AN ABSTRACT OF THE THESIS OF

Varut Phimolmas for the degree of Master of Science in Chemical Engineering presented on December 11, 1996. Title : The Effect of Temperature and Residence Time on the Distribution of Carbon, Sulfur and Nitrogen between Gaseous and Condensed Phase Products from Low Temperature Pyrolysis of Kraft Black Liquor.

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Prof. Wm. James Frederick

Laminar entrained flow reactor (LEFR) was used to determine the effect of temperature and residence time on the distribution of carbon, sulfur and nitrogen between gaseous and condensed phase products from low temperature pyrolysis of kraft black liquor. The operating furnace temperatures were between 400°C-600°C where the effect of condensable organic and organic sulfur compounds may be important. The residence times ranged from 0.3 to 2.0 seconds.

In the evolution of carbon as gases, an oxidizer was used to convert all oxidizable components in LEFR effluent gas to carbon dioxide which was detected by an infrared carbon dioxide meter. With this, measurement of total carbon in the gas phase, the fine particles, and the char residue were made. The carbon yield in the gas phase increased as residence time increased. The higher the temperature, the higher the carbon yield as gases phase at each residence time. The carbon yield in the fine particles differed very little with temperature at residence time below 1.1 seconds. At higher temperature, the carbon yield in the fine particles is about the same at 500°C and 600°C, but lower at 400°C. The

carbon yield in the char residue decreased as residence time increased. The carbon yield in the char residue at 500°C and residence time above 1.1 seconds was a little lower than at temperature 600°C, due to an apparent loss of char at 500°C. The char yield at 500°C was lower than expected based on the 400°C and 600°C data because of accumulation of larger, more highly swollen char particles at the tip of collector at this temperature.

The average of the sum of carbon recovered as char residue, gases, and fine particles was 96.2% at 600°C, 88.1% at 500°C, and 95.7% at 400°C. The main reason for the poorer carbon recovery at 500°C was the loss of char particles which accumulated on the tip of the collector. When the char yield at 500°C is increased so that the carbon balance closed to 96%, the char yield, carbon yield, and sulfur yield at 500°C fell between the values at 400°C and 600°C.

The sulfur yield in the char residue decreased as residence time increased. The higher the temperature, the lower the sulfur yield in the char residue. The nitrogen yield in the char residue also decreased as residence time increased.

The Effect of Temperature and Residence Time on the Distribution of Carbon, Sulfur, and Nitrogen between Gaseous and Condensed Phase Products from Low Temperature Pyrolysis of Kraft Black Liquor

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CHAPTER 1

INTRODUCTION

With the development of technology for converting wood to pulp suitable for paper and the invention of the paper machine during mid-nineteenth century, the production of paper in the U.S. increased by a factor of 10 in the 19^{th} century and almost 50 in the 20^{th} century. This rapid increase of paper production affects not only US paper use but also the environment. This is especially true for the chemical pulping processes. In chemical pulping processes, chemicals are used to extract lignin and separate the fibers to produce pulp for paper making. A lot of chemicals are used and some chemicals and by-products are discharged to environment. The predominant chemical pulping process world-wide is the kraft pulping process.

The kraft pulping process was invented in 1879 by Dahl, a German chemist. Dahl tried to use sodium sulfate was attempted to be used as a makeup chemical for soda pulping to regenerate NaOH; the result was that Na_2S was formed and, unexpectedly, gave much faster delignification and stronger pulp. Since shorter cooking times are required, resulting in less carbohydrate degradation, the kraft process has become the

dominant process for producing wood pulp. Moreover, Dahl invented the kraft chemical recovery process, the most important recovery process for pulping chemicals, which is now used world-wide. The kraft chemical recovery process recovers and regenerates the inorganic cooking chemicals, and generate large amounts of steam and electrical energy by burning the organic matter extracted from the wood. A simplified schematic diagram of the kraft pulping and recovery process is shown in Figure 1.1.

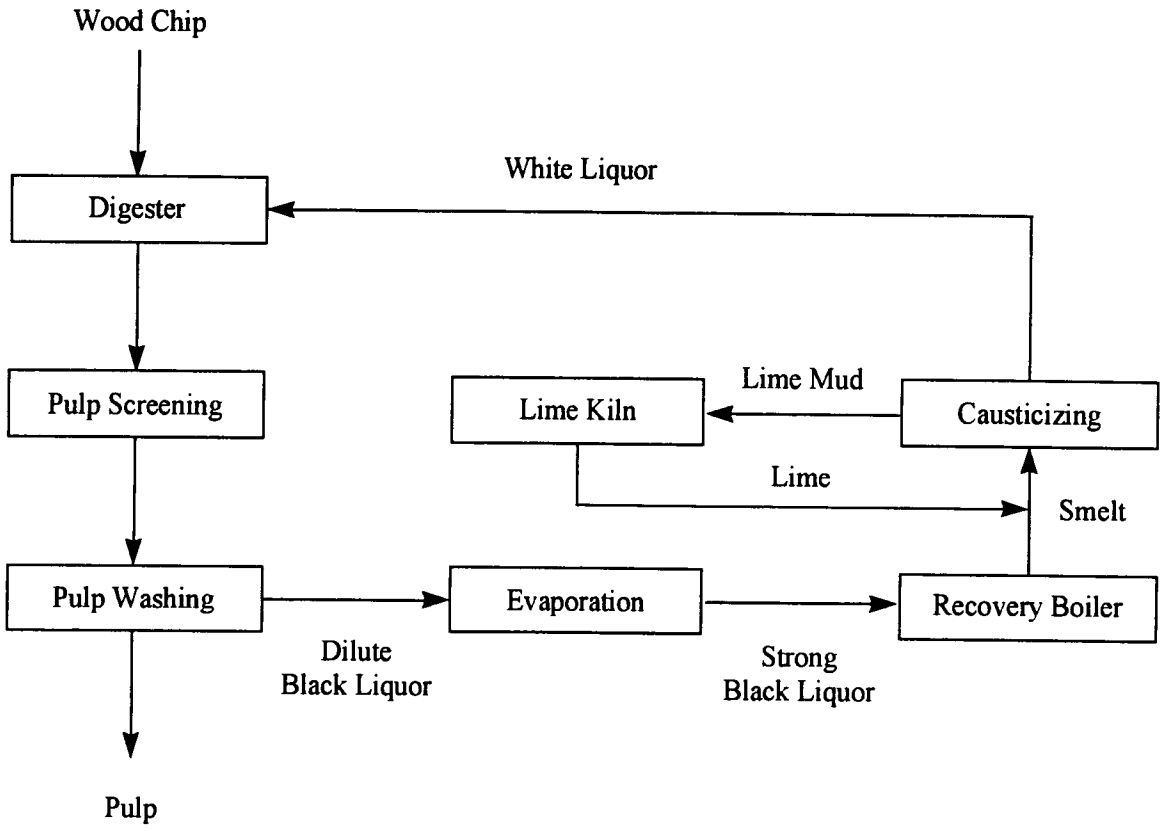

Figure 1.1 Simplified Schematic Diagram of the Kraft Pulping and Recovery Process

1.1 Kraft Pulping and Recovery Process

Kraft pulping is a full chemical pulping process and is useful for any wood species. It gives a high strength pulp, is tolerant to bark, and has an efficient energy and chemical recovery cycle. In kraft pulping, wood chips are mixed with pulping liquor (white liquor) consisting mainly of sodium hydroxide (NaOH) and sodium sulfide (Na_2S). The mixture is then processed in a pressurized reactor (digester) at temperatures of 160-180°C (320-356°F) for 0.5-3 hours to dissolve much of the lignin of wood fibers. After wood chips have been chemically broken down, discrete fibers are liberated and can be dispersed in water and reformed into a web called pulp. Pulp screening is the process provided in order to separated pulp from large shives, knots, dirt, and other debris before going to pulp washing process. Pulp washing is necessary to separate pulp from spent cooking chemicals called dilute black liquor. Proper pulp washing can minimize foaming problem, make-up chemical requirements, and discharge of pollutants. Pulp washers are almost always drum or counter flow washers which use countercurrent flow between stages such that the pulp moves opposite in direction to the flow of wash water. This design allows for the most removal of pulping chemicals with the least amount of water before going to recovery process.

Black liquor is the biomass waste liquor from the kraft pulping process after pulping is completed. It contains most of the original cooking inorganic elements and the degraded, dissolved wood substance. The latter include acetic acid, formic acid, saccharinic acids, numerous other carboxylic acids (all as the sodium salts), dissolved hemicelluloses (especially xylans), methanol, and hundreds of other components. The

weak black liquor, typically at 15% solid content, is fed into the multi-effect evaporators in order to concentrate the weak black liquor to strong black liquor about 65-70% solid content which is suitable for burning in recovery boiler and make heat recovery from liquor combustion as efficient as possible.

The recovery boiler is the most important unit in the recovery process. Tomlinson in conjunction with Babcock and Wilcox developed the first recovery boiler in the early 1930s. This led to the predominance of the kraft process in the past sixty years. Figure 1.2 is a diagram of a conventional Tomlinson kraft recovery boiler.

The purpose of the recovery boiler is to recover the inorganic chemicals as smelt, sodium carbonate (Na_2CO_3) and sodium sulfide (Na_2S), burn the organic chemicals so they are not discharged from the mill as pollutants, and recover the heat of combustion in the form of steam. After dilute black liquor is passed through the multi-effect evaporators, the strong black liquor is sprayed into the recovery boiler through side openings. The water evaporates and the organic materials removed from the wood form a char and then burn.

With respect to black liquor burning, the recovery boiler can be divided into three major zones. The *reducing zone* located at the bottom section is deficient in oxygen, so reduction reactions can occur. This allows the sulfur in the smelt to exit the boiler as Na_2S and not Na_2SO_4, which would be unsuitable for pulping. In the reducing zone, forced-draft fans introduce air near the bottom of the recovery boiler, providing about 40-50% of the air for combustion. The primary air supply is preheated to 150°C (300°F). It burns carbon from the char bed, leaving smelt. The *drying zone*, located about 5 meters above the boiler floor, is where the black liquor is injected and the secondary air ports

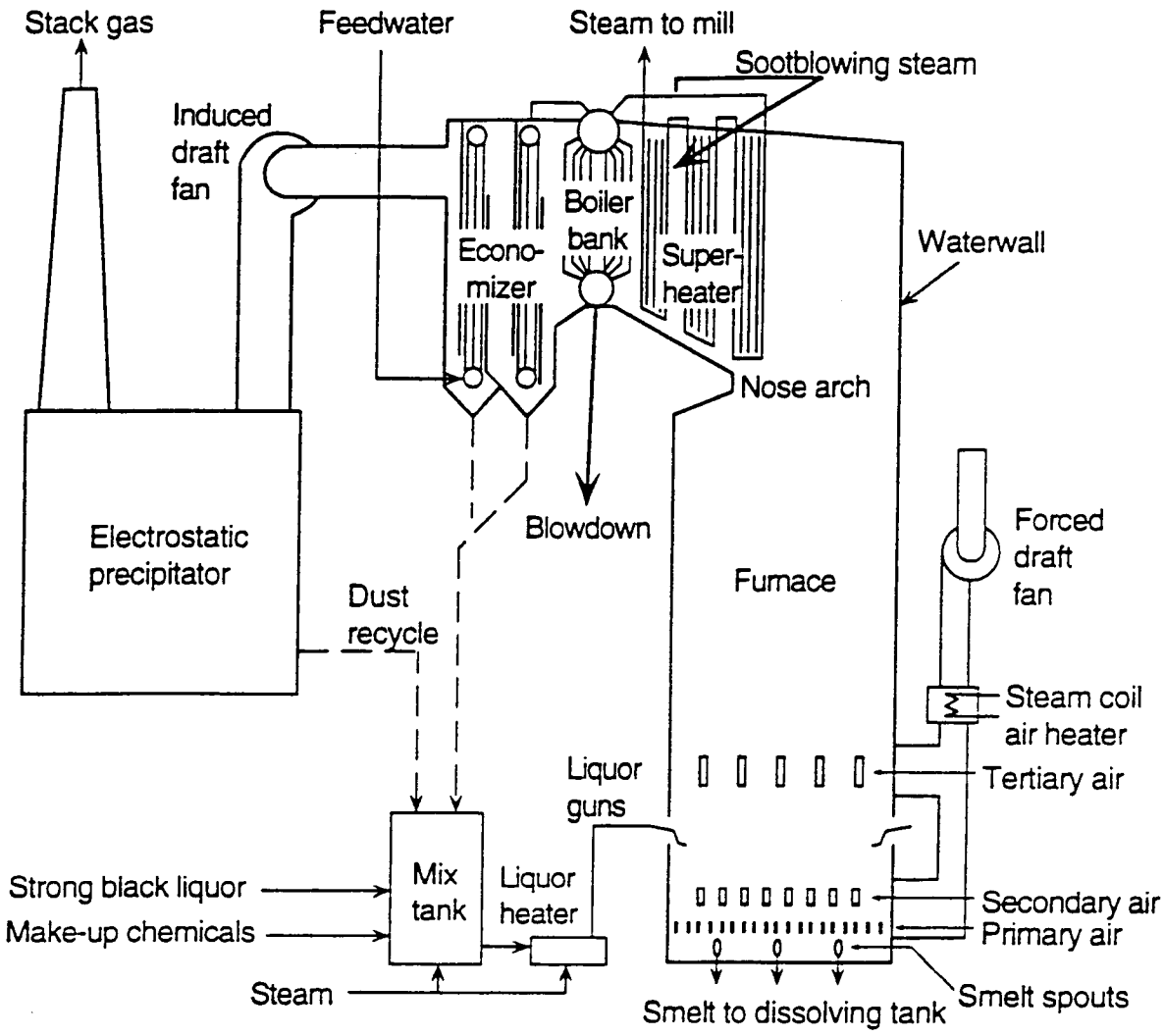

Figure 1.2 The Conventional Tomlinson Designed Kraft Recovery Boiler
(Frederick 1988, p.15)

supply 25-40% of the air required for complete combustion of the organic materials. In the drying zone, the remaining NaOH and sodium salts of organic acids are converted to Na_2CO_3. The *oxidizing zone* located at the upper section is where the remaining 15-20% of the air is supplied. Oxidative conditions are maintained to minimize total reduced sulfur (TRS) and carbon monoxide emission. The overall chemical reactions in the recovery boiler are :

Reduction of make-up chemical :

$$Na_2SO_4 + 4C \rightarrow \mathbf{Na_2S} + 4CO$$

Some examples of reactions in each zone are :

Oxidation zone (upper section) :

$$CO + 1/2O_2 \rightarrow CO_2$$

$$H_2 + 1/2O_2 \rightarrow H_2O$$

$$Na_2S + 2O_2 \rightarrow Na_2SO_4$$

$$H_2S + 11/2O_2 \rightarrow SO_2 + H_2O$$

Drying zone (middle section) :

$$\text{Organics} \rightarrow C + CO + H_2$$

$$2NaOH + CO_2 \rightarrow \mathbf{Na_2CO_3} + H_2O$$

Reduction zone (bottom section) :

$$\text{Organics} \rightarrow C + CO + H_2$$

$$2C + O_2 \rightarrow 2CO$$

$$Na_2SO_4 + 4C \rightarrow \mathbf{Na_2S} + 4CO$$

$$C + H_2O \rightarrow CO + H_2$$

At the bottom of the furnace of recovery boiler, the inorganic pulping chemicals are recovered as a molten smelt (Na_2CO_3 and Na_2S). Molten smelt is removed from the furnace and dissolved in water in the green liquor dissolving tank located below the recovery boiler to produce green liquor. The green liquor is then clarified in a settling tank or filter to remove dregs (undissolved materials in the green liquor) before the green liquor is causticized. The combination of molten smelt and large quantities of water in the boiler tubes make recovery boilers potentially explosive, a critical concern at all times.

The green liquor is mixed with lime (CaO) in a chemical reactor called a slaker. In the slaker, the lime is slaked to produce $Ca(OH)_2$. The reaction temperature is 99-105°C (210-220°F) and retention time is 10-15 minutes. Then, the solution is passed through the causticizers which are two to four continuous flow stirred reactors. The contents are stirred with a pitched blade turbine at 70-80 rpm. The liquor/lime slurry flows through them in series with a total retention time of 1.5-2.5 hours. In causticizers, the causticizing reaction is achieved when green liquor is treated with slaked lime ($Ca(OH)_2$) to regenerate the NaOH, white liquor before going to white liquor clarifier. The two chemical reactions are shown in the following.

Slaking reaction :

$$CaO + H_2O \rightarrow Ca(OH)_2$$

Causticizing reaction :

$$Ca(OH)_2 + Na_2CO_3 \leftrightarrow 2NaOH + CaCO_{3(S)}$$

A gravity sedimentation tank, the white liquor clarifier, is provided to remove the lime mud ($CaCO_3$) form the white liquor with the turbidity below 100 ppm. Single compartment white liquor clarifiers with at least 12 hours storage time is now used much more commonly, than the older multi-compartment clarifier design. The white liquor exiting the clarifier is ready for use in pulping.

Lime mud ($CaCO_3$) is washed to remove sodium salts in a lime mud washer and lime mud filter. The lime mud washer removes most of the 15-20% entrained alkali (Na_2O basis) from the lime mud. This is usually accomplished by sedimentation washing. In a settling tank (or two in series) where fresh (make-up) water is used to wash the lime mud. If it were not removed, the sodium salts would cause slagging in the kiln and reduced sulfur compounds would be released as H_2S. The lime mud filter is a rotary drum vacuum filter washer used for final lime washing and thickening to 60-70% solids before the lime enters the lime kiln. The lime kiln, normally rotary kiln, is a chemical reactor in which lime mud ($CaCO_3$) is dried, heated (with the retention time around 2-3 hours), and converted to lime (CaO). Lime is now ready to be recycled to slaker and mixed with green liquor. The process that occurs in the lime kiln is known as calcining, described by the chemical equation below.

Calcining reaction : $CaCO_3 + \text{heat} \rightarrow CaO + CO_{2\,(g)}$

In summary, the recovery process for kraft black liquor is as follows :

1. Concentration of black liquor by evaporation.

2. Combustion of strong black liquor to give the recovered inorganic chemicals in the form of smelt. The smelt, Na_2S and Na_2CO_3, dissolved in water gives green liquor.
3. Preparation of the white cooking liquor from green liquor. This is done by converting the Na_2CO_3 to NaOH using slaked lime ($Ca(OH)_2$), which is recovered as lime mud ($CaCO_3$).
4. Regeneration of calcium carbonate, $CaCO_3$, to calcium hydroxide, $Ca(OH)_2$.

1.2 Motivation of the Study

As discussed in the previous section, the recovery process is very important in kraft pulping. The recovery boiler is the main unit operation in the recovery process. Even though recovery boilers have been operated for more than fifty years, the fundamental chemical processes, especially pyrolysis and char combustion, remain not well understood. With the complex chemical composition of black liquor, it is difficult to predict the pyrolysis behavior of black liquor. It is also difficult to relate operational problems to liquor-specific characteristics.

During black liquor burning, the droplets dry, devolatilize, the resulting char burns, and finally homogeneous combustion of volatile gases occurs. Pyrolysis is an important step in which many species are released as volatiles and transformed to different species. Some of the species released cause problems with recovery boiler operation and control and/or the environment. These include alkali metal, sulfur release, nitrogen release, and aromatic hydrocarbon release. These chemical release are difficult to predict and explain.

Previous studies of black liquor pyrolysis can be divided into two categories, low heating rate measurements (Bhattacharya et al.,1986; Kubes, 1984; Li and van Heiningen, 1991) and single droplet measurements (Gairns et al., 1994; Hupa et al., 1982, 1987; Verrill and Nichols, 1993). Even though these studies provided a great deal of empirical understanding of black liquor burning, the data obtained is of limited value with respect to fundamental burning characteristics. Low heating rate experiments are of limited value because pyrolysis is complete before the particles begin to approach furnace temperatures. This can result in a higher char yield (Niksa et al.,1984) and a distribution of gaseous products that are not representative of those obtained at higher heating rates. Single droplet data are often difficult to interpret because of the steep temperature gradients within the droplets during devolatiolization. Due to these limitations, the data obtained is difficult to apply directly to industrial problems. Thus, the other new experimental method need to be used to provide data that can be used to understand and model black liquor pyrolysis.

Laminar entrained-flow reactors (LEFR) are commonly used to measure the pyrolysis and combustion characteristics of coal and other solid fuels (Quann et al., 1982; Hurt and Mitchell, 1992). There are two important features of LEFRs that make it possible to obtain fundamental pyrolysis and combustion data. First, a LEFRs the small particles of black liquor solids that are processed can be heated very rapidly, and temperature differences within the particles are negligible. Another important advantage is that all aspects of pyrolysis and combustion, e.g. carbon volatilization, char formation, sulfur release, sulfate reduction, and volatilization of sodium, potassium, and chloride, and the formation and destruction of nitrogen species, can be studied in a single experiment.

The products from a LEFR pyrolysis experiment with black liquor are char, fine particle, and gas. The procedures used to analyze these products depend on the purpose of study. For example, the inorganic species in char and fume can be analyzed by using a capillary electrophoresis analyzer (CES). NO in the product gas can be analyzed by using a chemiluminesence NO-NO_x analyzer. A Fourier-transform infrared spectrometer can be used to analyze hydrocarbon and organic sulfur species in the LEFR product gas.

Although FTIR can be used to analyze many hydrocarbon species in the LEFR product gas, there are important condensable products that can not be measured. These condensable products may contain aromatic hydrocarbon structure as well as sulfur. In an earlier experimental study of the pyrolysis products from black liquor using a laminar entrained-flow reactor (Sricharoenchaikul, 1994), the major carbon containing species were CO, CO_2, methane, and acetylene. The fraction of carbon converted to CO, CO_2, and methane increased continuously with increasing experimental temperature from 700 to 1000°C. Other carbon species went through a maximum with time at lower temperatures. The distribution of carbon among pyrolysis products (char, fume particles, and gas) was also measured in that study. Carbon not recovered in the gas, char, or fume particles was assumed to have condensed as tar. No experimental data were obtained at lower temperatures (<700°C) where the effect of condensable organic and organic sulfur compounds may be important. Condensable organic compounds have caused problems in low temperature black liquor gasifiers.

In the work reported here, the objective was to obtain new data on the pyrolysis rate for kraft black liquor solids at temperatures of 600°C and below. The data is to be used to better understand the kinetics of carbon conversion to gases during pyrolysis and

to lead to a model for carbon-containing gas evolution during pyrolysis of kraft black liquor.

1.3 Thesis Organization

Chapter 2 explains the objectives of this study. Chapter 3 is a literature review which discusses the general characteristics and composition of kraft black liquor solids, black liquor droplet combustion, the effect of temperature and residence time on the carbon in char residue and gas, the effect of temperature and residence time on the nitrogen and sulfur in char residue and gas, and sulfur species distributions from rapid pyrolysis of kraft black liquor solids. Chapter 4 explains the experimental procedure including the experimental set-up, and operation of the laminar entrained-flow reactor (LEFR), cyclone/filter assembly, product gas oxidizer, CO_2 gas analyzer, material preparation, and the experimental conditions. It also illustrates the procedures used in the experiments and analysis. The experimental results and discussion are presented in Chapter 5, and the conclusions of the study are summarized in Chapter 6. Finally, recommendations for future work are presented in Chapter 7.

Appendix A explains the principles and operation of the carbon, nitrogen and sulfur analyzer (CNS) used in this work. In Appendix B, experimental data and analytical results are presented.

CHAPTER 2

THESIS OBJECTIVES

The objectives of this were to :

1. Determine the effect of residence time and temperature on the distribution of carbon in the char residue, fine particles and gas products from pyrolysis of kraft black liquor solids at 600°C and below.

2. Determine the effect of residence time and temperature on the distribution of nitrogen in the char residue.

3. Determine the effect of residence time and temperature on the distribution of sulfur in the char residue.

CHAPTER 3

LITERATURE REVIEW

3.1 Characteristics and Composition of Black Liquor Solids

In the kraft pulping process, black liquor is an important chemical by-product. It contains most of the original inorganic cooking chemicals (mainly sodium and sulfur compounds), alkali lignin, saccharinic acids, polysaccharides, and other organic matter separated from wood during the pulping process. The initial concentration of weak black liquor is typically 15% dry solids which is not suitable for burning. Thus, evaporation is used to concentrate the weak black liquor to strong black liquor (about 65-70% solid content). An elemental analysis of black liquor solids from a typical black liquor from North American and Nordic wood species is shown in Table 3.1, and the range organic species constituting Kraft black liquor is shown in Table 3.2.

From the Table 3.1, carbon and oxygen are major elements in kraft black liquor. This corresponds with the organic species in kraft black liquor, i.e. that alkali lignin and hydroxy acids are the major organic species. In most North American wood-species, lignin comprises 18-25% of hardwoods, and 25-35% of those in softwoods. Lignin is a complex polymer consisting of phenylpropane units, is amorphous, and has a three dimensional structure. Lignin's molecular weight in wood is very high and not easily measured. Lignin is the adhesive or binder in wood that holds the fibers together. The

glass transition temperature of lignin (softening temperature) is approximately 130-150°C (265-300°F).

Table 3.1 Elemental analysis of typical black liquor solids from North American and Nordic wood species (Frederick et al.,1995)

Element	wt.%
Carbon	34 - 39
Hydrogen	3 - 5
Oxygen	33 - 38
Sodium	17 - 25
Sulfur	3 - 7
Potassium	0.1 - 2
Chloride	0.2 - 2
Nitrogen	0.04 - 0.2
Other	0.1 - 0.3

Table 3.2 Organic species in typical black liquor solids from North American and Nordic wood species. (Frederick et al., 1995)

Organic species	wt.%
Alkali lignin	30 - 45
Hydroxy acids	25 - 35
Extractives	3 - 5
Acetic acid	5
Formic acid	3
Methanol	1

The other hydrocarbon-organic species in kraft black liquor are extractives. Extractives are compounds diverse in nature with low to moderately high molecular weights. They are by definition soluble (extractable) in organic solvents or water. Extractives impart color, odor, taste, and, in some cases, decay resistance to wood. There are hundreds of compounds in the extractives of a single wood species. The composition of extractives varies widely from species to species. Typical examples of extractives are terpenes, triglycerides and their component fatty acids, and phenolic compounds.

Terpenes are a broad class of compounds appearing in relatively high quantities in the softwoods. Species such as pines have large amounts of terpenes. Mills pulping highly resinous species with the kraft process collect the terpenes and sell them. Hardwoods have very small amounts of the terpenes. Terpenes are made from phosphated isoprene units in the living wood cells. It is usually very easy to identify the individual isoprene building blocks of a terpene. Isoprene has the empirical formula of C_5H_8, monoterpenes have the empirical formula of $C_{10}H_{16}$, sesquiterpenes are $C_{15}H_{24}$, and the resinacids are oxygenate diterpenes and have the empirical formula of $C_{20}H_{32}O_2$. Turpentine consists of the volatile oils, especially the monoterpenes such as α- or β-pinene; these are also used in household pine oil cleaners that act as mild disinfectants and have a pleasant aroma. Because turpentine consists of volatile compounds, it is recovered from the vent gases given off while heating the digester.

The triglycerides and their component fatty acids are another important class of extractives. Triglycerides are esters of glycerol (a trifunctional alcohol) and three fatty acids. Most fatty acids exist as triglycerides in the wood; however, triglycerides are saponified during kraft cooking to liberate the free fatty acids. The principal components

are the C-18 fatty acids with varying amounts of unsaturation, that is, the presence of carbon-carbon double bonds such as oleic acid, linoleic acid, and linolenic acid.

Phenolic compounds are more common in heartwood than sapwood and are major constituents in the bard of many wood species. Some classes of these compounds are the flavonoids, which have a $C_6C_3C_6$ structure; the tannins, which are water-soluble; polyflavonoids and other polyphenol compounds that are used to convert animal hides into leather; and the lignans, which have two phenyl propane units (C_6C_3-C_3C_6) connected between the β-carbon atoms.

Another interesting aspect of the elemental composition of kraft black liquor is sulfur. Release of sulfur gases is a serious problem. Much of the sulfur released during black liquor burning is in the form of total reduced sulfur (TRS) which results in an odor problem. Also, these TRS gases can further react with oxygen to form sulfur dioxide (SO_2) which contributes to formation and hardening of deposits in heat transfer sections and corrosion of the recovery boiler. The sulfur in black liquor is present mainly in the form of inorganic sulfur such as sodium sulfide (Na_2S), sodium thiosulfate ($Na_2S_2O_3$), sodium sulfate (Na_2SO_4), sodium sulfite (Na_2SO_3), and polysulfide (Na_2S_x). These four inorganic sulfur species constitute 65-75% of the total sulfur in black liquor. Differences in the pulping and recovery processes from one mill to another can affect the distribution of sulfur species in kraft black liquor. For example, sodium sulfide is not found in oxidized black liquor, and the thiosulfate content of oxidized black liquor is higher than that of unoxidized liquors.

3.2 Black Liquor Droplet Combustion

There are four major stages that occur during black liquor droplet combustion, similar to those in the combustion of other solid and liquid fuels. Although the stages may overlap, it can be useful to visualize the stages of combustion as being separate and distinct. Figure 3.1 shows qualitatively the characteristic stages: drying, devolatilization, char burning, and smelt reactions. In the first stage, *drying*, water in the droplet is evaporated. The black liquor droplet does not ignite and the other stages can not begin until much of the water has been evaporated. The second stage of burning, *devolatilization*, is marked by the appearance of a flame at the droplet surface. The flame quickly engulfs the droplet, and the droplet swells continuously to several times its original volume while the flame is present. The flame disappears at the point when the droplet reaches its maximum volume. In the devolatilization stage, the organic material in black liquor droplet is degraded irreversibly into volatile compounds consisting of CO, CO_2, H_2O, light hydrocarbons, tars, H_2S and TRS compounds. These volatile compounds are burned when contacted with oxygen. The residual organic carbon along with inorganic (mostly in form of sodium salts) from the pulping chemicals is known as char.

Devolatilization is the loss of volatile matter from thermal decomposition of the organic fraction of black liquor. It begins when the droplet temperature approaches 200°C. The term devolatilization and pyrolysis are often used synonymously but devolatilization actually refers to the loss of volatile matter on heating while pyrolysis refers to the processes that occur, including devolatilization, when a particle or droplet is

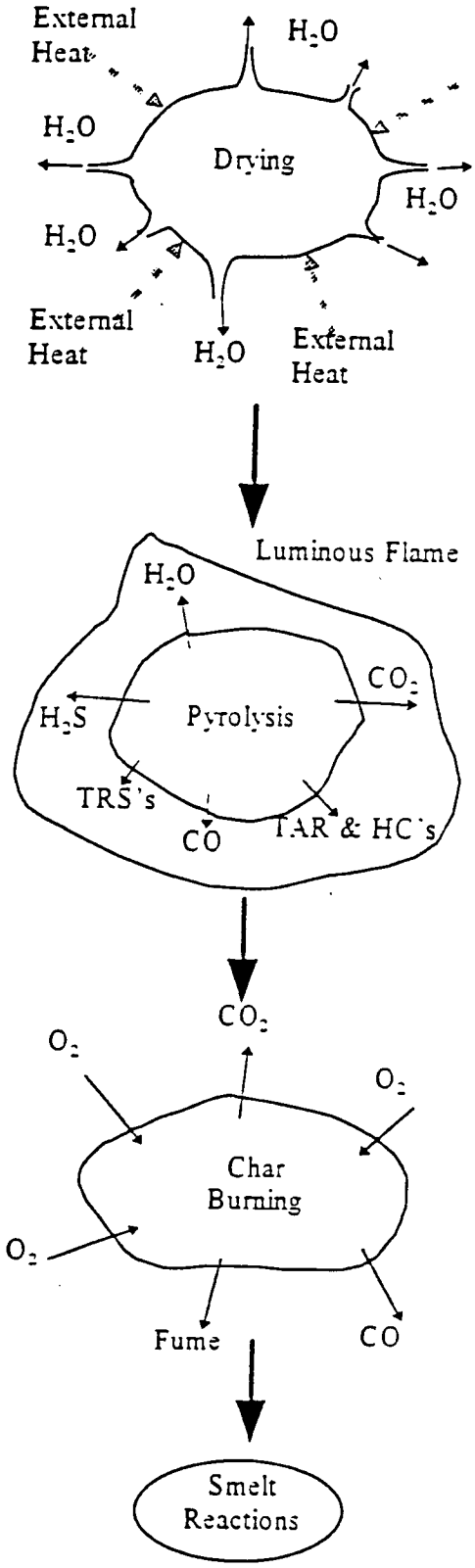

Figure 3.1 Black Liquor Droplet Burning Stages

heated in an inert environment. Devolatilization continues until a black liquor droplet has been reduced to a char particle, but pyrolysis continues as long as the char particle remains in a hot environment.

The third stage, *char burning*, begins when a black liquor particle has reached its largest volume and the flame around the droplet disappears. During the char burning stage, carbon in black liquor is oxidized to form CO and/or CO_2. The black liquor particle shrinks during burning and becomes a smelt droplet at the end. During char burning, carbon in the black liquor particle reacts with oxygen, CO_2, and H_2O vapor at the particle surface to form CO and/or CO_2. In the fourth and final burning stage, known as the *smelt reactions stage*, the smelt reacts with the surrounding gases and Na_2S is oxidized to Na_2SO_4. In this stage, fuming may occur and small particles may be ejected violently from the smelt droplet.

3.3 Pyrolysis of Kraft Black Liquor

Pyrolysis is the important part of the process of burning kraft black liquor. Pyrolysis can be often defined as chemical decomposition due to exposure to high temperature (Tromp and Moulijn, 1988) or specifically as thermal decomposition under inert atmospheres. Pyrolysis of organic matter produces three primary product groups including hydrogen rich gases, hydrogen rich condensable vapors (tar), and a carbon rich residue (char).

During pyrolysis, the least stable bonds in aromatic polymers such as lignin which are the functional group bridges between the aromatic building blocks are the first to

break. Bhattacharya et al (1986) stated that at low temperature, the carbonyl and mercaptan bonds are the weakest in black liquor. Their breaking leads to the production of CO_2 and H_2S. When the least stable bonds in aromatic polymers are broken, free radicals are produced. Then, the volatile free radicals react with other volatile free radicals to form stable volatile compounds, while the non-volatile free radicals react through polymerization and condensation reactions to form a more aromatic, carbon-rich condensed material. Stable volatiles may further crack to produce lighter hydrocarbons in higher temperature regions. With the bond breaking that occurs, higher temperatures cause dehydration reactions which produce hydrogen and carbon monoxide.

Pyrolysis experiments have traditionally been classified as either slow or rapid (Tromp and Moulijn, 1988). The heating rate of slow pyrolysis experiments is 0.1-1°C/s (Bhattacharya et al., 1986; Kubes, 1984; Li and Van Heiningen, 1991; etc.). The heating rate of rapid or flash pyrolysis experiments is 100-1000°C/s (Forssen et al., 1991; Gairns et al., 1994; Harper, 1989; Hupa et al., 1987).

Studies on the pyrolysis of black liquor solids indicate that pyrolysis begins when the organic matter in black liquor solid begin to degrade thermally between 200 and 250°C (Feuerstein et al., 1967; Kubes et al., 1982; Bhattacharya et al., 1986; Li, 1986; Miller, 1986; Soderhjelm et al., 1989; Li and Van Heiningen, 1991; Gairns et al., 1994; Srichronchaikul et al., 1995). The main gas compounds reported to be produced by black liquor pyrolysis are H_2, CO, CO_2, CH_4, C_2H_6, C_2H_2, (Feuerstein et al, 1967; Bhattacharya et al, 1986) and the other minor gas are water vapor, tars, and light sulfur-containing gases. Devolatilization is essentially complete when the residue temperature reaches 400-

500 (Li and van Heiningen,1991). The char residue contains the fixed carbon, some hydrogen, and most of the inorganic matter.

3.3.1 Char Residue Yields from Pyrolysis of Black Liquor

For most solid fuels, the char residue yields from pyrolysis vary widely depending upon fuel characteristics and process conditions. The char residues from coal and biomass fuels are normally reported on an ash-free basis. Black liquor yields much more ash residue than coal or most other biomass fuels, typically 35-45% of the dry solids mass. Thus, the char residue from pyrolysis of black liquor solids normally refers to the solid residue from pyrolysis including the ash as well as carbon and other elements that remain from the organic fraction. For the inorganic residue from pyrolysis or combustion, there are relatively volatile sodium salts including chloride, sulfate and/or sulfide, and carbonate (Reis et al., 1995).

For pyrolysis of coals at temperatures greater than 600 °C, char residue yields typically range from 35 to 70% on a dry, mineral ash-free basis. Both kinetic and stoichiometric factors determine the distribution of carbon between volatile gases and char residue. During devolatilization, the yield of carbon as volatile gases increases with increasing reaction temperature, and the fixed carbon in the char residue decreases (e.g. Anthony et al., 1975; Kobayashi et al., 1977; Solomon and Colket, 1979; Suuberg et al., 1979). Char residue yield data obtained for pyrolysis to the same final temperature but at different heating rates has at most a minor effect on pyrolysis char yield (Sprouse and Schuman, 1981; Niksa et al., 1985).

For pyrolysis of biomass fuels, char residue yields are much lower than with coals because of the higher oxygen content of biomass. The char residue yield from rapid pyrolysis of cellulose is less than 5% for pyrolysis temperatures above 400 (Hajallgol et al., 1982; Scott et al., 1988). For pyrolysis of lignocellulosic materials, char residue yields are higher, typically between 10-25% on a mineral free basis for rapid pyrolysis at temperatures above 500°C (i.e. Scott and Piskorz, 1984; Scott et al., 1985; Scott et al., 1988). The char residue yields for the larger particles are greater which indicate that there may be an effect of heating rate on pyrolysis residue yield. There is less data on the effect of heating rate on the split of carbon between volatile products and char residue species.

For pyrolysis of black liquor, data on the distribution of pyrolysis products between volatile matter and char residue is very limited. Bhattacharya et al. (1986) pyrolyzed low-sulfur black liquor solids in ceramic boats to final temperatures of 620-740°C and obtained char residue yields of 48-52%. Gairns et al. (1994) reported char residue yields for 20 mg droplets of kraft black liquor pyrolyzed in N_2 for 60 seconds at temperature from 500 to 900°C. The yield decreased from 70% at 500°C to 65% at 700°C, but then dropped to 41 % at 800°C. Fixed carbon yields were not reported in either of these studies.

Frederick et al. (1994) measured char residue from 2-3 mm droplets of kraft black liquor pyrolyzed for 10 seconds in a nitrogen atmosphere at temperatures from 700 to 1200°C. Their conditions corresponded to heating rates of the order of 100°C/s. Their char residue yields decreased with increasing temperature, from 68% at 700°C to 21% at 1200°C.

In rapid pyrolysis of black liquor using a laminar entrained-flow reactor (LEFR), dry black liquor solids with particle size of 90-125 microns were pyrolyzed at 700-1100°C, and char yields versus residence time between 0.3-2.2 seconds were reported by Carangal, 1994; and Pianpucktr 1995. Carangal reported char residue yields were 35-60% at residence time 0.85 seconds and 30-65% at residence time between 0.6-1.1 seconds.

In the Pianpucktr study, the char yield decreased as residence time increased. At 700°C, the char yield was 82% at 0.3 seconds, and it quickly decreased to 65% at 0.6 seconds. At residence times above 0.6 seconds, the char yield gradually decreased to 53% at 2.2 seconds. This indicates that the black liquor solids were volatilized rapidly until the residence time of 0.6 seconds, after which they were volatilized more gradually.

At 900°C and 1100°C, the char yields decreased during the residence times studied, 0.3-2.2 seconds. At the shortest residence time studied, 0.3 seconds, the char yield was 60% at 900°C and 50% at 1100°C. This implies that substantial amounts of volatile species in the black liquor solids were released at residence times below 0.3 seconds. The lowest char yield in this study was 20% at 1100°C and 2.2 seconds, i.e. 80% of black liquor solids were released as gas species. This indicates that considerable amounts of inorganic material in addition to C,H, and N, were vaporized.

In the Pianpucktr study, substantial amounts of volatile species in the black liquor solids were released at residence times below 0.3 seconds. The temperature of approximately 100 microns particle at short residence times were estimated using a model developed by Frederick (1990). Results of the Frederick model showed that at all of the furnace temperatures in the Pianpucktr study, the particles are within 1°C of the furnace temperature in less than 0.09 seconds as shown in Table 3.3. Further, the time to

complete loss of volatile pyrolysis products was less, approximately 0.02-0.04 seconds. These estimates indicate that at temperature of 700°C and above, the loss of volatile gases produced by pyrolytic decomposition of the organic matter in black liquor is complete before the particles reach their final temperature.

Table 3.3 Time to complete loss of volatile pyrolysis products, time for particles to reach the furnace temperature, and average heating rate during devolatilization versus furnace temperature for dry 100 micron black liquor particles as estimated using the devolatilization model of Frederick (Frederick, 1994).

Furnace temperature °C	Time to complete loss of volatile organic matter (s)	Time for particle to reach within 1°C of the furnace temperature (s)	Average heating rate during loss of volatile organic matter (°C/s)
700	0.041	0.089	15,400
900	0.029	0.075	25,600
1000	0.025	0.069	31,200
1100	0.022	0.064	37,300

3.3.2 Carbon Yield in Char Residue from Pyrolysis of Black Liquor

Frederick et al. (1994) measured the carbon yield in char residue from 2-3 mm droplets of a kraft black liquor pyrolyzed for 10 seconds in a nitrogen atmosphere at temperatures from 700-1200°C. Their conditions corresponded to heating rates of the order of 100°C/s. The amount of carbon initially in the black liquor that remained as carbon in the char residue decreased from 66% at 700°C to 18% at 1200°C. In similar

experiments with six kraft liquors at 800°C, the carbon in the char residue ranged from 26-48% of the carbon originally in the black liquor solids.

Frederick et al. (1995) measured the total carbon in the char residue collected at furnace temperatures between 700-1100°C and residence time between 0.3-1.6 seconds for 100 micron dry black liquor solids in a laminar entrained flow reactor. The total carbon versus time data are similar to the char residue data for the 100 micron - the carbon content of the char residue decreases rapidly during devolatilization ($t<0.3$ seconds). It continues to decrease but at a slower rate after devolatilization is complete. For temperatures 700-1100°C and a residence time of 0.3 seconds, the total carbon in char residue decreased from 68% at 700°C to 42% at 1100°C. At a residence time of 1.6 seconds, the total carbon in the char residue decreased from 50% at 700°C to 20% at 1100°C.

Frederick et al. (1995) compared the carbon in the char residue from LEFR experiments immediately after devolatiliation is completed with data from single droplet pyrolyzed for 60 seconds by Gairns et al. (1994). The trends of the carbon versus time data are similar to those for the char residue yields - the carbon decreases with increasing furnace temperature but more slowly for the 100 micron particles, and seems to approach an asymptotic value near 50% at higher furnace temperatures. The carbon remaining in the larger droplets continued to decrease as temperature increased. The Frederick study showed that using small black liquor particles (100 micron) gave more reliable char residue and char carbon yield data than those using 2-3 mm black liquor droplets. This is because inorganic reactions which occur after devolatilization is complete continue to remove carbon. These effects are the additional mass loss which is due to reactions that

occur in the char residue such as sulfate reduction (Cameron and Grace, 1985), carbonate reduction with the accompanying loss of sodium (Li and van Heiningen, 1990; Reis et al., 1995), and possibly by shedding of char residue fragments (Verrill et al., 1992). Moreover, Frederick's black liquor char residue and char carbon yield data did not decrease significantly with increasing furnace temperature above 900°C, and that they were not very sensitive to heating rate in the range ~100-10,000°C/s.

3.3.3 Product Gas from Pyrolysis of Black Liquor

The main gaseous products gas from pyrolysis of black liquor are H_2, CO, CO_2, CH_4, C_2H_6, C_2H_2 (Feuerstein et al., 1967; Bhattacharya et al, 1986) and the other minor gas are water vapor, tars and light sulfur-containing gases.

Bhattacharya et al. (1986) studied pyrolysis of black liquor solids in ceramic boats to a final temperature of 620-740°C, they reported the effects of reaction time and temperature on the composition of the major gaseous products for the largest particle size (-30+60 mesh). The products gas consisted of CO_2, CO, H_2, CH_4, and H_2S. With an increase in the pyrolysis temperature, the concentrations of CO_2, CH_4, and H_2S in the product gas decreased, while the concentrations of CO and H_2 increased. Unaccounted gases decreased with temperature and varied from 8 to 14 mole percent of the gaseous product. These unaccounted gases were most probably CH_3SH, $(CH_3)_2S$, and possibly SO_2. At a constant temperature, with an increase in reaction time, the concentration of CO_2, H_2S, and unaccounted gases decreased; the concentration of CO and H_2 increased, whereas the CH_4 concentration showed a maximum.

The oxygen in black liquor solids was distributed between the gas, solid residue, and tar. At 590°C, approximately 18 wt% of the oxygen in the black liquor solid left as carbon oxides (CO and CO_2), whereas at 740°C the carbon oxides account for 27 wt% of the feed oxygen. There was no appreciable effect of feed particle size on the gaseous composition. Since the trends in the composition of the product gases with time and temperature for the other two sizes were found to be similar, graphical plots were not shown for these fractions.

Goheen et al. (1976) studied the indirect pyrolysis of black liquor solids in the temperature range of 350-500°C. A typical analysis reported for the product gases was CH_4 5%, H_2S 15%, CO 30%, and CO_2 30% by volume. Bhattacharya et al. (1986) reported the range for product gases components was CH_4 1-5%, H_2S 8-20%, CO 25-45%, and CO_2 30-40% by volume.

3.3.4 Carbon-Containing Products and Carbon Recovered from Pyrolysis of Black Liquor

In experimental measurements of the pyrolysis products from black liquor using a laminar entrained-flow reactor (Sricharoenchaikul, 1994), dry black liquor solids with particle size 90-125 micron were entrained into the reactor at reactor temperatures of 700-1100°C and carbon-containing product and carbon recovered as light gases and char were reported. A large number of carbon-containing species were detected by Fourier-Transform Infrared spectrometer (FTIR) in the pyrolysis products as shown in Table 3.4.

The major carbon containing species were CO, CO_2, methane, and acetylene, while eleven other carbon-containing gases were measured quantitatively in amounts corresponding to less than 1% of the carbon in the black liquor solids fed to the reactor. The fraction of carbon converted to CO and methane increased continuously during the experiments. The fraction converted to CO_2 increased with time for experiments to 1000°C but went through a maximum at 1100°C. Other carbon species went through a maximum with time at lower temperatures.

Table 3.4 Carbon-containing pyrolysis products detected by FTIR, as % of carbon input, for 1.5 seconds residence time (Sricharoenchaikul, 1994)

% of Carbon	Temperature (°C)			
input as	700	800	900	1000
CO	1.10	4.11	5.88	29.9
CO_2	1.50	7.41	8.83	10.5
CH_4	0.45	2.11	2.60	5.90
C_2H_4	0.07	0.53	0.96	2.27
C_2H_2	0.00	0.05	0.19	0.52
CH_3OH	0.22	0.44	0.00	0.00
CH_2O	0.06	0.13	0.11	0.00
C_2H_4O	0.31	1.07	0.08	0.00
CH_3OCH_3	0.06	0.52	0.04	0.04
COS	0.00	0.01	0.00	0.00
CS_2	0.00	0.02	0.04	0.00

For carbon recovery at 1000°C, the fraction of the carbon in black liquor solids that was collected as gas increased with residence time to nearly 50% after 1.7 seconds. The amount of carbon collected as char decreased from 47% to 32% during the experiments. Most of the remaining carbon was probably tar which passed through the cyclone and hot filter - Bhattacharya et al. (1986) and Gairns et al. (1994) have reported tar yields of 7-35% of the black liquor solids input in slower heating rate experiments (~10°C/s and ~100°C/s respectively). At 1000°C, the unaccounted carbon remained fairly constant at about 40% of the carbon input until about 2.5 seconds, and then decreased to 15% of the carbon input. At 1100°C, almost all of the carbon was recovered as gases or char. In general there was a trend of increased carbon recovery as light gases and char with longer residence times and higher reactor temperatures due to decomposition of tar that is formed as primary pyrolysis products. This explanation is supported by measurements of the formation of various other carbon-containing light gases at residence times beyond 0.5 seconds, presumably as a result of the thermal decomposition of these tars. A small amount of carbon, typically 3-6% of the carbon input, was also collected on the filter.

3.3.5 Nitrogen in Char Residue from Pyrolysis of Black Liquor

Data on the retention of fuel nitrogen in the char residue of black liquor is limited. Aho et al. (1994) reported that 40-80% of the nitrogen in black liquor was converted to char nitrogen during devolatilization. Aho et al. measured the nitrogen retained in char residue for black liquor kept at 400°C for one hour. Forssen et al. (1995) measured the

percentage of the fuel nitrogen that was retained in the char residue of single droplets placed in a furnace for 300 seconds. The nitrogen retained decreased from 300 to 500°C, was constant at 20-30% of fuel N from 500-900°C, and was lower at 1000°C.

Carangal (1994) measured nitrogen retained in the char residue after devolatilization at furnace temperature between 700-1100°C and residence time between 0.3-2.2 seconds for 100 micron dry black liquor solids in a laminar entrained flow reactor. At residence times longer than 0.5 second, the char nitrogen yield is essentially the same at 700°C and 900°C. The nitrogen content of the char residue as a percentage of the nitrogen in the black liquor solids was substantially lower at 1100°C.

Table 3.5 Retention of nitrogen and carbon in char residue and the rates of decrease of nitrogen and carbon in the char residue during extended char pyrolysis. (Carangal, 1995)

Temperature (°C)	N and C in char residue at the end of devolatilization, (% of N and C in black liquor solids)		Rate of change of N and C in char residue, (%/s, based on N and C in black liquor solids)	
	Char N, (%)	Char C, (%)	Char N, (%/s)	Char C, (%/s)
700	56.7	71.3	-8.5	-6.1
900	49.6	63.0	-5.7	-6.2
1100	45.7	47.8	-12.9	-7.2

Table 3.5 compares the percentages of nitrogen and carbon retained in the char residue after devolatilization, obtained by extrapolating the data of nitrogen content of the char residue as a percentage of the nitrogen in the black liquor solids back to time zero.

The percentage of nitrogen retained in the char residue after devolatilization is less than the carbon retained at 700°C and 900°C, but about the same at 1100°C. Table 3.5 also compares the rates of depletion of nitrogen and carbon from the char residue, expressed as percent of the initial nitrogen or carbon per second. At 700°C, the char nitrogen seems to decrease more rapidly during devolatilization than the char carbon decreased. At longer times, the rate of nitrogen depletion from the char residue at 700°C and 900°C is about the same as the rate of carbon loss when expressed as a percentage of the nitrogen or carbon in the black liquor solids. At 1100°C, nitrogen is depleted more rapidly than carbon on the same basis.

3.3.6 Sulfur Species in Char Residue from Pyrolysis of Black Liquor

Sulfur behaves very differently than carbon or nitrogen during pyrolysis. Forssen et al. (1992) showed that the sulfur retained in the char residue after pyrolysis of black liquor went through a minimum with increasing furnace temperature at 600-700°C. The fraction of the sulfur initially in the black liquors that was retained in the char residue was independent of the sulfur content or the sulfur species distribution in the liquors used, increasing from about 20% at 300°C to 65% at 600°C and then decreasing to 25% at 1050°C. Forssen's analysis was based on data from his own experiments and from three other studies (Brink et al., 1970; Clay et al., 1984, 1987; Cantrell, 1986) involving a total of nine different kraft black liquors. Single droplets, 2-3 mm in diameter, were used in all four studies. Gairns et al. (1994) obtained somewhat different results, with the sulfur retained in the char residue increasing continuously from 33% at 500°C to 57% at 900°C.

Clay et al. (1984,1987) reported limited data on the distribution of sulfur species in char residue produced by pyrolysis of 1.5 mm droplets at 900°C. The predominant sulfur species in the char residue were thiosulfate, sulfide, and sulfate.

Frederick et al. (1995) studied sulfur species in char residue from pyrolysis of black liquor solids using laminar entrained flow reactor at furnace temperature between 700-1100°C and residence time between 0.3-1.6 seconds. Almost all of the thiosulfate initially present in the black liquor solids had disappeared in less than 0.3 seconds. The sulfite content of the char residue increased from zero to a flat maximum between 0.3 and 0.8 seconds, and then decreased to zero. The sulfate content was nearly constant for the first 0.8 seconds but then decreased, nearly disappearing after 1.6 seconds. The sulfide content remains at zero until after 0.7 seconds, and then increases rapidly.

In the Frederick study (1995), the effect of residence time and temperature on total sulfur in char residue was determined. At 900-1000°C, the sulfur content of the char residue has decreased to about 20% of the initial sulfur content of the black liquor solids before beginning to increase. At 700°C, the decrease in char residue sulfur content was slower, but the minimum value, achieved after 1 second particle residence time, was about the same. The sulfur in the char residue then increased with residence time.

A comparison between the Frederick et al. (1995) study of the sulfur content of the char residue after 1.5 seconds and data from other studies (Forssen et al., 1992; Gairns et al, 1994) was made. With the different experimental methods and equipment, Gairns et al. and Forssen et al. used 2-3 mm black liquor droplets, while Frederick et al. used dry, 100 microns particles. The Gairns et al. data agree very well with the Forssen et al. which was represented by a regression curve. However Frederick et al. data fell below Forssen's

curve. The main difference between Frederick et al. technique and that of Forssen et al. and Gairns et al. was that in Forssen et al. and Gairns et al. experiments, the product gas was removed immediately from the suspended single droplets. The droplets therefore pyrolyze in a nitrogen of helium atmosphere, without water vapor or CO_2 present. By contrast, Frederick et al. experiments were conducted at steady-state so that the gases and particles were not separated but flowed together through the reactor. The gases contain water vapor and CO_2 (Sricharoenchaikul, 1995). These can react with Na_2S to produce H_2S and COS, further reducing the sulfur content of the char residue (Li, 1989; Li and van Heiningen, 1994; Wag et al., 1995).

The fact that the sulfur content of the char residue decreased to around 20% at all temperatures was compatible with the sulfur gas versus time data from these experiments (Sricharoenchaikul et al., 1995). The total sulfur as gases increased rapidly with time, in the same time frame at which the char residue sulfur passes through minima. Most of the sulfur in the gas phase was organosulfur compounds.

The Frederick et al. (1995) data reported support a mechanism by which sulfur is first released from black liquor during devolatilization and is then recaptured by the inorganic species in the char residue. The data indicated that sulfur release during devolatilization was the result of decomposition of thiosulfate, sulfide, and organic sulfur to gases. At temperatures of 900°C and above, these were converted to sulfur gases in less than 0.3 seconds for the small particles used in this study. At 700°C, more than 1 second was required to reach the minimum. Sulfur gases are then recaptured by the char residue particles.

CHAPTER 4

EXPERIMENTAL PROCEDURE AND SAMPLE ANALYSIS

4.1 Experimental Set - up

The experimental set-up for pyrolysis of black liquor solids is shown by the simplified diagram in Figure 4.1. The major parts of the experiment are as follows :

- Reactor : Laminar Entrained-Flow Reactor (LEFR)
- Solids Separation Equipment : Cyclone/filter assembly
- Gas Analyzers : CO_2 Gas Analyzer
- Gas Oxidizer : Oxidizer

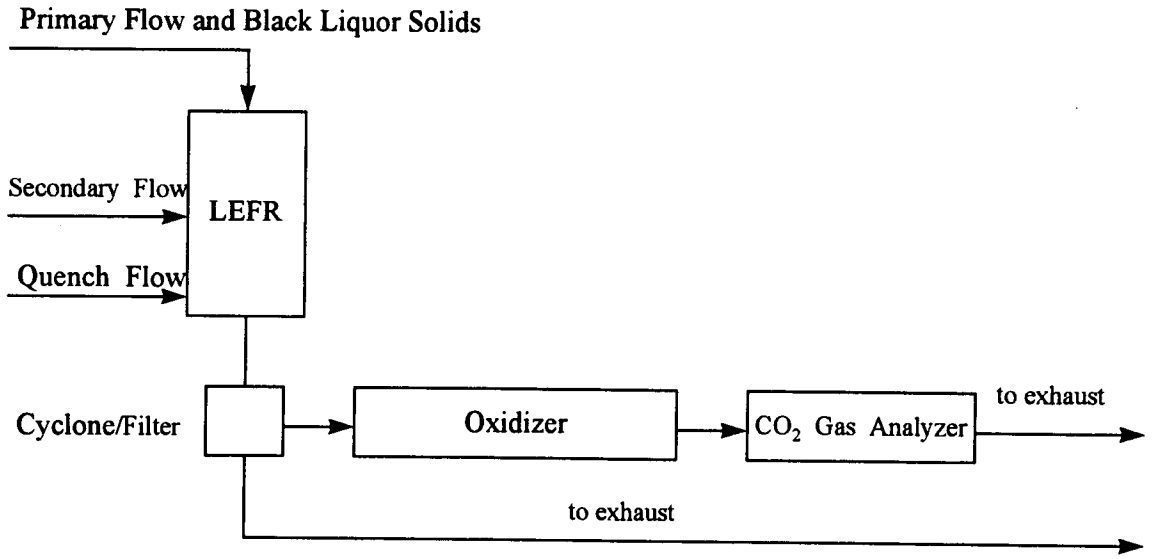

Figure 4.1 Simplified Schematic Diagram of Experimental Set-Up

4.1.1 Laminar Entrained Flow Reactor (LEFR)

A simplified schematic diagram of the Laminar Entrained-Flow Reactor is shown in Figure 4.2. The LEFR consists of two major parts, the reactor and the collector. The reactor consists coaxially of two cylindrical mullite tubes inserted in the furnace. The furnace is subdivided into three heating zones controlled by Omega CN76000 Microprocessor Based Temperature and Process Controllers capable of ramping to a set point temperature at a maximum heating rate of 300°C/hr. The downward flowing high temperature gas at laminar conditions include primary and secondary gas streams whose flow rates are controlled by Omega FMA5600 Electronic Mass Flow Meters (MFM).

The black liquor solids are entrained by the primary gas stream from the particle feeder and flow through the injector into the reactor at the center of the inner mullite tube. The particles and primary gas stream are prevented from premature heating while passing through the injector by cooling water flowing through the outer shell of the injector. The secondary gas stream enters the LEFR through the bottom and is preheated to the furnace temperature as it flows upward through the annular space between the mullite tubes. It then flows downward into the reactor through a flow straightener located at the top of the inner mullite tube. The flow straightener is used to obtain a uniform secondary gas velocity profile. The primary and secondary streams merge together to form a single laminar flow entering the reaction zone. The particles rapidly heat and react while exposed to the high temperature of the secondary gas stream and radiation from the reactor walls. The particle are heated rapidly at about 10^{4}°C/sec.

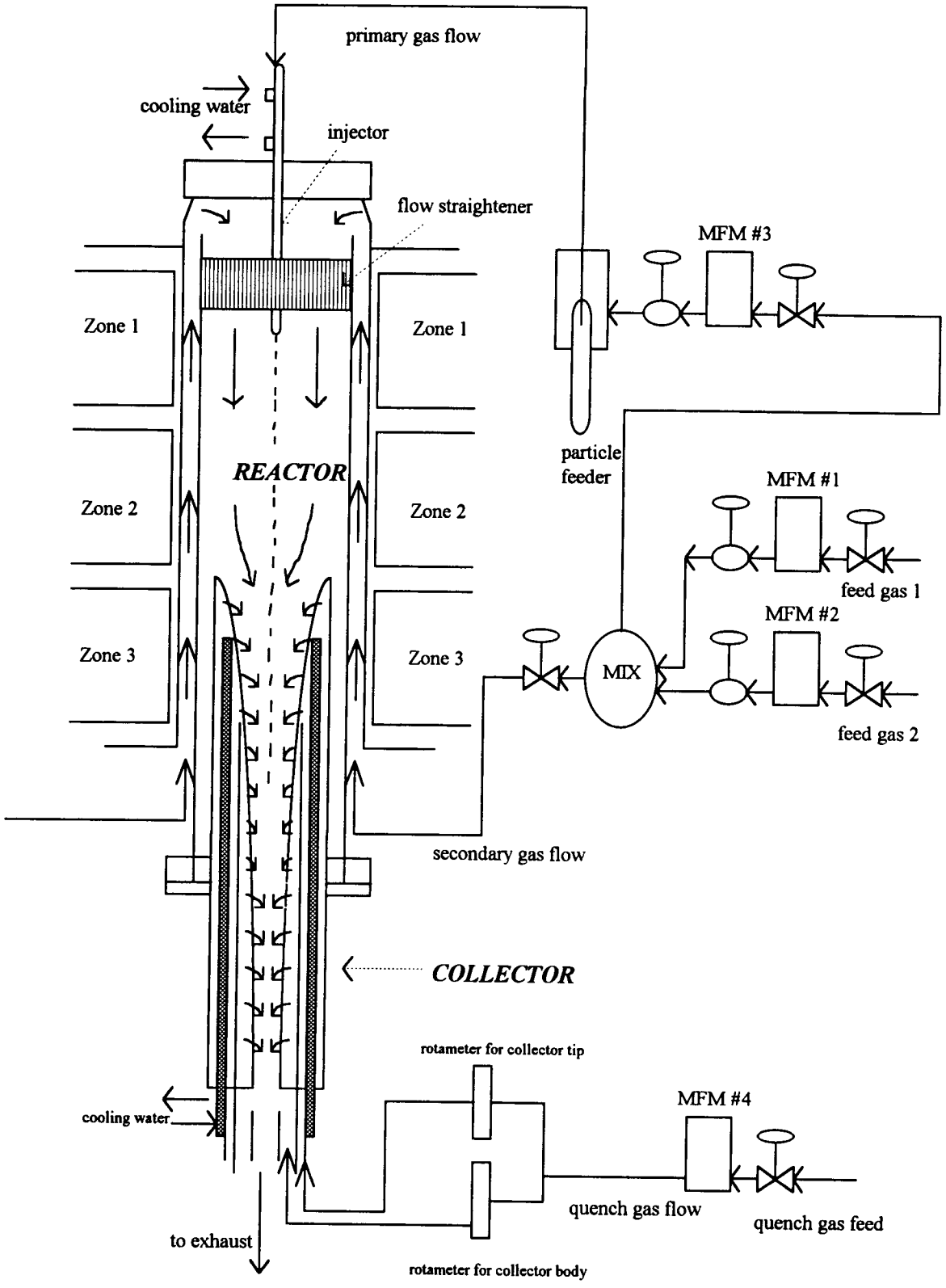

Figure 4.2 Laminar Entrained Flow Reactor

The residence time of the particles is controlled by adjusting the position of a movable collector and/or adjusting flow rate of primary and secondary streams. The residence time of the particles is calculated with a predictive model based on Flaxman's computational fluid dynamic algorithm (Flaxman and Hallett, 1987) and depends mainly on the furnace temperature, gas flow rate, and reaction path length. The particles are reacted for the required residence time and then are cooled by the quench gas stream to stop any further chemical reactions as they enter the collector.

The collector can be moved inside the reactor to vary the reaction pathlength to adjust the required residence time. The outer part of the collector is a mullite tube insulated inside with a layer of mullite fiber to minimize heating from the reactor walls. The inner wall of the collector is porous to allow distribution of the quench gas along the length of the collector. The porous wall is enclosed by a segmented shell of stainless steel, with two passes for cooling water to prevent the heating of the quench gas, and one for flowed path of quench gas stream. The porous wall has two sections of different permeabilities. The first is a very permeable section, approximately 2 cm in length located near the tip of the collector. About half of the quench gas enters through this section to decrease rapidly the gas and particle temperature. The second is a much less permeable wall section which comprises the rest of the porous wall. It allows quench gas to flow through the wall fast enough to prevent fine particles from depositing on the walls of the collector by thermophoresis.

4.1.2 Cyclone/Filter Assembly

The reactor effluent and the quench gas stream flow from the collector into a cyclone and filter assembly. The illustration of the cyclone/filter assembly is shown in Figure 4.3.

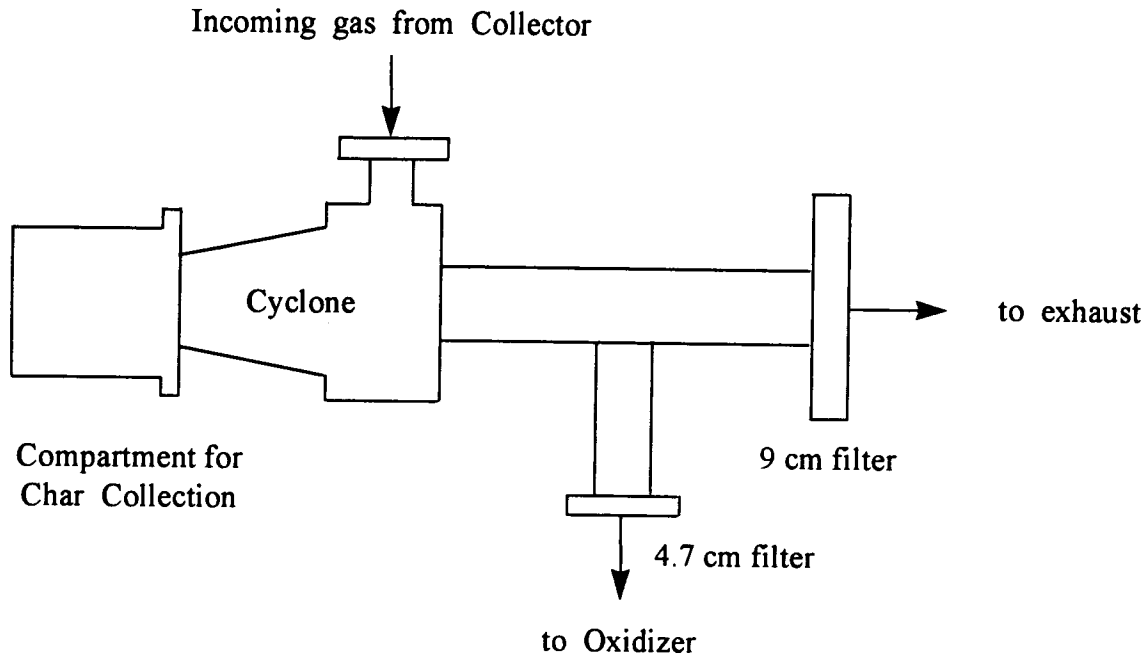

Figure 4.3 Cyclone/Filter Assembly

The particles are separated from the effluent gas by the cyclone with a nominal cut-off size of 3 μm. The particles collected in the cyclone are referred to as char. The effluent gas exiting the cyclone is filtered to obtain fine particles by means of two glass fiber filters with 0.8 μm pore size. Filters with this pore size are effective in collecting particles as small as 0.1 μm. The first filter, 9 cm in diameter, is located directly

downstream of the cyclone as shown in Figure 4.3. Gases passing through this filter go directly to the exhaust. The second filter, 4.7 cm in diameter is located perpendicular to the cyclone axis. Gases passing through this filter go directly to the oxidizer.

4.1.3 Oxidizer

In order to determine the carbon balance in pyrolysis of black liquor, the total carbon in the LEFR product gas needed to be measured. An oxidizer was connected to the LEFR by 5 feet of unheated tubing. It was used to convert all oxidizable carbon-containing components in the LEFR effluent gas to carbon dioxide.

A simplified schematic diagram of the cylindrical gas oxidizer is shown in Figure 4.4. The reaction chamber is a mullite tube inserted horizontally in the furnace. The furnace heating zone were controlled by an Omega CN76000 microprocessor-based temperature and process controller set at 900°C.

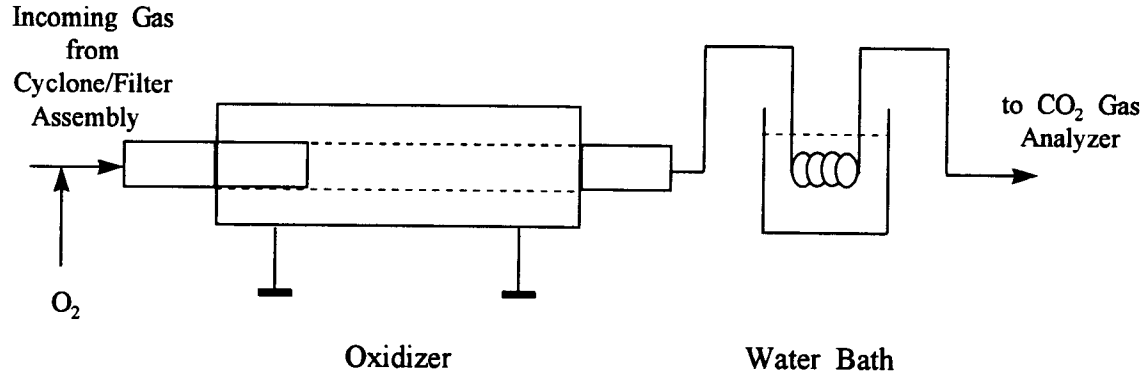

Figure 4.4 A Simplified Schematic Diagram of the Oxidizer

The LEFR effluent gas is mixed with air before flowing through the reaction chamber of the oxidizer. A flow straightener is used to obtain a uniform velocity profile. In the high-temperature (900°C) reaction chamber that has a constant level of oxygen, all oxdizable components are combusted to their stable oxides. Thus all carbon in the LEFR effluent gas is converted to carbon dioxide. The effluent gas from the oxidizer is still high (~500°C), and therefore a cooling coil in a water bath was used to decrease the effluent gas temperature to 25°C before it enters the CO_2 gas analyzer in order to prevent temperature fluctuations that effect accuracy of the CO_2 concentration reading, and also to prevent damage of analyzer sampling line.

4.1.4 CO_2 Gas Analyzer

The CO_2 Gas Analyzer used in the experiments is a Riken Infrared Analyzer Model RI-550. The effluent gas from the cylindrical gas oxidizer is drawn into the CO_2 gas analyzer through sampling line by means of an internal vacuum pump. The effluent gas passes through an optical system and the concentration of the constituent to be measured is read out directly on a meter.

Each gas molecule consisting of more than two different atoms has a dipole moment, and when exposed to infrared radiation, is excited and produces a wavelength equivalent to its specific vibration and rotation spectrum.

Every gas absorbs electromagnetic radiation in its own characteristic way; this electromagnetic fingerprint or spectra can be used to identify the gas constituent and determine its concentration.

Optical radiation is absorbed by gases to varying degrees depending on the wavelength of the radiation, the bandwidth of the radiation, and the number of absorbing molecules present between the source of radiation and the detector.

For a fixed radiation wavelength and bandwidth, the amount of radiation absorbed is proportional to the number of absorbing molecules. By measuring quantitatively the amount of radiation absorbed, one can determine the concentration of the gas. The optical schematic of the unit is shown in Figure 4.5.

There are two parallel identical optical paths, one for reference and the other for sample or measuring. A chopper mechanism, in a regular cycle, alternates the infrared beam to the detector between the sample and reference side. A sealed cell is placed on the reference side and a sample cell on the measurable gas side.

When gas is introduced into the sample cell, a specific wavelength is absorbed so that the infrared radiation reaching the detector is deminished in energy.

The higher the concentration of gas, the less energy of infrared radiation reaches the detector while the quantity of infrared radiation reaching the detector through the reference side is constant.

Therefore, the higher the concentration of the gas to be measured, the larger the difference of infrared radiation between the sample side and reference side. This difference is detected as an amplitude-of beam vibration. Beam vibration becomes a periodic variation of gas temperature in the detector which caused a periodic variation of pressure. This variation of pressure is detected by a condenser microphone, amplified, rectified and indicated as a gas concentration upon the meter.

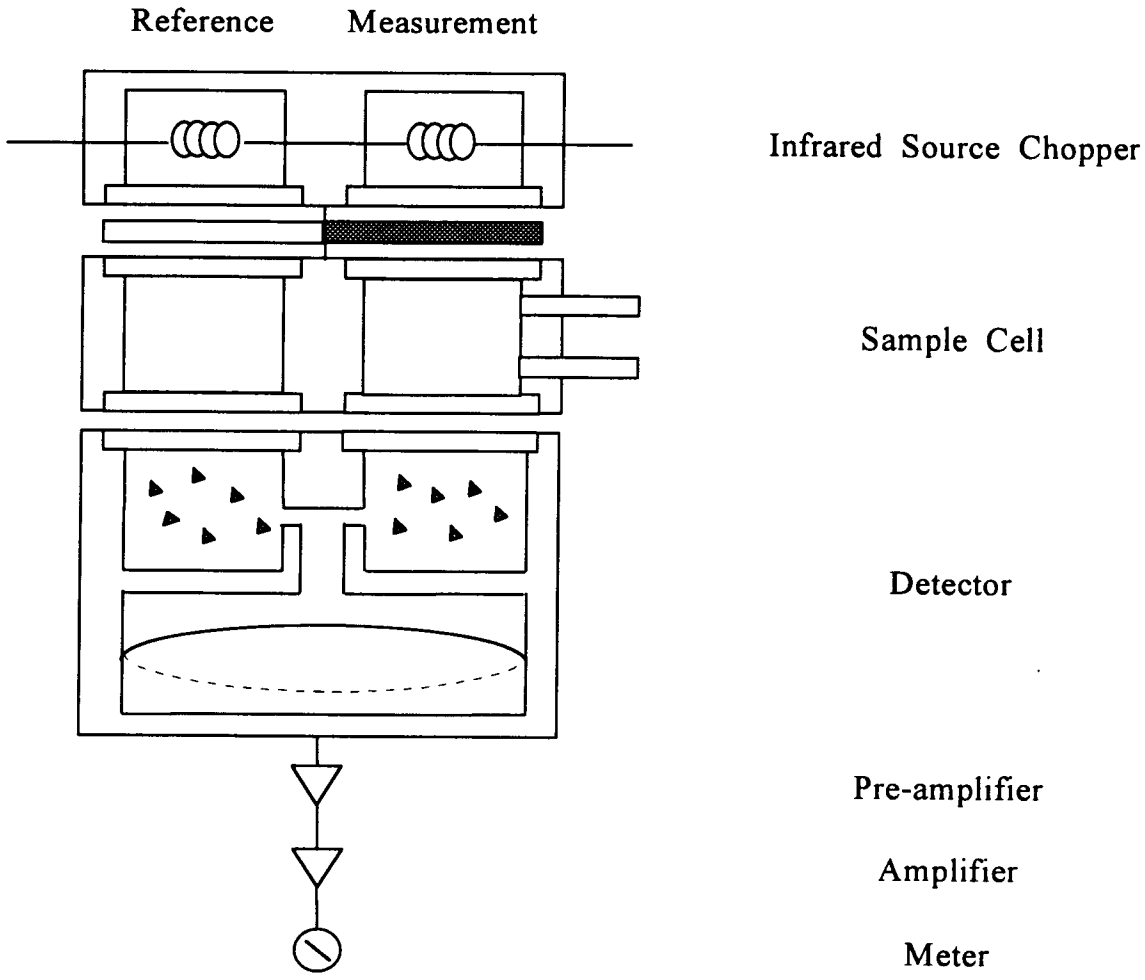

Figure 4.5 The Optical Schematic of CO_2 Gas Analyzer

4.2 Material

The black liquor solids used in this study were prepared from an oxidized southern pine kraft black liquor. The 2.5-gallon black liquor container was shaken well to ensure a uniform solids concentration before pouring the liquor into a stainless steel drying pan. The black liquor level in the pan was kept at 2 cm in order to prevent non-uniform deposition of inorganic solids during drying. The black liquor was dried in an oven at 80-

100°C for 24 hours. The dry black liquor solids were then carefully scraped from the pan and stored in a vacuum oven at 50°C for 48 hours to remove any remaining water without loss of any remaining volatile matter in the black liquor. The dried black liquor solids were then ground into powder with a coffee grinder. The black liquor powder was again stored in the vacuum oven at 50°C for 24 hours to remove moisture adsorbed during the grinding process. Then, the completely dried black liquor powder was sieved to provide black liquor solids in the 90-125 micron particle size range used in the LEFR experiments. All black liquor solid were kept in desiccator to avoid absorption of moisture. The elemental composition of the black liquor solids is shown in Table 4.1

Table 4.1 Elemental composition of the Black Liquor Solids

Element	wt. %
Carbon	34.8
Oxygen	35.3
Sodium	22.6
Hydrogen	3.0
Sulfur	2.9
Potassium	0.62
Chloride	0.67
Nitrogen	0.08

4.3 Experimental Conditions

For pyrolysis of black liquor solids, the effect of residence time at different temperatures was studied. The residence time was varied from 0.3 to 2.0 seconds and temperature was varied from 400°C to 600°C. The particle residence times were calculated by Flaxman's computational fluid dynamic and heat transfer model of particles in a laminar entrained flow reactor. The model had been modified to accounts for the swelling and mass loss behavior of kraft black liquor, and it accounts for momentum transport, gas-particle slip, and convective and radiative heat transfer between the gas, reactor wall, and particles. The residence time that can be achieved by the LEFR is limited by the reactor path length and maximum input gas flow rate. The experimental conditions in this study are shown in Table 4.2.

Table 4.2 Experimental Conditions

Residences time	Temperature (°C)		
(sec)	400	500	600
0.3	X	X	X
0.5	X	X	X
0.7	X	X	X
0.9	X	X	X
1.1	X	X	X
1.3	X	X	X
1.5	X	X	X
1.7	X	X	X
2.0	X	X	X

4.4 Experimental Procedure

4.4.1 Pre-run preparation

4.4.1.1 Laminar Entrained-Flow Reactor (LEFR)

- At room temperature, move the collector to the desired position and set the alignment of the collector to be center.
- Turn on water cooling system (The cooling system must be on all the time, even though the furnace is shut off. The cooling system can be off whenever the temperature of the reactor has come down to room temperature)
- Set the temperature controller to the desired set point. (maximum ramping rate is 200°C/hr)

4.4.1.2 Cyclone/Filter

- All filters are stored in an oven at 105°C to remove moisture.
- Cyclone and all connection parts must be cleaned and dried.
- Weight filter and place in the cyclone/filter system

4.4.1.3 Oxidizer

- Fill the water bath.
- Connect oxygen line to the oxidizer.
- Set the temperature controller to 900°C.

4.4.1.4 CO_2 Gas Analyzer

- With all power off, adjust mechanical zero on the meter with a small screwdriver, if necessary.
- Lift out the dust filter/drain separator and fill with absorbent cotton.
- Reset the dust filter/drain separator in previous position.
- Connect sampling line from cylindrical gas oxidizer to CO_2 gas analyzer.
- Turn on gas analyzer and allow 3 minutes for stabilization or 30 minutes for greatest accuracy.
- Turn switch to 'MEAS' (sampling pump is activated).
- Turn Zero adjusting knob and set indicating pointer on meter to zero.
- Check span adjustment using gas or test filter.

4.4.1.5 Feeding System

- Feeding tube and feeding connection must be clean and dry.
- Fill dry black liquor solid into feeding tube and weigh.
- Install the feeding tube in the feeding system.

4.4.2 Pyrolysis Runs

- Open quench & total gas flows and adjust until achieving the desired set point while the pressure is set at 25 psi.

- Open the primary flow until achieving the desired set point.
- Open excess oxygen flow to cylindrical gas oxidizer.
- Turn on the feeding motor and set to low speed allowing black liquor solids to be entrained to LEFR by the primary gas flow.
- Turn off the feeding motor immediately after particles start exiting the reactor while all gases are left flowing into the reactor and the collector.
- Attach cyclone/filter assembly to the bottom of the collector and connect sampling line from cyclone/filter assembly to cylindrical gas oxidizer.
- Turn on the feeding motor to start pyrolysis and run about 10 minutes for steady state condition.
- At the end of the experiment, turn off the primary flow and turn the feeding motor in reverse while total gas flow and quench flow are kept flowing around 2 more minutes until the CO_2 level, as display in CO_2 meter, is down to zero.
- Shut off all gas flow.
- Weight char and filter (collected fume) before placing in sample container.
- Reattach cyclone/filter assembly and then flush all the remaining particle in feeding line and LEFR by using maximum primary gas flow rate for approximately 1 minute.
- Weigh flushed char and flushed filter, then discard.
- Clean all necessary equipment and prepare for next run.

4.4.3 Sample Analysis

There are two kinds of solid samples as follows

1. Char collected by the cyclone

2. Fine particles collected by both the large and small filters

Char and Fume samples are analyzed for total carbon, nitrogen and sulfur by a Carbon, Nitrogen and Sulfur Analyzer (CNS). Refer to Appendix A for details of the operating theory of the CNS Analyzer.

CHAPTER 5

RESULTS AND DISCUSSION

In this chapter, the results from the experiments are divided into different sections according to the objectives of the study. In each section, the experimental results are shown and compared with the data from previous studies, and data trends are examined. The experimental conditions in this study were very different from those of previous studies. Although the experimental results in this study are not the same as those from previous studies, a comparison between the data presented here and earlier data can help to interpret the experimental results from this study.

5.1 Carbon Yield from Pyrolysis of Black Liquor Solids

5.1.1 Carbon Yield in Gas from Pyrolysis of Black Liquor Solids

In this study, all oxidizable product gases and tar from the LEFR which passed the fine particle filter were converted to carbon dioxide in an oxidizer. The CO_2 content of the gas exiting the oxidizer was measured, and the total carbon content in the gas at each experimental conditions was calculated based on the carbon dioxide concentration of product gas. The calculation procedure is shown in Appendix B.

Figure 5.1 shows the carbon yield in the gas versus residence time from pyrolysis of black liquor solids at 600°C. *The carbon yield in the gas increased as residence time*

increased. The reproducibility obtained in replicate runs was an average ±1.0% of the carbon in the black liquor solids input to the LEFR. At a residence time of 0.3 seconds, the carbon yield in the gas was 8% and it rapidly increased to 20% at residence time 1.1 seconds. It gradually increased to 23% at residence time 2.0 seconds.

Figure 5.2 and Figure 5.3 show the carbon yield in the gas phase versus residence time from pyrolysis of black liquor solids at 500°C and 400°C respectively. *The carbon yield in the gas phase increased as residence time increased.* The reproducibility in replicate runs at 500°C was an average ±0.8%, and at 400°C was ±1.4% of the carbon in the black liquor solids. For 500°C, at a residence time of 0.3 seconds, the carbon yield in the gas was 7%. It increased linearly as residence time increased to 23% at a residence time of 2.0 seconds. For 400°C, at residence times from 0.3 to 0.5 seconds, the carbon yield in the gas phase increased slowly to about 2%. At residence times from 0.5 to 1.5 seconds, the carbon yield in the gas phase increased more rapidly from 2% to 17%. At residence times above 1.5 seconds, the carbon yield in the gas phase gradually increased to 20% at residence time of 2.0 seconds.

Figure 5.4 compares the carbon yield in the gas phase versus residence time from pyrolysis of black liquor solids at temperature of 600°C, 500°C, and 400°C. *The higher the temperature, the higher the carbon yield as gases phase at each residence time.*

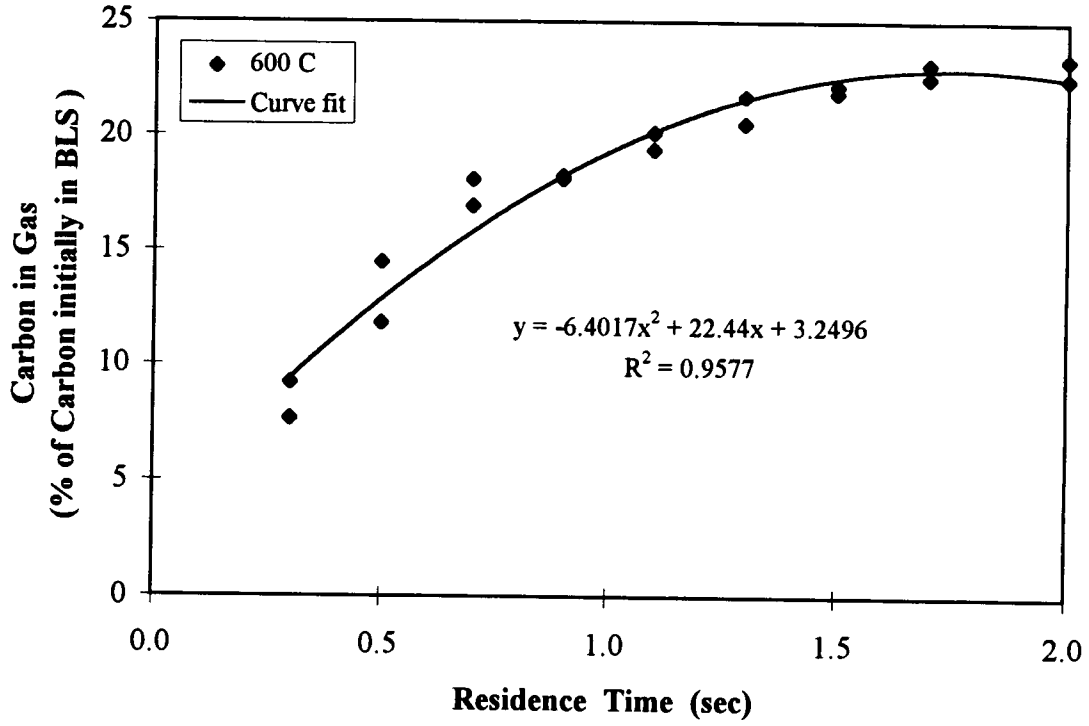

Figure 5.1 Carbon Yield in Gas from Pyrolysis of Black Liquor Solids at 600°C

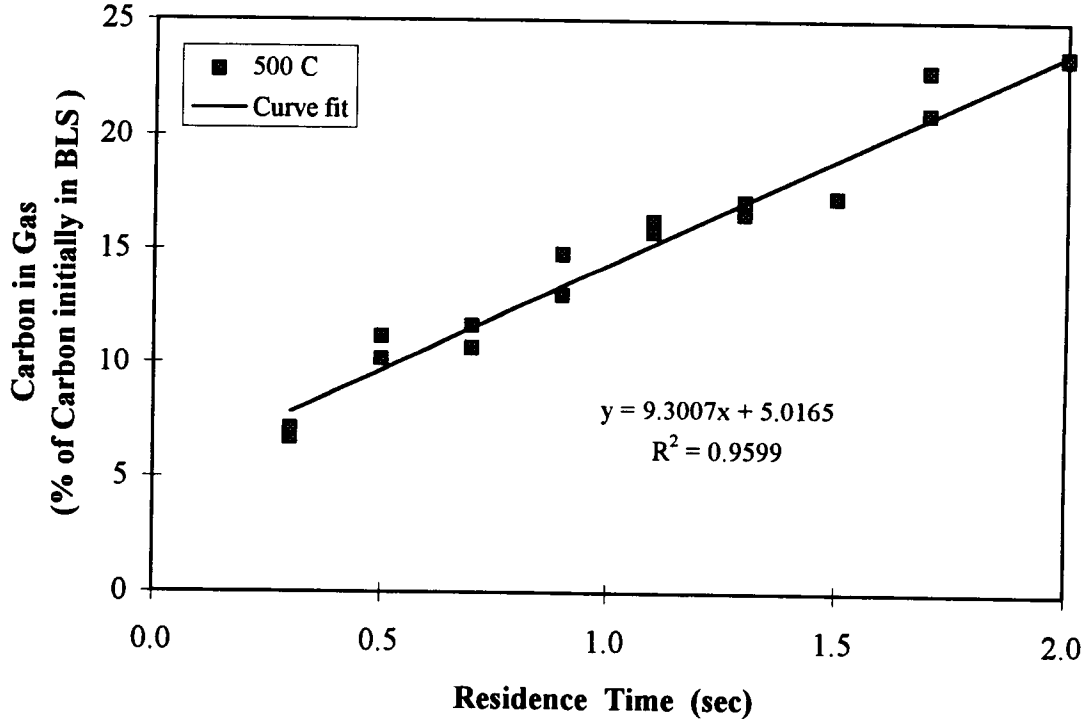

Figure 5.2 Carbon Yield in Gas from Pyrolysis of Black Liquor Solids at 500°C

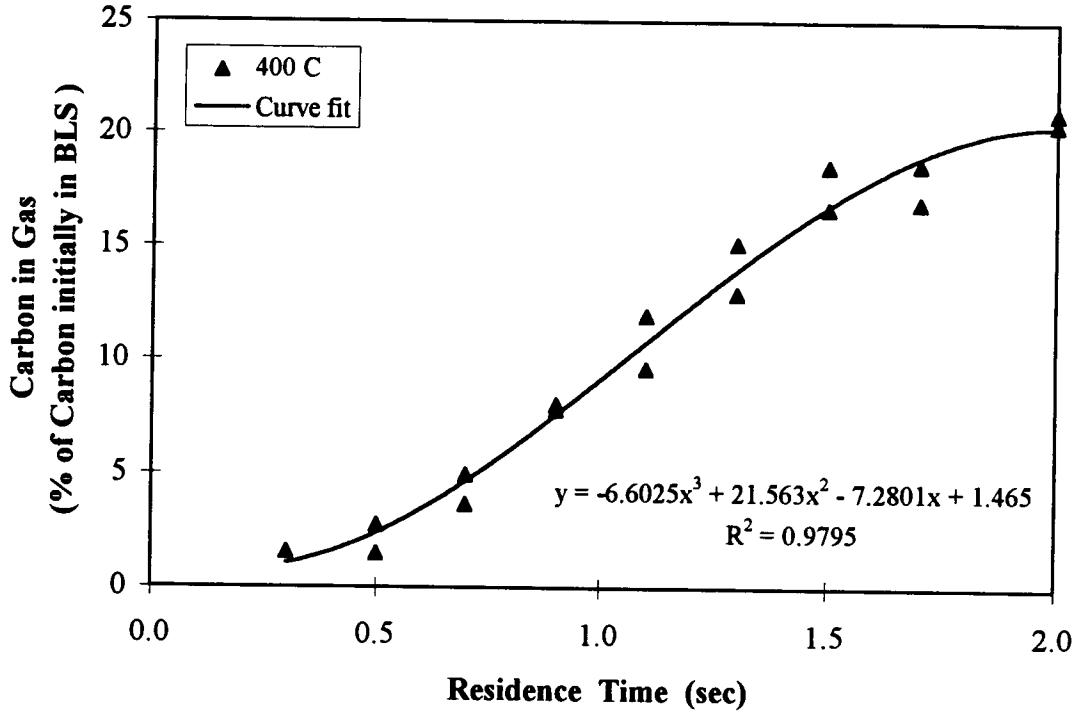

Figure 5.3 Carbon Yield in Gas from Pyrolysis of Black Liquor Solids at 400°C

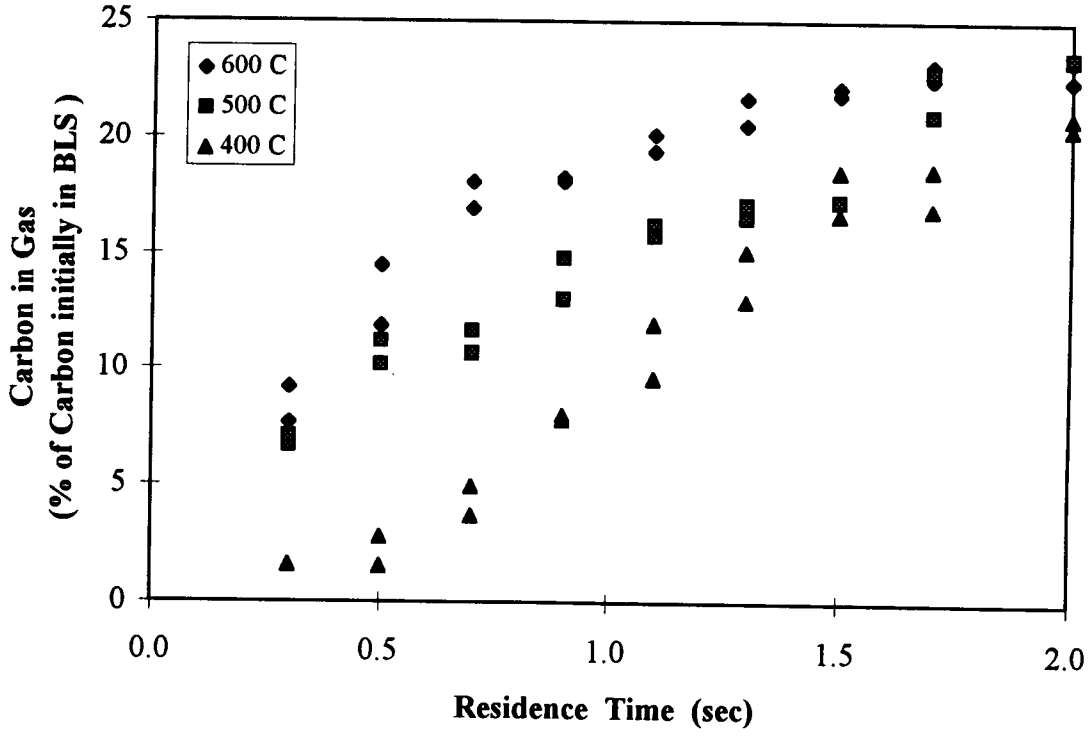

Figure 5.4 Carbon Yield in Gas from Pyrolysis of Black Liquor Solids at 400-600°C

5.1.2 Carbon Yield in the Fine Particles from Pyrolysis of Black Liquor Solids

In this study, *fine particles* refers to the particles that passed through the 3 μm cutoff cyclone and were collected on the filter down stream, they consisted mainly of tar and small char particles. The experimental temperatures were from 400 to 600°C which is too low for significant volatilization of sodium and potassium salts to occur. Thus, the fine particles are different from the inorganic condensation aerosols that are produced during pyrolysis of black liquor at much higher temperature (fume).

Figure 5.5 shows the carbon yield in the fine particles versus residence time form pyrolysis of black liquor solids at 600°C. *Overall, the carbon yield in the fine particles increased as residence time increased.* The reproducibility obtained in replicate runs was ±0.1 of the carbon input as black liquor solids. At residence times of 0.3-1.1 seconds, the carbon yield in the fine particle was constant 0.5%. At residence times above 1.1 seconds, the carbon yield in the fine particle increased rapidly to 2.5% at a residence time of 2.0 seconds.

Figure 5.6 and Figure 5.7 show the carbon yield in the fine particles versus residence time form pyrolysis of black liquor solids at 500°C and 400°C respectively. The carbon yield in the fine particles increased at 500°C. At 400°C, it was nearly constant until 1.5 seconds and then increased slowly. The reproducibility obtained in replicate runs at 500°C and at 400°C were an average ±0.1% of the carbon in the black liquor solids input. At the shortest residence time, 0.3 seconds, the carbon yield in the fine particles was 0.27% at 500°C and 0.31% at 400°C. At the longest residence time, 2.0 seconds, the carbon yield in the fine particles was an average 1.8% at 500°C and 1.0% at 400°C.

Figure 5.8 the compares the carbon yield in the fine particles versus residence time from pyrolysis of black liquor solids at temperature of 600°C, 500°C, and 400°C. The carbon yield in the fine particles differ very little with temperature at residence time below 1.1 seconds. At higher temperatures, the carbon yield in the fine particles is about the same at 500°C and 600°C, but lower at 400°C.

5.1.3 Carbon Yield in the Char Residue from Pyrolysis of Black Liquor Solids

Figure 5.9, Figure 5.10, and Figure 5.11 show the carbon yields in the char residue versus residence time from pyrolysis of black liquor solids at 600°C, 500°C, and 400°C respectively. *The carbon yield in the char residue decreased as residence time increased.* The reproducibility obtained in replicate runs was an average ±3.2% at 600°C, ±1.8% at 500°C, and ±2.2% at 400°C, all as percentage of carbon input as black liquor solids.

At 600°C, the carbon yield in the char residue decreased rapidly from 90% at a residence time of 0.3 seconds to 76% at residence time 1.1 seconds, and then gradually decreased to 70% at residence time 2.0 seconds. At 500°C, the carbon yield in the char residue decreased from 87% at a residence time of 0.3 seconds to 60% at residence time 2.0 seconds. At 400°C, the carbon yield in the char residue was constant at about 95% at residence times of 0.3-0.5 seconds. At residence times between 0.5-1.5 seconds, the carbon yield in the char residue rapidly decreased to 78%, and then decreased gradually to 75% at a residence time of 2.0 seconds.

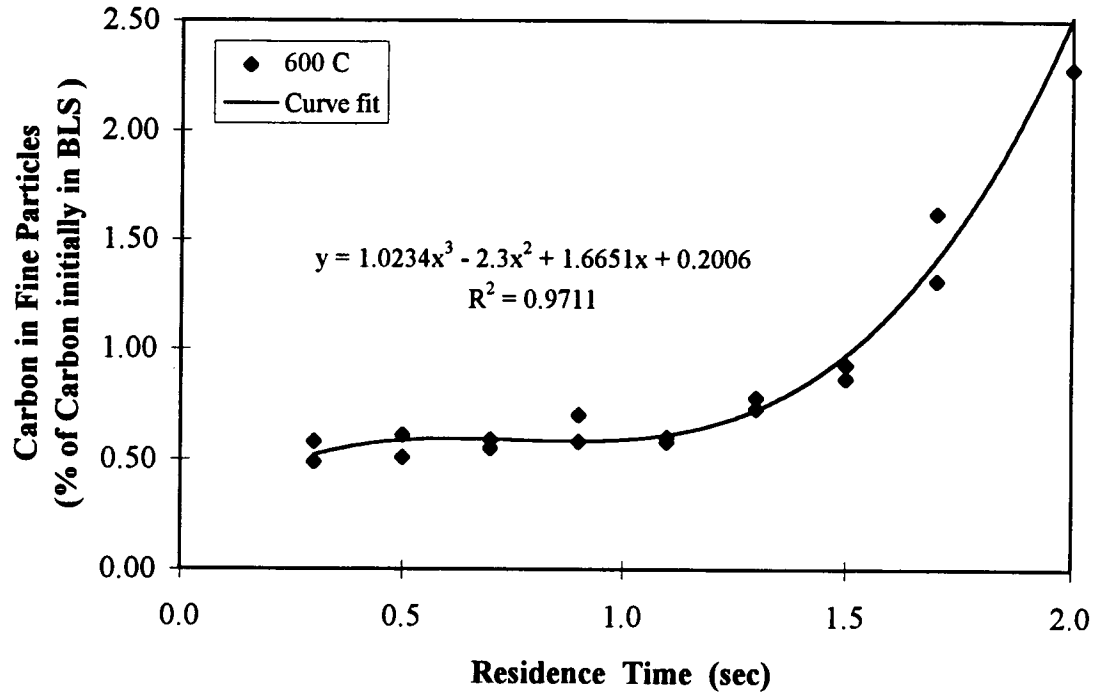

Figure 5.5 Carbon Yield in the Fine Particles from Pyrolysis of Black Liquor Solids at 600°C

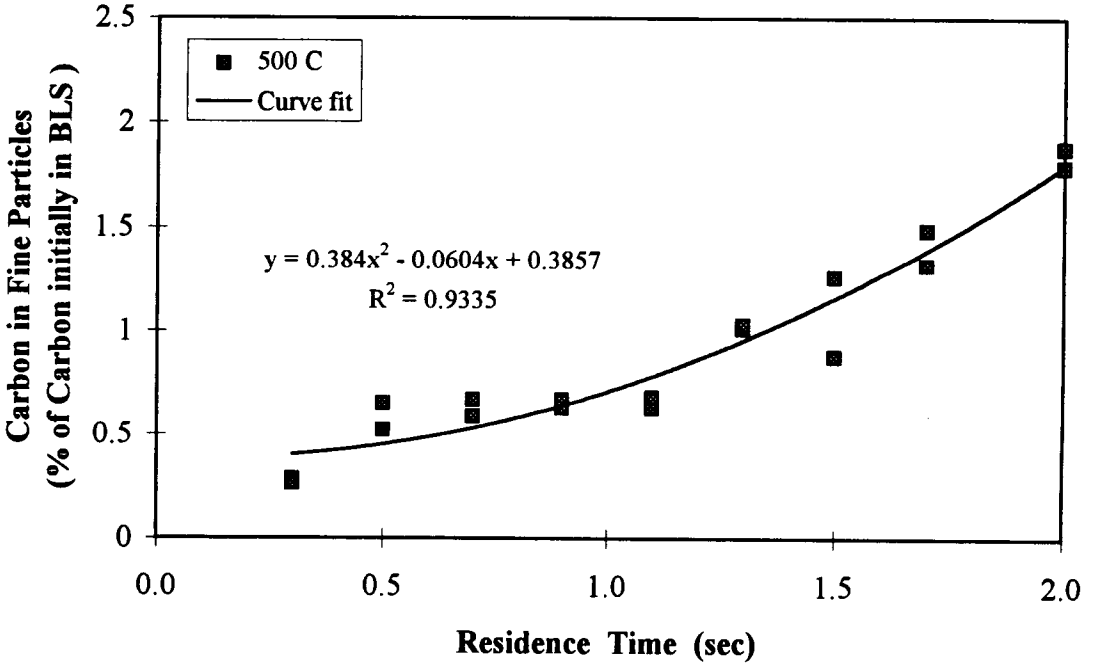

Figure 5.6 Carbon Yield in the Fine Particles from Pyrolysis of Black Liquor Solids at 500°C

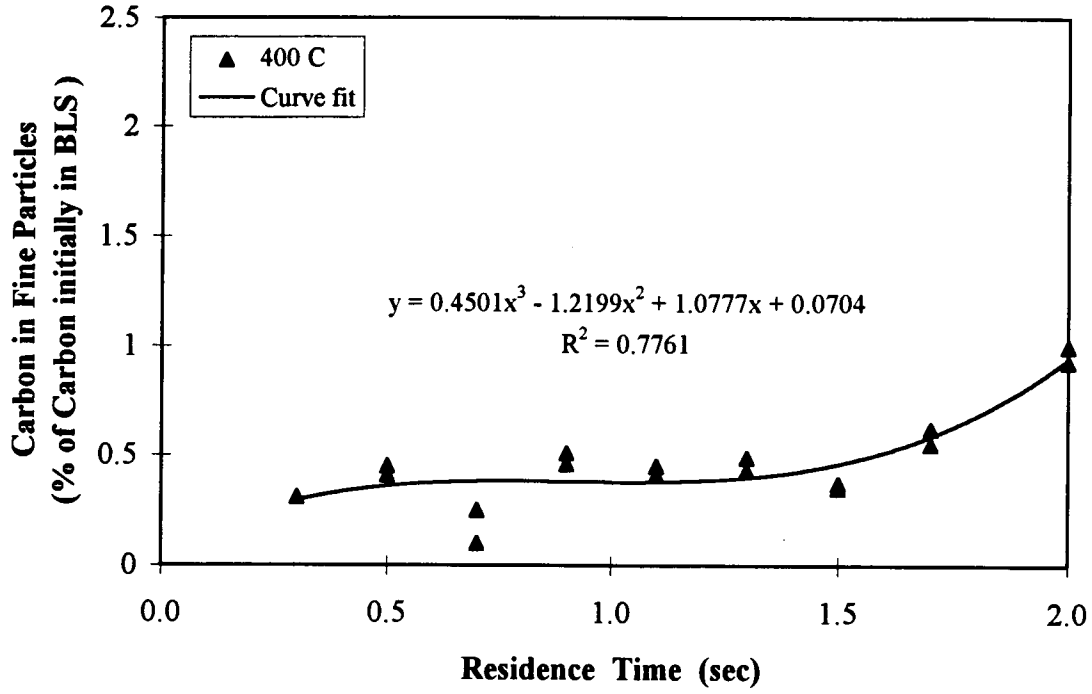

Figure 5.7 Carbon Yield in the Fine Particles from Pyrolysis of Black Liquor Solids at 400°C

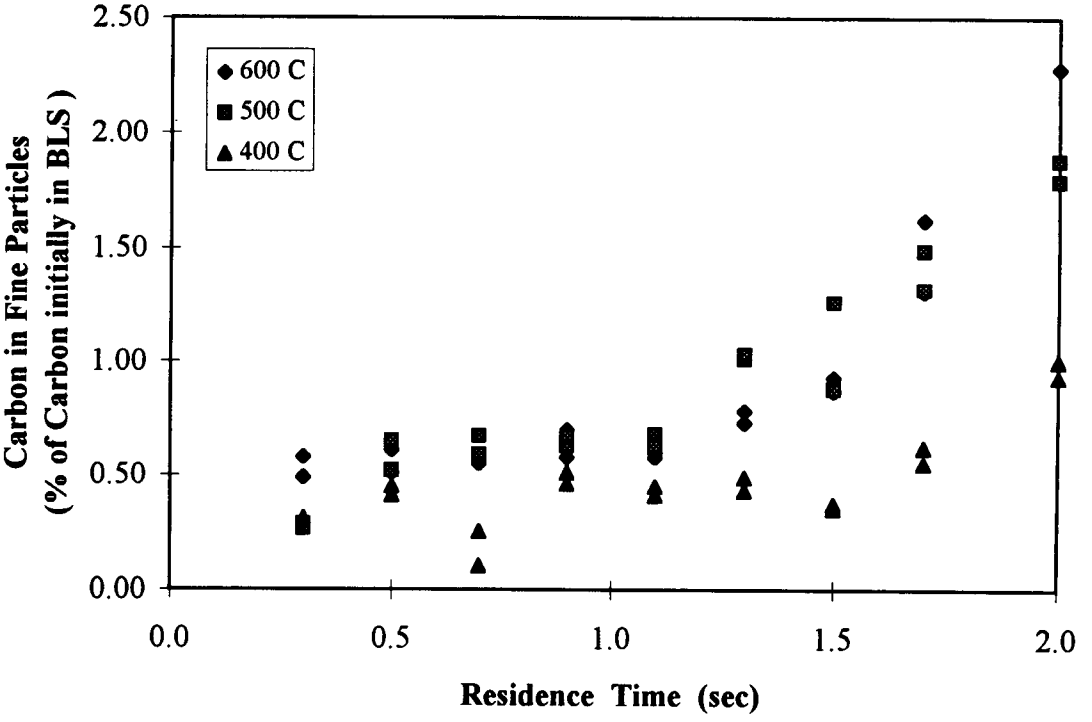

Figure 5.8 Carbon Yield in the Fine Particles from Pyrolysis of Black Liquor Solids at 400-600°C

Figure 5.12 compares the carbon yield in the char residue versus residence time from pyrolysis of black liquor solids at temperature of 600°C, 500°C, and 400°C. The carbon yield in the char residue at 400°C higher than those of 600°C. This is in accordance with the finding of Frederick et al., 1994; Frederick et al., 1995. Frederick et al. (1995) measured the total carbon in the char residue collected at furnace temperature between 700-1000°C and residence time between 0.3-1.6 seconds for 100 micron dry black liquor solids pyrolyzed in similar LEFR experiments. They reported that the carbon content of the char residue decreased rapidly during devolatilization ($t<0.3$ seconds) and continued to decrease but at a slower rate after devolatilization. Frederick (1995) reported that at a residence time of 0.3 seconds, the total carbon in the char residue decreased form 68% at 700°C to 42% at 1100°C. At a residence time of 1.6 seconds, the total carbon in char residue decreased from 50% at 700°C to 20% at 1100°C. In this study, the temperature range was lower than that used by Frederick et al. (1995), but the trends of the total carbon in char residue versus furnace temperature agree with Frederick's (1995) study.

For a temperature of 500°C and residence time above 1.1 seconds in this study, the carbon yield in char residue was a little lower than at a temperature of 600°C. This is the effect of the lower char residue yield at 500°C and residence time above 1.1 seconds.

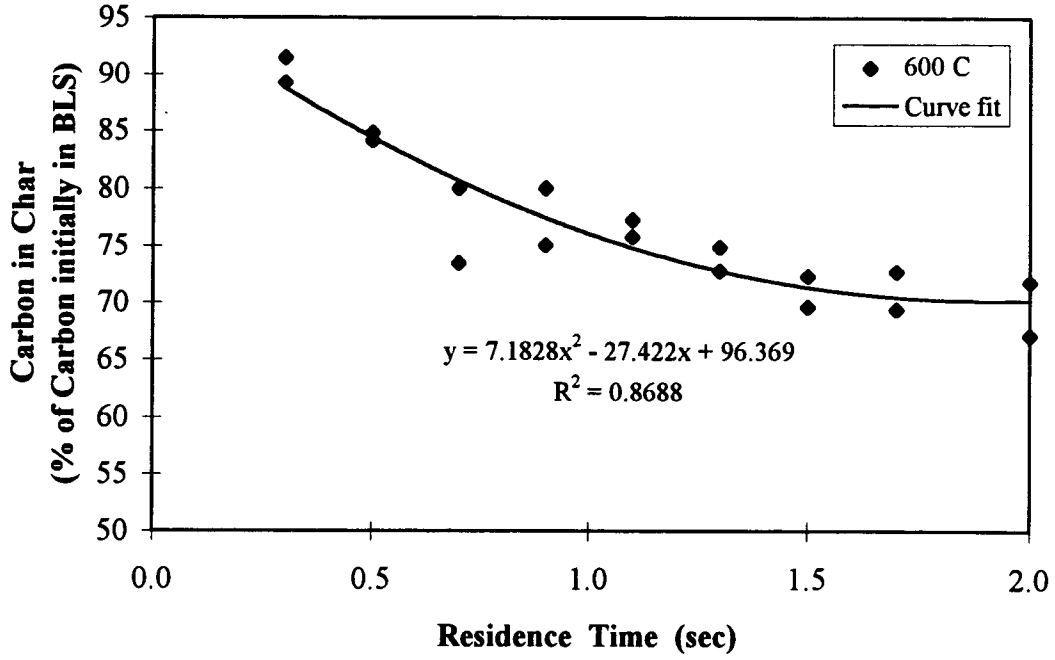

Figure 5.9 Carbon Yield in the Char Residue from Pyrolysis of Black Liquor Solids at 600°C

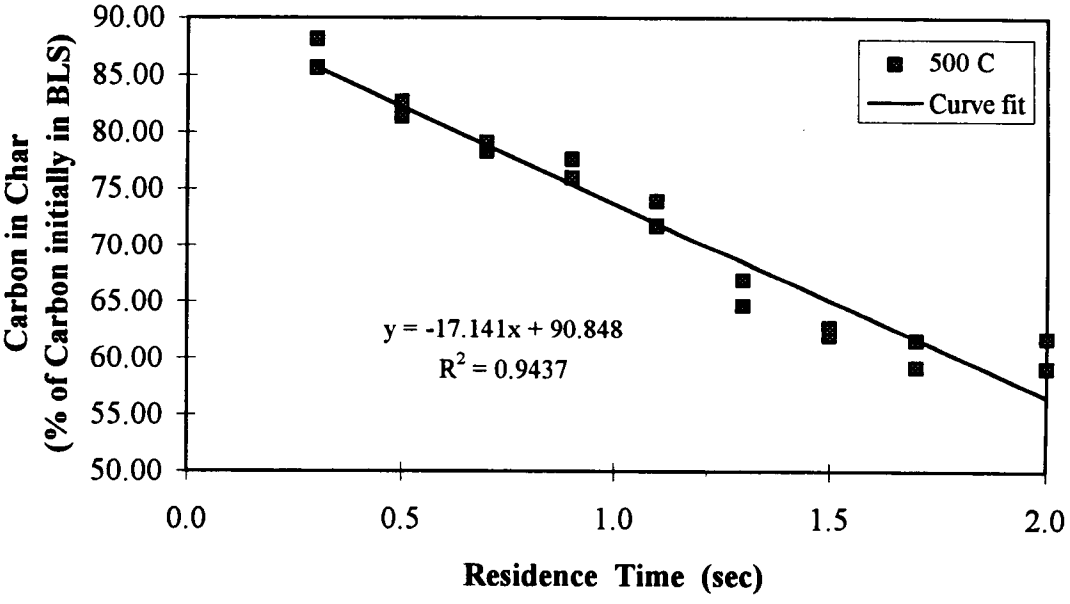

Figure 5.10 Carbon Yield in the Char Residue from Pyrolysis of Black Liquor Solids at 500°C

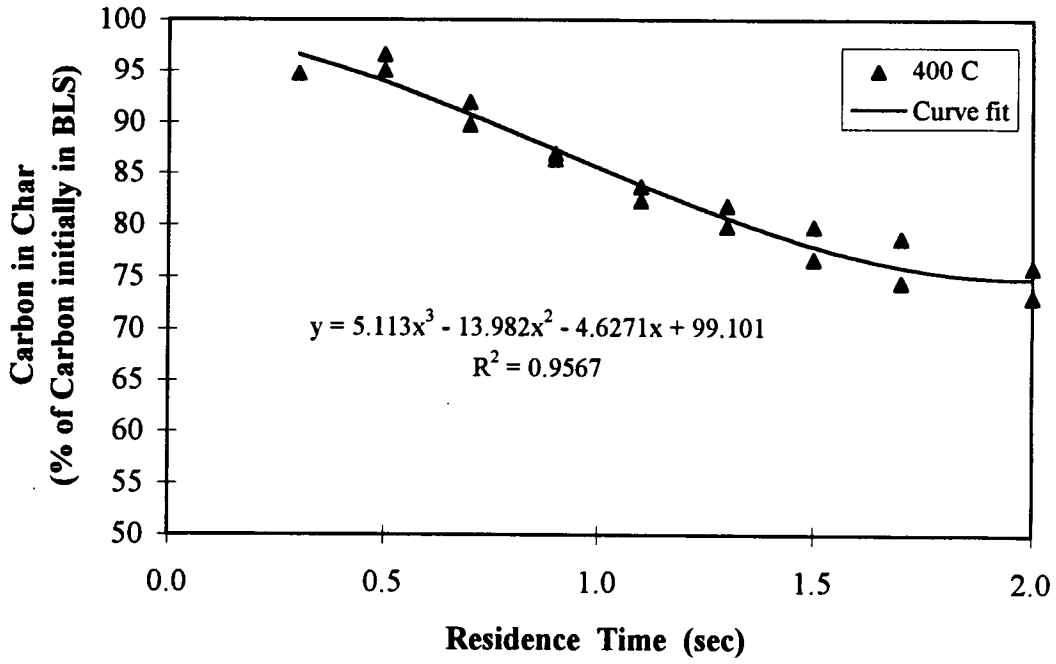

Figure 5.11 Carbon Yield in the Char Residue from Pyrolysis of Black Liquor Solids at 400°C

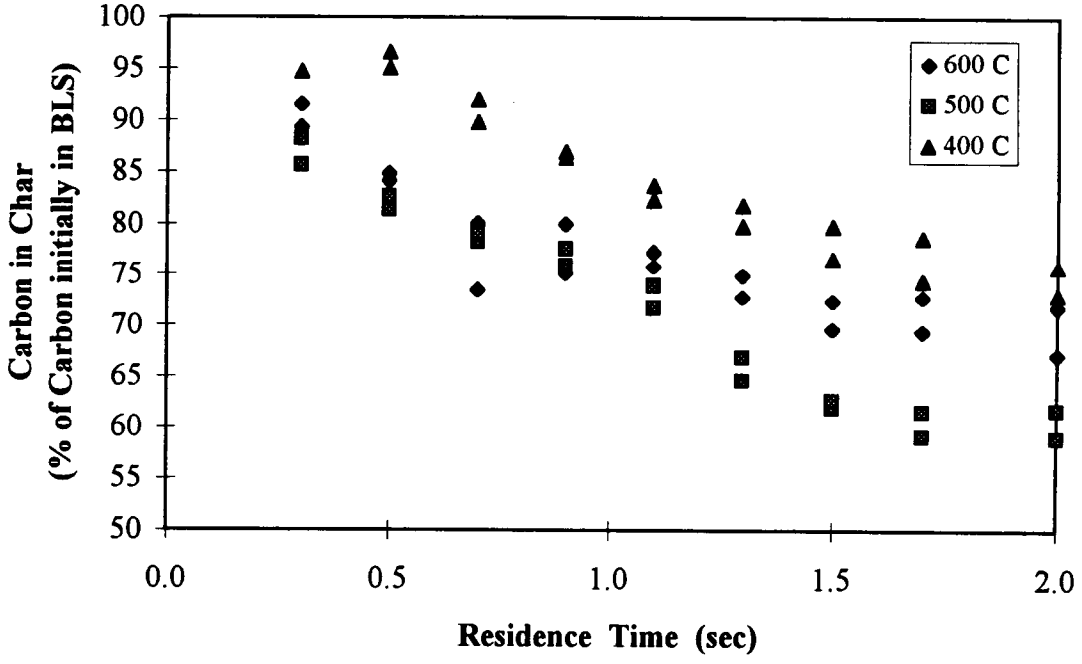

Figure 5.12 Carbon Yield in the Char Residue from Pyrolysis of Black Liquor Solids at 400-600°C

5.2 Fine Particle Yield from Pyrolysis of Black Liquor Solids

Figure 5.13 shows the fine particle yield versus residence time from pyrolysis of black liquor solids at 600°C. *The fine particle yield was very low, no greater than 1% of BLS, and overall increased as residence time increased.* The reproducibility obtained in replicate runs was an average ±0.1% of the carbon in the black liquor solids input. At residence time 0.3 seconds, the fine particle yield is 0.58% and decreased to 0.44% at residence time 0.5 seconds and constant until residence time 1.1 seconds. At residence time above 1.1 seconds, fine particle yield increased as residence time increased to 1.00% at residence time 2.0 seconds.

Figure 5.14 and Figure 5.15 show the fine particle yield versus residence time from pyrolysis of black liquor solids at 500°C and 400°C respectively. The results were qualitatively similar to those of 600°C, the fine particle yield increased as residence time increased for 500°C and 400°C. The reproducibility obtained in replicate runs was an average ±0.1 of the black liquor solids input at 500°C, and at 400°C. At 500°C, the fine particle yield increased from 0.29% at residence time 0.3 seconds to 0.81% at residence time 2.0 seconds. At 400°C, the fine particle yield was essentially constant over the entire range of residence times.

Figure 5.16 shows the comparison of the fine particle yield versus residence time from pyrolysis of black liquor solids between 600°C, 500°C, and 400°C. At residence times above 1.1 seconds, the fine particle yield increased more rapidly at higher temperatures but not at the lower temperature.

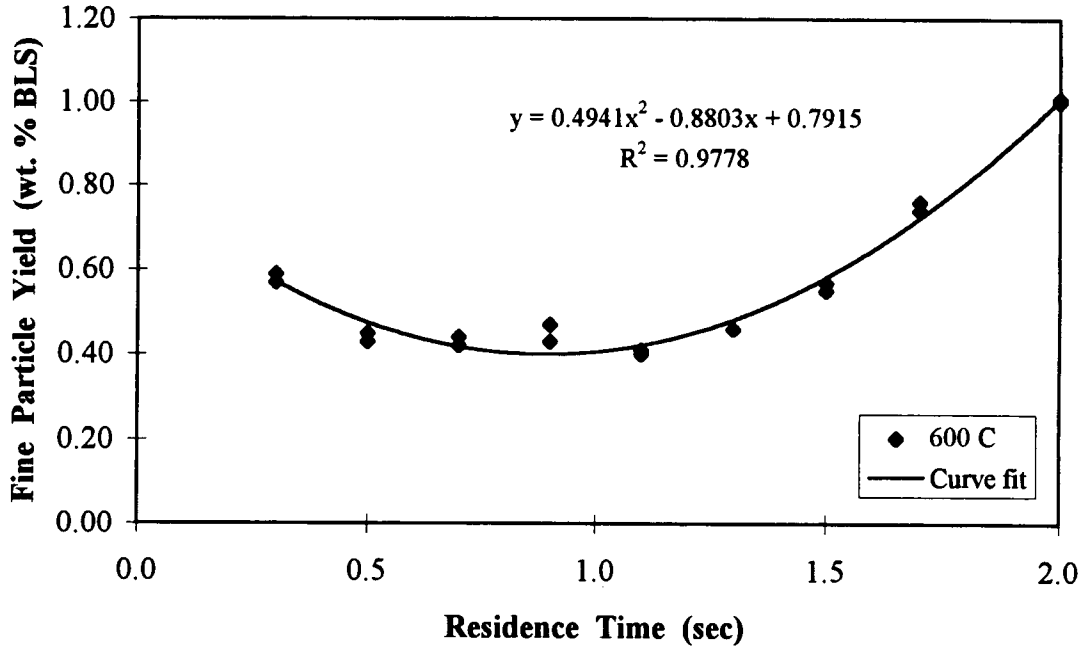

Figure 5.13 Fine Particle Yield from Pyrolysis of Black Liquor Solids at 600°C

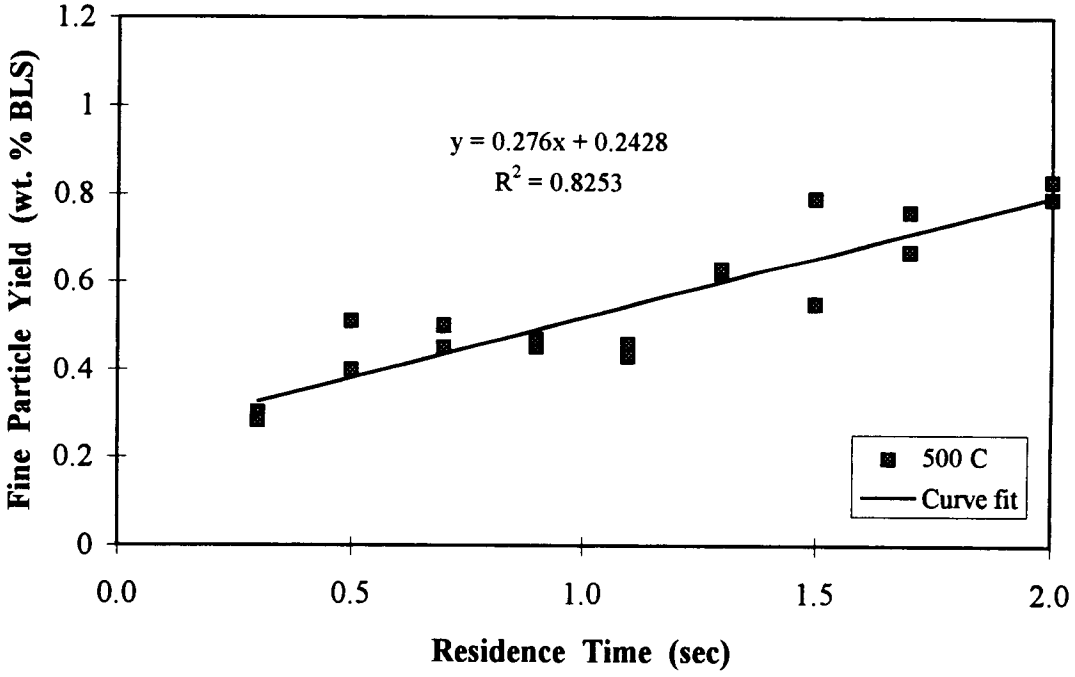

Figure 5.14 Fine Particle Yield from Pyrolysis of Black Liquor Solids at 500°C

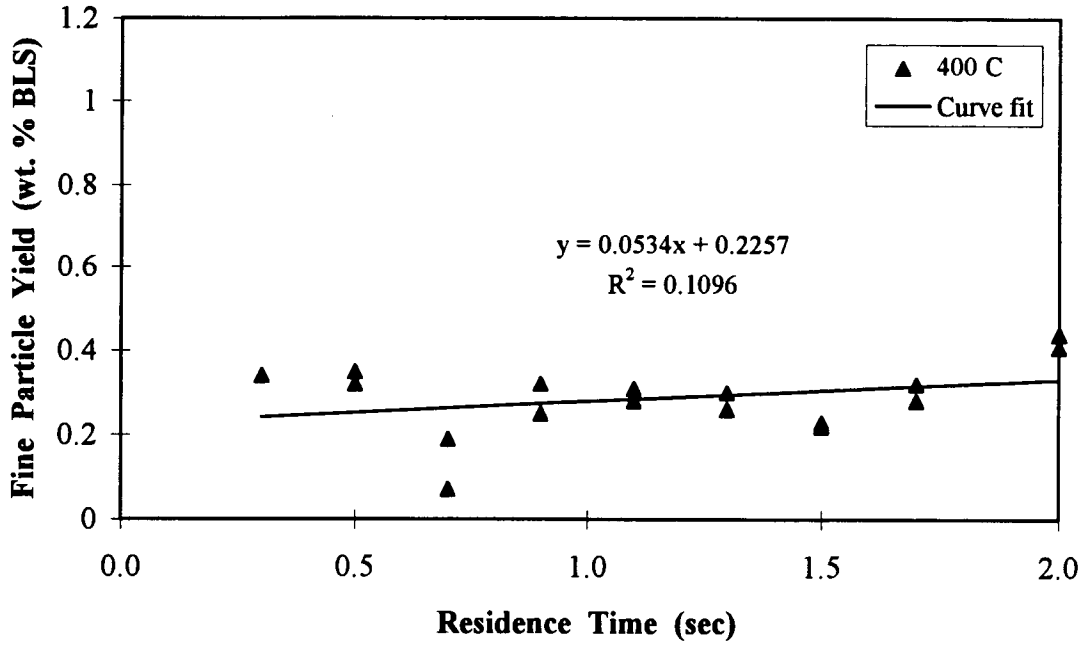

Figure 5.15 Fine Particle Yield from Pyrolysis of Black Liquor Solids at 400°C

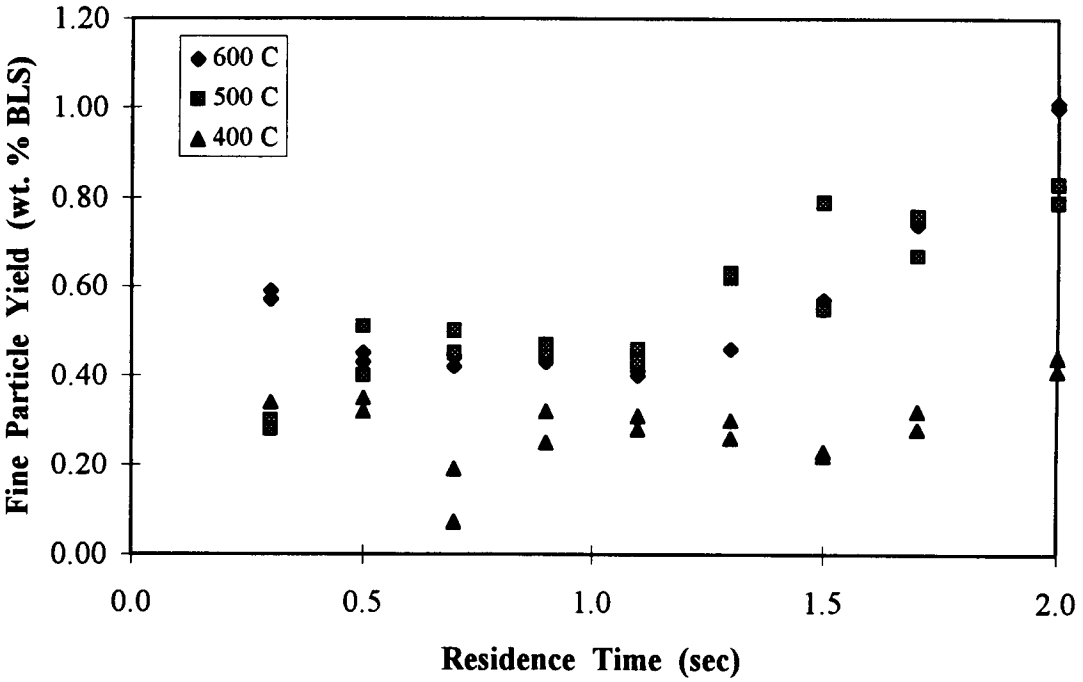

Figure 5.16 Fine Particle Yield from Pyrolysis of Black Liquor Solids at 400-600°C

5.3 Char Residue Yield from Pyrolysis of Black Liquor Solids

In this study, *char residue* refers to the solid residue from pyrolysis including the ash as well as carbon and other elements that remain from the organic matter in black liquor. The mineral ash free char residue is referred to as *char*. During pyrolysis, the char residue yield trends in the opposite direction of the volatile gas yield.

The char residue yield was used as a preliminary indicator of whether good closure of the carbon mass balance will be obtained. Incomplete collection of the char residue was formed to be the main problem in the LEFR runs. This was due mainly to collection of char particles on the tip of the collector. As an example, in some replicate runs the char yield varied from e.g. 91% to 93%. Reproducibility runs show that, when char losses are very minor, the char yield is reproducible within about ±2%. By comparing the char residue yield with previous char residue yield data, it can quickly be determined whether complete char collection was obtained. Experimental data is accepted or rejected, without a more detailed analysis. When runs are rejected for poor char recovery, additional runs at the same experimental conditions can be made.

Figure 5.17 shows the char residue yield versus residence time from pyrolysis of black liquor solids at 600°C. *The char residue yield decreased as residence time increased.* The reproducibility obtained in replicate runs was ±2%. At a residence time of 0.3 seconds, the char residue yield was 92% and it quickly decreased to 85% at a residence time of 0.5 seconds. At residence times above 0.5 seconds, the char residue yield gradually decreased to 75% at a residence time of 2.0 seconds. This indicates that the black liquor solids were volatilized rapidly until a residence time of 0.7 seconds. After

that they were volatilized more gradually. This is in accordance with the finding of Carangal, 1994; and Pianpucktr, 1995. Pianpucktr (1995), for example, reported that at 700°C char residue yield was 82% at 0.3 seconds and it quickly decreased to 65% at 0.6 seconds. At residence times above 0.6 seconds, the char residue yield gradually decreased to 53% at 2.2 seconds.

Figure 5.18 and Figure 5.19 show the char residue yield versus residence time from pyrolysis of black liquor solids at 500°C and 400°C respectively. The result were qualitatively the same as those at 600°C: the char residue yield decreased as residence time increased. The reproducibility obtained in replicate runs was ±1.9% at 500°C, and ±2.3% 400°C. At the shortest residence time, 0.3 seconds, the char residue yield was 92% at 500°C and 99% at 400°C. This indicates that at 400°C nearly all of the volatile species remained as black liquor solids at residence time 0.3 seconds, i.e. that the black liquor had barely begin to pyrolyze. At residence times above 0.3 seconds, the char residue yield gradually decreased until the longest residence time, 2.0 seconds. At 2.0 seconds the char residue yield was 65% at 500°C and 77% at 400°C.

Figure 5.20 shows the comparison of the char residue yield versus residence time from pyrolysis of black liquor solids between 600°C, 500°C, and 400°C. At residence time between 0.3-1.1 seconds, the char residue yield was about the same at 500°C and 600°C, but higher at 400°C. At residence time above 1.1 seconds, the experimental data from 600°C and 400°C agree well with the result of previous studies, but the experimental data at 500°C show that the char residue yield was lower than those of previous typical char residue yield data. Carangal (1994) reported char residue yield as a function of temperature at residence time 2.0 seconds and the char residue yield at 500°C was

73.16%. Table 5.1 shows the comparison of char residue yield from pyrolysis of black liquor solids at residence time 2.0 seconds between Carangal's (1994) extrapolated data and this experimental data.

Table 5.1 The comparison of char residue yield from pyrolysis of black liquor solids at residence time 2.0 seconds between Carangal's (1994) extrapolated data and this experimental data for runs made with dry black liquor solids from the same kraft black liquor

Temperature	Char Residue Yield (wt% BLS)	
(°C)	Carangal's (1994) calculation	Experimental data
600	67.6 ± 7.0	75 ± 2.0
500	73.2 ± 3.0	65 ± 1.9
400	78.8 ± 3.0	77 ± 2.3

From Table 5.1, at 600°C, the char residue yield from our experimental data was higher than that of Carangal's extrapolated data. At 500°C, the char residue yield from our experimental data was lower than that of Carangal's extrapolated data. At 400°C, the char residue yield from our experimental data agrees well with Carangal's extrapolated data.

From Carangal's experimental data at 600°C and 2.0 seconds residence time, the char residue yield varied from 60-73%. By comparison in our experimental data the yield varied from 73-75%. There is some overlap between Carangal's experimental char residue data and our experimental data. Since the greatest problem in these experiments is loss of char, we conclude the char residue yield result at 600°C, 2.0 seconds residence time is about 73-75%.

From the Carangal's experimental data at 500°C and 2.0 seconds residence time, the char residue yield was around 70%, compared to our experimental data where it was 63-65%. And also the char residue yields at 500°C for residence times above 1.1 seconds, shown in Figure 5.20, are lower than those at 600°C.

During devolatilization, black liquor droplets swell rapidly and continuously to a maximum volume at the end of devolatilization. In the experiments, the physical size of the swollen char particle at 500°C was bigger than those of 600°C, 400°C, and Black liquor solids shown from the Figure 5.21 to Figure 5.26. This is similar to the results reported by Miller (1986). Miller studied the effect of gas temperature, heating rate, initial solids content of the particle, and particle size on the maximum swollen volume of black liquor particles during evaporation and pyrolysis using single particle reactor. The gas temperature was varied from 300-900°C. Miller reported that the maximum swollen volume occurred at approximately 500°C. The pyrolyzing black liquor appeared to be most fluid at 500°C. The larger swollen char residue particle at 500°C, char residue accumulated at the top of collector and partially blocked the collector entrance. This prevented other char residue particles from entering the collector, and thus caused the lower char residue yield.

At 400°C, the effect of furnace temperature on the maximum swollen volume of black liquor was minor which is in accordance with the experimental results reported here. The char residue yield gradually decreased as the residence time increased and the char residue yield at the longest residence time of study (2.0 seconds) was in agreement with the Carangal's (1994) extrapolated data.

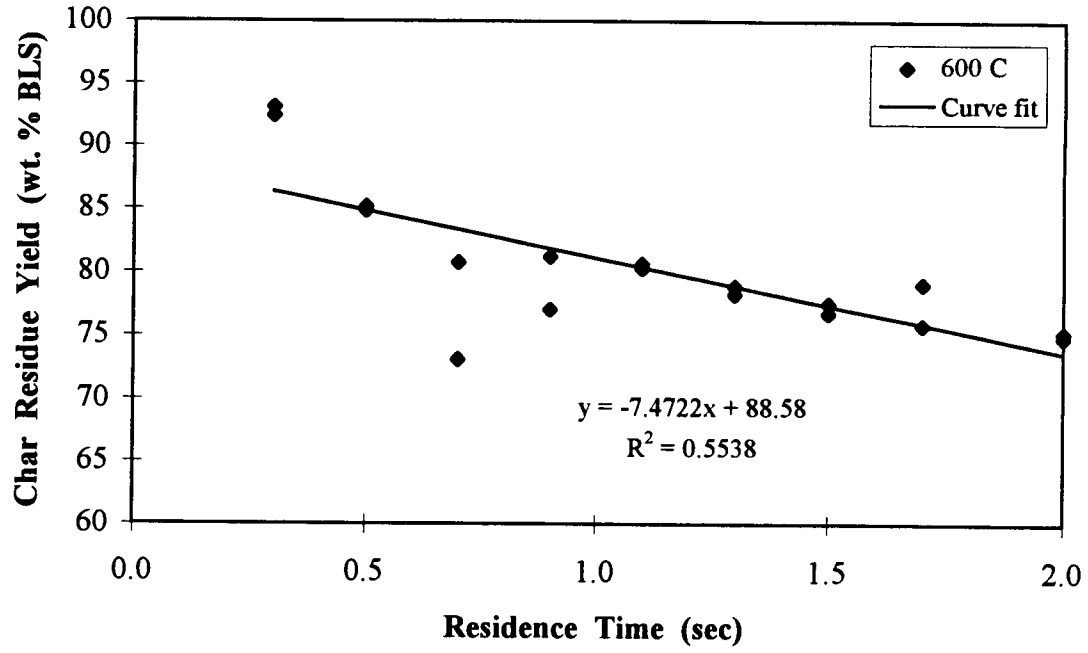

Figure 5.17 Char Residue Yield from Pyrolysis of Black Liquor Solids at 600°C

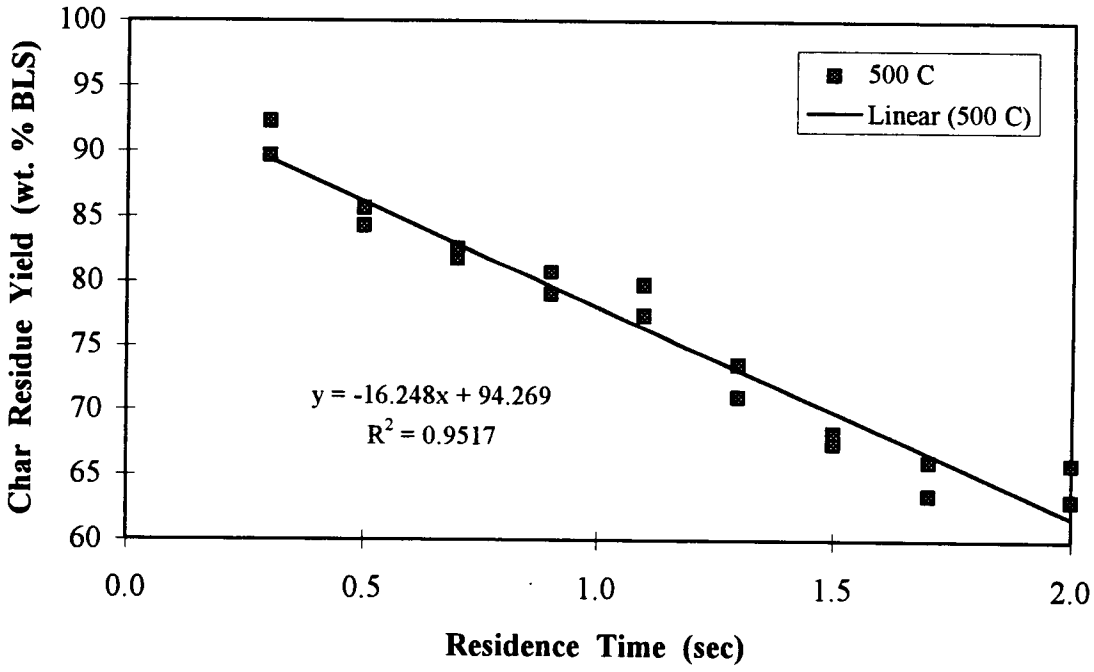

Figure 5.18 Char Residue Yield from Pyrolysis of Black Liquor Solids at 500°C

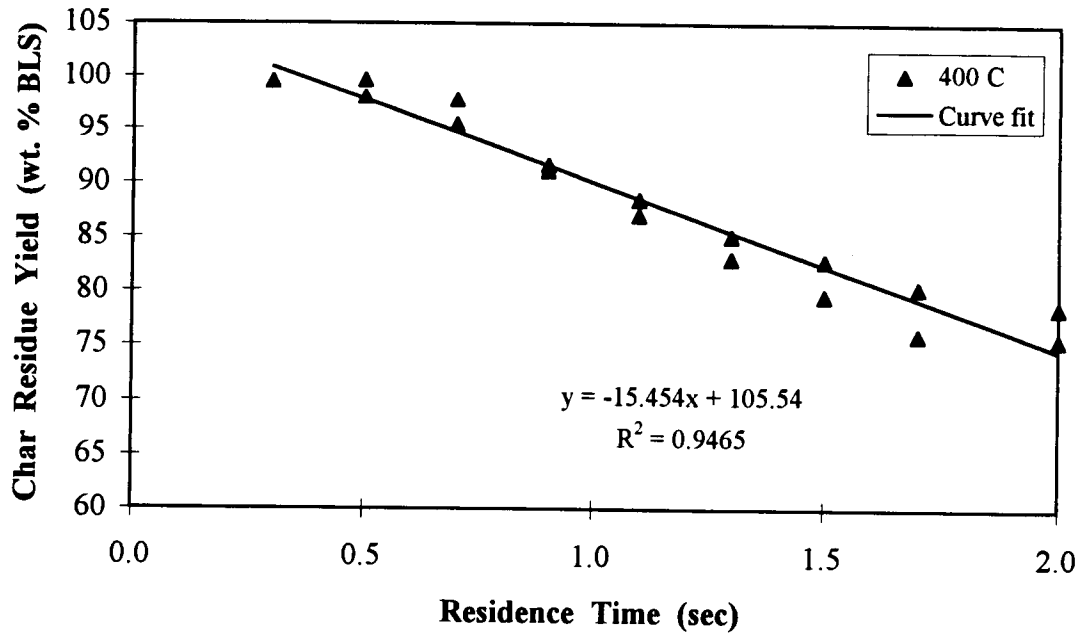

Figure 5.19 Char Residue Yield from Pyrolysis of Black Liquor Solids at 400°C

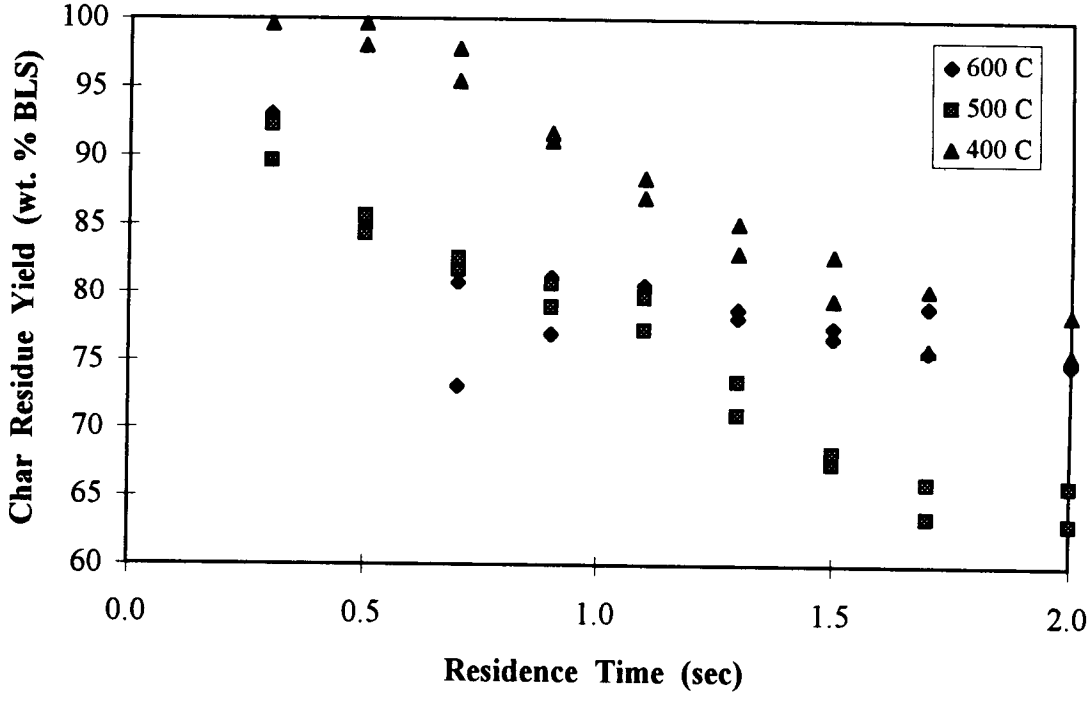

Figure 5.20 Char Residue Yield from Pyrolysis of Black Liquor Solids at 400-600°C

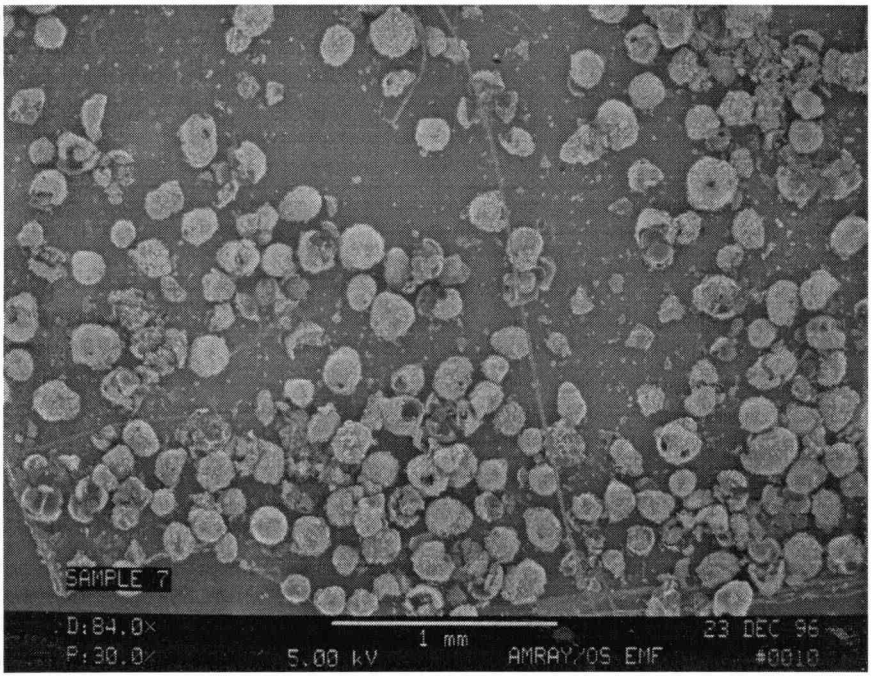

Figure 5.21 Char Residue Particles at 400°C, 2.0 seconds (30 times)

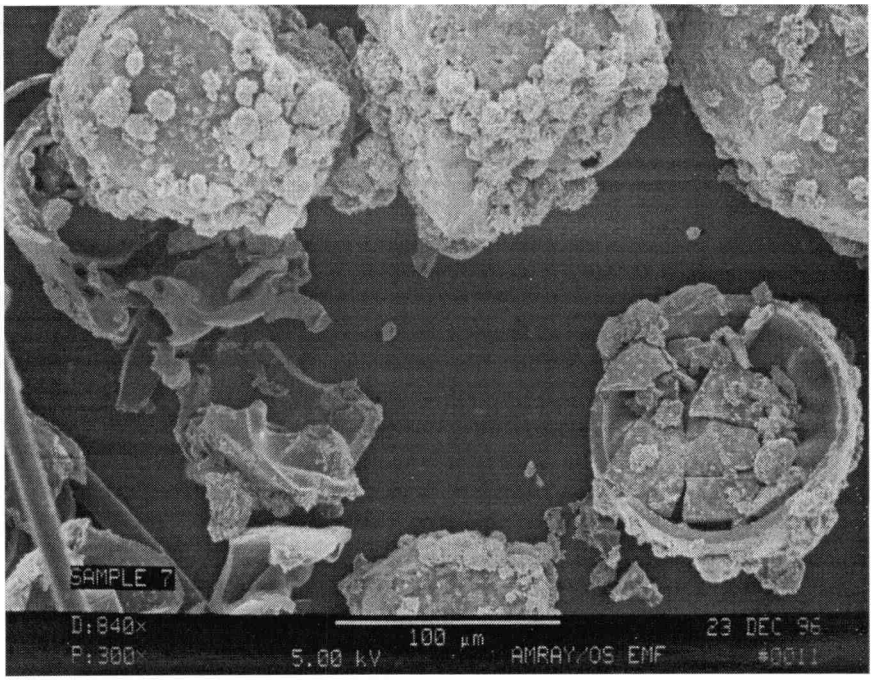

Figure 5.22 Char Residue Particles at 400°C, 2.0 seconds (300 times)

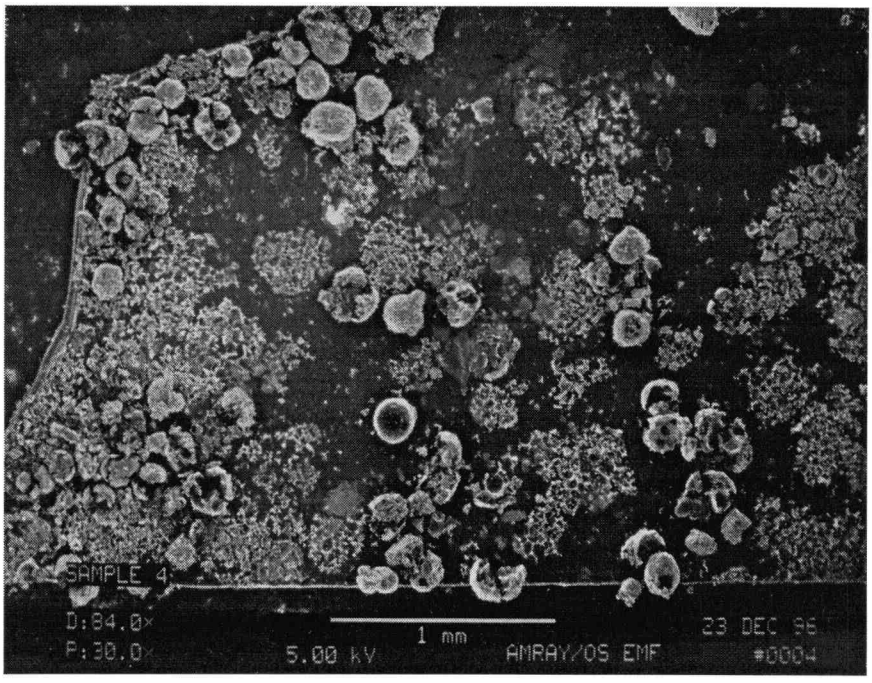

Figure 5.23 Char Residue Particles at 500°C, 2.0 seconds (30 times)

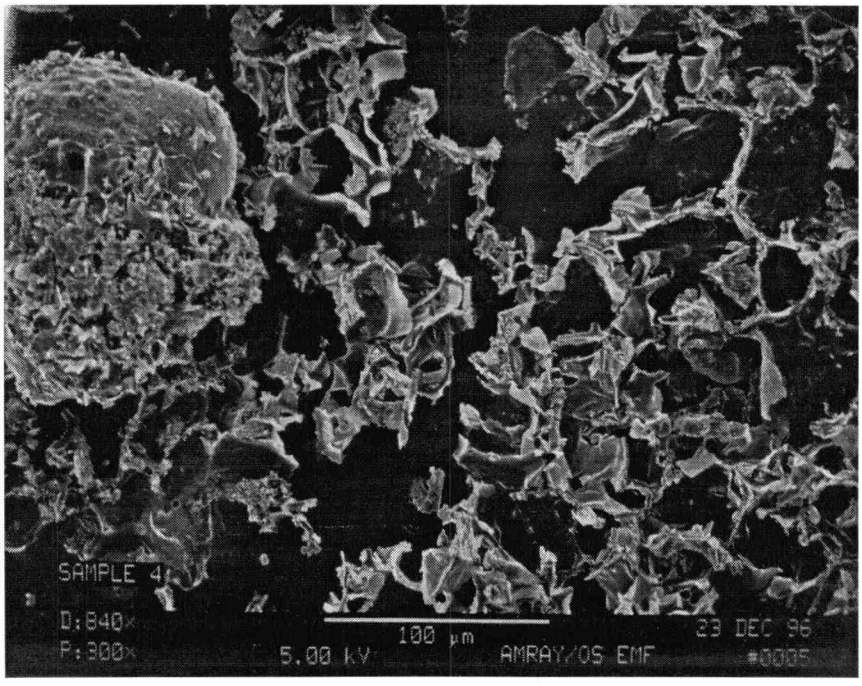

Figure 5.24 Char Residue Particles at 500°C, 2.0 seconds (300 times)

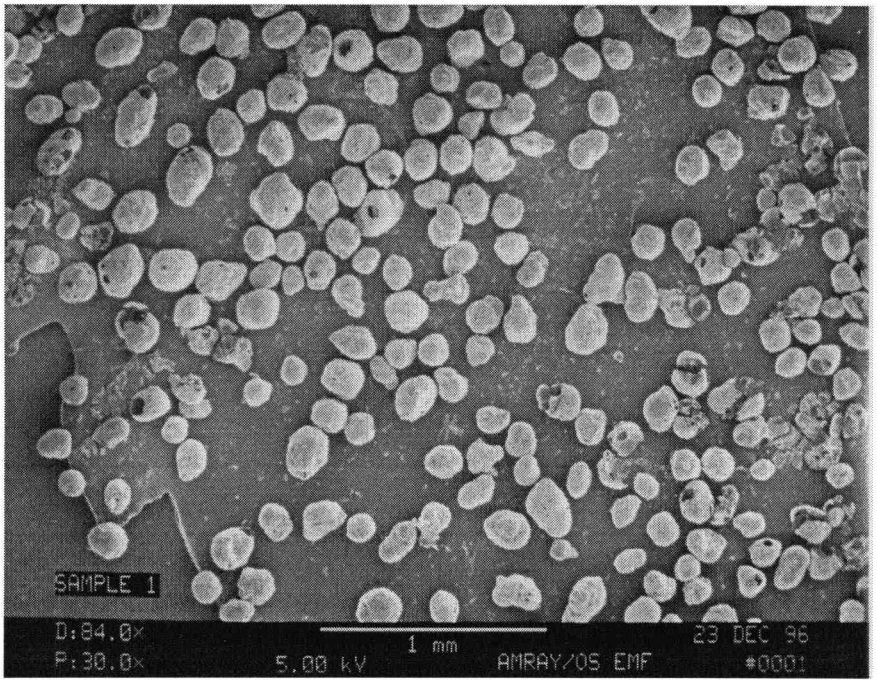

Figure 5.25 Char Residue Particles at 600°C, 2.0 seconds (30 times)

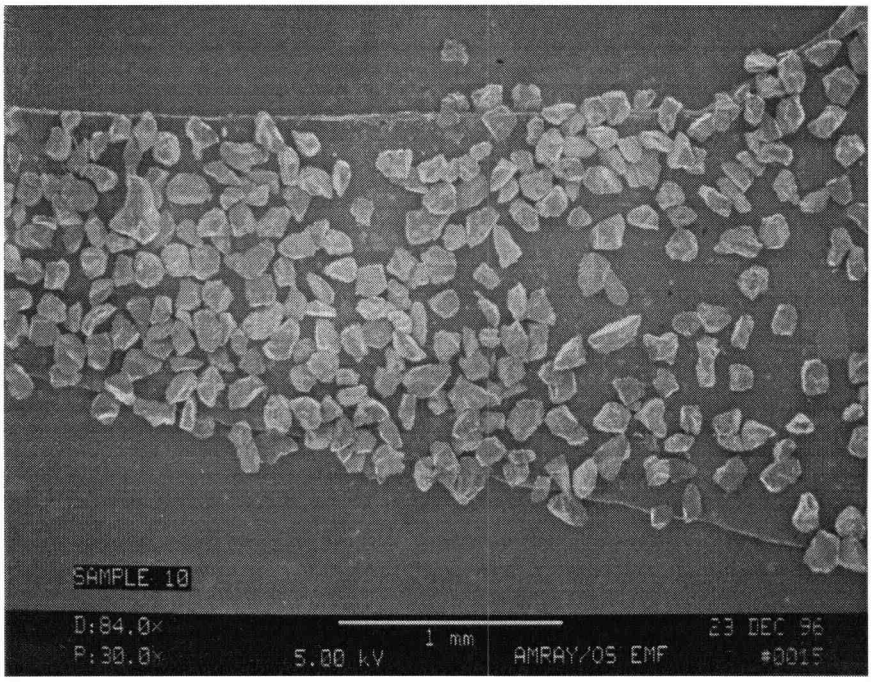

Figure 5.26 Black Liquor Solids (30 times)

5.4 Carbon Recovered from Pyrolysis of Black Liquor Solids

Carbon recovered as gases, fine particles, and char residue from pyrolysis of black liquor solids provided mass balances for carbon at each experimental condtion.

Carbon recovery in this study was calculated based on the carbon input as black liquor (100%) and carbon outputs including carbon in char, fine particle, and gas. Details of the calculations are shown in Appendix B. The average of carbon recovered from carbon yield in char, carbon yield in fume, and carbon yield in gas are as follow :

1. At temperature 600°C, average carbon recovery 96.2% (range 91.0-99.7%)
2. At temperature 500°C, average carbon recovery 88.1% (range 80.5-95.5%)
3. At temperature 400°C, average carbon recovery 95.7% (range 93.6-99.7%)

At temperatures of 600°C and 400°C, the average carbon recovery was very good. At temperature 500°C, the average carbon recovery was somewhat lower. As discussed in Section 5.3, at 500°C, the char residue yield was lower than expected based on the 400°C and 600°C data, and on Carangal's (1994) data, due to accumulation of the highly swollen char particle on the top of the collector in the LEFR. This reduced the average carbon recovery at 500°C.

These carbon recovery results, show that the data on distribution of carbon between char and gases can be considered reliable, especially at 400°C and 600°C. We now examine the data at 500°C where carbon recovery was poorer.

According to the discussion in section 5.2.2, the fine particles should consist mainly of tar or char fines. This can be confirmed by Figure 5.27, Figure 5.28, and Figure

5.29 which show non-carbon matter in the char residue and in the fine particles at 600°C, 500°C, and 400°C respectively. The non-carbon matter (inorganic matter) in the fine particle deceased as residence time increased. The non-carbon matter in the char residue remained constant as residence time increased. At residence time of 0.3 seconds, the non-carbon matter in the char and in the fine particles was the same, which indicates that the fine particles are very likely the same material as the char residue. At residence times above 0.3 seconds, the non-carbon matter in the fine particle decreased as residence time increased which indicates that the carbon content of the fine particles increase as residence time increases.

As discussed earlier, the main reason for the poorer carbon recovery at 500°C was the loss of char particles on the tip of the collector. The carbon yields as gas and fine particles at 500°C were consistent with the 400°C and 600°C data. The char residue and char carbon yield were therefore adjusted upward, base on the carbon recovered as gas and as fine particles, to give a carbon balance closure of 96%, the average for 400°C and 600°C runs. Details of the calculations are shown in Appendix B. The adjusted carbon yield in the char residue is shown in Figure 5.30. The curve of carbon yield in the char residue at 500°C has been shifted up and located between the curves of 400°C and 600°C. The char residue yield at 500°C was also adjusted and shown in the Figure 5.31. The curve of the char residue yield at 500°C is shifted up and located between the curve of 400°C and 600°C. Figure 5.32, Figure 5.33, and Figure 5.34 compares the carbon yield in the char residue, in the fine particles, and in the gas phase at 600°, adjusted-data of 500°C, and 400°C respectively.

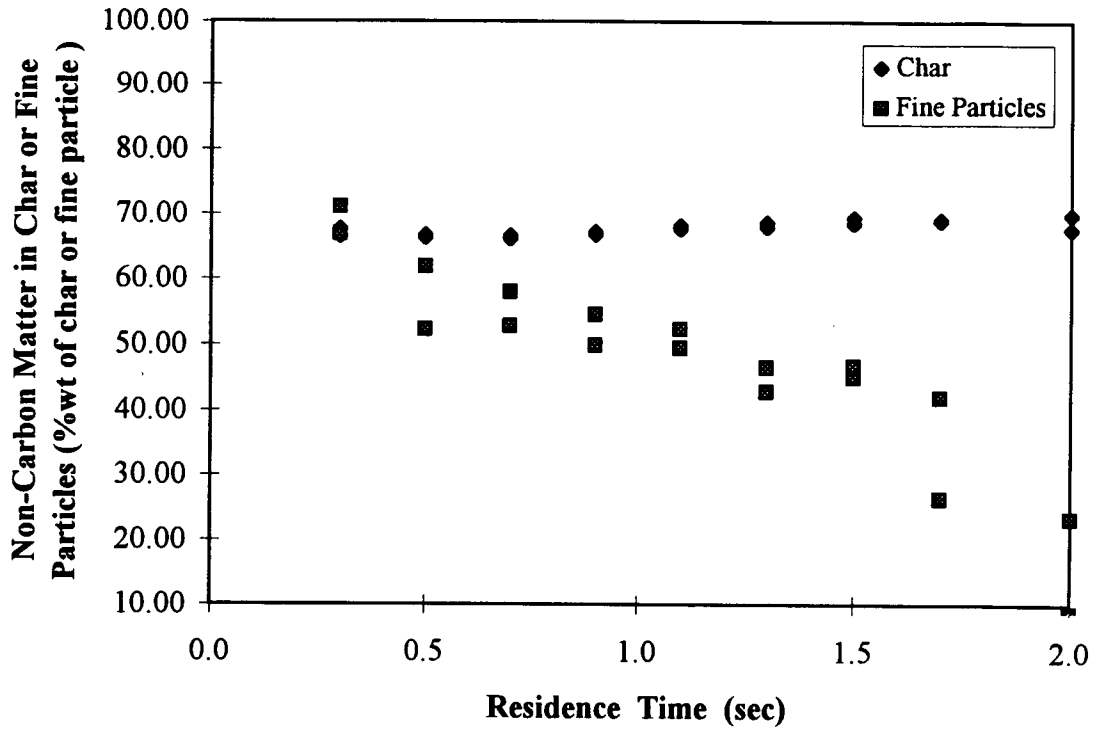

Figure 5.27 Non-Carbon Matter in Char or Fine Particles at 600°C

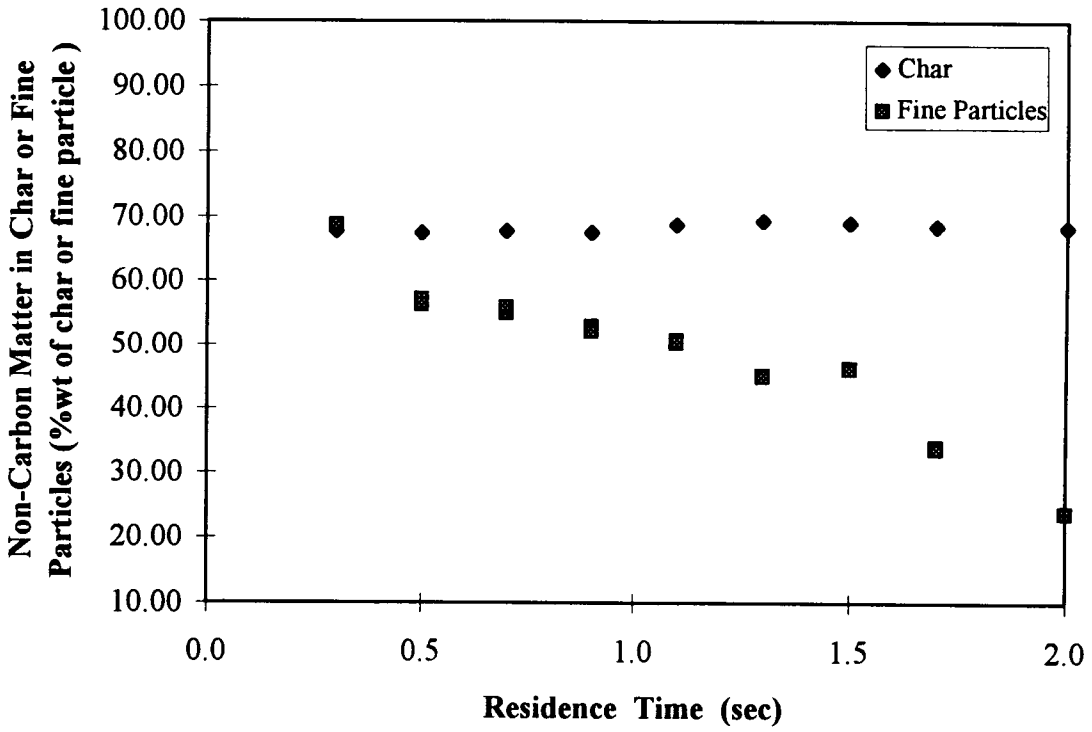

Figure 5.28 Non-Carbon Matter in Char or Fine Particles at 500°C

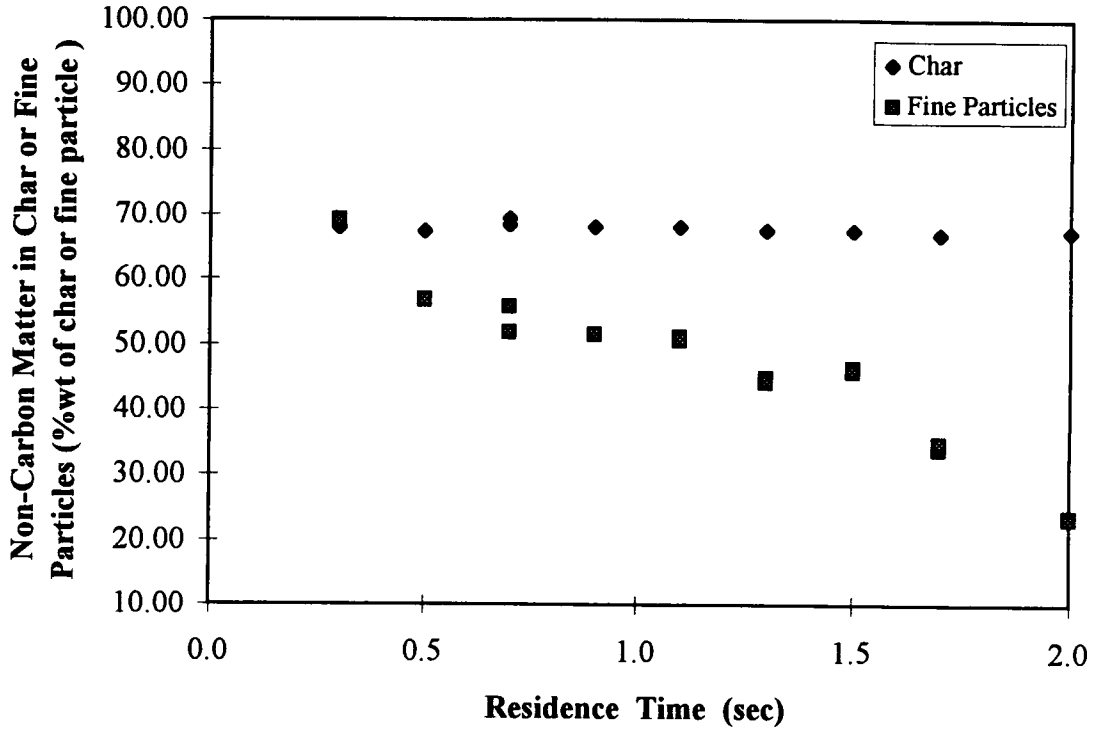

Figure 5.29 Non-Carbon Matter in Char or Fine Particles at 400°C

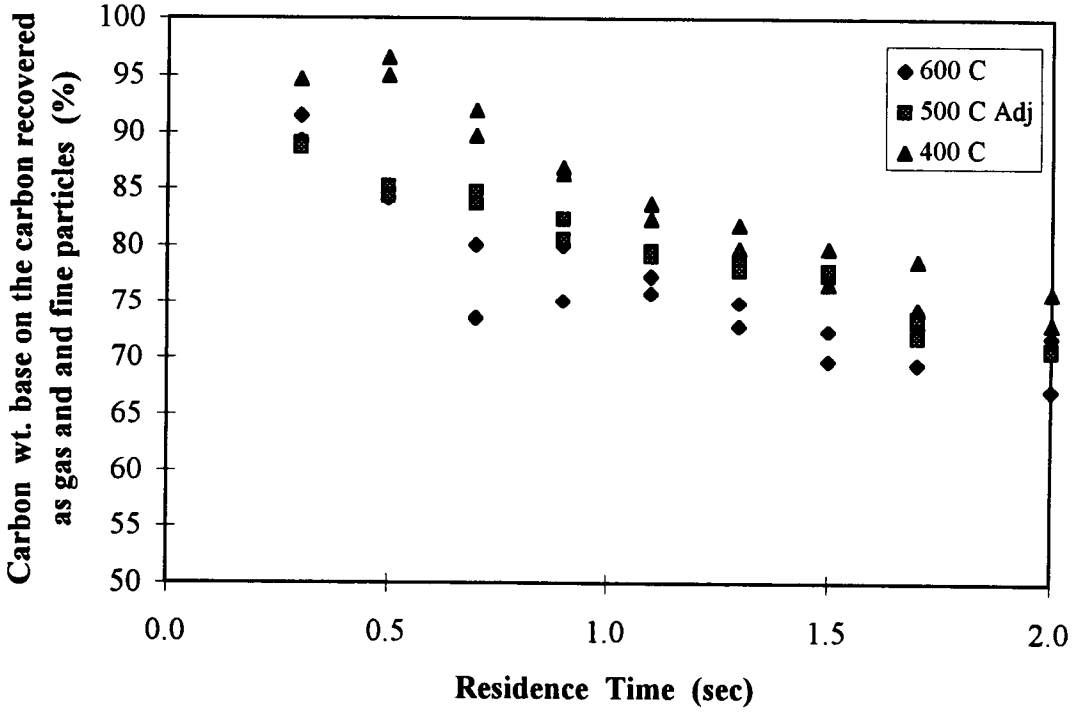

Figure 5.30 Carbon Yield in the Char Residue Base on the Carbon Recovered as gas and as fine Particles

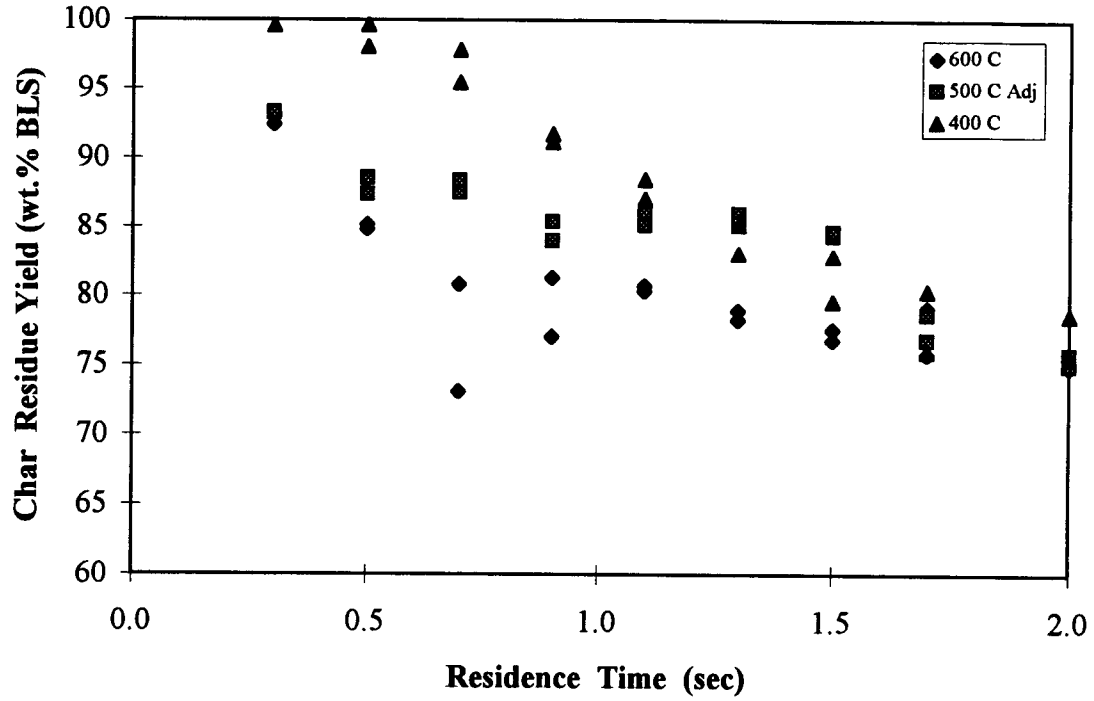

Figure 5.31 Adjusted Char Residue Yield from Pyrolysis of Black Liquor Solids

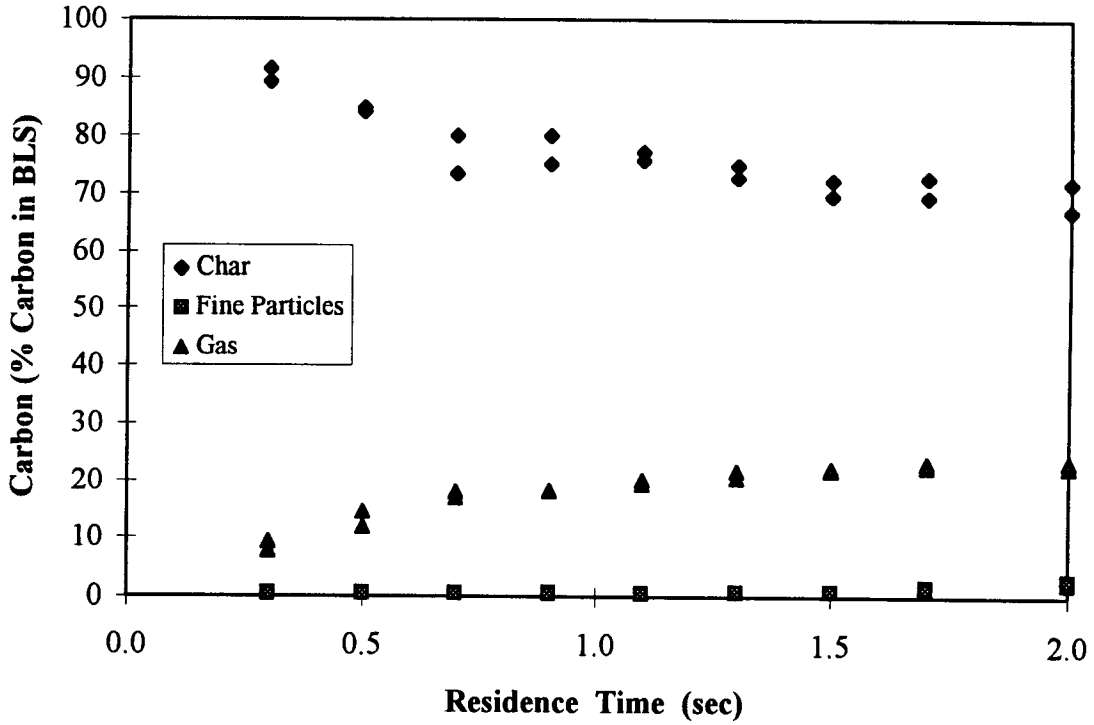

Figure 5.32 Carbon Yield in the Char Residue, Fine Particles, and Gas at 600°C

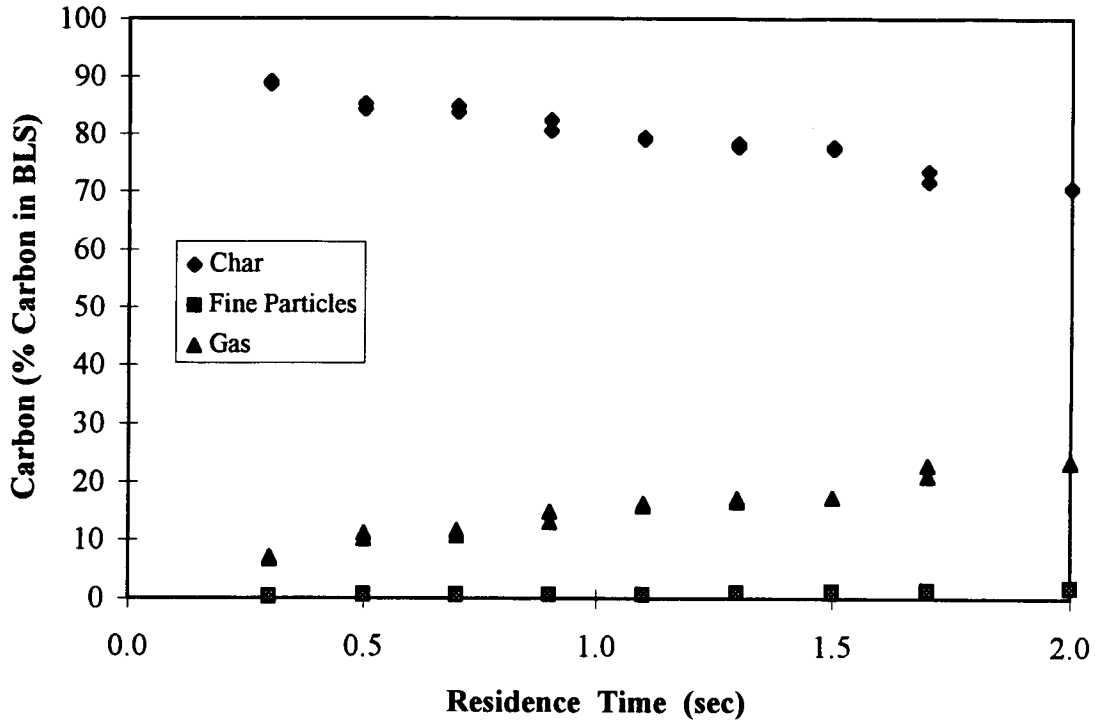

Figure 5.33 Carbon Yield in the Char Residue, Fine Particle, and Gas at 500°C

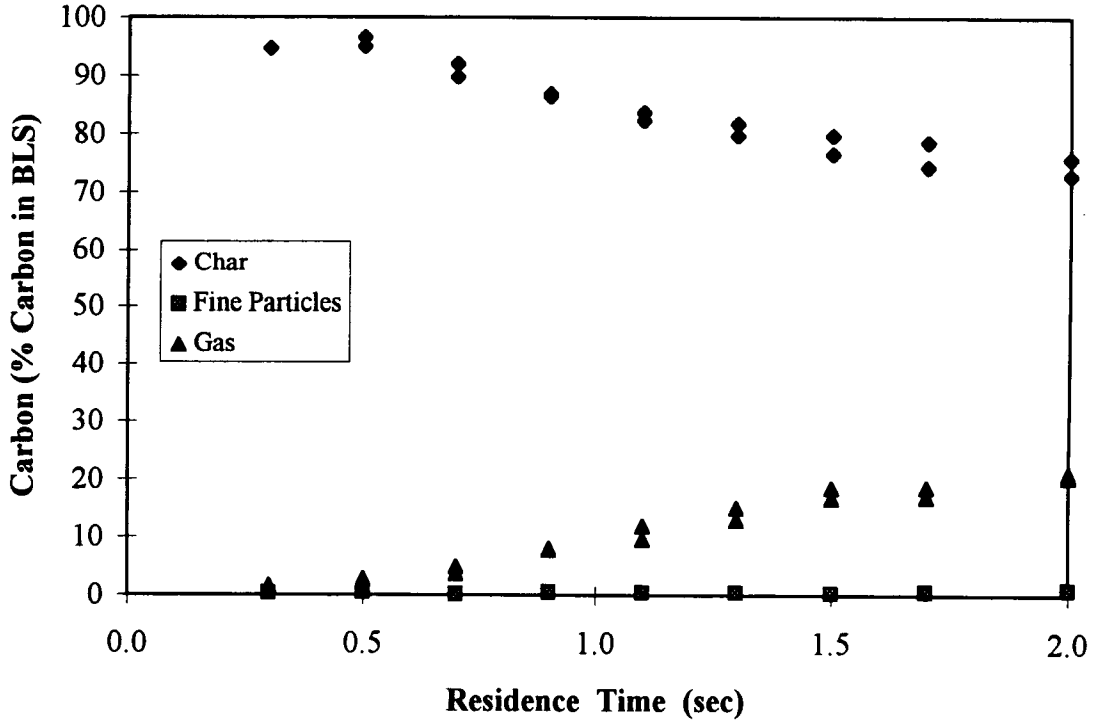

Figure 5.34 Carbon Yield in the Char Residue, Fine Particles, and gas at 400°C

5.5 Sulfur Yield in Char Residue from Pyrolysis of Black Liquor Solids

Figure 5.35, Figure 5.36, and Figure 5.37 show sulfur yields in the char residue versus residence time from pyrolysis of black liquor solids at 600°C, 500°C, and 400°C respectively. *The sulfur yield in the char residue decreased as residence time increased.* The reproducibility obtained in replicate runs was an average ±2.8% at 600°C, ±1.5% at 500°C, and ±1.9% at 400°C, all based on the sulfur in the black liquor input. At 600°C and a residence time of 0.3 seconds, the sulfur yield was 88%. If decreased rapidly until a residence time of 1.1 seconds, and then gradually decreased to 38% at a residence time of 2.0 seconds.

At 500°C and a residence time of 0.3 seconds, the sulfur yield was 90% and decreased with decreasing rate to 41% at a residence time of 2.0 seconds. At 400°C and a residence time of 0.3 seconds, the sulfur yield was 97% and gradually decreased to 56% at a residence time of 2.0 seconds.

Figure 5.38 compares the sulfur yield in the char residue versus residence time from pyrolysis of black liquor solids at temperature of 600°C, 500°C, and 400°C. *The higher the temperature, the lower the sulfur yield in the char residue.* The sulfur content of the char residue at residence time 2.0 seconds was 56% at 400°C, 41% at 500°C, and 38% at 600°C. This is in accordance with the finding of Forssen et al. (1992) stated that the sulfur retained in the char residue after pyrolysis of black liquor went through a minimum with increasing furnace temperature at 600-700°C. Forssen et al. studied pyrolysis of single droplet, 2-3 mm in diameter. The regression curve of Forssen et al.'s data showed that the sulfur content of the char residue at residence time after 1.5 seconds

was 54% at 400°C, 40% at 500°C, and 35% at 600°C. Also the data of, Gairns et al. (1994)'s study agree very well with the Forssen et al. curve. These results are in very good agreement with our experimental data. The data reported by Forssen et al. were for 9 different kraft black liquors. Their results indicate that there is relatively little difference in sulfur release during pyrolysis in their temperature range either between different kraft liquor of between different experimental methods.

Figure 5.39 compares the sulfur yield in the char residue from pyrolysis of black liquor solids at 400°C, 500°C, and 600°C, using the adjusted char yields at 500°C. The curve of sulfur yield at 500°C is shifted up and located between the curve of 400°C and 600°C.

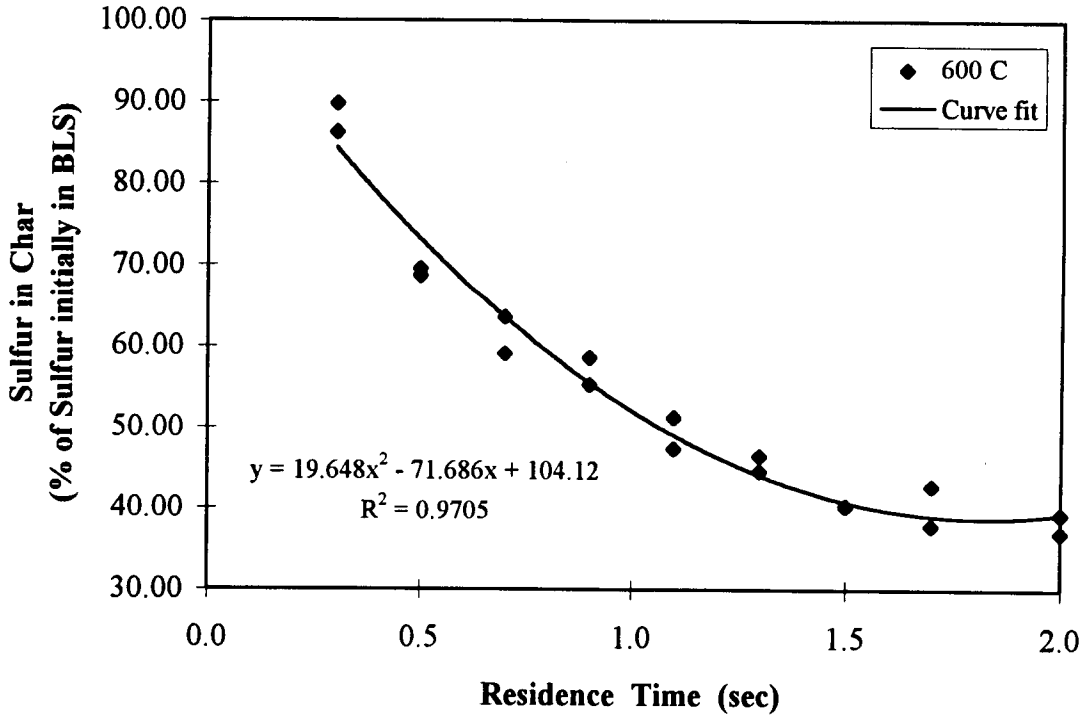

Figure 5.35 Sulfur Yield in the Char Residue from Pyrolysis of Black Liquor Solids at 600°C

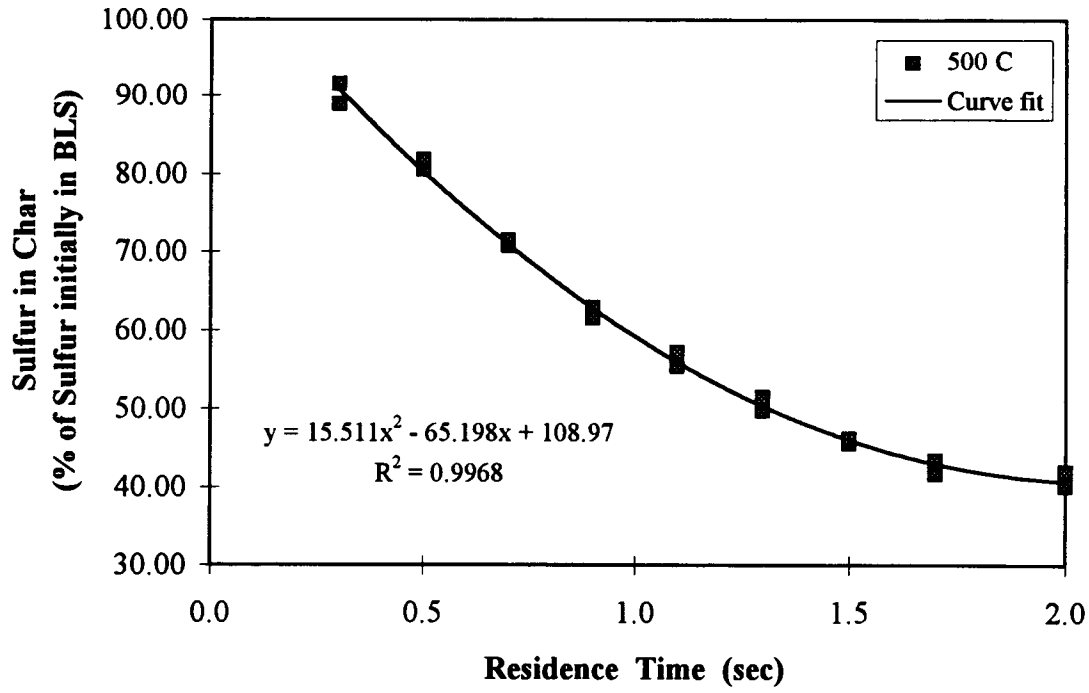

Figure 5.36 Sulfur Yield in the Char Residue from Pyrolysis of Black Liquor Solids at 500°C

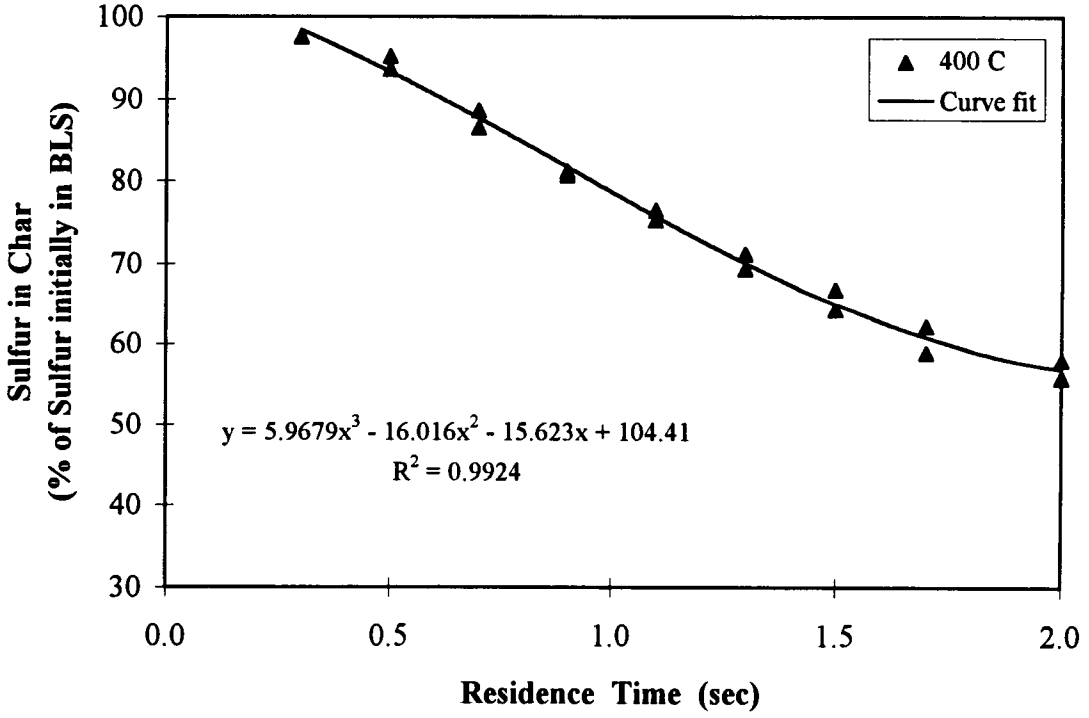

Figure 5.37 Sulfur Yield in the Char Residue from Pyrolysis of Black Liquor Solids at 400°C

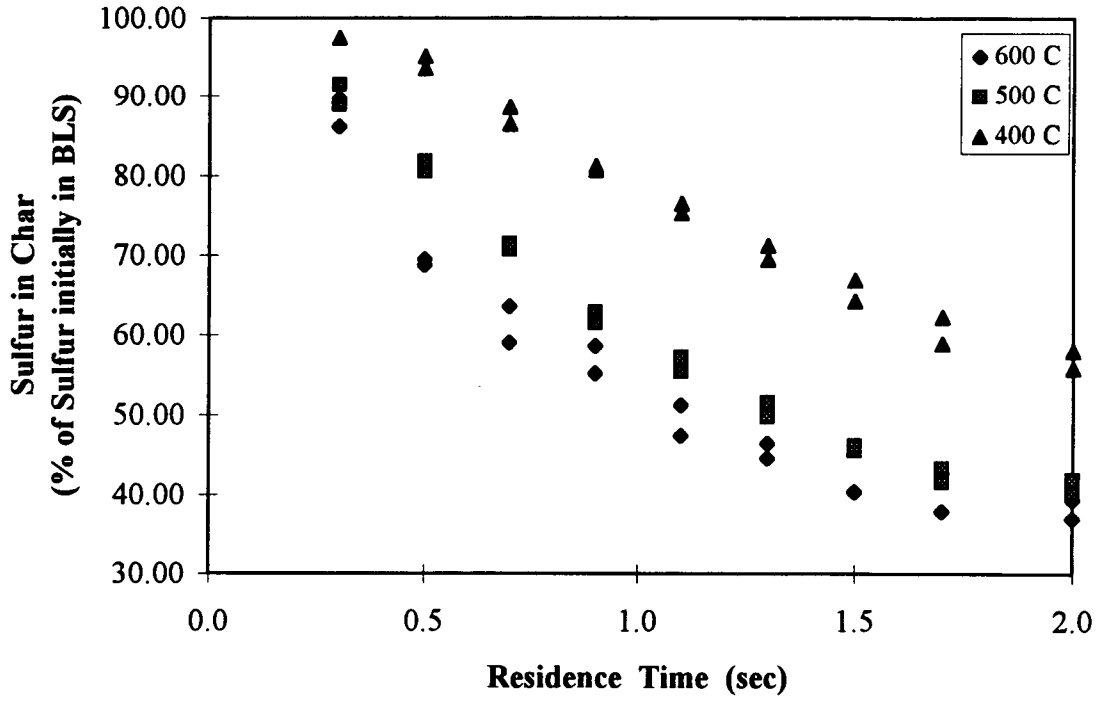

Figure 5.38 Sulfur Yield in the Char Residue from Pyrolysis of Black Liquor Solids at 400-600°C

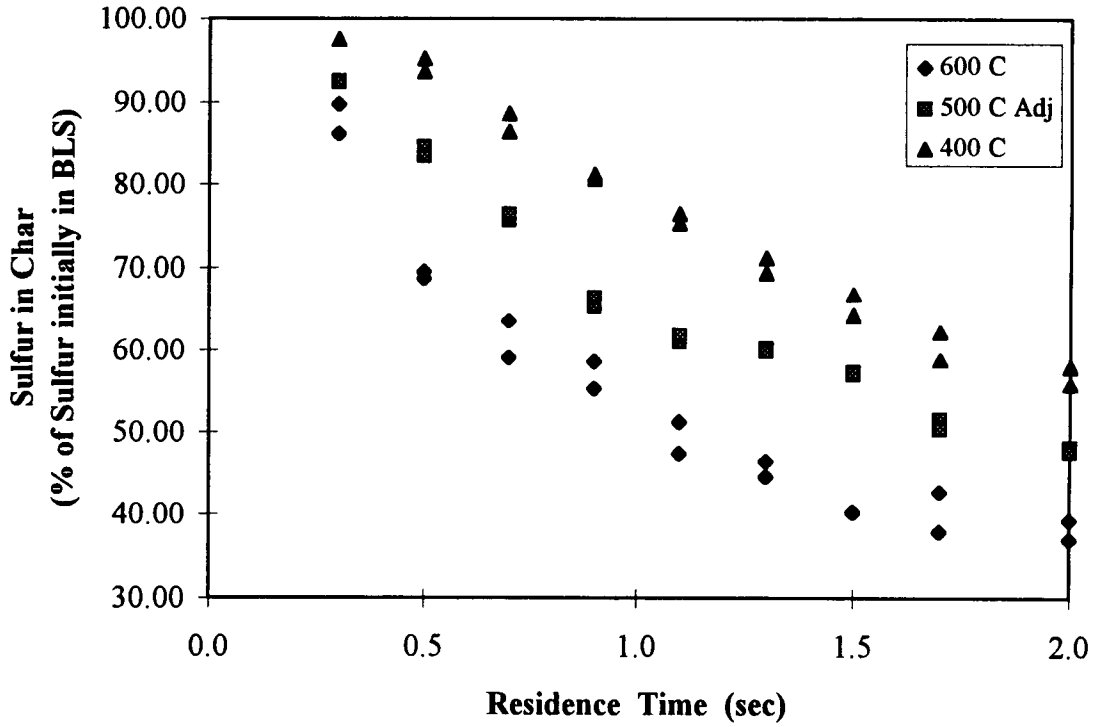

Figure 5.39 Adjusted Sulfur Yield in the Char Residue

5.6 Nitrogen Yield in Char Residue from Pyrolysis of Black Liquor Solids

Figure 5.40, Figure 5.41, and Figure 5.42 show the nitrogen yield in the char residue versus residence time from pyrolysis of black liquor solids at 600°C, 500°C, and 400°C respectively. *The nitrogen yield in the char residue decreased as residence time increased.* The reproducibility obtained in replicate runs was an average ±1.0% at 600°C, and ±2.0% at 500°C and 400°C, all as percentage of nitrogen in the black liquor solids input. At a residence time of 0.3 seconds, the nitrogen yield in the char residue was 86% at 600°C, 91% at 500°C, and 98% at 400°C. For all temperatures range, the nitrogen yield in the char residue decreased rapidly at the beginning and then gradually decreased until the longest residence time (2.0 seconds). At a residence time of 2.0 seconds, the nitrogen in the char residue was 59% at 600°C, 60% at 500°C, and 66% at 400°C. This is in accordance with the finding of Carangal (1995), who measured the nitrogen retained in the char residue after devolatilization at furnace temperatures between 700-1100°C and residence times between 0.3-2.2 seconds using the LEFR. Carangal reported that the nitrogen content in the char residue decreased rapidly at the beginning (residence time 0.3 seconds) and then decreased gradually at residence times longer than 0.5 seconds. The percentage of nitrogen retained in the char residue after devolatilization was 56% at 700°C, 49.6% at 900°C, and 45.7% at 1100°C.

Figure 5.43 compares the nitrogen in the char residue versus residence time from pyrolysis of black liquor solids at temperature of 600°C, 500°C, and 400°C. The data at 500°C is based on the uncorrected char yields. The nitrogen yield in the char residue at 600°C and 500°C data are about the same and lower than 400°C. At residence times

longer than 0.5 seconds, the nitrogen content in the char residue was nearly the same at 600°C and 500°C, and essentially the same in some experimental condition. And also, this is in accordance with the finding of Frederick et al.(1995). With the lower temperature condition in this study (400-600°C) compared to those of Frederick et al. study (700-1100°C), the nitrogen contents in char residue after devolatilization in this study (59-66%) were higher than those of Frederick study (45.7-56.7%).

Figure 5.44 compares the nitrogen yield in the char residue from pyrolysis of black liquor solids at 400°C, of 500°C , 600°C using the adjusted char yields at 500°C. The curve of nitrogen yield at 500°C is shifted up and located between the curve of 400°C and 600°C at residence times of 0.3-0.8 seconds, but at residence times above 0.8 seconds the adjusted-curve higher that at 400°C. It is not clear why the nitrogen data at 500°C is inconsistent with the sulfur and carbon data.

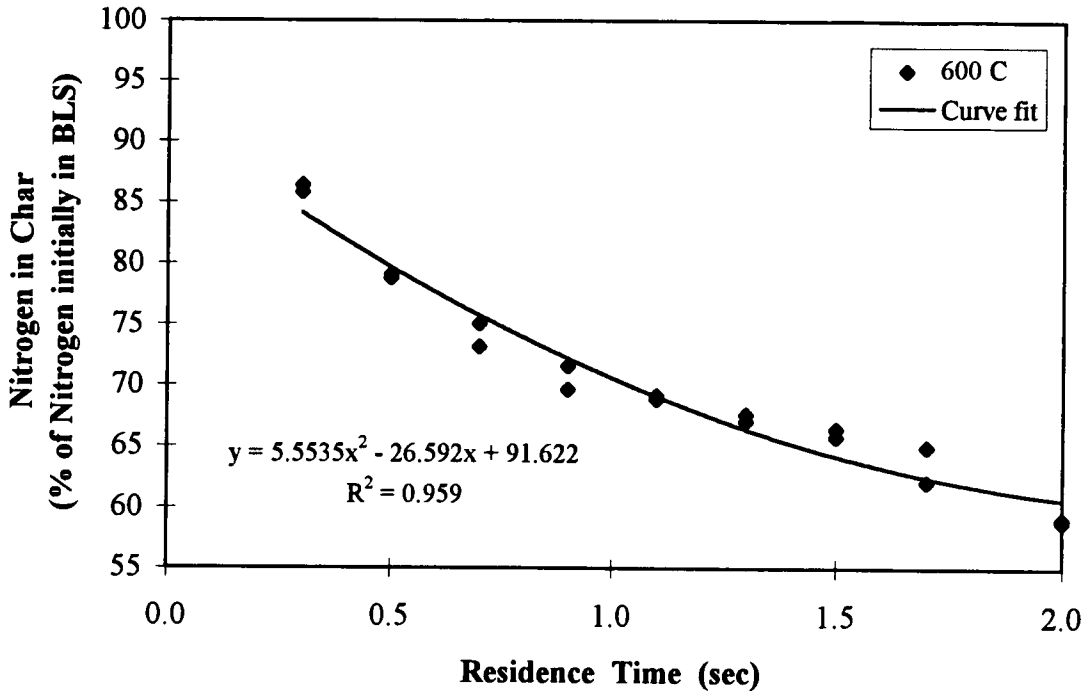

Figure 5.40 Nitrogen Yield in Char Residue from Pyrolysis of Black Liquor Solids at 600°C

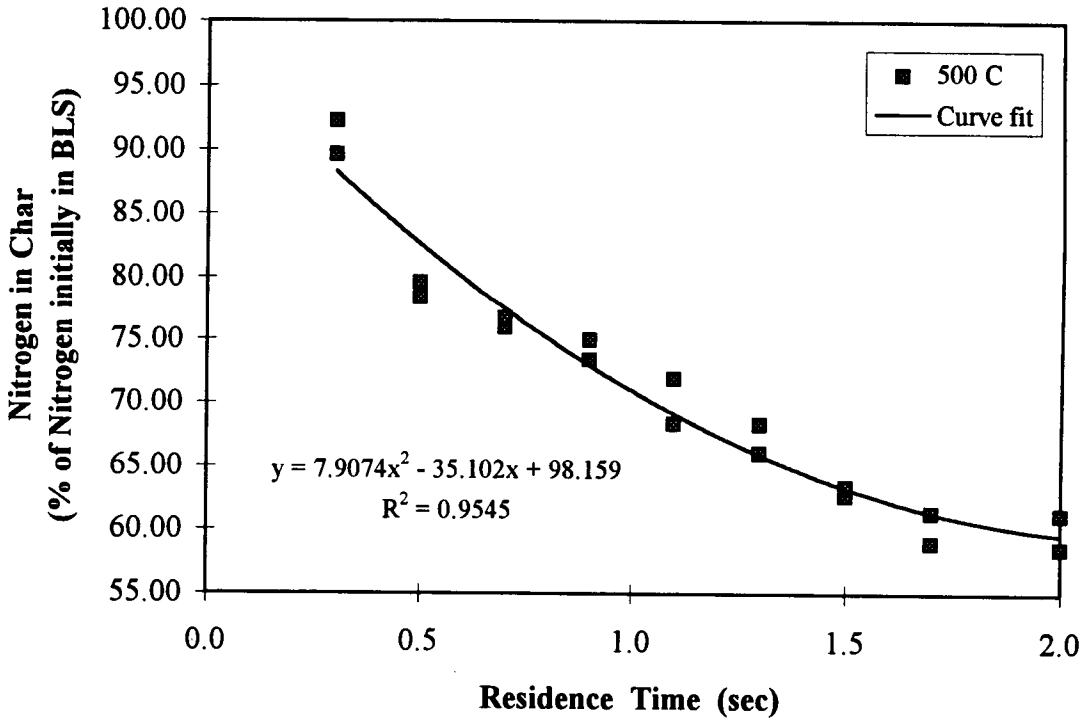

Figure 5.41 Nitrogen Yield in Char Residue from Pyrolysis of Black Liquor Solids at 500°C

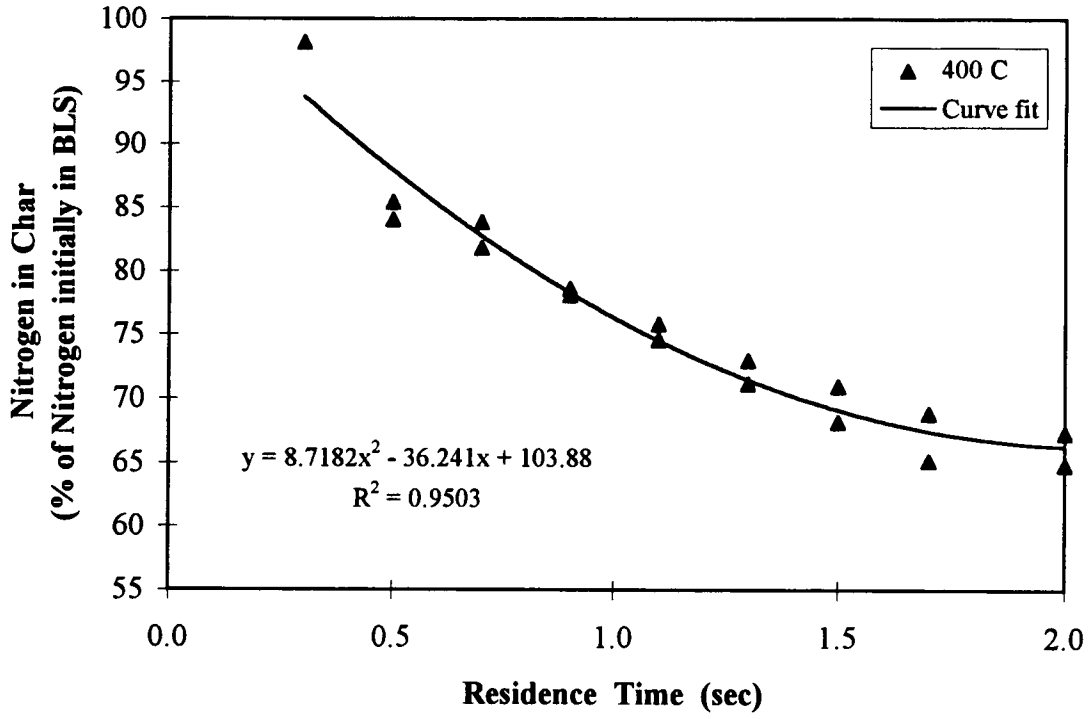

Figure 5.42 Nitrogen Yield in Char Residue from Pyrolysis of Black Liquor Solids at 400°C

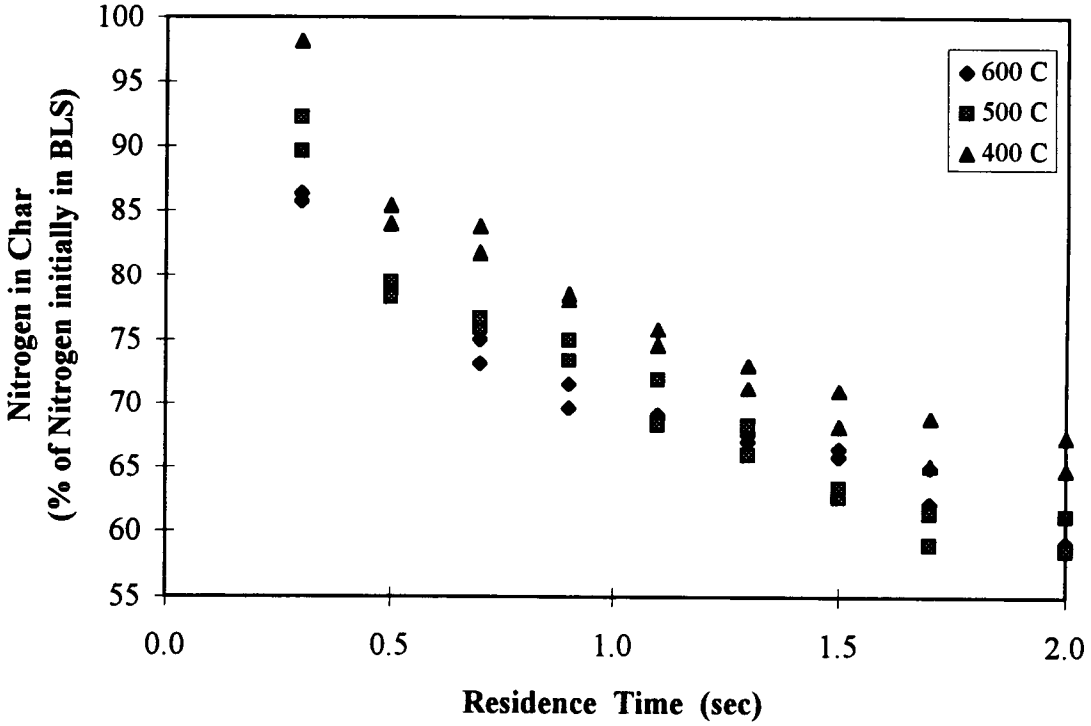

Figure 5.43 Nitrogen Yield in Char Residue from Pyrolysis of Black Liquor Solids at 400-600°C

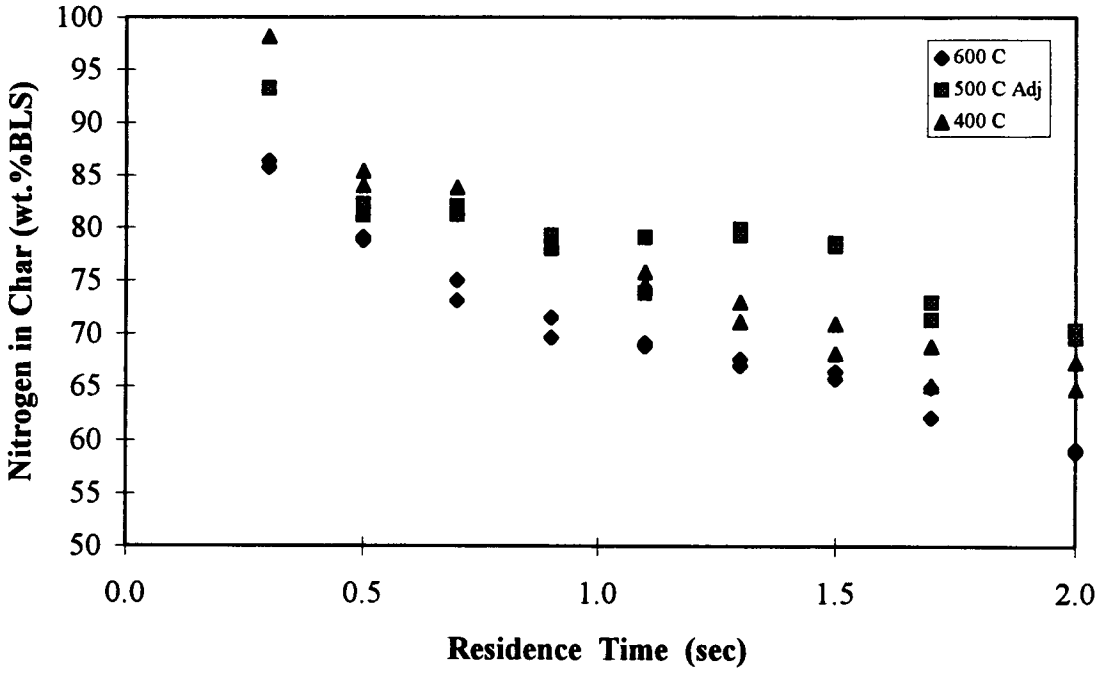

Figure 5.44 Adjusted Nitrogen Yield in the Char Residue

CHAPTER 6

SUMMARY AND CONCLUSIONS

6.1 Carbon Yield from Pyrolysis of Black Liquor Solids

6.1.1 Carbon Yield in the Gas Phase

- The carbon yield in the gas phase increased as residence time increased. The carbon yield in the gas phase at different temperatures and residence times are as follows :

  Temperature 600°C :

  Residence time 0.3 seconds : 8%

  Residence time 1.1 seconds : 20%

  Residence time 2.0 seconds : 23%

  Temperature 500°C :

  Residence time 0.3 seconds : 7%

  Residence time 2.0 seconds : 23%

  Temperature 400°C :

  Residence time 0.3-0.5 seconds : 2%

  Residence time 0.5-1.5 seconds : 17%

  Residence time 2.0 seconds : 20%

- The higher the temperature, the higher the carbon yield as gases phase at each residence time.

6.1.2 Carbon Yield in the Fine Particles

- The carbon yield in the fine particle at different temperatures and residence times are as follows :

  Temperature 600°C :

  Residence time 0.3 seconds : 0.50%

  Residence time 1.1 seconds : 0.50%

  Residence time 2.0 seconds : 2.50%

  Temperature 500°C :

  Residence time 0.3 seconds : 0.27%

  Residence time 2.0 seconds : 1.80%

  Temperature 400°C :

  Residence time 0.3 seconds : 0.31%

  Residence time 2.0 seconds : 1.00%

- The carbon yield in the fine particles differ very little with temperature at residence time below 1.1 seconds. At higher temperatures, the carbon yield in the fine particles is about the same at 500°C and 600°C, but lower at 400°C.

6.1.3 Carbon Yield in the Char Residue

- The carbon yield in the char residue decreased as residence time increased. The carbon yield in the char residue at different temperatures and residence times are as follows :

Temperature 600°C :

Residence time 0.3 seconds : 90%

Residence time 2.0 seconds : 70%

Temperature 500°C :

Residence time 0.3 seconds : 87% (Corrected : 90%)

Residence time 2.0 seconds : 60% (Corrected : 71%)

Temperature 400°C :

Residence time 0.3-0.5 seconds : 95%

Residence time 0.5-1.5 seconds : 78%

Residence time 2.0 seconds : 75%

- The carbon yield in the char residue at 500°C and residence times above 1.1 seconds was littler lower than at temperature 600°C, due to the effect of the low char residue yield at 500°C.

6.2 Fine Particle Yield from Pyrolysis of Black Liquor Solids

- The fine particle yield was very low, no greater than 1% of BLS, and overall increased as residence time increased. The fine particle yield at different temperatures and residence times are as follows :

Temperature 600°C :

Residence time 0.3 seconds : 0.58%

Residence time 2.0 seconds : 1.00%

Temperature 500°C :

Residence time 0.3 seconds : 0.29%

Residence time 2.0 seconds : 0.81%

Temperature 400°C :

Residence time 0.3 seconds : 0.34%

Residence time 2.0 seconds : 0.42%

- At residence times above 1.1 seconds, the fine particle yield increased more rapidly at higher temperatures but not at the lower temperature.

6.3 Char Residue Yield from Pyrolysis of Black Liquor Solids

- The char residue yield decreased as residence time increased. The char residue yield at different temperatures and residence times are as follows :

Temperature 600°C :

Residence time 0.3 seconds : 92%

Residence time 2.0 seconds : 75%

Temperature 500°C :

Residence time 0.3 seconds : 92% (Corrected char : 93%)

Residence time 2.0 seconds : 65% (Corrected char : 76%)

Temperature 400°C :

Residence time 0.3 seconds : 99%

Residence time 2.0 seconds : 77%

- The char yield at 500°C and residence time 2.0 seconds was lower than expected based on the 400°C and 600°C data and previous data. This is due to collection of large, highly swollen char particles at the tip of the collector at this temperature.

6.4 Carbon Recovered from Pyrolysis of Black Liquor Solids

- The average of carbon recovered from carbon yield in char, fine particle, and gas are as follows :

  - At 600°C, average carbon recovery : 96.2% (range 91.0-99.7%)
  - At 500°C, average carbon recovery : 88.1% (range 80.5-95.5)
    : 96% (corrected)
  - At 400°C, average carbon recovery : 95.7% (range 93.6-99.7%)

  (Note : The average carbon recovery at 500°C was little lower than those of 600°C and 400°C, due to the low char residue yield)

6.5 Sulfur Yield in the Char Residue from Pyrolysis of Black Liquor Solids

- The sulfur yield in the char residue decreased as residence time increased. The sulfur yield in the char residue at different temperatures and residence times are as follows :

Temperature 600°C :

Residence time 0.3 seconds : 88%

Residence time 2.0 seconds : 38%

Temperature 500°C :

Residence time 0.3 seconds : 90% (Corrected : 93%)

Residence time 2.0 seconds : 41% (Corrected : 48%)

Temperature 400°C :

Residence time 0.3 seconds : 97%

Residence time 2.0 seconds : 56%

- The higher the temperature, the lower the sulfur yield in the char residue.

6.6 Nitrogen Yield in the Char Residue from Pyrolysis of Black Liquor Solids

- The nitrogen yield in the char residue decreased as residence time increased. The nitrogen yield in the char residue at different temperatures and residence times are as follows :

Temperature 600°C :

Residence time 0.3 seconds : 86%

Residence time 2.0 seconds : 59%

Temperature 500°C :

Residence time 0.3 seconds : 91% (Corrected : 93%)

Residence time 2.0 seconds : 60% (Corrected : 69%)

Temperature 400°C :

Residence time 0.3 seconds : 98%

Residence time 2.0 seconds : 66%

RECOMMENDATIONS FOR FUTURE WORK

1. A model for evolution of carbon-containing gases during pyrolysis of kraft black liquor.

2. Estimation of tar content in gas phase at low temperatures.

3. A model for nitrogen and sulfur concentration in the char residue.

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APPENDICES

APPENDIX A

OPERATION THEORY OF CARBON, NITROGEN AND SULFUR ANALYZER

Operation Theory

The LECO CNS-2000 Carbon, Nitrogen and Sulfur Analyzer, is a non-dispersive, infrared, microcomputer based instrument, designed to measure the carbon, nitrogen and sulfur content in a wide variety of organic compounds. Figure App-A1 show the gas flow diagram of CNS Analyzer.

Analysis begin by weighing a sample (about 200 mg) and placing it into the sample holder referred to as a boat. When ANALYZE is selected and the sample is pushed into the combustion chamber at 1450 °C, the furnace and flow of oxygen gas, cause the sample to combust. The combustion process will convert any elemental carbon, sulfur and nitrogen into CO_2, SO_2, N_2, NO_X,. These gases are then passed through the IR (infrared) cells to determine the carbon and sulfur content and a TC (thermal conductivity) cell to determine N_2 .

Combustion gases are swept down and out the inner combustion tube and then up between the inner and outer combustion tubes. After exiting the furnace, the gases pass through two Anhydrone tubes, a particle filter and collect in the ballast tank. Oxygen flow is measured by the Oxygen Flow Rotameter before it enters the combustion chamber. The furnace temperature can be varied to control combustion.

After the ballast tank is filled with sample gas, the gas is permitted to equilibrate befor being released through the IR cells and the aliquot loop.

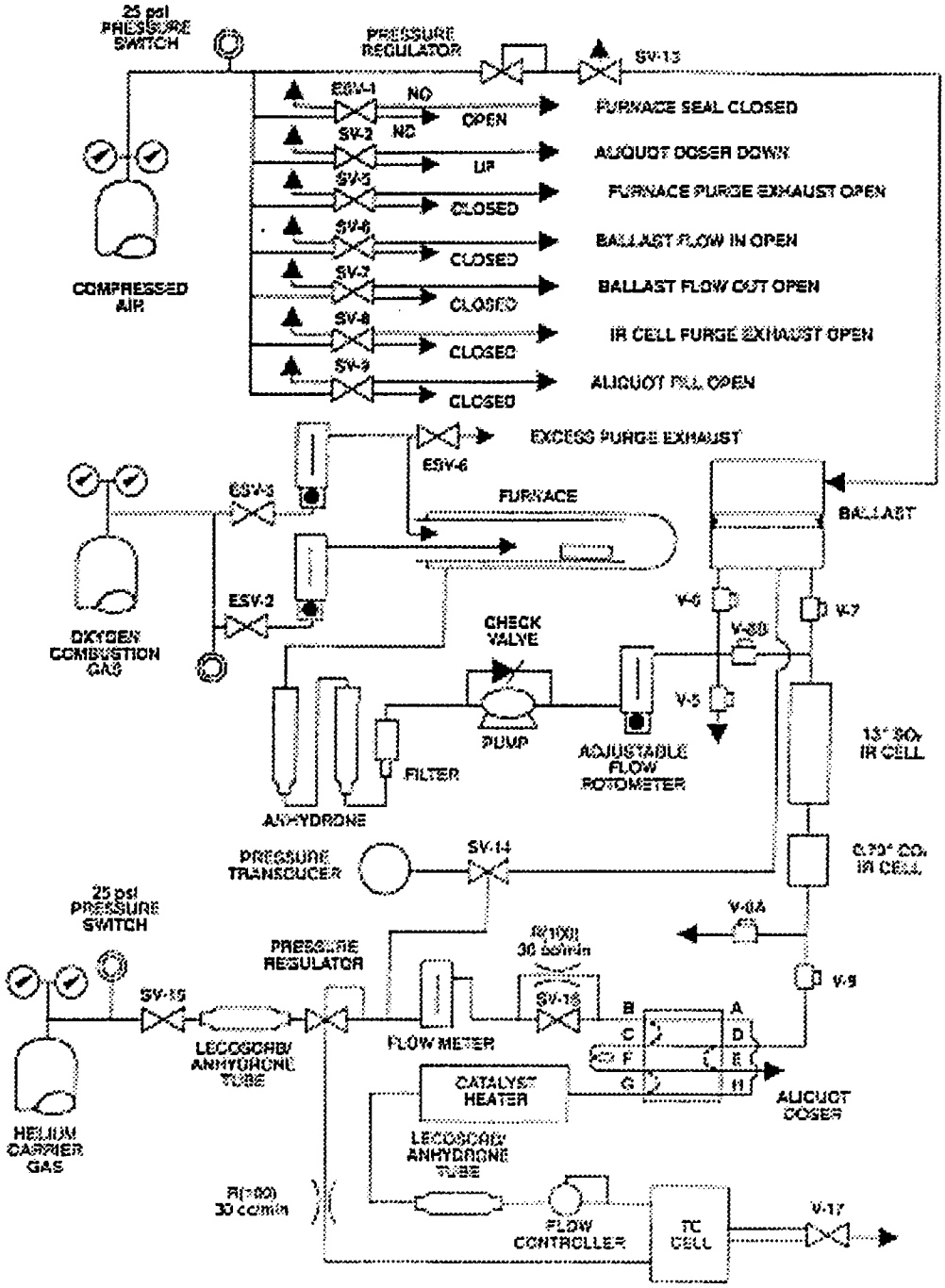

Figure App-A1 Gas Flow Diagram of CNS Analyzer

During the time ballast tank gases equilibrate, valve SV14 is open, permitting the pressure transducer to measure ballast tank pressure. Then valves V8A, V8B and SV14 close, and V7 and V9 open, permitting samples gas to exhaust through the carbon and sulfur IR cells and fill the aliquot loop. Shortly after, when the ballast tank pressure falls, valves V6, V8A, V8B and V9 close, trapping gas in the IR cells and aliquot doser.

While sample gas is trapped, valve V5 opens, allowing the combustion camber to be purged. This prepares the system to analyze another sample. The voltage output from the IR cells is also being read and processed by the computer. This produces the analysis results for carbon and sulfur.

Sample gas in the aliquot doser, is swept by the carrier gas to the catalyst heater where NO_X gases are reduced to N_2 . Then Lecosorb to remove CO_2 and anhydrone to remove H_2O . This leaves N_2 and helium to flow through one side of the TC cell.

The other side of the TC cell receives carrier gas from open valve SV15, after it is filtered by the carrier gas scrubber. The gases in both sides of the TC cell are compared, and an output voltage results. This voltage is feed to the computer where it processed, displayed and stored as the nitrogen measurement result.

After nitrogen result is determined, the measurement system is purged. Exhaust valves V5, V8, V9 and SV17 open, relieving the system of sample gas and preparing it for another analysis.

Infrared Radiation Detection

The descriptions which follow refer to carbon analysis. The analysis of sulfur is identical with only the necessary change to accommodate a different gas (SO_2).

The infrared source (IR) consists of nichrome wire which is resistance heated to 850°C. The IR source radiates visible energy as well as all wavelengths in the infrared spectrum.

Carbon dioxide absorbs IR energy at a precise wavelength within the IR spectrum. Energy from the IR source is absorbed as the gas passes through the cell, preventing it from reaching the IR detector. All other IR energy is prevented from reaching the IR detector by a narrow bandpass filter. Because of the wavelength filter, the absorption of IR energy can be attributed only to carbon dioxide (CO_2). The concentration of CO_2 is detected as a level of energy at the detector.

One IR cell is used as both a reference and for measurement. The total carbon, as carbon dioxide, is detected on a continuous and simultaneous basis. The cell consists of an IR source, chopper motor, a narrow bandpass filter, a condensing cone, an IR energy detector and the cell body. Radiated energy is chopped at a rate of 87.5 Hz. before it enters the cell body. The chopped energy enters the cell body through a window, travels through the cell body, then exits through a second window and a precise wavelength filter. The selective filter passes only the CO_2 absorption wavelength into a condensing cone which concentrates the energy at the detector. The solid state detector is AC coupled to a preamplifier. As the gas concentration increases the voltage to the preamp decreases.

The starting reference level, of "baseline", for the detector is established by running 100% oxygen through the cell. The pure oxygen environment permits the maximum amount of energy to reach the detector. This maximum energy level is AC coupled to the preamp where it is amplified, rectified and filtered. It is then sent to an analog to digital (A/D) converter where it is converted to a digital signal. The nominal voltage when read at the cell output, via the Ambient Monitor, is 8.500 VDC.

During every analysis the "baseline" is read by the computer, Then this level is adjusted digitally until a nominal level is achieved. For example, if the cell output is 8.400 VDC, then this level is change digitally until the level reads 8.500 VDC. This level change is done in the computer and used for a reference, if the cell output voltage were actually measured, no change would be observed.

As analysis begins, the cell output decreases with the amount of carbon (as CO_2) present in the cell. The computer reads the cell output nine times per second and produced data points which are stored in memory. The curve of graph formed by these data points is then processed by the computer and after calibration form a linear curve. The curve is then used by the computer to calculate the element weight percent of an unknown sample.

Thermal Conductivity Detection

The Thermal Conductivity Cell has the ability to detect the differences in the thermal conductivity of gasses, as shown in Table App-A1. The cell consists of two pairs of matched filaments used in four legs of a wheatstone bridge. Both pairs are maintained

in a constant gas flow. Only the gas type is different. The reference pair is subjected to only carrier gas, while the measurement pair is subjected to the sample gas mixed with carrier gas.

The resistors are made of tungsten wire, unlike the IR source which is made of nichrome wire.

Table App-A1 Thermal Conductivity of Gases

Gas	Symbol	Molecular Weight	Thermal Conductivity (calories/cm sec °Cx10^5)
Hydrogen	H_2	2	39
Helium	He	4	33
Neon	Ne	20	10.4
Oxygen	O_2	32	5.7
Nitrogen	N_2	28	5.6
Air (dry)	Air	29	5.4
Carbon Monoxide	CO	28	5.4
Argon	Ar	40	3.8
Carbon Dioxide	CO_2	44	3.3
Sulfur Dioxide	SO_2	64	1.6

The bridge is balanced while both sets of resistors are in identical environments, carrier gas. The bridge current causes self-heating of the filaments and keeps the filament temperature higher than the ambient oven temperature. The oven temperature is maintained at 50°C which eliminates the effects from normal room temperature variations.

As long as both resistors remain in the same environment in which the bridge was balanced, the bridge output will remain at minimum. Any disturbance of this environment will result in a change of increase in output.

The bridge is balanced when helium flows in both chambers of the cell. The introduction of nitrogen will cause the temperature of the measure filaments to increase because nitrogen has a lower thermal conductivity than helium. This causes the current through the filament to change. As the bridge becomes unbalanced it produces and output. The magnitude of the out put will vary due to the concentration of nitrogen.

Like the IR cell, the output from the TC cell is feed to a preamplifier. This in turn is feed to an analog to digital converter. The output, a digital signal, is then feed to the computer where it is processed, displayed and stored as the nitrogen measurement result.

APPENDIX B

EXPERIMENTAL DATA AND ANALYTICAL RESULTS

MATERIAL BALANCE					
DATA ACQUISITION FILE	FVJL601	FVJL602	FVJL603	FVJL604	FVJL605
Date	7/6/96	7/6/96	7/7/96	7/7/96	7/7/96
Raw Material	Valdosta	Valdosta	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125	90-125	90-125
Reactor Path Lenght (inch)	28.75	28.75	28.75	28.75	28.75
Residence Time (sec)	2.0	2.0	1.7	1.7	1.5
Temperature (c)	600	600	600	600	600
GAS FLOW					
Primary Flow	0.15	0.15	0.15	0.15	0.15
Total Flow (l/min)	8.00	8.00	11.00	11.00	13.80
N2 (l/min) : (100 %)	8.00	8.00	11.00	11.00	13.80
CO2 (l/min) : (0 %)	0.00	0.00	0.00	0.00	0.00
O2 (l/min) : (0 %)	0.00	0.00	0.00	0.00	0.00
Gas Sample Flow (l/min)	7.24	7.38	7.51	6.55	6.69
Total Running Time (min)	10.00	10.00	10.00	10.00	10.00
WEIGHT DATA					
Input					
1. BL Before (g)	20.0859	21.7559	20.8422	20.6563	20.7995
BL After (g)	14.6564	17.2948	16.2831	14.9224	15.2436
Input black liquor wt.(g)	***5.4295***	***4.4611***	***4.5591***	***5.7339***	***5.5559***
2. Flush Char wt. (g)	***0.0401***	***0.0456***	***0.0511***	***0.0425***	***0.0332***
3. Flush Filter Before (g)	0.4644	0.4694	0.5257	0.5233	0.5503
Flush Filter After (g)	0.4693	0.4761	0.5315	0.5325	0.5556
Flush Fume wt.(g)	***0.0049***	***0.0067***	***0.0058***	***0.0092***	***0.0053***
Total Input black liquor wt. (g)	**5.3845**	**4.4088**	**4.5022**	**5.6822**	**5.5174**
Output					
1. Fume Filter Before (g)	0.0874	0.0869	0.0868	0.0861	0.0865
Fume Filter After (g)	0.1023	0.0996	0.0954	0.0952	0.0925
Collected Fume wt. (g)	***0.0149***	***0.0127***	***0.0086***	***0.0091***	***0.006***
2. Fume Filter Before (gas outlet) (g)	0.4661	0.4666	0.4685	0.4687	0.4672
Fume Filter After (gas outlet) (g)	0.5053	0.4985	0.4931	0.5028	0.4928
Fume wt. (gas outlet) (g)	***0.0392***	***0.0319***	***0.0246***	***0.0341***	***0.0256***
Total Fume wt. in system (g)	***0.0541***	***0.0446***	***0.0332***	***0.0432***	***0.0316***
3. Char wt. (g)	***4.0334***	***3.3161***	***3.5597***	***4.3071***	***4.2375***
Total wt. output (g)	**4.0875**	**3.3607**	**3.5929**	**4.3503**	**4.2691**
Percentage of Total Output wt (%)	**75.91**	**76.23**	**79.80**	**76.56**	**77.38**
Percentage of Collected Fume (%)	**1.00**	**1.01**	**0.74**	**0.76**	**0.57**
Percentage of Collected Char (%)	**74.91**	**75.22**	**79.07**	**75.80**	**76.80**

MATERIAL BALANCE					
DATA ACQUISITION FILE	FVJL606	FVJL607	FVJL608	FVJL609	FVJL610
Date	7/7/96	7/8/96	7/8/96	7/8/96	7/8/96
Raw Material	Valdosta	Valdosta	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125	90-125	90-125
Reactor Path Lenght (inch)	28.75	28.75	28.75	28.75	28.75
Residence Time (sec)	1.5	1.3	1.3	1.1	1.1
Temperature (c)	600	600	600	600	600
GAS FLOW					
Primary Flow	0.15	0.15	0.15	0.22	0.22
Total Flow (l/min)	13.80	18.20	18.20	21.80	21.80
N2 (l/min) : (100 %)	13.80	18.20	18.20	21.80	21.80
CO2 (l/min) : (0 %)	0.00	0.00	0.00	0.00	0.00
O2 (l/min) : (0 %)	0.00	0.00	0.00	0.00	0.00
Gas Sample Flow (l/min)	6.71	7.41	8.05	7.78	7.84
Total Running Time (min)	10.00	10.00	10.00	10.00	10.00
WEIGHT DATA					
Input					
1. BL Before (g)	21.1191	21.5675	21.6221	20.9153	21.5366
BL After (g)	15.1868	16.6559	17.0753	15.9681	16.7768
Input black liquor wt.(g)	***5.9323***	***4.9116***	***4.5468***	***4.9472***	***4.7598***
2. Flush Char wt. (g)	***0.0272***	***0.0175***	***0.0155***	***0.0265***	***0.0197***
3. Flush Filter Before (g)	0.5300	0.5557	0.5339	0.5201	0.5271
Flush Filter After (g)	0.5427	0.5649	0.5441	0.5294	0.5327
Flush Fume wt.(g)	***0.0127***	***0.0092***	***0.0102***	***0.0093***	***0.0056***
Total Input black liquor wt. (g)	**5.8924**	**4.8849**	**4.5211**	**4.9114**	**4.7345**
Output					
1. Fume Filter Before (g)	0.0861	0.0869	0.0871	0.0868	0.0879
Fume Filter After (g)	0.0918	0.0907	0.0921	0.0899	0.0908
Collected Fume wt. (g)	***0.0057***	***0.0038***	***0.0050***	***0.0031***	***0.0029***
2. Fume Filter Before (gas outlet) (g)	0.4637	0.4696	0.4677	0.4705	0.4658
Fume Filter After (gas outlet) (g)	0.4906	0.4882	0.4835	0.4874	0.4818
Fume wt. (gas outlet) (g)	***0.0269***	***0.0186***	***0.0158***	***0.0169***	***0.0160***
Total Fume wt. in system (g)	***0.0326***	***0.0224***	***0.0208***	***0.0200***	***0.0189***
3. Char wt. (g)	***4.5686***	***3.8534***	***3.5371***	***3.9616***	***3.8025***
Total wt. output (g)	**4.6012**	**3.8758**	**3.5579**	**3.9816**	**3.8214**
Percentage of Total Output wt (%)	**78.09**	**79.34**	**78.70**	**81.07**	**80.71**
Percentage of Collected Fume (%)	**0.55**	**0.46**	**0.46**	**0.41**	**0.40**
Percentage of Collected Char (%)	**77.53**	**78.88**	**78.24**	**80.66**	**80.31**

MATERIAL BALANCE					
DATA ACQUISITION FILE	FVJL611	FVJL612	FVJL613	FVJL614	FVJL615
Date	7/8/96	7/8/96	7/9/96	7/9/96	7/9/96
Raw Material	Valdosta	Valdosta	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125	90-125	90-125
Reactor Path Lenght (inch)	25.75	25.75	19.75	19.75	13.75
Residence Time (sec)	0.9	0.9	0.7	0.7	0.5
Temperature (c)	600	600	600	600	600
GAS FLOW					
Primary Flow	0.30	0.30	0.30	0.30	0.28
Total Flow (l/min)	22.60	22.60	22.30	22.30	22.00
N2 (l/min) : (100 %)	22.60	22.60	22.30	22.30	22.00
CO2 (l/min) : (0 %)	0.00	0.00	0.00	0.00	0.00
O2 (l/min) : (0 %)	0.00	0.00	0.00	0.00	0.00
Gas Sample Flow (l/min)	8.08	7.83	8.00	8.05	8.04
Total Running Time (min)	10.00	10.00	10.00	10.00	10.00
WEIGHT DATA					
Input					
1. BL Before (g)	21.7261	21.2555	21.5593	21.5444	21.7606
BL After (g)	16.242	16.7153	17.0117	16.7092	17.2403
Input black liquor wt.(g)	***5.4841***	***4.5402***	***4.5476***	***4.8352***	***4.5203***
2. Flush Char wt. (g)	***0.0243***	***0.0235***	***0.0415***	***0.0296***	***0.0845***
3. Flush Filter Before (g)	0.5183	0.5535	0.5203	0.5476	0.5228
Flush Filter After (g)	0.5245	0.5615	0.5324	0.5549	0.5342
Flush Fume wt.(g)	***0.0062***	***0.0080***	***0.0121***	***0.0073***	***0.0114***
Total Input black liquor wt. (g)	**5.4536**	**4.5087**	**4.4940**	**4.7983**	**4.4244**
Output					
1. Fume Filter Before (g)	0.0861	0.0876	0.0876	0.0866	0.0868
Fume Filter After (g)	0.0901	0.0907	0.0913	0.0908	0.0905
Collected Fume wt. (g)	***0.0040***	***0.0031***	***0.0037***	***0.0042***	***0.0037***
2. Fume Filter Before (gas outlet) (g)	0.4656	0.4672	0.4791	0.4739	0.4731
Fume Filter After (gas outlet) (g)	0.4852	0.4851	0.4943	0.4906	0.4885
Fume wt. (gas outlet) (g)	***0.0196***	***0.0179***	***0.0152***	***0.0167***	***0.0154***
Total Fume wt. in system (g)	***0.0236***	***0.0210***	***0.0189***	***0.0209***	***0.0191***
3. Char wt. (g)	***4.2010***	***3.6627***	***3.6304***	***3.5083***	***3.7689***
Total wt. output (g)	**4.2246**	**3.6837**	**3.6493**	**3.5292**	**3.7880**
Percentage of Total Output wt (%)	**77.46**	**81.70**	**81.20**	**73.55**	**85.62**
Percentage of Collected Fume (%)	**0.43**	**0.47**	**0.42**	**0.44**	**0.43**
Percentage of Collected Char (%)	**77.03**	**81.24**	**80.78**	**73.12**	**85.18**

MATERIAL BALANCE			
DATA ACQUISITION FILE	FVJL616	FVJL617	FVJL618
Date	7/9/96	7/9/96	7/9/96
Raw Material	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125
Reactor Path Lenght (inch)	13.75	9.75	9.75
Residence Time (sec)	0.5	0.3	0.3
Temperature (c)	600	600	600
GAS FLOW			
Primary Flow	0.28	0.38	0.38
Total Flow (l/min)	22.00	29.00	29.00
N2 (l/min) : (100 %)	22.00	29.00	29.00
CO2 (l/min) : (0 %)	0.00	0.00	0.00
O2 (l/min) : (0 %)	0.00	0.00	0.00
Gas Sample Flow (l/min)	8.00	8.08	8.12
Total Running Time (min)	10.00	10.00	10.00
WEIGHT DATA			
Input			
1. BL Before (g)	21.4458	20.7797	21.4915
BL After (g)	15.9914	16.0875	15.9531
Input black liquor wt.(g)	***5.4544***	***4.6922***	***5.5384***
2. Flush Char wt. (g)	***0.0185***	***0.0861***	***0.0179***
3. Flush Filter Before (g)	0.5206	0.5409	0.5232
Flush Filter After (g)	0.5353	0.5569	0.5381
Flush Fume wt.(g)	***0.0147***	***0.0160***	***0.0149***
Total Input black liquor wt. (g)	**5.4212**	**4.5901**	**5.5056**
Output			
1. Fume Filter Before (g)	0.0864	0.0869	0.0861
Fume Filter After (g)	0.0904	0.0912	0.0914
Collected Fume wt. (g)	***0.0040***	***0.0043***	***0.0053***
2. Fume Filter Before (gas outlet) (g)	0.4796	0.4681	0.4697
Fume Filter After (gas outlet) (g)	0.5001	0.4909	0.4958
Fume wt. (gas outlet) (g)	***0.0205***	***0.0228***	***0.0261***
Total Fume wt. in system (g)	***0.0245***	***0.0271***	***0.0314***
3. Char wt. (g)	***4.5995***	***4.2696***	***5.0851***
Total wt. output (g)	**4.6240**	**4.2967**	**5.1165**
Percentage of Total Output wt (%)	**85.29**	**93.61**	**92.93**
Percentage of Collected Fume (%)	**0.45**	**0.59**	**0.57**
Percentage of Collected Char (%)	**84.84**	**93.02**	**92.36**

MATERIAL BALANCE					
DATA ACQUISITION FILE	FVAG601	FVAG602	FVAG603	FVAG604	FVAG605
Date	8/7/96	8/7/96	8/8/96	8/8/96	8/8/96
Raw Material	Valdosta	Valdosta	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125	90-125	90-125
Reactor Path Lenght (inch)	28.75	28.75	28.75	28.75	28.75
Residence Time (sec)	2.0	2.0	1.7	1.7	1.5
Temperature (c)	500	500	500	500	500
GAS FLOW					
Primary Flow	0.15	0.15	0.15	0.15	0.15
Total Flow (l/min)	8.60	8.60	12.20	12.20	15.70
N2 (l/min) : (100 %)	8.60	8.60	12.20	12.20	15.70
CO2 (l/min) : (0 %)	0.00	0.00	0.00	0.00	0.00
O2 (l/min) : (0 %)	0.00	0.00	0.00	0.00	0.00
Gas Sample Flow (l/min)	7.46	7.54	7.84	7.98	7.72
Total Running Time (min)	10.00	10.00	10.00	10.00	9.00
WEIGHT DATA					
Input					
1. BL Before (g)	20.8591	20.5032	20.6908	20.8184	20.3886
BL After (g)	15.7574	15.9561	16.4436	17.6973	17.3975
Input black liquor wt.(g)	***5.1017***	***4.5471***	***4.2472***	***3.1211***	***2.9911***
2. Flush Char wt. (g)	***0.0000***	***0.0000***	***0.0000***	***0.0000***	***0.0000***
3. Flush Filter Before (g)	0.5122	0.5285	0.5349	0.5611	0.5491
Flush Filter After (g)	0.5302	0.5452	0.5443	0.5696	0.5624
Flush Fume wt.(g)	***0.0180***	***0.0167***	***0.0094***	***0.0085***	***0.0133***
Total Input black liquor wt. (g)	**5.0837**	**4.5304**	**4.2378**	**3.1126**	**2.9778**
Output					
1. Fume Filter Before (g)	0.0874	0.0881	0.0876	0.0869	0.0878
Fume Filter After (g)	0.1003	0.0996	0.0961	0.0916	0.0926
Collected Fume wt. (g)	***0.0129***	***0.0115***	***0.0085***	***0.0047***	***0.0048***
2. Fume Filter Before (gas outlet) (g)	0.4709	0.4662	0.4685	0.4694	0.4745
Fume Filter After (gas outlet) (g)	0.4981	0.4923	0.4921	0.4856	0.4932
Fume wt. (gas outlet) (g)	***0.0272***	***0.0261***	***0.0236***	***0.0162***	***0.0187***
Total Fume wt. in system (g)	***0.0401***	***0.0376***	***0.0321***	***0.0209***	***0.0235***
3. Char wt. (g)	***3.3487***	***2.8562***	***2.7995***	***1.9759***	***2.0084***
Total wt. output (g)	**3.3888**	**2.8938**	**2.8316**	**1.9968**	**2.0319**
Percentage of Total Output wt (%)	**66.66**	**63.88**	**66.82**	**64.15**	**68.23**
Percentage of Collected Fume (%)	**0.79**	**0.83**	**0.76**	**0.67**	**0.79**
Percentage of Collected Char (%)	**65.87**	**63.05**	**66.06**	**63.48**	**67.45**

MATERIAL BALANCE					
DATA ACQUISITION FILE	FVAG606	FVAG607	FVAG608	FVAG609	FVAG610
Date	8/8/96	8/8/96	8/8/96	8/13/96	8/13/96
Raw Material	Valdosta	Valdosta	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125	90-125	90-125
Reactor Path Lenght (inch)	28.75	28.75	28.75	28.75	28.75
Residence Time (sec)	1.5	1.3	1.3	1.1	1.1
Temperature (c)	500	500	500	500	500
GAS FLOW					
Primary Flow	0.15	0.15	0.15	0.25	0.25
Total Flow (l/min)	15.70	20.60	20.60	23.80	23.80
N2 (l/min) : (100 %)	15.70	20.60	20.60	23.80	23.80
CO2 (l/min) : (0 %)	0.00	0.00	0.00	0.00	0.00
O2 (l/min) : (0 %)	0.00	0.00	0.00	0.00	0.00
Gas Sample Flow (l/min)	8.18	8.27	8.26	6.82	6.76
Total Running Time (min)	9.00	6.00	8.00	10.00	10.00
WEIGHT DATA					
Input					
1. BL Before (g)	20.2547	21.6434	21.4339	20.6165	20.7138
BL After (g)	16.6628	19.4576	20.0207	16.3334	16.3048
Input black liquor wt.(g)	***3.5919***	***2.1858***	***1.4132***	***4.2831***	***4.4090***
2. Flush Char wt. (g)	***0.0000***	***0.0000***	***0.0000***	***0.0000***	***0.0000***
3. Flush Filter Before (g)	0.5256	0.5354	0.5345	0.5533	0.5265
Flush Filter After (g)	0.5398	0.5461	0.5465	0.5701	0.5426
Flush Fume wt.(g)	***0.0142***	***0.0107***	***0.0120***	***0.0168***	***0.0161***
Total Input black liquor wt. (g)	**3.5777**	**2.1751**	**1.4012**	**4.2663**	**4.3929**
Output					
1. Fume Filter Before (g)	0.0883	0.0881	0.0873	0.0857	0.0861
Fume Filter After (g)	0.0928	0.0906	0.0893	0.0882	0.0889
Collected Fume wt. (g)	***0.0045***	***0.0025***	***0.0020***	***0.0025***	***0.0028***
2. Fume Filter Before (gas outlet) (g)	0.4687	0.4707	0.4727	0.4722	0.4663
Fume Filter After (gas outlet) (g)	0.4838	0.4816	0.4795	0.4882	0.4839
Fume wt. (gas outlet) (g)	***0.0151***	***0.0109***	***0.0068***	***0.0160***	***0.0176***
Total Fume wt. in system (g)	***0.0196***	***0.0134***	***0.0088***	***0.0185***	***0.0204***
3. Char wt. (g)	***2.4421***	***1.5456***	***1.0306***	***3.3014***	***3.5031***
Total wt. output (g)	**2.4617**	**1.5590**	**1.0394**	**3.3199**	**3.5235**
Percentage of Total Output wt (%)	**68.81**	**71.67**	**74.18**	**77.82**	**80.21**
Percentage of Collected Fume (%)	**0.55**	**0.62**	**0.63**	**0.43**	**0.46**
Percentage of Collected Char (%)	**68.26**	**71.06**	**73.55**	**77.38**	**79.74**

MATERIAL BALANCE					
DATA ACQUISITION FILE	FVAG611	FVAG612	FVAG613	FVAG614	FVAG615
Date	8/13/96	8/13/96	8/14/96	8/14/96	8/14/96
Raw Material	Valdosta	Valdosta	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125	90-125	90-125
Reactor Path Lenght (inch)	23.75	23.75	17.75	17.75	12.75
Residence Time (sec)	0.9	0.9	0.7	0.7	0.5
Temperature (c)	500	500	500	500	500
GAS FLOW					
Primary Flow	0.30	0.30	0.29	0.29	0.29
Total Flow (l/min)	22.00	22.00	20.00	20.00	20.10
N2 (l/min) : (100 %)	22.00	22.00	20.00	20.00	20.10
CO2 (l/min) : (0 %)	0.00	0.00	0.00	0.00	0.00
O2 (l/min) : (0 %)	0.00	0.00	0.00	0.00	0.00
Gas Sample Flow (l/min)	6.63	6.75	6.85	6.84	6.80
Total Running Time (min)	10.00	10.00	10.00	10.00	10.00
WEIGHT DATA					
Input					
1. BL Before (g)	21.2234	21.4586	20.6886	21.3525	20.0361
BL After (g)	15.7966	16.5101	16.9143	15.8638	15.7151
Input black liquor wt.(g)	***5.4268***	***4.9485***	***3.7743***	***5.4887***	***4.3210***
2. Flush Char wt. (g)	***0.0000***	***0.0000***	***0.0000***	***0.0000***	***0.0000***
3. Flush Filter Before (g)	0.5234	0.5247	0.5271	0.5301	0.0000
Flush Filter After (g)	0.5352	0.5352	0.5388	0.5457	0.0000
Flush Fume wt.(g)	***0.0118***	***0.0105***	***0.0117***	***0.0156***	***0.0000***
Total Input black liquor wt. (g)	**5.4150**	**4.9380**	**3.7626**	**5.4731**	**4.3210**
Output					
1. Fume Filter Before (g)	0.0865	0.0872	0.0871	0.0867	0.0858
Fume Filter After (g)	0.0906	0.0901	0.0892	0.0904	0.0888
Collected Fume wt. (g)	***0.0041***	***0.0029***	***0.0021***	***0.0037***	***0.0030***
2. Fume Filter Before (gas outlet) (g)	0.4702	0.4706	0.4693	0.4701	0.4711
Fume Filter After (gas outlet) (g)	0.4902	0.4909	0.4861	0.4909	0.4901
Fume wt. (gas outlet) (g)	***0.0200***	***0.0203***	***0.0168***	***0.0208***	***0.0190***
Total Fume wt. in system (g)	***0.0241***	***0.0232***	***0.0189***	***0.0245***	***0.0220***
3. Char wt. (g)	***4.3718***	***3.9025***	***3.0763***	***4.5202***	***3.6438***
Total wt. output (g)	**4.3959**	**3.9257**	**3.0952**	**4.5447**	**3.6658**
Percentage of Total Output wt (%)	**81.18**	**79.50**	**82.26**	**83.04**	**84.84**
Percentage of Collected Fume (%)	**0.45**	**0.47**	**0.50**	**0.45**	**0.51**
Percentage of Collected Char (%)	**80.73**	**79.03**	**81.76**	**82.59**	**84.33**

MATERIAL BALANCE					
DATA ACQUISITION FILE	FVAG616	FVAG617	FVAG618	FVAG619	FVAG620
Date	8/14/96	8/14/96	8/14/96	8/15/96	8/15/96
Raw Material	Valdosta	Valdosta	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125	90-125	90-125
Reactor Path Lenght (inch)	12.75	9.75	9.75	28.75	28.75
Residence Time (sec)	0.5	0.3	0.3	2.0	2.0
Temperature (c)	500	500	500	400	400
GAS FLOW					
Primary Flow	0.29	0.42	0.42	0.15	0.15
Total Flow (l/min)	20.10	29.40	29.40	9.90	9.90
N2 (l/min) : (100 %)	20.10	29.40	29.40	9.90	9.90
CO2 (l/min) : (0 %)	0.00	0.00	0.00	0.00	0.00
O2 (l/min) : (0 %)	0.00	0.00	0.00	0.00	0.00
Gas Sample Flow (l/min)	6.81	6.92	6.92	6.73	6.74
Total Running Time (min)	10.00	10.00	9.00	7.00	7.00
WEIGHT DATA					
Input					
1. BL Before (g)	21.5842	21.3222	21.2576	21.1412	21.1032
BL After (g)	16.0378	15.8861	16.8503	19.2061	18.2734
Input black liquor wt.(g)	***5.5464***	***5.4361***	***4.4073***	***1.9351***	***2.8298***
2. Flush Char wt. (g)	***0.0000***	***0.0000***	***0.0000***	***0.0000***	***0.0000***
3. Flush Filter Before (g)	0.0000	0.0000	0.0000	0.0000	0.0000
Flush Filter After (g)	0.0000	0.0000	0.0000	0.0000	0.0000
Flush Fume wt.(g)	***0.0000***	***0.0000***	***0.0000***	***0.0000***	***0.0000***
Total Input black liquor wt. (g)	**5.5464**	**5.4361**	**4.4073**	**1.9351**	**2.8298**
Output					
1. Fume Filter Before (g)	0.0869	0.0867	0.0864	0.0866	0.0872
Fume Filter After (g)	0.0898	0.0884	0.0881	0.0883	0.0902
Collected Fume wt. (g)	***0.0029***	***0.0017***	***0.0017***	***0.0017***	***0.0030***
2. Fume Filter Before (gas outlet) (g)	0.4716	0.4663	0.4733	0.4703	0.4713
Fume Filter After (gas outlet) (g)	0.4911	0.4811	0.4841	0.4765	0.4808
Fume wt. (gas outlet) (g)	***0.0195***	***0.0148***	***0.0108***	***0.0062***	***0.0095***
Total Fume wt. in system (g)	***0.0224***	***0.0165***	***0.0125***	***0.0079***	***0.0125***
3. Char wt. (g)	***4.7505***	***4.8722***	***4.0662***	***1.5201***	***2.1397***
Total wt. output (g)	**4.7729**	**4.8887**	**4.0787**	**1.5280**	**2.1522**
Percentage of Total Output wt (%)	**86.05**	**89.93**	**92.54**	**78.96**	**76.05**
Percentage of Collected Fume (%)	**0.40**	**0.30**	**0.28**	**0.41**	**0.44**
Percentage of Collected Char (%)	**85.65**	**89.63**	**92.26**	**78.55**	**75.61**

MATERIAL BALANCE					
DATA ACQUISITION FILE	FVAG621	FVAG622	FVAG623	FVAG624	FVAG625
Date	8/15/96	8/15/96	8/15/96	8/15/96	8/16/96
Raw Material	Valdosta	Valdosta	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125	90-125	90-125
Reactor Path Lenght (inch)	28.75	28.75	28.75	28.75	28.75
Residence Time (sec)	1.7	1.7	1.5	1.5	1.3
Temperature (c)	400	400	400	400	400
GAS FLOW					
Primary Flow	0.15	0.15	0.15	0.15	0.25
Total Flow (l/min)	14.60	14.60	19.20	19.20	20.00
N2 (l/min) : (100 %)	14.60	14.60	19.20	19.20	20.00
CO2 (l/min) : (0 %)	0.00	0.00	0.00	0.00	0.00
O2 (l/min) : (0 %)	0.00	0.00	0.00	0.00	0.00
Gas Sample Flow (l/min)	6.77	6.87	6.83	7.05	6.85
Total Running Time (min)	8.00	8.00	9.00	10.00	7.00
WEIGHT DATA					
Input					
1. BL Before (g)	20.9799	21.4593	21.4381	21.2487	20.8757
BL After (g)	16.8671	17.4396	16.7426	17.4777	18.5586
Input black liquor wt.(g)	***4.1128***	***4.0197***	***4.6955***	***3.771***	***2.3171***
2. Flush Char wt. (g)	***0.0000***	***0.0000***	***0.0000***	***0.0000***	***0.0000***
3. Flush Filter Before (g)	0.0000	0.0000	0.0000	0.0000	0.0000
Flush Filter After (g)	0.0000	0.0000	0.0000	0.0000	0.0000
Flush Fume wt.(g)	***0.0000***	***0.0000***	***0.0000***	***0.0000***	***0.0000***
Total Input black liquor wt. (g)	**4.1128**	**4.0197**	**4.6955**	**3.7710**	**2.3171**
Output					
1. Fume Filter Before (g)	0.0854	0.0854	0.0864	0.0878	0.0861
Fume Filter After (g)	0.0874	0.0876	0.0878	0.0891	0.0871
Collected Fume wt. (g)	***0.0020***	***0.0022***	***0.0014***	***0.0013***	***0.0010***
2. Fume Filter Before (gas outlet) (g)	0.4702	0.4656	0.4732	0.4709	0.4692
Fume Filter After (gas outlet) (g)	0.4798	0.4761	0.4821	0.4784	0.4751
Fume wt. (gas outlet) (g)	***0.0096***	***0.0105***	***0.0089***	***0.0075***	***0.0059***
Total Fume wt. in system (g)	***0.0116***	***0.0127***	***0.0103***	***0.0088***	***0.0069***
3. Char wt. (g)	***3.1248***	***3.2285***	***3.7358***	***3.1228***	***1.9236***
Total wt. output (g)	**3.1364**	**3.2412**	**3.7461**	**3.1316**	**1.9305**
Percentage of Total Output wt (%)	**76.26**	**80.63**	**79.78**	**83.04**	**83.32**
Percentage of Collected Fume (%)	**0.28**	**0.32**	**0.22**	**0.23**	**0.30**
Percentage of Collected Char (%)	**75.98**	**80.32**	**79.56**	**82.81**	**83.02**

MATERIAL BALANCE					
DATA ACQUISITION FILE	FVAG626	FVAG627	FVAG628	FVAG629	FVAG630
Date	8/16/96	8/16/96	8/16/96	8/16/96	8/16/96
Raw Material	Valdosta	Valdosta	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125	90-125	90-125
Reactor Path Lenght (inch)	28.75	28.75	28.75	21.75	21.75
Residence Time (sec)	1.3	1.1	1.1	0.9	0.9
Temperature (c)	400	400	400	400	400
GAS FLOW					
Primary Flow	0.25	0.40	0.40	0.30	0.30
Total Flow (l/min)	20.00	20.20	20.20	21.20	21.20
N2 (l/min) : (100 %)	20.00	20.20	20.20	21.20	21.20
CO2 (l/min) : (0 %)	0.00	0.00	0.00	0.00	0.00
O2 (l/min) : (0 %)	0.00	0.00	0.00	0.00	0.00
Gas Sample Flow (l/min)	6.81	6.81	6.81	6.76	6.74
Total Running Time (min)	10.00	10.00	9.00	10.00	8.00
WEIGHT DATA					
Input					
1. BL Before (g)	21.0514	21.3485	21.4198	21.7911	21.6795
BL After (g)	16.5389	16.4113	17.2829	17.8243	18.5944
Input black liquor wt.(g)	***4.5125***	***4.9372***	***4.1369***	***3.9668***	***3.0851***
2. Flush Char wt. (g)	***0.0000***	***0.0000***	***0.0000***	***0.0000***	***0.0000***
3. Flush Filter Before (g)	0.0000	0.0000	0.0000	0.0000	0.0000
Flush Filter After (g)	0.0000	0.0000	0.0000	0.0000	0.0000
Flush Fume wt.(g)	***0.0000***	***0.0000***	***0.0000***	***0.0000***	***0.0000***
Total Input black liquor wt. (g)	**4.5125**	**4.9372**	**4.1369**	**3.9668**	**3.0851**
Output					
1. Fume Filter Before (g)	0.0861	0.0862	0.0867	0.0859	0.0862
Fume Filter After (g)	0.0877	0.0885	0.0884	0.0874	0.0872
Collected Fume wt. (g)	***0.0016***	***0.0023***	***0.0017***	***0.0015***	***0.001***
2. Fume Filter Before (gas outlet) (g)	0.4711	0.4706	0.4741	0.4751	0.4721
Fume Filter After (gas outlet) (g)	0.4813	0.4834	0.4841	0.4864	0.4789
Fume wt. (gas outlet) (g)	***0.0102***	***0.0128***	***0.0100***	***0.0113***	***0.0068***
Total Fume wt. in system (g)	***0.0118***	***0.0151***	***0.0117***	***0.0128***	***0.0078***
3. Char wt. (g)	***3.8421***	***4.2969***	***3.6589***	***3.6146***	***2.8285***
Total wt. output (g)	**3.8539**	**4.3120**	**3.6706**	**3.6274**	**2.8363**
Percentage of Total Output wt (%)	**85.40**	**87.34**	**88.73**	**91.44**	**91.94**
Percentage of Collected Fume (%)	**0.26**	**0.31**	**0.28**	**0.32**	**0.25**
Percentage of Collected Char (%)	**85.14**	**87.03**	**88.45**	**91.12**	**91.68**

MATERIAL BALANCE					
DATA ACQUISITION FILE	FVAG631	FVAG632	FVAG633	FVAG634	FVAG635
Date	8/18/96	8/18/96	8/18/96	8/18/96	8/18/96
Raw Material	Valdosta	Valdosta	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125	90-125	90-125
Reactor Path Lenght (inch)	15.75	15.75	11.75	11.75	9.75
Residence Time (sec)	0.7	0.7	0.5	0.5	0.3
Temperature (c)	400	400	400	400	400
GAS FLOW					
Primary Flow	0.30	0.30	0.30	0.30	0.50
Total Flow (l/min)	14.80	14.80	17.30	17.30	21.00
N2 (l/min) : (100 %)	14.80	14.80	17.30	17.30	21.00
CO2 (l/min) : (0 %)	0.00	0.00	0.00	0.00	0.00
O2 (l/min) : (0 %)	0.00	0.00	0.00	0.00	0.00
Gas Sample Flow (l/min)	6.72	6.75	6.75	6.74	6.75
Total Running Time (min)	6.00	10.00	10.00	10.00	10.00
WEIGHT DATA					
Input					
1. BL Before (g)	21.4672	21.3816	21.4917	21.8221	21.3802
BL After (g)	17.9179	16.9926	16.8844	17.7278	16.4422
Input black liquor wt.(g)	***3.5493***	***4.3890***	***4.6073***	***4.0943***	***4.9380***
2. Flush Char wt. (g)	***0.0000***	***0.0000***	***0.0000***	***0.0000***	***0.0000***
3. Flush Filter Before (g)	0.0000	0.0000	0.0000	0.0000	0.0000
Flush Filter After (g)	0.0000	0.0000	0.0000	0.0000	0.0000
Flush Fume wt.(g)	***0.0000***	***0.0000***	***0.0000***	***0.0000***	***0.0000***
Total Input black liquor wt. (g)	**3.5493**	**4.3890**	**4.6073**	**4.0943**	**4.9380**
Output					
1. Fume Filter Before (g)	0.0879	0.0852	0.0867	0.0852	0.0865
Fume Filter After (g)	0.0881	0.0871	0.0889	0.0872	0.0889
Collected Fume wt. (g)	***0.0002***	***0.0019***	***0.0022***	***0.0020***	***0.0024***
2. Fume Filter Before (gas outlet) (g)	0.4709	0.4724	0.4731	0.4766	0.4762
Fume Filter After (gas outlet) (g)	0.4733	0.4789	0.4858	0.4889	0.4908
Fume wt. (gas outlet) (g)	***0.0024***	***0.0065***	***0.0127***	***0.0123***	***0.0146***
Total Fume wt. in system (g)	***0.0026***	***0.0084***	***0.0149***	***0.0143***	***0.0170***
3. Char wt. (g)	***3.4712***	***4.1884***	***4.5907***	***4.0140***	***4.9162***
Total wt. output (g)	**3.4738**	**4.1968**	**4.6056**	**4.0283**	**4.9332**
Percentage of Total Output wt (%)	**97.87**	**95.62**	**99.96**	**98.39**	**99.90**
Percentage of Collected Fume (%)	**0.07**	**0.19**	**0.32**	**0.35**	**0.34**
Percentage of Collected Char (%)	**97.80**	**95.43**	**99.64**	**98.04**	**99.56**

Carbon Yield in Fume, Char, and Gas at 600 °C					
DATA ACQUISITION FILE	FVJL601	FVJL602	FVJL603	FVJL604	FVJL605
Reactor Path Lenght (inch)	28.75	28.75	28.75	28.75	28.75
Residence Time (sec)	2.0	2.0	1.7	1.7	1.5
Temperature (c)	600	600	600	600	600
Mass of Carbon in Gas :					
1st and 2nd Flow of N_2 (l/min)	8.00	8.00	11.00	11.00	13.80
Quench Flow (l/min)	12.80	12.80	16.50	16.50	20.70
Total gas Flow at Outlet (l/min)	*20.80*	*20.80*	*27.50*	*27.50*	*34.50*
Total Running Time (min)	10.00	10.00	10.00	10.00	10.00
Percentage of CO_2 at Outlet (%)	0.40	0.34	0.26	0.32	0.24
Volumatic Flow of CO_2 (l/min)	*0.0832*	*0.07072*	*0.0715*	*0.0880*	*0.0828*
Total Volume of CO_2 (l)	*0.8320*	*0.7072*	*0.7150*	*0.8800*	*0.8280*
Mass of CO_2 (g)	*1.4968*	*1.2723*	*1.2863*	*1.5831*	*1.4896*
Mol of CO_2 (mol)	*0.0340*	*0.0289*	*0.0292*	*0.0360*	*0.0339*
Mol of C (mol)	*0.0340*	*0.0289*	*0.0292*	*0.0360*	*0.0339*
Total Mass of Carbon in Gas (g)	**0.4082**	**0.3470**	**0.3508**	**0.4318**	**0.4062**
Carbon Balance :					
Input :					
Total Input Black Liquor wt. (g)	5.3845	4.4088	4.5022	5.6822	5.5174
Carbon wt % in Black Liquor	33.66	33.66	33.66	33.66	33.66
Carbon wt in Black Liquor (g)	***1.8124***	***1.4840***	***1.5154***	***1.9126***	***1.8572***
Output :					
1.Total Fume wt. (g)	0.0541	0.0446	0.0332	0.0432	0.0316
Carbon wt % in Fume (%)	76.29	91.09	74.12	57.89	54.86
Carbon wt in Fume (g)	***0.0413***	***0.0406***	***0.0246***	***0.0250***	***0.0173***
2.Char wt. (g)	4.0334	3.3161	3.5597	4.3071	4.2375
Carbon wt % in Char (%)	32.29	30.05	30.99	30.83	30.54
Carbon wt in Char (g)	***1.3024***	***0.9965***	***1.1032***	***1.3279***	***1.2941***
3.Total Mass of Carbon in Gas (g)	***0.4082***	***0.3470***	***0.3508***	***0.4318***	***0.4062***
Total Carbon wt. of Output (g)	***1.7519***	***1.3841***	***1.4786***	***1.7846***	***1.7177***
Carbon Yield in Fume (%)	**2.28**	**2.74**	**1.62**	**1.31**	**0.93**
Carbon Yield in Char (%)	**71.86**	**67.15**	**72.79**	**69.43**	**69.68**
Carbon Yield in Gas (%)	**22.52**	**23.38**	**23.15**	**22.57**	**21.87**
Total Carbon Yield of Output (%)	**96.66**	**93.27**	**97.57**	**93.31**	**92.49**

Carbon Yield in Fume, Char, and Gas at 600 °C					
DATA ACQUISITION FILE	FVJL606	FVJL607	FVJL608	FVJL609	FVJL610
Reactor Path Lenght (inch)	28.75	28.75	28.75	28.75	28.75
Residence Time (sec)	1.5	1.3	1.3	1.1	1.1
Temperature (c)	600	600	600	600	600
Mass of Carbon in Gas :					
1st and 2nd Flow of N_2 (l/min)	13.80	18.20	18.20	21.80	21.80
Quench Flow (l/min)	20.70	27.30	27.30	32.70	32.70
Total gas Flow at Outlet (l/min)	*34.50*	*45.50*	*45.50*	*54.50*	*54.50*
Total Running Time (min)	10.00	10.00	10.00	10.00	10.00
Percentage of CO_2 at Outlet (%)	0.26	0.16	0.14	0.12	0.12
Volumatic Flow of CO_2 (l/min)	*0.0897*	*0.0728*	*0.0637*	*0.0654*	*0.0654*
Total Volume of CO_2 (l)	*0.8970*	*0.7280*	*0.6370*	*0.6540*	*0.6540*
Mass of CO_2 (g)	*1.6137*	*1.3097*	*1.1460*	*1.1765*	*1.1765*
Mol of CO_2 (mol)	*0.0367*	*0.0298*	*0.0260*	*0.0267*	*0.0267*
Mol of C (mol)	*0.0367*	*0.0298*	*0.0260*	*0.0267*	*0.0267*
Total Mass of Carbon in Gas (g)	**0.4401**	**0.3572**	**0.3125**	**0.3209**	**0.3209**
Carbon Balance :					
Input :					
Total Input Black Liquor wt. (g)	5.8924	4.8849	4.5211	4.9114	4.7345
Carbon wt % in Black Liquor	33.66	33.66	33.66	33.66	33.66
Carbon wt in Black Liquor (g)	***1.9834***	***1.6443***	***1.5218***	***1.6532***	***1.5936***
Output :					
1.Total Fume wt. (g)	0.0326	0.0224	0.0208	0.0200	0.0189
Carbon wt % in Fume (%)	52.91	53.53	57.31	47.95	50.32
Carbon wt in Fume (g)	***0.0172***	***0.0120***	***0.0119***	***0.0096***	***0.0095***
2.Char wt. (g)	4.5689	3.8534	3.5371	3.9616	3.8025
Carbon wt % in Char (%)	31.43	31.98	31.33	32.26	31.79
Carbon wt in Char (g)	***1.4360***	***1.2323***	***1.1082***	***1.2780***	***1.2088***
3.Total Mass of Carbon in Gas (g)	***0.4401***	***0.3572***	***0.3125***	***0.3209***	***0.3209***
Total Carbon wt. of Output (g)	***1.8934***	***1.6015***	***1.4326***	***1.6085***	***1.5392***
Carbon Yield in Fume (%)	**0.87**	**0.73**	**0.78**	**0.58**	**0.60**
Carbon Yield in Char (%)	**72.40**	**74.95**	**72.82**	**77.31**	**75.85**
Carbon Yield in Gas (%)	**22.19**	**21.72**	**20.54**	**19.41**	**20.13**
Total Carbon Yield of Output (%)	**95.46**	**97.40**	**94.14**	**97.30**	**96.58**

Carbon Yield in Fume, Char, and Gas at 600 °C					
DATA ACQUISITION FILE	FVJL611	FVJL612	FVJL613	FVJL614	FVJL615
Reactor Path Lenght (inch)	25.75	25.75	19.75	19.75	13.75
Residence Time (sec)	0.9	0.9	0.7	0.7	0.5
Temperature (c)	600	600	600	600	600
Mass of Carbon in Gas :					
1st and 2nd Flow of N_2 (l/min)	22.60	22.60	22.30	22.30	22.00
Quench Flow (l/min)	33.90	33.90	33.50	33.50	33.00
Total gas Flow at Outlet (l/min)	*56.50*	*56.50*	*55.80*	*55.80*	*55.00*
Total Running Time (min)	10.00	10.00	10.00	10.00	10.00
Percentage of CO_2 at Outlet (%)	0.12	0.10	0.10	0.10	0.08
Volumatic Flow of CO_2 (l/min)	*0.0678*	*0.0565*	*0.0558*	*0.0558*	*0.0440*
Total Volume of CO_2 (l)	*0.6780*	*0.5650*	*0.5580*	*0.5580*	*0.4400*
Mass of CO_2 (g)	*1.2197*	*1.0164*	*1.0038*	*1.0038*	*0.7916*
Mol of CO_2 (mol)	*0.0277*	*0.0231*	*0.0228*	*0.0228*	*0.0180*
Mol of C (mol)	*0.0277*	*0.0231*	*0.0228*	*0.0228*	*0.0180*
Total Mass of Carbon in Gas (g)	**0.3327**	**0.2772**	**0.2738**	**0.2738**	**0.2159**
Carbon Balance :					
Input :					
Total Input Black Liquor wt. (g)	5.4536	4.5087	4.4940	4.7983	4.4244
Carbon wt % in Black Liquor	33.66	33.66	33.66	33.66	33.66
Carbon wt in Black Liquor (g)	***1.8357***	***1.5176***	***1.5127***	***1.6151***	***1.4893***
Output :					
1.Total Fume wt. (g)	0.0236	0.0210	0.0189	0.0209	0.0191
Carbon wt % in Fume (%)	44.88	50.48	47.13	42.31	47.93
Carbon wt in Fume (g)	***0.0106***	***0.0106***	***0.0089***	***0.0088***	***0.0092***
2.Char wt. (g)	4.2010	3.6627	3.6304	3.5083	3.7689
Carbon wt % in Char (%)	32.83	33.16	33.36	33.84	33.26
Carbon wt in Char (g)	***1.3792***	***1.2146***	***1.2111***	***1.1872***	***1.2535***
3.Total Mass of Carbon in Gas (g)	***0.3327***	***0.2772***	***0.2738***	***0.2738***	***0.2159***
Total Carbon wt. of Output (g)	***1.7224***	***1.5024***	***1.4938***	***1.4698***	***1.4786***
Carbon Yield in Fume (%)	**0.58**	**0.70**	**0.59**	**0.55**	**0.61**
Carbon Yield in Char (%)	**75.13**	**80.03**	**80.06**	**73.51**	**84.17**
Carbon Yield in Gas (%)	**18.12**	**18.27**	**18.10**	**16.95**	**14.50**
Total Carbon Yield of Output (%)	**93.83**	**98.99**	**98.75**	**91.00**	**99.28**

Carbon Yield in Fume, Char, and Gas at 600 °C			
DATA ACQUISITION FILE	FVJL616	FVJL617	FVJL618
Reactor Path Lenght (inch)	13.75	9.75	9.75
Residence Time (sec)	0.5	0.3	0.3
Temperature (c)	600	600	600
Mass of Carbon in Gas :			
1st and 2nd Flow of N_2 (l/min)	22.00	29.00	29.00
Quench Flow (l/min)	33.00	43.50	43.50
Total gas Flow at Outlet (l/min)	*55.00*	*72.50*	*72.50*
Total Running Time (min)	10.00	10.00	10.00
Percentage of CO_2 at Outlet (%)	0.08	0.04	0.04
Volumatic Flow of CO_2 (l/min)	*0.0440*	*0.0290*	*0.0290*
Total Volume of CO_2 (l)	*0.4400*	*0.2900*	*0.2900*
Mass of CO_2 (g)	*0.7916*	*0.5217*	*0.5217*
Mol of CO_2 (mol)	*0.0180*	*0.0119*	*0.0119*
Mol of C (mol)	*0.0180*	*0.0119*	*0.0119*
Total Mass of Carbon in Gas (g)	**0.2159**	**0.1423**	**0.1423**
Carbon Balance :			
Input :			
Total Input Black Liquor wt. (g)	5.4212	4.5901	5.5056
Carbon wt % in Black Liquor	33.66	33.66	33.66
Carbon wt in Black Liquor (g)	***1.8248***	***1.5450***	***1.8532***
Output :			
1.Total Fume wt. (g)	0.0245	0.0271	0.0314
Carbon wt % in Fume (%)	38.11	32.89	28.64
Carbon wt in Fume (g)	***0.0093***	***0.0089***	***0.0090***
2.Char wt. (g)	4.5995	4.2696	5.0851
Carbon wt % in Char (%)	33.66	32.30	33.34
Carbon wt in Char (g)	***1.5482***	***1.3791***	***1.6954***
3.Total Mass of Carbon in Gas (g)	***0.2159***	***0.1423***	***0.1423***
Total Carbon wt. of Output (g)	***1.7734***	***1.5303***	***1.8466***
Carbon Yield in Fume (%)	**0.51**	**0.58**	**0.49**
Carbon Yield in Char (%)	**84.84**	**89.26**	**91.48**
Carbon Yield in Gas (%)	**11.83**	**9.21**	**7.68**
Total Carbon Yield of Output (%)	**97.19**	**99.05**	**99.65**

Carbon Yield in Fume, Char, and Gas at 500 °C					
DATA ACQUISITION FILE	FVAG601	FVAG602	FVAG603	FVAG604	FVAG605
Reactor Path Lenght (inch)	28.75	28.75	28.75	28.75	28.75
Residence Time (sec)	2.0	2.0	1.7	1.7	1.5
Temperature (c)	500	500	500	500	500
Mass of Carbon in Gas :					
1st and 2nd Flow of N_2 (l/min)	8.60	8.60	12.20	12.20	15.70
Quench Flow (l/min)	12.90	12.90	18.30	18.30	23.60
Total gas Flow at Outlet (l/min)	*21.50*	*21.50*	*30.50*	*30.50*	*39.30*
Total Running Time (min)	10.00	10.00	10.00	10.00	9.00
Percentage of CO_2 at Outlet (%)	0.38	0.34	0.20	0.16	0.10
Volumatic Flow of CO_2 (l/min)	*0.0817*	*0.0731*	*0.0610*	*0.0488*	*0.0393*
Total Volume of CO_2 (l)	*0.8170*	*0.7310*	*0.6100*	*0.4880*	*0.3537*
Mass of CO_2 (g)	*1.4698*	*1.3151*	*1.0974*	*0.8779*	*0.6363*
Mol of CO_2 (mol)	*0.0334*	*0.0299*	*0.0249*	*0.0200*	*0.0145*
Mol of C (mol)	*0.0334*	*0.0299*	*0.0249*	*0.0200*	*0.0145*
Total Mass of Carbon in Gas (g)	**0.4008**	**0.3587**	**0.2993**	**0.2394**	**0.1735**
Carbon Balance :					
Input :					
Total Input Black Liquor wt. (g)	5.0837	4.5304	4.2378	3.1126	2.9778
Carbon wt % in Black Liquor	33.66	33.66	33.66	33.66	33.66
Carbon wt in Black Liquor (g)	***1.7112***	***1.5249***	***1.4264***	***1.0477***	***1.0023***
Output :					
1.Total Fume wt. (g)	0.0401	0.0376	0.0321	0.0209	0.0235
Carbon wt % in Fume (%)	76.29	76.29	66.01	66.01	53.89
Carbon wt in Fume (g)	***0.0306***	***0.0287***	***0.0212***	***0.0138***	***0.0127***
2.Char wt. (g)	3.3487	2.8562	2.7995	1.9759	2.0084
Carbon wt % in Char (%)	31.56	31.56	31.38	31.38	30.92
Carbon wt in Char (g)	***1.0568***	***0.9014***	***0.8785***	***0.6200***	***0.6210***
3.Total Mass of Carbon in Gas (g)	***0.4008***	***0.3587***	***0.2993***	***0.2394***	***0.1735***
Total Carbon wt. of Output (g)	***1.4883***	***1.2888***	***1.1990***	***0.8733***	***0.8072***
Carbon Yield in Fume (%)	**1.79**	**1.88**	**1.49**	**1.32**	**1.26**
Carbon Yield in Char (%)	**61.76**	**59.11**	**61.59**	**59.18**	**61.96**
Carbon Yield in Gas (%)	**23.43**	**23.52**	**20.98**	**22.85**	**17.31**
Total Carbon Yield of Output (%)	**86.97**	**84.51**	**84.05**	**83.35**	**80.53**

Carbon Yield in Fume, Char, and Gas at 500 °C					
DATA ACQUISITION FILE	FVAG606	FVAG607	FVAG608	FVAG609	FVAG610
Reactor Path Lenght (inch)	28.75	28.75	28.75	28.75	28.75
Residence Time (sec)	1.5	1.3	1.3	1.1	1.1
Temperature (c)	500	500	500	500	500
Mass of Carbon in Gas :					
1st and 2nd Flow of N_2 (l/min)	15.70	20.60	20.60	23.80	23.80
Quench Flow (l/min)	23.60	30.90	30.90	35.70	35.70
Total gas Flow at Outlet (l/min)	*39.30*	*51.50*	*51.50*	*59.50*	*59.50*
Total Running Time (min)	9.00	6.00	8.00	10.00	10.00
Percentage of CO_2 at Outlet (%)	0.12	0.08	0.04	0.08	0.08
Volumatic Flow of CO_2 (l/min)	*0.0472*	*0.0412*	*0.0206*	*0.0476*	*0.0476*
Total Volume of CO_2 (l)	*0.4244*	*0.2472*	*0.1648*	*0.4760*	*0.4760*
Mass of CO_2 (g)	*0.7636*	*0.4447*	*0.2965*	*0.8563*	*0.8563*
Mol of CO_2 (mol)	*0.0174*	*0.0101*	*0.0067*	*0.0195*	*0.0195*
Mol of C (mol)	*0.0174*	*0.0101*	*0.0067*	*0.0195*	*0.0195*
Total Mass of Carbon in Gas (g)	**0.2082**	**0.1213**	**0.0809**	**0.2335**	**0.2335**
Carbon Balance :					
Input :					
Total Input Black Liquor wt. (g)	3.5777	2.1751	1.4012	4.2663	4.3929
Carbon wt % in Black Liquor	33.66	33.66	33.66	33.66	33.66
Carbon wt in Black Liquor (g)	***1.2043***	***0.7321***	***0.4716***	***1.4360***	***1.4787***
Output :					
1.Total Fume wt. (g)	0.0196	0.0134	0.0088	0.0185	0.0204
Carbon wt % in Fume (%)	53.89	55.42	55.42	49.14	49.14
Carbon wt in Fume (g)	***0.0106***	***0.0074***	***0.0049***	***0.0091***	***0.0100***
2.Char wt. (g)	2.4421	1.5456	1.0306	3.3014	3.5031
Carbon wt % in Char (%)	30.92	30.63	30.63	31.22	31.22
Carbon wt in Char (g)	***0.7551***	***0.4734***	***0.3157***	***1.0307***	***1.0937***
3.Total Mass of Carbon in Gas (g)	***0.2082***	***0.1213***	***0.0809***	***0.2335***	***0.2335***
Total Carbon wt. of Output (g)	***0.9739***	***0.6021***	***0.4014***	***1.2733***	***1.3372***
Carbon Yield in Fume (%)	**0.88**	**1.01**	**1.03**	**0.63**	**0.68**
Carbon Yield in Char (%)	**62.70**	**64.66**	**66.93**	**71.77**	**73.96**
Carbon Yield in Gas (%)	**17.29**	**16.57**	**17.14**	**16.26**	**15.79**
Total Carbon Yield of Output (%)	**80.87**	**82.24**	**85.11**	**88.67**	**90.44**

Carbon Yield in Fume, Char, and Gas at 500 ° C					
DATA ACQUISITION FILE	FVAG611	FVAG612	FVAG613	FVAG614	FVAG615
Reactor Path Lenght (inch)	23.75	23.75	17.75	17.75	12.75
Residence Time (sec)	0.9	0.9	0.7	0.7	0.5
Temperature (c)	500	500	500	500	500
Mass of Carbon in Gas :					
1st and 2nd Flow of N_2 (l/min)	22.00	22.00	20.00	20.00	20.10
Quench Flow (l/min)	33.00	33.00	30.00	30.00	30.20
Total gas Flow at Outlet (l/min)	*55.00*	*55.00*	*50.00*	*50.00*	*50.30*
Total Running Time (min)	10.00	10.00	10.00	10.00	10.00
Percentage of CO_2 at Outlet (%)	0.10	0.08	0.06	0.08	0.06
Volumatic Flow of CO_2 (l/min)	*0.0550*	*0.044*	*0.0300*	*0.0400*	*0.0302*
Total Volume of CO_2 (l)	*0.5500*	*0.4400*	*0.3000*	*0.4000*	*0.3018*
Mass of CO_2 (g)	*0.9895*	*0.7916*	*0.5397*	*0.7196*	*0.5429*
Mol of CO_2 (mol)	*0.0225*	*0.0180*	*0.0123*	*0.0164*	*0.0123*
Mol of C (mol)	*0.0225*	*0.0180*	*0.0123*	*0.0164*	*0.0123*
Total Mass of Carbon in Gas (g)	**0.2699**	**0.2159**	**0.1472**	**0.1963**	**0.1481**
Carbon Balance :					
Input :					
Total Input Black Liquor wt. (g)	5.4150	4.9380	3.7626	5.4731	4.3210
Carbon wt % in Black Liquor	33.66	33.66	33.66	33.66	33.66
Carbon wt in Black Liquor (g)	***1.8227***	***1.6621***	***1.2665***	***1.8422***	***1.4544***
Output :					
1.Total Fume wt. (g)	0.0241	0.0232	0.0189	0.0245	0.0220
Carbon wt % in Fume (%)	47.68	47.68	44.72	44.72	43.02
Carbon wt in Fume (g)	***0.0115***	***0.0111***	***0.0085***	***0.0110***	***0.0095***
2.Char wt. (g)	4.3718	3.9025	3.0763	4.5202	3.6438
Carbon wt % in Char (%)	32.36	32.36	32.23	32.23	32.49
Carbon wt in Char (g)	***1.4147***	***1.2628***	***0.9915***	***1.4569***	***1.1839***
3.Total Mass of Carbon in Gas (g)	***0.2699***	***0.2159***	***0.1472***	***0.1963***	***0.1481***
Total Carbon wt. of Output (g)	***1.6961***	***1.4898***	***1.1471***	***1.6641***	***1.3414***
Carbon Yield in Fume (%)	**0.63**	**0.67**	**0.67**	**0.59**	**0.65**
Carbon Yield in Char (%)	**77.62**	**75.98**	**78.29**	**79.08**	**81.40**
Carbon Yield in Gas (%)	**14.81**	**12.99**	**11.62**	**10.65**	**10.18**
Total Carbon Yield of Output (%)	**93.05**	**89.63**	**90.58**	**90.33**	**92.23**

Carbon Yield in Fume, Char, and Gas at 500 °C			
DATA ACQUISITION FILE	FVAG616	FVAG617	FVAG618
Reactor Path Lenght (inch)	12.75	9.75	9.75
Residence Time (sec)	0.5	0.3	0.3
Temperature (c)	500	500	500
Mass of Carbon in Gas :			
1st and 2nd Flow of N_2 (l/min)	20.10	29.40	29.40
Quench Flow (l/min)	33.00	33.00	30.00
Total gas Flow at Outlet (l/min)	*53.10*	*62.40*	*59.40*
Total Running Time (min)	10.00	10.00	9.00
Percentage of CO_2 at Outlet (%)	0.08	0.04	0.04
Volumatic Flow of CO_2 (l/min)	*0.0425*	*0.02496*	*0.0238*
Total Volume of CO_2 (l)	*0.4248*	*0.2496*	*0.2138*
Mass of CO_2 (g)	*0.7642*	*0.4490*	*0.3847*
Mol of CO_2 (mol)	*0.0174*	*0.0102*	*0.0087*
Mol of C (mol)	*0.0174*	*0.0102*	*0.0087*
Total Mass of Carbon in Gas (g)	**0.2084**	**0.1225**	**0.1049**
Carbon Balance :			
Input :			
Total Input Black Liquor wt. (g)	5.5464	5.4361	4.4073
Carbon wt % in Black Liquor	33.66	33.66	33.66
Carbon wt in Black Liquor (g)	***1.8669***	***1.8298***	***1.4835***
Output :			
1.Total Fume wt. (g)	0.0224	0.0165	0.0125
Carbon wt % in Fume (%)	43.02	30.77	30.77
Carbon wt in Fume (g)	***0.0096***	***0.0051***	***0.0038***
2.Char wt. (g)	4.7505	4.8722	4.0662
Carbon wt % in Char (%)	32.49	32.16	32.16
Carbon wt in Char (g)	***1.5434***	***1.5669***	***1.3077***
3.Total Mass of Carbon in Gas (g)	***0.2084***	***0.1225***	***0.1049***
Total Carbon wt. of Output (g)	***1.7615***	***1.6944***	***1.4165***
Carbon Yield in Fume (%)	**0.52**	**0.28**	**0.26**
Carbon Yield in Char (%)	**82.67**	**85.63**	**88.15**
Carbon Yield in Gas (%)	**11.16**	**6.69**	**7.07**
Total Carbon Yield of Output (%)	**94.35**	**92.60**	**95.48**

Carbon Yield in Fume, Char, and Gas at 400 °C					
DATA ACQUISITION FILE	FVAG619	FVAG620	FVAG621	FVAG622	FVAG623
Reactor Path Lenght (inch)	28.75	28.75	28.75	28.75	28.75
Residence Time (sec)	2.0	2.0	1.7	1.7	1.5
Temperature (c)	400	400	400	400	400
Mass of Carbon in Gas :					
1st and 2nd Flow of N_2 (l/min)	9.90	9.90	14.60	14.60	19.20
Quench Flow (l/min)	14.90	14.90	21.90	21.90	28.80
Total gas Flow at Outlet (l/min)	*24.80*	*24.80*	*36.50*	*36.50*	*48.00*
Total Running Time (min)	7.00	8.00	9.00	8.00	8.00
Percentage of CO_2 at Outlet (%)	0.16	0.20	0.16	0.16	0.14
Volumatic Flow of CO_2 (l/min)	*0.0397*	*0.0496*	*0.0584*	*0.0584*	*0.0672*
Total Volume of CO_2 (l)	*0.2778*	*0.3968*	*0.5256*	*0.4672*	*0.5376*
Mass of CO_2 (g)	*0.4997*	*0.7138*	*0.9456*	*0.8405*	*0.9671*
Mol of CO_2 (mol)	*0.0114*	*0.0162*	*0.0215*	*0.0191*	*0.0220*
Mol of C (mol)	*0.0114*	*0.0162*	*0.0215*	*0.0191*	*0.0220*
Total Mass of Carbon in Gas (g)	**0.1363**	**0.1947**	**0.2579**	**0.2292**	**0.2638**
Carbon Balance :					
Input :					
Total Input Black Liquor wt. (g)	1.9351	2.8298	4.1128	4.0197	4.6955
Carbon wt % in Black Liquor	33.66	33.66	33.66	33.66	33.66
Carbon wt in Black Liquor (g)	***0.6514***	***0.9525***	***1.3844***	***1.3530***	***1.5805***
Output :					
1.Total Fume wt. (g)	0.0079	0.0125	0.0116	0.0127	0.0103
Carbon wt % in Fume (%)	76.29	76.29	66.01	66.01	53.89
Carbon wt in Fume (g)	***0.0060***	***0.0095***	***0.0077***	***0.0084***	***0.0056***
2.Char wt. (g)	1.5201	2.1397	3.1248	3.2285	3.7358
Carbon wt % in Char (%)	32.52	32.52	32.98	32.98	32.44
Carbon wt in Char (g)	***0.4943***	***0.6958***	***1.0306***	***1.0648***	***1.2119***
3.Total Mass of Carbon in Gas (g)	***0.1363***	***0.1947***	***0.2579***	***0.2292***	***0.2638***
Total Carbon wt. of Output (g)	***0.6366***	***0.9001***	***1.2961***	***1.3024***	***1.4812***
Carbon Yield in Fume (%)	**0.93**	**1.00**	**0.55**	**0.62**	**0.35**
Carbon Yield in Char (%)	**75.89**	**73.05**	**74.44**	**78.69**	**76.68**
Carbon Yield in Gas (%)	**20.92**	**20.44**	**18.63**	**16.94**	**16.69**
Total Carbon Yield of Output (%)	**97.74**	**94.49**	**93.62**	**96.26**	**93.72**

Carbon Yield in Fume, Char, and Gas at 400 °C					
DATA ACQUISITION FILE	FVAG624	FVAG625	FVAG626	FVAG627	FVAG628
Reactor Path Lenght (inch)	28.75	28.75	28.75	28.75	28.75
Residence Time (sec)	1.5	1.3	1.3	1.1	1.1
Temperature (c)	400	400	400	400	400
Mass of Carbon in Gas :					
1st and 2nd Flow of N_2 (l/min)	19.20	20.00	20.00	20.20	20.20
Quench Flow (l/min)	28.80	30.00	30.00	30.30	30.30
Total gas Flow at Outlet (l/min)	*48.00*	*50.00*	*50.00*	*50.50*	*50.50*
Total Running Time (min)	10.00	8.00	10.00	10.00	9.00
Percentage of CO_2 at Outlet (%)	0.10	0.06	0.08	0.08	0.06
Volumatic Flow of CO_2 (l/min)	*0.0480*	*0.0300*	*0.0400*	*0.0404*	*0.0303*
Total Volume of CO_2 (l)	*0.4800*	*0.2400*	*0.4000*	*0.4040*	*0.2727*
Mass of CO_2 (g)	*0.8635*	*0.4318*	*0.7196*	*0.7268*	*0.4906*
Mol of CO_2 (mol)	*0.0196*	*0.0098*	*0.0164*	*0.0165*	*0.0111*
Mol of C (mol)	*0.0196*	*0.0098*	*0.0164*	*0.0165*	*0.0111*
Total Mass of Carbon in Gas (g)	**0.2355**	**0.1178**	**0.1963**	**0.1982**	**0.1338**
Carbon Balance :					
Input :					
Total Input Black Liquor wt. (g)	3.7710	2.3171	4.5125	4.9372	4.1369
Carbon wt % in Black Liquor	33.66	33.66	33.66	33.66	33.66
Carbon wt in Black Liquor (g)	***1.2693***	***0.7799***	***1.5189***	***1.6619***	***1.3925***
Output :					
1.Total Fume wt. (g)	0.0088	0.0069	0.0118	0.0151	0.0117
Carbon wt % in Fume (%)	53.89	55.42	55.42	49.14	49.14
Carbon wt in Fume (g)	***0.0047***	***0.0038***	***0.0065***	***0.0074***	***0.0057***
2.Char wt. (g)	3.1228	1.9236	3.8421	4.2969	3.6589
Carbon wt % in Char (%)	32.44	32.36	32.36	31.85	31.85
Carbon wt in Char (g)	***1.0130***	***0.6225***	***1.2433***	***1.3686***	***1.1654***
3.Total Mass of Carbon in Gas (g)	***0.2355***	***0.1178***	***0.1963***	***0.1982***	***0.1338***
Total Carbon wt. of Output (g)	***1.2533***	***0.7441***	***1.4461***	***1.5742***	***1.3049***
Carbon Yield in Fume (%)	**0.37**	**0.49**	**0.43**	**0.45**	**0.41**
Carbon Yield in Char (%)	**79.81**	**79.81**	**81.86**	**82.35**	**83.69**
Carbon Yield in Gas (%)	**18.55**	**15.10**	**12.92**	**11.93**	**9.61**
Total Carbon Yield of Output (%)	**98.74**	**95.40**	**95.21**	**94.73**	**93.71**

Carbon Yield in Fume, Char, and Gas at 400 °C					
DATA ACQUISITION FILE	FVAG629	FVAG630	FVAG631	FVAG632	FVAG633
Reactor Path Lenght (inch)	21.75	21.75	15.75	15.75	11.75
Residence Time (sec)	0.9	0.9	0.7	0.7	0.5
Temperature (c)	400	400	400	400	400
Mass of Carbon in Gas :					
1st and 2nd Flow of N_2 (l/min)	21.20	21.20	14.80	14.80	17.30
Quench Flow (l/min)	31.80	31.80	22.20	22.20	26.00
Total gas Flow at Outlet (l/min)	*53.00*	*53.00*	*37.00*	*37.00*	*43.30*
Total Running Time (min)	10.00	8.00	6.00	10.00	10.00
Percentage of CO_2 at Outlet (%)	0.04	0.04	0.04	0.04	0.02
Volumatic Flow of CO_2 (l/min)	*0.0212*	*0.0212*	*0.0148*	*0.0148*	*0.0087*
Total Volume of CO_2 (l)	*0.2120*	*0.1696*	*0.0888*	*0.1480*	*0.0866*
Mass of CO_2 (g)	*0.3814*	*0.3051*	*0.1598*	*0.2663*	*0.1558*
Mol of CO_2 (mol)	*0.0087*	*0.0069*	*0.0036*	*0.0061*	*0.0035*
Mol of C (mol)	*0.0087*	*0.0069*	*0.0036*	*0.0061*	*0.0035*
Total Mass of Carbon in Gas (g)	**0.1040**	**0.0832**	**0.0436**	**0.0726**	**0.0425**
Carbon Balance :					
Input :					
Total Input Black Liquor wt. (g)	3.9668	3.0851	3.5493	4.3890	4.6073
Carbon wt % in Black Liquor	33.66	33.66	33.66	33.66	33.66
Carbon wt in Black Liquor (g)	***1.3352***	***1.0384***	***1.1947***	***1.4773***	***1.5508***
Output :					
1.Total Fume wt. (g)	0.0128	0.0078	0.0026	0.0084	0.0149
Carbon wt % in Fume (%)	47.68	67.68	44.72	44.72	43.02
Carbon wt in Fume (g)	***0.0061***	***0.0053***	***0.0012***	***0.0038***	***0.0064***
2.Char wt. (g)	3.6146	2.8285	3.4712	4.1884	4.5907
Carbon wt % in Char (%)	31.90	31.90	31.64	31.64	32.61
Carbon wt in Char (g)	***1.1531***	***0.9023***	***1.0983***	***1.3252***	***1.4970***
3.Total Mass of Carbon in Gas (g)	***0.1040***	***0.0832***	***0.0436***	***0.0726***	***0.0425***
Total Carbon wt. of Output (g)	***1.2632***	***0.9908***	***1.1430***	***1.4016***	***1.5459***
Carbon Yield in Fume (%)	**0.46**	**0.51**	**0.10**	**0.25**	**0.41**
Carbon Yield in Char (%)	**86.36**	**86.89**	**91.93**	**89.70**	**96.53**
Carbon Yield in Gas (%)	**7.79**	**8.01**	**3.65**	**4.92**	**2.74**
Total Carbon Yield of Output (%)	**94.60**	**95.41**	**95.67**	**94.87**	**99.68**

Carbon Yield in Fume, Char, and Gas at 400 °C		
DATA ACQUISITION FILE	FVAG634	FVAG635
Reactor Path Lenght (inch)	11.75	9.75
Residence Time (sec)	0.5	0.3
Temperature (c)	400	400
Mass of Carbon in Gas :		
1st and 2nd Flow of N_2 (l/min)	17.30	21.00
Quench Flow (l/min)	26.00	31.50
Total gas Flow at Outlet (l/min)	*20.80*	*52.50*
Total Running Time (min)	10.00	10.00
Percentage of CO_2 at Outlet (%)	0.02	0.01
Volumatic Flow of CO_2 (l/min)	*0.0042*	*0.0053*
Total Volume of CO_2 (l)	*0.0416*	*0.0525*
Mass of CO_2 (g)	*0.0748*	*0.0944*
Mol of CO_2 (mol)	*0.0017*	*0.0021*
Mol of C (mol)	*0.0017*	*0.0021*
Total Mass of Carbon in Gas (g)	**0.0204**	**0.0258**
Carbon Balance :		
Input :		
Total Input Black Liquor wt. (g)	4.0943	4.9380
Carbon wt % in Black Liquor	33.66	33.66
Carbon wt in Black Liquor (g)	***1.3781***	***1.6621***
Output :		
1.Total Fume wt. (g)	0.0143	0.0170
Carbon wt % in Fume (%)	43.02	30.77
Carbon wt in Fume (g)	***0.0062***	***0.0052***
2.Char wt. (g)	4.0140	4.9162
Carbon wt % in Char (%)	32.61	32.00
Carbon wt in Char (g)	***1.3090***	***1.5732***
3.Total Mass of Carbon in Gas (g)	***0.0204***	***0.0258***
Total Carbon wt. of Output (g)	***1.3355***	***1.6042***
Carbon Yield in Fume (%)	**0.45**	**0.31**
Carbon Yield in Char (%)	**94.98**	**94.65**
Carbon Yield in Gas (%)	**1.48**	**1.55**
Total Carbon Yield of Output (%)	**96.91**	**96.51**

Nitrogen Yield in Fume, and Char at 600 °C					
DATA ACQUISITION FILE	FVJL601	FVJL602	FVJL603	FVJL604	FVJL605
Date	7/6/96	7/6/96	7/7/96	7/7/96	7/7/96
Raw Material	Valdosta	Valdosta	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125	90-125	90-125
Reactor Path Lenght (inch)	28.75	28.75	28.75	28.75	28.75
Residence Time (sec)	2.0	2.0	1.7	1.7	1.5
Temperature (c)	600	600	600	600	600
Nitrogen wt.% in Fume :					
1. Fume Filter Before (g)	0.0874	0.0869	0.0868	0.0861	0.0865
Fume Filter After (g)	0.1023	0.0996	0.0954	0.0952	0.0925
Collected Fume wt. (g)	*0.0149*	*0.0127*	*0.0086*	*0.0091*	*0.006*
2. Fume Filter Before (gas outlet) (g)	0.4661	0.4666	0.4685	0.4687	0.4672
Fume Filter After (gas outlet) (g)	0.5053	0.4985	0.4931	0.5028	0.4928
Fume wt. (gas outlet) (g)	*0.0392*	*0.0319*	*0.0246*	*0.0341*	*0.0256*
Total Fume wt. in system (g)	***0.0541***	***0.0446***	***0.0332***	***0.0432***	***0.0316***
Total Paper weight (g)	***0.5535***	***0.5535***	***0.5553***	***0.5548***	***0.5537***
Percentage of Nitrogen (P+F) (%)	0.04	0.04	0.03	0.03	0.01
Percentage of Nitrogen in Paper(%)	0.00	0.00	0.00	0.00	0.00
Nitrogen wt. in Paper+fume (g)	0.0002	0.0002	0.0002	0.0002	0.0001
Nitrogen wt. in Paper (g)	0.00000	0.00000	0.00000	0.00000	0.00000
Nitrogen wt. in Fume (g)	0.0002	0.0002	0.0002	0.0002	0.0001
Nitrogen wt.% in Fume	**0.45**	**0.54**	**0.53**	**0.42**	**0.19**
Nitrogen Balance :					
Input :					
Total Input Black Liquor wt. (g)	5.3845	4.4088	4.5022	5.6822	5.5174
Nitrogen wt. % in Black Liquor (%)	0.07	0.07	0.07	0.07	0.07
Nitrogen wt. in Black Liquor (g)	0.003769	0.003086	0.003152	0.003978	0.003862
Output :					
1. Total Fume wt. (g)	0.0541	0.0446	0.0332	0.0432	0.0316
Nitrogen wt. % in Fume (%)	0.45	0.54	0.53	0.42	0.19
Nitrogen wt. in Fume (g)	0.000243	0.000239	0.000177	0.000179	0.000059
2. Char wt. (g)	4.0334	3.3161	3.5597	4.3071	4.2375
Nitrogen wt. % in Char (%)	0.055	0.055	0.055	0.06	0.06
Nitrogen wt. in Char (g)	0.002218	0.001824	0.001958	0.002584	0.002543
Nitrogen Yield in Fume (%)	**6.45**	**7.75**	**5.60**	**4.51**	**1.52**
Nitrogen Yield in Char (%)	**58.86**	**59.10**	**62.12**	**64.97**	**65.83**
Estimate Nitrogen Yield in Gas(%)	**34.70**	**33.15**	**32.27**	**30.52**	**32.65**

Nitrogen Yield in Fume, and Char at 600 °C					
DATA ACQUISITION FILE	FVJL606	FVJL607	FVJL608	FVJL609	FVJL610
Date	7/7/96	7/8/96	7/8/96	7/8/96	7/8/96
Raw Material	Valdosta	Valdosta	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125	90-125	90-125
Reactor Path Lenght (inch)	28.75	28.75	28.75	28.75	28.75
Residence Time (sec)	1.5	1.3	1.3	1.1	1.1
Temperature (c)	600	600	600	600	600
Nitrogen wt.% in Fume :					
1. Fume Filter Before (g)	0.0861	0.0869	0.0871	0.0868	0.0879
Fume Filter After (g)	0.0918	0.0907	0.0921	0.0899	0.0908
Collected Fume wt. (g)	*0.0057*	*0.0038*	*0.0050*	*0.0031*	*0.0029*
2. Fume Filter Before (gas outlet) (g)	0.4637	0.4696	0.4677	0.4705	0.4658
Fume Filter After (gas outlet) (g)	0.4906	0.4882	0.4835	0.4874	0.4818
Fume wt. (gas outlet) (g)	*0.0269*	*0.0186*	*0.0158*	*0.0169*	*0.0160*
Total Fume wt. in system (g)	***0.0326***	***0.0224***	***0.0208***	***0.0200***	***0.0189***
Total Paper weight (g)	***0.5498***	***0.5565***	***0.5548***	***0.5573***	***0.5537***
Percentage of Nitrogen (P+F) (%)	0.01	0.01	0.01	0.01	0.01
Percentage of Nitrogen in Paper(%)	0.00	0.00	0.00	0.00	0.00
Nitrogen wt. in Paper+fume (g)	0.0001	0.0001	0.0001	0.0001	0.0001
Nitrogen wt. in Paper (g)	0.00000	0.00000	0.00000	0.00000	0.00000
Nitrogen wt. in Fume (g)	0.0001	0.0001	0.0001	0.0001	0.0001
Nitrogen wt.% in Fume	**0.18**	**0.26**	**0.28**	**0.29**	**0.30**
Nitrogen Balance :					
Input :					
Total Input Black Liquor wt. (g)	5.8924	4.8849	4.5211	4.9114	4.7345
Nitrogen wt. % in Black Liquor (%)	0.07	0.07	0.07	0.07	0.07
Nitrogen wt. in Black Liquor (g)	0.004125	0.003419	0.003165	0.003438	0.003314
Output :					
1. Total Fume wt. (g)	0.0326	0.0224	0.0208	0.0200	0.0189
Nitrogen wt. % in Fume (%)	0.18	0.26	0.28	0.29	0.30
Nitrogen wt. in Fume (g)	0.000058	0.000058	0.000058	0.000058	0.000057
2. Char wt. (g)	4.5689	3.8534	3.5371	3.9616	3.8025
Nitrogen wt. % in Char (%)	0.06	0.06	0.06	0.06	0.06
Nitrogen wt. in Char (g)	0.002741	0.002312	0.002122	0.002377	0.002282
Nitrogen Yield in Fume (%)	**1.41**	**1.69**	**1.82**	**1.68**	**1.73**
Nitrogen Yield in Char (%)	**66.46**	**67.61**	**67.06**	**69.14**	**68.84**
Estimate Nitrogen Yield in Gas(%)	**32.13**	**30.69**	**31.12**	**29.18**	**29.43**

Nitrogen Yield in Fume, and Char at 600 °C					
DATA ACQUISITION FILE	FVJL611	FVJL612	FVJL613	FVJL614	FVJL615
Date	7/8/96	7/8/96	7/9/96	7/9/96	7/9/96
Raw Material	Valdosta	Valdosta	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125	90-125	90-125
Reactor Path Lenght (inch)	25.75	25.75	19.75	19.75	13.75
Residence Time (sec)	0.9	0.9	0.7	0.7	0.5
Temperature (c)	600	600	600	600	600
Nitrogen wt.% in Fume :					
1. Fume Filter Before (g)	0.0861	0.0876	0.0876	0.0866	0.0868
Fume Filter After (g)	0.0901	0.0907	0.0913	0.0908	0.0905
Collected Fume wt. (g)	*0.0040*	*0.0031*	*0.0037*	*0.0042*	*0.0037*
2. Fume Filter Before (gas outlet) (g)	0.4656	0.4672	0.4791	0.4739	0.4731
Fume Filter After (gas outlet) (g)	0.4852	0.4851	0.4943	0.4906	0.4885
Fume wt. (gas outlet) (g)	*0.0196*	*0.0179*	*0.0152*	*0.0167*	*0.0154*
Total Fume wt. in system (g)	***0.0236***	***0.0210***	***0.0189***	***0.0209***	***0.0191***
Total Paper weight (g)	***0.5517***	***0.5548***	***0.5667***	***0.5605***	***0.5599***
Percentage of Nitrogen (P+F) (%)	0.01	0.01	0.01	0.01	0.005
Percentage of Nitrogen in Paper(%)	0.00	0.00	0.00	0.00	0.00
Nitrogen wt. in Paper+fume (g)	0.0001	0.0001	0.0001	0.0001	0.0000
Nitrogen wt. in Paper (g)	0.00000	0.00000	0.00000	0.00000	0.00000
Nitrogen wt. in Fume (g)	0.0001	0.0001	0.0001	0.0001	0.0000
Nitrogen wt.% in Fume	**0.24**	**0.27**	**0.31**	**0.28**	**0.15**
Nitrogen Balance :					
Input :					
Total Input Black Liquor wt. (g)	5.4536	4.5087	4.494	4.7983	4.4244
Nitrogen wt. % in Black Liquor (%)	0.07	0.07	0.07	0.07	0.07
Nitrogen wt. in Black Liquor (g)	0.003818	0.003156	0.003146	0.003359	0.003097
Output :					
1. Total Fume wt. (g)	0.0236	0.0210	0.0189	0.0209	0.0191
Nitrogen wt. % in Fume (%)	0.24	0.27	0.31	0.28	0.15
Nitrogen wt. in Fume (g)	0.000058	0.000058	0.000059	0.000058	0.000029
2. Char wt. (g)	4.2010	3.6627	3.6304	3.5083	3.7689
Nitrogen wt. % in Char (%)	0.065	0.06	0.065	0.07	0.065
Nitrogen wt. in Char (g)	0.002731	0.002198	0.002360	0.002456	0.002450
Nitrogen Yield in Fume (%)	**1.51**	**1.82**	**1.86**	**1.73**	**0.93**
Nitrogen Yield in Char (%)	**71.53**	**69.63**	**75.01**	**73.12**	**79.10**
Estimate Nitrogen Yield in Gas(%)	**26.96**	**28.54**	**23.13**	**25.15**	**19.97**

Nitrogen Yield in Fume, and Char at 600 °C			
DATA ACQUISITION FILE	FVJL616	FVJL617	FVJL618
Date	7/9/96	7/9/96	7/9/96
Raw Material	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125
Reactor Path Lenght (inch)	13.75	9.75	9.75
Residence Time (sec)	0.5	0.3	0.3
Temperature (c)	600	600	600
Nitrogen wt.% in Fume :			
1. Fume Filter Before (g)	0.0864	0.0869	0.0861
Fume Filter After (g)	0.0904	0.0912	0.0914
Collected Fume wt. (g)	*0.0040*	*0.0043*	*0.0053*
2. Fume Filter Before (gas outlet) (g)	0.4796	0.4681	0.4697
Fume Filter After (gas outlet) (g)	0.5001	0.4909	0.4958
Fume wt. (gas outlet) (g)	*0.0205*	*0.0228*	*0.0261*
Total Fume wt. in system (g)	***0.0245***	***0.0271***	***0.0314***
Total Paper weight (g)	***0.5660***	***0.5550***	***0.5558***
Percentage of Nitrogen (P+F) (%)	0.005	0.005	0.005
Percentage of Nitrogen in Paper(%)	0.00	0.00	0.00
Nitrogen wt. in Paper+fume (g)	0.0000	0.0000	0.0000
Nitrogen wt. in Paper (g)	0.00000	0.00000	0.00000
Nitrogen wt. in Fume (g)	0.0000	0.0000	0.0000
Nitrogen wt.% in Fume	**0.12**	**0.11**	**0.09**
Nitrogen Balance :			
Input :			
Total Input Black Liquor wt. (g)	5.4212	4.5901	5.5056
Nitrogen wt. % in Black Liquor (%)	0.07	0.07	0.07
Nitrogen wt. in Black Liquor (g)	0.003795	0.003213	0.003854
Output :			
1. Total Fume wt. (g)	0.0245	0.0271	0.0314
Nitrogen wt. % in Fume (%)	0.12	0.11	0.09
Nitrogen wt. in Fume (g)	2.9525E-05	2.9105E-05	0.00002936
2. Char wt. (g)	4.5995	4.2696	5.0851
Nitrogen wt. % in Char (%)	0.065	0.065	0.065
Nitrogen wt. in Char (g)	0.002990	0.002775	0.003305
Nitrogen Yield in Fume (%)	**0.78**	**0.91**	**0.76**
Nitrogen Yield in Char (%)	**78.78**	**86.37**	**85.77**
Estimate Nitrogen Yield in Gas(%)	**20.44**	**12.72**	**13.47**

Nitrogen Yield in Fume, and Char at 500 °C					
DATA ACQUISITION FILE	FVAG601	FVAG602	FVAG603	FVAG604	FVAG605
Date	8/7/96	8/7/96	8/8/96	8/8/96	8/8/96
Raw Material	Valdosta	Valdosta	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125	90-125	90-125
Reactor Path Lenght (inch)	28.75	28.75	28.75	28.75	28.75
Residence Time (sec)	2.0	2.0	1.7	1.7	1.5
Temperature (c)	500	500	500	500	500
Nitrogen wt.% in Fume :					
1. Fume Filter Before (g)	0.0874	0.0881	0.0876	0.0869	0.0878
Fume Filter After (g)	0.1003	0.0996	0.0961	0.0916	0.0926
Collected Fume wt. (g)	*0.0129*	*0.0115*	*0.0085*	*0.0047*	*0.0048*
2. Fume Filter Before (gas outlet) (g)	0.4709	0.4662	0.4685	0.4694	0.4745
Fume Filter After (gas outlet) (g)	0.4981	0.4923	0.4921	0.4856	0.4932
Fume wt. (gas outlet) (g)	*0.0272*	*0.0261*	*0.0236*	*0.0162*	*0.0187*
Total Fume wt. in system (g)	***0.0401***	***0.0376***	***0.0321***	***0.0209***	***0.0235***
Total Paper weight (g)	***0.5583***	***0.5543***	***0.5561***	***0.5563***	***0.5623***
Percentage of Nitrogen (P+F) (%)	0.04	0.04	0.03	0.03	0.01
Percentage of Nitrogen in Paper(%)	0.00	0.00	0.00	0.00	0.00
Nitrogen wt. in Paper+fume (g)	0.0002	0.0002	0.0002	0.0002	0.0001
Nitrogen wt. in Paper (g)	0.00000	0.00000	0.00000	0.00000	0.00000
Nitrogen wt. in Fume (g)	0.0002	0.0002	0.0002	0.0002	0.0001
Nitrogen wt.% in Fume	**0.60**	**0.63**	**0.55**	**0.83**	**0.25**
Nitrogen Balance :					
Input :					
Total Input Black Liquor wt. (g)	5.0837	4.5304	4.2378	3.1126	2.9778
Nitrogen wt. % in Black Liquor (%)	0.07	0.07	0.07	0.07	0.07
Nitrogen wt. in Black Liquor (g)	0.003559	0.003171	0.002966	0.002179	0.002084
Output :					
1. Total Fume wt. (g)	0.0401	0.0376	0.0321	0.0209	0.0235
Nitrogen wt. % in Fume (%)	0.60	0.63	0.55	0.83	0.25
Nitrogen wt. in Fume (g)	0.000239	0.000237	0.000176	0.000173	0.000059
2. Char wt. (g)	3.3487	2.8562	2.7995	1.9759	2.0084
Nitrogen wt. % in Char (%)	0.065	0.065	0.065	0.065	0.065
Nitrogen wt. in Char (g)	0.002177	0.001857	0.001820	0.001284	0.001305
Nitrogen Yield in Fume (%)	**6.73**	**7.47**	**5.95**	**7.95**	**2.81**
Nitrogen Yield in Char (%)	**61.17**	**58.54**	**61.34**	**58.95**	**62.63**
Estimate Nitrogen Yield in Gas(%)	**32.11**	**33.99**	**32.71**	**33.11**	**34.56**

Nitrogen Yield in Fume, and Char at 500 °C					
DATA ACQUISITION FILE	FVAG606	FVAG607	FVAG608	FVAG609	FVAG610
Date	8/8/96	8/8/96	8/8/96	8/13/96	8/13/96
Raw Material	Valdosta	Valdosta	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125	90-125	90-125
Reactor Path Lenght (inch)	28.75	28.75	28.75	28.75	28.75
Residence Time (sec)	1.5	1.3	1.3	1.1	1.1
Temperature (c)	500	500	500	500	500
Nitrogen wt.% in Fume :					
1. Fume Filter Before (g)	0.0883	0.0881	0.0873	0.0857	0.0861
Fume Filter After (g)	0.0928	0.0906	0.0893	0.0882	0.0889
Collected Fume wt. (g)	*0.0045*	*0.0025*	*0.002*	*0.0025*	*0.0028*
2. Fume Filter Before (gas outlet) (g)	0.4687	0.4707	0.4727	0.4722	0.4663
Fume Filter After (gas outlet) (g)	0.4838	0.4816	0.4795	0.4882	0.4839
Fume wt. (gas outlet) (g)	*0.0151*	*0.0109*	*0.0068*	*0.0160*	*0.0176*
Total Fume wt. in system (g)	***0.0196***	***0.0134***	***0.0088***	***0.0185***	***0.0204***
Total Paper weight (g)	***0.5570***	***0.5588***	***0.5600***	***0.5579***	***0.5524***
Percentage of Nitrogen (P+F) (%)	0.01	0.01	0.01	0.01	0.01
Percentage of Nitrogen in Paper(%)	0.00	0.00	0.00	0.00	0.00
Nitrogen wt. in Paper+fume (g)	0.0001	0.0001	0.0001	0.0001	0.0001
Nitrogen wt. in Paper (g)	0.0000	0.00000	0.00000	0.00000	0.00000
Nitrogen wt. in Fume (g)	0.0001	0.0001	0.0001	0.0001	0.0001
Nitrogen wt.% in Fume	**0.29**	**0.43**	**0.65**	**0.31**	**0.28**
Nitrogen Balance :					
Input :					
Total Input Black Liquor wt. (g)	3.5777	2.1751	1.4012	4.2663	4.3929
Nitrogen wt. % in Black Liquor (%)	0.07	0.07	0.07	0.07	0.07
Nitrogen wt. in Black Liquor (g)	0.002504	0.001523	0.000981	0.002986	0.003075
Output :					
1. Total Fume wt. (g)	0.0196	0.0134	0.0088	0.0185	0.0204
Nitrogen wt. % in Fume (%)	0.29	0.43	0.65	0.31	0.28
Nitrogen wt. in Fume (g)	0.000058	0.000057	0.000057	0.000058	0.000057
2. Char wt. (g)	2.4421	1.5456	1.0306	3.3014	3.5031
Nitrogen wt. % in Char (%)	0.065	0.065	0.065	0.065	0.06
Nitrogen wt. in Char (g)	0.001587	0.001005	0.000670	0.002146	0.002102
Nitrogen Yield in Fume (%)	**2.30**	**3.76**	**5.80**	**1.93**	**1.86**
Nitrogen Yield in Char (%)	**63.38**	**65.98**	**68.30**	**71.86**	**68.35**
Estimate Nitrogen Yield in Gas(%)	**34.31**	**30.26**	**25.90**	**26.21**	**29.78**

Nitrogen Yield in Fume, and Char at 500 °C					
DATA ACQUISITION FILE	FVAG611	FVAG612	FVAG613	FVAG614	FVAG615
Date	8/13/96	8/13/96	8/14/96	8/14/96	8/14/96
Raw Material	Valdosta	Valdosta	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125	90-125	90-125
Reactor Path Lenght (inch)	23.75	23.75	17.75	17.75	12.75
Residence Time (sec)	0.9	0.9	0.7	0.7	0.5
Temperature (c)	500	500	500	500	500
Nitrogen wt.% in Fume :					
1. Fume Filter Before (g)	0.0865	0.0872	0.0871	0.0867	0.0858
Fume Filter After (g)	0.0906	0.0901	0.0892	0.0904	0.0888
Collected Fume wt. (g)	*0.0041*	*0.0029*	*0.0021*	*0.0037*	*0.003*
2. Fume Filter Before (gas outlet) (g)	0.4702	0.4706	0.4693	0.4701	0.4711
Fume Filter After (gas outlet) (g)	0.4902	0.4909	0.4861	0.4909	0.4901
Fume wt. (gas outlet) (g)	*0.0200*	*0.0203*	*0.0168*	*0.0208*	*0.0190*
Total Fume wt. in system (g)	***0.0241***	***0.0232***	***0.0189***	***0.0245***	***0.0220***
Total Paper weight (g)	***0.5567***	***0.5578***	***0.5564***	***0.5568***	***0.5569***
Percentage of Nitrogen (P+F) (%)	0.01	0.01	0.01	0.01	0.005
Percentage of Nitrogen in Paper(%)	0.00	0.00	0.00	0.00	0.00
Nitrogen wt. in Paper+fume (g)	0.0001	0.0001	0.0001	0.0001	0.0000
Nitrogen wt. in Paper (g)	0.0000	0.00000	0.00000	0.00000	0.00000
Nitrogen wt. in Fume (g)	0.0001	0.0001	0.0001	0.0001	0.0000
Nitrogen wt.% in Fume	**0.24**	**0.25**	**0.30**	**0.24**	**0.13**
Nitrogen Balance :					
Input :					
Total Input Black Liquor wt. (g)	5.415	4.938	3.7626	5.4731	4.321
Nitrogen wt. % in Black Liquor (%)	0.07	0.07	0.07	0.07	0.07
Nitrogen wt. in Black Liquor (g)	0.003791	0.003457	0.002634	0.003831	0.003025
Output :					
1. Total Fume wt. (g)	0.0241	0.0232	0.0189	0.0245	0.0220
Nitrogen wt. % in Fume (%)	0.24	0.25	0.30	0.24	0.13
Nitrogen wt. in Fume (g)	0.000058	0.000058	0.000058	0.000058	0.000029
2. Char wt. (g)	4.3718	3.9025	3.0763	4.5202	3.6438
Nitrogen wt. % in Char (%)	0.065	0.065	0.065	0.065	0.065
Nitrogen wt. in Char (g)	0.002842	0.002537	0.002000	0.002938	0.002368
Nitrogen Yield in Fume (%)	**1.53**	**1.68**	**2.18**	**1.52**	**0.96**
Nitrogen Yield in Char (%)	**74.97**	**73.38**	**75.92**	**76.69**	**78.30**
Estimate Nitrogen Yield in Gas(%)	**23.50**	**24.93**	**21.90**	**21.79**	**20.74**

Nitrogen Yield in Fume, and Char at 500 °C			
DATA ACQUISITION FILE	FVAG616	FVAG617	FVAG618
Date	8/14/96	8/14/96	8/14/96
Raw Material	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125
Reactor Path Lenght (inch)	12.75	9.75	9.75
Residence Time (sec)	0.5	0.3	0.3
Temperature (c)	500	500	500
Nitrogen wt.% in Fume :			
1. Fume Filter Before (g)	0.0869	0.0867	0.0864
Fume Filter After (g)	0.0898	0.0884	0.0881
Collected Fume wt. (g)	*0.0029*	*0.0017*	*0.0017*
2. Fume Filter Before (gas outlet) (g)	0.4716	0.4663	0.4733
Fume Filter After (gas outlet) (g)	0.4911	0.4811	0.4841
Fume wt. (gas outlet) (g)	*0.0195*	*0.0148*	*0.0108*
Total Fume wt. in system (g)	***0.0224***	***0.0165***	***0.0125***
Total Paper weight (g)	***0.5585***	***0.5530***	***0.5597***
Percentage of Nitrogen (P+F) (%)	0.005	0.005	0.005
Percentage of Nitrogen in Paper(%)	0.00	0.00	0.00
Nitrogen wt. in Paper+fume (g)	0.0000	0.0000	0.0000
Nitrogen wt. in Paper (g)	0.0000	0.00000	0.00000
Nitrogen wt. in Fume (g)	0.0000	0.0000	0.0000
Nitrogen wt.% in Fume	**0.13**	**0.17**	**0.23**
Nitrogen Balance :			
Input :			
Total Input Black Liquor wt. (g)	5.5464	5.4361	4.4073
Nitrogen wt. % in Black Liquor (%)	0.07	0.07	0.07
Nitrogen wt. in Black Liquor (g)	0.003882	0.003805	0.003085
Output :			
1. Total Fume wt. (g)	0.0224	0.0165	0.0125
Nitrogen wt. % in Fume (%)	0.13	0.17	0.23
Nitrogen wt. in Fume (g)	0.000029	0.000028	0.000029
2. Char wt. (g)	4.7505	4.8722	4.0662
Nitrogen wt. % in Char (%)	0.065	0.07	0.07
Nitrogen wt. in Char (g)	0.003088	0.003411	0.002846
Nitrogen Yield in Fume (%)	**0.75**	**0.75**	**0.93**
Nitrogen Yield in Char (%)	**79.53**	**89.63**	**92.26**
Estimate Nitrogen Yield in Gas(%)	**19.72**	**9.62**	**6.81**

Nitrogen Yield in Fume, and Char at 400 °C					
DATA ACQUISITION FILE	FVAG619	FVAG620	FVAG621	FVAG622	FVAG623
Date	8/15/96	8/15/96	8/15/96	8/15/96	8/15/96
Raw Material	Valdosta	Valdosta	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125	90-125	90-125
Reactor Path Lenght (inch)	28.75	28.75	28.75	28.75	28.75
Residence Time (sec)	2.0	2.0	1.7	1.7	1.5
Temperature (c)	400	400	400	400	400
Nitrogen wt.% in Fume :					
1. Fume Filter Before (g)	0.0866	0.0872	0.0854	0.0854	0.0864
Fume Filter After (g)	0.0883	0.0902	0.0874	0.0876	0.0878
Collected Fume wt. (g)	*0.0017*	*0.0030*	*0.0020*	*0.0022*	*0.0014*
2. Fume Filter Before (gas outlet) (g)	0.4703	0.4713	0.4702	0.4656	0.4732
Fume Filter After (gas outlet) (g)	0.4765	0.4808	0.4798	0.4761	0.4821
Fume wt. (gas outlet) (g)	*0.0062*	*0.0095*	*0.0096*	*0.0105*	*0.0089*
Total Fume wt. in system (g)	***0.0079***	***0.0125***	***0.0116***	***0.0127***	***0.0103***
Total Paper weight (g)	***0.5569***	***0.5585***	***0.5556***	***0.5510***	***0.5596***
Percentage of Nitrogen (P+F) (%)	0.04	0.04	0.03	0.03	0.01
Percentage of Nitrogen in Paper(%)	0.00	0.00	0.00	0.00	0.00
Nitrogen wt. in Paper+fume (g)	0.0002	0.0002	0.0002	0.0002	0.0001
Nitrogen wt. in Paper (g)	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen wt. in Fume (g)	0.0002	0.0002	0.0002	0.0002	0.0001
Nitrogen wt.% in Fume	**2.86**	**1.83**	**1.47**	**1.33**	**0.55**
Nitrogen Balance :					
Input :					
Total Input Black Liquor wt. (g)	1.9351	2.8298	4.1128	4.0197	4.6955
Nitrogen wt. % in Black Liquor (%)	0.07	0.07	0.07	0.07	0.07
Nitrogen wt. in Black Liquor (g)	0.001355	0.001981	0.002879	0.002814	0.003287
Output :					
1. Total Fume wt. (g)	0.0079	0.0125	0.0116	0.0127	0.0103
Nitrogen wt. % in Fume (%)	2.86	1.83	1.47	1.33	0.55
Nitrogen wt. in Fume (g)	0.000226	0.000228	0.000170	0.000169	0.000057
2. Char wt. (g)	1.5201	2.1397	3.1248	3.2285	3.7358
Nitrogen wt. % in Char (%)	0.06	0.06	0.06	0.06	0.06
Nitrogen wt. in Char (g)	0.000912	0.001284	0.001875	0.001937	0.002241
Nitrogen Yield in Fume (%)	**16.68**	**11.53**	**5.91**	**6.01**	**1.73**
Nitrogen Yield in Char (%)	**67.33**	**64.81**	**65.12**	**68.84**	**68.20**
Estimate Nitrogen Yield in Gas(%)	**15.99**	**23.66**	**28.97**	**25.15**	**30.07**

Nitrogen Yield in Fume, and Char at 400 °C					
DATA ACQUISITION FILE	FVAG624	FVAG625	FVAG626	FVAG627	FVAG628
Date	8/15/96	8/16/96	8/16/96	8/16/96	8/16/96
Raw Material	Valdosta	Valdosta	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125	90-125	90-125
Reactor Path Lenght (inch)	28.75	28.75	28.75	28.75	28.75
Residence Time (sec)	1.5	1.3	1.3	1.1	1.1
Temperature (c)	400	400	400	400	400
Nitrogen wt.% in Fume :					
1. Fume Filter Before (g)	0.0878	0.0861	0.0861	0.0862	0.0867
Fume Filter After (g)	0.0891	0.0871	0.0877	0.0885	0.0884
Collected Fume wt. (g)	*0.0013*	*0.0010*	*0.0016*	*0.0023*	*0.0017*
2. Fume Filter Before (gas outlet) (g)	0.4709	0.4692	0.4711	0.4706	0.4741
Fume Filter After (gas outlet) (g)	0.4784	0.4751	0.4813	0.4834	0.4841
Fume wt. (gas outlet) (g)	*0.0075*	*0.0059*	*0.0102*	*0.0128*	*0.0100*
Total Fume wt. in system (g)	***0.0088***	***0.0069***	***0.0118***	***0.0151***	***0.0117***
Total Paper weight (g)	***0.5587***	***0.5553***	***0.5572***	***0.5568***	***0.5608***
Percentage of Nitrogen (P+F) (%)	0.01	0.01	0.01	0.01	0.01
Percentage of Nitrogen in Paper(%)	0.00	0.00	0.00	0.00	0.00
Nitrogen wt. in Paper+fume (g)	0.0001	0.0001	0.0001	0.0001	0.0001
Nitrogen wt. in Paper (g)	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen wt. in Fume (g)	0.0001	0.0001	0.0001	0.0001	0.0001
Nitrogen wt.% in Fume	**0.64**	**0.81**	**0.48**	**0.38**	**0.49**
Nitrogen Balance :					
Input :					
Total Input Black Liquor wt. (g)	3.771	2.3171	4.5125	4.9372	4.1369
Nitrogen wt. % in Black Liquor (%)	0.07	0.07	0.07	0.07	0.07
Nitrogen wt. in Black Liquor (g)	0.002640	0.001622	0.003159	0.003456	0.002896
Output :					
1. Total Fume wt. (g)	0.0088	0.0069	0.0118	0.0151	0.0117
Nitrogen wt. % in Fume (%)	0.64	0.81	0.48	0.38	0.49
Nitrogen wt. in Fume (g)	0.000057	0.000056	0.000057	0.000057	0.000057
2. Char wt. (g)	3.1228	1.9236	3.8421	4.2969	3.6589
Nitrogen wt. % in Char (%)	0.06	0.06	0.06	0.06	0.06
Nitrogen wt. in Char (g)	0.001874	0.001154	0.002305	0.002578	0.002195
Nitrogen Yield in Fume (%)	**2.15**	**3.47**	**1.80**	**1.65**	**1.98**
Nitrogen Yield in Char (%)	**70.98**	**71.16**	**72.98**	**74.60**	**75.81**
Estimate Nitrogen Yield in Gas(%)	**26.87**	**25.38**	**25.22**	**23.75**	**22.21**

Nitrogen Yield in Fume, and Char at 400 °C					
DATA ACQUISITION FILE	FVAG629	FVAG630	FVAG631	FVAG632	FVAG633
Date	8/16/96	8/16/96	8/18/96	8/18/96	8/18/96
Raw Material	Valdosta	Valdosta	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125	90-125	90-125
Reactor Path Lenght (inch)	23.75	23.75	17.75	17.75	12.75
Residence Time (sec)	0.9	0.9	0.7	0.7	0.5
Temperature (c)	400	400	400	400	400
Nitrogen wt.% in Fume :					
1. Fume Filter Before (g)	0.0859	0.0862	0.0879	0.0852	0.0867
Fume Filter After (g)	0.0874	0.0872	0.0881	0.0871	0.0889
Collected Fume wt. (g)	*0.0015*	*0.0010*	*0.0002*	*0.0019*	*0.0022*
2. Fume Filter Before (gas outlet) (g)	0.4751	0.4721	0.4709	0.4724	0.4731
Fume Filter After (gas outlet) (g)	0.4864	0.4789	0.4733	0.4789	0.4858
Fume wt. (gas outlet) (g)	*0.0113*	*0.0068*	*0.0024*	*0.0065*	*0.0127*
Total Fume wt. in system (g)	***0.0128***	***0.0078***	***0.0026***	***0.0084***	***0.0149***
Total Paper weight (g)	***0.5610***	***0.5583***	***0.5588***	***0.5576***	***0.5598***
Percentage of Nitrogen (P+F) (%)	0.01	0.01	0.01	0.01	0.005
Percentage of Nitrogen in Paper(%)	0.00	0.00	0.00	0.00	0.00
Nitrogen wt. in Paper+fume (g)	0.0001	0.0001	0.0001	0.0001	0.0000
Nitrogen wt. in Paper (g)	0.0000	0.00000	0.00000	0.00000	0.00000
Nitrogen wt. in Fume (g)	0.0001	0.0001	0.0001	0.0001	0.0000
Nitrogen wt.% in Fume	**0.45**	**0.73**	**2.16**	**0.67**	**0.19**
Nitrogen Balance :					
Input :					
Total Input Black Liquor wt. (g)	3.9668	3.0851	3.5493	4.3890	4.6073
Nitrogen wt. % in Black Liquor (%)	0.07	0.07	0.07	0.07	0.07
Nitrogen wt. in Black Liquor (g)	0.002777	0.002160	0.002485	0.003072	0.003225
Output :					
1. Total Fume wt. (g)	0.0128	0.0078	0.0026	0.0084	0.0149
Nitrogen wt. % in Fume (%)	0.45	0.73	2.16	0.67	0.19
Nitrogen wt. in Fume (g)	0.000057	0.000057	0.000056	0.000057	0.000029
2. Char wt. (g)	3.6146	2.8285	3.4712	4.1884	4.5907
Nitrogen wt. % in Char (%)	0.06	0.06	0.06	0.06	0.06
Nitrogen wt. in Char (g)	0.002169	0.001697	0.002083	0.002513	0.002754
Nitrogen Yield in Fume (%)	**2.07**	**2.62**	**2.26**	**1.84**	**0.89**
Nitrogen Yield in Char (%)	**78.10**	**78.59**	**83.83**	**81.80**	**85.41**
Estimate Nitrogen Yield in Gas(%)	**19.83**	**18.79**	**13.91**	**16.36**	**13.70**

Nitrogen Yield in Fume, and Char at 400 °C		
DATA ACQUISITION FILE	FVAG634	FVAG635
Date	8/18/96	8/18/96
Raw Material	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125
Reactor Path Lenght (inch)	12.75	9.75
Residence Time (sec)	0.5	0.3
Temperature (c)	400	400
Nitrogen wt.% in Fume :		
1. Fume Filter Before (g)	0.0852	0.0865
Fume Filter After (g)	0.0872	0.0889
Collected Fume wt. (g)	*0.002*	*0.0024*
2. Fume Filter Before (gas outlet) (g)	0.4766	0.4762
Fume Filter After (gas outlet) (g)	0.4889	0.4908
Fume wt. (gas outlet) (g)	*0.0123*	*0.0146*
Total Fume wt. in system (g)	***0.0143***	***0.0170***
Total Paper weight (g)	***0.5618***	***0.5627***
Percentage of Nitrogen (P+F) (%)	0.005	0.005
Percentage of Nitrogen in Paper(%)	0.00	0.00
Nitrogen wt. in Paper+fume (g)	0.000029	0.000029
Nitrogen wt. in Paper (g)	0.0000	0.0000
Nitrogen wt. in Fume (g)	0.000029	0.000029
Nitrogen wt.% in Fume	**0.20**	**0.17**
Nitrogen Balance :		
Input :		
Total Input Black Liquor wt. (g)	4.0943	4.938
Nitrogen wt. % in Black Liquor (%)	0.07	0.07
Nitrogen wt. in Black Liquor (g)	0.002866	0.003457
Output :		
1. Total Fume wt. (g)	0.0143	0.0170
Nitrogen wt. % in Fume (%)	0.20	0.17
Nitrogen wt. in Fume (g)	0.000029	0.000029
2. Char wt. (g)	4.0140	4.9162
Nitrogen wt. % in Char (%)	0.06	0.069
Nitrogen wt. in Char (g)	0.002408	0.003392
Nitrogen Yield in Fume (%)	**1.01**	**0.84**
Nitrogen Yield in Char (%)	**84.03**	**98.14**
Estimate Nitrogen Yield in Gas(%)	**14.96**	**1.03**

Sulfur Yield in Fume, and Char at 600 °C					
DATA ACQUISITION FILE	FVJL601	FVJL602	FVJL603	FVJL604	FVJL605
Date	7/6/96	7/6/96	7/7/96	7/7/96	7/7/96
Raw Material	Valdosta	Valdosta	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125	90-125	90-125
Reactor Path Lenght (inch)	28.75	28.75	28.75	28.75	28.75
Residence Time (sec)	2.0	2.0	1.7	1.7	1.5
Temperature (c)	600	600	600	600	600
Sulfur wt.% in Fume					
1. Fume Filter Before (g)	0.0874	0.0869	0.0868	0.0861	0.0865
Fume Filter After (g)	0.1023	0.0996	0.0954	0.0952	0.0925
Collected Fume wt. (g)	*0.0149*	*0.0127*	*0.0086*	*0.0091*	*0.006*
2. Fume Filter Before (gas outlet) (g)	0.4661	0.4666	0.4685	0.4687	0.4672
Fume Filter After (gas outlet) (g)	0.5053	0.4985	0.4931	0.5028	0.4928
Fume wt. (gas outlet) (g)	*0.0392*	*0.0319*	*0.0246*	*0.0341*	*0.0256*
Total Fume wt. in system (g)	***0.0541***	***0.0446***	***0.0332***	***0.0432***	***0.0316***
Total Paper weight (g)	***0.5535***	***0.5535***	***0.5553***	***0.5548***	***0.5537***
Percentage of Sulfur (P+F) (%)	0.24	0.24	0.16	0.16	0.06
Percentage of Sulfur in Paper (%)	0.00	0.00	0.00	0.00	0.00
Sulfur wt. in Paper+fume (g)	0.0015	0.0014	0.0009	0.0010	0.0004
Sulfur wt. in Paper (g)	0.00000	0.00000	0.00000	0.00000	0.00000
Sulfur wt. in Fume (g)	0.0015	0.0014	0.0009	0.0010	0.0004
Sulfur **wt.% in Fume**	**2.70**	**3.22**	**2.84**	**2.21**	**1.11**
Sulfur Balance :					
Input :					
Total Input Black Liquor wt. (g)	5.3845	4.4088	4.5022	5.6822	5.5174
Sulfur wt. % in Black Liquor (%)	2.44	2.44	2.44	2.44	2.44
Sulfur wt. in Black Liquor (g)	0.1314	0.1076	0.1099	0.1386	0.1346
Output :					
1. Total Fume wt. (g)	0.0541	0.0446	0.0332	0.0432	0.0316
Sulfur wt. % in Fume (%)	2.70	3.22	2.84	2.21	1.11
Sulfur wt. in Fume (g)	0.001458	0.001435	0.000942	0.000957	0.000351
2. Char wt. (g)	4.0334	3.3161	3.5597	4.3071	4.2375
Sulfur wt. % in Char (%)	1.28	1.20	1.32	1.22	1.28
Sulfur wt. in Char (g)	0.0516	0.0398	0.0470	0.0525	0.0542
Sulfur Yield in Fume (%)	**1.11**	**1.33**	**0.86**	**0.69**	**0.26**
Sulfur Yield in Char (%)	**39.30**	**36.99**	**42.77**	**37.90**	**40.29**
Estimate Sulfur Yield in Gas (%)	**59.59**	**61.67**	**56.37**	**61.41**	**59.45**

Sulfur Yield in Fume, and Char at 600 °C					
DATA ACQUISITION FILE	FVJL606	FVJL607	FVJL608	FVJL609	FVJL610
Date	7/7/96	7/8/96	7/8/96	7/8/96	7/8/96
Raw Material	Valdosta	Valdosta	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125	90-125	90-125
Reactor Path Lenght (inch)	28.75	28.75	28.75	28.75	28.75
Residence Time (sec)	1.5	1.3	1.3	1.1	1.1
Temperature (c)	600	600	600	600	600
Sulfur wt.% in Fume :					
1. Fume Filter Before (g)	0.0861	0.0869	0.0871	0.0868	0.0879
Fume Filter After (g)	0.0918	0.0907	0.0921	0.0899	0.0908
Collected Fume wt. (g)	*0.0057*	*0.0038*	*0.0050*	*0.0031*	*0.0029*
2. Fume Filter Before (gas outlet) (g)	0.4637	0.4696	0.4677	0.4705	0.4658
Fume Filter After (gas outlet) (g)	0.4906	0.4882	0.4835	0.4874	0.4818
Fume wt. (gas outlet) (g)	*0.0269*	*0.0186*	*0.0158*	*0.0169*	*0.0160*
Total Fume wt. in system (g)	***0.0326***	***0.0224***	***0.0208***	***0.0200***	***0.0189***
Total Paper weight (g)	***0.5498***	***0.5565***	***0.5548***	***0.5573***	***0.5537***
Percentage of Sulfur (P+F) (%)	0.06	0.04	0.04	0.02	0.02
Percentage of Sulfur in Paper (%)	0.00	0.00	0.00	0.00	0.00
Sulfur wt. in Paper+fume (g)	0.0003	0.0002	0.0002	0.0001	0.0001
Sulfur wt. in Paper (g)	0.00000	0.00000	0.00000	0.00000	0.00000
Sulfur wt. in Fume (g)	0.0003	0.0002	0.0002	0.0001	0.0001
Sulfur wt.% in Fume	**1.07**	**1.03**	**1.11**	**0.58**	**0.61**
Sulfur Balance :					
Input :					
Total Input Black Liquor wt. (g)	5.8924	4.8849	4.5211	4.9114	4.7345
Sulfur wt. % in Black Liquor (%)	2.44	2.44	2.44	2.44	2.44
Sulfur wt. in Black Liquor (g)	0.1438	0.1192	0.1103	0.1198	0.1155
Output :					
1. Total Fume wt. (g)	0.0326	0.0224	0.0208	0.0200	0.0189
Sulfur wt. % in Fume (%)	1.07	1.03	1.11	0.58	0.61
Sulfur wt. in Fume (g)	0.000349	0.000232	0.000230	0.000115	0.000115
2. Char wt. (g)	4.5689	3.8534	3.5371	3.9616	3.8025
Sulfur wt. % in Char (%)	1.27	1.38	1.45	1.55	1.44
Sulfur wt. in Char (g)	0.0580	0.0532	0.0513	0.0614	0.0548
Sulfur Yield in Fume (%)	**0.24**	**0.19**	**0.21**	**0.10**	**0.10**
Sulfur Yield in Char (%)	**40.36**	**44.61**	**46.49**	**51.24**	**47.40**
Estimate Sulfur Yield in Gas (%)	**59.40**	**55.19**	**53.30**	**48.66**	**52.50**

Sulfur Yield in Fume, and Char at 600 °C					
DATA ACQUISITION FILE	FVJL611	FVJL612	FVJL613	FVJL614	FVJL615
Date	7/8/96	7/8/96	7/9/96	7/9/96	7/9/96
Raw Material	Valdosta	Valdosta	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125	90-125	90-125
Reactor Path Lenght (inch)	25.75	25.75	19.75	19.75	13.75
Residence Time (sec)	0.9	0.9	0.7	0.7	0.5
Temperature (c)	600	600	600	600	600
Sulfur wt.% in Fume :					
1. Fume Filter Before (g)	0.0861	0.0876	0.0876	0.0866	0.0868
Fume Filter After (g)	0.0901	0.0907	0.0913	0.0908	0.0905
Collected Fume wt. (g)	*0.0040*	*0.0031*	*0.0037*	*0.0042*	*0.0037*
2. Fume Filter Before (gas outlet) (g)	0.4656	0.4672	0.4791	0.4739	0.4731
Fume Filter After (gas outlet) (g)	0.4852	0.4851	0.4943	0.4906	0.4885
Fume wt. (gas outlet) (g)	*0.0196*	*0.0179*	*0.0152*	*0.0167*	*0.0154*
Total Fume wt. in system (g)	***0.0236***	***0.0210***	***0.0189***	***0.0209***	***0.0191***
Total Paper weight (g)	***0.5517***	***0.5548***	***0.5667***	***0.5605***	***0.5599***
Percentage of Sulfur (P+F) (%)	0.02	0.02	0.03	0.03	0.02
Percentage of Sulfur in Paper (%)	0.00	0.00	0.00	0.00	0.00
Sulfur wt. in Paper+fume (g)	0.0001	0.0001	0.0002	0.0002	0.0001
Sulfur wt. in Paper (g)	0.00000	0.00000	0.00000	0.00000	0.00000
Sulfur wt. in Fume (g)	0.0001	0.0001	0.0002	0.0002	0.0001
Sulfur wt.% in Fume	**0.49**	**0.55**	**0.93**	**0.83**	**0.61**
Sulfur Balance :					
Input :					
Total Input Black Liquor wt. (g)	5.4536	4.5087	4.494	4.7983	4.4244
Sulfur wt. % in Black Liquor (%)	2.44	2.44	2.44	2.44	2.44
Sulfur wt. in Black Liquor (g)	0.1331	0.1100	0.1097	0.1171	0.1080
Output :					
1. Total Fume wt. (g)	0.0236	0.0210	0.0189	0.0209	0.0191
Sulfur wt. % in Fume (%)	0.49	0.55	0.93	0.83	0.61
Sulfur wt. in Fume (g)	0.000115	0.000115	0.000176	0.000174	0.000116
2. Char wt. (g)	4.2010	3.6627	3.6304	3.5083	3.7689
Sulfur wt. % in Char (%)	1.75	1.76	1.92	1.97	1.97
Sulfur wt. in Char (g)	0.0735	0.0645	0.0697	0.0691	0.0742
Sulfur Yield in Fume (%)	**0.09**	**0.10**	**0.16**	**0.15**	**0.11**
Sulfur Yield in Char (%)	**55.25**	**58.60**	**63.57**	**59.03**	**68.78**
Estimate Sulfur Yield in Gas (%)	**44.67**	**41.30**	**36.27**	**40.82**	**31.12**

Sulfur Yield in Fume, and Char at 600 °C			
DATA ACQUISITION FILE	FVJL616	FVJL617	FVJL618
Date	7/9/96	7/9/96	7/9/96
Raw Material	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125
Reactor Path Lenght (inch)	13.75	9.75	9.75
Residence Time (sec)	0.5	0.3	0.3
Temperature (c)	600	600	600
Sulfur wt.% in Fume :			
1. Fume Filter Before (g)	0.0864	0.0869	0.0861
Fume Filter After (g)	0.0904	0.0912	0.0914
Collected Fume wt. (g)	*0.0040*	*0.0043*	*0.0053*
2. Fume Filter Before (gas outlet) (g)	0.4796	0.4681	0.4697
Fume Filter After (gas outlet) (g)	0.5001	0.4909	0.4958
Fume wt. (gas outlet) (g)	*0.0205*	*0.0228*	*0.0261*
Total Fume wt. in system (g)	***0.0245***	***0.0271***	***0.0314***
Total Paper weight (g)	***0.5660***	***0.5550***	***0.5558***
Percentage of Sulfur (P+F) (%)	0.02	0.03	0.03
Percentage of Sulfur in Paper(%)	0.00	0.00	0.00
Sulfur wt. in Paper+fume (g)	0.0001	0.0002	0.0002
Sulfur wt. in Paper (g)	0.00000	0.00000	0.00000
Sulfur wt. in Fume (g)	0.0001	0.0002	0.0002
Sulfur wt.% in Fume	**0.48**	**0.64**	**0.56**
Sulfur Balance :			
Input :			
Total Input Black Liquor wt. (g)	5.4212	4.5901	5.5056
Sulfur wt. % in Black Liquor (%)	2.44	2.44	2.44
Sulfur wt. in Black Liquor (g)	0.1323	0.1120	0.1343
Output :			
1. Total Fume wt. (g)	0.0245	0.0271	0.0314
Sulfur wt. % in Fume (%)	0.48	0.64	0.56
Sulfur wt. in Fume (g)	0.000118	0.000175	0.000176
2. Char wt. (g)	4.5995	4.2696	5.0851
Sulfur wt. % in Char (%)	2.00	2.26	2.37
Sulfur wt. in Char (g)	0.0920	0.0965	0.1205
Sulfur Yield in Fume (%)	**0.09**	**0.16**	**0.13**
Sulfur Yield in Char (%)	**69.54**	**86.16**	**89.71**
Estimate Sulfur Yield in Gas (%)	**30.37**	**13.69**	**10.16**

Sulfur Yield in Fume, and Char at 500 °C					
DATA ACQUISITION FILE	FVAG601	FVAG602	FVAG603	FVAG604	FVAG605
Date	8/7/96	8/7/96	8/8/96	8/8/96	8/8/96
Raw Material	Valdosta	Valdosta	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125	90-125	90-125
Reactor Path Lenght (inch)	28.75	28.75	28.75	28.75	28.75
Residence Time (sec)	2.0	2.0	1.7	1.7	1.5
Temperature (c)	500	500	500	500	500
Sulfur wt.% in Fume :					
1. Fume Filter Before (g)	0.0874	0.0881	0.0876	0.0869	0.0878
Fume Filter After (g)	0.1003	0.0996	0.0961	0.0916	0.0926
Collected Fume wt. (g)	*0.0129*	*0.0115*	*0.0085*	*0.0047*	*0.0048*
2. Fume Filter Before (gas outlet) (g)	0.4709	0.4662	0.4685	0.4694	0.4745
Fume Filter After (gas outlet) (g)	0.4981	0.4923	0.4921	0.4856	0.4932
Fume wt. (gas outlet) (g)	*0.0272*	*0.0261*	*0.0236*	*0.0162*	*0.0187*
Total Fume wt. in system (g)	***0.0401***	***0.0376***	***0.0321***	***0.0209***	***0.0235***
Total Paper weight (g)	***0.5583***	***0.5543***	***0.5561***	***0.5563***	***0.5623***
Percentage of Sulfur (P+F) (%)	0.24	0.24	0.16	0.16	0.06
Percentage of Sulfur in Paper (%)	0.00	0.00	0.00	0.00	0.00
Sulfur wt. in Paper+fume (g)	0.0014	0.0014	0.0009	0.0009	0.0004
Sulfur wt. in Paper (g)	0.0000	0.00000	0.00000	0.00000	0.00000
Sulfur wt. in Fume (g)	0.0014	0.0014	0.0009	0.0009	0.0004
Sulfur wt.% in Fume	**3.58**	**3.78**	**2.93**	**4.42**	**1.50**
Sulfur Balance :					
Input :					
Total Input Black Liquor wt. (g)	5.0837	4.5304	4.2378	3.1126	2.9778
Sulfur wt. % in Black Liquor (%)	2.44	2.44	2.44	2.44	2.44
Sulfur wt. in Black Liquor (g)	0.1240	0.1105	0.1034	0.0759	0.0727
Output :					
1. Total Fume wt. (g)	0.0401	0.0376	0.0321	0.0209	0.0235
Sulfur wt. % in Fume (%)	3.58	3.78	2.93	4.42	1.50
Sulfur wt. in Fume (g)	0.001436	0.001421	0.000941	0.000924	0.000351
2. Char wt. (g)	3.3487	2.8562	2.7995	1.9759	2.0084
Sulfur wt. % in Char (%)	1.55	1.55	1.6	1.6	1.65
Sulfur wt. in Char (g)	0.0519	0.0443	0.0448	0.0316	0.0331
Sulfur Yield in Fume (%)	**1.16**	**1.29**	**0.91**	**1.22**	**0.48**
Sulfur Yield in Char (%)	**41.84**	**40.05**	**43.32**	**41.63**	**45.61**
Estimate Sulfur Yield in Gas (%)	**57.00**	**58.67**	**55.77**	**57.16**	**53.91**

Sulfur Yield in Fume, and Char at 500 °C					
DATA ACQUISITION FILE	FVAG606	FVAG607	FVAG608	FVAG609	FVAG610
Date	8/8/96	8/8/96	8/8/96	8/13/96	8/13/96
Raw Material	Valdosta	Valdosta	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125	90-125	90-125
Reactor Path Lenght (inch)	28.75	28.75	28.75	28.75	28.75
Residence Time (sec)	1.5	1.3	1.3	1.1	1.1
Temperature (c)	500	500	500	500	500
Sulfur wt.% in Fume :					
1. Fume Filter Before (g)	0.0883	0.0881	0.0873	0.0857	0.0861
Fume Filter After (g)	0.0928	0.0906	0.0893	0.0882	0.0889
Collected Fume wt. (g)	*0.0045*	*0.0025*	*0.002*	*0.0025*	*0.0028*
2. Fume Filter Before (gas outlet) (g)	0.4687	0.4707	0.4727	0.4722	0.4663
Fume Filter After (gas outlet) (g)	0.4838	0.4816	0.4795	0.4882	0.4839
Fume wt. (gas outlet) (g)	*0.0151*	*0.0109*	*0.0068*	*0.0160*	*0.0176*
Total Fume wt. in system (g)	***0.0196***	***0.0134***	***0.0088***	***0.0185***	***0.0204***
Total Paper weight (g)	***0.5570***	***0.5588***	***0.5600***	***0.5579***	***0.5524***
Percentage of Sulfur (P+F) (%)	0.06	0.04	0.04	0.02	0.02
Percentage of Sulfur in Paper (%)	0.00	0.00	0.00	0.00	0.00
Sulfur wt. in Paper+fume (g)	0.0003	0.0002	0.0002	0.0001	0.0001
Sulfur wt. in Paper (g)	0.0000	0.00000	0.00000	0.00000	0.00000
Sulfur wt. in Fume (g)	0.0003	0.0002	0.0002	0.0001	0.0001
Sulfur wt.% in Fume	**1.77**	**1.71**	**2.59**	**0.62**	**0.56**
Sulfur Balance :					
Input :					
Total Input Black Liquor wt. (g)	3.5777	2.1751	1.4012	4.2663	4.3929
Sulfur wt. % in Black Liquor (%)	2.44	2.44	2.44	2.44	2.44
Sulfur wt. in Black Liquor (g)	0.0873	0.0531	0.0342	0.1041	0.1072
Output :					
1. Total Fume wt. (g)	0.0196	0.0134	0.0088	0.0185	0.0204
Sulfur wt. % in Fume (%)	1.77	1.71	2.59	0.62	0.56
Sulfur wt. in Fume (g)	0.0003	0.0002	0.0002	0.0001	0.0001
2. Char wt. (g)	2.4421	1.5456	1.0306	3.3014	3.5031
Sulfur wt. % in Char (%)	1.65	1.71	1.71	1.75	1.75
Sulfur wt. in Char (g)	0.0403	0.0264	0.0176	0.0578	0.0613
Sulfur Yield in Fume (%)	**0.40**	**0.43**	**0.67**	**0.11**	**0.11**
Sulfur Yield in Char (%)	**46.16**	**49.80**	**51.55**	**55.50**	**57.19**
Estimate Sulfur Yield in Gas (%)	**53.44**	**49.77**	**47.79**	**44.39**	**42.70**

Sulfur Yield in Fume, and Char at 500 °C					
DATA ACQUISITION FILE	FVAG611	FVAG612	FVAG613	FVAG614	FVAG615
Date	8/13/96	8/13/96	8/14/96	8/14/96	8/14/96
Raw Material	Valdosta	Valdosta	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125	90-125	90-125
Reactor Path Lenght (inch)	23.75	23.75	17.75	17.75	12.75
Residence Time (sec)	0.9	0.9	0.7	0.7	0.5
Temperature (c)	500	500	500	500	500
Sulfur wt.% in Fume :					
1. Fume Filter Before (g)	0.0865	0.0872	0.0871	0.0867	0.0858
Fume Filter After (g)	0.0906	0.0901	0.0892	0.0904	0.0888
Collected Fume wt. (g)	*0.0041*	*0.0029*	*0.0021*	*0.0037*	*0.003*
2. Fume Filter Before (gas outlet) (g)	0.4702	0.4706	0.4693	0.4701	0.4711
Fume Filter After (gas outlet) (g)	0.4902	0.4909	0.4861	0.4909	0.4901
Fume wt. (gas outlet) (g)	*0.0200*	*0.0203*	*0.0168*	*0.0208*	*0.0190*
Total Fume wt. in system (g)	***0.0241***	***0.0232***	***0.0189***	***0.0245***	***0.0220***
Total Paper weight (g)	***0.5567***	***0.5578***	***0.5564***	***0.5568***	***0.5569***
Percentage of Sulfur (P+F) (%)	0.02	0.02	0.03	0.03	0.02
Percentage of Sulfur in Paper (%)	0.00	0.00	0.00	0.00	0.00
Sulfur wt. in Paper+fume (g)	0.0001	0.0001	0.0002	0.0002	0.0001
Sulfur wt. in Paper (g)	0.0000	0.00000	0.00000	0.00000	0.00000
Sulfur wt. in Fume (g)	0.0001	0.0001	0.0002	0.0002	0.0001
Sulfur wt.% in Fume	**0.48**	**0.50**	**0.91**	**0.71**	**0.53**
Sulfur Balance :					
Input :					
Total Input Black Liquor wt. (g)	5.4150	4.9380	3.7626	5.4731	4.3210
Sulfur wt. % in Black Liquor (%)	2.44	2.44	2.44	2.44	2.44
Sulfur wt. in Black Liquor (g)	0.1321	0.1205	0.0918	0.1335	0.1054
Output :					
1. Total Fume wt. (g)	0.0241	0.0232	0.0189	0.0245	0.0220
Sulfur wt. % in Fume (%)	0.48	0.50	0.91	0.71	0.53
Sulfur wt. in Fume (g)	0.0001	0.0001	0.0002	0.0002	0.0001
2. Char wt. (g)	4.3718	3.9025	3.0763	4.5202	3.6438
Sulfur wt. % in Char (%)	1.90	1.90	2.11	2.11	2.33
Sulfur wt. in Char (g)	0.0831	0.0741	0.0649	0.0954	0.0849
Sulfur Yield in Fume (%)	**0.09**	**0.10**	**0.19**	**0.13**	**0.11**
Sulfur Yield in Char (%)	**62.87**	**61.54**	**70.70**	**71.42**	**80.53**
Estimate Sulfur Yield in Gas (%)	**37.04**	**38.36**	**29.11**	**28.45**	**19.36**

Sulfur Yield in Fume, and Char at 500 °C			
DATA ACQUISITION FILE	FVAG616	FVAG617	FVAG618
Date	8/14/96	8/14/96	8/14/96
Raw Material	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125
Reactor Path Lenght (inch)	12.75	9.75	9.75
Residence Time (sec)	0.5	0.3	0.3
Temperature (c)	500	500	500
Sulfur wt.% in Fume :			
1. Fume Filter Before (g)	0.0869	0.0867	0.0864
Fume Filter After (g)	0.0898	0.0884	0.0881
Collected Fume wt. (g)	*0.0029*	*0.0017*	*0.0017*
2. Fume Filter Before (gas outlet) (g)	0.4716	0.4663	0.4733
Fume Filter After (gas outlet) (g)	0.4911	0.4811	0.4841
Fume wt. (gas outlet) (g)	*0.0195*	*0.0148*	*0.0108*
Total Fume wt. in system (g)	***0.0224***	***0.0165***	***0.0125***
Total Paper weight (g)	***0.5585***	***0.5530***	***0.5597***
Percentage of Sulfur (P+F) (%)	0.02	0.03	0.03
Percentage of Sulfur in Paper (%)	0.00	0.00	0.00
Sulfur wt. in Paper+fume (g)	0.0001	0.0002	0.0002
Sulfur wt. in Paper (g)	0.0000	0.00000	0.00000
Sulfur wt. in Fume (g)	0.0001	0.0002	0.0002
Sulfur wt.% in Fume	**0.52**	**1.04**	**1.37**
Sulfur Balance :			
Input :			
Total Input Black Liquor wt. (g)	5.5464	5.4361	4.4073
Sulfur wt. % in Black Liquor (%)	2.44	2.44	2.44
Sulfur wt. in Black Liquor (g)	0.1353	0.1326	0.1075
Output :			
1. Total Fume wt. (g)	0.0224	0.0165	0.0125
Sulfur wt. % in Fume (%)	0.52	1.04	1.37
Sulfur wt. in Fume (g)	0.0001	0.0002	0.0002
2. Char wt. (g)	4.7505	4.8722	4.0662
Sulfur wt. % in Char (%)	2.33	2.42	2.42
Sulfur wt. in Char (g)	0.1107	0.1179	0.0984
Sulfur Yield in Fume (%)	**0.09**	**0.13**	**0.16**
Sulfur Yield in Char (%)	**81.79**	**88.89**	**91.50**
Estimate Sulfur Yield in Gas (%)	**18.13**	**10.98**	**8.34**

Sulfur Yield in Fume, and Char at 400 °C					
DATA ACQUISITION FILE	FVAG619	FVAG620	FVAG621	FVAG622	FVAG623
Date	8/15/96	8/15/96	8/15/96	8/15/96	8/15/96
Raw Material	Valdosta	Valdosta	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125	90-125	90-125
Reactor Path Lenght (inch)	28.75	28.75	28.75	28.75	28.75
Residence Time (sec)	2.0	2.0	1.7	1.7	1.5
Temperature (c)	400	400	400	400	400
Sulfur wt.% in Fume :					
1. Fume Filter Before (g)	0.0866	0.0872	0.0854	0.0854	0.0864
Fume Filter After (g)	0.0883	0.0902	0.0874	0.0876	0.0878
Collected Fume wt. (g)	*0.0017*	*0.0030*	*0.0020*	*0.0022*	*0.0014*
2. Fume Filter Before (gas outlet) (g)	0.4703	0.4713	0.4702	0.4656	0.4732
Fume Filter After (gas outlet) (g)	0.4765	0.4808	0.4798	0.4761	0.4821
Fume wt. (gas outlet) (g)	*0.0062*	*0.0095*	*0.0096*	*0.0105*	*0.0089*
Total Fume wt. in system (g)	***0.0079***	***0.0125***	***0.0116***	***0.0127***	***0.0103***
Total Paper weight (g)	***0.5569***	***0.5585***	***0.5556***	***0.5510***	***0.5596***
Percentage of Sulfur (P+F) (%)	0.24	0.24	0.16	0.16	0.06
Percentage of Sulfur in Paper (%)	0.00	0.00	0.00	0.00	0.00
Sulfur wt. in Paper+fume (g)	0.0014	0.0014	0.0009	0.0009	0.0003
Sulfur wt. in Paper (g)	0.0000	0.0000	0.0000	0.0000	0.0000
Sulfur wt. in Fume (g)	0.0014	0.0014	0.0009	0.0009	0.0003
Sulfur wt.% in Fume	**17.16**	**10.96**	**7.82**	**7.10**	**3.32**
Sulfur Balance :					
Input :					
Total Input Black Liquor wt. (g)	1.9351	2.8298	4.1128	4.0197	4.6955
Sulfur wt. % in Black Liquor (%)	2.44	2.44	2.44	2.44	2.44
Sulfur wt. in Black Liquor (g)	0.0472	0.0690	0.1004	0.0981	0.1146
Output :					
1. Total Fume wt. (g)	0.0079	0.0125	0.0116	0.0127	0.0103
Sulfur wt. % in Fume (%)	17.16	10.96	7.82	7.10	3.32
Sulfur wt. in Fume (g)	0.0014	0.0014	0.0009	0.0009	0.0003
2. Char wt. (g)	1.5201	2.1397	3.1248	3.2285	3.7358
Sulfur wt. % in Char (%)	1.80	1.80	1.89	1.89	1.97
Sulfur wt. in Char (g)	0.0274	0.0385	0.0591	0.0610	0.0736
Sulfur Yield in Fume (%)	**2.87**	**1.98**	**0.90**	**0.92**	**0.30**
Sulfur Yield in Char (%)	**57.95**	**55.78**	**58.85**	**62.21**	**64.24**
Estimate Sulfur Yield in Gas (%)	**39.18**	**42.24**	**40.24**	**36.87**	**35.47**

Sulfur Yield in Fume, and Char at 400 °C					
DATA ACQUISITION FILE	FVAG624	FVAG625	FVAG626	FVAG627	FVAG628
Date	8/15/96	8/16/96	8/16/96	8/16/96	8/16/96
Raw Material	Valdosta	Valdosta	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125	90-125	90-125
Reactor Path Lenght (inch)	28.75	28.75	28.75	28.75	28.75
Residence Time (sec)	1.5	1.3	1.3	1.1	1.1
Temperature (c)	400	400	400	400	400
Sulfur wt.% in Fume :					
1. Fume Filter Before (g)	0.0878	0.0861	0.0861	0.0862	0.0867
Fume Filter After (g)	0.0891	0.0871	0.0877	0.0885	0.0884
Collected Fume wt. (g)	*0.0013*	*0.0010*	*0.0016*	*0.0023*	*0.0017*
2. Fume Filter Before (gas outlet) (g)	0.4709	0.4692	0.4711	0.4706	0.4741
Fume Filter After (gas outlet) (g)	0.4784	0.4751	0.4813	0.4834	0.4841
Fume wt. (gas outlet) (g)	*0.0075*	*0.0059*	*0.0102*	*0.0128*	*0.0100*
Total Fume wt. in system (g)	***0.0088***	***0.0069***	***0.0118***	***0.0151***	***0.0117***
Total Paper weight (g)	***0.5587***	***0.5553***	***0.5572***	***0.5568***	***0.5608***
Percentage of Sulfur (P+F) (%)	0.06	0.04	0.04	0.02	0.02
Percentage of Sulfur in Paper (%)	0.00	0.00	0.00	0.00	0.00
Sulfur wt. in Paper+fume (g)	0.0003	0.0002	0.0002	0.0001	0.0001
Sulfur wt. in Paper (g)	0.0000	0.0000	0.0000	0.0000	0.0000
Sulfur wt. in Fume (g)	0.0003	0.0002	0.0002	0.0001	0.0001
Sulfur wt.% in Fume	**3.87**	**3.26**	**1.93**	**0.76**	**0.98**
Sulfur Balance :					
Input :					
Total Input Black Liquor wt. (g)	3.7710	2.3171	4.5125	4.9372	4.1369
Sulfur wt. % in Black Liquor (%)	2.44	2.44	2.44	2.44	2.44
Sulfur wt. in Black Liquor (g)	0.0920	0.0565	0.1101	0.1205	0.1009
Output :					
1. Total Fume wt. (g)	0.0088	0.0069	0.0118	0.0151	0.0117
Sulfur wt. % in Fume (%)	3.87	3.26	1.93	0.76	0.98
Sulfur wt. in Fume (g)	0.0003	0.0002	0.0002	0.0001	0.0001
2. Char wt. (g)	3.1228	1.9236	3.8421	4.2969	3.6589
Sulfur wt. % in Char (%)	1.97	2.04	2.04	2.11	2.11
Sulfur wt. in Char (g)	0.0615	0.0392	0.0784	0.0907	0.0772
Sulfur Yield in Fume (%)	**0.37**	**0.40**	**0.21**	**0.09**	**0.11**
Sulfur Yield in Char (%)	**66.86**	**69.41**	**71.19**	**75.26**	**76.48**
Estimate Sulfur Yield in Gas (%)	**32.77**	**30.19**	**28.61**	**24.64**	**23.40**

Sulfur Yield in Fume, and Char at 400 °C					
DATA ACQUISITION FILE	FVAG629	FVAG630	FVAG631	FVAG632	FVAG633
Date	8/16/96	8/16/96	8/18/96	8/18/96	8/18/96
Raw Material	Valdosta	Valdosta	Valdosta	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125	90-125	90-125	90-125
Reactor Path Lenght (inch)	23.75	23.75	17.75	17.75	12.75
Residence Time (sec)	0.9	0.9	0.7	0.7	0.5
Temperature (c)	400	400	400	400	400
Sulfur wt.% in Fume :					
1. Fume Filter Before (g)	0.0859	0.0862	0.0879	0.0852	0.0867
Fume Filter After (g)	0.0874	0.0872	0.0881	0.0871	0.0889
Collected Fume wt. (g)	*0.0015*	*0.0010*	*0.0002*	*0.0019*	*0.0022*
2. Fume Filter Before (gas outlet) (g)	0.4751	0.4721	0.4709	0.4724	0.4731
Fume Filter After (gas outlet) (g)	0.4864	0.4789	0.4733	0.4789	0.4858
Fume wt. (gas outlet) (g)	*0.0113*	*0.0068*	*0.0024*	*0.0065*	*0.0127*
Total Fume wt. in system (g)	***0.0128***	***0.0078***	***0.0026***	***0.0084***	***0.0149***
Total Paper weight (g)	***0.5610***	***0.5583***	***0.5588***	***0.5576***	***0.5598***
Percentage of Sulfur (P+F) (%)	0.02	0.02	0.03	0.03	0.02
Percentage of Sulfur in Paper (%)	0.00	0.00	0.00	0.00	0.00
Sulfur wt. in Paper+fume (g)	0.0001	0.0001	0.0002	0.0002	0.0001
Sulfur wt. in Paper (g)	0.0000	0.00000	0.00000	0.00000	0.00000
Sulfur wt. in Fume (g)	0.0001	0.0001	0.0002	0.0002	0.0001
Sulfur wt.% in Fume	**0.90**	**1.45**	**6.48**	**2.02**	**0.77**
Sulfur Balance :					
Input :					
Total Input Black Liquor wt. (g)	3.9668	3.0851	3.5493	4.3890	4.6073
Sulfur wt. % in Black Liquor (%)	2.44	2.44	2.44	2.44	2.44
Sulfur wt. in Black Liquor (g)	0.0968	0.0753	0.0866	0.1071	0.1124
Output :					
1. Total Fume wt. (g)	0.0128	0.0078	0.0026	0.0084	0.0149
Sulfur wt. % in Fume (%)	0.90	1.45	6.48	2.02	0.77
Sulfur wt. in Fume (g)	0.0001	0.0001	0.0002	0.0002	0.0001
2. Char wt. (g)	3.6146	2.8285	3.4712	4.1884	4.5907
Sulfur wt. % in Char (%)	2.16	2.16	2.21	2.21	2.33
Sulfur wt. in Char (g)	0.0781	0.0611	0.0767	0.0926	0.1070
Sulfur Yield in Fume (%)	**0.12**	**0.15**	**0.19**	**0.16**	**0.10**
Sulfur Yield in Char (%)	**80.66**	**81.16**	**88.58**	**86.43**	**95.15**
Estimate Sulfur Yield in Gas (%)	**19.22**	**18.69**	**11.22**	**13.41**	**4.75**

Sulfur Yield in Fume, and Char at 400 °C		
DATA ACQUISITION FILE	FVAG634	FVAG635
Date	8/18/96	8/18/96
Raw Material	Valdosta	Valdosta
Particle Size (micron)	90-125	90-125
Reactor Path Lenght (inch)	12.75	9.75
Residence Time (sec)	0.5	0.3
Temperature (c)	400	400
Sulfur wt.% in Fume :		
1. Fume Filter Before (g)	0.0852	0.0865
Fume Filter After (g)	0.0872	0.0889
Collected Fume wt. (g)	*0.0020*	*0.0024*
2. Fume Filter Before (gas outlet) (g)	0.4766	0.4762
Fume Filter After (gas outlet) (g)	0.4889	0.4908
Fume wt. (gas outlet) (g)	*0.0123*	*0.0146*
Total Fume wt. in system (g)	***0.0143***	***0.0170***
Total Paper weight (g)	***0.5618***	***0.5627***
Percentage of Sulfur (P+F) (%)	0.02	0.03
Percentage of Sulfur in Paper (%)	0.00	0.00
Sulfur wt. in Paper+fume (g)	0.0001	0.0002
Sulfur wt. in Paper (g)	0.0000	0.0000
Sulfur wt. in Fume (g)	0.0001	0.0002
Sulfur wt.% in Fume	**0.81**	**1.02**
Sulfur Balance :		
Input :		
Total Input Black Liquor wt. (g)	4.0943	4.938
Sulfur wt. % in Black Liquor (%)	2.44	2.44
Sulfur wt. in Black Liquor (g)	0.0999	0.1205
Output :		
1. Total Fume wt. (g)	0.0143	0.0170
Sulfur wt. % in Fume (%)	0.81	1.02
Sulfur wt. in Fume (g)	0.0001	0.0002
2. Char wt. (g)	4.0140	4.9162
Sulfur wt. % in Char (%)	2.33	2.39
Sulfur wt. in Char (g)	0.0935	0.1175
Sulfur Yield in Fume (%)	**0.12**	**0.14**
Sulfur Yield in Char (%)	**93.62**	**97.52**
Estimate Sulfur Yield in Gas (%)	**6.27**	**2.34**

Adjusted Carbon Yield in Char of Pyrolysis of Black Liquor							
Residence Time	Temperature (°C)						
(sec)	600	500	400	C% in gas	% in Fine Pr	Correction Fc	Adj. Char 500C
2.0	71.86	61.76	75.89	23.43	1.79	1.15	70.78
2.0	67.15	59.11	73.05	23.52	1.88	1.19	70.60
1.7	72.79	61.59	74.44	20.98	1.49	1.19	73.53
1.7	69.43	59.18	78.69	22.85	1.32	1.21	71.83
1.5	69.68	61.96	76.68	17.31	1.26	1.25	77.43
1.5	72.40	62.70	79.81	17.29	0.88	1.24	77.83
1.3	74.95	64.66	79.81	16.57	1.01	1.21	78.42
1.3	72.82	66.93	81.86	17.14	1.03	1.16	77.83
1.1	77.31	71.77	82.35	16.26	0.63	1.10	79.11
1.1	75.85	73.96	83.69	15.79	0.68	1.08	79.53
0.9	75.13	77.62	86.36	14.81	0.63	1.04	80.56
0.9	80.03	75.98	86.89	12.99	0.67	1.08	82.34
0.7	80.06	78.29	91.93	11.62	0.67	1.07	83.71
0.7	73.51	79.08	89.70	10.65	0.59	1.07	84.76
0.5	84.17	81.4	96.53	10.18	0.65	1.05	85.17
0.5	84.84	82.67	94.98	11.16	0.52	1.02	84.32
0.3	89.26	85.63	94.65	6.69	0.28	1.04	89.03
0.3	91.48	88.15		7.07	0.26	1.01	88.67

Adjusted Char Yield in Pyrolysis of Black Liquor					
Residence Time	Temperature (°C)				
(sec)	600	500	400	Con. Fac.	500 Adj
2.0	74.91	65.87	78.55	1.15	75.75
2.0	75.22	63.05	75.61	1.19	75.03
1.7	79.07	66.06	75.98	1.19	78.61
1.7	75.80	63.48	80.32	1.21	76.81
1.5	76.80	67.45	79.56	1.25	84.31
1.5	77.53	68.26	82.81	1.24	84.64
1.3	78.88	71.06	83.02	1.21	85.98
1.3	78.24	73.55	85.14	1.16	85.32
1.1	80.66	77.38	87.03	1.10	85.12
1.1	80.31	79.74	88.45	1.08	86.12
0.9	77.03	80.73	91.12	1.04	83.96
0.9	81.24	79.03	91.68	1.08	85.35
0.7	80.78	81.76	97.8	1.07	87.48
0.7	73.12	82.59	95.43	1.07	88.37
0.5	85.18	84.33	99.64	1.05	88.55
0.5	84.84	85.65	98.04	1.02	87.36
0.3	93.02	89.63	99.56	1.04	93.22
0.3	92.36	92.26		1.01	93.18

Adjusted Sulfur Yield in Pyrolysis of Black Liquor					
Residence Time	Temperature (°C)				
(sec)	600	500	400	Con. Fac.	500 Adj
2.0	39.30	41.84	57.95	1.15	48.12
2.0	36.99	40.05	55.78	1.19	47.66
1.7	42.77	43.32	58.85	1.19	51.55
1.7	37.90	41.63	62.21	1.21	50.37
1.5	40.29	45.61	64.24	1.25	57.01
1.5	40.36	46.16	66.86	1.24	57.24
1.3	44.61	49.80	69.41	1.21	60.26
1.3	46.49	51.55	71.19	1.16	59.80
1.1	51.24	55.50	75.26	1.10	61.05
1.1	47.40	57.19	76.48	1.08	61.77
0.9	55.25	62.87	80.66	1.04	65.38
0.9	58.60	61.54	81.16	1.08	66.46
0.7	63.57	70.70	88.58	1.07	75.65
0.7	59.03	71.42	86.43	1.07	76.42
0.5	68.78	80.53	95.15	1.05	84.56
0.5	69.54	81.79	93.62	1.02	83.43
0.3	86.16	88.89	97.52	1.04	92.45
0.3	89.71	91.50		1.01	92.42

Adjusted Nitrogen Yield in Pyrolysis of Black Liquor					
Residence Time	Temperature (°C)				
(sec)	600	500	400	Con. Fac.	500 Adj
2.0	58.86	61.17	67.33	1.15	70.35
2.0	59.10	58.54	64.81	1.19	69.66
1.7	62.12	61.34	65.12	1.19	72.99
1.7	64.97	58.95	68.84	1.21	71.33
1.5	65.83	62.63	68.20	1.25	78.29
1.5	66.46	63.38	70.98	1.24	78.59
1.3	67.61	65.98	71.16	1.21	79.84
1.3	67.06	68.30	72.98	1.16	79.23
1.1	69.14	71.86	74.60	1.10	79.05
1.1	68.84	68.35	75.81	1.08	73.82
0.9	71.53	74.97	78.10	1.04	77.97
0.9	69.63	73.38	78.59	1.08	79.25
0.7	75.01	75.92	83.83	1.07	81.23
0.7	73.12	76.69	81.80	1.07	82.06
0.5	79.10	78.3	85.41	1.05	82.22
0.5	78.78	79.53	84.03	1.02	81.12
0.3	86.37	89.63	98.14	1.04	93.22
0.3	85.77	92.26		1.01	93.18