0.075	mass fraction			
4	0.30302	0.30742	0.00440	12.93	7.41	2.1 - 3.3	2.1		coal flow (m	15	min	Equiv. Ratio	1.698	w/inj. no solid fuel			
5	0.30290	0.30485	0.00195	5.73	1.68	1.1 - 2.1	1.1					mol. wt. wet	28.119	g/mol			
6	0.30319	0.30341	0.00022	0.65	1.03	0.7 - 1.1	0.7					dens@inlet	573.042	g/m^3			
7	0.30333	0.30339	0.00006	0.18	0.85	0.4 - 0.7	0.4					mdot duct	493.103	g/min	minus ash		
Backup Filter	0.33234	0.33263	0.00029	0.85	0.00	0 -0.4	0					vduct	26.535	meters/min			
												vduct	1.448	ft/sec			
		total mass	0.03402						dens@STP	1202.19	g/m^3	dens@imp	918.711	g/m^3			
									BACKFIRE BURNERS			mol wt dry	28.469	g/mol			
												dens@rota	1213.279	g/m^3			
Notes	1.)	The 0 foil was overloaded							mdotBF1 CH4	19.1647973	g/min	volflowratero	0.000	m^3/min			
	2.)	see raw data sheet for additional notes							mdotBF1 Air	503.352845	g/min	volflowratero	0.000	ft^3/min			
	3.)								phi	1.529	A/F equiv ratio						
	4.)								mdotAir/mdotF	26.2371098		mdotrota	0.000	g/min			
	5.)				Before	After						mdotimp	0.000	g/min			
	6.)			Presep A	0.306	0.33947			mdotBF2 CH4	0	g/min	volflowimp	0.000	m^3/min			
				Connect B	0.30278	0.32466			mdotBF2 Air	0	g/min	volflowimp	0.000	ft^3/min			
				Probe C	0.30231	0.30369			phi	#DIV/0!	A/F equiv rati	vinlet	0.000	m/min			
									mdotAir/mdotF	#DIV/0!		vinlet	0.000	ft/sec			
												mdotcoal	0.00000	g/min			
									actual ash	0.03402	g	expected ash	0.0000	g			
												%Diff ash	100.000	%	based on actual		

Table G.13: Test 05269401

Date	5/26/94	mo/day/yr	Main NG	57.0	%	Upper T	1062.5	c									
Coal	Upper Freepo	source	Main Air	41.0	%	Sample T	360	C(350-380)									
	cleaned	process		29.0	psig	Lower T	628	c									
test no	05269401	m/d/ynum	BF1NG	45.0	%	Coal feed	820	units	Imp Init diam	0.5625	inches						
test dur	15.00	minutes	BF1Air	4.4	units,front	Coal feed cor	1.1	g/m	Mainduct rad	4	inches						
Coal Properties (Rel. only)				4.4	units, back	Vacuum Reto		%	Main Gas Flo	0.67	fraction	mdot CH4	16.050	g/min			
Upper Freepor			BF2NG		%	Vacuum Reto		in hg	Main Air Flot	0.41	fraction	mdot Main A	475.929	g/min			
grams	moles/100g		BF2Air		units,front	atomizer air		units	Main Air Flot	29	psig	phi	1.726	units			
64.57	5.38				units, back	atomizer air		psig	Inj Air Reto	0	%	mole fract	1.003				
4.07	4.07		Inj Reto		%	atomizer H2O	250	mm	Inj Air Reto	0	psig	O2	1.003	moles/min	CH4&Air only		
3.92	0.25		Inj Reto		psig	exit duct T		F				H2O	2.006	moles/min	CH4&Air only		
1.63	0.12					over furn T		F	Coal Composition on Elemental level			N2	13.035	moles/min	CH4&Air only		
2.07	0.06								Carbon(mon	5.38	moles/100g	O2	1.481	moles/min	CH4&Air only		
23.23	23.23								Hydrogen (n	4.07	moles/100g	mdot air inj	0.000	g/min			
0.51	0.03								Oxygen (mo	0.25	moles/100g	O2	0.000	moles/min	inj Air only		
100									Nitrogen (m	0.12	moles/100g	N2	0.000	moles/min	inj Air only		
									Sulfur(mon)	0.06	moles/100g	Dry O2 w/in	9.424	vol%	tot w/o coal		
									Ash	23.23	g/100g	DryO2w/o in	9.424	vol%	t w/o coal&inj		
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % lt size rnge	Size Range micrometers	ECD micro m		H2O	0.03	moles/100g	Coal Fractio	0.011	mdotcoal/100g			
												O2	1.062	moles/min	total		
									mdot coal	1.1	g/min	H2O	2.029	moles/min	total		
Preseparator			0.00000	0.00	100.00	100 & up	10		Probe inlet T	360	degC	N2	13.036	moles/min	total		
0	0.27673	0.28215	0.00542	23.59	76.41	90 -100	9		Impactor Init	100	degC (est. T	SO2	0.0007	moles/min	total		
1	0.27622	0.28120	0.00498	21.67	54.74	58 - 90	58		Vacuum Rot	0	in Hg	O2	1.391	moles/min	total		
2	0.30725	0.30982	0.00257	11.18	43.56	47 - 58	47		Vacuum Rot	23	degC (est. T	Dry O2	8.978	vol%			
3	0.30731	0.31130	0.00399	17.36	26.20	33 - 47	33		Vacuum Rot	0	CFH	H20 wt	0.074	mass fraction			
4	0.30729	0.31081	0.00352	15.32	10.88	21 - 33	21		coal flow tim	15	min	Equiv. Ratio	1.726	w/inj, no solid fuel			
5	0.30461	0.30651	0.00190	8.27	2.61	11 - 21	11					mol wt wet	28.131	g/mol			
6	0.30646	0.30676	0.00030	1.31	1.31	07 - 11	07					dens@inlet	541.592	g/m^3			
7	0.30530	0.30534	0.00004	0.17	1.13	04 - 07	04					mdot duct	492.822	g/min	minus ash		
Backup Filter	0.33204	0.33230	0.00026	1.13	0.00	0 -04	0					vduct	28.060	meters/min			
												vduct	1.531	ll/secs			
		total mass	0.02298						dens@STP	1292.10	g/m^3	dens@imp	919.108	g/m^3			
									BACKFIRE BURNER8								
												mol wt dry	29.458	g/mol			
												dens@reto	1212.836	g/m^3			
									mdotBF1 CH4	18.7977071	g/min	volflwrateto	0.000	m^3/min			
Notes	Imp. Flowrate 60.0 SCFH								mdotBF1 Air	503.352845	g/min	volflwrateto	0.000	ll^3/min			
	1)	stage 0 was overloaded							phi	1.563	A/F equiv ratio						
	2)	see notes on original data sheet							mdotAirmdotF	29.8201566		mdotrote	0.000	g/min			
	3)											mdotimp	0.000	g/min			
	4)								mdotBF2 CH4	0	g/min	volflwimp	0.000	m^3/min			
	5)								mdotBF2 Air	0	g/min	volflwimp	0.000	ll^3/min			
	6)								phi	#DIV/0!	A/F equiv rati	vinlet	0.000	m/min			
									mdotAirmdotF	#DIV/0!		vinlet	0.000	ll/secs			
												mdotcoal	0.00000	g/min			
									actual ash	0.02298	g	expected ash	0.0000	g			
												%Diff ash	100.000	%	based on actual		

Table G.14: Test 05269402

Date	5/26/94	mo/day/yr	Main NG	57.0	%	Upper T	1057.6	c									
Coal	Upper Freepo	source	Main Air	41.0	%	Sample T	365	c									
	cleaned	process		29.0	psig	Lower T	823	c									
test no	05269402	m/d/ynum	BF1NG	46.0	%	Coal feed	820	units	Imp inlt diam	0.5625	inches						
test dur.	15.00	minutes	BF1Air	4.4	units,front	Coal feed cori	1.1	g/m	Maindust rec	4	inches						
Coal Properies: (Ref. only)				4.4	units, back	Vacuum Reto		%	Main Gas Ro	0.57	fraction	mdot CH4	16.050	g/min			
Upper Freeport			BF2NG		%	Vacuum Reto		in hg	Main Air Rot	0.41	fraction	mdot Main A	475.928	g/min			
grams	moles/100g		BF2Air		units,front	atomizer air		units	Main Air Rot	29	psig	phi	1.728	units			
84.57	5.38				units, back	atomizer air		psig	Inj Air Reto	0	%	mole fract	1.003				
4.07	4.07		Inj Reto		%	atomizer H2O	250+	mm	Inj Air Reto	0	psig	O02	1.003	moles/min	CH4&Air only		
3.92	0.25		Inj Reto		psig	exit duct T		F				H20	2.006	moles/min	CH4&Air only		
1.63	0.12					over furn T		F	Coal Composition on Elemental level			N2	13.035	moles/min	CH4&Air only		
2.07	0.06								Carbon(mon	5.38	moles/100g	O2	1.461	moles/min	CH4&Air only		
23.23	23.23								Hydrogen (r	4.07	moles/100g	mdot air inj	0.000	g/min			
0.51	0.03								Oxygen (mo	0.25	moles/100g	O2	0.000	moles/min	Inj Air only		
100									Nitrogen (m	0.12	moles/100g	N2	0.000	moles/min	Inj Air only		
									Sulfur(mon)	0.06	moles/100g	Dry O2 w/in	9.424	vol%	tot. w/o coal		
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum % s size rge	Size Range micrometers	ECD micro m		Ash	23.23	g/100g	DryO2w/o in	9.424	vol%	t w/o coal&inj		
									H2O	0.03	moles/100g	Coal Fractio	0.011	mdotcoal/100g			
												O02	1.982	moles/min	total		
									mdot coal	1.1	g/min	H20	2.029	moles/min	total		
Preseperator			0.00000	0.00	100.00	100 & up	10		Probe inlet T	365	degC	N2	13.036	moles/min	total		
0	0.27632	0.28104	0.00472	19.04	80.96	90 -100	9		Impactor Ink	100	degC (est. T	902	0.0007	moles/min	total		
1	0.27621	0.28132	0.00511	20.61	60.35	58 - 90	58		Vacuum Rot	0	in Hg	O2	1.391	moles/min	total		
2	0.30721	0.30976	0.00255	10.29	50.06	47 - 58	47		Vacuum Rot	23	degC (est. T	Dry O2	8.979	vol%			
3	0.30703	0.31215	0.00512	20.65	29.41	33 - 47	33		Vacuum Rot	0	CFH	H20 wt	0.074	mass fraction			
4	0.30771	0.31195	0.00424	17.10	12.30	21 - 33	21		coal flow lim	15	min	Equiv Ratio	1.728	w/inj, no solid fuel			
5	0.30843	0.31076	0.00233	9.40	2.90	11 - 21	11					mol wt wet	28.131	g/mol			
6	0.31085	0.31131	0.00046	1.86	1.05	07 - 11	07					dens@inlet	537.347	g/m^3			
7	0.30841	0.30846	0.00005	0.20	0.85	04 - 07	04					mdot duct	492.822	g/min	minus ash		
Backup Filter	0.33289	0.33309	0.00021	0.85	0.00	0 -04	0					vduct	29.281	meters/min			
												vduct	1.543	ft/sec			
		total mass	0.02479						dens@STP	1202.10	g/m^3	dens@imp	919.108	g/m^3			
									BACKFIRE BURNER'S			mol wt dry	29.458	g/mol			
												dens@rota	1212.836	g/m^3			
									mdotBF1 CH	19.1847673	g/min	volflowratero	0.000	m^3/min			
Notes									mdotBF1 Air	503.352945	g/min	volflowratero	0.000	ft^3/min			
									phi	1.529	A/F equiv ratio						
									mdotAirmdotF	26.2371098		mdotrota	0.000	g/min			
												mdotimp	0.000	g/min			
									mdotBF2 CH	0	g/min	volflwimp	0.000	m^3/min			
									mdotBF2 Air	0	g/min	volflwimp	0.000	ft^3/min			
									phi	#DIV/0!	A/F equiv rati	vinlet	0.000	m/min			
									mdotAirmdotF	#DIV/0!		vinlet	0.000	ft/sec			
												mdotcoal	0.00000	g/min			
									actual ash	0.02479	g	expected as	0.0000	g			
												%Dif ash	100.000	%	based on actual		

Table G.15: Test 05279401

Date	5/27/94	mo/day/yr	Main NG	57 0	%	Upper T	1075	c									
Coal	Upper Freepo	source	Main Air	40 5	%	Sample T	350	C(est)									
	cleaned	process		28 5	psig	Lower T	623	c									
test no	05279401	m/d/ynum	BF1NG	45 0	%	Coal feed	820	units	inj inlt diam	0 5625	inches						
test dur	15 00	minutes	BF1Air	4 4	units,front	Coal feed cor	1 1	g/m	Mainduct rad	4	inches						
Coal Properties (Ref only)				4 4	units, back	Vacuum Rota		%	Main Gas Ro	0 57	fraction	mdot CH4	16 050	g/min			
Upper Freeport			BF2NG		%	Vacuum Rota		in hg	Main Air Rot	0 405	fraction	mdot Main A	467 427	g/min			
grams	moles/100g		BF2Air		units,front	atomizer air		units	Main Air Rot	28 5	psig	phi	1 697	units			
64 57	5 38				units, back	atomizer air		psig	Inj Air Rota	0	%	mole fract	1 003				
4 07	4 07		Inj Rota		%	atomizer H2O	250	mm	Inj Air Rota	0	psig	CO2	1 003	moles/min	CH4&Air only		
3 92	0 25		Inj Rota		psig	exit duct T		F				H20	2 006	moles/min	CH4&Air only		
1 63	0 12					over lum T		F				N2	12 802	moles/min	CH4&Air only		
2 07	0 09								Coal Composition on Elemental level			O2	1 399	moles/min	CH4&Air only		
23 23	23 23								Carbon(mon	5 39	moles/100g	mdot air inj	0 000	g/min			
0 51	0 03								Hydrogen (n	4 07	moles/100g	O2	0 000	moles/min	Inj Air only		
100									Oxygen (mo	0 25	moles/100g	N2	0 000	moles/min	Inj Air only		
									Nitrogen (m	0 12	moles/100g	Dry O2 w/in	0 199	vol%	tot w/o coal		
									Sulfur(mon	0 06	moles/100g	DryO2w/o ir	0 199	vol%	t w/o coal&inj		
									Ash	23 23	g/100g	Coal Fractio	0 011	mdot coal/100g			
Stage	Initial(g)	Final(g)	Net(g)	% in size	Cum %	Size Range	ECD		H2O	0 03	moles/100g	CO2	1 062	moles/min	total		
				range	lt size mge	micrometers	micro m					H20	2 029	moles/min	total		
Precseparator			0 00000	0 00	100 00	10 0 & up	10		mdot coal	1 1	g/min	N2	12 803	moles/min	total		
0	0 27814	0 28431	0 00517	20 52	79 48	9 0 -10 0	9		Probe inlet T	350	degC	SO2	0 0007	moles/min	total		
1	0 27983	0 28526	0 00543	21 55	57 94	5 8 - 9 0	5 8		Impactor Inl	100	degC (est T	O2	1 329	moles/min	total		
2	0 30837	0 31134	0 00297	11 79	46 15	4 7 - 5 8	4 7		Vacuum Rot	0	in Hg	Dry O2	8 746	vol%			
3	0 30873	0 31352	0 00479	19 01	27 14	3 3 - 4 7	3 3		Vacuum Rot	23	degC (est	H20 wt	0 075	mass fraction			
4	0 30653	0 31056	0 00403	15 99	11 15	2 1 - 3 3	2 1		Vacuum Rot	0	CFM	Equiv Ratio	1 697	w/inl, no solid fuel			
5	0 30618	0 30838	0 00223	8 85	2 30	1 1 - 2 1	1 1		coal flow tim	15	min	mol wt wet	28 119	g/mol			
6	0 30570	0 30613	0 00043	1 71	0 60	0 7 - 1 1	0 7					dens@inlet	550 047	g/m^3			
7	0 31017	0 31027	0 00010	0 40	0 20	0 4 - 0 7	0 4					mdot duct	484 921	g/min	minus ash		
Backup Filter	0 33350	0 33355	0 00005	0 20	0 00	0 -0 4	0					vduct	27 152	meters/min			
												vduct	1 491	l/sec			
		total mass	0 02529						dens@STP	1202 10	g/m^3	dens@inj	918 712	g/m^3			
									BACKFIRE BURNERS			mol wt dry	29 470	g/mol			
												dens@rota	1213 329	g/m^3			
									mdotBF1 CH4	16 7677071	g/min	volflwrotero	0 000	m^3/min			
Notes									mdotBF1 Air	500 464966	g/min	volflwrotero	0 000	l/^3/min			
[illegible]									phi	1 554	A/F equiv ratio						
									mdotA/mdotF	29 0652819		mdotrota	0 000	g/min			
												mdotimp	0 000	g/min			
									mdotBF2 CH4	0	g/min	volflwimp	0 000	m^3/min			
									mdotBF2 Air	0	g/min	volflwimp	0 000	l/^3/min			
									phi	#DIV/0!	A/F equiv rati	vinlet	0 000	m/min			
									mdotA/mdotF	#DIV/0!		vinlet	0 000	l/sec			
												mdotcoal	0 00000	g/min			
									actual ash	0 0252	g	expected as	0 0000	g			
												%Diff ash	100 000	%	based on actual		

Table G.16: Test 05319401

Date	5/31/94	mo/day/yr	Main NG	57.0	%	Upper T	1067.5	c									
Coal	Illinois #6	source	Main Air	41.0	%	Sample T	330	c									
	37 - 85 um	process		29.0	psig	Lower T	630	c									
test no	05319401	m/d/ynum	BF1NG	46.0	%	Coal feed	920	units	amp init dem	0.5625	inches						
test dur	15.00	minutes	BF1Air	4.4	units,front	Coal feed cor	1.1	g/m	Mainduct rad	4	inches						
Coal Properties (Ref. only)				4.4	units, back	Vacuum Roto		%	Main Gas Flo	0.57	fraction	mdot CH4	18.050	g/min			
Illinois #6			BF2NG		%	Vacuum Roto		in hg	Main Air Rot	0.41	fraction	mdot Main A	479.928	g/min			
grams	atomwt/100g		BF2Air		units,front	atomizer air		units	Main Air Rot	29	psig	phi	1.728	units			
59.87	4.99				units, back	atomizer air		psig	Inj Air Roto	0	%	mole fract	1.003				
4.55	4.55		Inj Roto		%	atomizer H2O	250.0	mm	Inj Air Roto	0	psig	CO2	1.003	moles/min	CH4&Air only		
8.52	0.53		Inj Roto		psig	exit duct T		F				H20	2.006	moles/min	CH4&Air only		
1.37	0.10					over furn T		F				N2	13.035	moles/min	CH4&Air only		
3.78	0.12								Coal Composition on Elemental level			O2	1.461	moles/min	CH4&Air only		
8.62	8.62								Carbon(mon	4.99	moles/100g	mdot air inj	0.000	g/min			
13.31	0.74								Hydrogen (n	4.55	moles/100g	O2	0.000	moles/min	Inj Air only		
100									Oxygen (mo	0.53	moles/100g	N2	0.000	moles/min	Inj Air only		
									Nitrogen (m	0.10	moles/100g	Dry O2 w/in	9.424	vol%	tot w/o coal		
									Sulfur(mon	0.12	moles/100g	DryO2w/o ir	9.424	vol%	t w/o coal&inj		
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum % fl. size mas	Size Range micrometers	ECD micro m		Ash	8.62	g/100g						
									H2O	0.74	moles/100g	Coal Fractio	0.011	mdot coal/100g			
												CO2	1.058	moles/min	total		
									mdot coal	1.1	g/min	H20	2.039	moles/min	total		
Preseparator			0.00000	0.00	100.00	100 A up	10		Probe inlet T	330	degC	N2	13.038	moles/min	total		
0	0.27862	0.28373	0.00511	25.18	74.82	90 -100	9		Impactor Ink	100	degC (est. T	SO2	0.0013	moles/min	total		
1	0.27789	0.28223	0.00424	20.90	53.92	58 - 90	58		Vacuum Rot	0	in Hg	O2	1.395	moles/min	total		
2	0.30897	0.30873	0.00176	8.67	45.24	47 - 58	47		Vacuum Rot	23	deg C (est. T	Dry O2	9.005	vol%			
3	0.30490	0.30849	0.00359	17.69	27.55	33 - 47	39		Vacuum Rot	0	CFH	H20 wt	0.074	mass fraction			
4	0.30829	0.30915	0.00286	14.10	13.45	21 - 33	21		coal flow (m	15	min	Equiv. Ratio	1.728	w/inj, no solid fuel			
5	0.30724	0.30843	0.00119	5.86	7.59	11 - 21	11					mol wt wet	29.123	g/mol			
6	0.30707	0.30721	0.00014	0.69	6.90	07 - 11	07					dens@inlet	669.377	g/m^3			
7	0.30608	0.30608	0.00000	0.00	6.90	04 - 07	04					mdot duct	492.983	g/min	minus ash		
Backup Filter	0.32866	0.33006	0.00140	6.90	0.00	0 -04	0					vduct	28.746	meters/min			
												vduct	1.459	ll/sec			
		total mass	0.02029						dens@STP	1292.10	g/m^3	dens@inp	919.951	g/m^3			
									BACKFIRE BURNER8			mol wt dry	29.456	g/mol			
												dens@roto	1212.750	g/m^3			
									mdotBF1 CH4	19.1847873	g/min	volflwrotero	0.000	m^3/min			
Notes		Presep	0.30644	0.31739	0.01095				mdotBF1 Air	500.352845	g/min	volflwrotero	0.000	ll^3/min			
		connect	0.30727	0.32864	0.02137				phi	1.529	A/F equiv ratio						
		probe	0.30611	0.30698	0.00087				mdotA/mdotF	26.2371098		mdotroto	0.000	g/min			
			Sum		0.03319							mdotimp	0.000	g/min			
									mdotBF2 CH4	0	g/min	volflwimp	0.000	m^3/min			
									mdotBF2 Air	0	g/min	volflwimp	0.000	ll^3/min			
									phi	#DIV/0!	A/F equiv rati	vinlet	0.000	m/min			
									mdotA/mdotF	#DIV/0!		vinlet	0.000	ll/sec			
												mdotcoal	0.00000	g/min			
									actual ash	0.02029	g	expected as	0.0000	g			
												%Diff ash	100.000	%	based on actual		

Table G.17: Test 06019401

Date	6/1/94	mo/day/yr	Main NG	57 6	%	Upper T	1057 5	c									
Coal	Upper Freepo	source	Main Air	41 0	%	Sample T	330	C(est.)									
	37 : 85 µm	process		28 0	psig	Lower T	642	c									
test no	06019401	m/d/ynum	BF1NG	46 0	%	Coal feed	820	units	imp inlt diam	0 5625	inches						
test dur	15 00	minutes	BF1Air	4 4	units,front	Coal feed cor	1 1	g/m	Mainduct dia	4	inches						
Coal Properties	(Rel only)			4 4	units, back	Vacuum Roto		%	Main Gas Ro	0 575	fraction	mdot CH4	16 191	g/min			
			BF2NG		%	Vacuum Roto		in hg	Main Air Rot	0 41	fraction	mdot Main A	475 928	g/min			
grams	moles/100g		BF2Air		units,front	atomizer air		units	Main Air Rot	29	psig	phi	1 719	units			
					units, back	atomizer air		psig	Inj Air Roto	0	%	mole fract	1 012				
			Inj Roto		%	atomizer H2O	250+	mm	Inj Air Roto	0	psig	CO2	1 012	moles/min	CH4&Air only		
			Inj Roto		psig	exit duct T		F				H20	2 024	moles/min	CH4&Air only		
						over lum T		F	Coal Composition on Elemental level			N2	13 035	moles/min	CH4&Air only		
									Carbon(mon	0 00	moles/100g	O2	1 443	moles/min	CH4&Air only		
									Hydrogen (n	0 00	moles/100g	mdot air inj	0 000	g/min			
									Oxygen (mo	0 00	moles/100g	O2	0 000	moles/min	Inj Air only		
									Nitrogen (m	0 00	moles/100g	N2	0 000	moles/min	Inj Air only		
									Sulfur(mon)	0 00	moles/100g	Dry O2 w/in	9 316	vol%	tot w/o coal		
									Ash	0 00	g/100g	DryO2w/o in	9 316	vol%	t w/o coal&inj		
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum % ft size mpe	Size Range micrometers	ECD micro m		H2O	0 00	moles/100g	Coal Fractio	0 011	mdotcoal/100g			
												CO2	1 012	moles/min	total		
									mdot coal	1 1	g/min	H20	2 024	moles/min	total		
Preseperator			0 00000	0 00	100 00	100 & up	19		Probe Inlet T	330	degC	N2	13 035	moles/min	total		
0	0 27828	0 28343	0 01515	61 21	38 79	9 0 - 10 0	9		Impactor Inl	100	degC (est. T	SO2	0 0000	moles/min	total		
1	0 27955	0 28422	0 00467	18 87	19 92	5 8 - 9 0	5 8		Vacuum Rot	0	in Hg	O2	1 443	moles/min	total		
2	0 30636	0 30803	0 00167	6 75	13 17	4 7 - 5 8	4 7		Vacuum Rot	23	degC (est. T	Dry O2	9 316	vol%			
3	0 30781	0 30895	0 00114	4 61	8 57	3 3 - 4 7	3 3		Vacuum Rot	0	CFH	H20 wt	0 074	mass fraction			
4	0 30633	0 30698	0 00065	2 55	6 02	2 1 - 3 3	2 1		coal flow lin	15	min	Equiv Ratio	1 719	w/inj, no solid fuel			
5	0 30741	0 30776	0 00034	1 37	4 65	1 1 - 2 1	1 1					mol wt wet	29 098	g/mol			
6	0 30649	0 30657	0 00008	0 32	4 32	0 7 - 1 1	0 7					dens@inlet	567 877	g/m^3			
7	0 30720	0 30724	0 00004	0 16	4 16	0 4 - 0 7	0 4					mdot duct	493 218	g/min	minus ash		
Backup Filter	0 33344	0 33447	0 00103	4 16	0 00	0 -0 4	0					vduct	26 782	meters/min			
												vduct	1 461	ft/sec			
		total mass	0 02475						dens@STP	1202 10	g/m^3	dens@imp	918 042	g/m^3			
									BACKFIRE BURNERS			mol wt dry	29 418	g/mol			
												dens@roto	1211 178	g/m^3			
									mdotBF1 CH4	19 1847973	g/min	volflmeterp	0 000	m^3/min			
Notes		Presep	0 30795	0 35538	0 04743				mdotBF1 Air	503 352845	g/min	volflmeterp	0 000	ft^3/min			
		connect	0 3076	0 33342	0 02582				phi	1 529	A/F equiv ratio						
		probe	0 3065	0 32233	0 01583				mdotAir/mdotF	26 2371099		mdotroto	0 000	g/min			
			Sum		0 15908							mdotimp	0 000	g/min			
									mdotBF2 CH4	0	g/min	volflwimp	0 000	m^3/min			
		The preseperator is pretty full, stages 0 and 1 are overloaded, and are							mdotBF2 Air	0	g/min	volflwimp	0 000	ft^3/min			
		very black. I don't think we completely burned							phi	#DIV/0!	A/F equiv rati	vinlet	0 000	m/min			
									mdotAir/mdotF	#DIV/0!		vinlet	0 000	ft/sec			
												mdotcoal	0 00000	g/min			
									actual ash	0 02475	g	expected as	0 0000	g			
												%Diff ash	100 000	%	based on actual		

Table G.18: Test 06029401

Date	6/2/94	mo/day/yr	Main NG	57.0	%	Upper T	1067.9	c									
Coal	Kentucky #11	source	Main Air	41.0	%	Sample T	350	c									
	37 - 85 µm	process		29.0	psig	Lower T	637	c									
test no	06029401	m/d/yrnum	BF1NG	0.0	%	Coal feed	820	units	Imp Init diam	0.5625	inches						
test dur	15.00	minutes	BF1Air	4.4	units,front	Coal feed cor	1.1	g/m	Meindvct rad	4	inches						
Coal Properties	(Ret. only)			4.4	units, back	Vacuum Roto		%	Main Gas Ro	0.57	fraction	mdot CH4	18.050	g/min			
Kentucky #11			BF2NG		%	Vacuum Roto		in hg	Main Air Rot	0.41	fraction	mdot Main A	475.928	g/min			
grams	atomwt/100g		BF2Air		units,front	atomizer air		units	Main Air Rot	29	psig	phi	1.728	units			
57.79	4.81				units, back	atomizer air		psig	Inj Air Roto	0	%	mole fract	1.003				
4.42	4.42		Inj Roto		%	atomizer H2O	250	mm	Inj Air Rota	0	psig	CO2	1.003	moles/min	CH4&Air only		
7.64	0.48		Inj Roto		psig	exit duct T		F				H20	2.008	moles/min	CH4&Air only		
1.29	0.09					over furn T		F	Coal Composition on Elemental level			N2	13.035	moles/min	CH4&Air only		
4.22	0.13								Carbon(mon	4.81	moles/100g	O2	1.461	moles/min	CH4&Air only		
20.96	20.96								Hydrogen (r	4.42	moles/100g	mdot air inj	0.000	g/min			
3.84	0.21								Oxygen (mo	0.48	moles/100g	O2	0.000	moles/min	Inj Air only		
100.1									Nitrogen (m	0.09	moles/100g	N2	0.000	moles/min	Inj Air only		
									Sulfur(mon	0.13	moles/100g	Dry O2 w/in	9.424	vol%	tot w/o coal		
									Ash	20.96	g/100g	DryO2w/o ir	9.424	vol%	t w/o coal&inj		
Stage	(initial(g)	Final(g)	Net(g)	% in size range	Cum % fi size rnge	Size Range micrometers	ECD micro m		H20	0.21	moles/100g	Coal Fractio	0.011	mdotcoal/100g			
												CO2	1.056	moles/min	total		
									mdot coal	1.1	g/min	H20	2.033	moles/min	total		
Presseparator			0.00000	0.00	100.00	10.0 & up	10		Probe inlet T	350	degC	N2	13.036	moles/min	total		
0	0.27776	0.28371	0.00595	44.80	55.20	9.0 - 10.0	9		Impactor Ink	100	degC (est. T	SO2	0.0015	moles/min	total		
1	0.27823	0.28094	0.00271	20.41	34.79	5.8 - 9.0	5.8		Vacuum Rot	0	in Hg	O2	1.397	moles/min	total		
2	0.30805	0.30911	0.00105	7.91	26.88	4.7 - 5.8	4.7		Vacuum Rot	23	degC (est. T	Dry O2	9.017	vol%			
3	0.30767	0.30874	0.00107	8.06	18.83	3.3 - 4.7	3.3		Vacuum Rot	0	CFH	H20 wt	0.074	mass fraction			
4	0.30752	0.30822	0.00070	5.27	13.55	2.1 - 3.3	2.1		coal flow tim	15	min	Equiv. Ratio	1.728	w/inj. no solid fuel			
5	0.30682	0.30731	0.00049	3.69	9.86	1.1 - 2.1	1.1					mol wt wet	28.126	g/mol			
6	0.30456	0.30465	0.00009	0.68	9.19	0.7 - 1.1	0.7					dens@inlet	550.184	g/m^3			
7	0.30779	0.30777	0.00001	0.08	9.11	0.4 - 0.7	0.4					mdot duct	492.847	g/min	minus ash		
Backup Filter	0.32853	0.32974	0.00121	9.11	0.00	0 - 0.4	0					vduct	27.623	meters/min			
												vduct	1.507	ft/sec			
		total mass	0.01328						dens@STP	1202.10	g/m^3	dens@imp	918.940	g/m^3			
									BACKFIRE BURNERS								
												mol wt dry	29.455	g/mol			
												dens@roto	1212.701	g/m^3			
Notes		Presep	0.30727	0.35799	0.05039				mdotBF1 CH4	0	g/min	volflwrotero	0.000	m^3/min			
[illegible]		connect	0.30680	0.32168	0.01488				mdotBF1 Air	503.352845	g/min	volflwrotero	0.000	ft^3/min			
		probe	0.30833	0.31057	0.00224				phi	#DIV/0!	A/F equiv ratio						
			Sum		0.06751				mdotAirdotF	#DIV/0!		mdotrota	0.000	g/min			
												mdotimp	0.000	g/min			
									mdotBF2 CH4	0	g/min	volflwimp	0.000	m^3/min			
									mdotBF2 Air	0	g/min	volflwimp	0.000	ft^3/min			
									phi	#DIV/0!	A/F equiv ratio	vinlet	0.000	m/min			
									mdotAirdotF	#DIV/0!		vinlet	0.000	ft/sec			
												mdotcoal	0.00000	g/min			
									actual ash	0.01328	g	expected ash	0.0000	g			
												%Diff ash	100.000	%	based on actual		

Table G.19: Test 09089401

Date	9/8/94	mo/day/yr	Main NG	57.0	%	Upper T	1190	c									
Coal	Kentucky #11	source	Main Air	41.0	%	Sample T	655	c									
	raw	process		31.8	psig	Lower T	560	c									
test no	09089401	m/d/ynum	BF1NG	46.0	%	Coal feed	820	units	imp init diam	0.5625	inches						
test dur	15.00	minutes	BF1Air	4.5	units,front	Coal feed cor	1.1	g/m	Mainduct rad	4	inches						
Coal Properties	(Ref only)			4.5	units, back	Vacuum Roto	62.0	%	Main Gas Ro	0.57	fraction	mdot CH4	16.050	g/min			
Kentucky #11			BF2NG	0.0	%	Vacuum Roto	10.0	in hg	Main Air Rot	0.41	fraction	mdot Main A	490.938	g/min			
grams	atomwt/100g		BF2Air	0.0	units,front	atomizer air	full open	units	Main Air Rot	31.8	psig	phi	1.783	units			
57.73	4.81			0.0	units, back	atomizer air		psig	Inj Air Roto	10	%	mole fract	1.003				
4.42	4.42		Inj Roto	10	%	atomizer H2O	180	mm	Inj Air Roto	39	psig	CO2	1.003	moles/min	CH4&Air only		
7.64	0.48		Inj Roto	39	psig	exit duct T	90	F				H20	2.006	moles/min	CH4&Air only		
1.29	0.09					over lvm T	105	F	Coal Composition on Elemental level			N2	13.446	moles/min	CH4&Air only		
4.22	0.13								Carbon(mon	4.81	moles/100g	O2	1.570	moles/min	CH4&Air only		
20.96	20.96								Hydrogen (n	4.42	moles/100g	mdot air inj	10.831	g/min			
3.84	0.21								Oxygen (mo	0.48	moles/100g	O2	0.079	moles/min	Inj Air only		
100.1									Nitrogen (m	0.09	moles/100g	N2	0.297	moles/min	Inj Air only		
									Sulfur(mon)	0.13	moles/100g	Dry O2 w/in	10.057	vol%	tot w/o coal		
									Ash	20.96	g/100g	DryO2w/o Ir	9.800	vol%	t w/o coal&inj		
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum % lt size mge	Size Range micrometers	ECD micro m		H2O	0.21	moles/100g	Coal Fraction	0.011	mdotcoal/100g			
												CO2	1.056	moles/min	total		
Preseparator	0.30398	0.33583	0.03185	41.47	58.53	10.0 & up	10		mdot coal	1.1	g/min	H20	2.033	moles/min	total		
0	0.27818	0.29240	0.01422	18.52	40.01	9.0 -10.0	9		Probe Inlet T	655	degC	N2	13.744	moles/min	total		
1	0.27794	0.28920	0.01126	14.66	25.35	5.8 - 9.0	5.8		Impactor Ink	100	degC (est. T	SO2	0.0015	moles/min	total		
2	0.30404	0.30891	0.00487	6.34	19.01	4.7 - 5.8	4.7		Vacuum Rot	10	in Hg	O2	1.585	moles/min	total		
3	0.30383	0.31093	0.00710	9.24	9.77	3.3 - 4.7	3.3		Vacuum Rot	23	degC (est. T	Dry O2	9.672	vol%			
4	0.30369	0.30896	0.00528	6.88	2.89	2.1 - 3.3	2.1		Vacuum Rot	62	CFH	H20 wt	0.071	mass fraction			
5	0.30449	0.30639	0.00191	2.49	0.40	1.1 - 2.1	1.1		coal flow lim	15	min	Equiv Ratio	1.822	w/inj, no solid fuel			
6	0.30484	0.30499	0.00015	0.20	0.21	0.7 - 1.1	0.7					mol wt wet	28.181	g/mol			
7	0.30480	0.30480	0.00000	0.00	0.21	0.4 - 0.7	0.4					dens@inlet	369.815	g/m^3			
Backup Filter	0.33158	0.33174	0.00016	0.21	0.00	0 -0.4	0					mdot duct	518.689	g/min	minus ash		
												vduct	43.250	meters/min			
		total mass	0.07690									vduct	2.360	l/l/sec			
									dens@STP	1202.10	g/m^3	dens@imp	920.075	g/m^3			
									BACKFIRE BURNERS			mol wt dry	29.421	g/mol			
												dens@roto	806.736	g/m^3			
									mdotBF1 CH	19.1847673	g/min	volflwratero	0.024	m^3/min			
Notes	Stage 0 overloaded. Dumped what I could back on. Roughly 90 to 95% ended up back on								mdotBF1 Air	531.028958	g/min	volflwratero	0.647	l/l^3/min			
	stage								phi	1.913	A/F equiv ratio						
									mdotA/mdotF	27.6797133		mdotrato	19.938	g/min			
	Stage 1 slightly off center, but good catch											mdotimp	20.806	g/min			
									mdotBF2 CH	0	g/min	volflwimp	0.023	m^3/min			
	There seemed to be char in with the stages. Black dust was on the perimeter of the								mdotBF2 Air	0	g/min	volflwimp	0.799	l/l^3/min			
	collection plates. The filter stage also had a light dusting of roughly 100 particles.								phi	#DIV/0!	A/F equiv rati	vinlet	350.914	m/min			
	Aerosol shouldn't be visible.								mdotA/mdotF	#DIV/0!		vinlet	19.189	l/l/sec			
												mdotcoal	0.00925	g/min			
									actual ash	0.0768	g	expected as	0.1397	g			
												%Def ash	80.632	%	based on actual		

Table G.20: Test 09099401

Date	9/9/94	mo/day/yr	Main NG	57.0	%	Upper T	1180	c									
Coal	Kentucky #11	source	Main Air	41.0	%	Sample T	660	c									
	raw	process		31.5	psig	Lower T	560	c									
test no	09099401	m/d/ynum	BF1NG	46.0	%	Coal feed	820	units	inj inlt diam	0.5625	inches						
test dur	15.00	min/sec	BF1Air	4.5	units,front	Coal feed cor	1.1	g/m	Mainduct rad	4	inches						
Coal Properties	(Rel only)			4.5	units, back	Vacuum Roto	63.0	%	Main Gas Ro	0.57	fraction	mdot CH4	16.050	g/min			
Kentucky #11			BF2NG		%	Vacuum Roto	10.0	in hg	Main Air Rot	0.41	fraction	mdot Main A	499.352	g/min			
grams	atomwt/100g		BF2Air		units,front	atomizer air	full open	units	Main Air Rot	31.5	psig	phi	1.777	units			
57.73	4.81				units, back	atomizer air		psig	Inj Air Roto	10	%	mole fract	1.003				
4.42	4.42		Inj Roto	10	%	atomizer H2O	185	mm	Inj Air Roto	39	psig	CO2	1.003	moles/min	CH4&Air only		
7.64	0.48		Inj Roto	39	psig	exit duct T	90	F				H20	2.006	moles/min	CH4&Air only		
1.29	0.09					over furn T	105	F	Coal Composition on Elemental level			N2	13.403	moles/min	CH4&Air only		
4.22	0.13								Carbon(mon	4.81	moles/100g	O2	1.558	moles/min	CH4&Air only		
20.96	20.96								Hydrogen (n	4.42	moles/100g	mdot air inj	19.831	g/min			
3.84	0.21								Oxygen (mo	0.48	moles/100g	O2	0.079	moles/min	inj Air only		
100.1									Nitrogen (m	0.09	moles/100g	N2	0.297	moles/min	inj Air only		
									Sulfur(mon)	0.13	moles/100g	Dry O2 w/in	19.029	vol%	tot w/o coal		
									Ash	20.96	g/100g	DryO2w/o ir	9.762	vol%	tot w/o coal&inj		
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum % ft. size rnge	Size Range micrometers	ECD micro m		H2O	0.21	moles/100g	Coal Fraction	0.011	mdot/coal/100g			
												CO2	1.056	moles/min	total		
									mdot coal	1.1	g/min	H20	2.033	moles/min	total		
Presseparator	0.30281	0.35395	0.05114	52.81	47.39	100 & up	10		Probe inlet T	660	degC	N2	13.700	moles/min	total		
0	0.28125	0.29681	0.01556	16.01	31.39	90 -100	9		Impactor Inl	100	degC (est T	SO2	0.0015	moles/min	total		
1	0.28003	0.29195	0.01192	12.26	19.12	58 - 90	58		Vacuum Rot	10	in Hg	O2	1.573	moles/min	total		
2	0.30444	0.30948	0.00502	5.16	13.96	47 - 58	47		Vacuum Rot	23	degC (est T	Dry O2	9.634	vol%			
3	0.30410	0.31044	0.00634	6.52	7.44	33 - 47	33		Vacuum Rot	63	CFH	H20 wt	0.071	mass fraction			
4	0.30096	0.30621	0.00525	5.40	2.04	21 - 33	21		coal flow lin	15	min	Equiv. Ratio	1.816	w/in, no solid fuel			
5	0.30053	0.30226	0.00173	1.78	0.26	11 - 21	11					mol wt wet	28.159	g/mol			
6	0.29990	0.30004	0.00014	0.14	0.11	07 - 11	07					dens@inlet	360.097	g/m^3			
7	0.30027	0.30028	0.00001	0.01	0.10	04 - 07	04					mdot duct	517.103	g/min	minus ash		
Backup Filter	0.33140	0.33150	0.00010	0.10	0.00	0 -04	0					vduct	44.292	meters/min			
												vduct	2.418	ft/sec			
		total mass	0.09721						dens@STP	1292.10	g/m^3	dens@imp	920.009	g/m^3			
									BACKFIRE BURNERS			mol wt dry	29.423	g/mol			
												dens@rota	808.790	g/m^3			
									mdotBF1 CH4	19.1947673	g/min	volf/wrotero	0.024	m^3/min			
Notes	The filter has a mush side and a smooth side I put filter in rough side up								mdotBF1 Air	529.31309	g/min	volf/wrotero	0.980	ft^3/min			
									phi	1.606	A/F equiv ratio						
	Bumped stage 3 when removing it. Some ash fell off into the pan dish. I'll knock what								mdotArndotF	27.5902794		mdotrota	19.652	g/min			
	I can back on during weighing. --Sept 12 - caught vast majority of knocked off ash											mdotimp	21.149	g/min			
	while weighing								mdotBF2 CH4	0	g/min	volf/wrimp	0.023	m^3/min			
									mdotBF2 Air	0	g/min	volf/wrimp	0.812	ft^3/min			
	Stages 0,1,2 were all heavy, with some loose ash and some slight ash loss by motion								phi	#DIV/0!	A/F equiv rat	vinlet	366.329	m/min			
									mdotArndotF	#DIV/0!		vinlet	20.031	ft/sec			
												mdotcoal	0.00943	g/min			
									actual ash	0.09721	g	expected as	0.1414	g			
												%Diff ash	45.502	%	based on actual		

Table G.21: Test 09159401

Date	9/15/94	mo/day/yr	Main NG	57.0	%	Upper T	1190	c									
Coal	Upper Freepo	source	Main Air	40.5	%	Sample T	700	c									
	raw	process		31.0	psig	Lower T	578	C (est)									
test no	09159401	m/d/ynum	BF1NG	46.0	%	Coal feed	820	units	imp init diam	0.5625	inches						
test dur	15.00	minutes	BF1Air	4.8	units,front	Coal feed cor	1.1	g/m	Mainduct rad	4	inches						
Coal Properties	(Ref only)			4.8	units, back	Vacuum Roto	62.0	%	Main Gas Ro	0.57	fraction	mdot CH4	16.050	g/min			
Upper Freeport			BF2NG		%	Vacuum Roto	9.5	in hg	Main Air Rot	0.405	fraction	mdot Main A	480.761	g/min			
grams	moles/100g		BF2Air		units,front	atomizer air	full open	units	Main Air Rot	31	psig	phi	1.746	units			
64.57	5.38				units, back	atomizer air		psig	Inj Air Roto	10	%	mole fract	1.003				
4.07	4.07		Inj Roto	10	% (est)	atomizer H2O	207	mm	Inj Air Roto	39	psig	CO2	1.003	moles/min	CH4&Air only		
3.92	0.25		Inj Roto	39	psig (est)	exit duct T		F				H2O	2.008	moles/min	CH4&Air only		
1.93	0.12					over furn T		F	Coal Composition on Elemental level			N2	13.168	moles/min	CH4&Air only		
2.07	0.06								Carbon(mon	5.38	moles/100g	O2	1.495	moles/min	CH4&Air only		
23.23	23.23								Hydrogen (n	4.07	moles/100g	mdot air inj	10.831	g/min			
0.51	0.03								Oxygen (mo	0.25	moles/100g	O2	0.079	moles/min	Inj Air only		
100									Nitrogen (m	0.12	moles/100g	N2	0.297	moles/min	Inj Air only		
									Sulfur(mon)	0.06	moles/100g	Dry O2 w/n	9.816	vol%	tot w/o coal		
									Ash	23.23	g/100g	DryO2w/o Ir	9.548	vol%	t w/o coal&Inj		
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum % R size mge	Size Range micrometers	ECD micro m		H2O	0.03	moles/100g	Coal Fractio	0.011	mdotcoal/100g			
												CO2	1.082	moles/min	total		
									mdot coal	1.1	g/min	H20	2.029	moles/min	total		
Preseparator	0.30153	0.35636	0.05473	56.56	43.44	10.0 & up	10		Probe inlet T	700	degC	N2	13.465	moles/min	total		
0	0.27798	0.29116	0.01318	13.62	29.82	9.0 -10.0	9		Impactor Init	100	degC (est)	SO2	0.0007	moles/min	total		
1	0.27717	0.28611	0.00894	9.24	20.58	5.0 - 9.0	5.8		Vacuum Rot	9.5	in Hg	O2	1.505	moles/min	total		
2	0.30111	0.30488	0.00377	3.90	16.68	4.7 - 5.0	4.7		Vacuum Rot	23	degC (est T	Dry O2	9.387	vol%			
3	0.30065	0.30721	0.00656	6.78	9.90	3.3 - 4.7	3.3		Vacuum Rot	62	CFH	H20 wt	0.072	mass fraction			
4	0.30261	0.30817	0.00556	5.75	4.15	2.1 - 3.3	2.1		coal flow tim	15	min	Equiv. Ratio	1.785	w/in, no solid fuel			
5	0.30236	0.30550	0.00314	3.25	0.91	1.1 - 2.1	1.1					mol wt wet	28.152	g/mol			
6	0.30277	0.30334	0.00057	0.59	0.32	0.7 - 1.1	0.7					dens@inlet	352.608	g/m^3			
7	0.30169	0.30176	0.00007	0.07	0.25	0.4 - 0.7	0.4					mdot duct	508.487	g/min	minus ash		
Backup Filter	0.33109	0.33130	0.00024	0.25	0.00	0 -0.4	0					vduct	44.469	meters/min			
												vduct	2.420	ft/sec			
		total mass	0.09676						dens@STP	1202.10	g/m^3	dens@tmp	919.805	g/m^3			
									BACKFIRE BURNERS			mol wt dry	29.437	g/mol			
												dens@ratio	827.413	g/m^3			
									mdotBF1 CH4	19.1847973	g/min	volflowmeter	0.024	m^3/min			
Notes	The coal feeder is squeaking like a son of a bitch!								mdotBF1 Air	661.53712	g/min	volflowmeter	0.857	ft^3/min			
									phi	1.706	A/F equiv ratio						
	The samples all came out pretty black. I wonder how well they burned. All stages look good- no mass loss by overload								mdotAir/mdotF	29.2999468		mdotinrete	20.089	g/min			
												mdotimp	21.641	g/min			
									mdotBF2 CH4	0	g/min	volflwimp	0.024	m^3/min			
									mdotBF2 Air	0	g/min	volflwimp	0.831	ft^3/min			
									phi	#DIV/0!	A/F equiv rati	vinlet	382.804	m/min			
									mdotAir/mdotF	#DIV/0!		vinlet	20.937	ft/sec			
												mdotcoal	0.01089	g/min			
									actual ash	0.09676	g	expected ash	0.1631	g			
												%Diff ash	69.589	%	based on actual		

Table G.22: Test 09169401

Date	9/16/94	mo/day/yr	Main NG	57 0	%	Upper T	1180	c									
Coal	Upper Freepor	source	Main Air	41 0	%	Sample T	700	c									
	raw	process		91 9	psig	Lower T	578	c									
test no	09169401	m/d/ynum	BF1NG	46 0	%	Coal feed	820	units	inp init diam	0 5625	inches						
test dur	15 00	minutes	BF1Air	4 8	units,front	Coal feed cor	1 1	g/m	Mainduct rad	4	inches						
Coal Properies (Ref only)				4 8	units, back	Vacuum Roto	63 0	%	Main Gas Flo	0 57	fraction	mdot CH4	16 050	g/min			
Upper Freeport			BF2NG		%	Vacuum Roto	9 5	in hg	Main Air Rot	0 41	fraction	mdot Main A	499 352	g/min			
grams	moles/100g		BF2Air		units,front	atomizer air	full open	units	Main Air Fnot	31 5	psig	phi	1 777	units			
64 57	5 36				units, back	atomizer air		psig	Inj Air Roto	10	%	mole fract	1 003				
4 07	4 07		Inj Roto	10	%	atomizer H2O	207	mm	Inj Air Rota	39	psig	CO2	1 003	moles/min	CH4&Air only		
3 92	0 25		Inj Roto	39	psig	exit duct T	92	F				H20	2 006	moles/min	CH4&Air only		
1 63	0 12					over furn T	105	F	Coal Composition on Elemental level			N2	13 403	moles/min	CH4&Air only		
2 07	0 06								Carbon(mon	5 36	moles/100g	O2	1 658	moles/min	CH4&Air only		
23 23	23 23								Hydrogen (n	4 07	moles/100g	mdot air inj	10 831	g/min			
0 81	0 03								Oxygen (mo	0 28	moles/100g	O2	0 079	moles/min	inj Air only		
100									Nitrogen (m	0 12	moles/100g	N2	0 297	moles/min	inj Air only		
									Sulfur(mon)	0 06	moles/100g	Dry O2 w/in	10 020	vol%	tot w/o coal		
									Ash	23 23	g/100g	DryO2w/o in	9 792	vol%	t w/o coal&inj		
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum % lt. size mpe	Size Range micrometers	ECD micro m		H2O	0 03	moles/100g	Coal Fractio	0 011	mdot coal/100g			
												CO2	1 092	moles/min	total		
									mdot coal	1 1	g/min	H20	2 029	moles/min	total		
Presseparator	0 30313	0 36224	0 05911	57 89	42 11	100 & up	10		Probe inlet T	700	degC	N2	13 700	moles/min	total		
0	0 27859	0 29048	0 01189	11 65	30 46	90 -100	9		Impactor Inl	100	degC (est	SO2	0 0007	moles/min	total		
1	0 27918	0 28855	0 00937	9 18	21 28	5 8 - 9 0	5 8		Vacuum Rot	9 5	in Hg	O2	1 568	moles/min	total		
2	0 30349	0 30773	0 00424	4 15	17 13	4 7 - 5 8	4 7		Vacuum Rot	23	degC (est.	Dry O2	9 599	vol%			
3	0 30251	0 30949	0 00698	6 84	10 29	3 3 - 4 7	3 3		Vacuum Rot	63	CFH	H20 wt	0 071	mass fraction			
4	0 30419	0 31019	0 00600	5 88	4 42	2 1 ; 3 3	2 1		coal flow ter	15	min	Equiv Ratio	1 016	w/in, no solid fuel			
5	0 30277	0 30638	0 00359	3 52	0 90	1 1 - 2 1	1 1					mol wt wet	28 164	g/mol			
6	0 30285	0 30356	0 00071	0 70	0 21	0 7 - 1 1	0 7					dens@inlet	352 748	g/m^3			
7	0 30158	0 30184	0 00026	0 06	0 15	0 4 - 0 7	0 4					mdot duct	517 078	g/min	minus ash		
Backup Filter	0 33234	0 33249	0 00015	0 15	0 00	0 -0 4	0					vduct	46 202	meters/min			
												vduct	2 496	ft/sec			
		total mass	0 10210						dens@STP	1202 10	g/m^3	dens@imp	920 179	g/m^3			
									BACKFIRE BURNERS			mol wt dry	29 426	g/mol			
												dens@rota	827 107	g/m^3			
Notes	Coal feeder is still squeeking, but seems to be feeding ok								mdotBF1 CH4	19 1847973	g/min	volf/wratero	0 025	m^3/min			
									mdotBF1 Air	564 600829	g/min	volf/wratero	0 871	ft^3/min			
									phi	1 715	A/F equiv ratio						
	It still seems that the ash is way too dark. I'm not so sure this stuff is totally burned								mdotA/mdotF	29 4266314		mdot/rota	20 399	g/min			
	Upper freeport may need a higher temperature											mdot/imp	21 949	g/min			
									mdotBF2 CH4	0	g/min	vol/wimp	0 024	m^3/min			
									mdotBF2 Air	0	g/min	vol/wimp	0 842	ft^3/min			
									phi	#DIV/0!	A/F equiv rati	vinlet	388 109	m/min			
									mdotA/mdotF	#DIV/0!		vinlet	21 222	ft/sec			
												mdotcoal	0 01085	g/min			
									actual ash	0 1021	g	expected as	0 1827	g			
												%Diff ash	-58 357	%	based on actual		

Table G.23: Test 09219401

Date	9/21/94	mo/day/yr	Main NG	57.5	%	Upper T	1180	c										
Coal	Illinois #6	source	Main Air	41.0	%	Sample T	700	c										
	raw	process		31.5	psig	Lower T	580	c										
test no	09219401	m/d/ynum	BF1NG	46.0	%	Coal feed	820	units	inp init dian	0.5625	inches							
test dur	15.00	minutes	BF1Air	4.5	units,front	Coal feed cor	1.1	g/m	Mainduct rac	4	inches							
Coal Properties	(Ref. only)			4.8	units, back	Vacuum Roto	67.0	%	Main Gas Ro	0.575	fraction	mdot CH4	16.191	g/min				
Illinois #6			BF2NG		%	Vacuum Roto	7.8	in hg	Main Air Rot	0.41	fraction	mdot Main A	489.352	g/min				
grams	atomwt/100g		BF2Air		units,front	atomizer air	full open	units	Main Air Rot	31.9	psig	phi	1.761	units				
59.87	4.99				units, back	atomizer air		psig	Inj Air Roto	10	%	mole fract	1.012					
4.55	4.55		Inj Roto	10	%	atomizer H2O	203	mm	Inj Air Roto	39	psig	CO2	1.012	moles/min	CH4&Air only			
8.52	0.53		Inj Roto	39	psig	exit duct T		F				H20	2.024	moles/min	CH4&Air only			
1.37	0.10					over furn T		F	Coal Composition on Elemental level			N2	13.403	moles/min	CH4&Air only			
3.76	0.12								Carbon(mon	4.99	moles/100g	O2	1.541	moles/min	CH4&Air only			
8.62	8.62								Hydrogen (r	4.55	moles/100g	mdot air inj	10.831	g/min				
13.31	0.74								Oxygen (mo	0.53	moles/100g	O2	0.079	moles/min	Inj Air only			
100									Nitrogen (m	0.10	moles/100g	N2	0.297	moles/min	Inj Air only			
									Sulfur(mon)	0.12	moles/100g	Dry O2 w/in	9.918	vol%	tot w/o coal			
	'sep21 7:30am								Ash	8.62	g/100g	DryO2w/o in	9.657	vol%	tot w/o coal&inj			
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum % in size mge	Size Range micrometers	ECD micro m		H2O	0.74	moles/100g	Coal Fractior	0.011	mdotcoal/100g				
												CO2	1.067	moles/min	total			
Preseparator	0.30023	0.32791	0.02768	56.37	43.63	10.0 & up	10		mdot coal	1.1	g/min	H20	2.057	moles/min	total			
0	0.27827	0.28243	0.00416	12.55	31.08	9.0 - 10.0	9		Probe inlet T	700	degC	N2	13.700	moles/min	total			
1	0.27934	0.28424	0.00490	9.98	21.10	8.0 - 9.0	8.0		Impactor Ink	100	degC (est. T	SO2	0.0013	moles/min	total			
2	0.30067	0.30304	0.00237	4.83	16.27	7.0 - 8.0	7.0		Vacuum Rot	7.75	in Hg	O2	1.554	moles/min	total			
3	0.30276	0.30647	0.00371	7.56	8.72	6.0 - 7.0	6.0		Vacuum Rot	23	degC (est. T	Dry O2	9.520	vol%				
4	0.30203	0.30437	0.00234	4.77	3.95	5.0 - 6.0	5.1		Vacuum Rot	67	CFH	H20 wt	0.072	mass fraction				
5	0.30292	0.30372	0.00080	1.63	2.32	4.1 - 5.1	4.1		coal flow tin	15	min	Equiv Ratio	1.000	w/in, no solid fuel				
6	0.30091	0.30104	0.00013	0.26	2.06	3.7 - 4.1	3.7					mol wt wet	28.150	g/mol				
7	0.30347	0.30354	0.00007	0.14	1.91	3.4 - 3.7	3.4					dens@inlet	352.680	g/m^3				
Backup Filter	0.33169	0.33263	0.00094	1.91	0.00	0.0 - 3.4	0					mdot duct	517.378	g/min	minus ash			
												vduct	45.250	meters/min				
		total mass	0.04910									vduct	2.469	ft/sec				
									dens@STP	1292.10	g/m^3	dens@imp	919.734	g/m^3				
									BACKFIRE BURNERS			mol wt dry	29.429	g/mol				
												dens@roto	898.016	g/m^3				
									mdotBF1 CH4	19.1847673	g/min	volflwrate/p	0.027	m^3/min				
Notes	Went about 1 minute on pump prior to coal test (full impactor hookup), trying to								mdotBF1 Air	546.956859	g/min	volflwrate/p	0.965	ft^3/min				
	stabilize the flowrate. The flow rate oscillated about 10 units for the first 12 minute								phi	1.661	A/F equiv ratio							
	because of water in the line and roto. It stabilized and probably didn't effect the flow								mdotA/mdotF	29.5099554		mdotroto	24.643	g/min				
												mdotimp	29.435	g/min				
	I cleaned, dried, desiccated and weighed the foils and filter on sept 19 around 10 am,								mdotBF2 CH4	0	g/min	volflwimp	0.029	m^3/min				
	and loaded the impactor. The impactor was placed in the over for 24 hours at 110 C,								mdotBF2 Air	0	g/min	volflwimp	1.015	ft^3/min				
	then the oven was turned off. After about 18 hours, the foils and filter was reweighed								phi	#DIV/0!	A/F equiv rati	vinlet	467.643	m/min				
	the two weight meesurements are recorded here								mdotA/mdotF	#DIV/0!		vinlet	25.871	ft/sec				
	sep19 10am	sep21 7:3a	delta															
Preseparator	0.30027	0.30023	-0.00004									mdotcoal	0.00484	g/min				
0	0.27831	0.27827	-0.00004						actual ash	0.0491	g	expected as	0.0727	g				
1	0.27943	0.27934	-0.00009															
2	0.30071	0.30067	-0.00004															
3	0.30277	0.30276	-0.00001															
4	0.30206	0.30203	-0.00003									%Diff ash	-48.005	%	based on actual			
5	0.30296	0.30292	-0.00004															
6	0.30091	0.30091	0.00000															
7	0.30348	0.30347	-0.00001															
Backup Filter	0.33179	0.33169	-0.00010															
		mass chg	-0.00049															

Table G.24: Test 09239401

Date	9/23/94	mo/day/yr	Main NG	57.6	%	Upper T	1185	c									
Coal	Illinois #6	source	Main Air	41.0	%	Sample T	725	c									
	raw	process		31.5	psig	Lower T	595	c									
test no	09239401	m/d/ynum	BF1NG	46.0	%	Coal feed	820	units	imp inlt diam	0.5625	inches						
test dur	15.00	minutes	BF1Air	4.8	units,front	Coal feed cor	1.1	g/m	Mainduct rad	4	inches						
Coal Properies	(Ref. only)			4.8	units, back	Vacuum Roto	65.0	%	Main Gas Ro	0.575	fraction	mdot CH4	19.191	g/min			
Illinois #6			BF2NG		%	Vacuum Roto	7.5	in hg	Main Air Rot	0.41	fraction	mdot Main A	489.352	g/min			
grams	atomwt/100g		BF2Air		units,front	atomizer air	full open	units	Main Air Rot	31.6	psig	phi	1.791	units			
59.87	4.99				units, back	atomizer air		psig	Inj Air Roto	10	%	mole fract	1.012				
4.55	4.55		Inj Roto	10	% (est)	atomizer H2O	235	mm	Inj Air Roto	39	psig	O2	1.012	moles/min	CH4&Air only		
8.52	0.53		Inj Roto	39	psig (est)	exit duct T	98	F				H20	2.024	moles/min	CH4&Air only		
1.37	0.10					over furn T	105	F	Coal Composition on Elemental level			N2	13.403	moles/min	CH4&Air only		
3.76	0.12								Carbon(mon	4.99	moles/100g	O2	1.941	moles/min	CH4&Air only		
8.62	8.62								Hydrogen (n	4.55	moles/100g	mdot air inj	10.831	g/min			
13.31	0.74								Oxygen (mo	0.53	moles/100g	O2	0.079	moles/min	Inj Air only		
100									Nitrogen (m	0.10	moles/100g	N2	0.297	moles/min	Inj Air only		
									Sulfur(mon)	0.12	moles/100g	Dry O2 w/in	9.918	vol%	tot w/o coal		
									Ash	8.92	g/100g	DryO2w/o in	9.857	vol%	t w/o coal&inj		
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum % lt size mge	Size Range micrometers	ECD micro m		H2O	0.74	moles/100g	Coal Fractio	0.011	mdot(coal)/100g			
												CO2	1.067	moles/min	total		
									mdot coal	1.1	g/min	H20	2.057	moles/min	total		
Presepsrator	0.30393	0.33008	0.02613	54.68	45.32	100 & up	10		Probe inlet T	725	degC	N2	13.700	moles/min	total		
0	0.27921	0.28541	0.00620	12.97	32.35	90 -100	9		Impactor Inl	100	degC (est. T	SO2	0.0013	moles/min	total		
1	0.27844	0.28344	0.00500	10.46	21.89	5.8 - 9.0	5.8		Vacuum Rot	7.5	in Hg	O2	1.554	moles/min	total		
2	0.30082	0.30322	0.00240	5.02	16.87	4.7 - 5.8	4.7		Vacuum Rot	23	degC (est. T	Dry O2	9.820	vol%			
3	0.30071	0.30468	0.00397	8.31	8.56	3.3 - 4.7	3.3		Vacuum Rot	65	CFH	H20 wt	0.072	mass fraction			
4	0.30279	0.30525	0.00255	5.34	3.22	2.1 - 3.3	2.1		coal flow im	15	min	Equiv. Ratio	1.800	w/inj, no solid fuel			
5	0.30169	0.30244	0.00078	1.59	1.63	1.1 - 2.1	1.1					mol wt wet	28.160	g/mol			
6	0.30172	0.30180	0.00008	0.17	1.46	0.7 - 1.1	0.7					dens@inlet	343.748	g/m^3			
7	0.30109	0.30111	0.00005	0.10	1.36	0.4 - 0.7	0.4					mdot duct	517.379	g/min	minus ash		
Backup Filter	0.33346	0.33411	0.00065	1.36	0.00	0 -0.4	0					vduct	48.412	meters/min			
												vduct	2.693	ft/sec			
		total mass	0.04779						dens@STP	1202.10	g/m^3	dens@rmp	910.734	g/m^3			
									BACKFIRE BURNERS			mol wt dry	29.429	g/mol			
												dens@rota	908.133	g/m^3			
									mdotBF1 CH4	19.1847673	g/min	volflwrotame	0.027	m^3/min			
Notes	Flow and pressure dropped to 65% @ 7.5 in Hg at 12 minutes from 67% @ 8.0 in Hg at 2								mdotBF1 Air	564.800829	g/min	volflwrotame	0.942	ft^3/min			
	minutes								phi	1.715	A/F equiv ratio						
									mdotA/mdotF	29.4290314		mdotrota	24.214	g/min			
	The duct temperatures have been fluctuating between 90 and 110F ove the last couple											mdotimp	25.080	g/min			
	of days. The coolant flow hasn't been fluctuating that much.								mdotBF2 CH4	0	g/min	volflwimp	0.028	m^3/min			
									mdotBF2 Air	0	g/min	volflwimp	1.001	ft^3/min			
	The thermocouple read erratic for a moment on the upper T. I think it was a loose								phi	#DIV/0!	A/F equiv rati	vinlet	479.227	m/min			
	fitting, because it stabilized after pushing the male/female fitting together better. I								mdotA/mdotF	#DIV/0!		vinlet	25.676	ft/sec			
	don't think this thermocouple is fried yet.																
												mdotcoal	0.00478	g/min			
	Foil 0 was off center. Lost a couple spots. I tried knocking the piles back onto the foil								actual ash	0.04779	g	expected as	0.0717	g			
	with about 50% success.																
												%Diff ash	-50.073	%	based on actual		

Table G.25: Test 10069401

Date	10/6/94	mo/day/yr	Main NG	64 5	%	Upper T	1173	c									
Coal	Blank	source	Main Air	41 0	%	Sample T	770	c									
		process		31 0	psig	Lower T	635	c									
test no	10069401	m/d/ynum	BF1NG	45 0	%	Coal feed	0	units	Imp Init diam	0 5625	inches						
test dur	15 00	minutes	BF1Air	4 7	units,front	Coal feed con	0	g/m	Mainduct rad	4	inches						
Coal Properties	(Rel only)			4 7	units, back	Vacuum Roto		%	Main Gas Flo	0 545	fraction	mdot CH4	15 348	g/min			
			BF2NG		%	Vacuum Rotg	68 0	in hg	Main Air Rot	0 41	fraction	mdot Main A	486 697	g/min			
grams	moles/100g		BF2Air		units,front	atomizer air	full	units	Main Air Rot	31	psig	phi	1 648	units			
					units, back	atomizer air		psig	Inj Air Roto	10	%	mole fract	0 959				
			Inj Roto	10	%	atomizer H2O	238	mm	Inj Air Roto	39	psig	CO2	0 959	moles/min	CH4&Air only		
			Inj Roto	39	psig	exit duct T	69	F				H20	1 918	moles/min	CH4&Air only		
						over furn T	105	F	Coal Composition on Elemental level			N2	13 330	moles/min	CH4&Air only		
									Carbon(mon	0 00	moles/100g	O2	1 627	moles/min	CH4&Air only		
									Hydrogen (m	0 00	moles/100g	mdot air Inj	10 831	g/min			
									Oxygen (mor	0 00	moles/100g	O2	0 079	moles/min	Inj Air only		
									Nitrogen (mo	0 00	moles/100g	N2	0 297	moles/min	Inj Air only		
									Sulfur(mon)	0 00	moles/100g	Dry O2 w/N	10 471	vol%	tot w/o coal		
									Ash	0 00	g/100g	DryO2w/o I	10 223	vol%	t w/o coal&inj		
Stage	Initial(g)	Final(g)	Net(g)	% in size	Cum %	Size Range	ECD		H20	0 00	moles/100g	Coal Fractio	0 000	mdotcoal/100g			
				range	lt size rnge	micrometers	micro m					CO2	0 959	moles/min	total		
									mdot coal	0	g/min	H20	1 918	moles/min	total		
Presepserator	0 30550	0 30588	0 00038	131 03	-31 03	100 & up	10		Probe inlet T	770	degC	N2	13 627	moles/min	total		
0	0 27982	0 27981	-0 00001	-3 45	-27 59	90 -100	9		Impactor Init	100	degC (est T	SO2	0 0000	moles/min	total		
1	0 27639	0 27638	-0 00001	-3 45	-24 14	58 - 90	5 8		Vacuum Rot	68	in Hg	O2	1 706	moles/min	total		
2	0 30725	0 30727	0 00002	6 90	-31 03	47 - 58	4 7		Vacuum Rot	23	degC (est T	Dry O2	10 471	vol%			
3	0 29837	0 29836	-0 00001	-3 45	-27 59	33 - 47	3 3		Vacuum Rot	0	CFH	H20 wt	0 067	mass fraction			
4	0 30374	0 30374	0 00000	0 00	-27 59	21 - 33	2 1		coal flow lin	15	min	Equiv Ratio	1 889	w/inj, no solid fuel			
5	0 30233	0 30232	-0 00001	-3 45	-24 14	11 - 21	1 1					mol wt wet	28 164	g/mol			
6	0 30328	0 30327	-0 00001	-3 45	-20 69	07 - 11	0 7					dens@ inlet	329 079	g/m^3			
7	0 30322	0 30320	-0 00002	-6 90	-13 79	04 - 07	0 4					mdot duct	512 674	g/min	minus ash		
Backup Filter	0 33231	0 33227	-0 00004	-13 79	0 00	0 -04	0					vduct	48 059	meters/min			
												vduct	2 626	lt/sec			
		total mass	0 00029						dens@STP	1202 10	g/m^3	dens@ Imp	920 185	g/m^3			
									BACKFIRE BURNERS			mol wt dry	29 361	g/mol			
												dens@roto	-1577 048	g/m^3			
									mdotBF1 CH4	18 76770712	g/min	volf/wrotero	#NUM!	m^3/min			
Notes									mdotBF1 Air	549 8364295	g/min	volf/wrotero	#NUM!	l/^3/min			
11/29 Incomplete									phi	1 707	A/F equiv ratio						
									mdotA/mdotF	29 2970487		mdotroto	#NUM!	g/min			
												mdotimp	#NUM!	g/min			
									mdotBF2 CH4	0	g/min	volf/wimp	#NUM!	m^3/min			
									mdotBF2 Air	0	g/min	volf/wimp	#NUM!	l/^3/min			
									phi	#DIV/0!	A/F equiv ratio	vinlet	#NUM!	m/min			
									mdotA/mdotF	#DIV/0!		vinlet	#NUM!	lt/sec			
												mdotcoal	#NUM!	g/min			
									actual ash	0 00029	g	expected ash	#NUM!	g			
												%Def ash	#NUM!	%	based on actual		

Table G.26: Test 10079401

Date	10/7/94	mo/day/yr	Main NG	51.5	%	Upper T	1125	c (new tc)									
Coal	Kentucky #11	source	Main Air	41.0	%	Sample T	759	c									
	raw	process		31.5	psig	Lower T	928	c									
test no	10079401	m/d/yynum	BF1NG	45.0	%	Coal feed	820	units	Imp Init diam	0.5625	inches						
test dur	15.00	minutes	BF1Air	4.7	units,(fron	Coal feed cor	1.1	g/m	Mainduct rad	4	inches						
Coal Properties	(Ref. only)			4.7	units, back	Vacuum Roto	68.0	%	Main Gas Ro	0.515	fraction	mdot CH4	14.501	g/min			
Kentucky #11			BF2NG		%	Vacuum Roto	8.0	in hg	Main Air Rot	0.41	fraction	mdot Main A	489.352	g/min			
grams	atomwt/100g		BF2Air		units,(fron	atomizer air		units	Main Air Rot	31.5	psig	phi	1.967	units			
57.73	4.81				units, back	atomizer air		psig	Inj Air Roto	10	%	mole fract	0.906				
4.42	4.42		Inj Roto	10	%	atomizer H2O	233	mm	Inj Air Roto	39	psig	CO2	0.906	moles/min	CH4&Air only		
7.64	0.48		Inj Roto	39	psig	exit duct T	89	F				H20	1.813	moles/min	CH4&Air only		
1.29	0.09					over furn T	105	F	Coal Composition on Elemental level			N2	13.403	moles/min	CH4&Air only		
4.22	0.13								Carbon(mon	4.81	moles/100g	O2	1.752	moles/min	CH4&Air only		
20.96	20.96								Hydrogen (n	4.42	moles/100g	mdot air inj	10.831	g/min			
3.84	0.21								Oxygen (mo	0.48	moles/100g	O2	0.079	moles/min	Inj Air only		
100.1									Nitrogen (m	0.09	moles/100g	N2	0.297	moles/min	Inj Air only		
									Sulfur(mon)	0.13	moles/100g	Dry O2 w/in	11.139	vol%	tot w/o coal		
									Ash	20.89	g/100g	DryO2w/o in	10.909	vol%	t w/o coal&inj		
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum % R size rnge	Size Range micrometers	ECD micro m		H2O	0.21	moles/100g	Coal Fractio	0.011	mdot/coalV100g			
												CO2	0.959	moles/min	total		
									mdot coal	1.1	g/min	H20	1.839	moles/min	total		
Presepartor	0.30180	0.36587	0.06427	58.89	41.11	10.0 & up	10		Probe inlet T	759	degC	N2	13.700	moles/min	total		
0	0.28109	0.29605	0.01496	13.71	27.40	9.0 - 10.0	9		Impactor Init	100	degC (est. T	O2	0.0016	moles/min	total		
1	0.28063	0.29160	0.01097	10.05	17.35	5.8 - 9.0	5.8		Vacuum Rot	6	in Hg	O2	1.767	moles/min	total		
2	0.30181	0.30781	0.00580	5.31	12.03	4.7 - 5.8	4.7		Vacuum Rot	23	degC (est. T	Dry O2	10.756	vol%			
3	0.30192	0.30850	0.00658	6.03	6.00	3.3 - 4.7	3.3		Vacuum Rot	68	CFH	H20 wt	0.064	mass fraction			
4	0.30366	0.30803	0.00437	4.00	2.00	2.1 - 3.3	2.1		coal flow lim	15	min	Equiv. Ratio	2.010	w/inj. ng solid fuel			
5	0.30183	0.30339	0.00156	1.43	0.57	1.1 - 2.1	1.1					mol wt wet	28.223	g/mol			
6	0.30140	0.30156	0.00016	0.15	0.42	0.7 - 1.1	0.7					dens@inlet	333.283	g/m^3			
7	0.29957	0.29958	0.00001	0.01	0.41	0.4 - 0.7	0.4					mdot duct	515.554	g/min	minus ash		
Backup Filter	0.33345	0.33390	0.00045	0.41	0.00	0 -0.4	0					vduct	47.701	meters/min			
												vduct	2.903	ft/sec			
		total mass	0.10913						dens@STP	1292.10	g/m^3	dens@imp	922.114	g/m^3			
									BACKFIRE BURNERS			mol wt dry	29.368	g/mol			
												dens@roto	886.036	g/m^3			
									mdotBF1 CH4	18.7977071	g/min	volf/waters	0.028	m^3/min			
Notes									mdotBF1 Air	552.838116	g/min	volf/waters	0.973	ft^3/min			
									phi	1.717	A/F equiv ratio						
									mdotA/mdotF	29.456881		mdot/rote	24.413	g/min			
												mdot/imp	26.088	g/min			
									mdotBF2 CH4	0	g/min	volf/wimp	0.028	m^3/min			
									mdotBF2 Air	0	g/min	volf/wimp	0.999	ft^3/min			
									phi	#DIV/0!	A/F equiv ratio	vinlet	488.227	m/min			
									mdotA/mdotF	#DIV/0!		vinlet	26.697	ft/sec			
												mdot/coal	0.01197	g/min			
									actual ash	0.10913	g	expected ash	0.1750	g			
												%Diff ash	-60.359	%	based on actual		

Table G.27: Test 10119401

Date	10/11/94	mo/day/yr	Main NG	51.0	%	Upper T	1118	c									
Coal	Kentucky #11	source	Main Air	41.0	%	Sample T	744	c									
	raw	process		31.5	psig	Lower T	623	c									
test no	10119401	m/d/ynum	BF1NG	45.0	%	Coal feed	620	units	Imp Init diam	0.5625	inches						
test dur	15.00	minutes	BF1Air	4.6	units,front	Coal feed cor	1.1	g/m	Meinduct rad	4	inches						
Coal Properties	(Ret. only)			4.6	units, back	Vacuum Reto	68.0	%	Main Gas Ro	0.51	fraction	mdot CH4	14.360	g/min			
Kentucky #11			BF2NG	0.0	%	Vacuum Reto	8.0	in hg	Main Air Rot	0.41	fraction	mdot Main A	499.352	g/min			
grams	atom wt/100g		BF2Air	0.0	units,front	atomizer air		units	Main Air Rot	31.5	psig	phi	1.996	units			
57.73	4.81			0.0	units, back	atomizer air		psig	Inj Air Reto	10	%	mole fract	0.898				
4.42	4.42		Inj Reto	10	%	atomizer H2O	209	mm	Inj Air Reto	39	psig	CO2	0.998	moles/min	CH4&Air only		
7.64	0.48		Inj Reto	39	psig	exit duct T	89	F				H20	1.795	moles/min	CH4&Air only		
1.29	0.09					over furn T	107	F	Coal Composition on Elemental level			N2	13.403	moles/min	CH4&Air only		
4.22	0.13								Carbon(mon	4.81	moles/100g	O2	1.770	moles/min	CH4&Air only		
20.96	20.96								Hydrogen (n	4.42	moles/100g	mdot air inj	10.831	g/min			
3.84	0.21								Oxygen (mo	0.48	moles/100g	O2	0.079	moles/min	Inj Air only		
100.1									Nitrogen (m	0.09	moles/100g	N2	0.297	moles/min	Inj Air only		
									Sulfur(mon)	0.13	moles/100g	Dry O2 w/in	11.240	vol%	tot w/o coal		
									Ash	20.96	g/100g	DryO2w/o in	11.012	vol%	t w/o coal&Inj		
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % R. size rnge	Size Range micrometers	ECD micro m		H2O	0.21	moles/100g	Coal Fractio	0.011	mdotcoal/100g			
												CO2	0.950	moles/min	total		
Preseparator	0.30208	0.36513	0.06305	53.88	46.12	10.0 & up	10		mdot coal	1.1	g/min	H20	1.822	moles/min	total		
0	0.27665	0.29803	0.01938	16.56	29.56	9.0 -10.0	9		Probe Inlet T	744	degC	N2	13.700	moles/min	total		
1	0.27765	0.29044	0.01279	10.93	18.63	5.8 - 9.0	5.8		Impactor Init	100	degC (est. T	SO2	0.0015	moles/min	total		
2	0.30080	0.30735	0.00655	5.60	13.03	4.7 - 5.8	4.7		Vacuum Rot	8	in Hg	O2	1.785	moles/min	total		
3	0.30325	0.31099	0.00774	6.61	6.42	3.3 - 4.7	3.3		Vacuum Rot	23	degC (est. T	Dry O2	10.857	vol%			
4	0.30232	0.30753	0.00521	4.45	1.97	2.1 - 3.3	2.1		Vacuum Rot	68	CFH	H20 wt	0.064	mass fraction			
5	0.30460	0.30639	0.00179	1.53	0.44	1.1 - 2.1	1.1		coal flow tim	15	min	Equiv. Ratio	2.030	w/inj, no solid fuel			
6	0.30390	0.30405	0.00015	0.13	0.31	0.7 - 1.1	0.7					mol wt wet	28.229	g/mol			
7	0.30442	0.30446	0.00004	0.03	0.27	0.4 - 0.7	0.4					dens@inlet	338.270	g/m^3			
Backup Filter	0.32798	0.32830	0.00032	0.27	0.00	0 -0.4	0					mdot duct	516.413	g/min	minus ash		
												vduct	40.985	meters/min			
		total mass	0.11702									vduct	2.664	ft/sec			
									dens@STP	1202.10	g/m^3	dens@Imp	922.306	g/m^3			
									BACKFIRE BURNERS			mol wt dry	29.363	g/mol			
												dens@reto	885.885	g/m^3			
									mdotBF1 CH4	10.7677071	g/min	volflwrateIn	0.026	m^3/min			
Notes	Plenty of black particles above the 0 stage orifices. The preesp looked good and brown.								mdotBF1 Air	541.075903	g/min	volflwrateIn	0.873	ft^3/min			
									phi	1.680	A/F equiv ratio						
	The 0 stage is way overloaded. Neat piles of brown ash, with black particles on edges								mdotAir/mdotF	28.8301389		mdotIreto	24.406	g/min			
	and end in equidistant lines between brown ash piles. Same with stage 1, but only a											mdotImp	26.064	g/min			
	small amount of black particles								mdotBF2 CH4	0	g/min	volflwImp	0.028	m^3/min			
									mdotBF2 Air	0	g/min	volflwImp	0.998	ft^3/min			
	The stages get cleaner as they go down. The brown piles are almost 100% of particles								phi	#DIV/0!	A/F equiv ratio	vinlet	490.800	m/min			
	by stage 4 or 5. The filter, as before (last test), has hundreds of black particles								mdotAir/mdotF	#DIV/0!		vinlet	25.280	ft/sec			
	>10microns																
												mdotcoal	0.01166	g/min			
	Turning up main NG post test to 62%. Oct 11, 4:12pm								actual ash	0.11702	g	expected as	0.1749	g			
	I knocked some ash of stage 0 when loading (<1%)																
												%Diff ash	-49.454	%	based on actual		

Table G.28: Test 10139401

Date	10/13/94	mo/day/yr	Main NG	62 0	%	Upper T	1249	c new tc											
Coal	Kentucky #11	source	Main Air	41 0	%	Sample T	813	c											
	raw	process		32 0	psig	Lower T	663	c											
test no	10139401	m/d/ynum	BF1NG	45 0	%	Coal feed	820	units	Imp inlt diam	0 5625	inches								
test dur	15 00	minutes	BF1Air	4 6	units,front	Coal feed cor	1 1	g/m	Mainduct dia	4	inches								
Coal Properies	(Ref only)			4 6	units, back	Vacuum Roto	67 0	%	Main Gas Ro	0 62	fraction	mdot CH4	17 458	g/min					
Kentucky #11			BF2NG		%	Vacuum Roto	8 9	in hg	Main Air Rot	0 41	fraction	mdot Main A	491 993	g/min					
grams	atomwt/100g		BF2Air		units,front	atomizer air	full open	units	Main Air Rot	32	psig	phi	1 642	units					
57 73	4 81				units, back	atomizer air		psig	Inj Air Roto	9	%	mole fract	1 091						
4 42	4 42		Inj Roto	9	%	atomizer H2O	250±	mm	Inj Air Roto	39	psig	CO2	1 091	moles/min	CH4&Air only				
7 84	0 48		Inj Roto	39	psig	exit duct T	90	F				H20	2 192	moles/min	CH4&Air only				
1 29	0 09					over furn T	108	F	Coal Composition on Elemental level			N2	13 475	moles/min	CH4&Air only				
4 22	0 13								Carbon(mon	4 81	moles/100g	O2	1 402	moles/min	CH4&Air only				
20 96	20 96								Hydrogen (n	4 42	moles/100g	mdot air inj	9 748	g/min					
3 84	0 21								Oxygen (mo	0 48	moles/100g	O2	0 071	moles/min	Inj Air only				
100 1									Nitrogen (m	0 09	moles/100g	N2	0 267	moles/min	Inj Air only				
									Sulfur(mon	0 13	moles/100g	Dry O2 w/in	9 031	vol%	tot w/o coal				
									Ash	20 96	g/100g	DryO2w/o ir	9 778	vol%	t w/o coal&inj				
Stage	Initial(g)	Final(g)	Net(g)	% in size	Cum %	Size Range	ECD		H2O	0 21	moles/100g	Coal Fractio	0 011	mdotcoal/100g					
				range	R size mar	micrometers	micro m					CO2	1 144	moles/min	total				
									mdot coal	1 1	g/min	H20	2 209	moles/min	total				
Presepeator	0 30144	0 36357	0 06213	56 39	41 61	100 & up	10		Probe inlet T	813	degC	N2	13 743	moles/min	total				
0	0 27603	0 29003	0 01500	14 10	27 52	90 -100	9		Impactor Inl	100	degC (est. T	SO2	0 0015	moles/min	total				
1	0 27940	0 29051	0 01111	10 44	17 08	5 8 - 9 0	5 8		Vacuum Rot	8	in Hg	O2	1 409	moles/min	total				
2	0 30149	0 30804	0 00461	4 33	12 74	4 7 - 5 8	4 7		Vacuum Rot	23	degC (est. T	Dry O2	9 644	vol%					
3	0 30045	0 30752	0 00707	6 64	6 10	3 3 - 4 7	3 3		Vacuum Rot	87	CFH	H20 wt	0 078	mass fraction					
4	0 30034	0 30510	0 00476	4 47	1 63	2 1 - 3 3	2 1		coal flow ra	15	min	Equiv Ratio	1 676	w/inj, no solid fuel					
5	0 30113	0 30239	0 00126	1 18	0 44	1 1 - 2 1	1 1					mol wt wet	28 103	g/mol					
6	0 30187	0 30199	0 00012	0 11	0 33	0 7 - 1 1	0 7					dens@inlet	315 962	g/m^3					
7	0 30310	0 30312	0 00002	0 02	0 31	0 4 - 0 7	0 4					mdot duct	520 068	g/min	minus ash				
Backup Filter	0 32762	0 32795	0 00033	0 31	0 00	0 -0 4	0					vduct	50 853	meters/min					
												vduct	2 775	l/sec					
		total mass	0 10641						dens@STP	1202 10	g/m^3	dens@imp	816 185	g/m^3					
									BACKFIRE BURNERS			mol wt dry	29 472	g/mol					
												dens@roto	889 188	g/m^3					
Notes	Black particles above stage 0								mdotBF1 CH4	10 7677071	g/mn	volflwrotero	0 027	m^3/min					
									mdotBF1 Air	643 995622	g/mn	volflwrotero	0 960	l^3/min					
	Stage 0 slightly overloaded Stage 1 looked very good Very slight overload								phi	1 669	A/F equiv ratio								
	Bumped stage 3 while unloading Lost some ash, maybe up to 5%								mdotA/mdotF	29 9657293		mdotrgte	24 182	g/min					
												mdotimp	26 184	g/min					
	Some black particles on filter Not near as bad as cold tests Maybe 50 to 100								mdotBF2 CH4	0	g/mn	volflwimp	0 028	m^3/min					
	particles visible								mdotBF2 Air	0	g/mn	volflwimp	1 007	l^3/min					
									phi	#DIV/0!	A/F equiv rat	vinlet	517 869	m/min					
	I washed the particles from stage) and stage 1 orifice plates into seperator cup								mdotA/mdotF	#DIV/0!		vinlet	28 317	l/sec					
												mdotcoal	0 01161	g/min					
									actual ash	0 10641	g	expected ash	0 1741	g					
												%Diff ash	-63 630	%	based on actual				

Table G.29: Test 10149401

Date	10/14/94	mo/day/yr	Main NG	62.0	%	Upper T	1250	c									
Coal	Kentucky #11	source	Main Air	41.0	%	Sample T	817	c									
	raw	process		31.9	psig	Lower T	662	c									
test no	10149401	m/d/ynum	BF1NG	45.0	%	Coal feed	820	units	inp inlt diam	0.5625	inches						
test dur	15.00	minutes	BF1Air	4.7	units,front	Coal feed cor	1.1	g/m	Mainduct rad	4	inches						
Coal Properies	(Rel only)			4.7	units, back	Vacuum Roto	68.0	%	Main Gas Ro	0.62	fraction	mdot CH4	17.458	g/min			
Kentucky #11			BF2NG		%	Vacuum Roto	7.8	in hg	Main Air Rot	0.41	fraction	mdot Main A	491.466	g/min			
grams	atomwt/100g		BF2Air		units,front	atomizer air	full open	units	Main Air Rot	31.9	psig	phi	1.641	units			
57.73	4.81				units, back	atomizer air		psig	Inj Air Roto	10	%	mole fract	1.091				
4.42	4.42		Inj Roto	10	%	atomizer H2O	250 c	mm	Inj Air Roto	39	psig	CO2	1.091	moles/min	CH4&Air only		
7.64	0.48		Inj Roto	39	psig	exit duct T	90	F				H20	2.182	moles/min	CH4&Air only		
1.29	0.09					over furn T	109	F	Coal Composition on Elemental level			N2	13.491	moles/min	CH4&Air only		
4.22	0.13								Carbon(mon	4.81	moles/100g	O2	1.398	moles/min	CH4&Air only		
20.96	20.96								Hydrogen (n	4.42	moles/100g	mdot air inj	10.831	g/min			
3.64	0.21								Oxygen (mo	0.48	moles/100g	O2	0.079	moles/min	inj Air only		
100.1									Nitrogen (m	0.09	moles/100g	N2	0.297	moles/min	inj Air only		
									Sulfur(mon)	0.13	moles/100g	Dry O2 w/in	9.046	vol%	tot w/o coal		
									Ash	20.96	g/100g	DryO2w/o ir	8.764	vol%	t w/o coal&inj		
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum % lt size rge	Size Range micrometers	ECD micro m		H2O	0.21	moles/100g	Coal Fractio	0.011	mdot(coal/100g			
												CO2	1.144	moles/min	total		
Preseparator	0.30327	0.35879	0.05552	55.28	44.71	100 & up	10		mdot coal	1.1	g/min	H20	2.209	moles/min	total		
0	0.27831	0.28302	0.01471	14.65	30.06	90 -100	9		Probe inlet T	817	degC	N2	13.758	moles/min	total		
1	0.27588	0.28722	0.01134	11.29	18.76	58 - 90	58		Impactor Inlt	100	degC (est T	SO2	0.0015	moles/min	total		
2	0.29872	0.30340	0.00468	4.66	14.10	47 - 58	47		Vacuum Rot	7.8	in Hg	O2	1.413	moles/min	total		
3	0.30220	0.30965	0.00745	7.42	6.68	33 - 47	33		Vacuum Rot	23	degC (est T	Dry O2	8.659	vol%			
4	0.30311	0.30786	0.00475	4.73	1.95	21 - 33	21		Vacuum Rot	68	CFH	H20 wt	0.076	mass fraction			
5	0.30043	0.30183	0.00140	1.39	0.55	11 - 21	11		coal flow lin	15	min	Equiv Ratio	1.677	w/inj, no solid fuel			
6	0.30240	0.30254	0.00014	0.14	0.42	07 - 11	07					mol wt wet	28.104	g/mol			
7	0.30208	0.30212	0.00004	0.04	0.38	04 - 07	04					dens@inlet	314.213	g/m^3			
Backup Filter	0.32823	0.32861	0.00038	0.38	0.00	0 -04	0					mdot duct	520.924	g/min	minus ash		
												vduct	51.093	meters/min			
		total mass	0.10041									vduct	2.768	ft/sec			
									dens@STP	1292.19	g/m^3	dens@Imp	818.210	g/m^3			
									BACKFIRE BURNER8			mol wt dry	29.471	g/mol			
												dens@mole	897.271	g/m^3			
Notes	Noticed post test that I had the impingers on backwards oops It still did its job, but								mdotBF1 CH4	18.7877071	g/min	volflwmeter	0.028	m^3/min			
	I'll correct it before next test								mdotBF1 Air	556.226197	g/min	volflwmeter	0.979	ft^3/min			
									phi	1.724	A/F equiv ratio						
	I bumped the zero foil while loading it. I probably lost 5% of the particles								mdotAtmdotF	29.5841252		mdotmole	24.878	g/min			
												mdotimp	29.935	g/min			
	For some reason, the filter always throws the zero cal off by about - 00004								mdotBF2 CH4	0	g/min	volflwimp	0.028	m^3/min			
	Probably the filter is wiping dust off the plate, but I can never see dust on it								mdotBF2 Air	0	g/min	volflwimp	1.036	ft^3/min			
	before I put the filter on								phi	#DIV/0!	A/F equiv rati	vinlet	534.682	m/min			
									mdotAtmdotF	#DIV/0!		vinlet	29.237	ft/sec			
												mdotcoal	0.01193	g/min			
									actual ash	0.10041	g	expected ash	0.1769	g			
												%Diff ash	-78.195	%	based on actual		

Table G.30: Test 10169401

Date	10/16/94	mo/day/yr	Main NG	62.0	%	Upper T	1245	c											
Coal	Upper Freepor	source	Main Air	41.0	%	Sample T	813	c											
	raw	process		31.5	psig	Lower T	950	c											
test no	10169401	m/d/ynum	BF1NG	45.0	%	Coal feed	920	units	Imp Init diam	0.5625	inches								
test dur	15.00	minutes	BF1Air	4.7	units,front	Coal feed cor	1.1	g/m	Mainduct rad	4	inches								
Coal Properties (Rel only)				4.7	units, back	Vacuum Roto	67.0	%	Main Gas Ro	0.62	fraction	mdot CH4	17.458	g/min					
Upper Freepor			BF2NG		%	Vacuum Roto	8.0	in hg	Main Air Rot	0.41	fraction	mdot Main A	489.352	g/min					
grams	moles/100g		BF2Air		units,front	atomizer air	full open	units	Main Air Rot	31.5	psig	phi	1.634	units					
64.57	5.38				units, back	atomizer air		psig	Inj Air Roto	10	%	mole fract	1.091						
4.07	4.07		Inj Roto	10	%	atomizer H2O	259+	mm	Inj Air Roto	39	psig	CO2	1.091	moles/min	CH4&Air only				
3.92	0.25		Inj Roto	39	psig	exit duct T	90	F				H20	2.182	moles/min	CH4&Air only				
1.63	0.12					over furn T	108	F	Coal Composition on Elemental level			N2	13.403	moles/min	CH4&Air only				
2.07	0.06								Carbon(mon	5.38	moles/100g	O2	1.382	moles/min	CH4&Air only				
23.23	23.23								Hydrogen (n	4.07	moles/100g	mdot air inj	10.831	g/min					
0.51	0.03								Oxygen (mo	0.25	moles/100g	O2	0.079	moles/min	Inj Air only				
100									Nitrogen (m	0.12	moles/100g	N2	0.297	moles/min	Inj Air only				
									Sulfur(mon)	0.06	moles/100g	Dry O2 w/in	8.892	vol%	tot w/o coal				
									Ash	23.23	g/100g	DryO2w/o in	8.707	vol%	tot w/o coal&inj				
Stage	Initial(g)	Final(g)	Net(g)	% in size	Cum %	Size Range	ECD		H2O	0.03	moles/100g	Coal Fractio	0.011	mdotcoal/100g					
				range	lt size mge	micrometers	micro m					CO2	1.150	moles/min	total				
									mdot coal	1.1	g/min	H20	2.205	moles/min	total				
Presseparator	0.30133	0.35240	0.05107	53.67	46.13	100 & up	10		Probe Inlet T	813	degC	N2	13.700	moles/min	total				
0	0.27755	0.28915	0.01160	12.23	33.90	90 -100	9		Impactor Init	100	degC (est T	SO2	0.0007	moles/min	total				
1	0.27290	0.28256	0.00966	10.19	23.71	56 - 90	56		Vacuum Rot	8	in Hg	O2	1.392	moles/min	total				
2	0.29680	0.30147	0.00467	4.93	18.78	47 - 56	47		Vacuum Rot	29	degC (est T	Dry O2	8.567	vol%					
3	0.30404	0.31176	0.00772	8.14	10.64	33 - 47	33		Vacuum Rot	67	CFH	H20 wt	0.077	mass fraction					
4	0.30089	0.30691	0.00602	6.35	4.29	21 - 33	21		coal flow tim	15	min	Equiv Ratio	1.670	w/inj, no solid fuel					
5	0.30332	0.30654	0.00322	3.40	0.90	11 - 21	11					mol wt wet	28.106	g/mol					
6	0.30494	0.30548	0.00052	0.55	0.35	07 - 11	07					dens@inlet	315.393	g/m^3					
7	0.30387	0.30392	0.00005	0.05	0.30	04 - 07	04					mdot duct	518.485	g/min	minus ash				
Backup Filter	0.32806	0.32834	0.00028	0.30	0.00	0 -04	0												
												vduct	50.693	meters/min					
		total mass	0.09481									vduct	2.766	lt/sec					
									dens@STP	1202.10	g/m^3	dens@mp	918.274	g/m^3					
									BACKFIRE BURNERS			mol wt dry	29.477	g/mol					
												dens@rota	889.345	g/m^3					
									mdotBF1 CH4	19.7977071	g/min	vol/wratero	0.027	m^3/min					
Notes	I screwed up this test at the beginning I turned the pump on and then the coal feed as								mdotBF1 Air	552.839119	g/min	vol/wratero	0.960	lt^3/min					
	always I forgot to configure the coal feed air for feed Instead it was in bypass mode I								phi	1.717	A/F equiv ratio								
	turned off the pump and disconnected the impactor from the furnace I reconfigured								mdotA/mdotF	29.45689		mdotrota	24.188	g/min					
	the coal feed, tested it, and turned it off I rehooked up the impactor and forgot to turn											mdotimp	26.193	g/min					
	on the pump prior to the coal feed start I ran about 20 seconds before I started the								mdotBF2 CH4	0	g/min	vol/wimp	0.029	m^3/min					
	pump I don't think it will effect anything beyond some large particles falling into the								mdotBF2 Air	0	g/min	vol/wimp	1.007	lt^3/min					
	presseparator								phi	#DIV/0!	A/F equiv rati	vinlet	518.010	m/min					
									mdotA/mdotF	#DIV/0!		vinlet	28.325	lt/sec					
	Stage 0 was overloaded Ash is black I washed excess of stage 0 and slight bit of stage																		
	1 into the presep											mdotcoal	0.01291	g/min					
									actual ash	0.09481	g	expected as	0.1936	g					
	the cap to the impactor separated two tests ago Not unusual - I usually just force it																		
	back together Two tests ago I used high temp superglue to hold it The manufacturer																		
	used glue originally It separated again this test I'm going to have to find a new method for securing it											%Diff ash	-194.237	%	based on actual				

Table G.31: Test 10219401

Date	10/21/94	mo/day/yr	Main NG	61.8	%	Upper T	1243	c (max)											
Coal	Upper Freepor	source	Main Air	41.0	%	Sample T	807	c (max)											
	raw	process		31.8	psig	Lower T	662	c (max)											
test no	10219401	m/d/ynum	BF1NG	45.0	%	Coal feed	820	units	imp init diam	0.5625	inches								
test dur	15.00	minutes	BF1Air	4.6	units,front	Coal feed cor	1.1	g/m	Mainduct rad	4	inches								
Coal Properties (Ref only)				4.7	units, back	Vacuum Roto	67.0	%	Main Gas Ro	0.616	(fraction	mdot CH4	17.401	g/min					
Upper Freepor			BF2NG		%	Vacuum Roto	8.0	in hg	Main Air Rot	0.41	fraction	mdot Main A	490.936	g/min					
grams	moles/100g		BF2Air		units,front	atomizer air		units	Main Air Rot	31.8	psig	phi	1.644	units					
64.57	5.38				units, back	atomizer air		psig	Inj Air Roto	10	%	mole fract	1.088						
4.07	4.07		Inj Roto	10	%	atomizer H2O	250	mm	Inj Air Roto	39	psig	CO2	1.089	moles/min	CH4&Air only				
9.92	0.25		Inj Roto	39	psig	exit duct T	90	F				H20	2.175	moles/min	CH4&Air only				
1.93	0.12					over furn T	108	F	Coal Composition on Elemental level			N2	13.446	moles/min	CH4&Air only				
2.07	0.06								Carbon(mon	5.38	moles/100g	O2	1.491	moles/min	CH4&Air only				
23.23	23.23								Hydrogen (n	4.07	moles/100g	mdot air inj	10.631	g/min					
0.61	0.03								Oxygen (mo	0.25	moles/100g	O2	0.079	moles/min	Inj Air only				
100									Nitrogen (m	0.12	moles/100g	N2	0.297	moles/min	Inj Air only				
									Sulfur(mon)	0.06	moles/100g	Dry O2 w/in	9.073	vol%	tot w/o coal				
									Ash	23.23	g/100g	DryO2w/o in	8.792	vol%	tot w/o coal&inj				
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum % fl size rnge	Size Range micrometers	ECD micro m		H2O	0.03	moles/100g	Coal Fractio	0.01	mdotcoal/100g					
												CO2	1.147	moles/min	total				
									mdot coal	1.1	g/min	H20	2.198	moles/min	total				
Preseparator	0.30190	0.35927	0.05737	59.62	40.38	100 & up	10		Probe inlet T	807	degC	N2	13.744	moles/min	total				
0	0.27875	0.28997	0.01322	13.74	26.64	90 -100	9		Impactor Ink	100	degC (est. T	SO2	0.0007	moles/min	total				
1	0.27835	0.28813	0.00978	10.16	16.48	58 - 90	58		Vacuum Rot	8	in Hg	O2	1.410	moles/min	total				
2	0.30081	0.30526	0.00445	4.62	11.86	47 - 58	47		Vacuum Rot	23	degC (est. T	Dry O2	8.651	vol%					
3	0.30194	0.30920	0.00726	7.54	4.31	33 - 47	33		Vacuum Rot	67	CFH	H20 wt	0.076	mass fraction					
4	0.30287		0.00	0.00	4.31	21 - 33	21		coal flow tm	15	min	Equiv. Ratio	1.680	w/ml, no solid fuel					
5	0.30360	0.30690	0.00330	3.43	0.88	11 - 21	11					mol wt wet	28.110	g/mol					
6	0.30093	0.30139	0.00046	0.48	0.41	07 - 11	07					dens@inlet	317.195	g/m^3					
7	0.30312	0.30321	0.00009	0.09	0.31	04 - 07	04					mdot duct	529.915	g/min	minus ash				
Backup Filter	0.32795	0.32825	0.00030	0.31	0.00	0 -04	0					vduct	50.554	meters/min					
												vduct	2.759	ft/sec					
		total mass	0.09523						dens@STP	1292.19	g/m^3	dens@imp	918.421	g/m^3					
									BACKFIRE BURNERS			mol wt dry	28.475	g/mol					
												dens@sta	889.219	g/m^3					
									mdotBF1 CH4	18.7977071	g/min	volflowstero	0.027	m^3/min					
Notes	The coal feeder squeeksl								mdotBF1 Air	548.72992	g/min	volflowstero	0.960	ft^3/min					
									phi	1.704	A/F equiv ratio								
	Stage 0 orifice plate is pretty ashed Stage 0 is slight overload								mdotAirmdotF	29.2379786		mdotrota	24.183	g/min					
												mdotimp	26.175	g/min					
	I dropped stage 4 while transfering it post test from the oven to the dessicator box at								mdotBF2 CH4	0	g/min	volflowimp	0.028	m^3/min					
	least 1/2 the ash was lost Stage 4 data is invalid								mdotBF2 Air	0	g/min	volflowimp	1.000	ft^3/min					
									phi	#DIV/0!	A/F equiv rati	vinlet	514.695	m/min					
									mdotAirmdotF	#DIV/0!		vinlet	28.144	ft/sec					
												mdotcoal	0.01280	g/min					
									actual ash	0.09623	g	expected as	0.1929	g					
												%Diff ash	-100.486	%	based on actual				

Table G.32: Test 10259401

Date	10/25/94	mo/day/yr	Main NG	62 0	%	Upper T	1245	c(max)									
Coal	Upper Freepor	source	Main Air	41 0	%	Sample T	805	c									
	raw	process		31 9	psig	Lower T	693	c									
test no	10259401	m/d/ynum	BF1NG	45 0	%	Coal feed	820	units	Imp inlt diam	0 5625	inches						
test dur	15 00	minutes	BF1Air	4 6	units,front	Coal feed cor	1 1	g/m	Mainduct rad	4	inches						
Coal Properies (Raf only)				4 7	units, back	Vacuum Rota	60 5	%	Main Gas Flo	0 62	fraction	mdot CH4	17 458	g/min			
Upper Freepor			BF2NG		%	Vacuum Rota	11 0	in hg	Main Air Flo	0 41	fraction	mdot Main A	491 466	g/min			
grams	moles/100g		BF2Air		unity,front	atomizer air	full open	units	Main Air Pre	31 9	psig	phi	1 641	units			
64 57	5 38				units, back	atomizer air		psig	Inj Air Rota	10	%	mole fract	1 091				
4 07	4 07		Inj Rota	10	%	atomizer H2O	235	mm	Inj Air Rota	39	psig	O2	1 091	moles/min	CH4&Air only		
3 92	0 25		Inj Rota	39	psig	exit duct T	89	F				H20	2 182	moles/min	CH4&Air only		
1 63	0 12					over furn T	106	F	Coal Composition on Elemental level			N2	13 491	moles/min	CH4&Air only		
2 07	0 06								Carbon(mon	5 38	moles/100g	O2	1 398	moles/min	CH4&Air only		
23 23	23 23								Hydrogen (n	4 07	moles/100g	mdot air inj	10 831	g/min			
0 51	0 03								Oxygen (mo	0 25	moles/100g	O2	0 079	moles/min	Inj Air only		
100									Nitrogen (m	0 12	moles/100g	N2	0 297	moles/min	Inj Air only		
									Sulfur(mon)	0 06	moles/100g	Dry O2 w/in	9 046	vol%	tot w/o coal		
									Ash	23 23	g/100g	DryO2w/o in	8 784	vol%	(w/o coal&in)		
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum % lt size rnge	Size Range micrometers	ECD micro m		H2O	0 03	moles/100g	Coal Fractio	0 011	mdotcoal/100g			
												CO2	1 150	moles/min	total		
									mdot coal	1 1	g/min	H20	2 205	moles/min	total		
Preseperator	0 30368	0 35269	0 04898	57 77	42 23	100 & up	10		Probe inlet T	805	degC	N2	13 756	moles/min	total		
0	0 28072	0 28830	0 00759	8 94	33 29	80 -100	9		Impactor Inl	100	degC (est	SO2	0 0007	moles/min	total		
1	0 28029	0 28818	0 00787	9 28	24 01	58 - 80	5 8		Vacuum Rot	11	in Hg	O2	1 407	moles/min	total		
2	0 30166	0 30500	0 00334	3 94	20 07	47 - 58	4 7		Vacuum Rot	23	degC (est	Dry O2	8 629	vol%			
3	0 30137	0 30804	0 00667	7 87	12 21	33 - 47	3 3		Vacuum Rot	60 5	CFH	H20 wt	0 076	mass fraction			
4	0 30104	0 30697	0 00593	6 98	5 33	21 - 33	2 1		coal flow ra	15	min	Equiv. Ratio	1 977	w/tot. no solid fuel			
5	0 29901	0 30246	0 00347	4 09	1 24	11 - 21	1 1					mol wt wet	28 108	g/mol			
6	0 29978	0 30053	0 00075	0 88	0 35	07 - 11	0 7					dens@inlet	317 766	g/m^3			
7	0 30360	0 30371	0 00011	0 13	0 22	04 - 07	0 4					mdot duct	520 599	g/min	minus ash		
Backup Filters	0 37867	0 37888	0 00019	0 22	0 00	0 -04	0					vduct	50 520	meters/min			
												vduct	2 757	l/l/sec			
		total mass	0 08479						dens@STP	1202 10	g/m^3	dens@inp	918 369	g/m^3			
									BACKFIRE BURNERS								
												mol wt dry	28 474	g/mol			
												dens@inlp	787 665	g/m^3			
									mdotBF1 CH4	16 7977071	g/min	volflinrelerp	0 023	m^3/min			
Notes	The T-couple freaked out for about 1 minute I tightened the connections and it settled								mdotBF1 Air	549 319535	g/min	volflinrelerp	0 805	l/l^3/min			
	down Crud may have burned off the t-couple also								phi	1 706	A/F equiv ratio						
									mdotA/mdotF	29 2994004		mdotinlp	17 519	g/min			
	"I cut the nuclepore filter down to regular filter diameter"The nuclepore filter is extremely hard to											mdotimp	18 962	g/min			
	work with It is so lightweight and flimsy, and electrostatic sensitive, that an accurate weight								mdotBF2 CH4	0	g/min	volflwimp	0 021	m^3/min			
	measurment is difficult " I preheated the nuclepore on the paper it came packed with I'm leav								mdotBF2 Air	0	g/min	volflwimp	0 729	l/l^3/min			
	it on the paper except to weigh it, even in the dessicator box I think Ill weigh the reg filter and								phi	#DIV/0!	A/F equiv ratio	vinlet	372 193	m/min			
	nuclepore filter at the same time post test, because separating them might result in mass loss."								mdotA/mdotF	#DIV/0!		vinlet	20 352	l/l/sec			
	nuclepore filter really adds resistance I may have to get a larger pump " The nuclepore filter																
	looked clean post test I doubt if I should have seen anything " Electrostatic charge is a pain with											mdotcoal	0 00931	g/min			
	the nuclepores - Ant magnet!								actual ash	0 08479	g	expected as	0 1396	g			
		pretest	positest														
	nuc filter	0 04844	0 04870	0 00026													
	glass filter	0 33023	0 33016	-0 00007													
	glass and nuc	0 37867	0 37899	0 00032								%Diff ash	-64 650	%	based on actual		
	(pretest glass and nuc not weighed together)																

Table G.33: Test 11039401

Date	11/3/94	mo/day/yr	Main NG	61.5	%	Upper T	1254	c(New T-cpl)										
Coal	Upper Freepo	source	Main Air	41.0	%	Sample T	800	c										
	37 - 65 um	process		31.5	psig	Lower T	650	c										
test no	11039401	m/d/ynum	BF1NG	45.0	%	Coal feed	820	units	inj inlt diam	0.5625	inches							
test dur	15.00	minutes	BF1Air	4.7	units,front	Coal feed cor	1.1	g/m	Mainduct rad	4	inches							
Coal Properies (Ref only)				4.7	units, back	Vacuum Rota	69.0	%	Main Gas Ro	0.615	fraction	mdot CH4	17.317	g/min				
Upper Freepor			BF2NG		%	Vacuum Rota	7.5	in hg	Main Air Rot	0.41	fraction	mdot Main A	489.392	g/min				
grams	moles/100g		BF2Air		units,front	elomizer air	full open	units	Main Air Rot	31.5	psig	phi	1.647	units				
64.57	5.38				units, back	elomizer air		psig	Inj Air Rota	10	%	mole fract	1.082					
4.07	4.07		Inj Rota	10	%	elomizer H2O	250+	mm	Inj Air Rota	39	psig	CO2	1.082	moles/min	CH4&Air only			
3.92	0.25		Inj Rota	39	psig	exit duct T	102	F				H2O	2.165	moles/min	CH4&Air only			
1.63	0.12					over tum T	110	F	Coal Composition on Elemental Anal			N2	13.403	moles/min	CH4&Air only			
2.07	0.06								Carbon(mon	5.38	moles/100g	O2	1.400	moles/min	CH4&Air only			
23.23	23.23								Hydrogen (n	4.07	moles/100g	mdot air inj	10.831	g/min				
0.51	0.03								Oxygen (mo	0.25	moles/100g	O2	0.078	moles/min	Inj Air only			
100									Nitrogen (m	0.12	moles/100g	N2	0.297	moles/min	Inj Air only			
									Sulfur(mon)	0.06	moles/100g	Dry O2 w/in	9.095	vol%	tot w/o coal			
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum % fl size rge	Size Range micrometers	ECD micro m		Ash	23.23	g/100g	DryO2w/o in	8.813	vol%	t w/o coal&inj			
									H2O	0.03	moles/100g	Coal Fractio	0.011	mdotcoal/100g				
												CO2	1.141	moles/min	total			
									mdot coal	1.1	g/min	H2O	2.197	moles/min	total			
Preseperator	0.30113	0.40961	0.10848	79.84	20.36	100 & up	10		Probe inlet T	800	degC	N2	13.700	moles/min	total			
0	0.27906	0.29823	0.01917	14.07	6.28	90 -100	9		Impactor Inl	100	degC (est. T	SO2	0.0007	moles/min	total			
1	0.27770	0.28146	0.00376	2.76	3.52	58 - 90	58		Vacuum Rot	7.5	in Hg	O2	1.408	moles/min	total			
2	0.30186	0.30354	0.00168	1.23	2.29	47 - 58	47		Vacuum Rot	23	degC (est. T	Dry O2	8.671	vol%				
3	0.30192	0.30226	0.00094	0.69	1.60	33 - 47	33		Vacuum Rot	69	CFH	H20 wt	0.076	mass fraction				
4	0.30428	0.30484	0.00056	0.41	1.19	21 - 33	21		coal flow tim	15	min	Equiv. Ratio	1.693	w/inj, no solid fuel				
5	0.30339	0.30376	0.00037	0.27	0.92	11 - 21	11					mol wt wet	28.111	g/mol				
6	0.30386	0.30399	0.00013	0.10	0.82	07 - 11	07					dens@inlet	910.279	g/m^3				
7	0.30258	0.30284	0.00008	0.06	0.76	04 - 07	04					mdot duct	518.345	g/min	minus ash			
Backup Filter	0.33036	0.33140	0.00104	0.76	0.00	0 -04	0					vduct	80.092	meters/min				
												vduct	2.732	ft/sec				
		total mass	0.13621						dens@STP	1202.19	g/m^3	dens@imp	910.463	g/m^3				
									BACKFIRE BURNER8			mol wt dry	29.472	g/mol				
												dens@mfc	909.455	g/m^3				
									mdotBF1 CH4	19.7677071	g/min	voltlwrate/c	0.028	m^3/min				
									mdotBF1 Air	652.838116	g/min	voltlwrate/c	1.000	ft^3/min				
Notes	* Ash is very black, as usual for Upper Freeport								phi	1.717	A/F equiv ratio							
	* I put the impingers on backwards again No big deal The feeder is not squeaking								mdotAirmdotF	29.455881		mdotrate	25.760	g/min				
	* The preseperator is very full of ash deposits, even on the walls The 0 stage orifice plate has a lot of particles also Very dense coating where the three preseperator orifices exit on the 0 stage orifice plate											mdotimp	27.878	g/min				
									mdotBF2 CH4	0	g/min	voltlwimp	0.030	m^3/min				
	* Stage 0 is overloaded								mdotBF2 Air	0	g/min	voltlwimp	1.072	ft^3/min				
	* Stage 1 is slightly overloaded								phi	#DIV/0!	A/F equiv rate	vinlet	544.605	m/min				
	* Old T-couple gave up. Failed high, low. Looks ok, but doesn't work								mdotAirmdotF	#DIV/0!		vinlet	29.779	ft/sec				
	* Filter has 1 particle on it large enough to see																	
												mdotcoal	0.01374	g/min				
									actual ash	0.13621	g	expected ash	0.2061	g				
												%Diff ash	-51.342	%	based on actual			

Table G.34: Test 11049401

Date	11/4/94	mo/day/yr	Main NG	82 0	%	Upper T	1245	c									
Coal	Upper Freepo	source	Main Air	41 0	%	Sample T	820	c									
	37 - 45 um	process		31 8	psig	Lower T	661	c									
test no	11049401	m/d/ynum	BF1NG	45 0	%	Coal feed	820	units	imp init diam	0 5625	inches						
test dur	15 00	minutes	BF1Air	4 7	units,front	Coal feed cor	1 1	g/m	Meinduct rad	4	inches						
Coal Properties (Ref only)				4 7	units, back	Vacuum Roto	69 0	%	Main Gas Ro	0 62	(raction	mdot CH4	17 456	g/min			
Upper Freepori			BF2NG		%	Vacuum Roto	7 8	in hg	Main Air Rot	0 41	(raction	mdot Main A	490 938	g/min			
grams	moles/100g		BF2Air		units,front	atomizer air	fullopen	units	Main Air Rot	31 8	psig	phi	1 639	units			
64 57	5 38				units, back	atomizer air		psig	Inj Air Roto	10	%	mole fract	1 091				
4 07	4 07		Inj Roto	10	%	atomizer H2O	215	mm	Inj Air Roto	39	psig	CO2	1 091	moles/min	CH4&Air only		
3 92	0 25		Inj Roto	39	psig	exit duct T	110	F				H20	2 182	moles/min	CH4&Air only		
1 63	0 12					over turn T	110	F	Coal Composition on Elemental level			N2	13 446	moles/min	CH4&Air only		
2 07	0 06								Carbon(mon	5 38	moles/100g	O2	1 394	moles/min	CH4&Air only		
23 23	23 23								Hydrogen (n	4 07	moles/100g	mdot air inj	10 831	g/min			
0 51	0 03								Oxygen (mo	0 25	moles/100g	O2	0 079	moles/min	inj Air only		
100									Nitrogen (m	0 12	moles/100g	N2	0 297	moles/min	inj Air only		
									Sulfur(mon)	0 06	moles/100g	Dry O2 w/in	9 032	vol%	tot w/o coal		
									Ash	23 23	g/100g	DryO2w/o in	8 750	vol%	t w/o coal&inj		
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum % fi size mes	Size Range micrometers	ECD micro m		H2O	0 03	moles/100g	Coal Fractio	0 011	mdot/coal/100g			
												CO2	1 150	moles/min	total		
Presseparator	0 29601	0 30135	0 00534	72 96	27 04	10 0 & up	10		mdot coal	1 1	g/min	H20	2 205	moles/min	total		
0	0 28025	0 30020	0 02595	19 86	7 19	8 0 -10 0	9		Probe inlet T	900	degC	N2	13 744	moles/min	total		
1	0 28926	0 27289	0 00463	3 54	3 64	5 6 - 8 0	6 8		Impactor Init	100	degC (est. T	SO2	0 0007	moles/min	total		
2	0 29637	0 30029	0 00192	1 47	2 17	4 7 - 5 6	4 7		Vacuum Rot	7 75	in Hg	O2	1 403	moles/min	total		
3	0 30174	0 30268	0 00094	0 72	1 45	3 3 - 4 7	3 3		Vacuum Rot	23	degC (est. T	Dry O2	8 609	vol%			
4	0 30097	0 30150	0 00053	0 41	1 05	2 1 - 3 3	2 1		Vacuum Rot	69	CFH	H20 wt	0 076	mass fraction			
5	0 30126	0 30156	0 00032	0 24	0 80	1 1 - 2 1	1 1		coal flow tin	15	min	Equiv Ratio	1 675	w/inj, ng solid fuel			
6	0 30277	0 30291	0 00014	0 11	0 70	0 7 - 1 1	0 7					mol wt wet	28 106	g/mol			
7	0 30313	0 30317	0 00004	0 03	0 67	0 4 - 0 7	0 4					dens@inlet	319 239	g/m^3			
Backup Filter	0 33050	0 33137	0 00087	0 67	0 00	0 -0 4	0					mdot duct	520 072	g/min	minus ash		
												vduct	50 236	meters/min			
		total mass	0 13068									vduct	2 741	ft/sec			
									dens@STP	1202 10	g/m^3	dens@imp	818 346	g/m^3			
									BACKFIRE BURNERS			mol wt dry	29 475	g/mol			
												dens@roto	899 414	g/m^3			
									mdotBF1 CH4	18 7977971	g/min	volflw/atero	0 028	m^3/min			
Notes	* The vacuum pump flowrate bumped up and down early in the test, about 5 units, but								mdotBF1 Air	554 63014	g/min	volflw/atero	0 995	ft^3/min			
	settled down in about 30 seconds								phi	1 722	A/F equiv ratio						
	* Stage 0 was extremely overloaded Stage 1 was overloaded, and stage 2 was very								mdotAirndotF	29 5523655		mdot/roto	25 335	g/min			
	slightly overloaded											mdot/imp	27 428	g/min			
	* Where the presep meets the cap of the impactor, ash fell out during removal The								mdotBF2 CH4	0	g/min	volflw/imp	0 030	m^3/min			
	presep was quite full again with particles stuck high on the walls								mdotBF2 Air	0	g/min	volflw/imp	1 055	ft^3/min			
	* I left the stage 0 foil on its supporting plate until weighing I knocked the								phi	#DIV/0!	A/F equiv rati	vinlet	535 886	m/min			
	supporting plate clean over the foil prior to weighing Some didn't make the transfer,								mdotAirndotF	#DIV/0!		vinlet	29 303	ft/sec			
	less than 1%																
												mdot/coal	0 01348	g/min			
									actual ash	0 13068	g	expected as	0 2021	g			
												%Diff ash	-54 586	%	based on actual		

Table G.35: Test 11079401

Date	11/7/94	mo/day/yr	Main NG	62.0	%	Upper T	1243	c											
Coal	Upper Freepor	source	Main Air	41.0	%	Sample T	799	c											
	18 - 37 µm	process		31.7	psig	Lower T	650	c											
test no	11079401	m/d/ynum	BF1NG	45.0	%	Coal feed	820	units	Imp init diam	0.5625	inches								
test dur	15.00	minutes	BF1Air	4.7	units,front	Coal feed cor	1.1	g/m	Maindvct rad	4	inches								
Coal Properties (Ref only)				4.7	units, back	Vacuum Roto	68.0	%	Main Gas Ro	0.62	fraction	mdot CH4	17.458	g/min					
Upper Freepor			BF2NG		%	Vacuum Roto	8.0	in hg	Main Air Rot	0.41	fraction	mdot Main A	490.410	g/min					
grams	moles/100g		BF2Air		units,front	atomizer air	full open	units	Main Air Rot	31.7	psig	phi	1.637	units					
64.57	5.38				units, back	atomizer air		psig	Inj Air Roto	10	%	mole fract	1.091						
4.07	4.07		Inj Roto	10	%	atomizer H2O	237	mm	Inj Air Roto	39	psig	CO2	1.091	moles/min	CH4&Air only				
3.92	0.25		Inj Roto	39	psig	exit duct T	105	F				H20	2.182	moles/min	CH4&Air only				
1.63	0.12					over furn T	110	F	Coal Composition on Elemental level			N2	13.432	moles/min	CH4&Air only				
2.07	0.06								Carbon(mon	5.38	moles/100g	O2	1.390	moles/min	CH4&Air only				
23.23	23.23								Hydrogen (n	4.07	moles/100g	mdot air inj	10.831	g/min					
0.51	0.03								Oxygen (mo	0.25	moles/100g	O2	0.079	moles/min	Inj Air only				
100									Nitrogen (m	0.12	moles/100g	N2	0.297	moles/min	Inj Air only				
									Sulfur(mon)	0.06	moles/100g	Dry O2 w/in	9.019	vol%	tot w/o coal				
									Ash	23.23	g/100g	DryO2w/o ir	8.736	vol%	t w/o coal&Inj				
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum % R size rnge	Size Range micrometers	ECD micro m		H2O	0.03	moles/100g	Coal Fractio	0.011	mdotcoalV100g					
												CO2	1.150	moles/min	total				
									mdot coal	1.1	g/min	H20	2.205	moles/min	total				
Presepartor	0.30292	0.40114	0.09822	71.59	28.41	100 A up	10		Probe Inlet T	798	degC	N2	13.729	moles/min	total				
0	0.27654	0.29950	0.02296	15.26	13.13	90 -100	9		Impactor Init	100	degC (est. T	SO2	0.0007	moles/min	total				
1	0.27709	0.28782	0.01073	7.82	5.31	58 - 90	5.8		Vacuum Rot	8	in Hg	O2	1.399	moles/min	total				
2	0.30613	0.31021	0.00408	2.97	2.34	47 - 58	4.7		Vacuum Rot	23	degC (est. T	Dry O2	8.595	vol%					
3	0.30060			0.00	2.34	33 - 47	3.3		Vacuum Rot	68	CFH	H20 wt	0.076	mass fraction					
4	0.30275	0.30447	0.00172	1.25	1.09	21 - 33	2.1		coal flow tim	15	min	Equiv. Ratio	1.673	w/in, no solid fuel					
5	0.29864	0.29924	0.00060	0.44	0.65	11 - 21	1.1					mol wt wet	28.197	g/mol					
6	0.30579	0.30599	0.00020	0.15	0.50	07 - 11	0.7					dens@inlet	319.926	g/m^3					
7	0.30409	0.30421	0.00012	0.09	0.42	04 - 07	0.4					mdot duct	519.543	g/min	minus ash				
Backup Filter	0.33056	0.33115	0.00057	0.42	0.00	0 -0.4	0					vduct	50.092	meters/min					
												vduct	2.735	ft/sec					
		total mass	0.13720						dens@STP	1202.19	g/m^3	dens@imp	918.322	g/m^3					
									BACKFIRE BURNERS			mol wt dry	29.479	g/mol					
												dens@roto	889.302	g/m^3					
									mdotBF1 CH4	18.7977071	g/min	voltlwratero	0.028	m^3/min					
Notes	* Lost some of stage 0 to static cling to the petri dish								mdotBF1 Air	554.033443	g/min	voltlwratero	0.975	ft^3/min					
	* Stage 3 weight lost due to static								phi	1.720	A/F equiv ratio								
	* This coal (unburned) is pretty much identical to the 85-37 um coal. It flows like molasses, almost liquid. The feeder isn't squeaking								mdotA/mdotF	29.5205717		mdotroto	24.548	g/min					
												mdotimp	26.578	g/min					
	* Stages are not near as overloaded as previous tests (85-37um)								mdotBF2 CH4	0	g/min	voltlwimp	0.029	m^3/min					
	* STATIC CLING IS REALLY SCREWING UP the measuring procedure. Something must be done								mdotBF2 Air	0	g/min	voltlwimp	1.022	ft^3/min					
									phi	#DIV/0!	A/F equiv rati	vinlet	518.328	m/min					
	* Shielding the scale seems to help stabilize the weight measurement. I've started shielding it with an open three ring binder, creating a wall								mdotA/mdotF	#DIV/0!		vinlet	28.342	ft/sec					
												mdotcoal	0.01397	g/min					
									actual ash	0.1372	g	expected as	0.1991	g					
												%Diff ash	-52.915	%	based on actual				

Table G.36: Test 11109401

Date	11/10/94	mo/day/yr	Main NG	62.0	%	Upper T	1250	c											
Coal	Upper Freepor	source	Main Air	41.2	%	Sample T	800	c											
	18 - 37 um	process		31.8	psig	Lower T	656	c											
test no	11109401	m/d/ynum	BF1NG	45.0	%	Coal feed	820	units	inj init diam	0.5625	inches								
test dur	15.00	minutes	BF1Air	4.7	units,front	Coal feed cor	1.1	g/m	Manduct rad	4	inches								
Coal Properties (Ref only)				4.7	units, back	Vacuum Rota	69.0	%	Main Gas Ro	0.62	fraction	mdot CH4	17.458	g/min					
Upper Freepor			BF2NG		%	Vacuum Rota	8.0	in hg	Main Air Rot	0.412	fraction	mdot Main A	493.333	g/min					
grams	moles/100g		BF2Air		units,front	atomizer air	full open	units	Main Air Rot	31.8	psig	phi	1.647	units					
64.57	5.38				units, back	atomizer air		psig	Inj Air Rota	10	%	mole fract	1.091						
4.07	4.07		Inj Rota	10	%	atomizer H2O	235	mm	Inj Air Rota	39.5	psig	CO2	1.091	moles/min	CH4&Air only				
3.92	0.25		Inj Rota	39.5	psig	exit duct T	110	F				H20	2.182	moles/min	CH4&Air only				
1.83	0.12					over furn T	110	F	Coal Composition on Elemental level			N2	13.512	moles/min	CH4&Air only				
2.07	0.06								Carbon(mon	5.38	moles/100g	O2	1.411	moles/min	CH4&Air only				
23.23	23.23								Hydrogen (r	4.07	moles/100g	mdot air inj	10.882	g/min					
0.51	0.03								Oxygen (mo	0.25	moles/100g	O2	0.070	moles/min	Inj Air only				
100									Nitrogen (m	0.12	moles/100g	N2	0.298	moles/min	Inj Air only				
									Sulfur(mon	0.06	moles/100g	Dry O2 w/in	9.094	vol%	tot w/o coal				
									Ash	23.23	g/100g	DryO2w/o in	8.813	vol%	t w/o coal&inj				
Stage	(initial(g)	Final(g)	Net(g)	% in size	Cum. %	Size Range	ECD		H2O	0.03	moles/100g	Coal Fractio	0.011	mdotcoal/100g					
				range	R. size rge	micrometers	micro m					CO2	1.159	moles/min	total				
									mdot coal	1.1	g/min	H20	2.205	moles/min	total				
Preseperator	0.32820	0.43799	0.10979	73.86	26.14	100 & up	10		Probe inlet T	800	degC	N2	13.811	moles/min	total				
0	0.29727	0.31806	0.02079	13.99	12.15	90 :10 0	9		Impactor Ini	100	degC (est T	CO2	0.0007	moles/min	total				
1	0.29705	0.30788	0.01083	7.29	4.86	5.8 - 9.0	5.8		Vacuum Rot	8	in Hg	O2	1.421	moles/min	total				
2	0.32538		0.00000	0.00	4.86	4.7 - 5.8	4.7		Vacuum Rot	23	degC (est T	Dry O2	8.979	vol%					
3	0.33013	0.33442	0.00429	2.89	1.98	3.3 - 4.7	3.3		Vacuum Rot	68	CFH	H20 wt	0.076	mass fraction					
4	0.33016	0.33201	0.00185	1.24	0.73	2.1 - 3.3	2.1		coal flow tim	15	min	Equiv. Ratio	1.593	w/ini, no solid fuel					
5	0.33069	0.33123	0.00054	0.36	0.37	1.1 - 2.1	1.1					mol wt wet	28.111	g/mol					
6	0.32327	0.32340	0.00013	0.09	0.28	0.7 - 1.1	0.7					dens@inlet	319.276	g/m^3					
7	0.32677	0.32678	0.00001	0.01	0.28	0.4 - 0.7	0.4					mdot duct	922.917	g/min	minus ash				
Backup Filter	0.33117	0.33158	0.00041	0.28	0.00	0 -0.4	0					vduct	50.466	meters/min					
												vduct	2.754	l/l/sec					
		total mass	0.14864						dens@STP	1292.10	g/m^3	dens@imp	819.455	g/m^3					
									BACKFIRE BURNERS			mol wt dry	29.472	g/mol					
												dens@ratio	889.182	g/m^3					
									mdotBF1 CH4	19.7977071	g/min	volflowratero	0.028	m^3/min					
									mdotBF1 Air	554.63014	g/min	volflowratero	0.975	(l^3/min					
Notes	* I bumped stage 2 as I removed it, and lost about 1/2 the ash								phi	1.722	A/F equiv ratio								
	* I'm using a new dessicator, instead of CaSO4 - its silica gel in a 2"x4" packet. I might switch back, because there isn't much surface area associated with this one								mdotAirmdotF	29.5523655		mdotrota	24.643	g/min					
	* Static electricity on the foils and plastic petri dishes is a big problem. Some particles are very likely to jump when petri dishes are moved. They cling to the dishes											mdotimp	28.560	g/min					
	* I cut slots on the wall of the petri dishes so that foils are easier to remove and insert. It seems to help								mdotBF2 CH4	0	g/min	volflwimp	0.029	m^3/min					
									mdotBF2 Air	0	g/min	volflwimp	1.021	(l^3/min					
									phi	#DIV/0!	A/F equiv rat	vinlet	618.871	m/min					
									mdotAirmdotF	#DIV/0!		vinlet	29.372	(l/sec					
												mdotcoal	0.01799	g/min					
									actual ash	0.14864	g	expected as	0.1948	g					
												%Dif ash	31.977	%	based on actual				

Table G.37: Test 11119401

Date	11/11/94	mo/day/yr	Main NG	91.8	%	Upper T	1239	c(max)										
Coal	Upper Freepo	source	Main Air	41.0	%	Sample T	798	c(max)										
	18 - 37 um	process		31.8	psig	Lower T	649	c(max)										
test no	11119401	m/d/ynum	BF1NG	45.0	%	Coal feed	820	units	imp infl diam	0.5625	inches							
test dur	15.00	minutes	BF1Air	4.7	units,front	Coal feed cor	1.1	g/m	Mainduct rad	4	inches							
Coal Properies (Ref. only)				4.7	units, back	Vacuum Roto	68.0	%	Main Gas Ro	0.618	(fraction		mdot CH4	17.401	g/min			
Upper Freepor			BF2NG		%	Vacuum Roto	0.0	in hg	Main Air Rot	0.41	(fraction		mdot Main A	490.936	g/min			
grams	moles/100g		BF2Air		units,front	atomizer air	full open	units	Main Air Rot	31.8	psig		phi	1.644	units			
64.57	5.38				units, back	atomizer air		psig	Inj Air Roto	10	%		mole fract	1.088				
4.07	4.07		Inj Roto	10	%	atomizer H2O	200	mm	Inj Air Roto	39	psig		CO2	1.088	moles/min	CH4&Air only		
3.92	0.25		Inj Roto	39	psig	exit duct T	103	F					H20	2.175	moles/min	CH4&Air only		
1.63	0.12					cyclone T	119	F	Coal Composition on Elemental level				N2	13.446	moles/min	CH4&Air only		
2.07	0.09								Carbon(mon	5.38	moles/100g		O2	1.401	moles/min	CH4&Air only		
23.23	23.23								Hydrogen (m	4.07	moles/100g		mdot air inj	10.831	g/min			
0.51	0.03								Oxygen (mo	0.25	moles/100g		O2	0.079	moles/min	Inj Air only		
100									Nitrogen (m	0.12	moles/100g		N2	0.297	moles/min	Inj Air only		
									Sulfur(mon)	0.06	moles/100g		Dry O2 w/in	9.073	vol%	tot w/o coal		
									Ash	23.23	g/100g		DryO2w/o ir	8.792	vol%	t w/o coal&in		
Stage	Initial(g)	Final(g)	Net(g)	% in size	Cum %	Size Range	ECD		H2O	0.03	moles/100g		Coal Fractio	0.011	mdotcoal/100g			
				range	lt size spe	micrometers	micro m						CO2	1.147	moles/min	total		
									mdot coal	1.1	g/min		H20	2.198	moles/min	total		
Preseperator	0.21344	0.30848	0.09504	67.88	32.12	10.0 & up	10		Probe inlet T	798	degC		N2	13.744	moles/min	total		
0	0.27383	0.29722	0.02329	16.63	15.49	9.0 - 10.0	9		Impactor Inl	100	degC (est. T		O2	0.0007	moles/min	total		
1	0.27484	0.28535	0.01071	7.65	7.84	5.8 - 9.0	5.8		Vacuum Rot	6	in Hg		O2	1.410	moles/min	total		
2	0.32821	0.33241	0.00420	3.00	4.84	4.7 - 5.8	4.7		Vacuum Rot	23	degC (est. T		Dry O2	8.651	vol%			
3	0.32708	0.33110	0.00404	2.89	1.96	3.3 - 4.7	3.3		Vacuum Rot	68	CFH		H20 wt	0.076	mass fraction			
4	0.32364	0.32533	0.00169	1.21	0.75	2.1 - 3.3	2.1		coal flow (m	15	min		Equiv. Ratio	1.689	w/inj, no solid fuel			
5	0.32866	0.32918	0.00052	0.37	0.38	1.1 - 2.1	1.1						mol wt wet	28.110	g/mol			
6	0.32723	0.32793	0.00010	0.07	0.31	0.7 - 1.1	0.7						dens@inlet	319.661	g/m^3			
7	0.21384	0.21388	0.00004	0.03	0.28	0.4 - 0.7	0.4						mdot duct	520.016	g/min	minus ash		
Backup Filter	0.32950	0.32989	0.00039	0.28	0.00	0 -0.4	0						vduct	50.132	meters/min			
													vduct	2.736	l/sec			
		total mass	0.14002						dens@STP	1202.10	g/m^3		dens@inp	818.421	g/m^3			
									BACKFIRE BURNERS				mol wt dry	28.473	g/mol			
													dens@inlo	889.219	g/m^3			
Notes	* Used light gauge aluminum for preseperator and stage 7. Regular foil was used up								mdotBF1 CH4	16.7677071	g/min		volflwratem	0.028	m^3/min			
	* I put the silica gel packet in one petri dish and filled the two other dessicator petri								mdotBF1 Air	554.63014	g/min		volflwratem	0.975	l^3/min			
	dishes with CaSO4. I don't think it matters much								phi	1.722	A/F equiv ratio							
	* Light gauge aluminum is usually not rigid enough to use as a substrate, but the gol								mdotA/mdotF	29.5523656			mdotimp	24.544	g/min			
	mixed in with this batch of foils. I put the light foil on the #7 stage, because the												mdotimp	26.565	g/min			
	particles seems to stick well to this stage								mdotBF2 CH4	0	g/min		volflwimp	0.029	m^3/min			
	* After measuring the temperature at the top of the reactor for about 10 minutes, I								mdotBF2 Air	0	g/min		volflwimp	1.021	l^3/min			
	pull the t-couple out. As it cooled, I heard and felt the shell pop and crackle. On								phi	#DIV/0!	A/F equiv rati		vinlet	518.023	m/min			
	inspection, I saw that a layer of the T-couple fractured off the SS shaft. Bizarre!								mdotA/mdotF	#DIV/0!			vinlet	28.326	l/sec			
	*I used the grounded brush for the first time, while the stages were in the impactor. I																	
	brushed the petri dishes, inside and out. It seemed to help								actual ash	0.14002	g		mdotcoal	0.01305	g/min			
	* The slots in the petri dishes are helping out, too												expected as	0.1958	g			
													%Diff ash	39.843	%	based on actual		

Table G.38: Test 11149401

Date	11/14/94	mo/day/yr	Main NG	61.0	%	Upper T	1246	c(max)										
Coal	Upper Freepor	source	Main Air	41.0	%	Sample T	798	c(max)										
	< 18 µm	process		31.8	psig	Lower T	649	c(max)										
test no	11149401	m/d/ynum	BF1NG	45.0	%	Coal feed	820	units	inj inlt diam	0.5625	inches							
test dur	15.00	minutes	BF1Air	4.6	units,front	Coal feed cor	1.1	g/m	Mainduct dia	4	inches							
Coal Properties (Rel. only)				4.7	units, back	Vacuum Reto	68.0	%	Main Gas Flo	0.61	fraction	mdot CH4	17.176	g/min				
Upper Freepor			BF2NG		%	Vacuum Reto	9.0	in hg	Main Air Rot	0.41	fraction	mdot Main A	490.939	g/min				
grams	moles/100g		BF2Air		units,front	atomizer air	full open	units	Main Air Rot	31.8	psig	phi	1.666	units				
84.57	5.38				units, back	atomizer air		psig	Inj. Air Flolo	10	%	mole fract	1.074					
4.07	4.07		Inj Flolo	10	%	atomizer H2O	218	mm	Inj Air Flolo	39	psig	CO2	1.074	moles/min	CH4&Air only			
3.92	0.25		Inj Flolo	39	psig	exit duct T	103	F				H2O	2.147	moles/min	CH4&Air only			
1.63	0.12					over furn T	110	F				N2	13.446	moles/min	CH4&Air only			
2.07	0.06								Coal Composition on Elemental level			O2	1.429	moles/min	CH4&Air only			
23.23	23.23								Carbon(mon	5.38	moles/100g	mdot air inj	10.831	g/min				
0.51	0.03								Hydrogen (n	4.07	moles/100g	O2	0.079	moles/min	Inj Air only			
100									Oxygen (mo	0.25	moles/100g	N2	0.297	moles/min	Inj Air only			
									Nitrogen (m	0.12	moles/100g	Dry O2 w/in	9.238	vol%	tot w/o coal			
									Sulfur(mon)	0.06	moles/100g	DryO2w/o in	8.961	vol%	tot w/o coal&inj			
									Ash	23.23	g/100g	Coal Fractio	0.011	mdot/coal/100g				
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % lt. size rnge	Size Range micrometers	BCD micro m		H2O	0.03	moles/100g	CO2	1.133	moles/min	total			
												H2O	2.170	moles/min	total			
									mdot coal	1.1	g/min	N2	13.744	moles/min	total			
Preseparator	0.32516	0.37036	0.04520	39.18	60.82	100 & up	10		Probe Inlet T	798	degC	SO2	0.0007	moles/min	total			
0	0.27519	0.28570	0.01051	9.11	51.71	90 -100	9		Impactor Inl	100	degC (est. T	O2	1.438	moles/min	total			
1	0.27552	0.29295	0.01743	15.11	36.60	58 - 90	58		Vacuum Rot	6	in Hg	Dry O2	8.816	vol%				
2	0.32618	0.33648	0.01030	8.93	27.68	47 - 58	47		Vacuum Rot	23	degC (est. T	H20 wt	0.075	mass fraction				
3	0.32870	0.34505	0.01635	14.17	13.50	33 - 47	33		Vacuum Rot	68	CFH	Equiv. Ratio	1.702	w/inj, no solid fuel				
4	0.32751	0.33842	0.01091	9.46	4.05	21 - 33	21		coal flow tim	15	min	mol wt wet	28.118	g/mol				
5	0.32876	0.33271	0.00395	3.42	0.62	11 - 21	11					dens@inlet	319.966	g/m^3				
6	0.32949	0.32982	0.00033	0.29	0.34	07 - 11	07					mdot duct	519.790	g/min	minus ash			
7	0.32884	0.32895	0.00011	0.10	0.24	04 - 07	04					vduct	50.084	meters/min				
Backup Filter	0.32874	0.32902	0.00028	0.24	0.00	0 -04	0					vduct	2.739	ft/sec				
		total mass	0.11537						dens@STP	1292.10	g/m^3	dens@inp	919.722	g/m^3				
									BACKFIRE BURNERS			mol wt dry	29.495	g/mol				
												dens@reto	888.972	g/m^3				
									mdotBF1 CH4	18.7977071	g/min	volflw/stero	0.026	m^3/min				
Notes	* It's very difficult to see the raw coal through the injector line the semitransparent								mdotBF1 Air	549.72982	g/min	volflw/stero	0.975	ft^3/min				
	tygon is black from the dust								phi	1.704	A/F equiv ratio							
	* Stage 3 and 4 had high mounds of ash. Lost a bit to static electricity								mdotA/mdotF	29.2378796		mdot/reto	24.534	g/min				
	*General Note The impactor seems to be much warmer than 100 C by the end of a test											mdot/imp	26.527	g/min				
	Inlet T is probably much higher than 100 C								mdotBF2 CH4	0	g/min	volflw/imp	0.029	m^3/min				
	* I forgot to put the T-couple out of the bottom port. It fried by the time I								mdotBF2 Air	0	g/min	volflw/imp	1.029	ft^3/min				
	remembered it (about 1 hour)								phi	#DIV/0!	A/F equiv ratio	vinlet	517.111	m/min				
	* Preseperator load looks light and lighter colored than ash from larger sized coals								mdotA/mdotF	#DIV/0!		vinlet	28.276	ft/sec				
	* I didn't use my antistatic brush on this batch, to see if it comes out better than the																	
	next (brushed) batches. There is jump already visible on this bunch											mdot/coal	0.01304	g/min				
	* Stage 1 is darker than stage 0								actual ash	0.11537	g	expected as	0.1956	g				
												%Diff ash	-69.551	%	based on actual			

Table G.39: Test 11149402

Date	11/14/94	mo/day/yr	Main NG	61.0	%	Upper T	1246	c(see notes)											
Coal	Upper Freepo	source	Main Air	41.0	%	Sample T	798	c(see notes)											
	< 18 um	process		31.6	psig	Lower T	649	c(see notes)											
test no	11149402	m/d/ynum	BF1NG	45.0	%	Coal feed	820	units	inp inlt diam	0.5625	inches								
test dur	15.00	minutes	BF1Air	4.6	units,front	Coal feed cor	1.1	g/m	Mainduct rad	4	inches								
Coal Properies (Rel only)				4.7	units, back	Vacuum Roto	68.0	%	Main Gas Ro	0.61	fraction	mdot CH4	17.176	g/min					
Upper Freepor			BF2NG		%	Vacuum Roto	7.5	in hg	Main Air Rot	0.41	fraction	mdot Main A	490.938	g/min					
grams	moles/100g		BF2Air		units,front	atomizer air	full open	units	Main Air Rot	31.8	psig	phi	1.666	units					
64.57	5.38				units, back	atomizer air		psig	Inj Air Roto	10	%	mole fract	1.074						
4.07	4.07		Inj Roto	10	%	atomizer H2O	215	mm	Inj Air Roto	39	psig	CO2	1.074	moles/min	CH4&Air only				
3.92	0.25		Inj Roto	39	psig	exit duct T	112	F				H20	2.147	moles/min	CH4&Air only				
1.63	0.12					over turn T	115	F	Coal Composition on Elemental level			N2	13.446	moles/min	CH4&Air only				
2.07	0.06								Carbon(mon	5.38	moles/100g	O2	1.429	moles/min	CH4&Air only				
23.23	23.23								Hydrogen (r	4.07	moles/100g	mdot air inj	10.831	g/min					
0.51	0.03								Oxygen (mo	0.25	moles/100g	O2	0.079	moles/min	Inj Air only				
100									Nitrogen (m	0.12	moles/100g	N2	0.297	moles/min	Inj Air only				
									Sulfur(mon	0.06	moles/100g	Dry O2 w/in	9.238	vol%	tot w/o coal				
									Ash	23.23	g/100g	DryO2w/o ir	8.961	vol%	t w/o coal&inj				
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum % lt size mpe	Size Range micrometers	ECD micro m		H2O	0.03	moles/100g	Coal Fractio	0.011	mdotcoal/100g					
												CO2	1.133	moles/min	total				
									mdot coal	1.1	g/min	H20	2.170	moles/min	total				
Preseparator	0.32688	0.37590	0.05002	41.59	58.59	10.0 & up	10		Probe inlet T	798	degC	N2	13.744	moles/min	total				
0	0.29680	0.30708	0.01048	8.70	49.80	9.0 - 10.0	9		Impactor Inl	100	degC (est. T	SO2	0.0007	moles/min	total				
1	0.29753	0.31298	0.01545	12.82	36.98	5.8 - 9.0	5.8		Vacuum Rot	7.5	in Hg	O2	1.438	moles/min	total				
2	0.32888	0.33889	0.01093	8.32	28.66	4.7 - 5.8	4.7		Vacuum Rot	23	degC (est. T	Dry O2	9.916	vol%					
3	0.32812	0.34357	0.01545	12.82	15.84	3.3 - 4.7	3.9		Vacuum Rot	68	CFH	H20 wt	0.075	mass fraction					
4	0.32665	0.33894	0.01029	8.54	7.30	2.1 - 3.3	2.1		coal flow lin	15	min	Equiv Ratio	1.702	w/inj, no solid fuel					
5	0.32756	0.33135	0.00379	3.14	4.16	1.1 - 2.1	1.1					mol wt wet	28.119	g/mol					
6	0.32921	0.33026	0.00105	0.87	3.29	0.7 - 1.1	0.7					dens@inlet	319.986	g/m^3					
7	0.32851	0.33020	0.00167	1.39	1.90	0.4 - 0.7	0.4					mdot duct	519.790	g/min	minus ash				
Backup Filter	0.32800	0.33029	0.00229	1.90	0.00	0 -0.4	0					vduct	50.094	meters/min					
												vduct	2.733	ft/sec					
		total mass	0.12052						dens@STP	1292.19	g/m^3	dens@inp	919.722	g/m^3					
									BACKFIRE BURNERS			mol wt dry	29.465	g/mol					
												dens@roto	909.231	g/m^3					
									mdot(BF1 CH	19.7977071	g/min	volflw/stero	0.028	m^3/min					
									mdot(BF1 Air	649.72992	g/min	volflw/stero	0.988	ft^3/min					
Notes	* The preseperator looks heavier this time. Also, when I cleaned the coal injector,								phi	1.704	A/F equiv ratio								
	there was alot of raw coal (pretest). Did the injector clog last test?								mdot(Air&mdotF	29.2379709		mdot(orig	25.977	g/min					
	* Stage 3 lost about 1% on pein dish											mdot(imp	27.439	g/min					
	* The foil wasn't quite centered on stage 5. About 10 dots ended up on the plate (out of																		
	about 200). I brushed them back onto the foil. No big problem								mdot(BF2 CH	0	g/min	volflw/imp	0.030	m^3/min					
	*Whoa! Stage 7 is freaken' loaded! Big black dots. Typically, you can't even see the								mdot(BF2 Air	0	g/min	volflw/imp	1.055	ft^3/min					
	mass. Something very strange happened on this test								phi	#DIV/0!	A/F equiv rati	v/inlet	534.888	m/min					
	* The filter is totally black! Not just slightly, but black as night, with small								mdot(Air&mdotF	#DIV/0!		v/inlet	29.248	ft/sec					
	divisions of white were the filter holder supports at																		
	*There is blowby on all stages (Black streaks away from the foils). I'M PRETTY SURE											mdot/coal	0.01349	g/min					
	THIS IS DUE TO OVERLOAD AT THE SMALLER PARTICLE SIZES								actual ash	0.12052	g	expected ast	0.2023	g					
	* T-couple broke pretest, so no temperatures were measured specifically for this																		
	test. The previous test, done only a couple hours earlier, supplied the indicated																		
	temperatures											%Diff ash	67.888	%	based on actual				

Table G.40: Test 11169401

Date	11/16/94	mo/day/yr	Main NG	61 5	%	Upper T	1238	c(max)											
Coal	Upper Freepor	source	Main Air	41 0	%	Sample T	777	c(max)											
	< 10 um	process		31 8	psig	Lower T	933	c(max)											
test no	11169401	m/d/ynum	BF1NG	45 0	%	Coal feed	820	units	inp inlt diam	0 5625	inches								
test dur	5 00	minutes	BF1Air	4 6	units,front	Coal feed cor	1 1	g/m	Mainduct rad	4	inches								
Coal Properties (Rel only)				4 7	units, back	Vacuum Rota	67 0	%	Main Gas Ro	0 619	fraction		mdot CH4	17 317	g/min				
Upper Freepor			BF2NG		%	Vacuum Rota	7 5	in hg	Main Air Rot	0 41	fraction		mdot Main A	490 938	g/min				
grams	moles/100g		BF2Air		units,front	atomizer air	full open	units	Main Air Rot	31 8	psig		phi	1 652	units				
64 57	5 38				units, back	atomizer air		psig	Inj Air Rota	10	%		mole fract	1 082					
4 07	4 07		Inj Rota	10	%	atomizer H2O	250+	mm	Inj Air Rota	39	psig		CO2	1 082	moles/min	CH4&Air only			
3 92	0 25		Inj Rota	39	psig	exit duct T	103	F					H20	2 165	moles/min	CH4&Air only			
1 63	0 12					over furn T	110	F	Coal Composition on Elemental level				N2	13 446	moles/min	CH4&Air only			
2 07	0 06								Carbon(mon	5 38	moles/100g		O2	1 412	moles/min	CH4&Air only			
23 23	23 23								Hydrogen (t	4 07	moles/100g		mdot air inj	10 831	g/min				
0 51	0 03								Oxygen (mo	0 25	moles/100g		O2	0 078	moles/min	Inj Air only			
100									Nitrogen (m	0 12	moles/100g		N2	0 297	moles/min	Inj Air only			
									Sulfur(mon	0 06	moles/100g		Dry O2 w/in	9 135	vol%	tot w/o coal			
									Ash	23 23	g/100g		DryO2w/o in	6 655	vol%	t w/o coal&inj			
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum % fl size rnge	Size Range micrometers	ECD micro m		H2O	0 03	moles/100g		Coal Fractio	0 011	mdotcoal/100g				
													CO2	1 141	moles/min	total			
Presepernior	0 32752	0 34160	0 01408	42 39	57 62	100 & up	10		mdot coal	1 1	g/min		H20	2 167	moles/min	total			
0	0 27655	0 27912	0 00257	7 74	49 88	90 -100	9		Probe inlet T	777	degC		N2	13 744	moles/min	total			
1	0 27858	0 28290	0 00434	13 06	36 82	5 8 - 9 0	5 8		Impactor Inl	100	degC (est T		SO2	0 0007	moles/min	total			
2	0 32851	0 33121	0 00270	8 13	28 69	4 7 - 5 8	4 7		Vacuum Rot	7 5	in Hg		O2	1 421	moles/min	total			
3	0 32714	0 33220	0 00506	15 23	13 46	3 3 - 4 7	3 3		Vacuum Rot	23	degC (est T		Dry O2	8 713	vol%				
4	0 32940	0 33252	0 00312	9 39	4 06	2 1 - 3 3	2 1		Vacuum Rot	67	CFH		H20 wt	0 076	mass fraction				
5	0 32521	0 32616	0 00095	2 86	1 20	1 1 - 2 1	1 1		coal flow im	5	min		Equiv Ratio	1 099	w/inj, no solid fuel				
6	0 32628	0 32645	0 00017	0 51	0 69	0 7 - 1 1	0 7						mol wt wet	28 114	g/mol				
7	0 32658	0 32661	0 00003	0 09	0 60	0 4 - 0 7	0 4						dens@Inlet	926 299	g/m^3				
Backup Filter	0 32886	0 32906	0 00020	0 60	0 00	0 -0 4	0						mdot duct	519 931	g/min	minus ash			
													vduct	49 135	meters/min				
		total mass	0 03322										vduct	2 681	ft/sec				
									dens@STP	1202 19	g/m^3		dens@Imp	918 534	g/m^3				
									BACKFIRE BURNER9				mol wt dry	29 470	g/mol				
													dens@rota	909 389	g/m^3				
									mdotBF1 CH4	18 7977071	g/min		volflwrateng	0 029	m^3/min				
Notes	* New T- couple								mdotBF1 Air	548 72982	g/min		volflwrateng	0 971	ft^3/min				
	* Since this is a five minute test, while others are 15, I ran for 10 minutes with no coal feed prior to 5 minutes with coal feed This way we get the same background (temperature in impactor, random particles from walls, etc								phi	1 704	A/F equiv ratio								
									mdotAirmdotF	29 2379709			mdotrota	25 011	g/min				
	* The new T-couple is reading about 10 C lower than my previous one The fuel/air settings are the same It may be a bias in the T-couple I have been running about 4 times higher air flow in the coal injector all day, to clean it out Maybe it caused the bias I'll find out by next run, by setting the injector at the nominal flowrate all night												mdotimp	27 060	g/min				
									mdotBF2 CH4	0	g/min		volflwimp	0 029	m^3/min				
									mdotBF2 Air	0	g/min		volflwimp	1 040	ft^3/min				
									phi	#DIV/0!	A/F equiv rati		vinlet	617 258	m/min				
									mdotAirmdotF	#DIV/0!			vinlet	28 284	ft/sec				
	* I replaced the swage nut ferrule connecting the impactor to the teflon exit line It was getting necked																		
													mdotcoal	0 01330	g/min				
	*VERY LIGHT (weight) ashing on stages No overloads								actual ash	0 03322	g		expected as	0 0665	g				
													%Diff ash	-100 166	%	based on actual			

Table G.41: Test 11219401

Date	11/21/94	mo/day/yr	Main NG	61.5	%	Upper T	1244	c(max)									
Coal	Upper Freepo	source	Main Air	41.0	%	Sample T	798	c(max)									
	< 16 µm	process		31.8	psig	Lower T	649	c(max)									
test no	11219401	m/d/ynum	BF1NG	45.0	%	Coal feed	820	units	inj inlt diam	0.5625	inches						
test dur	5.00	minutes	BF1Air	4.6	units,front	Coal feed cor	1.1	g/m	Mainduct rad	4	inches						
Coal Properties (Rel. only)				4.7	units, back	Vacuum Reto	68.0	%	Main Gas Ro	0.615	fraction	mdot CH4	17.317	g/min			
Upper Freepor			BF2NG		%	Vacuum Reto	9.0	in hg	Main Air Rot	0.41	fraction	mdot Main A	490.938	g/min			
grams	moles/100g		BF2Air		units,front	atomizer air	full open	units	Main Air Rot	31.8	psig	phi	1.652	units			
64.57	5.38				units, back	atomizer air		psig	Inj Air Reto	10	%	mole fract	1.082				
4.07	4.07		Inj Reto	10	%	atomizer H2O	244	mm	Inj Air Reto	39	psig	CO2	1.082	moles/min	CH4&Air only		
3.92	0.25		Inj Reto	39	psig	exit duct T	103	F				H20	2.165	moles/min	CH4&Air only		
1.63	0.12					over furn T	119	F	Coal Composition on Elemental level			N2	13.449	moles/min	CH4&Air only		
2.07	0.06								Carbon(mon	5.38	moles/100g	O2	1.412	moles/min	CH4&Air only		
23.23	23.23								Hydrogen (n	4.07	moles/100g	mdot air inj	10.831	g/min			
0.51	0.03								Oxygen (mo	0.25	moles/100g	O2	0.079	moles/min	inj Air only		
100									Nitrogen (m	0.12	moles/100g	N2	0.297	moles/min	inj Air only		
									Sulfur(mon	0.06	moles/100g	Dry O2 w/in	9.135	vol%	tot w/o coal		
									Ash	23.23	g/100g	DryO2w/o ir	8.855	vol%	t w/o coal&inj		
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum % lt size rng	Size Range micrometers	ECD micro m		H2O	0.03	moles/100g	Coal Fractio	0.011	mdotcoal/100g			
												CO2	1.141	moles/min	total		
									mdot coal	1.1	g/min	H20	2.187	moles/min	total		
Presepartor	0.32651	0.33078	0.01327	40.79	59.21	100 & up	10		Probe inlet T	798	degC	N2	13.744	moles/min	total		
0	0.29913	0.30175	0.00262	8.05	51.15	90 -100	9		Impactor Inlt	100	degC (est. T	SO2	0.0007	moles/min	total		
1	0.29879	0.30316	0.00437	13.43	37.72	58 - 90	58		Vacuum Rot	8	in Hg	O2	1.421	moles/min	total		
2	0.32705	0.32978	0.00273	8.39	29.33	47 - 58	47		Vacuum Rot	23	degC (est. T	Dry O2	8.713	vol%			
3	0.32872	0.33381	0.00509	15.65	13.68	33 - 47	33		Vacuum Rot	68	CFH	H20 wt	0.076	mass fraction			
4	0.32486	0.32807	0.00321	9.87	3.81	21 - 33	21		coal flow lin	5	min	Equiv. Ratio	1.689	w/inj, no solid fuel			
5	0.32883	0.32973	0.00090	2.77	1.05	11 - 21	11					mol wt wet	28.114	g/mol			
6	0.32844	0.32857	0.00013	0.40	0.65	07 - 11	07					dens@inlet	319.900	g/m^3			
7	0.33020	0.33023	0.00003	0.09	0.55	04 - 07	04					mdot duct	519.931	g/min	minus ash		
Backup Filter	0.32791	0.32809	0.00018	0.55	0.00	0 -04	0					vduct	50.118	meters/min			
												vduct	2.795	ft/sec			
		total mass	0.03253						dens@STP	1202.10	g/m^3	dens@mp	818.534	g/m^3			
									BACKFIRE BURNERS			mol wt dry	29.470	g/mol			
												dens@roto	889.126	g/m^3			
									mdotBF1 CH4	18.7977071	g/min	voltlwroterg	0.028	m^3/min			
Notes	* I cleaned the foils and petris with white cloth and acetone as usual -static was								mdotBF1 Air	548.72992	g/min	voltlwroterg	0.975	ft^3/min			
	evident I then sprayed them with acetone and let it evaporate The static was gone								phi	1.704	A/F equiv ratio						
	This may be the solution to the problem								mdotAmdotF	29.2379799		mdotroto	24.540	g/min			
	* Stages looked good No overloads on any stages											mdotimp	26.551	g/min			
									mdotBF2 CH4	0	g/min	voltlwimp	0.029	m^3/min			
									mdotBF2 Air	0	g/min	voltlwimp	1.021	ft^3/min			
									phi	#DIV/0!	A/F equiv rati	vinlet	517.681	m/min			
									mdotAmdotF	#DIV/0!		vinlet	26.307	ft/sec			
												mdotcoal	0.01305	g/min			
									actual ash	0.03253	g	expected as	0.0652	g			
												%Del ash	-100.566	%	based on actual		

Table G.42: Test 11289401

Date	11/28/94	mo/day/yr	Main NG	62 0	%	Upper T	1249	o									
Coal	Upper Freepo	source	Main Air	41 0	%	Sample T	795	o									
	> 65 um	process		31 5	psig	Lower T	646	o									
test no	11289401	m/d/yynum	BF1NG	45 0	%	Coal feed	820	units	Imp Init diam	0 5625	inches						
test dur	6 00	minutes	BF1Air	4 7	units,front	Coal feed cor	1 1	g/m	Manduct rac	4	inches						
Coal Properties (Ref only)				4 6	units, back	Vacuum Roto	67 0	%	Main Gas Ro	0 62	fraction	mdot CH4	17 458	g/min			
Upper Freepor			BF2NG		%	Vacuum Roto	7 5	in hg	Main Air Rot	0 41	fraction	mdot Main A	499 352	g/min			
grams	moles/100g		BF2Air		units,front	atomizer air	full open	units	Main Air Rot	31 5	psig	phi	1 634	units			
64 57	5 38				units, back	atomizer air		psig	Inj Air Roto	10	%	mole fract	1 091				
4 07	4 07		Inj Roto	10	%	atomizer H2O	182	mm	Inj Air Roto	39	psig	O02	1 091	moles/min	CH4&Air only		
3 92	0 25		Inj Roto	39	psig	exit duct T	119	F				H20	2 182	moles/min	CH4&Air only		
1 63	0 12					over lum T	115	F	Coal Composition on Elemental level			N2	19 103	moles/min	CH4&Air only		
2 07	0 06								Carbon(mon	5 38	moles/100g	O2	1 382	moles/min	CH4&Air only		
23 23	23 23								Hydrogen (r	4 07	moles/100g	mdot air inj	10 831	g/min			
0 61	0 03								Oxygen (mo	0 25	moles/100g	O2	0 079	moles/min	Inj Air only		
100									Nitrogen (m	0 12	moles/100g	N2	0 297	moles/min	Inj Air only		
									Sulfur(mon	0 06	moles/100g	Dry O2 w/in	8 992	vol%	tot w/o coal		
									Ash	23 23	g/100g	DryO2w/o in	8 707	vol%	t w/o coal&inj		
Stage	Initial(g)	Final(g)	Net(g)	% in size	Cum %	Size Range	ECD		H2O	0 03	moles/100g	Coal Fractio	0 011	mdotcoal/100g			
				range	ft size mge	micrometers	micro m					CO2	1 150	moles/min	total		
									mdot coal	1 1	g/min	H20	2 205	moles/min	total		
Presseparator	0 32851	0 35066	0 02215	73 76	26 24	100 & up	10		Probe inlet T	795	degC	N2	13 700	moles/min	total		
0	0 29883	0 30294	0 00411	13 69	12 55	90 -100	9		Impactor Ini	100	degC (est T	SO2	0 0007	moles/min	total		
1	0 30156	0 30281	0 00125	4 16	8 39	58 - 90	5 8		Vacuum Rot	7 5	in Hg	O2	1 392	moles/min	total		
2	0 32660	0 32774	0 00094	3 13	5 26	47 - 58	4 7		Vacuum Rot	23	degC (est T	Dry O2	8 567	vol%			
3	0 32755	0 32791	0 00036	1 20	4 06	33 - 47	3 3		Vacuum Rot	67	CFH	H20 wt	0 077	mass fraction			
4	0 32240	0 32270	0 00030	1 00	3 06	21 - 33	2 1		coal flow tim	5	min	Equiv Ratio	1 670	w/inj, no solid fuel			
5	0 32877	0 32897	0 00020	0 67	2 40	11 - 21	1 1					mol wt wet	28 106	g/mol			
6	0 33110	0 33115	0 00005	0 17	2 23	07 - 11	0 7					dens@inlet	320 708	g/m^3			
7	0 33171	0 33174	0 00003	0 10	2 13	04 - 07	0 4					mdot duct	519 485	g/min	minus ash		
Backup Filter	0 32740	0 32804	0 00064	2 13	0 00	0 -0 4	0					vduct	49 853	meters/min			
												vduct	2 720	ll/sec			
		total mass	0 03003						dens@STP	1202 10	g/m^3	dens@imp	918 274	g/m^3			
									BACKFIRE BURNERS			mol wt dry	29 477	g/mol			
												dens@roto	909 613	g/m^3			
									mdotBF1 CH4	19 7977071	g/min	volflwratero	0 028	m^3/min			
Notes	*There is quite a static charge being built up on the tygon feed tube of the coal injector. The min								mdotBF1 Air	549 856859	g/min	volflwratero	0 971	ll^3/min			
	matter seems to be imparting a charge. The hair on my arm stands straight up when I'm within a								phi	1 669	A/F equiv ratio						
	couple of inches								mdotA/mdotF	29 14351		mdotrgto	25 020	g/min			
	* Stage 0 is very strange. There aren't pits. Instead, there are blowout areas. A small clean circle											mdotimp	27 094	g/min			
	(1/4" or so in dia) surrounded by ash. There is plenty of ash on the perimeter of the holder. It								mdotBF2 CH4	0	g/min	volflwimp	0 039	m^3/min			
	looks like it bounced off the plate. Same with stage 1. Same with stage 2.								mdotBF2 Air	0	g/min	volflwimp	1 042	ll^3/min			
	* Stage 3 looks more or less normal, but overloaded								phi	#DIV/0!	A/F equiv rati	vinlet	526 937	m/min			
	* Stage 4 looks more or less normal, but overloaded								mdotA/mdotF	#DIV/0!		vinlet	28 813	ll/sec			
	*GRAINS ARE VISIBLE ON THE FILTER. 1000s of them																
												mdotcoal	0 01335	g/min			
									actual ash	0 03003	g	erpected as	0 0668	g			
												%Diff ash	-122 328	%	based on actual		

Table G.43: Test 12029401

Date	12/2/94	mo/day/yr	Main NG	62 5	%	Upper T	1245	c (max)											
Coal	Upper Freepo	source	Main Air	41 0	%	Sample T	791	c (max)											
	> 85 µm	process		32 0	psig	Lower T	647	c (max)											
test no	12029401	m/d/ynum	BF1NG	45 0	%	Coal feed	820	units	inp inlt diam	0 5625	inches								
test dur	5 00	minutes	BF1Air	4 6	units,front	Coal feed cor	1 1	g/m	Mainduct rad	4	inches								
Coal Properties	(Ref only)			4 5	units, back	Vacuum Roto	68 0	%	Main Gas Ro	0 625	fraction	mdot CH4	17 598	g/min					
Upper Freepor			BF2NG		%	Vacuum Roto	7 8	in hg	Main Air Rot	0 41	fraction	mdot Main A	491 993	g/min					
grams	moles/100g		BF2Air		units,front	atomizer air	full open	units	Main Air Rot	32	psig	phi	1 629	units					
64 57	5 38				units, back	atomizer air		psig	Inj Air Roto	10	%	mole fract	1 100						
4 07	4 07		Inj Roto	10	%	atomizer H2O	250	mm	Inj Air Roto	39 5	psig	O2	1 100	moles/min	CH4&Air only				
3 92	0 25		Inj Roto	39 5	psig	exit duct T	118	F				H20	2 200	moles/min	CH4&Air only				
1 83	0 12					over furn T	120	F	Coal Composition on Elemental level			N2	13 475	moles/min	CH4&Air only				
2 07	0 06								Carbon(mon	5 38	moles/100g	O2	1 394	moles/min	CH4&Air only				
23 23	23 23								Hydrogen (n	4 07	moles/100g	mdot air inj	10 882	g/min					
0 51	0 03								Oxygen (mo	0 25	moles/100g	O2	0 078	moles/min	inj Air only				
100									Nitrogen (m	0 12	moles/100g	N2	0 298	moles/min	inj Air only				
									Sulfur(mon	0 06	moles/100g	Dry O2 w/in	8 957	vol%	tot w/o coal				
									Ash	23 23	g/100g	DryO2w/o ir	8 672	vol%	t w/o coal&in				
Stage	Initial(g)	Final(g)	Net(g)	% in size	Cum %	Size Range	ECD		H2O	0 03	moles/100g	Coal Fractio	0 011	mdotcoal/100g					
				range	fl size mge	micrometers	micro m					CO2	1 159	moles/min	total				
									mdot coal	1 1	g/min	H20	2 222	moles/min	total				
Preseperator	0 32650	0 34491	0 01831	71 94	28 09	100 & up	10		Probe inlet T	791	degC	N2	13 774	moles/min	total				
0	0 29639	0 30185	0 00346	13 60	14 46	90 -100	9		Impactor inl	100	degC (est	SO2	0 0007	moles/min	total				
1	0 29901	0 30015	0 00114	4 48	9 98	5 6 - 9 0	5 6		Vacuum Rot	7 8	in Hg	O2	1 394	moles/min	total				
2	0 32770	0 32872	0 00102	4 01	5 97	4 7 - 5 6	4 7		Vacuum Rot	23	degC (est	Dry O2	8 535	vol%					
3	0 33166	0 33206	0 00036	1 49	4 48	3 3 - 4 7	3 3		Vacuum Rot	68	CFH	H20 wt	0 077	mass fraction					
4	0 32707	0 32729	0 00022	0 86	3 61	2 1 - 3 3	2 1		coal flow ter	5	min	Equiv Ratio	1 665	wfnl, no solid fuel					
5	0 32787	0 32779	0 00022	0 86	2 75	1 1 - 2 1	1 1					mol wt wet	28 104	g/mol					
6	0 32708	0 32716	0 00008	0 31	2 44	0 7 - 1 1	0 7					dens@inlet	321 890	g/m^3					
7	0 32667	0 32679	0 00003	0 12	2 32	0 4 - 0 7	0 4					mdot duct	521 317	g/min	minus ash				
Backup Filter	0 32821	0 32880	0 00059	2 32	0 00	0 -0 4	0					vduct	49 841	meters/min					
												vduct	2 725	ft/sec					
		total mass	0 02545						dens@STP	1202 10	g/m^3	dens@tmp	918 209	g/m^3					
									BACKFIRE BURNER8			mol wt dry	29 479	g/mol					
												dens@rota	897 497	g/m^3					
									mdotBF1 CH4	19 7977071	g/min	vol/rotatero	0 028	m^3/min					
Notes	* A window in the weighing room, about 20 ft from the scales, was open for venting a materials								mdotBF1 Air	538 082626	g/min	vol/rotatero	0 979	ft^3/min					
	experiment, and the scale was very finicky during pretest weighing								phi	1 671	A/F equiv ratio								
	* I grounded the coal injector probe to a water line to see if I could get a better ash distribution t								mdotA/mdotF	28 6700641		mdotrota	24 698	g/min					
	preventing static											mdotimp	28 956	g/min					
	* Static electricity in the line seems less today My hair doesn't stand up on end Also, its hard								mdotBF2 CH4	0	g/min	vol/rotimp	0 029	m^3/min					
	detect flow in the line visually Grains come out very uniformly								mdotBF2 Air	0	g/min	vol/rotimp	1 037	ft^3/min					
	* Stage 0 is identical to last test: Way overload with clean areas were ash should be								phi	#DIV/0!	A/F equiv rati	vinlet	522 336	m/min					
	* Stages 0 through 3 look terrible again Overloaded, and cleaner where there should be piles S								mdotA/mdotF	#DIV/0!		vinlet	28 662	ft/sec					
	3 is better than the previous ones Almost normal																		
	* Stage 4 was in very crooked data for this stage is screwed and for stage 5 by default Stage 5 did											mdotcoal	0 01321	g/min					
	look good								actual ash	0 02545	g	expected as	0 0681	g					
	* I can see micrograins on the filter, like last test																		
	* I swept (instead of my usual acetone wash) all overloads into the preseperator It worked about as																		
	well as the acetone wash																		
	* I ended up washing the presep out with acetone after sweeping, in order to get all the particles											%Diff ash	-159 589	%	based on actual				
	* Test was with 10 minutes of impactor run without coal (hooked up to furnace), followed by 5																		
	minutes with coal flowing																		

Table G.44: Test 12079401

Date	12/7/94	mo/day/yr	Main NG	62 2	%	Upper T	1250	g (max)											
Coal	Upper Freepo	source	Main Air	41 0	%	Sample T	793	g (max)											
	> 85 um	process		31 8	psig	Lower T	648	g (max)											
test no	12079401	m/d/yrnum	BF1NG	45 0	%	Coal feed	820	units	inp inlt diam	0 5625	inches								
test dur	1 00	minutes	BF1Air	4 5	units,front	Coal feed cor	1 1	g/m	Mainduct rad	4	inches								
Coal Properties (Ref only)				4 5	units, back	Vacuum Roto	87 0	%	Main Gas Ro	0 822	fraction	mdot CH4	17 514	g/min					
Upper Freepor			BF2NG		%	Vacuum Roto	7 5	in hg	Main Air Rot	0 41	fraction	mdot Main A	490 936	g/min					
grams	moles/100g		BF2Air		units,front	atomizer air	full open	units	Main Air Rot	31 8	psig	phi	1 634	units					
64 57	5 36				units, back	atomizer air		psig	Inj Air Roto	10	%	mole fract	1 095						
4 07	4 07		Inj Roto	10	%	atomizer H2O	183	mm	Inj Air Roto	39 5	psig	O2	1 095	moles/min	CH4&Air only				
3 92	0 25		Inj Roto	39 5	psig	exit duct T	113	F				H20	2 189	moles/min	CH4&Air only				
1 63	0 12					over furn T	129	F	Coal Composition on Elemental level			N2	13 446	moles/min	CH4&Air only				
2 07	0 06								Carbon(mon	5 38	moles/100g	O2	1 397	moles/min	CH4&Air only				
23 23	23 23								Hydrogen (n	4 07	moles/100g	mdot air inj	10 862	g/min					
0 51	0 03								Oxygen (mo	0 25	moles/100g	O2	0 079	moles/min	Inj Air only				
100									Nitrogen (m	0 12	moles/100g	N2	0 298	moles/min	Inj Air only				
									Sulfur(mon	0 06	moles/100g	Dry O2 w/n	8 892	vol%	tot w/o coal				
									Ash	23 23	g/100g	DryO2w/o c	8 708	vol%	t w/o coal&Inj				
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum % ft size rnge	Size Range micrometers	ECD micro m		H2O	0 03	moles/100g	Coal Fractio	0 011	mdotcoal/100g					
												CO2	1 154	moles/min	total				
									mdot coal	1 1	g/min	H20	2 212	moles/min	total				
Presepersior	0 32791	0 33353	0 00562	81 21	18 79	100 & up	10		Probe inlet T	793	degC	N2	13 745	moles/min	total				
0	0 29972	0 30041	0 00069	9 97	8 82	90 -100	9		Impactor inl	100	degC (est T	SO2	0 0007	moles/min	total				
1	0 29893	0 30009	0 00016	2 31	6 50	58 - 90	5 8		Vacuum Rot	7 5	in Hg	O2	1 396	moles/min	total				
2	0 32680	0 32695	0 00015	2 17	4 34	47 - 58	4 7		Vacuum Rot	23	degC (est T	Dry O2	8 569	vol%					
3	0 32614	0 32620	0 00006	0 87	3 47	33 - 47	3 3		Vacuum Rot	67	CFH	H20 wt	0 077	mass fraction					
4	0 32672	0 32674	0 00002	0 29	3 19	21 - 33	2 1		coal flow lm	1	min	Equiv Ratio	1 670	w/inj, no solid fuel					
5	0 32817	0 32819	0 00002	0 29	2 89	11 - 21	1 1					mol wt wet	28 106	g/mol					
6	0 32940	0 32940	0 00000	0 00	2 89	07 - 11	0 7					dens@inlet	321 309	g/m^3					
7	0 32716	0 32717	0 00001	0 14	2 75	04 - 07	0 4					mdot duct	520 178	g/min	minus ash				
Backup Filter	0 33168	0 33187	0 00019	2 75	0 00	0 -04	0					vduct	49 922	meters/min					
												vduct	2 724	ll/sec					
		total mass	0 00692						dens@STP	1202 10	g/m^3	dens@tmp	918 273	g/m^3					
									BACKFIRE BURNERS			mol wt dry	29 477	g/mol					
												dens@rota	909 609	g/m^3					
Notes	Pretest note Since previous test of 5 minutes was overloaded, I'm going for a 1 minute								mdotBF1 CH4	16 7077071	g/min	volflwrotero	0 028	m^3/min					
	test, with 14 minutes run w/o coal								mdotBF1 Air	531 026656	g/min	volflwrotero	0 971	ll^3/min					
	* Presepersior load is really light (visual weight estimate)								phi	1 649	A/F equiv ratio								
	*There are particles above the 0 stage orifice plate								mdotAirdotF	28 294818		mdotrota	25 020	g/min					
	*Stage 0 again has hardly any ash on the foil plate It blew off to the sides Stage 1											mdotimp	27 093	g/min					
	looks about clean, but with blowby anyway Stage 2 only has a visible pile in the								mdotBF2 CH4	0	g/min	volflwimp	0 030	m^3/min					
	center Stage 3 has no visble ash These stages look just like the 5 minute tests								mdotBF2 Air	0	g/min	volflwimp	1 042	ll^3/min					
	(12079401, for ex), but lighter loadings Stage 5 has the traditional visible piles,								phi	#DIV/0!	A/F equiv ratio	vinlet	525 944	m/min					
	while stage 4 only had extremely faint piles showing Stage 6 has very faint piles In								mdotAirdotF	#DIV/0!		vinlet	29 759	ll/sec					
	retrospect, all these piles are very faint, including stage 7 Five looks the most loaded,																		
	but not much											mdotcoal	0 01331	g/min					
	* The filter again has visible particles, on the order of 10 um								actual ash	0 00692	g	expected as	0 0133	g					
	*I dropped stage 6 face down, but I don't think it hurt No loose ash, and I dropped it a																		
	short distance onto clean cotton Little of the the two surfaces contacted																		
	* Temperature was measured about 8 hours post test No reason to expect it to change											%Diff ash	-92 331	%	based on actual				
	over that time period																		

APPENDIX H: ARTIFICIAL CHAR CASCADE IMPACTOR TEST SUMMARIES

The spreadsheets that follow summarize the detailed measurements and calculations required to determine the size distribution of ash for artificial char fuels. The series was conducted in association with Park (1995), using a natural-gas fired furnace. Ash samples were collected with a simple water cooled sampling probe and size-sorted with a Mark II cascade impactor.

Table H.1: Test log for artificial char experiments

Test Number	Char Name	A/F Equiv. (w/o char)	Furnace Flow Rate, grams	Dry O2, % (w/o char)
03019501	Ben 1.25 g	1.47	634	7.7
03139501	Ben 1.25 g	1.47	631	7.8
03029501	Ben 2.50 g	1.45	621	7.5
03149501	Ben 2.50 g	1.47	627	7.8
03039501	Ben 3.75 g	1.44	625	7.5
03149502	Ben 3.75 g	1.48	627	7.9
02279501	Ben 5.00 g	1.44	621	7.4
03149503	Ben 5.00 g	1.46	628	7.7
03129501	Cal 0.25 g	1.46	630	7.7
03079502	Cal 0.50 g	1.45	629	7.6
03079501	Cal 0.75 g	1.46	631	7.7
03069502	Cal 1.00 g	1.46	630	7.7
02219501	Pyr 0.93 g	1.44	625	7.5
03179502	Pyr 0.93 g	1.42	617	7.3
03039502	Pyr 1.85 g	1.44	625	7.5
03179501	Pyr 1.85 g	1.46	628	7.7
03069501	Pyr 2.78 g	1.46	630	7.7
03169501	Pyr 2.78 g	1.47	631	7.8
03169504	Pyr 3.70 g	1.47	627	7.8
02239501	Pyr 3.70 g	1.44	622	7.5
02149501	Suc50/C50	1.42	617	7.3
03129502	Suc50/C50	1.43	618	7.4
02069501	Suc50/C50	1.63	521	8.9
02179501	Suc75/C25	1.44	622	7.5
03169503	Suc75/C25	1.45	628	7.6

Table H.2: Test 02039501

Date:	2/3/95	mo/day/yr	Main NG:	62.5	%	Probe cint T:		F									
Coal:	AC 912	source	Main Air:	41.0	%	Probe cint thk	90	mm									
	Ben 5.00 g	process		31.8	psig	Comb prg p:		psig									
test no:	02039501	m/d/ynum	BF1NG:	45.0	%	Coal feed:	5@90%	units	Imp Init diam	0.5625	inches						
test dur:		min(est.)	BF1Air:	4.5	units,front	Coal feed conv		g/m	Mainduct rad	4	inches						
Coal Properties:	(Rel. only)			4.5	units, back	Vacuum Rate	72.0	%	Main Gas Rate	0.625	fraction	mdot CH4	17.598	g/min			
			BF2NG:		%	Vacuum Rate	9.5	in hg	Main Air Rate	0.41	fraction	mdot Main Air	490.838	g/min			
grams	atomwt/100g	Ult. Ana.	BF2Air:		units,front	atomizer air:	full open	units	Main Air Rate	31.8	psig	phi	1.928	units			
		Carbon			units, back	atomizer air:		psig	Inj Air Rate	20	%	mole fract	1.100				
		Hydrogen	Inj Rate:	20	%	atomizer H2O	147	mm	Inj Air Rate	39	psig	CO2	1.100	moles/min	CH4&Air only		
		Oxygen	Inj Rate:	39	psig	exit duct T:	94	F				H20	2.200	moles/min	CH4&Air only		
		Nitrogen				over turn T:	108	F	Coal Composition on Elemental level			N2	13.446	moles/min	CH4&Air only		
		Sulfur							Carbon(monat	0.00	moles/100g	O2	1.376	moles/min	CH4&Air only		
		Ash							Hydrogen (mo	0.00	moles/100g	mdot air inj	21.231	g/min			
		Moisture							Oxygen (mon	0.00	moles/100g	O2	0.156	moles/min	Inj Air only		
		Total							Nitrogen (mon	0.00	moles/100g	N2	0.581	moles/min	Inj Air only		
			Scale:	1					Sulfur(mon)	0.00	moles/100g	Dry O2 w/inj	8.181	vol%	tot w/o coal		
									Ash	0.00	g/100g	DryO2w/o inj	8.644	vol%	t.w/o coal&in		
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % & size rge	Size Range micrometers	T/C Port	Temp, C	H2O	0.00	moles/100g	Coal Fraction	0.000	mdotcoal/100g			
							Upper T					CO2	1.100	moles/min	total		
Presepparator	0.32861	0.33855	0.00994	45.38	54.61	10.0 & up	B		mdot coal	0	g/min	H20	2.200	moles/min	total		
0	0.29745	0.29997	0.00252	11.51	43.11	9.0 -10.0	C		Probe inlet T	0	degC	N2	14.028	moles/min	total		
1	0.29840	0.30073	0.00233	10.64	32.47	5.8 - 9.0	D		Impactor inlet	100	degC (est. T)	SO2	0.0000	moles/min	total		
2	0.33207	0.33351	0.00144	6.58	25.89	4.7 - 5.8	E		Vacuum Rate	9.5	in Hg	O2	1.931	moles/min	total		
3	0.32761	0.32985	0.00224	10.23	15.66	3.3 - 4.7	F		Vacuum Rate	23	degC (est. T)	Dry O2	9.191	vol%	total		
4	0.33004	0.33181	0.00177	8.08	7.58	2.1 - 3.3	G		Vacuum Rate	72	CFH	H20 wt	0.075	mass fraction			
5	0.32783	0.32878	0.00095	3.88	3.70	1.1 - 2.1	H		coal flow time	0	min						
6	0.32638	0.32867	0.00229	1.32	2.37	0.7 - 1.1	Bemp. T					mol wt wet	28.091	g/mol			
7	0.32824	0.32939	0.00115	0.68	1.69	0.4 - 0.7	J					dens@inlet	1254.008	g/m^3			
Backup Filter	0.33279	0.33316	0.00037	1.69	0.00	0 -0.4	low T					mdot duct	529.767	g/min	minus ash		
												vduct	13.027	meters/min			
		total mass:	0.02190									vduct	0.712	ft/sec			
									dens@STP	1292.19	g/m^3	dens@imp	917.813	g/m^3			
												mol wt dry	28.424	g/mol			
												dens@rota	827.043	g/m^3			
												volflwrateroto	0.928	m^3/min			
												volflwrateroto	0.995	ft^3/min			
Notes:																	
												mdotrota	23.310	g/min			
The coal feeder jammed about 10 minutes into the test. I think the data is ok, but the mass balance should be screwed up.												mdotimp	25.194	g/min			
The stages came out pretty black.												volflwimp	0.927	m^3/min			
There are traces of ashes on the plate of presepparator -less than 5% could be discontinued measurement -JP												volflwimp	0.969	ft^3/min			
The filter came out light brownish, sort of like a cigarette filter that had been used for a few puffs												vinlet	126.310	m/min			
												vinlet	6.952	ft/sec			
												mdotcoal	0.00000	g/min			
									actual ash:	0.0219	g	expected ash	0.0000	g			
												%Diff ash	100.000	%	based on actu		

Table H.3: Test 02069501

Table H.4: Test 02149501

Date:	2/14/95	mo/day/yr	Main NG:	93.0	%	Probe cint T:	140	F							
Coal:	AC #1	source	Main Air:	47.0	%	Probe cint thr:	160+	mm							
	Suc50/C50	process		33.0	psig	Comb prg p:		psig							
test no:	02149501	m/d/ynum	BF1NG:	44.0	%	Coal feed:	5.00%	units	Imp Init diam	0.6625	inches				
test dur:	15.00	min (est)	BF1Air:	3.8	units,front	Coal feed cor	1.1	g/m	Mainduct red	4	inches				
Coal Properties: (Rel. only)				3.8	units, back	Vacuum Roto	71.0	%	Main Gas Roto	0.83	fraction	mdot CH4	23.371	g/min	
			BF2NG:	20.0	%	Vacuum Roto	9.6	in hg	Main Air Roto	0.47	fraction	mdot Main Air	569.998	g/min	
grams	atomwt/100g	Ult. Ana.	BF2Air:	2.8	units,front	atomizer air:	full open	units	Main Air Roto	23	psig	phi	1.421	units	
		Carbon		2.8	units, back	atomizer air:		psig	Inj. Air Roto	20	%	mole fract	1.491		
		Hydrogen	Inj. Roto:	20	%	atomizer H2O	153	mm	Inj Air Roto	44	psig	CO2	1.491	moles/min	CH4&Air only
		Oxygen	Inj. Roto:	44	psig	exit duct T:	110	F				H2O	2.921	moles/min	CH4&Air only
		Nitrogen				over turn T:	120	F	Coal Composition on Elemental level			N2	15.612	moles/min	CH4&Air only
		Sulfur							Carbon(mon)	0.00	moles/100g	O2	1.231	moles/min	CH4&Air only
		Ash							Hydrogen (mo	0.00	moles/100g	mdot air inj	22.197	g/min	
		Moisture							Oxygen (mon)	0.00	moles/100g	O2	0.182	moles/min	Inj Air only
		Total							Nitrogen (mon	0.00	moles/100g	N2	0.608	moles/min	Inj Air only
			Scale:	1					Sulfur(mon)	0.00	moles/100g	Dry O2 w/inj	7.301	vol%	tot w/o coal
									Ash	0.00	g/100g	DryO2w/o inj	8.724	vol%	tl w/o coal&inj
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % R. size mon	Size Range micrometers	T/C Port	Temp, C	H2O	0.00	moles/100g	Coal Fraction	0.011	mdot/coal/100g	
												CO2	1.491	moles/min	total
									mdot coal	1.1	g/min	H2O	2.921	moles/min	total
Presseparator	0.32116	0.32211	0.00095	25.82	74.18	10.0 & up	B	1214	Probe Inlet T	988	degC	N2	16.220	moles/min	total
0	0.29892	0.29929	0.00037	10.05	64.13	9.0 -10.0	C	1193	Impactor Inlet	100	degC (est. T)	SO2	0.0000	moles/min	total
1	0.29780	0.29794	0.00014	3.80	60.33	5.8 - 9.0	D	1170	Vacuum Roto	9.6	in Hg	O2	1.392	moles/min	total
2	0.32859	0.32874	0.00015	4.35	55.99	4.7 - 5.8	E	1147	Vacuum Roto	23	degC (est. T)	Dry O2	7.301	vol%	total
3	0.32648	0.32662	0.00015	4.35	51.63	3.3 - 4.7	F	1109	Vacuum Roto	71	CFH	H20 wt	0.069	mass fraction	
4	0.32850	0.32875	0.00025	6.79	44.84	2.1 - 3.3	G	1076	coal flow time	15	min				
5	0.32746	0.32768	0.00021	5.71	39.13	1.1 - 2.1	H	1024				mol wt wet	27.988	g/mol	
6	0.32584	0.32596	0.00012	3.26	35.87	0.7 - 1.1	I	988				dens@inlet	274.842	g/m^3	
7	0.33265	0.33272	0.00007	1.90	33.97	0.4 - 0.7	J	900				mdot duct	616.668	g/min	minus ash
Backup Filter	0.33308	0.33433	0.00125	33.97	0.00	0 -0.4	K	830				vduct	60.188	meter/min	
												vduct	3.777	ft/sec	
		total mass:	0.00369						dens@STP	1202.10	g/m^3	dens@imp	914.420	g/m^3	
												mol wt dry	29.517	g/mol	
												dens@roto	929.697	g/m^3	
												volflwrateroto	0.026	m^3/min	
												volflwrateroto	0.983	ft^3/min	
Notes:	*)T/C J measurement is about 1" off centerline of reactor*) Coating on t-couple cracked off, like due to hitting it on something. *)The coal injector started with a pretty good initial blast of air because I opened the valve too fast. Effect unknown. *)Coal seems to be flowing well ten minutes into test. *) Syringes were loosened by twisting every few minutes to prevent jamming. *)Jammed right as first syringe went past end of body (i.e. end of test) *) Probably lost about one cc from dust after syringe went through. *) Stage 0 and 1 look completely clean. Presep has an extremely small amount of ash in it. Barely visible in stagnation region.											mdotroto	23.096	g/min	
												mdotimp	25.253	g/min	
												volflwimp	0.028	m^3/min	
												volflwimp	0.975	ft^3/min	
												vinlet	573.107	m/min	
												vinlet	31.338	ft/sec	
												mdotcoal	0.00000	g/min	
									actual ash:	0.00369	g	expected ash	0.0000	g	
												%Ult ash	100.000	%	based on actu

Table H.5: Test 02179501

Date:	2/17/95	mo/day/yr	Main NG:	83.0	%	Probe clnt T:	146	F								
Coal:	AC #2	source	Main Air:	47.5	%	Probe clnt flw:	160	mm								
	Suc75/C25	process		33.0	psig	Comb prg p:	5@90%	psig								
test no:	02179501	m/d/ynum	BF1NG:	44.0	%	Coal feed		units	Imp Init diam	0.5625	inches					
test dur:	15.67	minutes	BF1Air:	3.7	units,front	Coal feed conv		g/m	Meinduct leg	4	inches					
Coal Properties: (Ref. only)				3.7	units, back	Vacuum Roto	72.0	%	Main Gas Roto	0.83	fraction	mdot CH4	23.371	g/min		
			BF2NG:	19.5	%	Vacuum Roto	9.5	in hg	Main Air Roto	0.475	fraction	mdot Main Air	578.062	g/min		
grams	atomwt/100g	Ult. Ana.	BF2Air:	2.8	units,front	atomizer air:	full	units	Main Air Roto	33	psig	phi	1.439	units		
		Carbon		2.8	units, back	atomizer air:	full	psig	Inj. Air Roto	20	%	mole fract	1.481			
		Hydrogen	Inj. Roto:	20	%	atomizer H2O	205	mm	Inj Air Roto	44	psig	CO2	1.481	moles/min	CH4&Air only	
		Oxygen	Inj. Roto:	44	psig	exit duct T:	110	F				H20	2.921	moles/min	CH4&Air only	
		Nitrogen				over turn T:	95	F	Coal Composition on Elemental level			N2	15.778	moles/min	CH4&Air only	
		Sulfur							Carbon(mon+d	0.00	moles/100g	O2	1.276	moles/min	CH4&Air only	
		Ash							Hydrogen (mo	0.00	moles/100g	mdot air inj.	22.197	g/min		
		Moisture							Oxygen (mon)	0.00	moles/100g	O2	0.182	moles/min	Inj Air only	
		Total							Nitrogen (mon	0.00	moles/100g	N2	0.608	moles/min	Inj Air only	
			Scale:	1					Sulfur(mon)	0.00	moles/100g	Dry O2 w/inj	7.450	vol%	tot w/o coal	
									Ash	0.00	g/100g	DryO2w/o inj	6.868	vol%	t w/o coal&in	
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % R. size mge	Size Range micrometers	T/C Port	Temp, C	H2O	0.00	moles/100g	Coal Fraction	0.000	mdotcoal/100g		
												CO2	1.481	moles/min	total	
									mdot coal	0	g/min	H20	2.921	moles/min	total	
Preseparator	0.33056	0.33235	0.00179	30.44	69.56	10.0 & up	B	1209	Probe inlet T	977	degC	N2	16.386	moles/min	total	
0	0.29954	0.29993	0.00039	6.63	62.93	9.0 -10.0	C	1190	Impactor inlet	100	degC (est. T)	SO2	0.0000	moles/min	total	
1	0.30112	0.30146	0.00034	5.78	57.14	5.0 - 9.0	D	1169	Vacuum Roto	9.5	in Hg	O2	1.427	moles/min	total	
2	0.32716	0.32742	0.00027	4.59	52.55	4.7 - 5.0	E	1149	Vacuum Roto	23	degC (est. T)	Dry O2	7.450	vol%	total	
3	0.32727	0.32759	0.00032	5.44	47.11	3.3 - 4.7	F	1109	Vacuum Roto	72	CFH	H20 wt	0.085	mass fraction		
4	0.32890	0.32926	0.00036	6.05	41.16	2.1 - 3.3	G	1080	coal flow time	15.6667	min					
5	0.33090	0.33117	0.00027	4.59	36.56	1.1 - 2.1	H	1029				mol wt wet	27.996	g/mol		
6	0.32963	0.32980	0.00017	2.89	33.67	0.7 - 1.1	I	977				dens@inlet	272.942	g/m^3		
7	0.32885	0.32899	0.00011	1.87	31.80	0.4 - 0.7	J	909				mdot duct	921.830	g/min	minus ash	
Backup Filter	0.33178	0.33365	0.00187	31.80	0.00	0 -0.4	K	841				vduct	70.230	meters/min		
												vduct	3.840	ft/sec		
		total mass:	0.00589						dens@STP	1202.10	g/m^3	dens@imp	914.683	g/m^3		
												mol wt dry	28.510	g/mol		
												dens@roto	829.459	g/m^3		
Notes:												volflwreleroto	0.028	m^3/min		
												volflwreleroto	0.997	ft^3/min		
												mdotroto	23.413	g/min		
												mdotimp	25.576	g/min		
												volflwimp	0.028	m^3/min		
												volflwimp	0.997	ft^3/min		
												vinlet	584.473	m/min		
												vinlet	31.959	ft/sec		
												mdotcoal	0.00000	g/min		
									actual ash:	0.00588	g	expected ash	0.0000	g		
												%Dif ash	100.000	%	based on actu	

Table H.6: Test 02219501

Date:	2/21/95	mo/day/yr	Main NG:	83.0	%	Probe clnt T:	148	F									
Coal:	AC #4	source	Main Air:	47.5	%	Probe clnt flw:	145	mm									
	Pyr. 0.93 g	process		33.6	psig	Comb prg p:		psig									
test no:	02219501	m/d/ynum	BF1NG:	44.0	%	Coal feed:		units	Imp inlt diam	0.5625	inches						
test dur:	13.67	minutes	BF1Air:	3.8	units,front	Coal feed conv		g/m	Mainduct dia	4	inches						
Coal Properties: (Ref. only)				3.8	units, back	Vacuum Roto	72.0	%	Main Gas Roto	0.83	fraction	mdot CH4	23.371	g/min			
			BF2NG:	20.0	%	Vacuum Roto	9.6	in hg	Main Air Roto	0.475	fraction	mdot Main Air	579.073	g/min			
grams	atomwt/100g	Ult. Ana.	BF2Air:	2.8	units,front	atomizer air:	full	units	Main Air Roto	33.6	psig	phi	1.444	units			
		Carbon		2.8	units, back	atomizer air:	full	psig	Inj. Air Roto	20	%	mole fract.	1.461				
		Hydrogen	Inj. Roto:	20	%	atomizer H2O	180	mm	Inj Air Roto	44	psig	CO2	1.461	moles/min	CH4&Air only		
		Oxygen	Inj. Roto:	44	psig	exit duct T:	108	F				H20	2.921	moles/min	CH4&Air only		
		Nitrogen				over furn T:	110	F	Coal Composition on Elemental level			N2	15.860	moles/min	CH4&Air only		
		Sulfur							Carbon(monat	0.00	moles/100g	O2	1.297	moles/min	CH4&Air only		
		Ash							Hydrogen (mo	0.00	moles/100g	mdot air inj.	22.197	g/min			
		Moisture							Oxygen (mon	0.00	moles/100g	O2	0.162	moles/min	Inj Air only		
		Total							Nitrogen (mor	0.00	moles/100g	N2	0.608	moles/min	Inj Air only		
			Scale:	1					Sulfur(mon)	0.00	moles/100g	Dry O2 w/inj	7.523	vol%	tot w/o coal		
									Ash	0.00	g/100g	DryO2w/o inj	6.899	vol%	t.w/o coal&inj		
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % B. size max	Size Range micrometers	T/C Port	Temp, C.	H2O	0.00	moles/100g	Coal Fraction	0.000	mdotcoal/100g			
												CO2	1.461	moles/min	total		
									mdot coal	0	g/min	H20	2.921	moles/min	total		
Presseparator	0.32775	0.32878	0.00103	22.89	77.11	10.0 & up	B	1215	Probe inlet T	977	degC	N2	16.468	moles/min	total		
0	0.29914	0.29943	0.00029	6.44	70.67	9.0 -10.0	C	1199	Impactor inlet	100	degC (est. T)	SO2	0.0000	moles/min	total		
1	0.29846	0.29876	0.00030	6.67	64.00	5.8 - 9.0	D	1175	Vacuum Roto	9.6	in Hg	O2	1.459	moles/min	total		
2	0.32833	0.32857	0.00024	5.33	58.67	4.7 - 5.8	E	1150	Vacuum Roto	23	degC (est. T)	Dry O2	7.523	vol%	total		
3	0.32670	0.32716	0.00046	10.22	48.44	3.3 - 4.7	F	1115	Vacuum Roto	73	CFH	H20 wt.	0.064	mass fraction			
4	0.32821	0.32871	0.00050	11.11	37.33	2.1 - 3.3	G	1081	coal flow time	13.6667	min						
5	0.32718	0.32755	0.00037	8.22	29.11	1.1 - 2.1	H	1039				mol wt wet	28.000	g/mol			
6	0.32702	0.32716	0.00014	3.11	26.00	0.7 - 1.1	I	977				dens@inlet	272.980	g/m^3			
7	0.32763	0.32771	0.00008	1.78	24.22	0.4 - 0.7	J	907				mdot duct	924.641	g/min	minus ash		
Backup Filter	0.33247	0.33356	0.00109	24.22	0.00	0 -0.4	K	833				vduct	70.681	meters/min			
												vduct	3.859	ft/sec			
		total mass:	0.00450						dens@STP	1202.10	g/m^3	dens@inp	914.813	g/m^3			
												mol wt dry	29.508	g/mol			
												dens@roto	825.390	g/m^3			
Notes:												volflwrateroto	0.029	m^3/min			
												volflwrateroto	1.008	ft^3/min			
												mdotroto	23.560	g/min			
												mdotinp	25.725	g/min			
												volflwinp	0.028	m^3/min			
												volflwinp	0.993	ft^3/min			
												vinlet	587.794	m/min			
												vinlet	32.141	ft/sec			
												mdotcoal	0.00000	g/min			
									actual ash:	0.0045	g	expected ash	0.0000	g			
												%Diff ash	100.000	%	based on actu		

Table H.7: Test 02239501

Date:	2/23/95	m/day/yr	Main NG:	93.0	%	Probe clnt T:	149	F							
Coal:	AC 87	source	Main Air:	47.5	%	Probe clnt thk:	160	mm							
	Pyr 3.70 g	process		33.0	psig	Comb prg p:	7	psig							
test no:	02239501	m/d/ynum	BF1NG:	44.0	%	Coal feed:	5@90%	units	Imp Inlt diam	0.5625	inches				
test dur:	13.24	minutes	BF1Air:	3.9	units,front	Coal feed conv		g/m	Mainduct rad	4	inches				
Coal Properties: (Ref. only)				3.8	units, back	Vacuum Roto	73.0	%	Main Gas Roto	0.83	fraction	mdot CH4	23.371	g/min	
			BF2NG:	20.0	%	Vacuum Roto	9.6	in hg	Main Air Roto	0.475	fraction	mdot Main Air	578.062	g/min	
grams	atomwt/100g	Ult. Ana.	BF2Air:	2.9	units,front	atomizer air:	full	units	Main Air Roto	33	psig	phi	1.439	units	
		Carbon		2.8	units, back	atomizer air:	full	psig	Inj Air Roto	20	%	mole fract.	1.461		
		Hydrogen	Inj. Roto:	20	%	atomizer H2O	203	mm	Inj Air Roto	44	psig	CO2	1.461	moles/min	CH4&Air only
		Oxygen	Inj. Roto:	44	psig	exit duct T:	102	F				H2O	2.921	moles/min	CH4&Air only
		Nitrogen				over turn T:	102	F	Coal Composition on Elemental level			N2	15.778	moles/min	CH4&Air only
		Sulfur							Carbon(monat	0.00	moles/100g	O2	1.275	moles/min	CH4&Air only
		Ash							Hydrogen (mo	0.00	moles/100g	mdot air inj	22.197	g/min	
		Moisture							Oxygen (mon)	0.00	moles/100g	O2	0.182	moles/min	Inj Air only
		Total							Nitrogen (mor	0.00	moles/100g	N2	0.809	moles/min	Inj Air only
			Scale:	1					Sulfur(mon)	0.00	moles/100g	Dry O2 w/inj	7.460	vol%	tot w/o coal
									Ash	0.00	g/100g	DryO2w/o inj	6.986	vol%	t w/o coal&inj
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % lt. size rnge	Size Range micrometers	T/C Port	Temp, C.	H2O	0.00	moles/100g	Coal Fraction	0.000	mdotcoal/100g	
												CO2	1.461	moles/min	total
Preseperator	0.32646	0.33109	0.00463	39.17	60.83	10.0 & up	B	1217	mdot coal	0	g/min	H20	2.921	moles/min	total
0	0.29795	0.29876	0.00081	6.85	53.98	9.0 -10.0	C	1194	Probe Inlet T	975	degC	N2	15.396	moles/min	total
1	0.29958	0.30057	0.00099	7.53	46.45	5.8 - 9.0	D	1175	Injector Inlet	100	degC (est. T)	SO2	0.0000	moles/min	total
2	0.32581	0.32750	0.00069	5.84	40.61	4.7 - 5.8	E	1151	Vacuum Roto	9.6	in Hg	O2	1.437	moles/min	total
3	0.32733	0.32842	0.00109	9.22	31.39	3.3 - 4.7	F	1114	Vacuum Roto	23	degC (est. T)	Dry O2	7.460	vol%	total
4	0.32709	0.32820	0.00111	9.39	22.00	2.1 - 3.3	G	1078	Vacuum Roto	73	CFH	H20 wt	0.085	mass fraction	
5	0.32710	0.32789	0.00079	6.68	15.31	1.1 - 2.1	H	1024	coal flow time	13.24	min				
6	0.32686	0.32703	0.00017	1.44	13.87	0.7 - 1.1	I	975				mol wt wet	27.998	g/mol	
7	0.32522	0.32631	0.00009	0.76	13.11	0.4 - 0.7	J	897				dens@inlet	273.379	g/m^3	
Backup Filter	0.33083	0.33248	0.00165	13.11	0.00	0 -0.4	K	837				mdot duct	921.630	g/min	minus ash
												vduct	70.116	meter/min	
		total mass:	0.01182									vduct	3.834	ft/sec	
									dens@STP	1202.10	g/m^3	dens@inp	914.683	g/m^3	
												mol wt dry	29.510	g/mol	
												dens@rota	929.469	g/m^3	
Notes:												volflwrelerota	0.029	m^3/min	
												volflwrelerota	1.011	ft^3/min	
												mdotrota	23.738	g/min	
												mdotimp	25.931	g/min	
												volflwimp	0.028	m^3/min	
												volflwimp	1.001	ft^3/min	
												vinlet	591.842	m/min	
												vinlet	32.361	ft/sec	
												mdotcoal	0.00000	g/min	
									actual ash:	0.01182	g	expected ash	0.0000	g	
												%Diff ash	100.000	%	based on actu

Table H.8: Test 02279501

Date:	2/27/95	mo/day/yr	Main NG:	83.0	%	Probe clnt T:	148	F							
Coal:	AC #12	source	Main Air:	47.5	%	Probe clnt flr:	160	mm							
	Ben 5.00 g	process		33.0	psig	Comb prg p:	7	psig							
test no:	02279501	m/d/yynum	BF1NG:	44.0	%	Coal feed:	5@90%	units	imp init diam	0.5625	inches				
test dur:	12.17	minutes	BF1Air:	9.8	units,front	Coal feed conv		g/m	Meinduct req	4	inches				
Coal Properties: (Ref. only)				3.7	units, back	Vacuum Rota	72.0	%	Main Gas Rota	0.83	fraction	mdot CH4	23.371	g/min	
			BF2NG:	20.0	%	Vacuum Rota	9.4	in hg	Main Air Rota	0.475	fraction	mdot Main Air	576.062	g/min	
grams	atomwt/100g	Ult. Ana	BF2Air:	2.9	units,front	atomizer air:	full	units	Main Air Rota	33	psig	phi	1.436	units	
		Carbon		2.8	units, back	atomizer air:	full	psig	Inj Air Rota	20	%	mole fract	1.461		
		Hydrogen	Inj Rota:	20	%	atomizer H2O	201	mm	Inj Air Rota	43	psig	CO2	1.461	moles/min	CH4&Air only
		Oxygen	Inj Rota:	43	psig	exit duct T:	100	F				H20	2.921	moles/min	CH4&Air only
		Nitrogen				over furn T:	104	F	Coal Composition on Elemental level			N2	15.778	moles/min	CH4&Air only
		Sulfur							Carbon(monel	0.00	moles/100g	O2	1.275	moles/min	CH4&Air only
		Ash							Hydrogen (mo	0.00	moles/100g	mdot air inj	22.007	g/min	
		Moisture							Oxygen (mon)	0.00	moles/100g	O2	0.160	moles/min	Inj Air only
		Total							Nitrogen (mol	0.00	moles/100g	N2	0.603	moles/min	Inj Air only
			Scale:						Sulfur(mon)	0.00	moles/100g	Dry O2 w/inj	7.445	vol%	tot w/o coal
									Ash	0.00	g/100g	DryO2w/o inj	6.886	vol%	t.w/o coal&inj
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % lt. size mes	Size Range micrometers	T/C Port	Temp, C	H2O	0.00	moles/100g	Coal Fraction	0.000	mdotcoal/100g	
												CO2	1.461	moles/min	total
									mdot coal	0	g/min	H20	2.921	moles/min	total
Preseparator	0.32775	0.33458	0.00683	41.60	58.40	10.0 & up	B	1215	Probe inlet T	976	degC	N2	16.381	moles/min	total
0	0.29880	0.30090	0.00210	12.79	45.62	9.0 - 10.0	C	1195	Impactor inlet	100	degC (est. T)	SO2	0.0000	moles/min	total
1	0.29879	0.30019	0.00139	8.47	37.15	5.8 - 9.0	D	1177	Vacuum Rota	9.4	in Hg	O2	1.435	moles/min	total
2	0.32744	0.32856	0.00114	6.94	30.21	4.7 - 5.8	E	1153	Vacuum Rota	23	degC (est. T)	Dry O2	7.445	vol%	total
3	0.32749	0.32884	0.00164	9.98	20.23	2.3 - 4.7	F	1116	Vacuum Rota	72	CFH	H20 wt	9.066	mass fraction	
4	0.32774	0.32908	0.00134	8.16	12.07	2.1 - 2.3	G	1083	coal flow time	12.1666667	min				
5	0.32935	0.32713	0.00078	4.75	7.32	1.1 - 2.1	H	1033				mol wt wet	27.995	g/mol	
6	0.32825	0.32856	0.00031	1.89	6.03	0.7 - 1.1	I	976				dens@inlet	279.168	g/m^3	
7	0.32701	0.32721	0.00020	1.22	4.81	0.4 - 0.7	J	887				mdot duct	621.440	g/min	minus ash
Backup Filter	0.33179	0.33259	0.00079	4.81	0.00	0 -0.4	K	825							
												vduct	70.163	meter/min	
		total mass:	0.01642									vduct	3.836	ft/sec	
									dens@STP	1202.10	g/m^3	dens@imp	914.876	g/m^3	
												mol wt dry	29.510	g/mol	
												dens@roto	833.524	g/m^3	
												volflwrateroto	0.028	m^3/min	
Notes:												volflwrateroto	0.999	ft^3/min	
												mdotroto	23.585	g/min	
												mdotimp	25.765	g/min	
												volflwimp	0.028	m^3/min	
												volflwimp	0.995	ft^3/min	
												vinlet	899.325	m/min	
												vinlet	32.170	ft/sec	
												mdotcoal	0.00000	g/min	
									actual ash:	0.01642	g	expected ash	0.0000	g	
												%Diff ash	100.000	%	based on actu

Table H.9: Test 03019501

Date:	3/1/95	mo/day/yr	Main NG:	83.0	%	Probe strt T:	143	F											
Coal:	AG #9	source	Main Air:	48.0	%	Probe ctrl Itr	190	mm											
	Ben 1.25 g	process		31.0	psig	Comb psi p:	7	psig											
test no:	03019501	m/d/yr/num	BF1NG:	44.9	%	Coal feed	6.6	g/s	units	Imp. inj. diam		0.6625	inches						
test dur:	14.27	minutes	BF1Air:	3.8	units,ifront	Coal feed conv		g/m		Methodist inj.		4	inches						
Coal Properties:	(Ref. only)			3.8	units, back	Vacuum Rotd	72.0	%		Main Gas Rotd		0.83	fraction			mdot_CH4		23.371	g/min
			BF2NG:	20.0	%	Vacuum Rotd	9.5	in. hg		Main Air Rotd		9.49	fraction			mdot Main Air		688.199	g/min
grams	atom wt/1000	Ult. Anal.	BF2Air:	2.8	units,ifront	atomizer air:	full	units		Main Air Rotd		34	psig			zbl		1.491	units
		Carbon		2.8	units, back	atomizer air:	full	psig		Int. Air Rotd		20	%			mdot fuel		1.491	moles/min
		Hydrogen	Int. Rotd:	20	%	atomizer H2O	199	mm		Int Air Rotd		44	psig			CO2		2.921	moles/min
		Oxygen	Int. Rotd:	44	psig	exit duct T:	194	F								H2O		16.119	moles/min
		Nitrogen				over furn T:	194	F		Coal Composition on Elemental level						N2		1.383	moles/min
		Sulfur								Carbon(mandl		0.00	moles/100g			O2		82.197	g/min
		Ash								Hydrogen (mc		0.00	moles/100g			mdot air inj.		82.197	g/min
		Moisture								Oxygen (mcrl		0.00	moles/100g			O2		0.188	moles/min
		Total								Nitrogen (mcr		0.00	moles/100g			N2		0.669	moles/min
			Scale:	3						Sulfur(mcrl)		0.00	moles/100g			Dry O2 wtfrac		7.749	vol%
										Ash		0.00	g/100g			DryO2ave inj		7.209	vol%
										H2O		0.00	moles/100g			Coal Fraction		0.000	moles/100g
Stage	Initial(g)	Final(g)	Net(g)	% in size	Cum. %	Size Range	T/C	Port	Temp, C							CO2		1.491	moles/min
				range	fr. orig mat	micrometers				mdot coal		0	g/min			H2O		2.921	moles/min
Preseparator	0.32862	0.33393	0.00431	39.37	83.63	10.0 & up	B		1215	Probe inlet T		975	degC			N2		16.719	moles/min
0	0.29807	0.29935	0.00128	10.80	82.83	9.0 - 10.0	C		1195	Impactor inlet		190	degC (est. T)			SO2		0.0000	moles/min
1	0.30064	0.30164	0.00090	7.69	45.23	5.6 - 9.0	D		1172	Vacuum Rotd		9.5	in.Hg			O2		1.526	moles/min
2	0.32708	0.32800	0.00082	7.78	37.47	4.1 - 5.6	E		1149	Vacuum Rotd		83	degC (est. T)			Dry O2		7.749	vol%
3	0.33038	0.33145	0.00109	9.20	29.27	3.3 - 4.1	F		1119	Vacuum Rotd		72	CFM			H2O wt		0.082	mass fraction
4	0.32701	0.32805	0.00104	8.78	19.49	2.1 - 3.3	G		1081	coal flow time		14.27	min						
5	0.32858	0.32958	0.00097	4.81	10.71	1.1 - 2.1	H		1031							mol_wt_wet		28.011	g/mol
6	0.32690	0.32825	0.00025	2.11	5.90	0.7 - 1.1	I		975							dens @ inlet		275.838	g/m^3
7	0.32449	0.32469	0.00011	0.93	3.79	0.4 - 0.7	J		897							mdot_dscf		633.784	g/min
Backup Filter	0.33127	0.33265	0.00138	11.65	11.65	0.00 - 0.4	K		837							ydscf		71.447	meters/min
																ydscf		3.907	l/sec
		total mass:	0.01185							dens@STP		1202.19	g/m^3			dens@imp		916.197	g/m^3
																mol_wt_dry		28.499	g/mol
																dens @ stp		892.087	g/m^3
																volfl/min stp		0.928	m^3/min
Notes:																volfl/min stp		0.897	ft^3/min
																mdot/min		23.388	g/min
																mdot/mw		28.612	g/min
																volfl/min		0.928	m^3/min
																volfl/min		0.884	ft^3/min
																vl/dscf		581.787	m/min
																vl/dscf		31.811	l/sec
																mdot/coal		0.00000	g/min
										actual ash:		0.01185	g			expected ash		0.00000	g
																%act ash		100.000	%

Table H.10: Test 03029501

Date:	3/2/95	mo/day/yr	Main NG:	92.6	%	Probe cint T:	142	F							
Coal:	AC 810	source	Main Air:	47.5	%	Probe cint thr:	180	mm							
	Ben 2.50 g	process		33.0	psig	Comp prg p:	7	psig							
test no:	03029501	m/d/ynum	BF1NG:	44.0	%	Coal feed:	5@90%	units	Imp inlt diam	0.5625	inches				
test dur:		minutes	BF1Air:	3.8	units,front	Coal feed conv		g/m	Mainduct rad	4	inches				
Coal Properties:	(Ref. only)			3.8	units, back	Vacuum Rota	73.9	%	Main Gas Rota	0.825	fraction	mdot CH4	23.230	g/min	
			BF2NG:	20.0	%	Vacuum Rota	9.6	in hg	Main Air Rota	0.475	fraction	mdot Main Air	576.062	g/min	
grams	etomwt/100g	Ult. Ana.	BF2Air:	2.8	units,front	atomizer air:	full	units	Main Air Rota	33	psig	phi	1.446	units	
		Carbon		2.8	units, back	atomizer air:	full	psig	Inj Air Rota	20	%	mole fract	1.452		
		Hydrogen	Inj. Rota:	20	%	atomizer H2O	198	mm	Inj Air Rota	44	psig	CO2	1.452	moles/min	CH4&Air only
		Oxygen	Inj. Rota:	44	psig	exit duct T:	103	F				H2O	2.904	moles/min	CH4&Air only
		Nitrogen				over furn T:	102	F	Coal Composition on Elemental level			N2	16.778	moles/min	CH4&Air only
		Sulfur							Carbon(monet	0.00	moles/100g	O2	1.293	moles/min	CH4&Air only
		Ash							Hydrogen (mo	0.00	moles/100g	mdot air inj	22.197	g/min	
		Moisture							Oxygen (mon)	0.00	moles/100g	O2	0.192	moles/min	Inj Air only
		Total							Nitrogen (mor	0.00	moles/100g	N2	0.606	moles/min	Inj Air only
			Scale:	1					Sulfur(mon)	0.00	moles/100g	Dry O2 w/inj	7.538	vol%	tot w/o coal
									Ash	0.00	g/100g	DryO2w/o inj	9.978	vol%	t w/o coal&Inj
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % lt. size rnge	Size Range micrometers	T/C Port	Temp, C.	H2O	0.00	moles/100g	Coal Fraction	0.000	mdotcoal/100g	
												CO2	1.452	moles/min	total
									mdot coal	0	g/min	H2O	2.904	moles/min	total
Preseparator	0.32891	0.33344	0.00353	32.93	67.07	10.0 & up	B	1214	Probe inlet T	967	degC	N2	16.388	moles/min	total
0	0.29880	0.29880	0.00090	8.40	58.68	9.0 -10.0	C	1190	Impactor inlet	100	degC (est. T)	SO2	0.0000	moles/min	total
1	0.29692	0.29789	0.00097	9.05	49.63	5.8 - 9.0	D	1167	Vacuum Rota	9.6	in Hg	O2	1.454	moles/min	total
2	0.33570	0.33646	0.00076	7.09	42.54	4.7 - 5.8	E	1147	Vacuum Rota	23	degC (est. T)	Dry O2	7.538	vol%	total
3	0.32864	0.32998	0.00132	12.31	30.22	3.3 - 4.7	F	1109	Vacuum Rota	73	CFH	H2O wt	0.094	mass fraction	
4	0.32847	0.32973	0.00126	11.75	18.47	2.1 - 3.3	G	1079	coal flow time	0	min				
5	0.32893	0.32964	0.00071	6.62	11.85	1.1 - 2.1	H	1020				mol wt wet	28.000	g/mol	
6	0.32783	0.32805	0.00022	2.05	9.79	0.7 - 1.1	I	967				dens@inlet	275.189	g/m^3	
7	0.32879	0.32888	0.00009	0.84	8.95	0.4 - 0.7	J	893				mdot duct	921.489	g/min	minus ash
Backup Filter	0.33137	0.33233	0.00096	8.96	0.00	0 -0.4	K	820				vduct	99.641	meters/min	
												vduct	3.608	ft/sec	
		total mass:	0.01072						dens@STP	1202.10	g/m^3	dens@imp	914.839	g/m^3	
												mol wt dry	29.506	g/mol	
												dens@rota	929.337	g/m^3	
												volflwrateroto	0.029	m^3/min	
Notes:												volflwrateroto	1.011	ft^3/min	
												mdotroto	23.793	g/min	
												mdotimp	25.912	g/min	
												volflwimp	0.028	m^3/min	
												volflwimp	1.000	ft^3/min	
												vinlet	597.305	m/min	
												vinlet	32.114	ft/sec	
												mdotcoal	0.00000	g/min	
									actual ash:	0.01072	g	expected ash	0.0000	g	
												%Diff ash	100.000	%	based on actu

Table H.11: Test 03039501

Date:	3/3/95	mo/day/yr	Main NG:	83.0	%	Probe clnt T:	142	F							
Coal:	AC #11	source	Main Air:	47.5	%	Prbe clnt flw:	160	mm							
	Ben 3.75 g	process		33.5	psig	Comb prg p:	7	psig							
test no:	03039501	m/d/ynum	BF1NG:	44.0	%	Coal feed:	5@90%	units	Imp inlt diam	0.6625	inches				
test dur:	9.40	minutes	BF1Air:	3.9	units,front	Coal feed conv		g/m	Mainduct rad	4	inches				
Coal Properties: (Ref. only)				3.8	units, back	Vacuum Roto	73.0	%	Main Gas Roto	0.83	fraction	mdot CH4	23.371	g/min	
			BF2NG:	20.0	%	Vacuum Roto	9.5	in hg	Main Air Roto	0.475	fraction	mdot Main Air	570.073	g/min	
grams	atomwt/100g	Ult. Ana.	BF2Air:	2.8	units,front	atomizer air:	full	units	Main Air Roto	33.5	psig	phi	1.444	units	
		Carbon		2.7	units, back	atomizer air:	full	psig	Inj Air Roto	20	%	mole fract	1.481		
		Hydrogen	Inj. Roto:	20	%	atomizer H2O	195	mm	Inj Air Roto	44	psig	CO2	1.481	moles/min	CH4&Air only
		Oxygen	Inj. Roto:	44	psig	exit duct T:	102	F				H20	2.921	moles/min	CH4&Air only
		Nitrogen				over furn T:	98	F	Coal Composition on Elemental level			N2	15.660	moles/min	CH4&Air only
		Sulfur							Carbon(monat	0.00	moles/100g	O2	1.297	moles/min	CH4&Air only
		Ash							Hydrogen (mo	0.00	moles/100g	mdot air inj	22.197	g/min	
		Moisture							Oxygen (mon	0.00	moles/100g	O2	0.192	moles/min	Inj Air only
		Total							Nitrogen (mon	0.00	moles/100g	N2	0.608	moles/min	Inj Air only
			Scale:	1					Sulfur(mon)	0.00	moles/100g	Dry O2 w/inj	7.623	vol%	tot w/o coal
									Ash	0.00	g/100g	DryO2w/o inj	6.956	vol%	t w/o coal&inj
Stage	(initial(g)	Final(g)	Net(g)	% in size range	Cum. % lt. size mge	Size Range micrometers	T/C Port	Temp, C.	H2O	0.00	moles/100g	Coal Fraction	0.000	mdotcoal/100g	
												CO2	1.481	moles/min	total
									mdot coal	0	g/min	H20	2.921	moles/min	total
Presepertor	0.33061	0.33545	0.00484	36.31	63.69	10.0 & up	B	1210	Probe Inlet T	967	degC	N2	15.468	moles/min	total
0	0.29824	0.29943	0.00119	8.93	54.76	9.0 -10.0	C	1189	Impactor Inlet	100	degC (est. T)	SO2	0.0000	moles/min	total
1	0.29826	0.29935	0.00109	8.18	46.59	5.0 - 9.0	D	1169	Vacuum Roto	9.5	in Hg	O2	1.459	moles/min	total
2	0.33066	0.33172	0.00106	7.95	38.63	4.7 - 5.0	E	1144	Vacuum Roto	23	degC (est. T)	Dry O2	7.623	vol%	total
3	0.33204	0.33382	0.00178	13.35	25.28	3.3 - 4.7	F	1107	Vacuum Roto	73	CFH	H20 wt	0.084	mass fraction	
4	0.32752	0.32931	0.00179	13.43	11.85	2.1 - 3.3	G	1073	coal flow time	9.4	min				
5	0.33046	0.33123	0.00077	5.78	6.08	1.1 - 2.1	H	1019				mol wt wet	28.000	g/mol	
6	0.32843	0.32867	0.00024	1.80	4.28	0.7 - 1.1	I	967				dens@inlet	276.182	g/m^3	
7	0.32708	0.32718	0.00010	0.75	3.53	0.4 - 0.7	J	879				mdot duct	624.641	g/min	minus ash
Backup Filter	0.33037	0.33084	0.00047	3.53	0.00	0 -0.4	K	817				vduct	89.996	meters/min	
												vduct	3.827	ft/sec	
		total mass	0.01333						dens@STP	1202.10	g/m^3	dens@imp	914.813	g/m^3	
												mol wt dry	28.509	g/mol	
												dens@roto	829.368	g/m^3	
												volflwrotoroto	0.028	m^3/min	
Notes:												volflwrotoroto	1.011	ft^3/min	
												mdotroto	23.734	g/min	
												mdotimp	25.915	g/min	
												volflwimp	0.028	m^3/min	
												volflwimp	1.000	ft^3/min	
												vinlet	597.397	m/min	
												vinlet	32.119	ft/sec	
												mdotcoal	0.00000	g/min	
									actual ash	0.01333	g	expected ash	0.0000	g	
												%Diff ash	100.000	%	based on actu

Table H.12: Test 03039502

Date:	3/3/95	mo/day/yr	Main NG:	93.0	%	Probe clnt T:	140	F								
Coal:	AC #5	source	Main Air:	47.5	%	Probe clnt flw:	160	mm								
	Pyr 1.95 g	process		33.5	psig	Comb prg p:	7	psig								
test no:	03039502	m/d/ynum	BF1NG:	44.0	%	Coal feed:	5@80%	units	inj inlt diam	0.5625	inches					
test dur:	15.00	minutes	BF1Air:	3.8	units,front	Coal feed conv		g/m	Mainduct red	4	inches					
Coal Properties: (Rat. only)				3.8	units, back	Vacuum Rota	72.0	%	Main Gas Rota	0.83	fraction	mdot CH4	23.371	g/min		
			BF2NG:	20.0	%	Vacuum Rota	9.5	in hg	Main Air Rota	0.475	fraction	mdot Main Air	579.079	g/min		
grams	atomwt/100g	Ult. Ana	BF2Air:	2.8	units,front	atomizer air:	full	units	Main Air Rota	33.5	psig	phi	1.444	units		
		Carbon		2.8	units, back	atomizer air:	full	psig	Inj Air Rota	20	%	mole fract	1.461			
		Hydrogen	Inj Rota:	20	%	atomizer H2O	195	mm	Inj Air Rota	44	psig	O2	1.461	moles/min	CH4&Air only	
		Oxygen	Inj Rota:	44	psig	exit duct T:	107	F				H20	2.921	moles/min	CH4&Air only	
		Nitrogen				over furn T:	110	F	Coal Composition on Elemental level			N2	15.880	moles/min	CH4&Air only	
		Sulfur							Carbon(monat	0.00	moles/100g	O2	1.297	moles/min	CH4&Air only	
		Ash							Hydrogen (mo	0.00	moles/100g	mdot air inj	22.197	g/min		
		Moisture							Oxygen (mon	0.00	moles/100g	O2	0.182	moles/min	Inj Air only	
		Total							Nitrogen (mor	0.00	moles/100g	N2	0.608	moles/min	Inj Air only	
			Scale:	1					Sulfur(mon)	0.00	moles/100g	Dry O2 w/inj	7.523	vol%	tot w/o coal	
									Ash	0.00	g/100g	DryO2w/o inj	6.966	vol%	t w/o coal&in	
Stage	Initial(g)	Final(g)	Net(g)	% in size	Cum. %	Size Range	T/C Port	Temp, C	H2O	0.00	moles/100g	Coal Fraction	0.000	mdotcoal/100g		
				range	ft. size rnge	micrometers						CO2	1.461	moles/min	total	
									mdot coal	0	g/min	H20	2.921	moles/min	total	
Presepersior	0.32530	0.32690	0.00160	31.25	68.75	10.0 & up	B	1210	Probe inlet T	965	degC	N2	16.468	moles/min	total	
0	0.29776	0.29814	0.00038	7.42	61.33	9.0 -10.0	C	1190	Impactor inlet	100	degC (est. T)	SO2	0.0000	moles/min	total	
1	0.29939	0.29977	0.00038	7.42	53.91	5.8 - 9.0	D	1184	Vacuum Rota	9.5	in Hg	O2	1.459	moles/min	total	
2	0.32924	0.32957	0.00033	6.45	47.46	4.7 - 5.8	E	1142	Vacuum Rota	23	degC (est. T)	Dry O2	7.523	vol%	total	
3	0.32673	0.32722	0.00049	9.57	37.89	3.3 - 4.7	F	1106	Vacuum Rota	72	CFH	H20 wt	0.084	mass fraction		
4	0.32952	0.33010	0.00058	11.33	26.56	2.1 - 3.3	G	1070	coal flow time	15	min					
5	0.32890	0.32927	0.00037	7.23	19.34	1.1 - 2.1	H	1019				mol wt wet	28.000	g/mol		
6	0.32724	0.32733	0.00009	1.76	17.58	0.7 - 1.1	I	965				dens@inlet	275.626	g/m^3		
7	0.32810	0.32814	0.00004	0.78	16.80	0.4 - 0.7	J	892				mdot duct	924.041	g/min	minus ash	
Backup Filter	0.32802	0.32898	0.00096	16.80	0.00	0 -0.4	K	819				vduct	99.883	meters/min		
												vduct	3.821	ft/sec		
		total mass:	0.00512						dens@STP	1202.19	g/m^3	dens@inp	914.813	g/m^3		
												mol wt dry	29.606	g/mol		
												dens@rota	929.358	g/m^3		
Notes:												volflw/stdrota	0.028	m^3/min		
												volflw/stdrota	0.997	ft^3/min		
												mdotrota	23.408	g/min		
												mdotinp	25.560	g/min		
												volflwinp	0.028	m^3/min		
												volflwinp	0.997	ft^3/min		
												vinlet	579.416	m/min		
												vinlet	31.928	ft/sec		
												mdotcoal	0.00000	g/min		
									actual ash:	0.00512	g	expected ash	0.0000	g		
												%Diff ash	100.000	%	based on actu	

Table H.13: Test 03069501

Date:	3/6/95	mo/day/yr	Main NG:	83.0	%	Probe clnt T:	145	F							
Coal:	AC #6	source	Main Air:	47.7	%	Probe clnt flw:	160	mm							
	Pyr 2.76 g	process		34.0	psig	Comb prg p:	7	psig							
test no:	03069501	m/d/ynum	BF1NG:	44.0	%	Coal feed:	5@90%	units	Imp Init diam	0.5625	inches				
test dur:	13.29	minutes	BF1Air:	3.6	units,front	Coal feed conv		g/m	Mainduct red	4	inches				
Coal Properties:	(Ref. only)			3.7	units, back	Vacuum Rota	72.0	%	Main Gas Rota	0.83	fraction	mdot CH4	23.371	g/min	
			BF2NG:	20.0	%	Vacuum Rota	9.5	in hg	Main Air Rota	0.477	fraction	mdot Main Air	594.520	g/min	
grams	atomwt/100g	Ult. Ana.	BF2Air:	2.7	units,front	atomizer air:	Full	units	Main Air Rota	34	psig	phi	1.459	units	
		Carbon		2.6	units, back	atomizer air:	Full	psig	Inj Air Rota	20	%	mole fract.	1.491		
		Hydrogen	Inj. Rota:	20	%	atomizer H2O	180	mm	Inj Air Rota	44	psig	CO2	1.491	moles/min	CH4&Air only
		Oxygen	Inj. Rota:	44	psig	exit duct T:	102	F				H2O	2.921	moles/min	CH4&Air only
		Nitrogen				over turn T:	92	F	Coal Composition on Elemental level			N2	16.010	moles/min	CH4&Air only
		Sulfur							Carbon(monet	0.00	moles/100g	O2	1.337	moles/min	CH4&Air only
		Ash							Hydrogen (mo	0.00	moles/100g	mdot air inj	22.197	g/min	
		Moisture							Oxygen (mon)	0.00	moles/100g	O2	0.182	moles/min	Inj Air only
		Total							Nitrogen (mor	0.00	moles/100g	N2	0.608	moles/min	Inj Air only
			Scale:	3					Sulfur(mon)	0.00	moles/100g	Dry O2 w/inj	7.653	vol%	tot w/o coal
									Ash	0.00	g/100g	DryO2w/o inj	7.197	vol%	t.w/o coal&inj
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % lt. size mge	Size Range micrometers	T/C Port	Temp, C	H2O	0.00	moles/100g	Coal Fraction	0.000	mdotcoal/100g	
												CO2	1.491	moles/min	total
									mdot coal	0	g/min	H2O	2.921	moles/min	total
Presseparator	0.33090	0.33495	0.00405	36.23	63.77	10.0 & up	B	1216	Probe inlet T	988	degC	N2	16.018	moles/min	total
0	0.29741	0.29856	0.00115	10.29	53.49	9.0 - 10.0	C	1195	Impactor inlet	100	degC (est. T)	SO2	0.0000	moles/min	total
1	0.29695	0.29785	0.00089	7.96	45.53	6.8 - 9.0	D	1172	Vacuum Rota	9.5	in Hg	O2	1.498	moles/min	total
2	0.32864	0.32942	0.00078	6.98	38.55	4.7 - 6.8	E	1147	Vacuum Rota	23	degC (est. T)	Dry O2	7.653	vol%	total
3	0.32821	0.32930	0.00109	9.75	28.80	3.3 - 4.7	F	1109	Vacuum Rota	72	CFH	H20 wt	0.093	mass fraction	
4	0.32685	0.32795	0.00110	9.84	18.96	2.1 - 3.3	G	1074	coal flow time	13.29	min				
5	0.32744	0.32806	0.00062	5.55	13.42	1.1 - 2.1	H	1029				mol wt wet	28.007	g/mol	
6	0.32620	0.32642	0.00022	1.97	11.45	0.7 - 1.1	I	988				dens@inlet	275.029	g/m^3	
7	0.32654	0.32662	0.00008	0.72	10.73	0.4 - 0.7	J	873				mdot duct	630.088	g/min	minus ash
Backup Filter	0.33184	0.33304	0.00120	10.73	0.00	0 -0.4	K	810				vduct	70.946	meters/min	
												vduct	3.863	ft/sec	
		total mass:	0.01118						dens@STP	1202.10	g/m^3	dens@imp	916.043	g/m^3	
												mol wt dry	28.699	g/mol	
												dens@rota	929.177	g/m^3	
Notes:												volflw/stdrota	0.026	m^3/min	
												volflw/stdrota	0.997	ft^3/min	
												mdotrota	23.491	g/min	
												mdotimp	25.531	g/min	
												volflwimp	0.026	m^3/min	
												volflwimp	0.985	ft^3/min	
												vinlet	579.022	m/min	
												vinlet	31.691	ft/sec	
												mdotcoal	0.00000	g/min	
									actual ash:	0.01118	g	expected ash	0.0000	g	
												%Diff ash	100.000	%	based on actu

Table H.14: Test 03069502

Date:	3/6/95	mo/day/yr	Main NG:	83.0	%	Probe clnt T:	145	F								
Coal:	AC #17	source	Main Air:	47.7	%	Prbe clnt thr:	150	mm								
	Cal 1.00 g	process		34.0	psig	Comb prg p:	7	psig								
test no:	03069502	m/d/ynum	BF1NG:	44.0	%	Coal feed:	5@90%	units	Imp Inlt diam	0.5625	inches					
test dur:	13.28	minutes	BF1Air:	3.8	units,front	Coal feed conv		g/m	Mainduct rad	4	inches					
Coal Properties: (Rel. only)				3.8	units, back	Vacuum Rota	72.0	%	Main Gas Rota	0.83	fraction	mdot CH4	23.371	g/min		
			BF2NG:	20.0	%	Vacuum Rota	9.5	in hg	Main Air Rota	0.477	fraction	mdot Main Air	584.620	g/min		
grams	atomwt/100g	Ult. Anal.	BF2Air:	2.8	units,front	atomizer air:	full	units	Main Air Rota	34	psig	phi	1.468	units		
		Carbon		2.7	units, back	atomizer air:	full	psig	Inj. Air Rota	29	%	mole fract.	1.461			
		Hydrogen	Inj. Rota:	20	%	atomizer H2O	190	mm	Inj Air Rota	44	psig	CO2	1.461	moles/min	CH4&Air only	
		Oxygen	Inj. Rota:	44	psig	exit duct T:	104	F				H20	2.921	moles/min	CH4&Air only	
		Nitrogen				over furn T:	95	F	Coal Composition on Elemental level			N2	18.019	moles/min	CH4&Air only	
		Sulfur							Carbon(monat	0.00	moles/100g	O2	1.327	moles/min	CH4&Air only	
		Ash							Hydrogen (mo	0.00	moles/100g	mdot air inj	22.197	g/min		
		Moisture							Oxygen (mon	0.00	moles/100g	O2	0.162	moles/min	Inj Air only	
		Total							Nitrogen (mor	0.00	moles/100g	N2	0.608	moles/min	Inj Air only	
			Scale:	1					Sulfur(mon)	0.00	moles/100g	Dry O2 w/inj	7.653	vol%	tot w/o coal	
									Ash	0.00	g/100g	DryO2w/o inj	7.107	vol%	(t.w/o coal&inj	
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % R. size max	Size Range micrometers	T/C Port	Temp, C.	H2O	0.00	moles/100g	Coal Fraction	0.000	mdotcoal/100g		
												CO2	1.461	moles/min	total	
									mdot coal	0	g/min	H20	2.921	moles/min	total	
Presseparator	0.32755	0.32990	0.00235	44.59	55.41	10.0 & up	B	1217	Probe Inlet T	970	degC	N2	18.019	moles/min	total	
0	0.29773	0.29823	0.00050	9.49	45.92	9.0 -10.0	C	1196	Impactor Inlet	100	degC (est. T)	SO2	0.0000	moles/min	total	
1	0.29773	0.29810	0.00037	7.02	38.90	5.0 - 9.0	D	1171	Vacuum Rota	9.5	in Hg	O2	1.488	moles/min	total	
2	0.32843	0.32865	0.00022	4.17	34.72	4.7 - 5.0	E	1147	Vacuum Rota	23	degC (est. T)	Dry O2	7.653	vol%	total	
3	0.32720	0.32740	0.00020	3.80	30.93	3.3 - 4.7	F	1109	Vacuum Rota	72	CFH	H20 wt	0.083	mass fraction		
4	0.32675	0.32708	0.00033	6.26	24.67	2.1 - 3.3	G	1073	coal flow time	13.28	min					
5	0.32779	0.32802	0.00023	4.36	20.30	1.1 - 2.1	H	1019				mol wt wet	28.007	g/mol		
6	0.32614	0.32620	0.00006	1.14	19.17	0.7 - 1.1	I	970				dens@inlet	274.587	g/m^3		
7	0.32807	0.32868	0.00061	0.19	18.98	0.4 - 0.7	J	877				mdot duct	630.088	g/min	minus ash	
Backup Filter	0.33094	0.33194	0.00100	18.98	0.00	0 :0.4	K	812				vduct	70.760	meters/min		
												vduct	3.869	ft/sec		
		total mass:	0.00527						dens@STP	1202.10	g/m^3	dens@imp	915.043	g/m^3		
												mol wt dry	29.600	g/mol		
												dens@rota	829.177	g/m^3		
												volflwrateroto	0.028	m^3/min		
Notes:												volflwrateroto	0.997	ft^3/min		
												mdotroto	23.401	g/min		
												mdotimp	25.631	g/min		
												volflwimp	0.028	m^3/min		
												volflwimp	0.995	ft^3/min		
												vinlet	979.959	m/min		
												vinlet	31.712	ft/sec		
												mdotcoal	0.00000	g/min		
									actual ash:	0.00527	g	expected ash	0.0000	g		
												%Diff ash	100.000	%	based on actu	

Table H.15: Test 03079501

Date:	9/7/95	mo/day/yr	Main NG:	63.0	%	Probe cint T:	149	F							
Coal:	AC #16	source	Main Air:	47.6	%	Probe cint thk:	160	mm							
	Cal 0.75 g	process		34.0	psig	Comb prg p:	7	psig							
test no:	03079501	m/d/ynum	BF1NG:	44.0	%	Coal feed:	5@90%	units	Imp init diam	0.5625	inches				
test dur:	14.10	minutes	BF1Air:	3.8	units,front	Coal feed conv		g/m	Mainduct rad	4	inches				
Coal Properties: (Ref. only)				3.7	units, back	Vacuum Rota	72.0	%	Main Gas Rota	0.83	fraction	mdot CH4	23.371	g/min	
			BF2NG:	20.0	%	Vacuum Rota	9.5	in hg	Main Air Rota	0.478	fraction	mdot Main Air	595.745	g/min	
grams	atomwt/100g	Ult. Ana	BF2Air:	2.8	units,front	atomizer air:	Full	units	Main Air Rota	34	psig	phi	1.491	units	
		Carbon		2.7	units, back	atomizer air:	full	psig	Inj Air Rota	20	%	mole fract	1.491		
		Hydrogen	Inj. Rota:	20	%	atomizer H2O	192	mm	Inj Air Rota	44	psig	CO2	1.491	moles/min	CH4&Air only
		Oxygen	Inj. Rota:	44	psig	exit duct T:	103	F				H2O	2.921	moles/min	CH4&Air only
		Nitrogen				over furn T:	95	F	Coal Composition on Element		al level	N2	16.043	moles/min	CH4&Air only
		Sulfur							Carbon(mons	0.00	moles/100g	O2	1.345	moles/min	CH4&Air only
		Ash							Hydrogen (mo	0.00	moles/100g	mdot air inj	22.197	g/min	
		Moisture							Oxygen (mon	0.00	moles/100g	O2	0.192	moles/min	Inj Air only
		Total							Nitrogen (mon	0.00	moles/100g	N2	0.608	moles/min	Inj Air only
			Scale:	1					Sulfur(mon)	0.00	moles/100g	Dry O2 w/inj	7.682	vol%	tot w/o coal
									Ash	0.00	g/100g	DryO2w/o inj	7.138	vol%	tl w/o coal&inj
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % R. size mge	Size Range micrometers	T/C Port	Temp, C	H2O	0.00	moles/100g	Coal Fraction	0.000	mdot(coal/100g	
												CO2	1.491	moles/min	total
									mdot coal	0	g/min	H2O	2.921	moles/min	total
Presepersior	0.32620	0.32814	0.00194	42.17	57.83	10.0 & up	B	1217	Probe inlet T	970	degC	N2	16.651	moles/min	total
0	0.29749	0.29794	0.00045	9.78	48.04	9.0 -10.0	C	1193	Inspector inlet	109	degC (est. T)	SO2	0.0000	moles/min	total
1	0.29869	0.29889	0.00020	4.35	43.70	5.8 - 9.0	D	1172	Vacuum Rota	9.5	in Hg	O2	1.507	moles/min	total
2	0.32597	0.32619	0.00022	4.78	38.91	4.7 - 5.8	E	1145	Vacuum Rota	23	degC (est. T)	Dry O2	7.682	vol%	total
3	0.32585	0.32604	0.00019	4.13	34.78	3.3 - 4.7	F	1111	Vacuum Rota	72	CFH	H2O wt	0.083	mass fraction	
4	0.33069	0.33108	0.00019	4.13	30.65	2.1 - 3.3	G	1074	coal flow time	14.1	min				
5	0.32691	0.32620	0.00025	5.43	25.23	1.1 - 2.1	H	1021				mol wt wet	29.008	g/mol	
6	0.33171	0.33178	0.00005	1.09	24.13	0.7 - 1.1	I	970				dens@inlet	274.602	g/m^3	
7	0.32761	0.32766	0.00005	1.09	23.04	0.4 - 0.7	J	875				mdot duct	631.313	g/min	minus ash
Backup Filter	0.33192	0.33288	0.00106	23.04	0.00	0 -0.4	K	809				vduct	70.893	meters/min	
												vduct	3.876	ft/sec	
		total mass:	0.00460						dens@STP	1202.10	g/m^3	dens@imp	916.095	g/m^3	
												mol wt dry	29.499	g/mol	
												dens@rota	828.137	g/m^3	
												volflwrotcrota	0.028	m^3/min	
												volflwrotcrota	0.997	ft^3/min	
Notes:															
												mdotrota	23.399	g/min	
												mdotimp	25.525	g/min	
												volflwimp	0.028	m^3/min	
												volflwimp	0.986	ft^3/min	
												vinlet	579.776	m/min	
												vinlet	31.703	ft/sec	
												mdotcoal	0.00000	g/min	
									actual ash:	0.0046	g	expected ash	0.0000	g	
												%Diff ash	100.000	%	based on actu

Table H.16: Test 03079502

Date:	3/7/95	mo/day/yr	Main NG:	63.0	%	Probe cint T:	141	F							
Coal:	AC 615	source	Main Air:	47.6	%	Probe cint thr:	160	mm							
	Cal 0.50 g	process		34.0	psig	Comb prg p:	7	psig							
test no:	03079502	m/d/ynum	BF1NG:	44.0	%	Coal feed:	5@90%	units	Imp init diam	0.5625	inches				
test dur:	13.79	minutes	BF1Air:	3.8	units,front	Coal feed conv		g/m	Mainduct red	4	inches				
Coal Properties:	(Rel. only)			3.7	units, back	Vacuum Rotq	72.0	%	Main Gas Rotq	0.83	fraction	mdot CH4	23.371	g/min	
			BF2NG:	20.0	%	Vacuum Rotq	9.5	in hg	Main Air Rotq	0.476	fraction	mdot Main Air	583.294	g/min	
grams	atomwt/100g	Ult. Ana.	BF2Air:	2.8	units,front	atomizer air:	full	units	Main Air Rotq	34	psig	phi	1.454	units	
		Carbon		2.7	units, back	atomizer air:	full	psig	Inl. Air Rotq	20	%	mole fract.	1.481		
		Hydrogen	Inl. Rotq:	20	%	atomizer H2O	185	mm	Inl Air Rotq	44	psig	CO2	1.481	moles/min	CH4&Air only
		Oxygen	Inl. Rotq:	44	psig	exit duct T:	105	F				H20	2.921	moles/min	CH4&Air only
		Nitrogen				over furn T:	97	F	Coal Composition on Elemental level			N2	16.976	moles/min	CH4&Air only
		Sulfur							Carbon(monat	0.00	moles/100g	O2	1.328	moles/min	CH4&Air only
		Ash							Hydrogen (mo	0.00	moles/100g	mdot air inl	22.197	g/min	
		Moisture							Oxygen (mon	0.00	moles/100g	O2	0.192	moles/min	Inl Air only
		Total							Nitrogen (mor	0.00	moles/100g	N2	0.509	moles/min	Inl Air only
			Scale	2					Sulfur(mon)	0.00	moles/100g	Dry O2 w/inl	7.624	vol%	tot w/o coal
									Ash	0.00	g/100g	DryO2w/o inl	7.975	vol%	t w/p coal&inl
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % fl. size mpe	Size Range micrometers	T/C Port	Temp, C.	H2O	0.00	moles/100g	Coal Fraction	0.000	mdotcoal/100g	
												CO2	1.481	moles/min	total
									mdot coal	0	g/min	H20	2.921	moles/min	total
Preseperator	0.32739	0.32900	0.00162	40.00	60.00	10.0 & up	B	1216	Probe inlet T	997	degC	N2	16.684	moles/min	total
0	0.29905	0.29933	0.00028	6.91	53.09	9.0 -10.0	C	1193	Impactor inlet	100	degC (est. T)	SO2	0.0000	moles/min	total
1	0.29864	0.29879	0.00015	3.70	49.39	5.8 - 9.0	D	1166	Vacuum Rotq	9.5	in Hg	O2	1.489	moles/min	total
2	0.32761	0.32788	0.00016	3.70	45.68	4.7 - 5.8	E	1144	Vacuum Rotq	23	degC (est. T)	Dry O2	7.624	vol%	total
3	0.33579	0.33590	0.00011	2.72	42.96	3.3 - 4.7	F	1107	Vacuum Rotq	72	CFH	H20 wt	0.064	mass fraction	
4	0.32621	0.32644	0.00023	5.68	37.28	2.1 - 3.3	G	1074	coal flow time	13.79	min				
5	0.32422	0.32444	0.00022	5.43	31.85	1.1 - 2.1	H	1022				mol wt wet	28.905	g/mol	
6	0.32811	0.32817	0.00006	1.48	30.37	0.7 - 1.1	I	997				dens@inlet	275.235	g/m^3	
7	0.32720	0.32729	0.00009	2.22	28.15	0.4 - 0.7	J	956				mdot duct	928.862	g/min	minus ash
Backup Filter	0.33315	0.33429	0.00114	28.15	0.00	0 -0.4	K	815				vduct	70.455	meter/min	
												vduct	3.853	ft/sec	
		total mass	0.00405						dens@STP	1202.19	g/m^3	dens@imp	914.992	g/m^3	
												mol wt dry	29.601	g/mol	
												dens@roto	929.218	g/m^3	
												volflwrateroto	0.028	m^3/min	
												volflwrateroto	0.997	ft^3/min	
Notes:															
	One big particle in preseperator - JP														
	Aluminum foil in stage 3 was off-center. Missing 12 spots. Not Negligible... need to calculate over circle. JP											mdotroto	23.402	g/min	
												mdotimp	25.536	g/min	
												volflwimp	0.028	m^3/min	
												volflwimp	0.986	ft^3/min	
												vinlet	979.793	m/min	
												vinlet	31.646	ft/sec	
												mdotcoal	0.00000	g/min	
									actual ash:	0.00405	g	expected ash	0.0000	g	
												%Diff ash	100.000	%	based on actu

Table H.17: Test 03129501

Date:	3/12/95	mo/day/yr	Main NG:	93.0	%	Probe clnt T:	141	F							
Coal:	AC #14	source	Main Air:	48.2	%	Probe clnt flw:	160	mm							
	Cal 0.25 g	process		23.0	psig	Comb prg p:	7	psig							
test no:	03129501	m/d/yrnum	BF1NG:	44.0	%	Coal feed:	5@90%	units	Imp inlt diam	0.5625	inches				
test dur:	14.20	minutes	BF1Air:	3.8	units,(rot)	Coal feed conv		g/m	Mainduct rad	4	inches				
Coal Properties:	(Rel. only)			3.7	units, back	Vacuum Rota	73.0	%	Main Gas Rota	0.83	fraction	mdot CH4	23.371	g/min	
			BF2NG:	20.0	%	Vacuum Rota	9.5	in hg	Main Air Rota	0.482	fraction	mdot Main Air	594.551	g/min	
grams	atomwt/100g	Ult. Ana.	BF2Air:	2.7	units,(rot)	atomizer air:	full	units	Main Air Rota	33	psig	phi	1.458	units	
		Carbon		2.6	units, back	atomizer air:	full	psig	Int. Air Rota	20	%	mole fract	1.461		
		Hydrogen	Int. Rota:	20	%	atomizer H2O	193	mm	Int Air Rota	44	psig	O2	1.461	moles/min	CH4&Air only
		Oxygen	Int. Rota:	44	psig	exit duct T:	110	F				H20	2.921	moles/min	CH4&Air only
		Nitrogen				over turn T:	131	F				N2	16.010	moles/min	CH4&Air only
		Sulfur							Coal Composition on Elemental level			O2	1.337	moles/min	CH4&Air only
		Ash							Carbon(moist	0.00	moles/100g	mdot air in	22.197	g/min	
		Moisture							Hydrogen (mo	0.00	moles/100g	O2	0.182	moles/min	Int Air only
		Total							Oxygen (moi	0.00	moles/100g	N2	0.609	moles/min	Int Air only
			Scale:	1.5					Nitrogen (moi	0.00	moles/100g	Dry O2 w/int	7.654	vol%	tot w/o coal
									Sulfur(moi)	0.00	moles/100g	DryO2w/o int	7.107	vol%	t w/o coal&int
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % B. size incl	Size Range micrometers	T/C Port	Temp, C	Ash	0.00	g/100g	Coal Fraction	0.000	mdotcoal/100g	
									H2O	0.00	moles/100g	CO2	1.461	moles/min	total
Preseperator	0.32861	0.33022	0.00361	69.28	40.72	10.0 & up	B					H20	2.921	moles/min	total
0	0.29782	0.29805	0.00043	7.06	33.66	9.0 -10.0	C		mdot coal	0	g/min	N2	16.618	moles/min	total
1	0.29979	0.30004	0.00025	4.11	29.56	5.8 - 9.0	D		Probe Inlet T	0	degC	SO2	0.0000	moles/min	total
2	0.31590	0.31600	0.00020	3.28	26.27	4.7 - 5.8	E		Impactor Inlet	100	degC (est. T)	O2	1.498	moles/min	total
3	0.32528	0.32540	0.00012	1.97	24.30	3.3 - 4.7	F		Vacuum Rota	9.5	in Hg	Dry O2	7.654	vol%	total
4	0.32722	0.32741	0.00019	3.12	21.18	2.1 - 3.3	G		Vacuum Rota	23	degC (est. T)	H20 wt	0.093	mass fraction	
5	0.32803	0.32820	0.00017	2.79	18.39	1.1 - 2.1	H		Vacuum Rota	73	CFH				
6	0.32653	0.32660	0.00007	1.15	17.24	0.7 - 1.1	I		coal flow time	14.2	min	mol wt wet	28.007	g/mol	
7	0.32658	0.32665	0.00007	1.15	16.09	0.4 - 0.7	J					dens@inlet	1250.226	g/m^3	
Backup Filter	0.33328	0.33424	0.00096	16.09	0.00	0 -0.4	K					mdot duct	930.119	g/min	minus ash
												vduct	16.642	meters/min	
		total mass:	0.00609									vduct	0.850	ft/sec	
									dens@STP	1202.19	g/m^3	dens@imp	915.045	g/m^3	
												mol wt dry	29.500	g/mol	
												dens@roto	929.176	g/m^3	
												volflwrateroto	0.029	m^3/min	
												volflwrateroto	1.010	ft^3/min	
Notes:															
	* Temperature profile of the furnace is not measured due to T/C failure - JP											mdotroto	23.726	g/min	
	*Injector valve was initially open, which I didn't notice, so some char was blowing out from syringe											mdotimp	25.886	g/min	
	3 -negligible amount - JP											volflwimp	0.028	m^3/min	
	* One very big particle in the preseperator and 3 or 4 bigs (?)- JP											volflwimp	0.999	ft^3/min	
												vinlet	129.144	m/min	
												vinlet	7.082	ft/sec	
												mdotcoal	0.00000	g/min	
									actual ash:	0.00609	g	expected ash	0.0000	g	
												%Det ash	100.000	%	based on actu

Table H.18: Test 03129502

Date:	3/12/95	mo/day/yr	Main NG:	83.0	%	Probe clnt T:	144	F								
Coal:	AC #1	source	Main Air:	47.2	%	Prbe clnt flw:	160	mm								
	Suc60/C60	process		33.0	psig	Comb prg p:	7	psig								
test no:	03129502	m/d/ynum	BF1NG:	44.0	%	Coal feed:	5@90%	units	Imp inlt diam	0.5625	inches					
test dur:	13.73	minutes	BF1Air:	3.8	units,front	Coal feed conv		g/m	Mainduct rad	4	inches					
Coal Properties: (Ref. only)				3.7	units, back	Vacuum Rate	73.0	%	Main Gas Rate	0.83	fraction	mdot CH4	23.371	g/min		
			BF2NG:	20.0	%	Vacuum Rate	9.5	in hg	Main Air Rate	0.472	fraction	mdot Main Air	572.424	g/min		
grams	atomwt/100g	Ult. Ana	BF2Air:	2.7	units,front	atomizer air:	full	units	Main Air Rate	33	psig	phi	1.427	units		
		Carbon		2.6	units, back	atomizer air:	full	psig	Inj. Air Rate	20	%	mole fract.	1.481			
		Hydrogen	Inj. Rate:	20	%	atomizer H2O	193	mm	Inj Air Rate	44	psig	CO2	1.481	moles/min	CH4&Air only	
		Oxygen	Inj. Rate:	44	psig	exit duct T:	110	F				H2O	2.921	moles/min	CH4&Air only	
		Nitrogen				over furn T:	134	F	Coal Composition on Elemental level			N2	15.676	moles/min	CH4&Air only	
		Sulfur							Carbon(monat	0.00	moles/100g	O2	1.248	moles/min	CH4&Air only	
		Ash							Hydrogen (mo	0.00	moles/100g	mdot air inj	22.197	g/min		
		Moisture							Oxygen (mon	0.00	moles/100g	O2	0.162	moles/min	Inj Air only	
		Total							Nitrogen (mor	0.00	moles/100g	N2	0.606	moles/min	Inj Air only	
			Scale:	1					Sulfur(mon)	0.00	moles/100g	Dry O2 w/inj	7.361	vol%	tot w/o coal	
									Ash	0.00	g/100g	DryO2w/o inj	8.790	vol%	t.w/o coal&inj	
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % fr. size mov	Size Range micrometers	T/C Port	Temp, C	H2O	0.00	moles/100g	Coal Fraction	0.000	mdotcoal/100g		
												CO2	1.481	moles/min	total	
									mdot coal	0	g/min	H2O	2.921	moles/min	total	
Preseperator	0.32887	0.33056	0.00169	44.24	55.76	10.0 & up	B		Probe inlet T	0	degC	N2	15.288	moles/min	total	
0	0.29819	0.29848	0.00029	7.59	48.17	9.0 - 10.0	C		Impactor Inlet	100	degC (est. T)	SO2	0.0000	moles/min	total	
1	0.29950	0.29966	0.00016	4.19	43.98	5.8 - 9.0	D		Vacuum Rate	9.5	in Hg	O2	1.410	moles/min	total	
2	0.32925	0.32937	0.00012	3.14	40.84	4.7 - 5.8	E		Vacuum Rate	23	degC (est. T)	Dry O2	7.361	vol%	total	
3	0.32507	0.32522	0.00015	3.93	36.91	3.3 - 4.7	F		Vacuum Rate	73	CFH	H20 wt	0.085	mass fraction		
4	0.32953	0.32971	0.00018	4.71	32.20	2.1 - 3.3	G		coal flow time	13.73	min					
5	0.32824	0.32841	0.00017	4.46	27.75	1.1 - 2.1	H					mol wt wet	27.991	g/mol		
6	0.32556	0.32563	0.00007	1.83	25.92	0.7 - 1.1	I					dens@inlet	1249.517	g/m^3		
7	0.32724	0.32725	0.00001	0.26	25.65	0.4 - 0.7	J					mdot duct	617.992	g/min	minus ash	
Backup Filter	0.33292	0.33390	0.00098	25.65	0.00	0 - 0.4	K					vduct	18.251	meters/min		
												vduct	0.834	ft/sec		
		total mass:	0.00382						dens@STP	1202.10	g/m^3	dens@imp	914.629	g/m^3		
												mol wt dry	29.514	g/mol		
												dens@rota	929.583	g/m^3		
Notes:												volflwrelerota	0.029	m^3/min		
	* Apparently, no big particles in preseperator - JP											volflwrelerota	1.011	ft^3/min		
	* Very smooth run															
	* Again, temperature profiles not taken due to TC failure - JP											mdotrota	23.743	g/min		
												mdotimp	25.951	g/min		
												volflwimp	0.028	m^3/min		
												volflwimp	1.002	ft^3/min		
												vinlet	129.544	m/min		
												vinlet	7.084	ft/sec		
												mdotcoal	0.00000	g/min		
									actual ash:	0.00382	g	expected ash	0.0000	g		
												%Diff ash	100.000	%	based on actu	

Table H.19: Test 03139501

Date:	3/13/95	mo/day/yr	Main NG:	82.5	%	Probe cint T:	142	F								
Coal:	AC #9	source	Main Air:	48.0	%	Probe cint thr	160	mm								
	Ben 1.25 g	process		33.5	psig	Comb prg p:	7	psig								
test no:	03139501	m/d/ynum	BF1NG:	44.0	%	Coal feed	5@90%	units	Imp inj diam	0.5625	inches					
test dur:	10.00	minutes	BF1Air:	3.8	units,front	Coal feed conv		g/m	Mainduct rad	4	inches					
Coal Properties: (Ref. only)				3.8	units, back	Vacuum Roto	72.0	%	Main Gas Roto	0.825	fraction	mdot CH4	23.230	g/min		
			BF2NG:	20.0	%	Vacuum Roto	9.5	in hg	Main Air Roto	0.48	fraction	mdot Main Air	595.169	g/min		
grams	atomwt/100g	Ult. Ana.	BF2Air:	2.8	units,front	atomizer air:	full	units	Main Air Roto	33.5	psig	phi	1.499	units		
		Carbon		2.8	units, back	atomizer air:	full	psig	Inj Air Roto	20	%	mole fract	1.452			
		Hydrogen	Inj. Roto:	20	%	atomizer H2O	150	mm	Inj Air Roto	44	psig	CO2	1.452	moles/min	CH4&Air only	
		Oxygen	Inj. Roto:	44	psig	exit duct T:	110	F				H20	2.904	moles/min	CH4&Air only	
		Nitrogen				over turn T:	128	F				N2	16.027	moles/min	CH4&Air only	
		Sulfur							Coal Composition on Elemental level			O2	1.359	moles/min	CH4&Air only	
		Ash							Carbon(moist	0.00	moles/100g	mdot air inj	22.197	g/min		
		Moisture							Hydrogen (mo	0.00	moles/100g	O2	0.162	moles/min	inj Air only	
		Total							Oxygen (mon)	0.00	moles/100g	N2	0.608	moles/min	inj Air only	
			Scale:	1					Nitrogen (mor	0.00	moles/100g	Dry O2 w/inj	7.755	vol%	tot w/o coal	
									Sulfur(mon)	0.00	moles/100g	DryO2w/o inj	7.213	vol%	tot w/o coal&inj	
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % R. size rnge	Size Range micrometers	T/C Port	Temp, C	Ash	0.00	g/100g	Coal Fraction	0.000	mdotcoal/100g		
									H2O	0.00	moles/100g	CO2	1.452	moles/min	total	
									mdot coal	0	g/min	H20	2.904	moles/min	total	
Presseperator	0.32823	0.33039	0.00216	33.13	66.87	10.0 & up	B	1206	Probe inlet T	970	degC	N2	16.635	moles/min	total	
0	0.29989	0.30039	0.00050	7.67	59.20	9.0 -10.0	C	1188	Impactor inlet	100	degC (est. T)	SO2	0.0000	moles/min	total	
1	0.30235	0.30281	0.00046	7.06	52.15	5.8 - 9.0	D	1165	Vacuum Roto	9.5	in Hg	O2	1.521	moles/min	total	
2	0.32719	0.32758	0.00039	5.98	46.17	4.7 - 5.8	E	1141	Vacuum Roto	23	degC (est. T)	Dry O2	7.755	vol%	total	
3	0.32686	0.32631	0.00065	9.97	36.20	3.3 - 4.7	F	1108	Vacuum Roto	72	CFH	H20 wt	0.093	mass fraction		
4	0.32729	0.32802	0.00073	11.20	25.00	2.1 - 3.3	G	1072	coal flow time	10	min					
5	0.32707	0.32744	0.00037	5.67	19.33	1.1 - 2.1	H	1023				mol wt wet	29.012	g/mol		
6	0.32764	0.32777	0.00013	1.99	17.33	0.7 - 1.1	I	970				dens@inlet	274.641	g/m^3		
7	0.32768	0.32775	0.00007	1.07	16.26	0.4 - 0.7	J	892				mdot duct	630.596	g/min	minus ash	
Backup Filter	0.33243	0.33349	0.00106	16.26	0.00	0 -0.4	K	826				vduct	70.603	meters/min		
												vduct	3.872	ft/sec		
		total mass:	0.00652						dens@STP	1292.10	g/m^3	dens@imp	915.224	g/m^3		
												mol wt dry	29.495	g/mol		
												dens@roto	889.030	g/m^3		
												volflwrateroto	0.026	m^3/min		
												volflwrateroto	0.927	ft^3/min		
Notes:																
* Had to shut down test 10 minutes into run. Typical is 13 to 14 minutes. The downstream syringe started																
bypassing char out the back. The stages all look light. This test will most likely have to be scaled up to a full												mdotroto	23.395	g/min		
mass flow test.												mdotimp	25.509	g/min		
												volflwimp	0.028	m^3/min		
												volflwimp	0.984	ft^3/min		
												vinlet	579.333	m/min		
												vinlet	31.678	ft/sec		
												mdotcoal	0.00000	g/min		
									actual ash:	0.00652	g	expected ash	0.0000	g		
												%Diff ash	100.000	%	based on actu	

Table H.20: Test 03149501

Date:	3/14/95	mo/day/yr	Main NG:	82.0	%	Probe clnt T:	144	F							
Coal:	AC #10	source	Main Air:	48.0	%	Probe clnt thr	160	mm							
	Ben 2.50 g	process		33.0	psig	Comb prg p:	7	psig							
test no:	03149501	m/d/ynum	BF1NG:	44.0	%	Coal feed:	5@90%	units	Imp Init diam	0.5625	inches				
test dur:	12.45	minutes	BF1Air:	3.8	units,front	Coal feed conv		g/m	Mainduct rad	4	inches				
Coal Properties: (Ref. only)				3.8	units, back	Vacuum Rotg	72.0	%	Main Gas Roto	0.82	fraction	mdot CH4	23.089	g/min	
			BF2NG:	20.0	%	Vacuum Roto	9.5	in hg	Main Air Roto	0.48	fraction	mdot Main Air	592.126	g/min	
grams	etomwt/100g	Ult. Ana	BF2Air:	2.8	units,front	atomizer air:	full	units	Main Air Roto	33	psig	phi	1.499	units	
		Carbon		2.8	units, back	atomizer air:	full	psig	Inj Air Roto	20	%	mole fract	1.449		
		Hydrogen	Inj. Roto:	20	%	atomizer H2O	200	mm	Inj Air Roto	44	psig	CO2	1.443	moles/min	CH4&Air only
		Oxygen	Inj. Roto:	44	psig	exit duct T:	107	F				H20	2.889	moles/min	CH4&Air only
		Nitrogen				over turn T:	105	F	Coal Composition on Elemental level			N2	16.944	moles/min	CH4&Air only
		Sulfur							Carbon(monat	0.00	moles/100g	O2	1.354	moles/min	CH4&Air only
		Ash							Hydrogen (mo	0.00	moles/100g	mdot air inj	22.197	g/min	
		Moisture							Oxygen (mon	0.00	moles/100g	O2	0.162	moles/min	Inj Air only
		Total							Nitrogen (mor	0.00	moles/100g	N2	0.606	moles/min	Inj Air only
			Scale:	1					Sulfur(mon)	0.00	moles/100g	Dry O2 w/inj	7.770	vol%	tot w/o coal
									Ash	0.00	g/100g	DryO2w/o inj	7.229	vol%	t.w/o coal&inj
Stage	Initial(g)	Final(g)	Net(g)	% in size	Cum. %	Size Range	T/C Port	Temp, C	H2O	0.00	moles/100g	Coal Fraction	0.000	mdotcoal/100g	
				range	fr. size mor	micrometers						CO2	1.443	moles/min	(total
									mdot coal	0	g/min	H20	2.889	moles/min	total
Preseperator	0.32522	0.32790	0.00268	31.60	68.40	10.0 & up	B	1208	Probe Inlet T	971	degC	N2	16.552	moles/min	total
0	0.29891	0.29970	0.00079	9.32	59.08	9.0 -10.0	C	1188	Impactor Inlet	100	degC (est. T)	SO2	0.0000	moles/min	total
1	0.29703	0.29782	0.00079	9.32	49.76	8.0 - 9.0	D	1165	Vacuum Roto	9.5	in Hg	O2	1.519	moles/min	total
2	0.32625	0.32688	0.00063	7.43	42.33	4.7 - 8.8	E	1144	Vacuum Roto	23	degC (est. T)	Dry O2	7.770	vol%	total
3	0.32426	0.32537	0.00112	13.21	29.13	3.3 - 4.7	F	1108	Vacuum Roto	72	CFH	H20 wt	0.083	mass fraction	
4	0.32718	0.32823	0.00107	12.62	16.51	2.1 - 3.3	G	1074	coal flow time	12.45	min				
5	0.32644	0.32700	0.00056	6.60	9.91	1.1 - 2.1	H	1025				mol wt wet	28.013	g/mol	
6	0.32641	0.32659	0.00018	2.12	7.78	0.7 - 1.1	I	971				dens@inlet	274.428	g/m^3	
7	0.32782	0.32787	0.00005	0.59	7.19	0.4 - 0.7	J	880				mdot duct	627.412	g/min	minus ash
Backup Filter	0.32922	0.32993	0.00081	7.19	0.00	0 -0.4	K	828				vduct	70.600	meters/min	
												vduct	3.855	ft/sec	
		total mass	0.00848						dens@STP	1202.10	g/m^3	dens@imp	815.251	g/m^3	
												mol wt dry	29.494	g/mol	
												dens@roto	829.015	g/m^3	
												volflwrateroto	0.028	m^3/min	
Notes:												volflwrateroto	0.997	ft^3/min	
												mdotroto	23.394	g/min	
												mdotimp	25.606	g/min	
												volflwimp	0.026	m^3/min	
												volflwimp	0.884	ft^3/min	
												vinlet	570.707	m/min	
												vinlet	31.699	ft/sec	
												mdotcoal	0.00000	g/min	
									actual ash:	0.00848	g	expected ash	0.0000	g	
												%Diff ash	100.000	%	based on actu

Table H.21: Test 03149502

Date:	3/14/95	mo/day/yr	Main NG:	81.6	%	Probe clnt T:	141	F								
Coal:	AC #11	source	Main Air:	46.0	%	Probe clnt flw	160	mm								
	Ben 3.75 g	process		23.0	psig	Comb prg p:	7	psig								
test no:	03149502	m/d/ynum	BF1NG:	44.0	%	Coal feed:	5@90%	units	Imp Inli diam	0.5625	inches					
test dur:	12.15	minutes	BF1Air:	3.8	units,front	Coal feed conv		g/m	Mainduct rad	4	inches					
Coal Properties: (Ref. only)				3.8	units, back	Vacuum Rota	72.0	%	Main Gas Rota	0.815	fraction	mdot CH4	22.949	g/min		
			BF2NG:	20.0	%	Vacuum Rota	9.5	in hg	Main Air Rota	0.48	fraction	mdot Main Air	582.126	g/min		
grams	atom wt/100g	Ult. Ana.	BF2Air:	2.8	units,front	atomizer air:	full	units	Main Air Rota	33	psig	phi	1.478	units		
		Carbon		2.8	units, back	atomizer air:	full	psig	Inj. Air Rota	20	%	mole fract.	1.434			
		Hydrogen	Inj. Rota:	20	%	atomizer H2O	200	mm	Inj Air Rota	44	psig	CO2	1.434	moles/min	CH4&Air only	
		Oxygen	Inj. Rota:	44	psig	exit duct T:	193	F				H20	2.869	moles/min	CH4&Air only	
		Nitrogen				oven turn T:	97	F	Coal Composition on Elemental level			N2	15.944	moles/min	CH4&Air only	
		Sulfur							Carbon(monel	0.00	moles/100g	O2	1.372	moles/min	CH4&Air only	
		Ash							Hydrogen (mo	0.00	moles/100g	mdot air inj	22.197	g/min		
		Moisture							Oxygen (mon)	0.00	moles/100g	O2	0.192	moles/min	Inj Air only	
		Total							Nitrogen (mor	0.00	moles/100g	N2	0.808	moles/min	Inj Air only	
			Scale:	1.6					Sulfur(mon)	0.00	moles/100g	Dry O2 w/inj	7.857	vol%	tot w/o coal	
									Ash	0.00	g/100g	DryO2w/o inj	7.317	vol%	t w/o coal&inj	
Stage	Initial(g)	Final(g)	Net(g)	% in size	Cum. %	Size Range	T/C Port	Temp, C	H2O	0.00	moles/100g	Coal Fraction	0.000	mdotcoal/100g		
				range	lt. size mes	micrometers						CO2	1.434	moles/min	total	
									mdot coal	0	g/min	H20	2.869	moles/min	total	
Presepersitor	0.32908	0.33676	0.00768	44.34	55.66	10.0 & up	B		Probe inlet T	0	degC	N2	15.552	moles/min	total	
0	0.30029	0.30186	0.00157	9.06	46.59	9.0 - 10.0	C		Impactor Inlet	100	degC (est. T)	SO2	0.0000	moles/min	total	
1	0.30245	0.30371	0.00126	7.27	39.32	5.8 - 9.0	D		Vacuum Rota	9.5	in Hg	O2	1.634	moles/min	total	
2	0.32791	0.32924	0.00133	7.68	31.64	4.7 - 5.8	E		Vacuum Rota	23	degC (est. T)	Dry O2	7.857	vol%	total	
3	0.32781	0.32984	0.00203	11.72	19.92	3.3 - 4.7	F		Vacuum Rota	72	CFH	H20 wt	0.092	mass fraction		
4	0.32793	0.32966	0.00183	10.57	9.35	2.1 - 3.3	G		coal flow time	12.15	min					
5	0.32752	0.32837	0.00085	4.91	4.45	1.1 - 2.1	H					mol wt wet	28.018	g/mol		
6	0.32749	0.32776	0.00027	1.56	2.89	0.7 - 1.1	I					dens@inlet	1250.718	g/m^3		
7	0.32766	0.32777	0.00011	0.64	2.25	0.4 - 0.7	J					mdot duct	627.271	g/min	minus ash	
Backup Filter	0.32160	0.32189	0.00029	2.25	0.00	0 - 0.4	K					vduct	15.466	meters/min		
												vduct	0.849	ft/sec		
		total mass:	0.01732						dens@STP	1202.19	g/m^3	dens@imp	915.406	g/m^3		
												mol wt dry	29.490	g/mol		
												dens@roto	828.895	g/m^3		
												volflwrateroto	0.028	m^3/min		
												volflwrateroto	0.996	ft^3/min		
Notes:																
* I had the coal inj set at 50% (nominally 20%) when I measured prt B temp the first time. It read 1185C (nominal is 1210C). The injector makes a difference												mdotroto	23.389	g/min		
* A large amount of material is in the presepersitor! The char injector didn't appear to run poorly, so I'm not sure why there is so much in the presepersitor. All the stages looked pretty heavy. The filter looked clean.												mdotimp	25.487	g/min		
												volflwrateimp	0.028	m^3/min		
												volflwimp	0.983	ft^3/min		
												vinlet	127.102	m/min		
												vinlet	6.950	ft/sec		
												mdotcoal	0.00000	g/min		
									actual ash:	0.01732	g	expected ash	0.0000	g		
												%Diff ash	100.000	%	based on actu	

Table H.22: Test 03149503

Date:	3/14/95	mo/day/yr	Main NG:	82.6	%	Probe clnt T:	140	F								
Coal:	AC #12	source	Main Air:	48.0	%	Prbe clnt flw:	160	mm								
	Ben 5.00 g	process		33.0	psig	Comb prg p:	7	psig								
test no:	03149503	m/d/ynum	BF1NG:	44.0	%	Coal feed:	5@90%	units	Imp Inlt diam	0.5625	inches					
test dur:	12.65	minutes	BF1Air:	3.8	units,front	Coal feed conv		g/m	Mainduct red	4	inches					
Coal Properties: (Raf. only)				2.8	units, back	Vacuum Rota	72.0	%	Main Air Rota	0.48	fraction	mdot CH4	23.230	g/min		
			BF2NG:	20.0	%	Vacuum Rota	9.5	in hg	Main Air Rota	0.48	fraction	mdot Main Air	592.126	g/min		
grams	atomwt/100g	Ult. Ana.	BF2Air:	2.8	units,front	atomizer air:	full	units	Main Air Rota	33	psig	phi	1.480	units		
		Carbon		2.8	units, back	atomizer air:	full	psig	Inj Air Rota	20	%	mole fract.	1.452			
		Hydrogen	Inj Rota:	20	%	atomizer H2O	202	mm	Inj Air Rota	44	psig	CO2	1.452	moles/min	CH4&Air only	
		Oxygen	Inj Rota:	44	psig	ash duct T:	105	F				H20	2.904	moles/min	CH4&Air only	
		Nitrogen				over turn T:	97	F	Coal Composition on Elemental level			N2	15.944	moles/min	CH4&Air only	
		Sulfur							Carbon(monat	0.00	moles/100g	O2	1.337	moles/min	CH4&Air only	
		Ash							Hydrogen (mo	0.00	moles/100g	mdot air inj	22.197	g/min		
		Moisture							Oxygen (mon)	0.00	moles/100g	O2	0.182	moles/min	Inj Air only	
		Total							Nitrogen (mer	0.00	moles/100g	N2	0.808	moles/min	Inj Air only	
			Scale:	1.5					Sulfur(mon)	0.00	moles/100g	Dry O2 w/inj	7.683	vol%	tot w/o coal	
									Ash	0.00	g/100g	DryO2w/o inj	7.139	vol%	t w/o coal&inj	
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % .R. size rnge	Size Range micrometers	T/C Port	Temp, C	H2O	0.00	moles/100g	Coal Fraction	0.000	mdotcoal/100g		
												CO2	1.452	moles/min	total	
									mdot coal	0	g/min	H20	2.904	moles/min	total	
Presepersior	0.32541	0.33415	0.00874	45.21	54.79	10.0 & up	B	1208	Probe inlet T	972	degC	N2	15.552	moles/min	total	
0	0.29728	0.29959	0.00231	11.95	42.83	9.0 -10.0	C	1186	Impactor inlet	100	degC (est. T)	SO2	0.0000	moles/min	total	
1	0.29746	0.29923	0.00178	9.21	33.63	6.8 - 9.0	D	1167	Vacuum Rota	9.5	in Hg	O2	1.498	moles/min	total	
2	0.32599	0.32735	0.00136	7.04	26.59	4.7 - 6.8	E	1142	Vacuum Rota	23	degC (est. T)	Dry O2	7.693	vol%	total	
3	0.32726	0.32914	0.00188	9.73	16.86	3.3 - 4.7	F	1106	Vacuum Rota	72	CFH	H20 wt	0.083	mass fraction		
4	0.32636	0.32788	0.00152	7.86	9.00	2.1 - 3.3	G	1079	coal flow time	12.65	min					
5	0.32352	0.32428	0.00076	3.93	5.07	1.1 - 2.1	H	1018				mol wt wet	28.098	g/mol		
6	0.32380	0.32408	0.00018	0.93	4.14	0.7 - 1.1	I	972				dens@inlet	274.191	g/m^3		
7	0.32572	0.32582	0.00010	0.52	3.62	0.4 - 0.7	J	895				mdot duct	627.669	g/min	minus ash	
Backup Filter	0.32864	0.32934	0.00070	3.62	0.00	0 -0.4	K	820				vduct	79.584	meters/min		
												vduct	3.660	ft/sec		
		total mass:	0.01933						dens@STP	1202.10	g/m^3	dens@imp	915.096	g/m^3		
												mol wt dry	29.498	g/mol		
												dens@rota	829.136	g/m^3		
												volflwrateroto	0.028	m^3/min		
												volflwrateroto	0.997	ft^3/min		
Notes:																
* Stage 7 was slightly off center, but all spots hit the plate.												mdotroto	23.398	g/min		
* Presep has quite a bit of material, and stages 0 and 1 are slightly overloaded												mdotimp	26.525	g/min		
* Stage 2 has unevenly distributed ash spots : JP												volflwimp	0.028	m^3/min		
												volflwimp	0.985	ft^3/min		
												vinlet	580.705	m/min		
												vinlet	31.753	ft/sec		
												mdotcoal	0.00000	g/min		
									actual ash:	0.01933	g	expected ash	0.0000	g		
												%Diff ash	100.000	%	based on actu	

Table H.23: Test 03169501

Date:	3/16/95	mo/day/yr	Main NG:	82.5	%	Probe cint T:	146	F									
Coal:	AC #8	source	Main Air:	48.0	%	Probe cint flw:	160	mm									
	Pyr 2.78 g	process		33.5	psig	Comb prg p:	7	psig									
test no:	03169501	m/d/ynum	BF1NG:	44.0	%	Coal feed:	5@90%	units	imp init diam	0.6825	inches						
test dur:	12.39	minutes	BF1Air:	3.8	units,front	Coal feed conv		g/m	Meinduct red	4	inches						
Coal Properties:	(Rel. only)			3.8	units, back	Vacuum Roto	72.0	%	Main Gas Roto	0.825	fraction	mdot CH4	23.230	g/min			
			BF2NG:	20.0	%	Vacuum Roto	9.5	in hg	Main Air Roto	0.48	fraction	mdot Main Air	585.169	g/min			
grams	atom wt/100g	Wt. Ana.	BF2Air:	2.8	units,front	atomizer air:	full	units	Main Air Roto	33.5	psig	phi	1.468	units			
		Carbon		2.8	units, back	atomizer air:	full	psig	Inj. Air Roto	20	%	mole fract	1.452				
		Hydrogen	Inj. Roto:	20	%	atomizer H2O	175	mm	Inj Air Roto	44	psig	CO2	1.452	moles/min	CH4&Air only		
		Oxygen	Inj Roto:	44	psig	exit duct T:	112	F				H20	2.904	moles/min	CH4&Air only		
		Nitrogen				over turn T:	129	F	Coal Composition on Elemental level			N2	16.027	moles/min	CH4&Air only		
		Sulfur							Carbon(mon)	0.00	moles/100g	O2	1.359	moles/min	CH4&Air only		
		Ash							Hydrogen (mo	0.00	moles/100g	mdot air inj	22.197	g/min			
		Moisture							Oxygen (mon)	0.00	moles/100g	O2	0.162	moles/min	Inj Air only		
		Total							Nitrogen (mon	0.00	moles/100g	N2	0.608	moles/min	Inj Air only		
			Scale:	2.6					Sulfur(mon)	0.00	moles/100g	Dry O2 w/inj	7.765	vol%	tot w/o coal		
									Ash	0.00	g/100g	DryO2w/o inj	7.213	vol%	t.w/o coal&Inj		
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % & size rnge	Size Range micrometers	T/C Port	Temp, C.	H2O	0.00	moles/100g	Coal Fraction	0.000	mdotcoal/100g			
												CO2	1.452	moles/min	total		
									mdot coal	0	g/min	H20	2.904	moles/min	total		
Preseperator	0.32873	0.33522	0.00649	40.21	59.79	10.0 & up	B	1219	Probe inlet T	971	degC	N2	16.635	moles/min	total		
0	0.29659	0.29851	0.00192	11.90	47.89	9.0 -10.0	C	1188	Impactor inlet	100	degC (est. T)	SO2	0.0000	moles/min	total		
1	0.29805	0.29928	0.00123	7.62	40.27	5.8 - 9.0	D	1166	Vacuum Roto	9.5	in Hg	O2	1.521	moles/min	total		
2	0.32739	0.32839	0.00100	6.20	34.08	4.7 - 5.8	E	1149	Vacuum Roto	23	degC (est. T)	Dry O2	7.766	vol%	total		
3	0.32670	0.32720	0.00160	9.29	24.78	3.3 - 4.7	F	1109	Vacuum Roto	72	CFH	H20 wt	0.083	mass fraction			
4	0.32771	0.32907	0.00136	8.43	16.36	2.1 - 3.3	G	1078	coal flow time	12.39	min						
5	0.32634	0.32713	0.00079	4.89	11.46	1.1 - 2.1	H	1026				mol wt wet	28.012	g/mol			
6	0.32592	0.32615	0.00023	1.43	10.04	0.7 - 1.1	I	971				dens@inlet	274.420	g/m^3			
7	0.32551	0.32563	0.00012	0.74	9.29	0.4 - 0.7	J	897				mdot duct	930.598	g/min	minus ash		
Backup Filter	0.32906	0.33056	0.00150	9.29	0.00	0 -0.4	K	826									
												vduct	70.890	meters/min			
		total mass	0.01814									vduct	3.875	ft/sec			
									dens@STP	1202.10	g/m^3	dens@inp	915.224	g/m^3			
												mol wt dry	29.495	g/mol			
												dens@roto	929.036	g/m^3			
Notes:												volflwrotoroto	0.028	m^3/min			
												volflwrotroto	0.997	ft^3/min			
* The scale seems to have trouble going to zero after each weighing of the initial stages																	
* Small puff out back of syringe pretest												mdotroto	23.995	g/min			
* Prior to test, I let the syringes go in to far during loading by leaving the drive on. I recleaned the injector and refilled the syringes.												mdotimp	25.509	g/min			
												volflwimp	0.028	m^3/min			
* There is plenty in the preseperator. Some particles sitting on the 0 stage orifice plate												volflwimp	0.984	ft^3/min			
* Stage 0 is overloaded.												vinlet	579.799	m/min			
* The filter is really dirty.												vinlet	31.704	ft/sec			
												mdotcoal	0.00000	g/min			
									actual ash:	0.01814	g	expected ash	0.0000	g			
												%Diff ash	100.000	%	based on actu		

Table H.24: Test 03169503

Date:	3/16/95	mo/day/yr	Main NG:	93.0	%	Probe ctrl T:	143	F								
Coal:	AC #2	source	Main Air:	48.0	%	Probe ctrl flw:	160	mm								
	Suc75/C25	process		33.0	psig	Comb prg p:	7	psig								
test no:	03169503	m/d/ynum	BF1NG:	44.0	%	Coal feed:	5@90%	units	Imp inlt diam	0.5625	inches					
test dur:	13.57	minutes	BF1Air:	3.8	units,front	Coal feed conv		g/m	Mainduct rad	4	inches					
Coal Properties: (Ref. only)				3.7	units, back	Vacuum Roto	72.0	%	Main Gas Roto	0.83	fraction	mdot CH4	23.371	g/min		
			BF2NG:	20.0	%	Vacuum Roto	9.5	in hg	Main Air Roto	0.48	fraction	mdot Main Air	582.126	g/min		
grams	atomwt/100g	Ult. Ana.	BF2Air:	2.7	units,front	atomizer air:	full	units	Main Air Roto	33	psig	phi	1.452	units		
		Carbon		2.6	units, back	atomizer air:	full	psig	Inj Air Roto	20	%	mole fract.	1.491			
		Hydrogen	Inj Roto:	20	%	atomizer H2O	183	mm	Inj Air Roto	44	psig	CO2	1.461	moles/min	CH4&Air only	
		Oxygen	Inj Roto:	44	psig	exit duct T:	112	F				H20	2.921	moles/min	CH4&Air only	
		Nitrogen				over furn T:	106	F	Coal Composition on Elemental level			N2	15.944	moles/min	CH4&Air only	
		Sulfur							Carbon(monat	0.00	moles/100g	O2	1.319	moles/min	CH4&Air only	
		Ash							Hydrogen (mo	0.00	moles/100g	mdot air inj	22.197	g/min		
		Moisture							Oxygen (mon	0.00	moles/100g	O2	0.162	moles/min	Inj Air only	
		Total							Nitrogen (mon	0.00	moles/100g	N2	0.008	moles/min	Inj Air only	
			Scale:	2.6					Sulfur(mon)	0.00	moles/100g	Dry O2 w/inj	7.698	vol%	tot w/o coal	
									Ash	0.00	g/100g	DryO2w/o inj	7.045	vol%	t w/o coal&Inj	
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % ft. size rge	Size Range micrometers	T/C Port	Temp, C.	H2O	0.00	moles/100g	Coal Fraction	0.000	mdotcoal/100g		
												CO2	1.461	moles/min	total	
									mdot coal	0	g/min	H20	2.921	moles/min	total	
Presseperator	0.32540	0.32856	0.00316	34.64	65.16	10.0 & up	B	1209	Probe inlet T	974	degC	N2	16.552	moles/min	total	
0	0.29829	0.29913	0.00084	9.26	55.90	9.0 -10.0	C	1198	Impactor Inlet	100	degC (est. T)	SO2	0.0000	moles/min	total	
1	0.29765	0.29840	0.00075	8.27	47.63	8.0 - 9.0	D	1199	Vacuum Roto	9.5	in Hg	O2	1.461	moles/min	total	
2	0.32643	0.32710	0.00067	7.39	40.24	7.1 - 8.0	E	1145	Vacuum Roto	23	degC (est. T)	Dry O2	7.698	vol%	total	
3	0.32976	0.32859	0.00080	8.82	31.42	5.5 - 7.1	F	1108	Vacuum Roto	72	CFH	H20 wt	0.084	mass fraction		
4	0.32619	0.32688	0.00069	7.61	23.81	2.1 - 3.3	G	1077	coal flow time	13.57	min					
5	0.32421	0.32462	0.00041	4.52	16.29	1.1 - 2.1	H	1025				mol wt wet	28.004	g/mol		
6	0.32592	0.32608	0.00016	1.76	11.53	0.7 - 1.1	I	974				dens@inlet	273.676	g/m^3		
7	0.32568	0.32574	0.00006	0.66	10.65	0.4 - 0.7	J	897				mdot duct	927.694	g/min	minus ash	
Backup Filter	0.32972	0.33023	0.00151	16.65	0.00	0 -0.4	K	829				vduct	70.725	mole(s/min		
												vduct	3.867	ft/sec		
		total mass:	0.00907						dens@STP	1202.10	g/m^3	dens@imp	914.942	g/m^3		
												mol wt dry	28.603	g/mol		
												dens@roto	929.266	g/m^3		
												volflwrotoroto	0.028	m^3/min		
												volflwrotoroto	0.997	ft^3/min		
Notes:																
												mdotroto	23.404	g/min		
* A puff of char was blown out from the short cylinder - negligible amount - JP												mdotimp	25.644	g/min		
* Small amount of char still blowing out of #3syringe (first syringe where air enters), so held the syringe tight against the injector block for he first 5 minutes- then the problem went away. - JP												volflwrimp	0.028	m^3/min		
* Ran smooth - Jp												volflwrimp	0.999	ft^3/min		
* Small amount in presseperator - JP												vinlet	582.171	m/min		
* Ash looks black - JP												vinlet	31.934	ft/sec		
* I dumped lots of ash from the presseperator after weighing - JP																
												mdotcoal	0.00000	g/min		
									actual ash:	0.00907	g	expected ash	0.0000	g		
												%Diff ash	100.000	%	based on actu	

Table H.25: Test 03169504

Date:	3/16/95	mo/day/yr	Main NG:	82.0	%	Probe clnt T:	145	F							
Coal	AC #7	source	Main Air:	48.0	%	Prbe clnt flw:	160	mm							
	Pyr 3.70 g	process		33.0	psig	Comb prg p:	7	psig							
test no:	03169504	m/d/ynum	BF1NG:	44.0	%	Coal feed:	5@90%	units	Imp inlt diam	0.5625	inches				
test dur:	13.41	minutes	BF1Air:	3.8	units,front	Coal feed conv		g/m	Mainduct rad	4	inches				
Coal Properties: (Ref. only)				3.8	units, back	Vacuum Roto	72.0	%	Main Gas Roto	0.82	fraction	mdot CH4	23.089	g/min	
			BF2NG:	20.0	%	Vacuum Roto	9.5	in hg	Main Air Roto	0.48	fraction	mdot Main Air	582.126	g/min	
grams	atomwt/100g	Ult. Ana	BF2Air:	2.8	units,front	atomizer air:	full	units	Main Air Roto	33	psig	phi	1.489	units	
		Carbon		2.8	units, back	atomizer air:	full	psig	Inj. Air Roto	20	%	mole fract.	1.443		
		Hydrogen	Inj. Roto:	20	%	atomizer H2O	178	mm	Inj Air Roto	44	psig	CO2	1.443	moles/min	CH4&Air only
		Oxygen	Inj. Roto:	44	psig	exit duct T:	112	F				H2O	2.886	moles/min	CH4&Air only
		Nitrogen				over furn T:	108	F	Coal Composition on Elemental level			N2	15.944	moles/min	CH4&Air only
		Sulfur							Carbon(monet	0.00	moles/100g	O2	1.354	moles/min	CH4&Air only
		Ash							Hydrogen (mo	0.00	moles/100g	mdot air inj	22.197	g/min	
		Moisture							Oxygen (mon)	0.00	moles/100g	O2	0.162	moles/min	Inj Air only
		Total							Nitrogen (mon	0.00	moles/100g	N2	0.608	moles/min	Inj Air only
			Scale:						Sulfur(mon)	0.00	moles/100g	Dry O2 w/inj	7.770	vol%	tot w/o coal
									Ash	0.00	g/100g	DryO2w/o Inj	7.226	vol%	t.w/o coal&inj
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % lt. size rnge	Size Range micrometers	T/C Port	Temp, C.	H2O	0.00	moles/100g	Coal Fraction	0.000	mdotcoal/100g	
												CO2	1.443	moles/min	total
									mdot coal	0	g/min	H2O	2.888	moles/min	total
Preseparator	0.32784	0.33047	0.00263	31.84	68.16	10.0 & up	B	1208	Probe inlet T	972	degC	N2	16.552	moles/min	total
0	0.30022	0.30094	0.00072	8.72	59.44	9.0 -10.0	C	1188	Impactor inlet	100	degC (est. T)	SO2	0.0000	moles/min	total
1	0.29836	0.29909	0.00073	8.84	50.61	5.8 - 9.0	D	1166	Vacuum Roto	9.5	in Hg	O2	1.516	moles/min	total
2	0.32658	0.32698	0.00040	4.84	45.76	4.7 - 5.8	E	1145	Vacuum Roto	23	degC (est. T)	Dry O2	7.770	vol%	total
3	0.32672	0.32758	0.00086	10.41	35.35	3.3 - 4.7	F	1108	Vacuum Roto	72	CFH	H20 wt	0.093	mass fraction	
4	0.32755	0.32846	0.00091	11.02	24.33	2.1 - 3.3	G	1074	coal flow time	13.41	min				
5	0.32645	0.32701	0.00056	6.78	17.55	1.1 - 2.1	H	1025				mol wt wet	28.013	g/mol	
6	0.32683	0.32701	0.00018	2.18	15.38	0.7 - 1.1	I	972				dens@inlet	274.208	g/m^3	
7	0.32800	0.32810	0.00010	1.21	14.16	0.4 - 0.7	J	895				mdot duct	627.412	g/min	minus ash
Backup Filter	0.33041	0.33158	0.00117	14.16	0.00	0 -0.4	K	829				vduct	70.556	meters/min	
												vduct	3.850	ft/sec	
		total mass:	0.00826						dens@STP	1202.10	g/m^3	dens@imp	916.251	g/m^3	
												mol wt dry	28.494	g/mol	
												dens@roto	929.015	g/m^3	
												volflwrateroto	0.028	m^3/min	
Notes:												volflwrateroto	0.997	ft^3/min	
												mdotroto	23.394	g/min	
												mdotimp	25.506	g/min	
												volflwimp	0.028	m^3/min	
												volflwimp	0.984	ft^3/min	
												vinlet	580.173	m/min	
												vinlet	31.724	ft/sec	
												mdotcoal	0.00000	g/min	
									actual ash:	0.00826	g	expected ash	0.0000	g	
												%Diff ash	100.000	%	based on actu

Table H.26: Test 03179501

Data:	3/17/95	mo/day/yr	Main NG:	82.5	%	Probe clnt T:	143	F									
Coal:	AC #5	source	Main Air:	49.0	%	Probe clnt flw:	160	mm									
	Pyr 1.85 g	process		33.0	psig	Comb prg p:	7	psig									
test no:	03179501	m/d/ynum	BF1NG:	44.0	%	Coal feed	5@90%	units	Imp inlt diam	0.5625	inches						
test dur:		minutes	BF1Air:	3.8	units,front	Coal feed conv		g/m	Mainduct rad	4	inches						
Coal Properties: (Ref. only)				3.8	units, back	Vacuum Rota	72.0	%	Main Gas Rate	0.825	fraction	mdot CH4	23.230	g/min			
			BF2NG:	20.0	%	Vacuum Rota	9.5	in hg	Main Air Rate	0.48	fraction	mdot Main Air	682.126	g/min			
grams	atomwt/100g	UB Ana.	BF2Air:	2.8	units,front	atomizer air:	full	units	Main Air Rate	33	psig	phi	1.460	units			
		Carbon		2.8	units, back	atomizer air:	full	psig	Inj Air Rate	20	%	mole fract.	1.452				
		Hydrogen	Inj. Rate:	20	%	atomizer H2O	185	mm	Inj Air Rate	44	psig	CO2	1.452	moles/min	CH4&Air only		
		Oxygen	Inj. Rate:	44	psig	exit duct T:	109	F				H20	2.904	moles/min	CH4&Air only		
		Nitrogen				over turn T:	100	F	Coal Composition on Elemental level			N2	16.944	moles/min	CH4&Air only		
		Sulfur							Carbon(moist	0.00	moles/100g	O2	1.337	moles/min	CH4&Air only		
		Ash							Hydrogen (mo	0.00	moles/100g	mdot air inj	22.197	g/min			
		Moisture							Oxygen (mon	0.00	moles/100g	O2	0.162	moles/min	Inj Air only		
		Total							Nitrogen (mor	0.00	moles/100g	N2	0.608	moles/min	Inj Air only		
			Scale:	1					Sulfur(mon	0.00	moles/100g	Dry O2 w/inj	7.683	vol%	tot w/o coal		
									Ash	0.00	g/100g	DryO2w/o inj	7.136	vol%	t w/o coal&Inj		
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % s. size max	Size Range micrometers	T/C Port	Temp, C.	H2O	0.00	moles/100g	Coal Fraction	0.000	mdotcoal/100g			
												CO2	1.452	moles/min	total		
									mdot coal	0	g/min	H20	2.904	moles/min	total		
Presepersior	0.32730	0.33128	0.00398	47.55	52.45	10.0 & up	B	1207	Probe Inlet T	969	degC	N2	16.552	moles/min	total		
0	0.29785	0.29841	0.00056	6.69	45.76	9.0 -10.0	C	1185	Impactor Inlet	100	degC (est. T)	SO2	0.0000	moles/min	total		
1	0.29706	0.29755	0.00049	5.85	39.90	5.8 - 9.0	D	1164	Vacuum Rota	9.5	in Hg	O2	1.498	moles/min	total		
2	0.32528	0.32573	0.00045	5.38	34.53	4.7 - 5.8	E	1144	Vacuum Rota	23	degC (est. T)	Dry O2	7.683	vol%	total		
3	0.32545	0.32609	0.00064	7.65	28.88	3.3 - 4.7	F	1107	Vacuum Rota	72	CFH	H20 wt.	0.083	mass fraction			
4	0.32460	0.32522	0.00062	7.41	19.47	2.1 - 3.3	G	1068	coal flow time	0	min						
5	0.32663	0.32702	0.00039	4.66	14.81	1.1 - 2.1	H	1022				mol wt wet	29.008	g/mol			
6	0.32494	0.32507	0.00013	1.56	13.26	0.7 - 1.1	I	969				dens@inlet	274.824	g/m^3			
7	0.32539	0.32540	0.00002	0.24	12.02	0.4 - 0.7	J	888				mdot duct	627.563	g/min	minus ash		
Backup Filter	0.33099	0.33208	0.00109	13.02	0.00	0 -0.4	K	821				vduct	70.414	meters/min			
												vduct	3.860	ft/sec			
		total mass:	0.00837						dens@STP	1292.10	g/m^3	dens@imp	916.099	g/m^3			
												mol wt dry	29.498	g/mol			
												dens@rota	829.136	g/m^3			
												volflwrsterota	0.028	m^3/min			
Notes:												volflwrstrotg	0.997	ft^3/min			
* Turned off impactor after disconnecting from furnace. Ran about 15 seconds. No big deal, I believe.																	
* Temp. profile is not measured, but assumed to be similar to test 03179502 -JP												mdotrota	23.399	g/min			
												mdotimp	26.525	g/min			
												volflwimp	0.028	m^3/min			
												volflwimp	0.985	ft^3/min			
												vinlet	579.306	m/min			
												vinlet	31.677	ft/sec			
												mdotcoal	0.00000	g/min			
									actual ash	0.00837	g	expected ash	0.0000	g			
												%Dif ash	100.000	%	based on actu		

Table H.27: Test 03179502

Date:	3/17/95	mo/day/yr	Main NG:	53.0	%	Probe cint T:	144	F							
Coal:	AC #4	source	Main Air:	47.1	%	Probe cint thr:	180	mm							
	Pyr 0.93 g	process		33.0	psig	Comb prg p:	7	psig							
test no:	03179502	m/d/yr/num	BF1NG:	44.0	%	Coal feed:	5@90%	units	Imp inlt diam	0.6625	inches				
test dur:	12.88	minutes	BF1Air:	3.8	units,front	Coal feed conv		g/m	Mainduct rad	4	inches				
Coal Properties (Rel. only)				3.7	units, back	Vacuum Reg	72.0	%	Main Gas Rate	0.83	fraction	mdot CH4	23.371	g/min	
			BF2NG:	20.0	%	Vacuum Rate	9.5	in hg	Main Air Rate	0.471	fraction	mdot Main Air	571.211	g/min	
grams	atomwt/100g	Ult. Ana.	BF2Air:	2.7	units,front	atomizer air:	full	units	Main Air Rate	33	psig	phi	1.424	units	
		Carbon		2.6	units, back	atomizer air:	full	psig	Inj. Air Rate	20	%	mole fract	1.461		
		Hydrogen	Inj. Rate:	20	%	atomizer H2O	188	mm	Inj Air Rate	44	psig	CO2	1.461	moles/min	CH4&Air only
		Oxygen	Inj. Rate:	44	psig	exit duct T:	190	F				H20	2.921	moles/min	CH4&Air only
		Nitrogen				over furn T:	110	F	Coal Composition on Elemental level			N2	15.645	moles/min	CH4&Air only
		Sulfur							Carbon(mona	0.00	moles/100g	O2	1.240	moles/min	CH4&Air only
		Ash							Hydrogen (mo	0.00	moles/100g	mdot air inj	22.197	g/min	
		Moisture							Oxygen (mon	0.00	moles/100g	O2	0.182	moles/min	inj Air only
		Total							Nitrogen (mor	0.00	moles/100g	N2	0.608	moles/min	inj Air only
			Scale:	2					Sulfur(mon)	0.00	moles/100g	Dry O2 w/inj	7.331	vol%	tot w/o coal
									Ash	0.00	g/100g	DryO2w/o inj	6.767	vol%	t w/o coal&inj
Stage	Initial(g)	Final(g)	Net(g)	% in size range	Cum. % R. size max	Size Range micrometers	T/C Port	Temp, C	H2O	0.00	moles/100g	Coal Fraction	0.000	mdotcoal/100g	
												CO2	1.461	moles/min	total
									mdot coal	0	g/min	H20	2.921	moles/min	total
Presseperator	0.32566	0.32802	0.00236	37.34	62.66	10.0 & up	B	1207	Probe inlet T	969	degC	N2	15.253	moles/min	total
0	0.29576	0.29730	0.00054	8.54	54.11	9.0 -10.0	C	1185	Impactor inlet	100	degC (est. T)	SO2	0.0000	moles/min	total
1	0.29723	0.29765	0.00042	6.65	47.47	5.8 - 9.0	D	1164	Vacuum Rate	9.5	in Hg	O2	1.461	moles/min	total
2	0.32749	0.32787	0.00038	6.01	41.46	4.7 - 5.8	E	1144	Vacuum Rate	23	degC (est. T)	Dry O2	7.331	vol%	total
3	0.32592	0.32636	0.00044	6.96	34.49	3.3 - 4.7	F	1107	Vacuum Rate	72	CFH	H20 wt	9.099	mass fraction	
4	0.32628	0.32675	0.00047	7.44	27.06	2.1 - 3.3	G	1068	coal flow time	12.88	min				
5	0.32637	0.32672	0.00035	5.54	21.52	1.1 - 2.1	H	1023				mol wt wet	27.989	g/mol	
6	0.32631	0.32643	0.00012	1.90	19.62	0.7 - 1.1	I	969				dens @inlet	274.636	g/m^3	
7	0.32709	0.32722	0.00013	2.06	17.56	0.4 - 0.7	J	888				mdot duct	616.779	g/min	minus ash
Backup Filter	0.33100	0.33211	0.00111	17.56	0.00	0 -0.4	K	821				vduct	69.252	meters/min	
												vduct	3.787	ft/sec	
		total mass:	0.00632						dens@STP	1292.10	g/m^3	dens@imp	914.473	g/m^3	
												mol wt dry	29.516	g/mol	
												dens @rota	829.625	g/m^3	
Notes:												volflowrateroto	0.028	m^3/min	
												volflowrateroto	0.997	ft^3/min	
* Left the filter in the impactor for an extra 15 minutes (beyond the nominal 20 minutes). Shouldn't be a big deal.															
												mdotroto	23.420	g/min	
* Presep has some ash, but not alot. Filter is pretty dirty.												mdotimp	25.602	g/min	
												volflwimp	0.028	m^3/min	
												volflwimp	0.989	ft^3/min	
												vinlet	581.462	m/min	
												vinlet	31.795	ft/sec	
												mdotcoal	0.00000	g/min	
									actual ash:	0.00632	g	expected ash	0.0000	g	
												%Diff ash	100.000	%	based on actu

APPENDIX I: HOMOGENEOUS AND HETEROGENEOUS CONDENSATION COMPETITION MODEL

```
(* This code predicts the fate of vapor phase condensing species in a
  hot gas environment containing foreign particles. The heterogeneous
  condensation rate is assumed to be driven exclusively by diffusion
  to the particle surface. The rate is approximated for the entire
  range of Kn by the Fuchs and Stutugin (1971) relation.  The
  freestream vapor pressure is incrementally recalculated as
  condensation depletes the system.  Homogeneous nucleation and
  condensation is assumed to collect all remaining vapor phase
  material when/if the critical saturation ratio is achieved *)

Off[General::spell1]
Clear[nmolwt, dif, nliqdens, nσ, n, λ, kn, k, s, m, i, del, time, d]
```

(Universal constants *)*

```
k = 1.380*^-23;  (* ¬Boltzmann constant, N m/K *)
n_av = 6.023*^26; (* ¬Avogadro, molecules/kmol *)
gasconst = k * n_av ; (* J/(kmol·K) *)
```

```
(* NaCl properties *)
(* Properties compiled from Physical and Thermodynamic
  Properties of Pure Chemicals Data Compilation,
 T.E Daubert and R.P. Danner, editors *)

nmolwt = 58.443; (* ¬NaCl molecular wt, kg/kmol *)
nbp = 1738.15; (* ¬NaCl normal boiling point, K *)
m = nmolwt / n_av; (* ¬NaCl molecule weight, kg/molecule*)
nliqdens[τ_] := .40073 / (.10591^(1+(1-τ/3400)^.37537)) ;
(* ¬NaCl liquid density for 1073 K < T < 3400 K, kmol/m^3 *)

nmolvol = 1 / nliqdens[nbp];
(*¬NaCl molal volume at boiling point, m^3/kmol*)
ncoldia = (1.18 * 10^-9) * nmolvol^(1/3);
(* ¬NaCl collision diameter,
 meters.  Estimate based on method presented in Perry's
  Chemical Engineer's Handbook, 4 th ed. McGraw-Hill, 1963 *)

psat[τ_] :=
 Exp[56.543 - (2.6153*^4) / τ - 4.2034 * Log[τ] + (7.9833*^-4) * τ] ;
(* ¬NaCl saturated vapor press,
 1074 K < T < 1738 K, Pa.  Extrapolation to lower temperatures is
  similar to saturation pressure from NASA equilbrium code.*)

nσ[τ_] := .20133 * (1 - τ / 3400)^1.4978 ;
(* ¬NaCl surface tension for 1074 K < T < 1738 K, N/m *)

bdl = 2.667*^-10 ; (* NaCl bond length,
 meters.  CRC Handbook of Chemistry and Physics, 75 th Ed. *)
v_a = (4/3) π (ncoldia / 2)^3 ; (*  ¬NaCl molecule volume, estimate, m^3 *)
```

(* Other properties of the system *)

```
amolwt = 28.84; (* ¬Air molecular wt, kg/kmol *)
psys = 101325; (* ¬system pressure, Pa *)
```

(* NaCl diffusivity *)

```
(* prediction
  method from Perry's Chemical Engineers handbook*)

acoldia = 3.617 * 10^-10; (* ¬air collisional diameter, meters *)

id = .48; (* ¬collision integral for diffusion,
 f (k*T/energy-of-molec-interaction), from Perry's, # *);

coldia = (acoldia + ncoldia) / 2;
```

$$bee = \left(10.7 - 2.46 * \left(\frac{1}{nmolwt} + \frac{1}{amolwt}\right)^{.5}\right) * 10^{-4} * 1.01325 * 10^{-19};$$

```
(* ¬term in diffusivity equation,
 from Perry's, ((Pa*m^2*(kg/kmol)^.5)/(K^(1/2))) * (m^2/sec) *)
```

$$dif[\tau\_] := \frac{bee * \tau^{\frac{1}{2}} * \left(\frac{1}{nmolwt} + \frac{1}{amolwt}\right)^{.5}}{psys * coldia^2 * id} \quad (*(m^2)/sec*);$$

```
(* ¬diffusivity, mks units on all variables *)
```

(* Hot gas property functions *)

```
n[τ_] := psys / (gasconst * τ) ; (* ¬Total molar density, kmol/m^3 *)
```

$$\lambda[\tau\_] := 1 / \left(\sqrt{2}\ \pi\, n[\tau]\, n_{av}\, (3.385*^{-10})^2\right);$$

```
(* ¬Mean free path, meters *)
kn[τ_, dia_] := λ[τ] / dia ; (* Knudsen number, heteroparticle *)
```

(* Define condensation functions *)

```
current = 1*^6 ; (* droplet current, defines s_crit, molecules/cm^3 sec *)

het[τ_, pinf_, dia_] :=
 (2 π dia * dif[τ] (pinf - psat[τ] * Exp[4 nσ[τ] v_m / (dia * k τ)]) / (k * τ)) *
((1 + kn[τ, dia]) / (1 + 1.71 * kn[τ, dia] + 1.333 * (kn[τ, dia])^2));
     (* ¬diffusion rate to het particle,
 including Fuchs and Stutugin (1971) approximation, molecules/sec *)

s_crit[τ_, p_] := Exp[((-(16 π (nσ[τ])^3 v_m^2)) / (3 (k τ)^3)) /
      (Log[current / (2 * (p / (2 π m k τ)^.5) * ((p / (k τ)) v_m^(2/3)) *
  ((nσ[τ] v_m^(2/3)) / (k τ))^.5)])]^.5 ;
(* ¬saturation ratio at which homogeneous condensation starts,
 adapted from Friedlander (1977) *)

dcrit[τ_, p_] := 4 * nσ[τ] * v_m / (k * τ * Log[s_crit[τ, p]]);

i[τ_, p_, s_] := 2 * (p / (2 π m k τ)^.5) * ((p / (k τ)) v_m^(2/3)) *
  ((nσ[τ] v_m^(2/3)) / (k τ))^.5 * Exp[(-(16 π (nσ[τ])^3 v_m^2)) / (3 (k τ)^3 (Log[s])^2)]; (* droplet current
  calculated from saturation ratio, molecules/cm^3 sec, Friedlander (1977) *)
```

(* "Do" loop to examine vapor fate as a function of multiple input variables *)

```
docount = 0; (* Initialize counter of times through loop *)
ClearAll[para, delmass, sal]; (* clear output variables *)
para = {{"docount ", "dpo ", "dpt ",
   "aeta o ", "aeta t ", "pinit ", "theto ",
   "thett ", "tscrit ", "delmass ", "qrate "}};
AppendTo[para, {"num", "m", "m",
  "num", "num", "Pa", "K", "K", "K", "fract", "K/sec"}];
sal = {{"  ", "  ", "  ",
   "  ", "  ", "  ", "  "}};
(* label output variables *)
```

```
Do[docount = docount + 1; (* start "Do" loop with independent variable *)

(* Heteroparticle properties and quench rate*)
mr = 117.03; (* kgAir/kgWood, mixture ratio *)

kgwood = .47376; (* kg wood in system *)
kgair = mr * kgwood; (* kg air in sytem *)
kmoltot = (kgwood + kgair) / amolwt; (* kmols in system *)

dpo = 7.16 * 10^-6; (* large heteroparticle diameter, meter *)
no = 2.248 * 10^9 ; (* # of large hetero particles *)
dpt = .669 * 10^-6; (* small heteroparticle diameter, meter *)
nt = 1.2496 * 10^12 ; (* # of small hetero particles *)

qrate = 1000 ; (* quench rate, K/sec *)

(* Find the temperature at which hetero
   and homogeneous condensation starts *)

 Off[FindRoot::frmp]; (* suppress machine precision warning *)
  theto = temp /.
    FindRoot[het[temp, pinit, dpo] == 0, {temp, 900}, AccuracyGoal -> 0];
 (* calculate temperature at which
    heterogeneous condensation starts for large particles *)
thett = temp /.
    FindRoot[het[temp, pinit, dpt] == 0, {temp, 900}, AccuracyGoal -> 0];
 (* calculate temperature at which
    heterogeneous condensation starts for smaller particles *)

tscrit = temp /. FindRoot[pinit / psat[temp] - s_crit[temp, pinit] == 0,
     {temp, 750}, AccuracyGoal -> 3];
(* calculate temperature at which homogeneous condensation starts *)
On[FindRoot::frmp]; (* reactivate machine precision warning *)

tf = (theto - tscrit) / qrate; (* time to go from thet to tscrit, sec *)
del = tf / 100 ; (* timestep -
    100 steps over estimated time in condensation zone, seconds *)

(* Loop to determine mass fraction
   captured by heterogeneous condensation *)

For[time = 0; count = 0; pored = 0; ptred = 0;
  step = 1; s_cr = s_crit[tscrit, pinit]; s_sys = pinit / psat[theto];
t = theto; kmols = (pinit / psys) * kmoltot; pres = pinit; Clear[sol];
  sol = {{"s,sys", "s,cr", "pres", "tau", "time", "kmols", "lrgfrac"}};
  AppendTo[
   sal, {"s,sys", "s,cr", "pres", "tau", "time", "kmols", "lrgfrac"}],
(* set initial conditions:  time counter,
   times through For loop counter,
```

```
   large particle partial pressure counter,
   small particle partial pressure counter,
   step counter (for print subroutine),
   homogeneous and heterogeneous saturation ratios, temperature,
   molar density, NaCl partial pressure, clear storage variable,
   and give header names to output variables  *)


s_cr > s_sys && pres ≥ pinit * .01,
 (* test:  continue iteration until the calculated system saturation
    ratio is greater than critical saturation ratio or the
    partial pressure drops to 1/100 th of the inital value *)


time += del, (* step:  increment time step. Time
    is incremented after execution of body loop, below. *)

count = count + 1; (* count times through loop *)

τ = theto - qrate * (time + del / 2);
 (*  average temperature during time increment *)

hetmecho = NIntegrate[ ηo *
    het[theto - qrate * tyme, pres, dpo] 1/n_av, {tyme, time, time + del}];
 (* kmols collected by large
   particle het mechanism during time increment,kmols *)
If[τ ≤ thett,
   hetmecht = NIntegrate[ ηt * het[theto - qrate * tyme, pres, dpt] 1/n_av,
     {tyme, time, time + del}], hetmecht = 0];
 (* kmols collected by small
   particle het mechanism during time increment,kmols *)

kmols = kmols - hetmecho - hetmecht;  (* calculate
   reduction in freestream vapor mass after time increment *)
 pored = hetmecho + pored;
 (* cumulative kmols collected by large particles *)
 ptred = hetmecht + ptred;
 (* cumulative kmols collected by small particles *)
 lrgfrac = pored / (pored + ptred);
  (* fraction of kmols collected
   by the large het particles vs all het particles *)

pres = (kmols / kmoltot) * psys; (* new vapor pressure, Pa *)
 s_sys = N[pres / psat[τ]];
 s_cr = s_crit[τ, pres]; (* calculate vapor pressure,
  new saturation ratio, and new critical saturation ratio *)
AppendTo[sol, {s_sys, s_cr, pres, τ, time, kmols, lrgfrac}];
 (* save new variable values *)
```

```
  If[step == count, AppendTo[sal,
    {s_sys, s_cr, pres, t, time, kmols, lrgfrac}]; step = count + 8]];
 (* save every 8 th new variable value to a variable "sal". Limit
   output so that file is of managable size *) (* end of "For" loop *)

 delmass = (pinit/psys * kmoltot - kmols) / (pinit/psys * kmoltot);
 (* Calculate
   fraction of NaCl mass that condenses on het particles *)

AppendTo[para, {docount, dpo, dpt,
   ηo, ηt , pinit, theto, thett, tscrit, delmass, qrate}];
 (* save output values to variables for later examination *)

dur[docount] = ListPlot[Table[{sol[[i, 4]], sol[[i, 3]]}, {i, 2, count}],
   DisplayFunction -> Identity];
 (* save output data to graphics variable*)

duh[docount] = ListPlot[Table[{sol[[i, 4]], sol[[i, 2]]}, {i, 2, count}],
   DisplayFunction -> Identity],
 (* save output data to graphics variable*)

 {pinit, (5*^-6) * psys, (15*^-6) * psys, (5*^-6) * psys}];
(* End of "do" loop.  The initial
  partial pressure of the condensing vapor is incremented. *)
```

(Export results to external file for further data analysis *)*

```
Clear[stmp]
stmp = OpenWrite[ "out1", PageWidth -> 200];
Write[stmp,
 OutputForm[NumberForm[TableForm[{"mr=", mr}, TableSpacing -> {0, 2}],
   {7, 4}, ExponentFunction -> (If[0 < # < 0, Null, #]&),
   NumberFormat -> (SequenceForm[#1, "e", #3]&)]]];

Write[stmp,
 OutputForm[NumberForm[TableForm[N[para], TableSpacing -> {0, 2}],
   {7, 4}, ExponentFunction -> (If[0 < # < 0, Null, #]&),
   NumberFormat -> (SequenceForm[#1, "e", #3]&)]]];

Write[
 stmp, OutputForm[NumberForm[TableForm[sal, TableSpacing -> {0, 2}],
   {7, 4}, ExponentFunction -> (If[0 < # < 0, Null, #]&),
   NumberFormat -> (SequenceForm[#1, "e", #3]&)]]];
(* save para=
  {docount,dpo,dpt,ηo,ηt,pinit,theto,thett,tscrit,delmass,qrate}
   and sal to an output file named out1.  This file can
   be imported by  Microsoft Excel for data analysis. *)
Close[stmp];
```

```
(* Graphics routines and curve fits for run-
   time display of output *)

afit = Fit[Table[{para[[i, 7]], para[[i, 6]]},
    {i, 3, docount + 2}], {1, tp, tp^2, tp^3, tp^4}, tp]
afitp = Plot[afit, {tp, para[[docount + 2, 7]], para[[3, 7]]},
  DisplayFunction -> Identity];
a = ListPlot[Table[{para[[i, 7]], para[[i, 6]]}, {i, 3, docount + 2}],
  PlotJoined -> False, DisplayFunction -> Identity]
bfit = Fit[Table[{para[[i, 9]], para[[i, 6]]},
    {i, 3, docount + 2}], {1, tp, tp^2, tp^3, tp^4}, tp]
bfitp = Plot[bfit,
  {tp, para[[docount + 2, 9]], para[[3, 9]]}, DisplayFunction -> Identity];

b = ListPlot[Table[{para[[i, 9]], para[[i, 6]]}, {i, 3, docount + 2}],
  PlotJoined -> False, DisplayFunction -> Identity]

d = Show[Table[dur[dummy], {dummy, 1, docount}],
  PlotJoined -> True, DisplayFunction -> Identity]
Show[a, b, d, afitp, bfitp, DisplayFunction -> $DisplayFunction,
 GridLines -> Automatic, Frame -> True, RotateLabel -> True,
 FrameLabel -> {"Temperature, K", "Vapor Pressure, Pa", " ", " "}]

Show[Table[duh[dummy], {dummy, 1, docount}],
 DisplayFunction -> $DisplayFunction,
 GridLines -> Automatic, Frame -> True, RotateLabel -> True,
 FrameLabel -> {"Temperature, K", "Scrit, Pvap/Psat", " ", " "}]


1.74138 10^-9 + 8.24909 10^-7 tp + 0.000250491 tp^2 - 5.76697 10^-7 tp^3 + 3.

-Graphics-

1.85534 10^-9 + 7.95427 10^-7 tp + 0.000233106 tp^2 - 5.57819 10^-7 tp^3 + 3.

-Graphics-

-Graphics-
```

```
(* Subprogram to illustrate the regions of
   heterogeneous and homogeneous condensation*)

dpo = 7.16 * 10^-6; (* large heteroparticle diameter, meter *)
ηo = 3.6346 * 10^7 ; (* # of large hetero particles per m^3 of gas *)
dpt = .669 * 10^-6; (* small heteroparticle diameter, meter *)
ηt = 2.028 * 10^10 ; (* # of small hetero particles per m^3 of gas *)
pvapor = 14 ; (* Pa *)
Plot[{scrit[temp, pvapor], pvapor/psat[temp], het[temp, pvapor, dpo ],
  het[temp, pvapor, dpt], 1}, {temp, 940, 1030}, PlotRange -> {0, 4}]


regions =
 Table[{temp, scrit[temp, pvapor], pvapor/psat[temp], het[temp, pvapor, dpo ],
   het[temp, pvapor, dpt], dcrit[temp, pvapor]}, {temp, 940, 1030, 2}];

PrependTo[regions, {"temp        ", "scrit        ",
  "pvap/psat    ", "het f[dpo]   ", "het f[dpt]   ", "dcrit       "}];

TableForm[regions];

simp = OpenWrite[ "competit", PageWidth -> 200];

Write[simp, OutputForm[
  NumberForm[TableForm[{{"dpo          ", dpo}, {"dpt          ", dpt},
     {"pvapor      ", pvapor}}, TableSpacing -> {0, 2}],
   {7, 4}, NumberFormat -> (SequenceForm[#1, "e", #3]&)]]];

Write[simp,
 OutputForm[NumberForm[TableForm[N[regions], TableSpacing -> {0, 2}],
   {7, 4}, NumberFormat -> (SequenceForm[#1, "e", #3]&)]]];

Close[simp];
```

VITA

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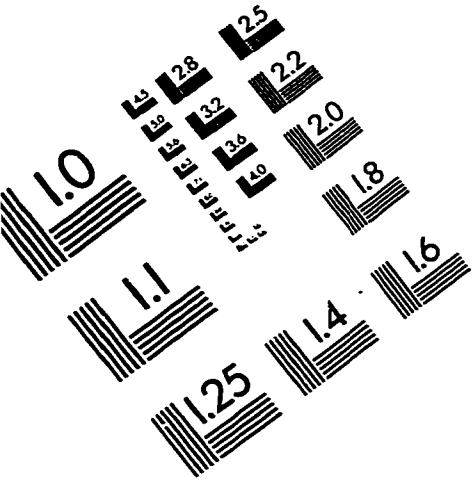
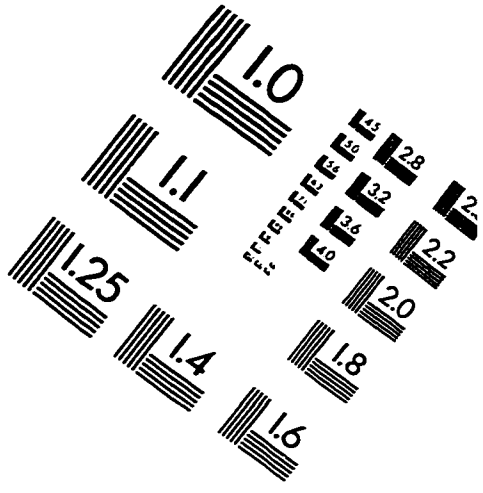
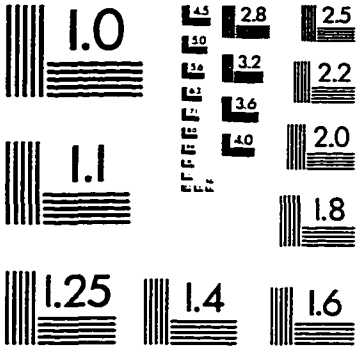
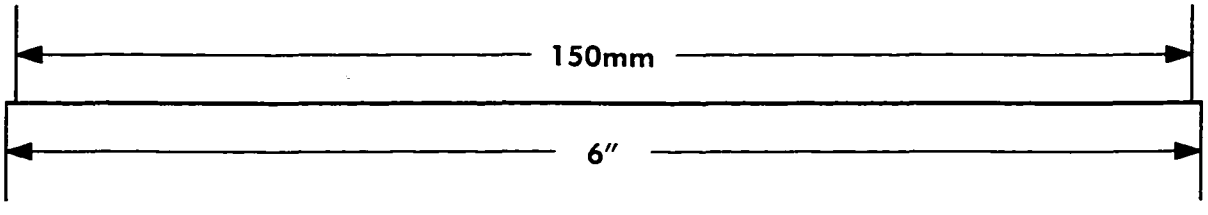
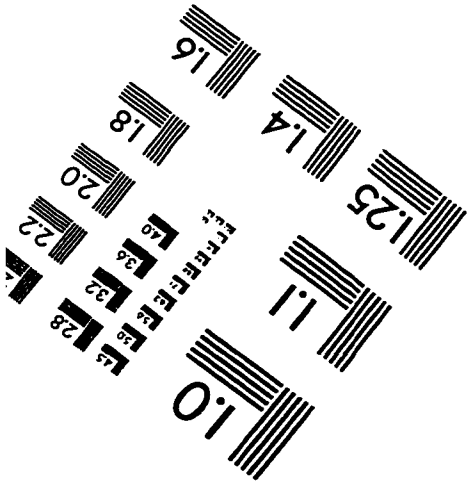
IMAGE EVALUATION TEST TARGET (QA-3)

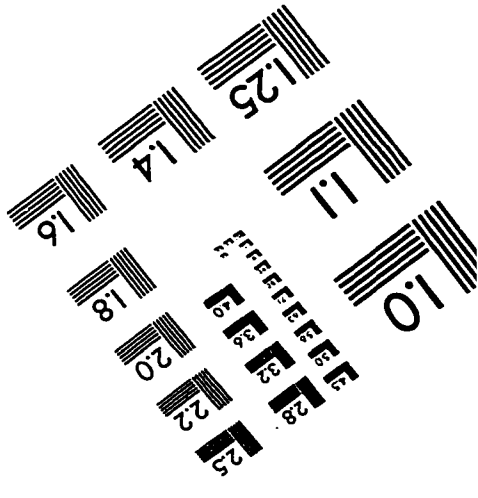












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