Forestry Biofuels Statewide Collaboration Center, Task B3:

Evaluation of Forest Biomass Processability

Final Report

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1. Executive Summary

Reasons for renewed interest in biofuels production include new policy and legislation such as sustainable biofuel targets in the US Energy Policy Act (EPC, 2005), foreign oil dependence reduction, reduction in harmful environmental impacts, and the ability to create a more diverse product industry. This study provides a technical screening of biofuels production feasibility from forest-based feedstock that can be implemented in Michigan. These feedstocks studied include poplar, willow, aspen, switchgrass, red maple, and balsam.

Two conversion pathways were considered within this work: dilute acid hydrolysis followed by enzymatic hydrolysis (biochemical mechanisms), and pyrolysis (thermal degradation mechanisms). These processes were evaluated on their production of valuable bio-fuels intermediates. The dilute acid pretreatment and enzymatic hydrolysis was evaluated on the production of sugars that can be fermented into fuels such as ethanol. Pyrolysis was evaluated based on the yield of liquid and gaseous phase products.

From study, we found that our results agree well with existing literature, and indicate that Michigan grown woody feedstocks can be processed into valuable products through either investigated method. This work found that yields of greater than 50% of biomass-embodied sugars can be extracted when processing woods such as poplar and willow, through dilute acid pretreatment and enzyme hydrolysis. Additionally, this study found that combined bio-oil and gas phase yields of greater than 50% mass can be obtained from fast pyrolysis, within a 500-700℃ range.

2. Introduction

The production of biofuels from biomass has gained accelerated interest in recent years as these fuels are increasingly economically-viable, renewable, and carbon-neutral energy sources. One reason for this renewed interest derives from new policy and legislation such as sustainable biofuel targets in the US Energy Policy Act (EPC, 2005) and Energy Independence and Security Act (EISA, 2007). In addition to these policies, renewable energy/fuel sources are substantially better for the environment because they are renewable, reduce environmental burdens over petroleum fuels, and provide a broader range of products marketable from Michigan's natural resources.

Currently the largest effort (and only well reviewed in the literature) comes from the production of corn ethanol, displacing over 4,600 million equivalent gallons of gasoline and fueling almost 5.5 million flexible fuel vehicles (Ethanol Market Penetration, 2011). These fuels, however, could be produced from any material that is rich in fermentable sugars such as lingocellulosic biomass. Because wood is an abundant, and sustainably managed resource in Michigan, it is an excellent candidate for such an alternative feedstock. Michigan feedstocks considered in this study include poplar, willow, aspen, balsam, red maple, and switchgrass.

A primary concern within assessing the processability of woody biomass for ethanol production is determining the quantity of fermentable monomer sugars that are recoverable from raw samples, as these sugars are then fermented to ethanol. It has been shown (Jensen et al., 2010, Morinelly et al., 2009, and Yat et al., 2006), that monomerization of complex molecules within woody biomass is effectively obtained through acid pretreatment and enzymatic hydrolysis. In partial-fulfillment of the proposed objectives, Michigan-viable feedstocks were analyzed for monomer sugar recovery.

In addition to using Michigan's woody feedstocks for fermentable sugar extraction, they can also be utilized through a process called pyrolysis. Pyrolysis is the thermal degradation of wood in the absence of oxygen. The process creates three products: a dense bio-oil, a low quality gas stream, and bio-char. The bio-oil is usually a dark and viscous oil, not unlike heavy petrol-oil, and can have faint smoky odors depending on the original feedstock (Czernik and Bridgwater, 2004). This oil is usually very acidic (pH around 2.5) and contains mostly water (15-30 wt%) and polar organics (75-80wt%) (Bridgwater et al., 1999 and Mohan et al., 2006). Within these polar organic compounds, common components, as demonstrated in this research, include: hydroxyaldehydes (such as glycolaldehyde), hydroxyketones, monomer sugars (such as glucose and xylose), sugar varients (such as levoglucosan), carboxylic acids (such as acetic and formic acid), and phenolics or cyclic compounds.

The bio-oil can be directly used for heating and electricity generation, or undergo further refining to a true hydrocarbon transportation fuel. The gas-phase product stream usually contains a mixture of low-value gases (CO, CO_2) with small amounts of higher-value combustibles

(methane, ethane). The solid residue remaining after pyrolysis (or torrefaction at low temperatures, 200-300˚C), is referred to as char, bio-char, or bio-coal. Bio-coal has similar properties to traditional coal, and in many cases can be used as a 'drop-in' replacement in existing infrastructure. In addressing the proposed objectives, Michigan-viable feedstocks were analyzed through pyrolysis for: (1) phase-distribution data (oil-gas-char), (2) detailed speciation of the oil and gas phase products, and (3) quantification of some major components detected with the bio-oil.

3. Methods

Detailed descriptions of experimental procedures are included in this section of the report. Equipment descriptions, along with the manufacture and model, are also included.

3.1. Dilute Acid Hydrolysis and Enzymatic Hydrolysis

The work performed to fulfill the Dilute Acid Hydrolysis and Enzymatic Hydrolysis (DAH-EH) requirements consisted of four major experimental steps: preparation of the biomass samples, dilute acid pretreatment, total pretreatment monomer analysis, and enzymatic hydrolysis. These methods were adopted from previous work carried out at Michigan Technological University (Jensen et al., 2010). A simplified block diagram was developed to visually represent and demonstrate the experimental stages, and is shown as Figure 1. The equipment utilized in DAH-EH includes: a W.S. Tyler Rotap (model RX-29, serial 9774) for particle size differentiation, a Marathon 21K centrifuge by FisherScientific for solid-liquid separation, an AC-48 Autoclave by New Brunswick Scientific for oligomer analysis, a 1200 series HPLC by Agilent for sugar detection and quantification, and an Orbit Environ-Shaker by Lab-Line Industries Inc. used during enzymatic hydrolysis.

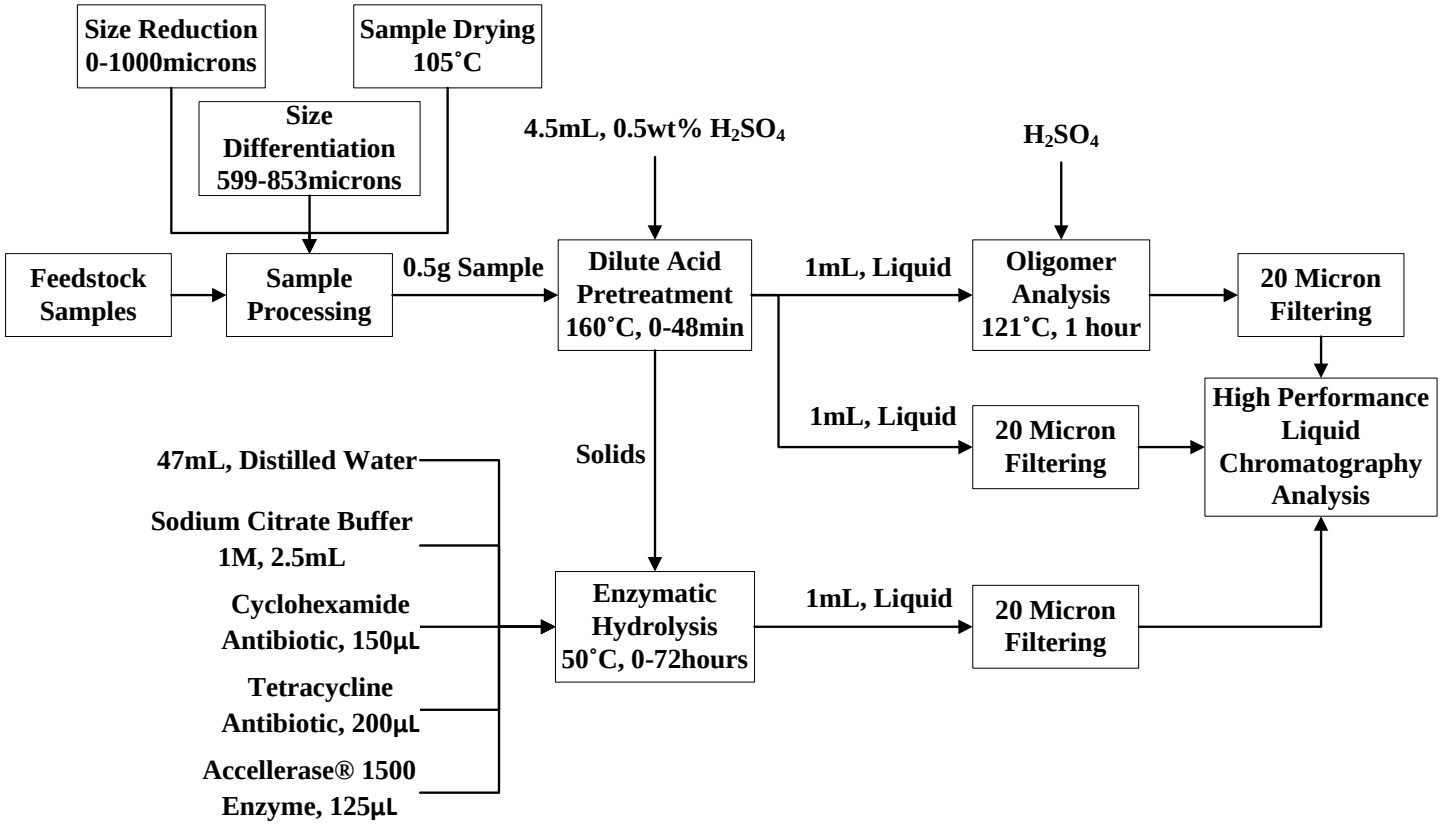

Figure 1: Simplified block diagram for the dilute acid pretreatment and enzymatic hydrolysis experiments.

3.1.1. Preparation of Biomass Samples

Prior to acid pretreatment or enzymatic hydrolysis within the experiments, each biomass sample is dried and milled into small pieces. Drying was performed through heating the sample in a drying oven at 105˚C until a difference in mass was no longer detected. The drying was performed in accordance with NREL's LAPS (Report NREL/TP-510-42620, 2008). A small scale hammer mill, located at MTU, was used to grind the dried biomass to an appropriate range of sizes. A rotap equipped with a range of analytical sieves was used in the particle size differentiation. The sampling was performed in accordance with NREL's LAPs (Report 2NREL/TP-510-42620, 2008) with modifications to adjust for appropriate sieve sizes (sizes larger than 28 Tyler Mesh, but smaller than 20 Tyler Mesh or approximately 599-853 microns).

3.1.2. Acid Pretreatment

Acid pretreatment is performed once the samples are dried and sorted. The optimum conditions for monomer extraction during dilute acid hydrolysis occur around 160˚C and 0.5 wt/wt% acid (Jensen et al., 2010). Individual samples are weighed and placed into a set of 9 stainless steel cylindrical reactor tubes, each containing 4.5mL of 0.5 wt/wt% sulfuric acid aqueous solution. After letting the dilute acid solution properly diffuse into the wood particles (no substantial reaction takes place due to low ambient conditions), the reactors tubes are submerged into a silicon oil constant temperature bath, which is initially set to 175°C. The bath and reactors come to thermal equilibrium around 160°C in approximately 3 minutes. The acid pretreatment reaction occurs as the temperature and pressure within the reaction vessels rise. The tubes are removed from the oil bath at varying points in time for analysis. In order to stop the reaction, the tubes are immediately submerged in an ice-water bath. The contents of each reactor tube is removed and collected when it has sufficiently cooled.

The subsequent liquid and solid portions are separated (the solid portion is carried onto enzymatic hydrolysis). A liquid sample from each reactor is rapidly centrifuged at 13,000RPM for 5 minutes. From the liquid fraction, 1mL is collected for High Performance Liquid Chromatography (HPLC) to analyze monomer sugar concentrations obtained directly from dilute acid pretreatment. Another 1mL of the liquid product is passed through a 20 micron filter and carried onto oligomer analysis (total monomer analysis).

The HPLC analysis delivers results in terms of retention time and peak area of detection. These data are correlated with monomer standard solutions; solutions with known concentrations of glucose, xylose, galactose, arabinose, and mannose. This method of analysis will result in an accurate representation of the monomer content within the samples. Dilution factors for acidification and neutralization are taken into account when performing all calculations. The sugar extracted in the greatest abundance during pretreatment is xylose, a 5-carbon sugar. Examples of sugar calibration curves are within Appendix A.

3.1.3. Total Pretreatment Monomer Analysis

In addition to direct monomer extraction from pretreatment, some sugars are extracted in their native disaccharide or polysaccharide (oligomer) forms. The quantification of these sugars requires introducing additional sulfuric acid to bring the concentration to 4 wt/wt% acid, followed by autoclaving (121˚C for 1 hour). All existing oligomer sugars should be degraded to their monomer form or other degradation products after this process is complete. A 1mL liquid aliquot of the resulting liquid fraction from each sample is used for oligomer sugar content analysis. The 1ml HPLC analysis aliquots are neutralized to a pH between 5 and 6, tested with litmus paper, and passed through a 20 micron filter prior to being run through the HPLC. Similar to the previous section, the monomer sugar content is obtained through standard curves.

Sugar Recovery Standards (SRS) are also used along with the acid pretreatment samples during oligomer analysis. These SRS are premade sugar solutions with known concentrations. Processing these will yield an amount of monomer sugars that are degraded to unwanted inhibitory products such as fufural and hydroxymethyl furfural. Similar to the acid pretreatment samples, the SRS are acidified to 4 wt/wt% acid prior to processing. SRS liquid samples are also neutralized to a pH between 5 and 6, tested with litmus paper, centrifuged, and analyzed with the HPLC for monomer concentration. Analysis of the SRS allows for determination of the concentration of monomer sugars that are degraded during autoclaving. The total sugars, expressed in total monomer equivalence, can be obtained by combining the initial monomer analysis of the pretreatment liquid and the oligomer analysis results. For all calculations care was taken to account for the level of monomer degradation in addition to dilution factors.

3.1.4. Enzymatic Hydrolysis

The solid portion of the biomass samples resulting from the acid pretreatment is introduced to enzymatic hydrolysis. During this procedure, enzymatic saccharification of cellulose from the pretreated lignocellulosic biomass to glucose occurs, with a minor xylose contribution as well. This allows for calculating the maximum extent of enzyme digestibility for biomass samples.

For enzymatic hydrolysis to take place the post acid pretreatment sample solids are rinsed with distilled water and then vacuum filtered to remove any excess liquid. The solids, still individual samples from their reactors, are each placed into a flask. A pre-enzymatic hydrolysis mixture added to the flasks includes: 47mL of distilled water, 2.5mL of 1M sodium citrate buffer, 200µL of tetracycline, and 150µL of cycloheximide. Tetracycline and cycloheximide are antibiotics utilized to prevent the growth of other organisms that might inhibit or consume the produced sugars. A control flask is also prepared to determine the impact of the biomass-accompanying liquids. The control flask is prepared in an identical fashion, but without and biomass.

Each flask of pre-enymatic hydrolysis mixture is tightly sealed and introduced to an incubated bench-top shaker for 1 hour at 50°C. After reaching thermal equilibrium within the shaker, *Accellerase® 1500* enzyme is added to each flask. An enzyme loading of 125μL *Accellerase® 1500* has shown to be effective in performing enzymatic hydrolysis (Jensen et al., 2010). Samples were taken to be analyzed every 24 hours, starting with an immediate sample withdraw. The samples are passed through a 20 micron filter prior to HPLC analysis. Similar to previous sections, the HPLC results are correlation to monomer sugar standard curves. The control flask is also analyzed via HPLC to determine any levels of incidental detection within a blank sample. The monomer content within the post enzymatic hydrolysis samples is calculated for the solid portion of the acid pretreated biomass sample, taking into account any contribution within the control as well as dilution factors.

3.2. Fast Pyrolysis and Gas Chromatography/Mass Spectroscopy

The use of GC/MS analysis to analyze the products of pyrolysis has had promising results, in terms of speciation and quantification, and become a popular method (Patwardhan et al., 2009, Patwardhan et al., 2010, Patwardhan et al., 2011, Jackson er al., 2009, Dizhbite er al., 2011). Figure 2 shows a simplified flow diagram for the Pyrolysis-GasChromatography-MassSpectroscopy (PY-GC-MS) experiment described blow. The micro-pyrolysis reactor used in this work was a model 5200HP Pyroprobe created by CDS Analytical. The gas chromatograph was a Trace GC Ultra (Model K8880181) created by Thermo-Finnigan (now ThemoFisher) and was operated with a 30 meter Rxi-5ms fused silica capillary column by Restek. The mass spectrometer was also created by ThermoFinnigan (now ThermoFisher) and is a model Trace DSQ. The microbalance used during the experiments is a model CM5 created by Citizen Scales Inc. and has a readability of 1µg.

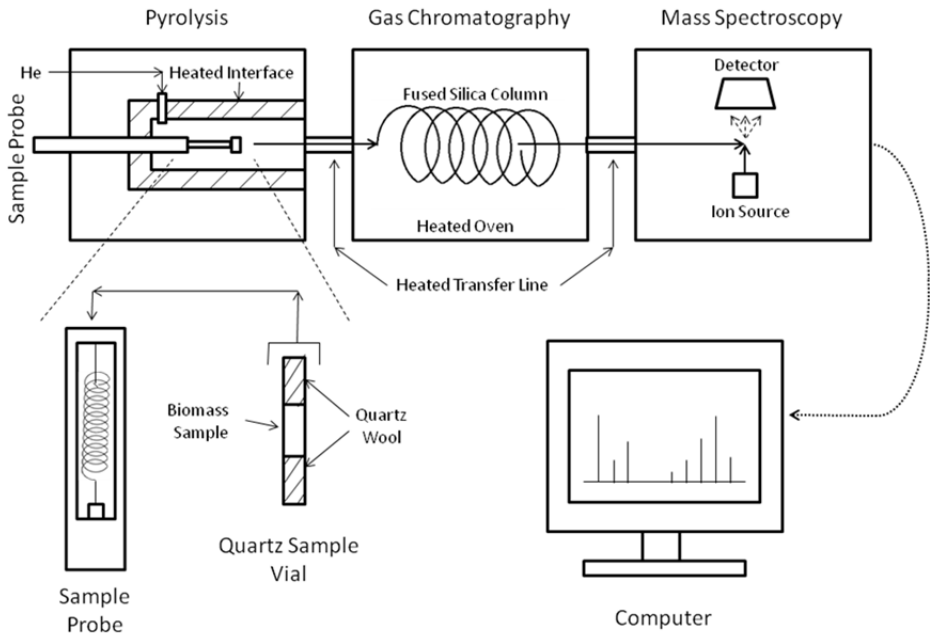

Figure 2: Simplified flow diagram for the PY-GC-MS experimental setup.

3.2.1. Pyrolysis and GC/MS Analysis

An experimental trial begins when an empty quartz vial (to hold the wood biomass sample for fast pyrolysis) is loaded into the sample probe along with two quartz wool plugs. The wool acts as a filter on either end of the vial, which is a hollow cylinder, allowing gases to flow through it while retaining the biomass and solid residues. After the empty vial is loaded into the micropyrolysis reactor with the probe, the materials undergo a pyrolysis cycle identical to that which is run on the biomass samples. This procedure is referred to as a *blank* and is performed

before each experimental trial as a quality control method. With a process identical to that which is run on the biomass, it can be demonstrated that the materials are perfectly clean and there is no residual matter anywhere in the system. Once it is established from the resulting chromatogram that the only signal is representative of noise, and low bleed from the fused silica column in the GC, the feedstock trial can begin.

Once a successful blank is obtained, biomass particles (further sieved with the rotap as before to a particle size range between 500 and 599microns) are loaded into the clean quartz reactor vial between the two quartz wool plugs. The vial containing the biomass sample is then inserted into the pyrolysis reactor via the sample probe. Once inside, the atmosphere is immediately purged with inert helium gas. When the sample is pyrolyzed it is very rapidly (>999˚C/second) heated up to an experimental temperature (500, 600, or 700˚C) and held there for 15 seconds. There is an interface time (2 minutes) after the heating begins where the inert gas passes through the sample probe and carries any resulting vapors through a heated transfer line to the mass spectrometer for analysis.

The GC/MS analysis conditions were modified from a published analysis method (Patwardhan et al., 2009). The GC oven temperature is initially set to a low temperature to allow the gases and vapors to condense and adsorb to the fused silica surface within the column. The oven is then slowly heated to remove the compounds at retention times, which are sent to the mass spectrometer with the helium carrier gas. Here, the molecules are fragmented using electrons generated with a heated filament. The resulting fragments are recorded as a mass spectrum. These mass spectra are then related to spectra of known compounds in the National Institute of Standards and Technology (NIST) libraries (contained in the GC/MS software), and the compounds are identified. The probability of a match is also reported. This probability determines the accuracy of the library search. From this analysis, the identity of major pyrolysis species is obtained. Furthermore, the GM/MS integrates the area under each identified peak, which is used to estimate the relative mass of each compound identified.

3.2.2. Gravimetric Analysis

Throughout the experiment, measurements are taken to obtain a gravimetric mass balance. For this procedure, some of the biomass sample is placed into a weighing tin and a mass is recorded. One of the wool plugs from a clean blank is then removed so the massed sample can be loaded into the vial. The discrete particles are carefully placed into the vial. The wool plug is placed back into the vial after the sample is loaded. The mass of the weighing tin and feedstock sample is then taken again, to get the mass of wood added to the vial by difference. The mass of sample added to the vial is then converted to a dry basis with the moisture content of the feedstock (determination of moisture is explained in the following section). At this point the sample vial can be place into the probe and the pyrolysis-GC/MS portion of the experiment can continue. The vial is then weighed again to obtain the mass of the sample that was pyrolyzed (representative of the pyrolysis oil and gases) by mass difference of the vial before and after the

pyrolysis trial. The difference between the dry biomass added to the sample vial and mass of sample leaving during pyrolysis is representative of the pyrolysis char.

3.2.3. Moisture Content Analysis

The moisture contents of the feedstocks are determined with a drying oven. In this procedure, the oven is held at a constant temperature of 105˚C and the sample masses are recorded over time. When the mass stops decreasing, the material is determined to be completely dry and the moisture content can be found. The moisture content is calculated as the difference between the samples initial weight minus its final weight, assuming that the entire sample mass loss is water moisture. These results are important, because when the samples are prepared for pyrolysis they contain moisture, whereas when they are weighed after the pyrolysis cycle they are completely dry. This allows the mass balance to account for the bound moisture leaving the feedstock, that isn't from dehydration reactions. The moisture content of the feedstocks range from 5.0-8.5%, and are shown in the results section.

4. Results

4.1. Dilute Acid Hydrolysis and Enzymatic Hydrolysis Results

For assessing the processability of biomass feedstocks, it is necessary to compile data for the sugar content available within the feedstocks of interest. A large portion of biomass feedstock consists of carbohydrates. Table 1 summarizes raw feedstock carbohydrate composition and moisture content. The carbohydrate composition analysis was performed prior to the FBSCC project, and was done independently of the moisture analysis using bone-dry materials.

Table 1: Sugar and lignin compositional analysis of raw biomass samples (wt%) (Yat et al.,2006). Carbohydrate composition is displayed as wt% of bone-dry sample.

	Moisture	Glucan	Xylan	Galactan	Araban	Mannan	Lignin
Aspen	7.5	52.43	14.60	3.52	2.41	5.32	26.69
Balsam	6.3	47.09	623	5.45	5.41	11.49	36.04
Basswood	8.5	43.99	15.31	3.41	3.49	2.91	28.44
Red Maple	7.1	43.18	17.69	5.71	4.13	5.37	36.49
Swithgrass	7.0	47.72	19.06	4.18	8.11	6.30	26.04
Willow	5.0						
Poplar	5.5						

4.1.1. Dilute Acid Hydrolysis and Enzymatic Hydrolysis Results from Previous Work

Using the acid pretreatment and enzymatic hydrolysis methods described above, the total sugar yield of different feedstocks were analyzed under different conditions. Acid concentrations from 0.25-0.75% and temperatures from 150-175˚C were considered. The results of percent theoretical yield captured are shown in Figure 3. More detailed data are tabulated along with their experimental conditions in Table 2.

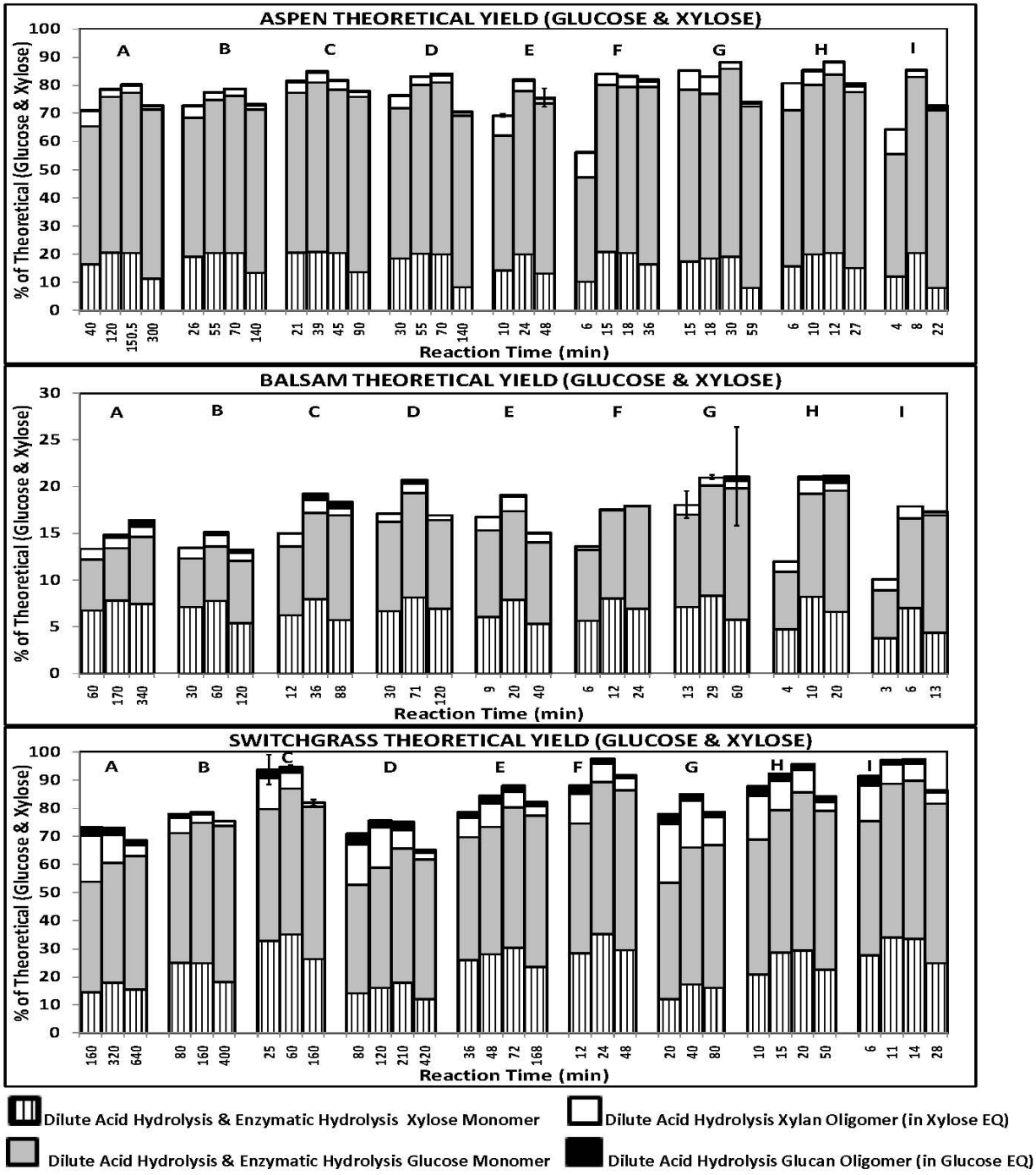

Figure 3: Total monomer sugar equivalence for Aspen, Balsam and Switchgrass. (A) 150°C, 0.25% H_2SO_4, (B) 150°C, 0.50% H_2SO_4, (C) 150°C, 0.75% H_2SO_4, (D) 160°C, 0.25% H_2SO_4, (E) 160°C, 0.50% H_2SO_4, (F) 160°C, 0.75% H_2SO_4, (G) 175°C, 0.25% H_2SO_4, (H) 175°C, 0.50% H_2SO_4, (I) 175°C, 0.75% H_2SO_4 . (Jensen et al., 2010)

Table 2: A-Aspen, BM-Balsam, and SG-Switchgrass dilute acid hydrolysis and enzymatic hydrolysis % yields for varying reaction conditions (Jensen et al., 2010).

Dilute Acid Hydolysis Reaction Conditions				% Theoretical Yields from Acid Hydrolysis (g sugar/g dry initial biomass)				Enzymatic Hydrolysis	
Species	Acid (wt %)	Temperature (°C)	Reaction Time (min)	Xylose Yield (%)	Xylan Oligomer (%)	Glucose Yield (%)	Glucan Oligomer (%)	Glucose Yield (%)	Xylose Yield (%)
A	0.25	150	150.5	12.4	1.6	1.6	0.3	36.8	1.0
A	0.50	150	70	12.6	1.6	1.8	0.1	35.8	0.7
A	0.75	150	45	12.6	2.1	1.8	0.2	37.3	0.7
A	0.25	160	70	12.3	1.7	1.8	0.4	39.2	0.8
A	0.50	160	24	12.1	2.3	1.5	0.3	37.8	0.9
A	0.75	160	18	12.6	2.3	1.8	0.2	37.9	0.8
A	0.25	175	30	11.9	1.4	2.8	0.3	42.3	0.5
A	0.50	175	12	12.6	2.7	2.5	0.3	40.3	0.6
A	0.75	175	8	12.9	1.5	2.6	0.2	39.6	0.4
BM	0.25	150	170	4.1	0.6	3.0	0.2	0.0	0.0
BM	0.50	150	60	4.1	0.7	3.0	0.1	0.1	0.0
BM	0.75	150	36	4.2	0.7	3.1	0.4	1.8	0.0
BM	0.25	160	71	4.3	0.6	3.2	0.2	2.8	0.0
BM	0.50	160	20	4.1	0.8	3.3	0.1	1.8	0.0
BM	0.75	160	12	4.2	0.0	3.2	0.0	1.8	0.0
BM	0.25	175	29	4.4	0.4	3.6	0.0	2.7	0.0
BM	0.50	175	10	4.3	0.8	3.4	0.2	2.5	0.0
BM	0.75	175	6	3.7	0.7	3.3	0.0	1.8	0.0
SG	0.25	150	320	6.7	5.0	2.2	1.3	19.8	2.3
SG	0.50	150	160	10.5	1.5	2.7	0.5	23.1	2.0
SG	0.75	150	60	16.2	2.9	3.6	1.0	23.1	1.5
SG	0.25	160	210	6.9	3.3	2.4	1.6	22.2	2.2
SG	0.50	160	72	13.0	2.8	3.1	1.0	22.7	2.3
SG	0.75	160	24	16.1	3.3	3.4	0.9	24.4	1.7
SG	0.25	175	40	6.2	8.4	2.1	1.2	23.1	2.4
SG	0.50	175	20	13.1	4.0	2.8	1.1	26.3	1.6
SG	0.75	175	14	16.0	3.0	4.0	0.9	25.1	0.9

In addition to taking experimental data, considerable effort has been placed into developing kinetic models for the reactions. The fact that the carbohydrate portion of biomass can be converted to a more usable monomer, from the hydrolysis of hemicelluloses, is of significant interest for interpreting the data collected in past studies. A linear four-step kinetic model is shown in Equation 1. This equation represents the degradation of xylose in hemicelluloses (XH). In this process, the original large and branched structure that exists in hemicelluloses is first broken down into much smaller chains of oligomer xylose (XO). The oligomers are then further degraded to monomer xylose (X). As sugars emerge in their monomer forms, they begin to degrade to unwanted products, such as furfural (F) and to other degradation products (D).

$$XH \overset{k_1}{\rightarrow} XO \overset{k_2}{\rightarrow} X \overset{k_3}{\rightarrow} F \overset{k_4}{\rightarrow} D \tag{1}$$

Each of the kinetic rate constants, k_i, can be calculated as function of absolute temperature (T) and acid concentration (C^{m_i}). The Arrhenius expression demonstrates this as shown in Equation 2.

$$k_i = A_{oi} C^{m_i} \exp\left(-\frac{E_i}{RT}\right) \tag{2}$$

where T is the absolute temperature (K), C is the acid concentration (wt %), A_{oi} is the pre-exponential factor (min^{-1}), m_i is the acid concentration exponent (unitless), E_i is the activation energy (kJ/mol), and R is the ideal gas constant ($8.3143x10^{-3}\ kJ/mol * K$). A summary of best fit kinetic rate constants is shown in Table 3. Arrhenius parameters were calculated using kinetic constants from Table 3. The fitted Arrhenius parameters for Equation 3 are shown in Table 4.

Table 3: Fitted Kinetic Constants to Experimental Data. (Morinelly et al., 2009)

k_i (min^{-1})	wt % H2SO4	Aspen			Balsam			Switchgrass		
		150 °C	160 °C	175 °C	150 °C	160 °C	175 °C	150 °C	160 °C	175 °C
k_1	0.25	0.055	0.127	0.300	0.014	0.044	0.119	0.008	0.017	0.069
	0.50	0.129	0.242	0.666	0.050	0.119	0.250	0.028	0.068	0.260
	0.75	0.190	0.275	0.666	0.075	0.150	0.324	0.151	0.211	0.554
k_2	0.25	0.047	0.086	0.151	0.122	0.264	0.593	0.005	0.011	0.022
	0.50	0.130	0.223	0.317	0.407	0.461	1.020	0.033	0.057	0.149
	0.75	0.182	0.284	0.642	0.433	1.800	2.110	0.089	0.140	0.344
k_3	0.25	0.001	0.003	0.015	0.003	0.007	0.018	0.004	0.007	0.025
	0.50	0.004	0.013	0.022	0.008	0.028	0.051	0.004	0.006	0.020
	0.75	0.006	0.010	0.042	0.012	0.036	0.114	0.004	0.010	0.021
k_4	0.25	0.003	0.002	0.031	0.036	0.085	0.171	0.005	0.008	0.034
	0.50	0.017	0.027	0.064	0.156	0.596	0.352	0.010	0.019	0.081
	0.75	0.029	0.047	0.086	0.211	1.070	0.720	0.028	0.114	0.149

Table 4: Fitted Arrhenius parameters to Equation 2 from kinetic constants in Table 3. (Morinelly et al., 2009)

		Acid (%wt.) Exponent	Pre-exponential Parameter	Activation Energy	Arrhenius Fit
	k_i	m_i (unitless)	A_{oi} (min^{-1})	Ei (kJ/mol)	R^2
Aspen	k1	0.88	1.94E+11	97	0.97
	k2	1.22	9.88E+07	69	0.98
	k3	1.20	1.38E+14	132	0.94
	k4	2.06	5.70E+11	106	0.86
Balsam	k1	1.21	2.07E+12	108	0.97
	k2	1.33	2.25E+10	84	0.91
	k3	1.55	5.65E+13	125	0.97
	k4	1.77	2.79E+08	70	0.81
Switchgrass	k1	2.24	1.04E+14	120	0.97
	k2	2.47	1.96E+10	89	0.99
	k3	0.06	4.75E+10	106	0.99
	k4	1.72	2.59E+13	120	0.98

4.1.2. Dilute Acid Hydrolysis and Enzymatic Hydrolysis Results from FBSCC Work

The major results for the DAH-EH for the FBSCC work are concentrated around the extraction of sugars from willow and poplar tree samples. The sugars considered here are glucose, xylose, galactose, and combined arabinose and mannose. Figures 4 and 5 show the average monomer sugar concentrations (g/L) obtained after dilute acid pretreatment for poplar and willow respectively. Figures 6 and 7 show the average oligomer concentration following dilute acid pretreatment expressed and monomer equivalence for poplar and willow respectively. Figures 8 and 10 show the total monomer extraction for glucose and xylose respectively, through all processing stages, assuming 72 hours of enzymatic hydrolysis for poplar. Figures 9 and 11 show the monomer values as percentages of their theoretical maximum extraction amount. Similarly, Figures 12, 13, 14, and 15 show the results for willow. Average enzymatic sugar liberation versus treatment time diagrams are located in Appendix B.

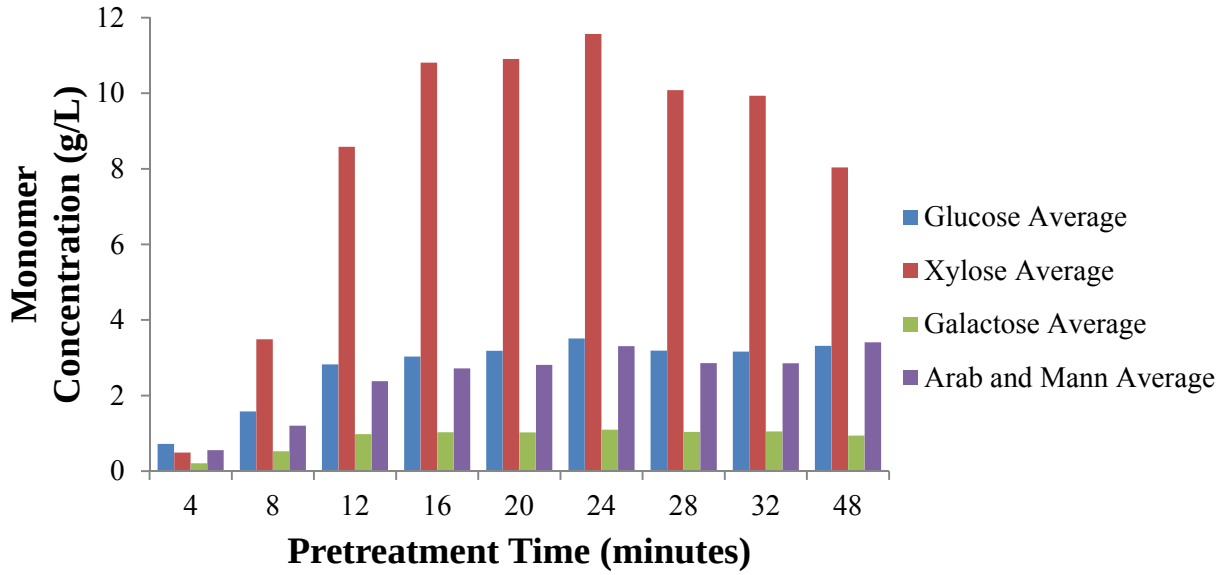

Figure 4: Average monomer concentrations versus reaction time obtained from poplar following dilute acid (0.5% wt. sulfuric acid, 160°C) pretreatment monomer extraction.

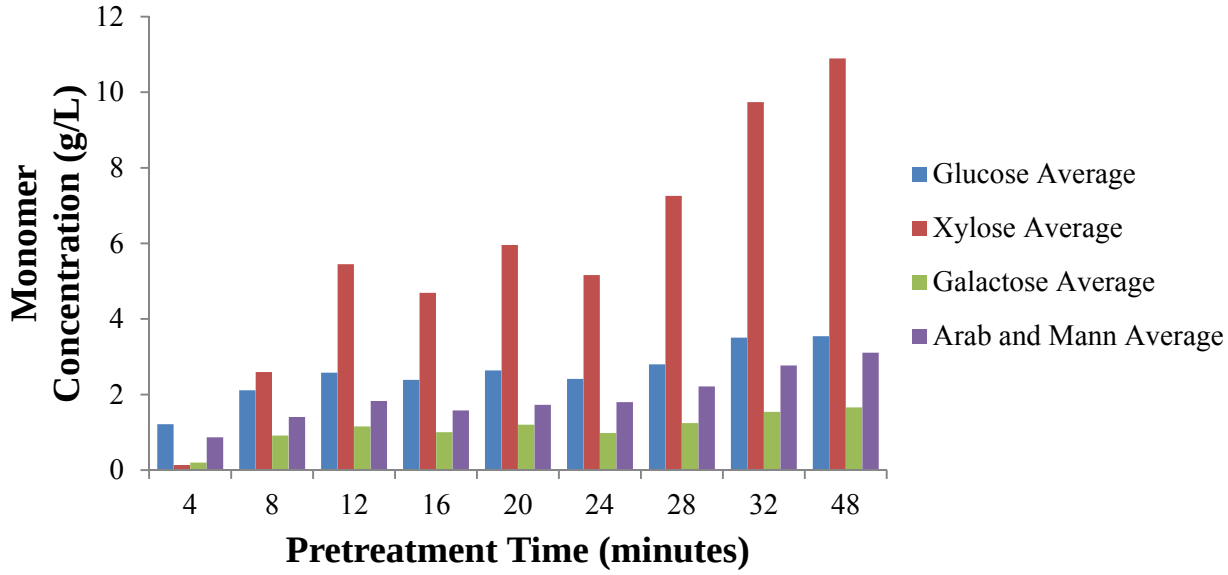

Figure 5: Average monomer concentrations versus reaction time obtained from willow following dilute acid (0.5% wt. sulfuric acid, 160°C) pretreatment monomer extraction.

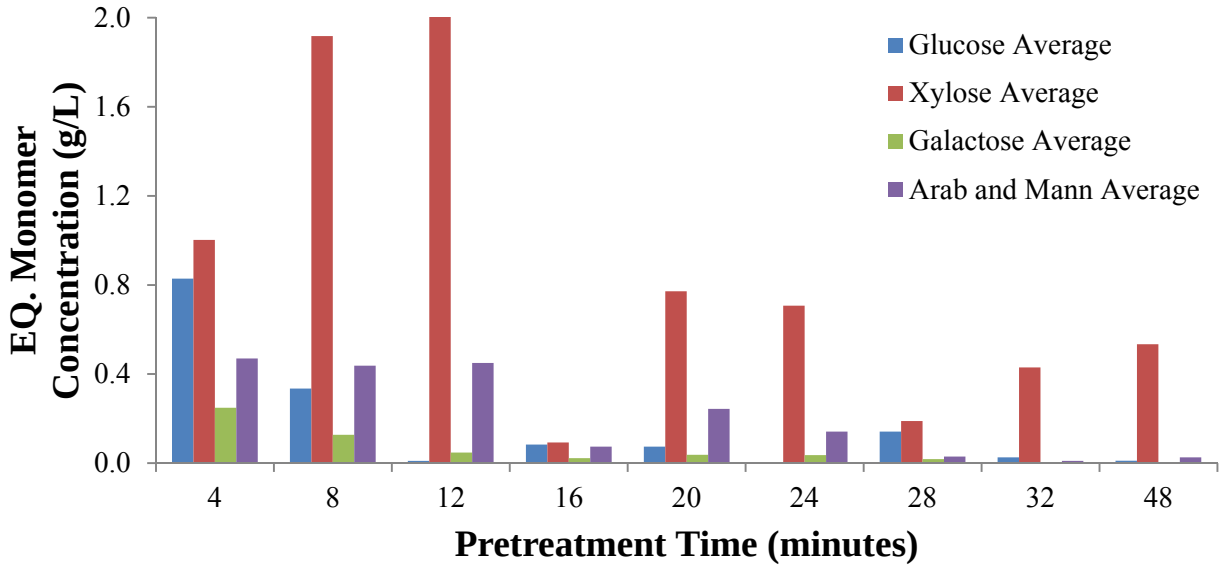

Figure 6: Average oligomer concentrations (expressed as monomer equivalents) versus reaction time obtained from poplar following dilute acid (0.5% wt. sulfuric acid, 160°C) pretreatment monomer extraction.

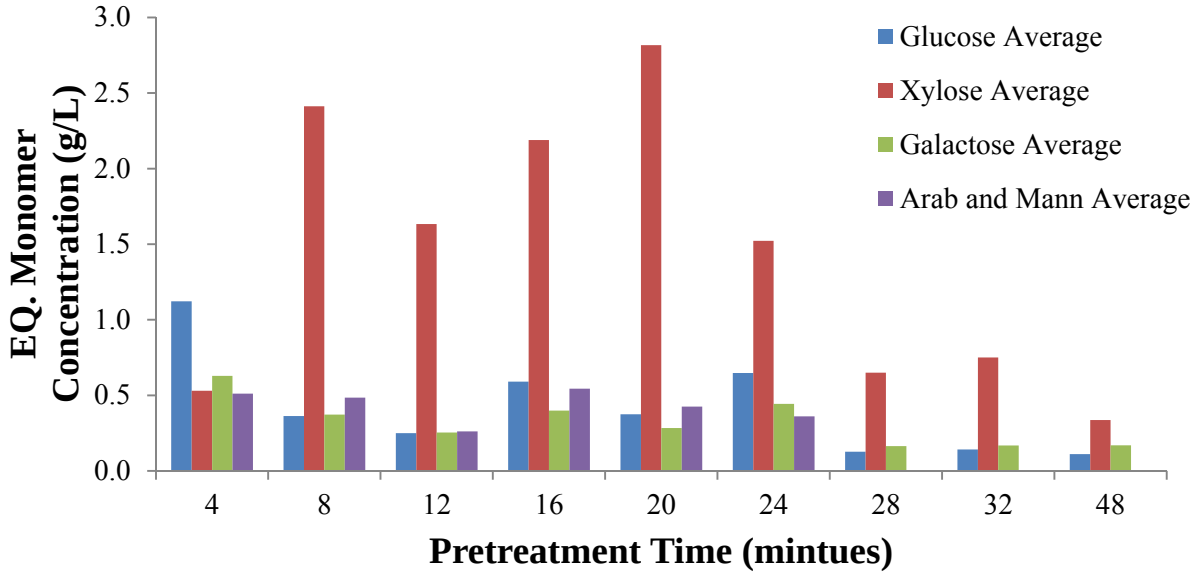

Figure 7: Average oligomer concentrations (expressed as monomer equivalents) versus reaction time obtained from willow following dilute acid (0.5% wt. sulfuric acid, 160°C) pretreatment monomer extraction.

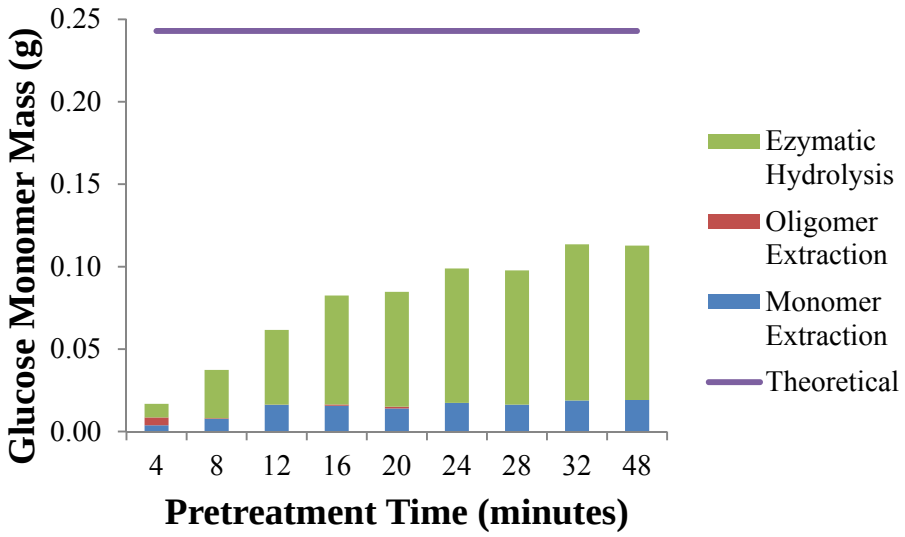

Figure 8: Total glucose monomer mass yields obtained from poplar with acid pretreatment monomer extraction, oligomer extraction, and enzymatic hydrolysis.

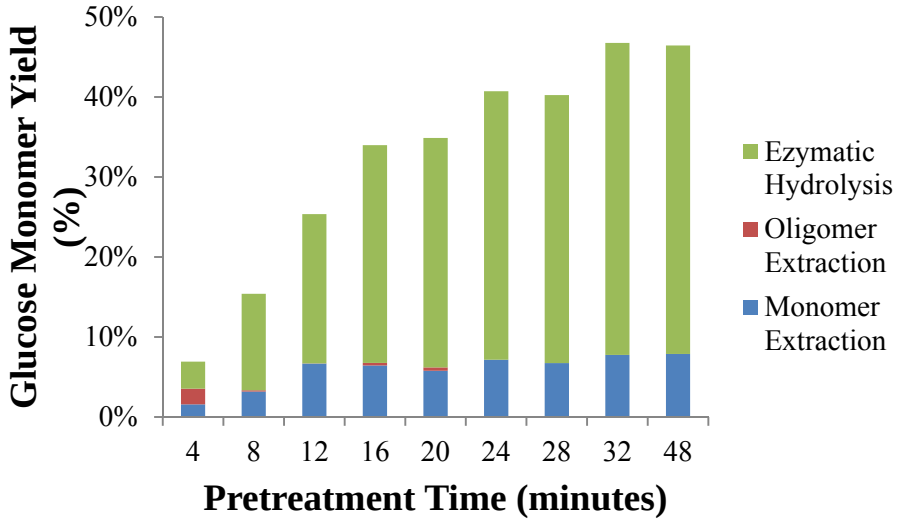

Figure 9: Total glucose monomer yields (% of theoretical) obtained from poplar with acid pretreatment monomer extraction, oligomer extraction, and enzymatic hydrolysis.

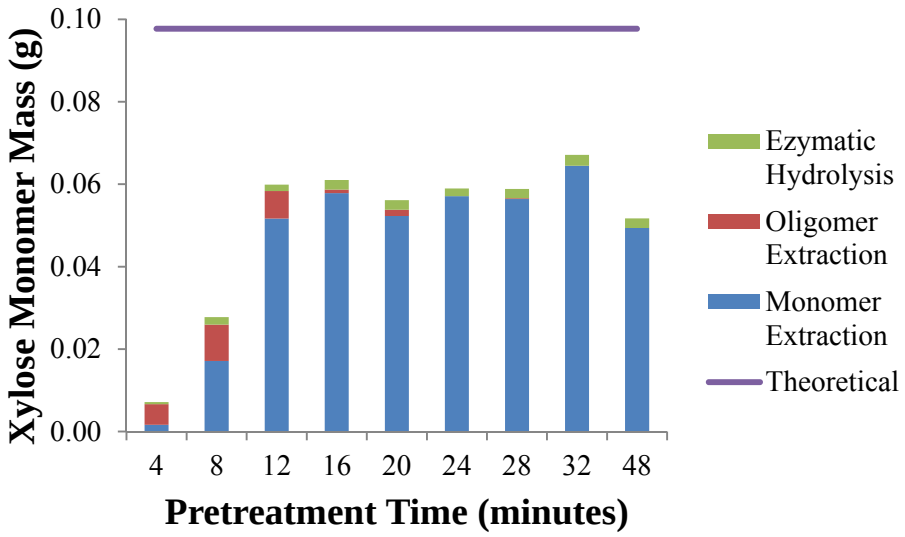

Figure 10: Total xylose monomer mass yields obtained from poplar following acid pretreatment monomer extraction, oligomer extraction, and enzymatic hydrolysis.

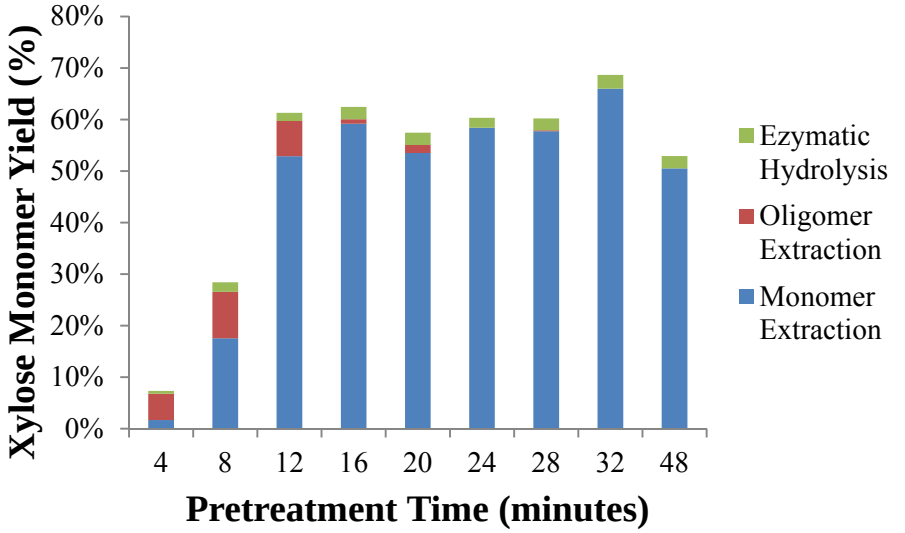

Figure 11: Total xylose monomer yields (% of theoretical) obtained from poplar following acid pretreatment monomer extraction, oligomer extraction, and enzymatic hydrolysis.

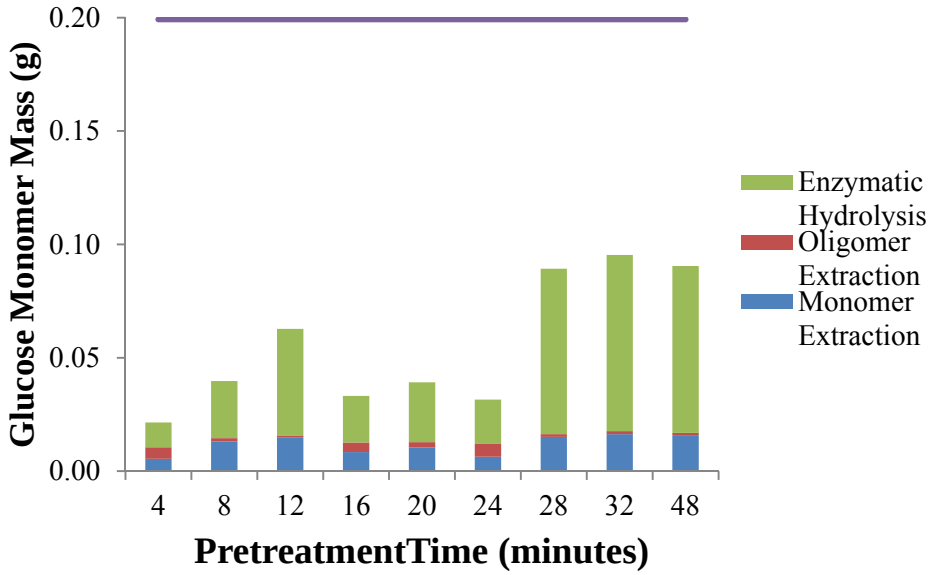

Figure 12: Total glucose monomer mass yields obtained from willow following acid pretreatment monomer extraction, oligomer extraction, and enzymatic hydrolysis.

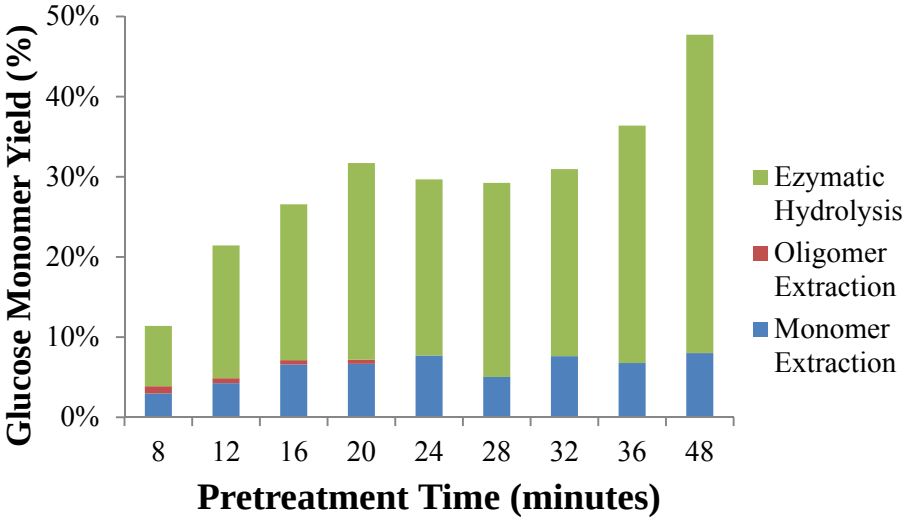

Figure 13: Total glucose monomer yields (% of theoretical) obtained from willow following acid pretreatment monomer extraction, oligomer extraction, and enzymatic hydrolysis

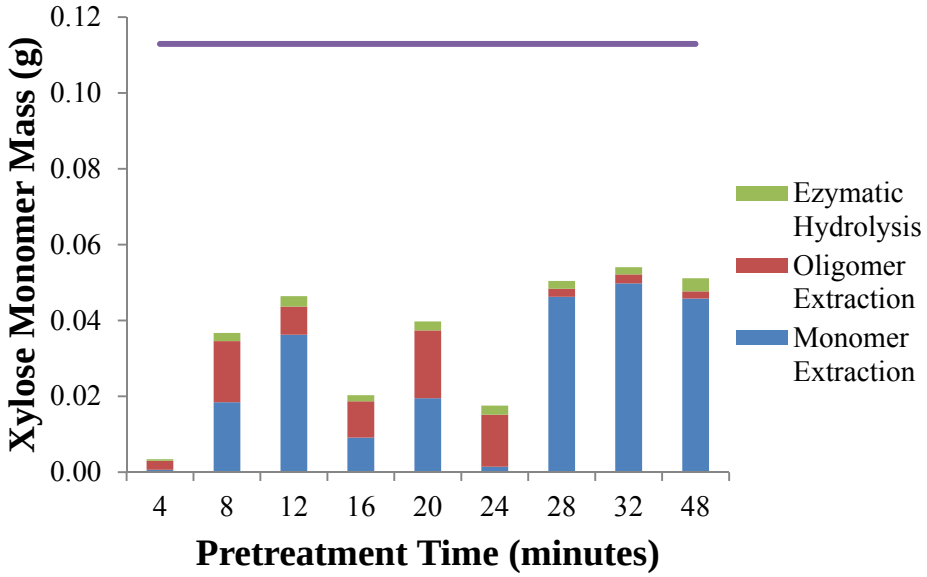

Figure 14: Total xylose monomer mass yields obtained from willow following acid pretreatment monomer extraction, oligomer extraction, and enzymatic hydrolysis.

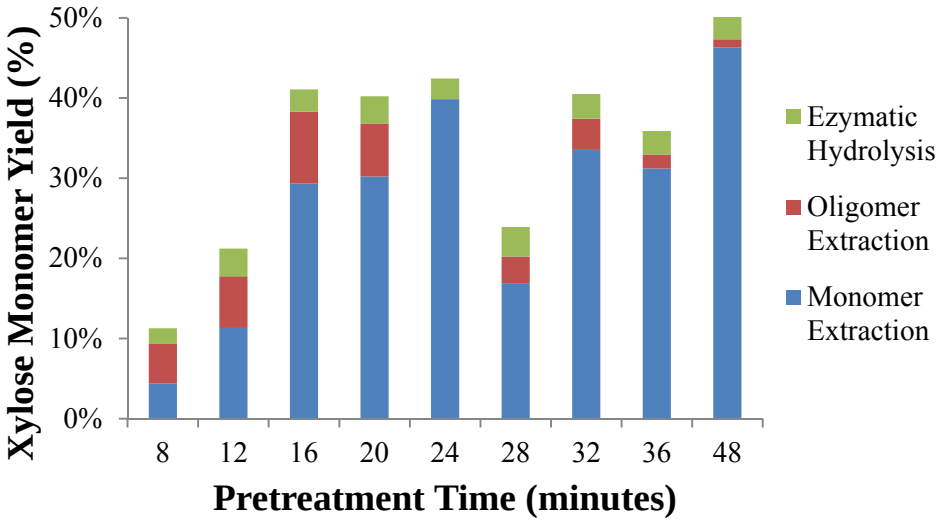

Figure 15: Total xylose monomer yields (% of theoretical) obtained from willow following acid pretreatment monomer extraction, oligomer extraction, and enzymatic hydrolysis.

4.2. Fast Pyrolysis and Gas Chromatography/Mass Spectroscopy Results

As mentioned previously, the main focus for pyrolysis processing results has been split into three categories: (1) phase distribution for targeting desired phase production, (2) bio-oil speciation to identify major components, and (3) product quantification to establish the most abundant compounds.

4.2.1. Fast Pyrolysis Phase Distribution

Figure 16 shows the combined distribution of pyrolysis oil and gas for different feedstocks over a large range of experimental temperatures. The remaining weight percent represents the mass remaining in the experimental vial as bio-coal. Also included in the figure is a literature trend for biomass between 400 and 600˚C (Bridgwater et al., 1999). The feedstocks shown were chosen to represent Michigan hardwoods (aspen), Michigan softwoods (balsam), and Michigan energy crops (switchgrass). Figure 17 shows the data for aspen with an S-curve fit to the data.

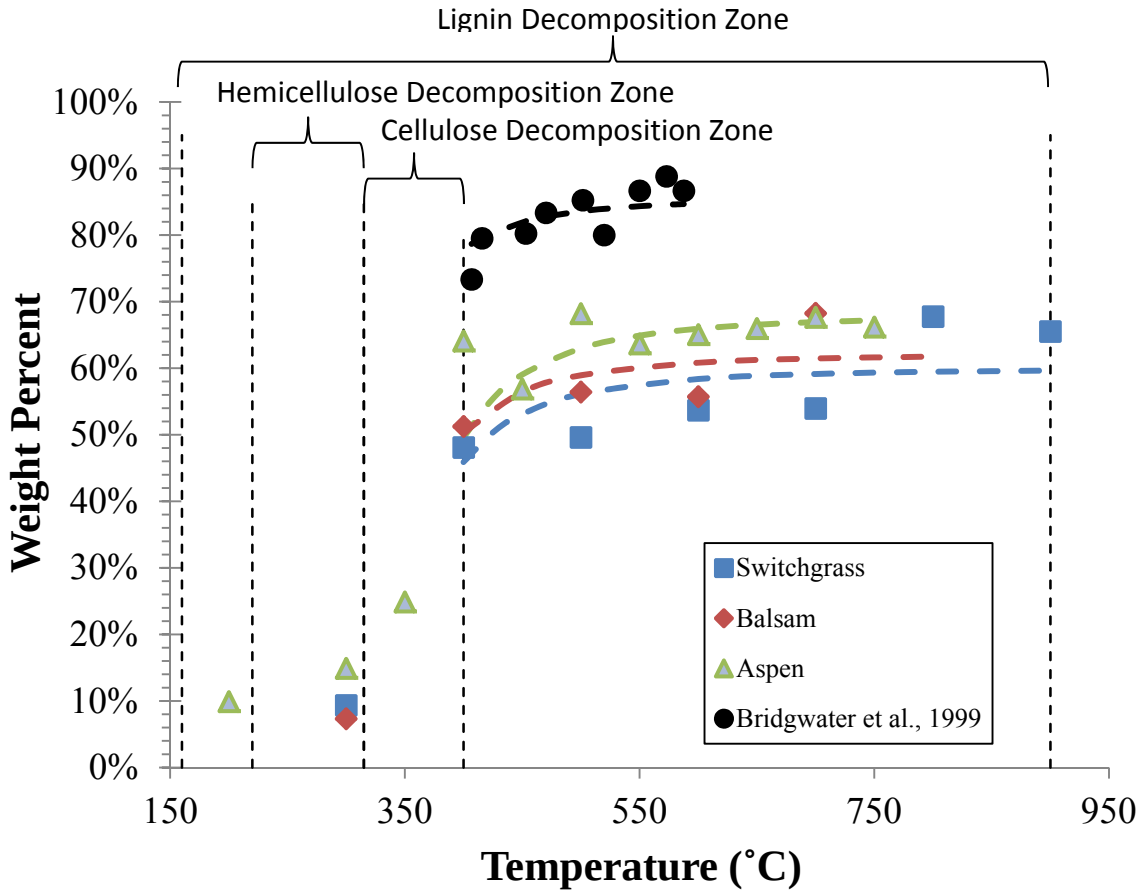

Figure 16: Average weight percents of combined bio-oil and gas products for aspen, balsam, and switchgrass.

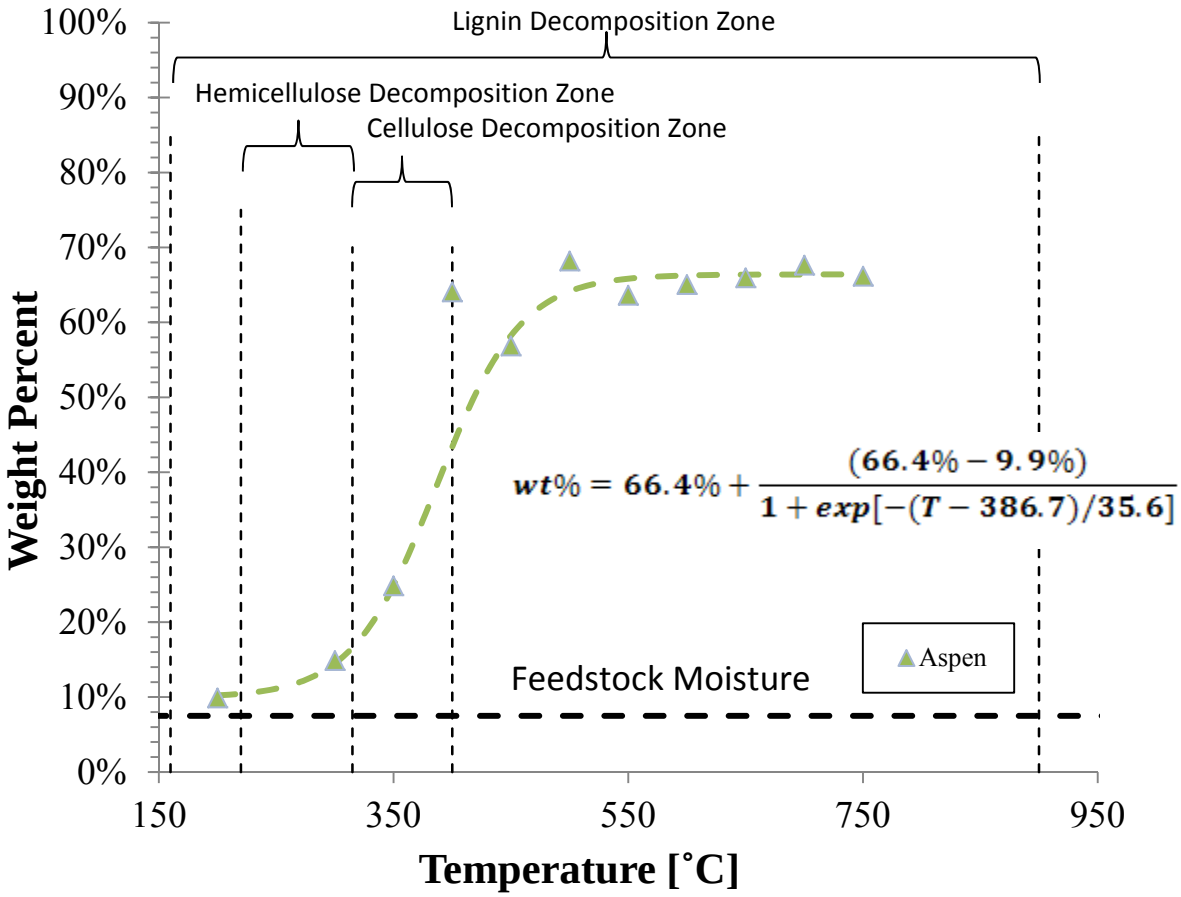

Figure 17: Average weight percents of combined bio-oil and gas products for aspen.

4.2.2. Fast Pyrolysis Product Speciation and Quantification

Many of the fast pyrolysis trials yielded very similar compounds. Because of this, a chromatogram of aspen will be displayed here as a common representative. Full experimental trial data from this section will be included as Appendix C. Figure 18 shows a chromatogram from a trial of aspen at 600˚C. Table 5 is a listing of NIST library results of some of the major peaks in addition to relative area. The tables (6-10) following that form a summary for all feedstock at different temperatures.

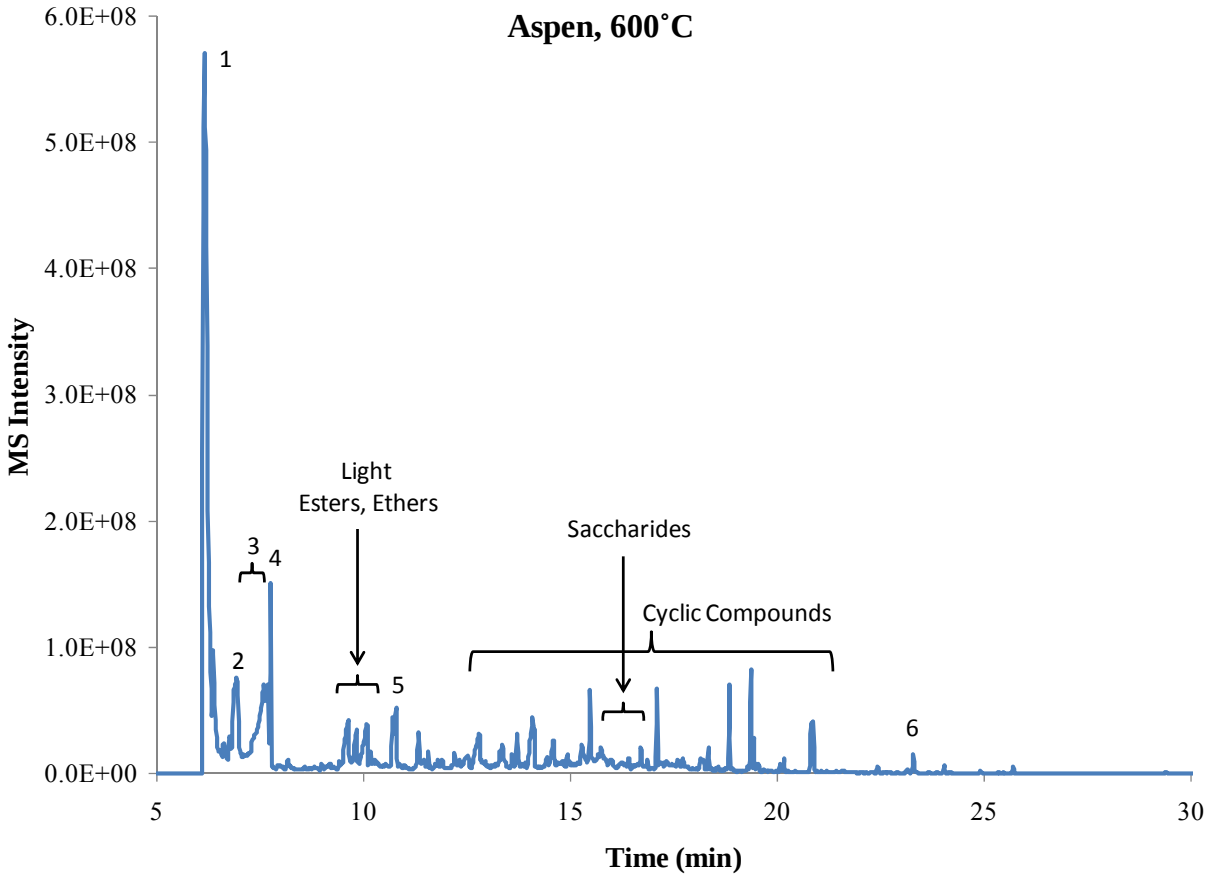

Figure 18: Chromatogram for an aspen trail at 600˚C.

Table 5: Peak identification and quantification for aspen.

		Peak Area		
Retention Time (Min)	**Name**	**500**	**600**	**700**
6.2	CO, CO2, H2O	20.0%	38.8%	53.4%
6.7	Propanal, 2,3-dihydroxy-	1.3%		
7.0	Acetaldehyde, hydroxy-	5.7%	7.7%	10.3%
7.6	Acetic acid	3.1%	12.1%	5.2%
7.8	2-Propanone, 1-hydroxy-	9.6%	11.9%	11.9%
9.6	Acetic acid, methyl ester		2.8%	3.0%
10.1	Acetic anhydride	3.1%		2.8%
10.8	3-Furaldehyde	2.3%	3.5%	2.6%
11.4	2-Furanmethanol	1.4%	1.5%	
11.6	1,2-Ethanediol, diacetate	0.3%		
12.8	Cyclopentanone, 2-methyl-			1.7%
13.7	Phenol			1.2%
14.6	2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	1.6%	2.0%	
15.3	Phenol, 3-methyl-			1.1%
15.5	Phenol, 2-methoxy-	2.4%	1.9%	1.4%
16.7	Benzaldehyde, 3-ethoxy-2-hydroxy-	1.1%		
17.0	Phenol, 2-methoxy-4-methyl-	1.9%	1.5%	0.7%
17.4	4H-Pyran-4-one, 5-hydroxy-2-(hydroxymethyl)-	1.4%		
18.4	2,4-Dimethoxytoluene	1.2%	1.0%	
19.4	Eucalyptol	3.6%	2.9%	1.1%
20.9	Phenol, 2-methoxy-4-(1-propenyl)-, (E)-	3.3%	2.3%	1.0%
22.6	3,4-Dimethoxy-5-hydroxybenzaldehyde	1.1%		
23.5	3-Hydroxycarbofuran	6.7%	0.8%	
24.2	à-D-Glucopyranoside, à-D-glucopyranosyl	5.2%		
25.2	Benzaldehyde, 4-hydroxy-3,5-dimethoxy-	1.8%		
		77.9%	90.7%	97.5%

Table 6: Peak identification and quantification for balsam.

		Peak Area		
Retention Time (Min)	**Name**	**500**	**600**	**700**
6.2	CO, CO2, H2O	44.5%	49.9%	49.7%
7.0	Acetaldehyde, hydroxy-	10.9%	9.4%	9.9%
7.6	Acetic acid	2.8%	3.8%	2.4%
7.8	2-Propanone, 1-hydroxy-	4.8%	7.3%	3.6%
9.6	Acetic acid, methyl ester	2.2%		1.6%
10.8	3-Furaldehyde	1.7%	1.7%	1.4%
11.4	2-Furanmethanol	1.0%		0.7%
12.8	Cyclopentanone, 2-methyl-	1.9%	1.8%	1.4%
13.7	Phenol			1.1%
14.6	2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	1.2%	1.4%	
15.3	Phenol, 3-methyl-	1.2%	2.0%	2.8%
15.5	Phenol, 2-methoxy-	6.5%	4.8%	2.9%
17.0	Phenol, 2-methoxy-4-methyl-	4.8%	3.7%	2.2%
19.4	Eucalyptol	1.5%	1.4%	1.7%
20.9	Phenol, 2-methoxy-4-(1-propenyl)-, (E)-	2.6%	2.1%	2.7%
		87.5%	89.1%	84.2%

Table 7: Peak identification and quantification for poplar.

		Peak Area		
Retention Time (Min)	**Name**	**500**	**600**	**700**
1.0	CO, CO2, H2O	12.6%	14.9%	17.3%
1.7	Acetaldehyde, hydroxy-	4.1%	3.3%	4.9%
2.2	Acetic acid	4.4%	4.8%	5.6%
2.5	2-Propanone, 1-hydroxy-	3.9%	3.1%	2.9%
4.8	Acetic acid, methyl ester	1.3%	1.3%	2.7%
5.7	3-Furaldehyde	1.2%	1.3%	1.3%
6.2	2-Furanmethanol	1.2%	1.0%	0.9%
8.6	Phenol		3.5%	2.9%
9.5	2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	1.0%	1.0%	0.9%
10.2	Phenol, 3-methyl-			0.7%
10.4	Phenol, 2-methoxy-	0.9%	1.5%	1.1%
12.1	Phenol, 2-methoxy-4-methyl-	0.9%		1.4%
15.0	Eucalyptol	0.4%	0.7%	4.4%
15.2	Phenol, 2-methoxy-4-(1-propenyl)-	0.1%		
16.0	Phenol, 2-methoxy-4-propyl-	0.2%		
17.1	à-D-Glucopyranoside, à-D-glucopyranosyl	4.5%		
17.6	Phenol, 2-methoxy-4-propyl-	0.4%	0.5%	0.6%
18.3	3-Hydroxycarbofuran	2.9%	3.5%	3.2%
		40.0%	40.4%	47.1%

Table 8: Peak identification and quantification for red maple.

		Peak Area		
Retention Time (Min)	**Name**	**500**	**600**	**700**
6.2	CO, CO2, H2O	53.9%	53.2%	53.2%
7.0	Acetaldehyde, hydroxy-	5.2%	2.2%	2.0%
7.6	Acetic acid	6.6%	5.3%	4.8%
7.8	2-Propanone, 1-hydroxy-	8.6%	6.4%	8.2%
9.6	Acetic acid, methyl ester	1.5%	2.3%	1.4%
10.8	3-Furaldehyde	2.4%	2.8%	2.6%
11.4	2-Furanmethanol	1.6%		
12.8	Cyclopentanone, 2-methyl-	2.1%		1.6%
13.7	Phenol			1.2%
14.6	2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	1.5%		1.2%
15.3	Phenol, 3-methyl-		0.9%	1.5%
15.5	Phenol, 2-methoxy-	2.5%	2.3%	1.9%
17.0	Phenol, 2-methoxy-4-methyl-	1.2%	1.2%	0.9%
18.4	Phenol, 2-methoxy-4-propyl-	0.5%	1.0%	1.4%
19.4	Eucalyptol	1.8%	2.5%	2.7%
20.9	Phenol, 2-methoxy-4-(1-propenyl)-, (E)-	0.6%	1.3%	2.2%
23.4	3-Hydroxycarbofuran			0.7%
		90.0%	81.5%	87.2%

Table 9: Peak identification and quantification for willow.

		Peak Area		
Retention Time (Min)	**Name**	**500**	**600**	**700**
1.2	CO, CO2, H2O	11.4%	14.1%	13.9%
1.7	Acetaldehyde, hydroxy-	3.9%	3.6%	4.8%
2.4	Acetic acid	3.7%	3.6%	3.5%
2.5	2-Propanone, 1-hydroxy-	4.2%	2.6%	1.8%
4.9	Acetic acid, methyl ester	0.8%	1.4%	1.5%
5.7	3-Furaldehyde	1.5%	1.5%	1.2%
6.2	2-Furanmethanol	1.0%	0.9%	0.7%
7.6	Cyclopentanone, 2-methyl-	2.1%	2.4%	1.7%
8.7	Phenol	0.8%	1.4%	1.0%
9.5	2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	0.8%	1.0%	0.7%
9.9	Phenol, 3-methyl-	0.2%	1.5%	2.0%
10.5	Phenol, 2-methoxy-	1.1%	1.8%	1.5%
12.1	Phenol, 2-methoxy-4-methyl-	1.4%	2.1%	1.8%
14.4	Eucalyptol	5.7%	6.0%	6.3%
15.18	Phenol, 2-methoxy-4-(1-propenyl)-, (E)-	0.3%	0.3%	
17.85	à-D-Glucopyranoside, à-D-glucopyranosyl		1.5%	
18.5	3-Hydroxycarbofuran	7.5%	5.3%	10.3%
		46.3%	50.9%	52.5%

Table 10: Peak identification and quantification for switchgrass.

		Peak Area		
Retention Time (Min)	**Name**	**500**	**600**	**700**
6.2	CO, CO2, H2O	50.6%	54.1%	49.3%
7.0	Acetaldehyde, hydroxy-	2.1%	1.6%	1.7%
7.6	Acetic acid	6.8%	7.4%	6.1%
7.8	2-Propanone, 1-hydroxy-	8.3%	6.7%	8.0%
9.6	Acetic acid, methyl ester	1.6%		1.4%
10.8	3-Furaldehyde	2.7%	2.9%	2.2%
12.8	Cyclopentanone, 2-methyl-	1.5%	0.6%	
13.7	Phenol			2.5%
14.6	2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	2.0%	1.6%	1.9%
15.3	Phenol, 3-methyl-	1.8%	1.2%	2.6%
15.5	Phenol, 2-methoxy-	3.6%	2.9%	2.6%
17.0	Phenol, 2-methoxy-4-methyl-	0.9%	0.8%	0.9%
19.4	Eucalyptol	0.9%	0.9%	1.4%
20.9	Phenol, 2-methoxy-4-(1-propenyl)-, (E)-	0.5%	0.6%	0.8%
		83.3%	81.1%	81.4%

Biomass gasification takes place with increasing pyrolysis temperature. Gasification is generally considered to take place at temperature of 700˚C or greater. Figure 19 shows the shift in products as pyrolysis temperature approach and enter the gasification range for aspen. Figures 20 through 25 show the average composition of the gas phase for each feedstock. Gasification of aspen to a very high temperature (900C) is shown in Figure 21 to establish a trend to high gasification temperatures. Hydrogen was excluded from most figures due to it very minimal contribution (<1%).

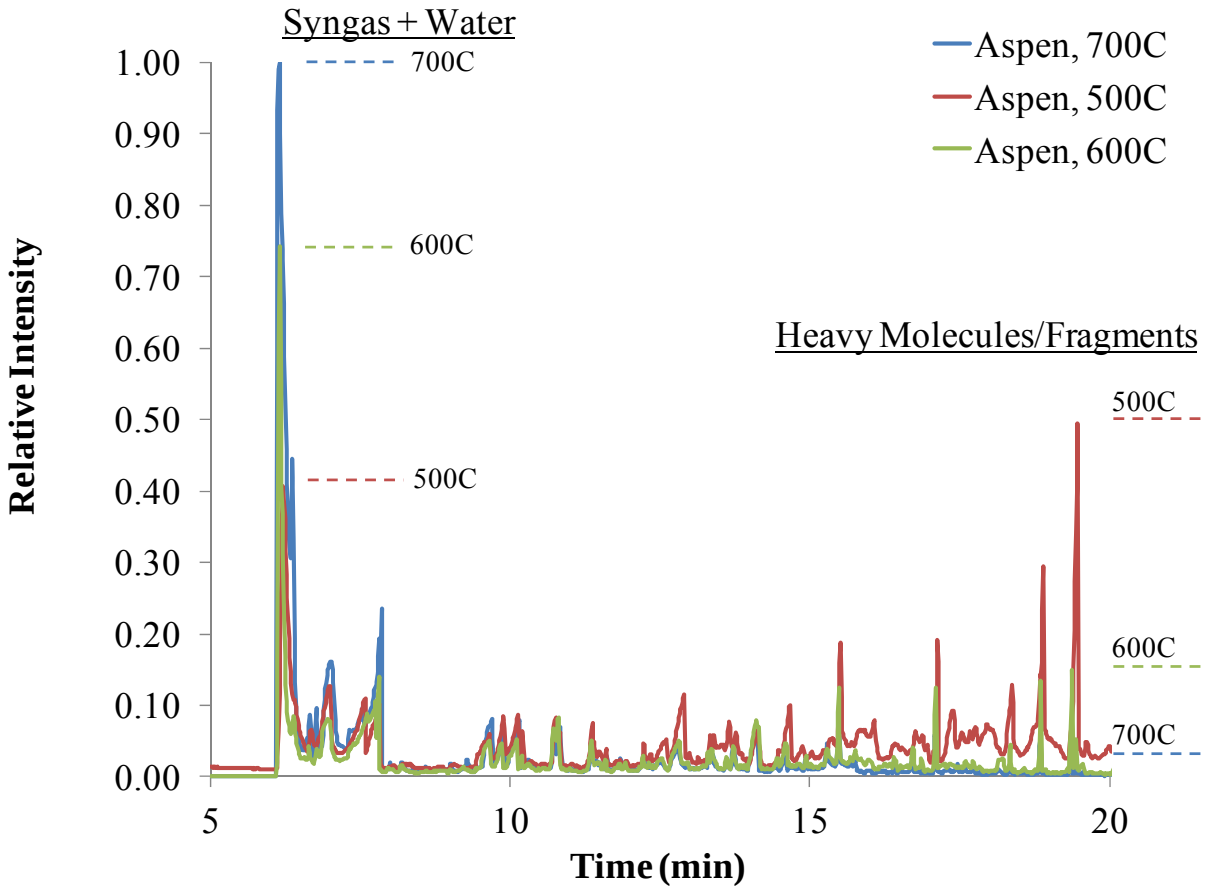

Figure 19: Change in product distribution for varying fast pyrolysis temperatures.

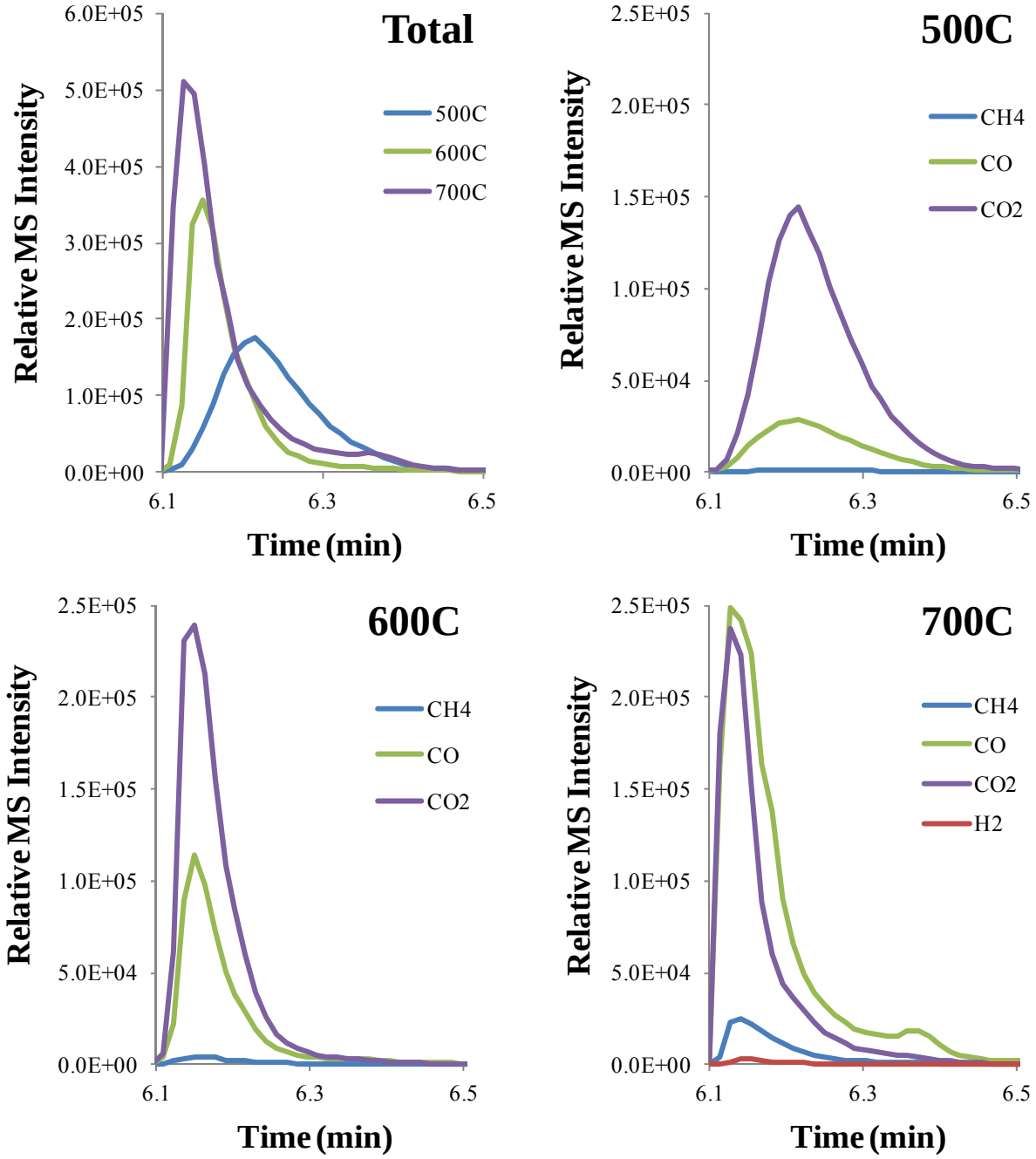

Figure 20: Effect of temperature on gaseous species yield for aspen.

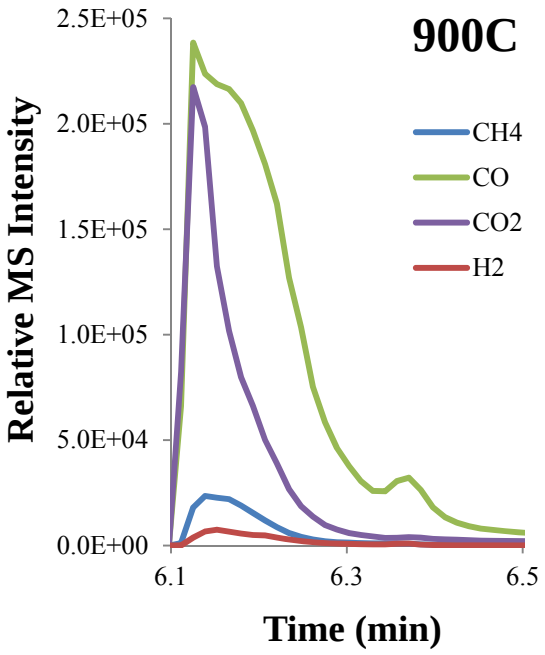

Figure 21: Aspen gasification at 900C

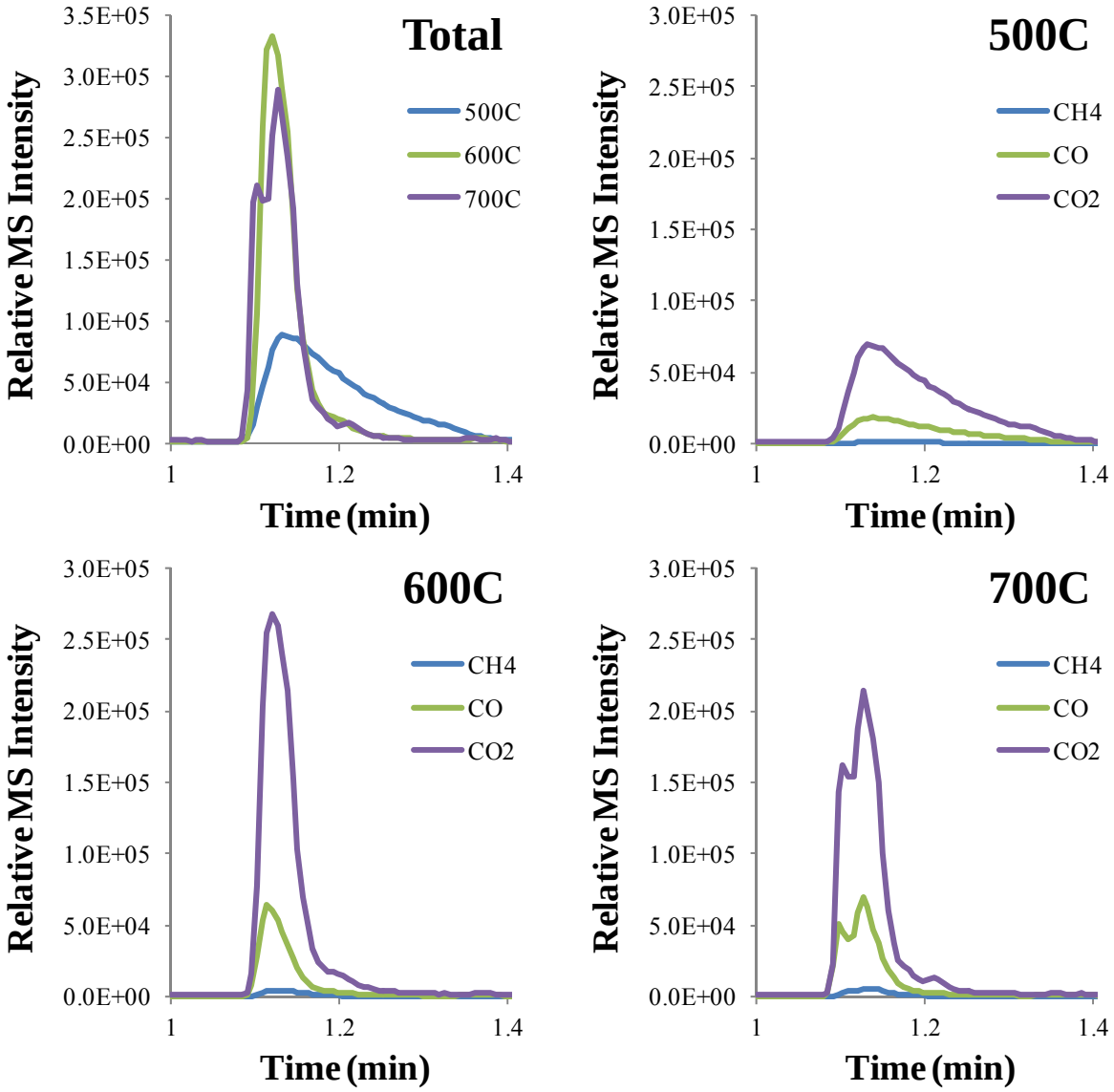

Figure 22: Effect of temperature on gaseous species yield for poplar.

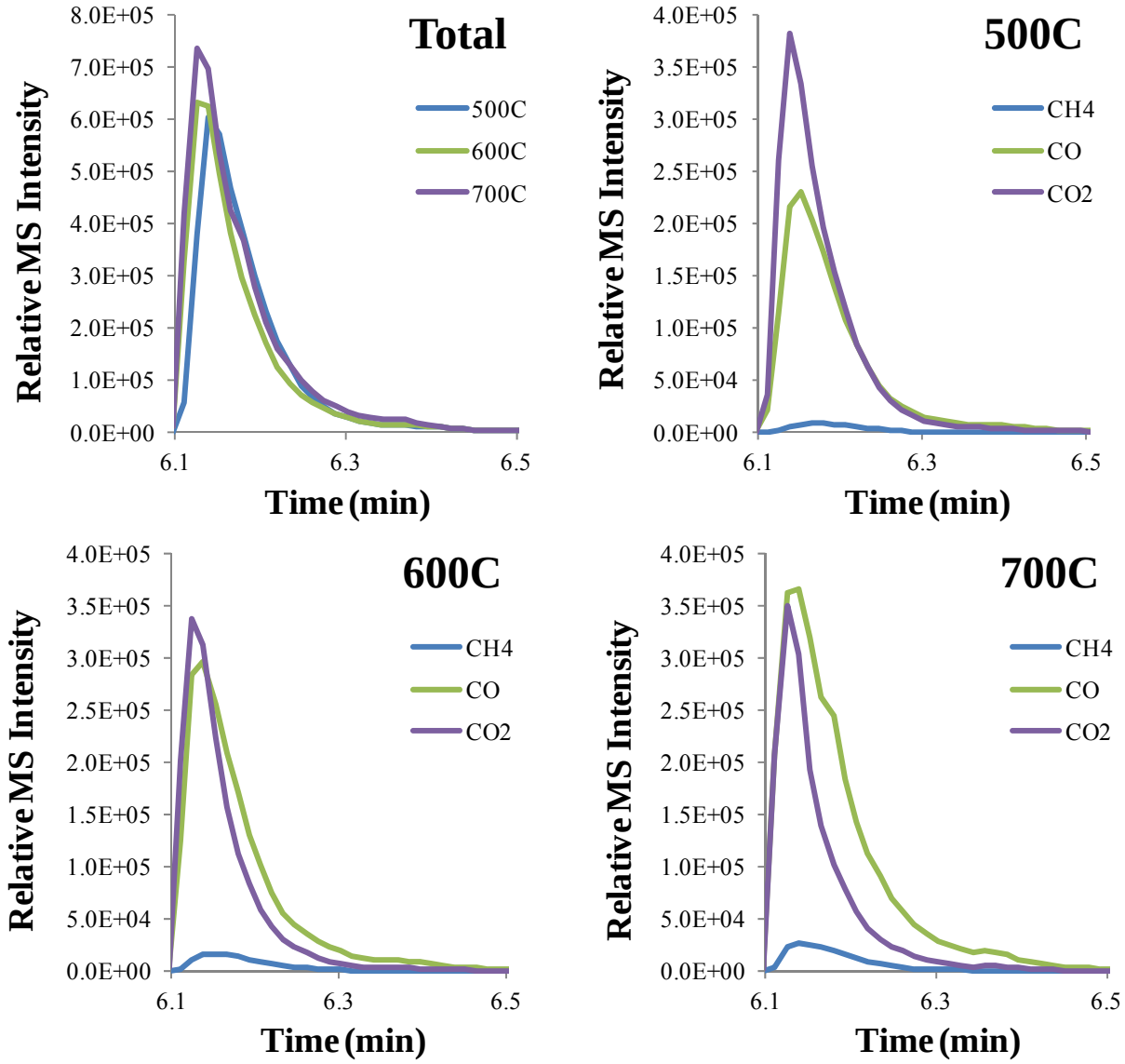

Figure 23: Effect of temperature on gaseous species yield for balsam.

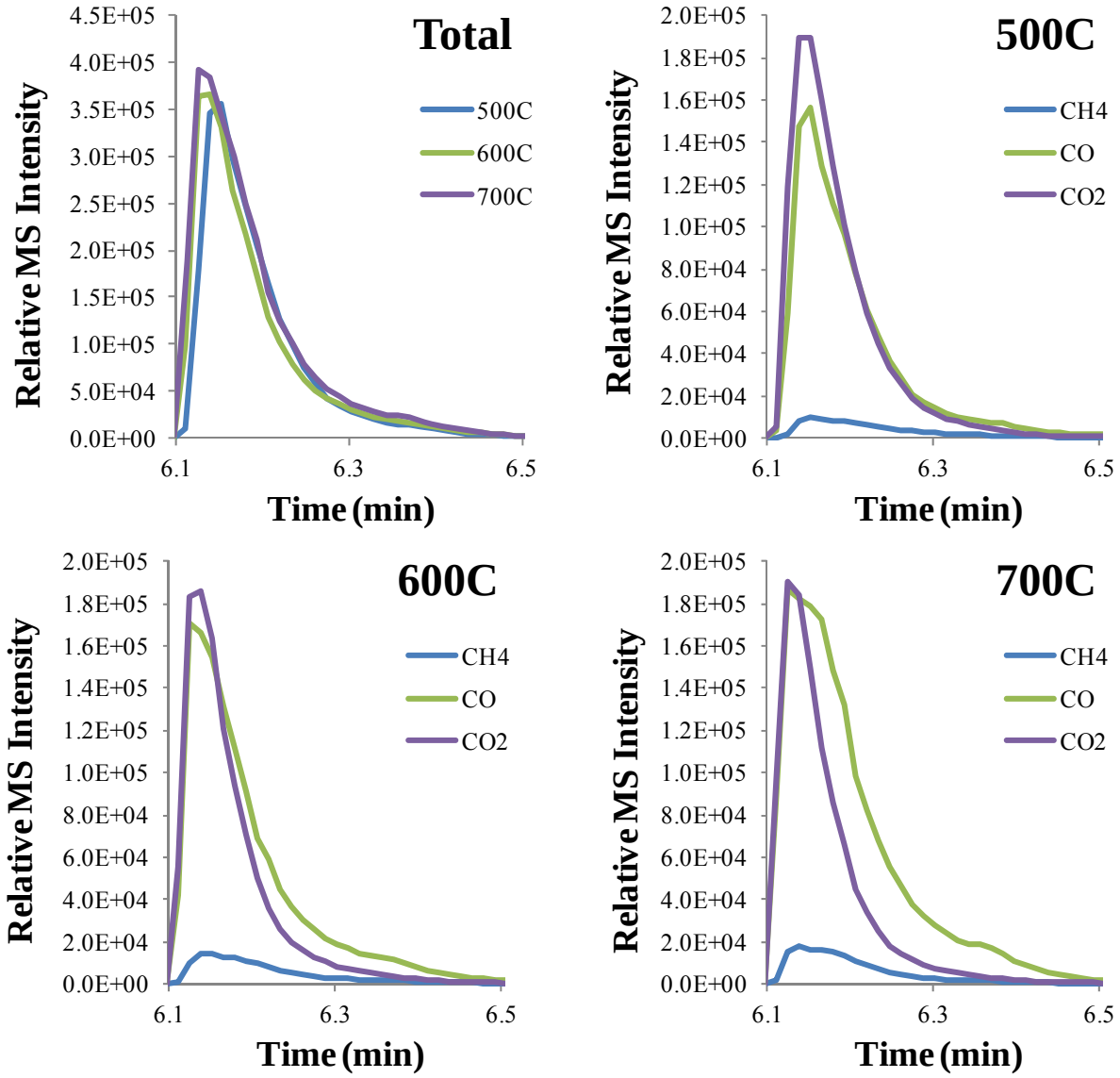

Figure 24: Effect of temperature on gaseous species yield for red maple.

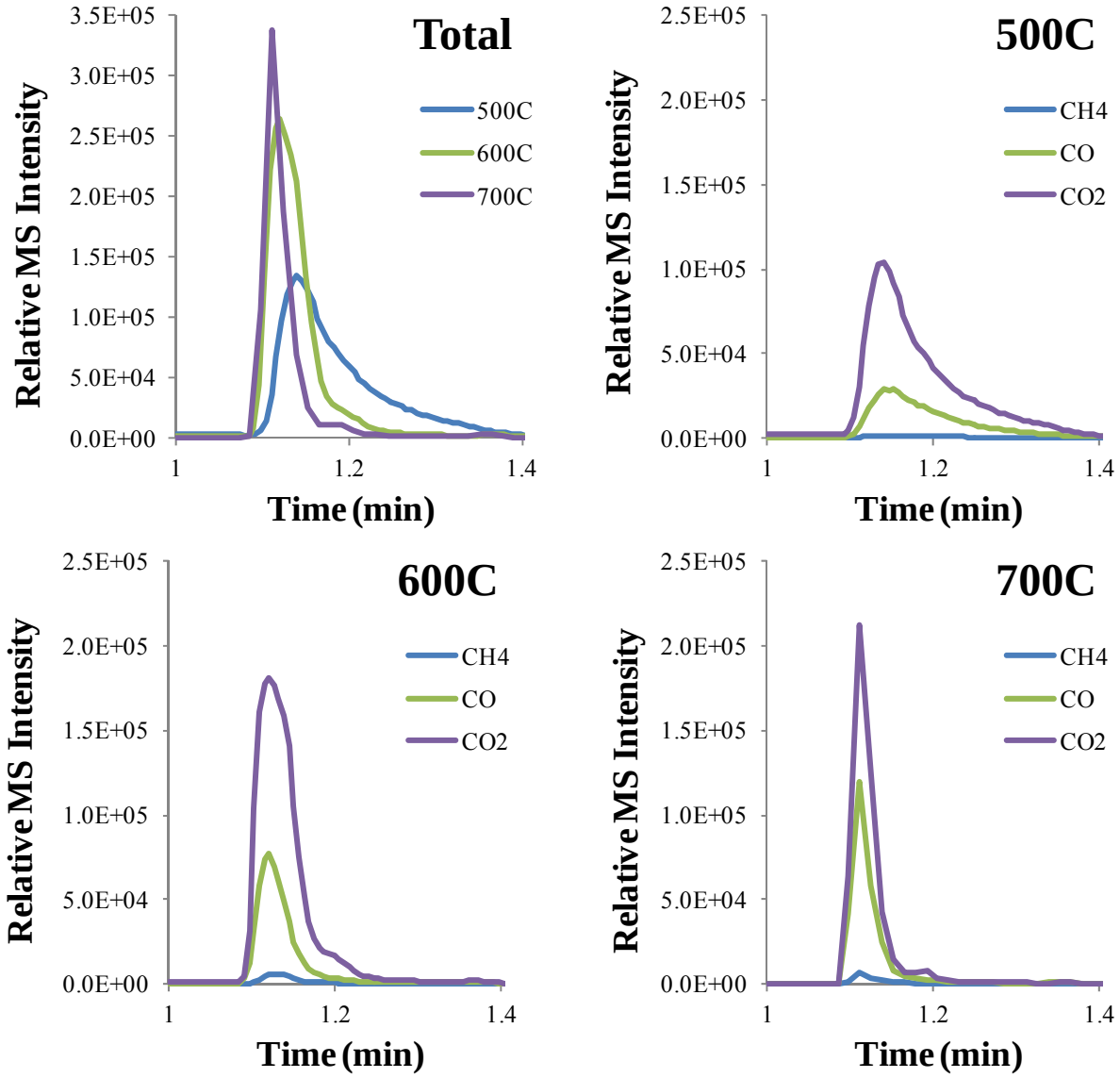

Figure 25: Effect of temperature on gaseous species yield for willow.

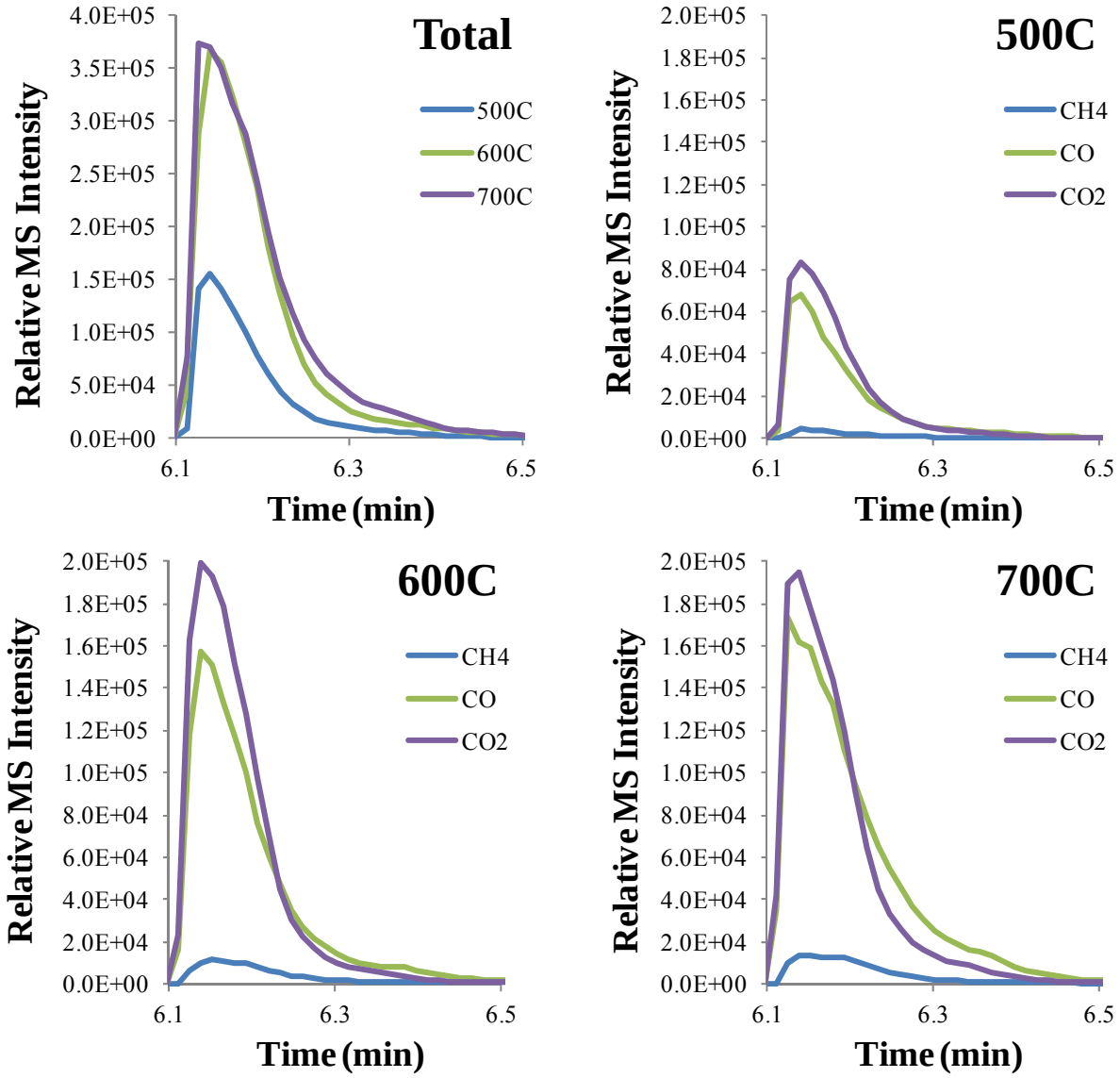

Figure 26: Effect of temperature on gaseous species yield for switchgrass.

5. Discussion

5.1. Hydrolysis Discussion

The hydrolysis results shown in Figures 4-15 are similar to results we have obtained previously using other forest feedstocks, but the overall sugar yields are lower in comparison. Dilute acid pretreatment of poplar and willow both display xylose as being the most prevalent monomer sugar. Xylose concentrations peak increase with pretreatment time for poplar, and then decline as monomer xylose is converted to furfural byproduct. This behavior of the xylose concentration is similar to that observed for other forest feedstocks and is consistent with the known reaction mechanisms for dilute acid hydrolysis. For willow, concentration of xylose continues to increase with reaction time and does not show indication of producing byproduct furfural from monomer xylose. Xylose accounts for more than half of the total monomer sugar concentration for both feedstocks. This compositional dominance is particularly evident at reaction times greater than 24 minutes in willow, and 8 minutes for poplar. Maximum xylose concentrations reach nearly 12 g/L at a reaction time of and 48 minutes for willow, and 24 minutes for poplar. It is generally understood that xylose is the main monomer component of hemicelluloses, which is the portion of biomass most readily attacked by dilute acid treatment.

Another important feature of our dilute acid hydrolysis results is the change in concentration of oligomer sugars over time during the reaction (Figures 6 and 7). Oligomer sugars are incomplete products of hydrolysis from the hemicelluloses (predominantly) and cellulose (minor) fractions of the wood. These molecules are intermediates between the native hemicelluloses and cellulose and the monomer sugars. Oligomer concentrations peak at early reaction times during dilute acid hydrolysis as carbohydrate break-down is initiated, these concentrations then decline as reaction time increases. Understanding oligomer sugar changes during a reaction is important because oligomers are not as fermentable as monomer sugars; reaction conditions should be adjusted to minimize oligomer sugar production and maximize monomer sugar generation.

Products of enzymatic hydrolysis of pre-treated poplar and willow are also shown in Appendix B. Glucose is the only monomer product of significance for enzymatic hydrolysis in these samples. This is expected because hemicellulose is nearly completely consumed and converted to monomer sugars after dilute acid hydrolysis. The only surprising result from these dilute acid and enzymatic hydrolysis experiments on poplar and willow is the relatively low total sugar yields (monomer and oligomer sugars) following the combined hydrolysis treatments. One reason for this might be that we do not know the composition of these feedstocks with high enough accuracy to complete a valid mass balance. Another explanation could be that the carbohydrate fractions of these feedstocks are more recalcitrant than for other forest feedstocks. Which of these reasons is correct is not yet understood and is beyond the scope of our preliminary processibility analysis for the FBSCC project.

From these hydrolysis experiments, we conclude that poplar and willow exhibit similar reaction behavior compared to other forest feedstocks studied previously with our experimental process (aspen, balsam, switchgrass, basswood, red maple), but that the yields are somewhat lower than previously expected for hardwood samples.

5.2. Pyrolysis Discussion

Figure 16 shows that there are large amounts (50-70%) of bio-oil and gas products that can be produced from the investigated feedstocks at the targeted experimental conditions. While our data suggests that the yields are lower than previous studies have found, the same general trend is observed in the temperature regions of interest for bio-oil production (500-700˚C). In addition, Figure 17 illustrates how the char formation (thus oil and gas) is affected by pyrolysis temperature through the degradation stages of cellulose, hemicelluloses, and lignin. At temperatures at or below 200˚C there is very little activity in the biomass, and the change in mass can be attributed to initial feedstock moisture. This moisture would appear in the collectable bio-oil. Over the hemicelluloses decomposition range, the mass appears to decease another 5-10% which agrees well with the previously cited 14.6% xylan content of aspen (Table 1). Similarly, the area around the cellulose decomposition range can have an impact of 30-50% which is close to the glucan concentration of 52%.

With over 300 compounds (Mohan et al, 2006) expected to reside in the bio-oil, it is a daunting task to characterize and quantify the product distribution. From this work, however, it is noticed that the majority (approximately 75%) of mass appears in only a small number of components. Based on the relative peak areas as detected by the GC/MS, it was found that approximately 30% of the oil phase is comprised of glycolaldehyde, acetic acid, acetol, aldehydes (such as 3-furaldehyde), and other well-known heavy products (such as 3-hydroxycarbofuran). The calculated acetic acid contribution is in agreement with another study done on hemicellulosic decomposition in rice husks which cites 14.5% acetic acid content in the resulting bio-oil (Isa et al., 2011). The calculated area for the combined CO, CO_2, and H_2O peak is also in agreement with combined water and gas literature values ranging from 35-45% (Bridgwater et al., 1999).

As the pyrolysis temperatures approach gasification ranges, the products were observed to shift more towards light oxygenated compounds and gaseous species. As Figure 19 clearly demonstrates, many of the heavier molecules such as phenolics or poly-phenolics (that would normally reside in the bio-oil) are further broken down into gaseous species. The figures that follow (20-26) show the gaseous breakdown for the investigated species as temperature increases. In addition to the aforementioned trends, these figures also illustrate that the species most affected by the temperature are the formation of carbon monoxide and methane. Hydrogen was also observed, but at very low quantities (<1%) even at the highest pyrolysis temperature. Because of this it was included in Figure 20 for completeness, but excluded from the others.

6. Conclusions

For the purposes of this preliminary study, our results agree well with existing literature, indicating that Michigan grown woody feedstocks can be processed to valuable product intermediates through either investigated method. This work found that processing woods such as poplar and willow through dilute acid pretreatment and enzyme hydrolysis yields greater than 50% of the total biomass-embodied sugars. These sugars can then be utilized for such processes as fermentation to ethanol. Secondly, this study found that within the investigated 500-700˚C fast pyrolysis temperature range, yields of greater than 50% mass can be expected for the combined bio-oil and gas phases. In addition, the bio-oil was found to be comprised mostly of hydroxyaldehydes (such as glycolaldehyde), hydroxyketones, sugar varients (such as levoglucosan), carboxylic acids (such as acetic and formic acid), and phenolics or cyclic compounds.

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Appendix A: Example HPLC Sugar Calibration Curve

The sugar standards are prepared prior to experiments and have known quantities of monomer sugars. The sugar standards' names are descriptive of their xylose concentration, i.e. a sugar standard with a zylose concentration of 2g/L is SS 2. The values used are integrated peak signal intensities obtained from the HPLC detector. The effective peak area obtained from integrating signal over time is then correlated to the standards' known concentrations.

Table 1: Concentrations of monomer Sugar Standards (SS) used in HPLC calibration.

Sugar Standard Composition

Sample	Xylose (g/L)	Glucose (g/L)	Galactose (g/L)	Arabinose (g/L)	Mannose (g/L)
SS 2	2.0	0.8	0.4	0.4	0.8
SS 5	5.0	2.0	1.0	1.0	2.0
SS 10	10.0	4.0	2.0	2.0	4.0
SS 15	15.0	6.0	3.0	3.0	6.0

Table 2: HPLC monomer sugar calibration curve values. Data Values are Refractive Index Signal Area [nRIU*s].

Sugar Standards 1, Before DAH Analysis

	Glucose	Xylose	Galactose	Ar. + Man.
Retention Time (min)	12.54	13.69	14.71	16.40
Sample				
SS 2	1.19E+05	2.82E+05	5.51E+04	1.75E+05
SS 5	2.95E+05	7.05E+05	1.45E+05	4.37E+05
SS 10	5.92E+05	1.41E+06	2.94E+05	8.73E+05
SS 15	8.82E+05	2.10E+06	4.40E+05	1.30E+06
Fit Slope	5.89E+04	1.41E+05	2.93E+04	8.69E+04

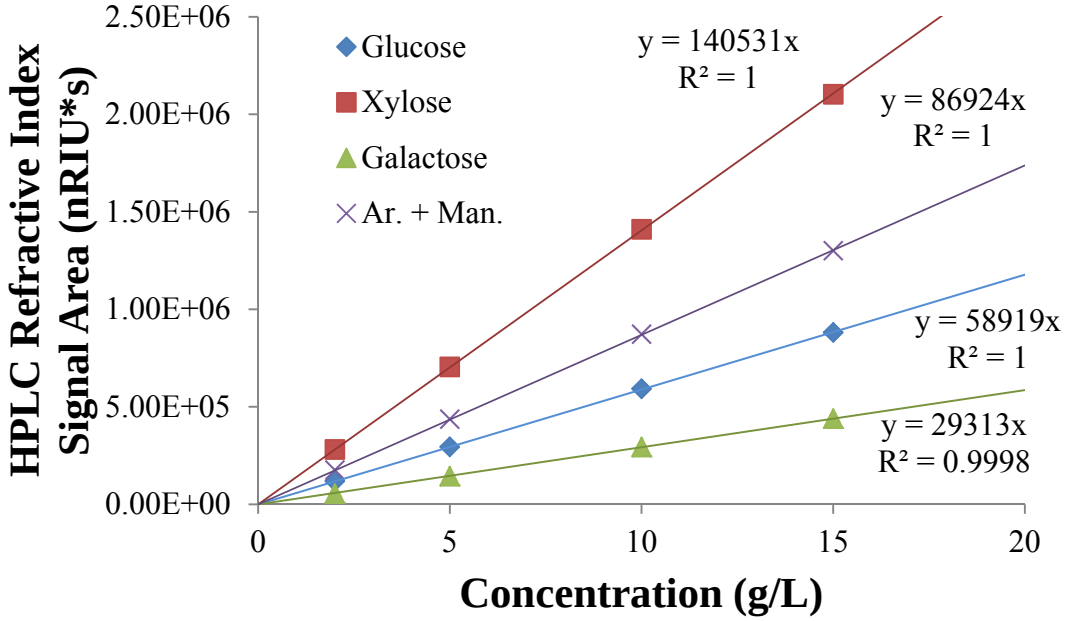

Figure 1: HPLC monomer sugar calibrations. Refractive Index Signal Area obtained from the HPLC detector is correlated to the known sugar concentrations.

Appendix B: Enzymatic Hydrolysis Production Curves

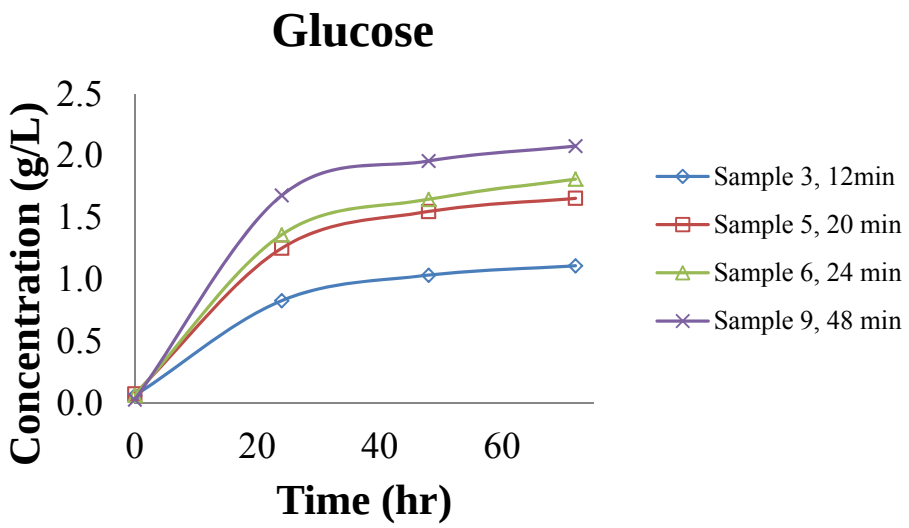

Figure 1: This figure represents glucose liberated from poplar through enzymatic hydrolysis as a function of reaction time . Samples were taken at approximately 0, 24, 48, and 72 hours for the peak acid pretreatment time(24mins) along with its half(12min) and double time(48min).

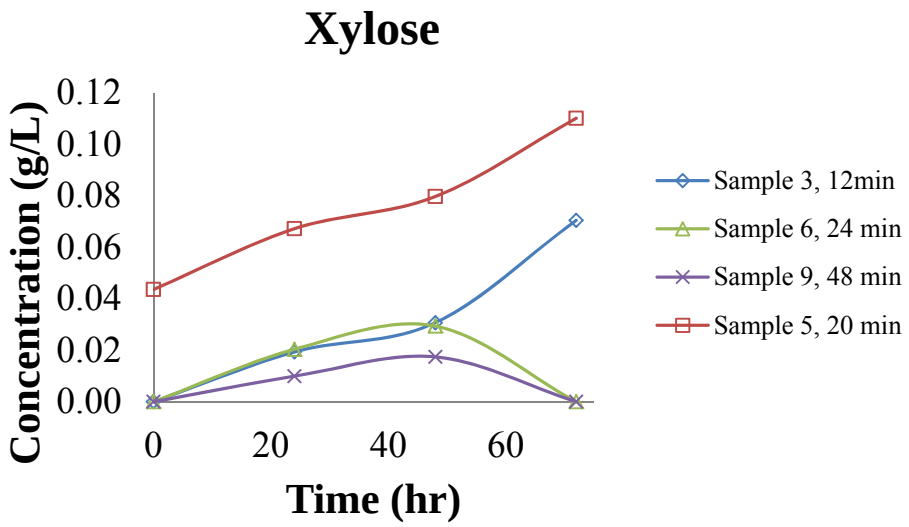

Figure 2: This figure represents xylose liberated from poplar through enzymatic hydrolysis as a function of reaction time. Samples were taken at approximately 0, 24, 48, and 72 hours for the peak acid pretreatment time(24mins) along with its half(12min) and double time(48min).

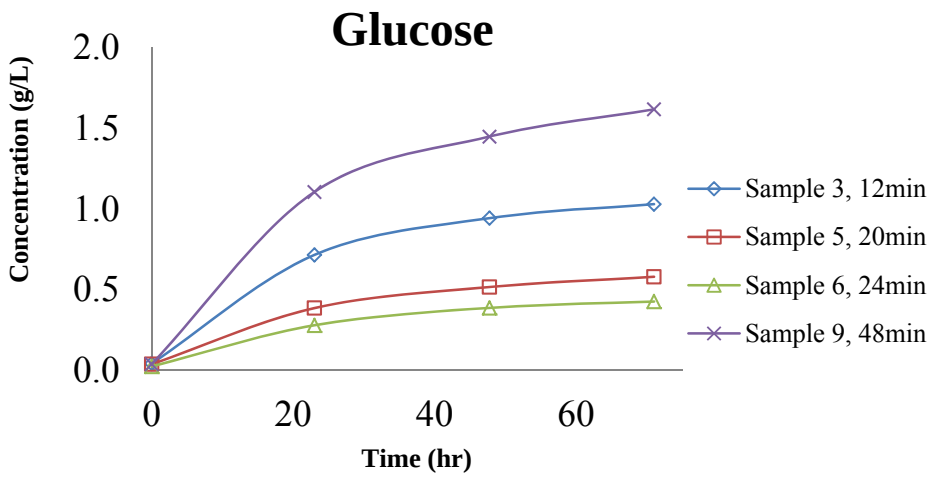

Figure 3: This figure represents glucose liberated from willow through enzymatic hydrolysis as a function of reaction time. Samples were taken at approximately 0, 24, 48, and 72 hours for the pretreatment time of 24mins along with its half(12min) and double time(48min).

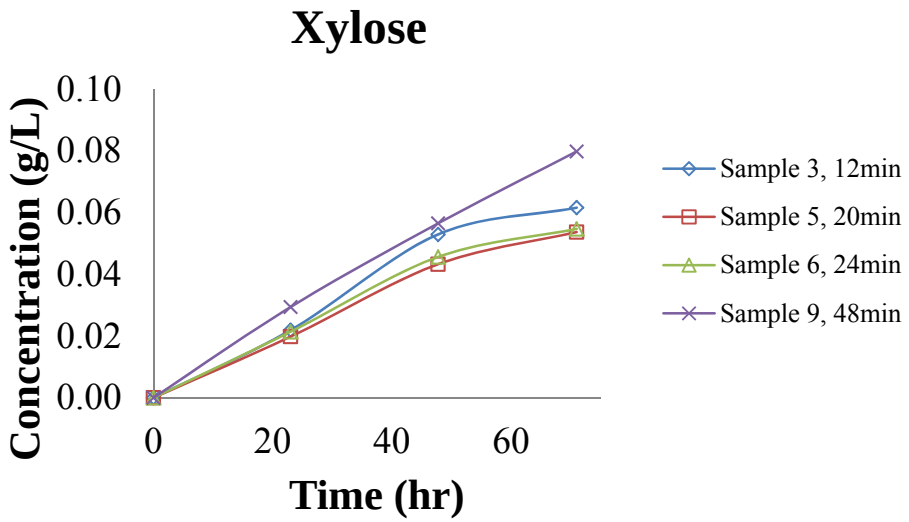

Figure 4: This figure represents xylose liberated from willow through enzymatic hydrolysis as a function of reaction time. Samples were taken at approximately 0, 24, 48, and 72 hours for the pretreatment time of 24mins along with its half(12min) and double time(48min).

Appendix C: Additional Fast Pyrolysis Product Speciation and Quantification Data

Data contained within this appendix are representative of experimental trials for all feedstocks. The data presented are the individual chromatograms (Figures1-36) and NIST database matches (Tables 2-37) for compounds in large abundance. Note that if a database match has a low probability, this is likely due to multiple compounds eluting at the same time point as the libraries are developed for pure species. In these instances, further investigation would be needed to determine the likely species. The figures and tables that are associated with each species are summarized in Table 1.

Table 1: Location designation for experimental data within Appendix B.

	Aspen	Balsam	Poplar	Red maple	Willow	Switchgrass
500˚C	Fig. 1,2 Table 2,3	Fig. 7,8 Table 8,9	Fig. 13,14 Table 14,15	Fig. 19,20 Table 20,21	Fig. 25,26 Table 26,27	Fig. 31,32 Table 32,33
600˚C	Fig. 3,4 Table 4,5	Fig. 9,10 Table 10,11	Fig. 15,16 Table 16,17	Fig. 21,22 Table 22,23	Fig. 27,28 Table 28,29	Fig. 33,34 Table 34,35
700˚C	Fig. 5,6 Table 6,7	Fig. 11,12 Table 12,13	Fig. 17,18 Table 18,19	Fig. 23,24 Table 24,25	Fig. 29,30 Table 30,31	Fig. 35.36 Table 36,37

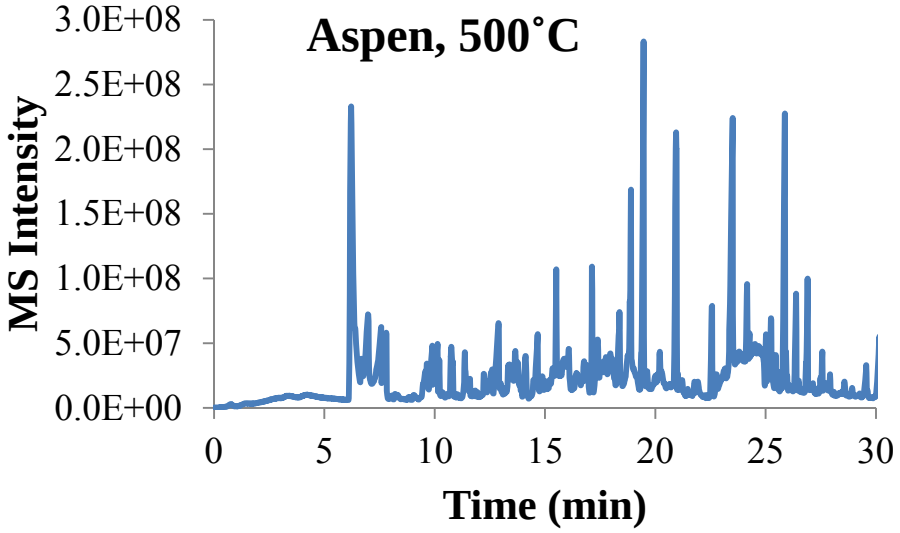

Figure 1: Chromatogram for aspen fast pyrolysis trial at 500˚C.

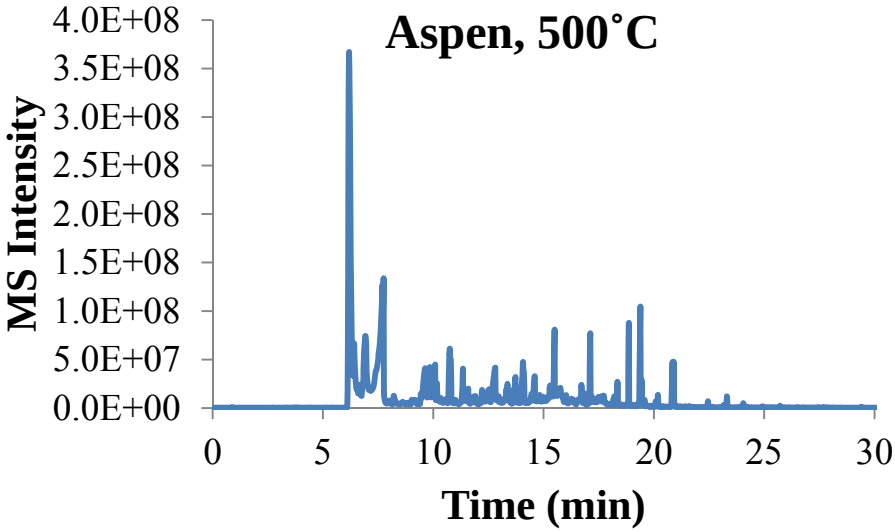

Figure 2: Chromatogram for aspen fast pyrolysis trial at 500˚C.

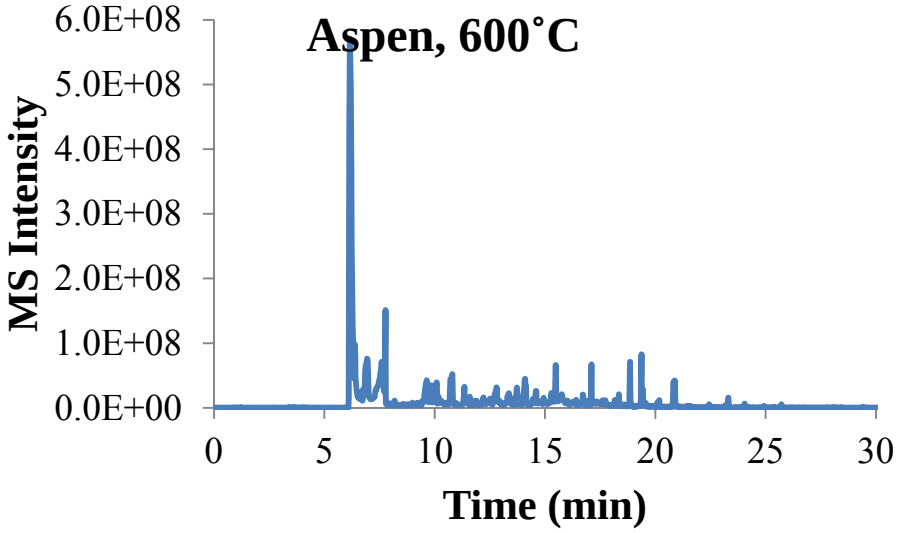

Figure 3: Chromatogram for aspen fast pyrolysis trial at 600˚C.

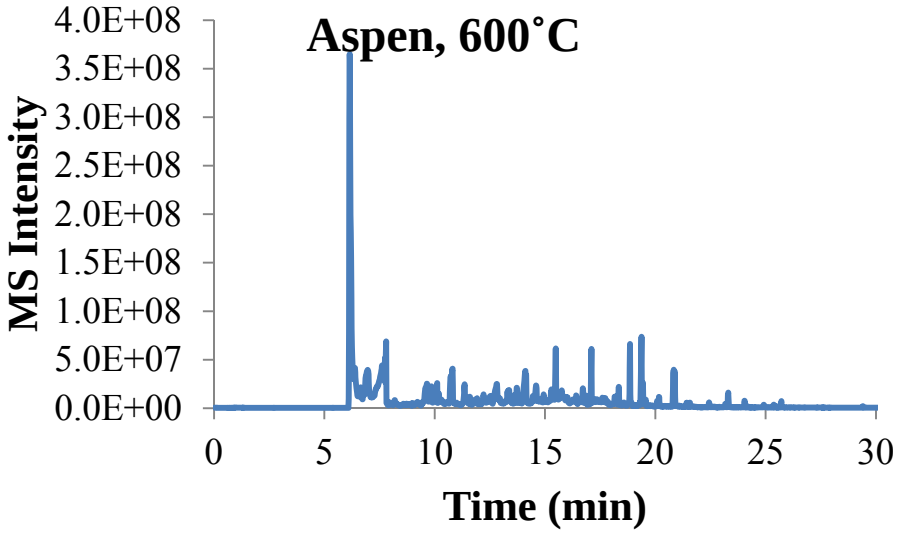

Figure 4: Chromatogram for aspen fast pyrolysis trial at 600˚C.

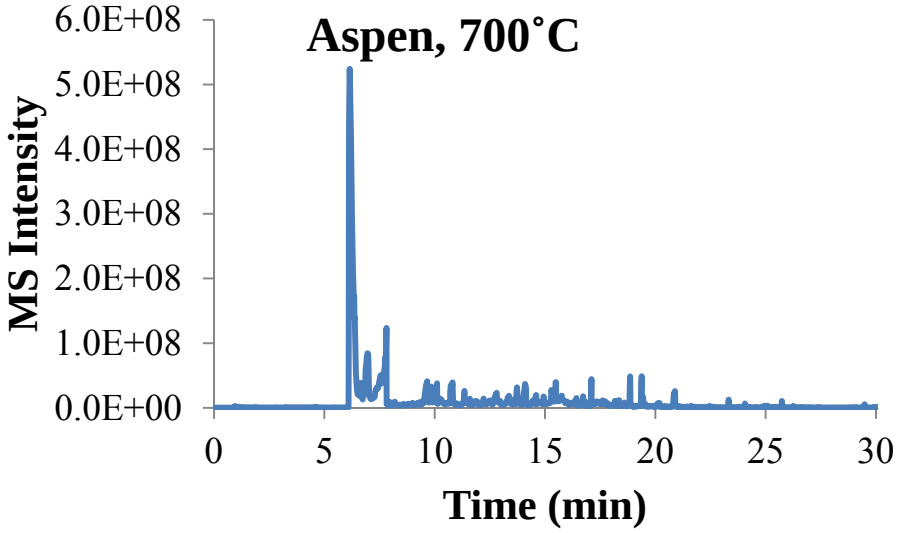

Figure 5: Chromatogram for aspen fast pyrolysis trial at 700˚C.

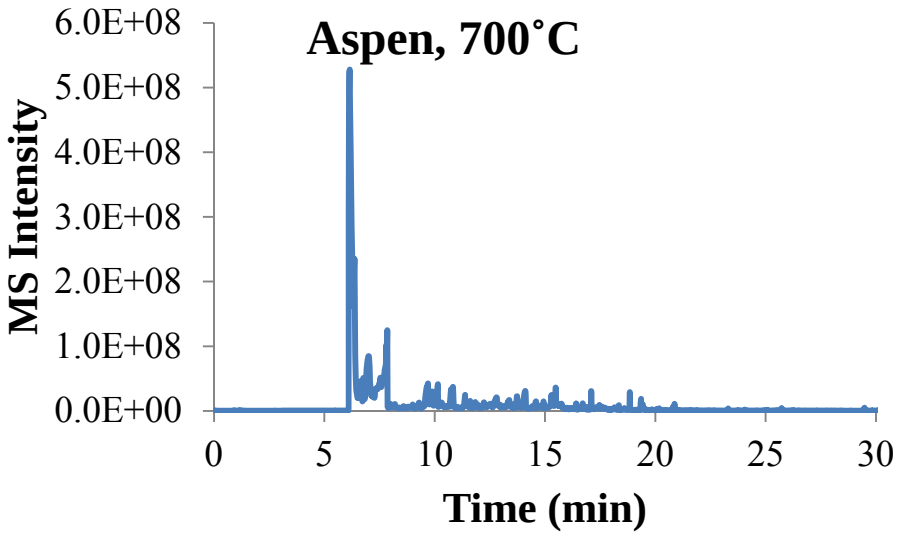

Figure 6: Chromatogram for aspen fast pyrolysis trial at 700˚C.

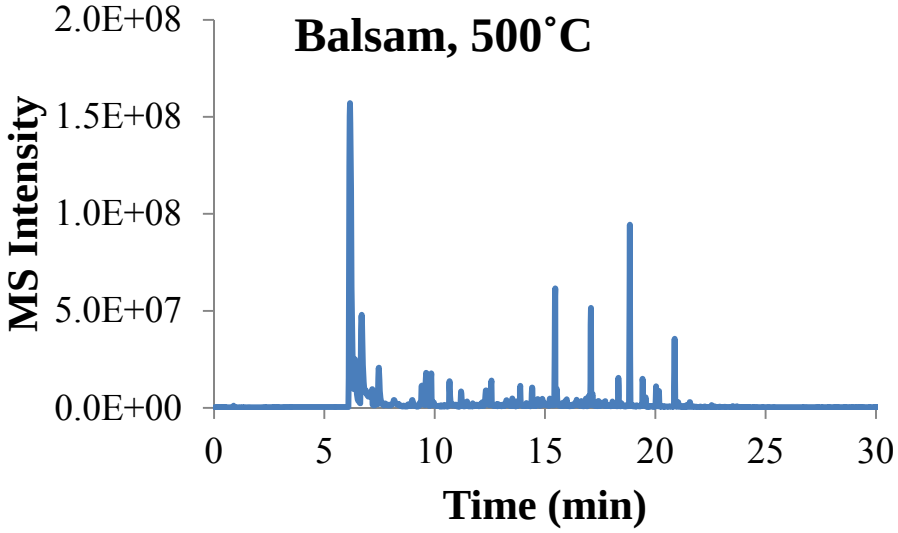

Figure 7: Chromatogram for balsam fast pyrolysis trial at 500˚C.

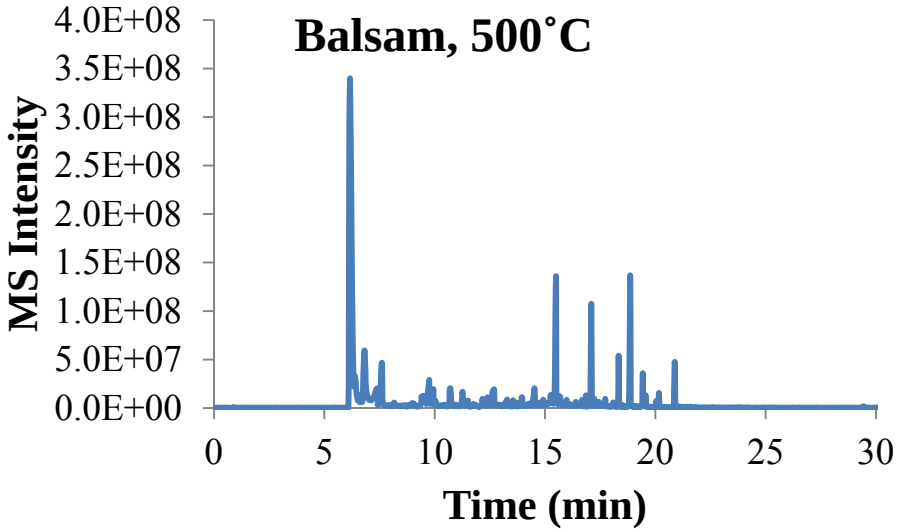

Figure 8: Chromatogram for balsam fast pyrolysis trial at 500˚C.

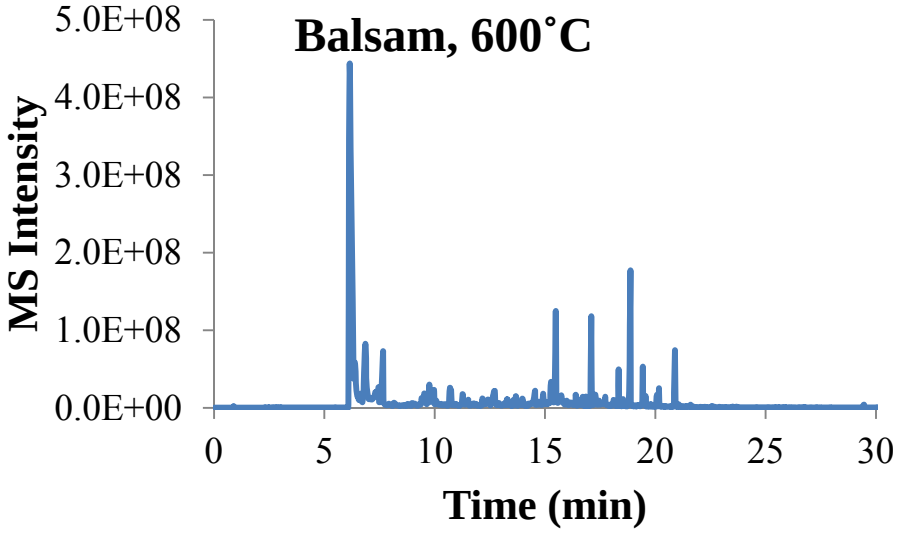

Figure 9: Chromatogram for balsam fast pyrolysis trial at 600˚C.

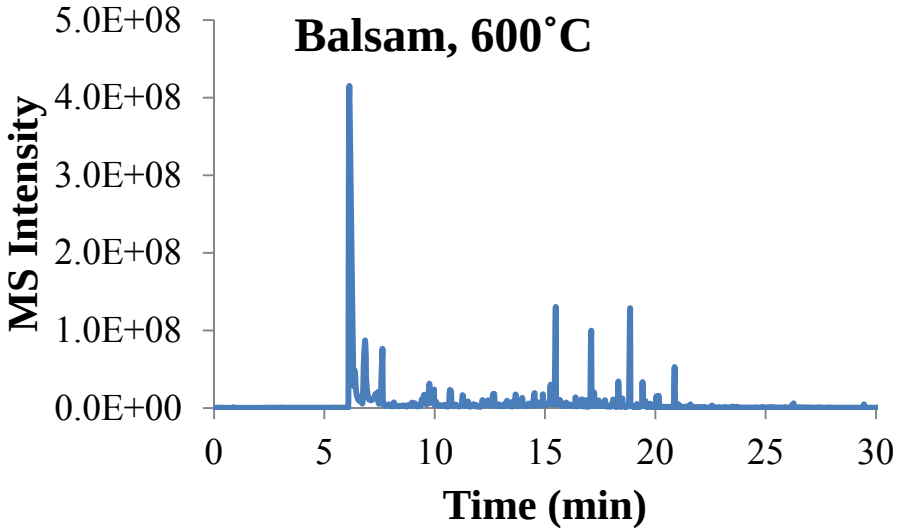

Figure 10: Chromatogram for balsam fast pyrolysis trial at 600˚C.

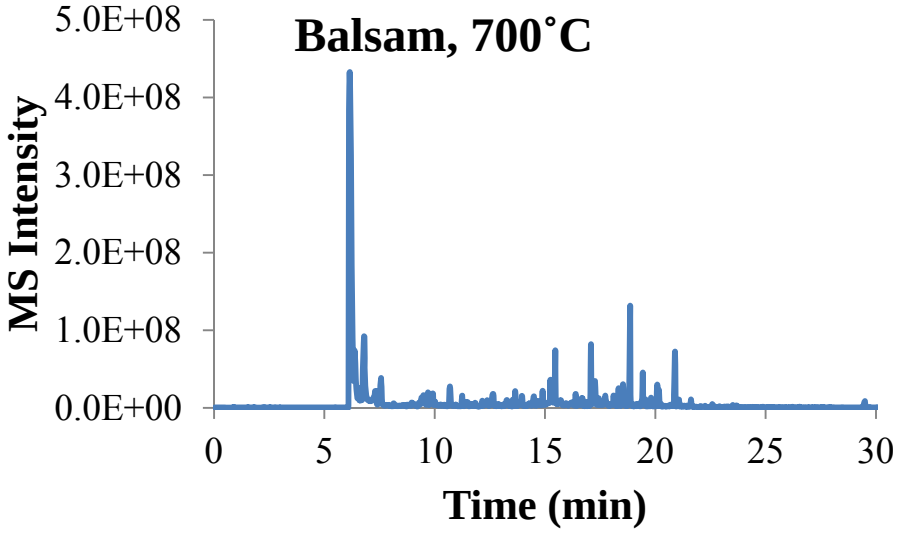

Figure 11: Chromatogram for balsam fast pyrolysis trial at 700˚C.

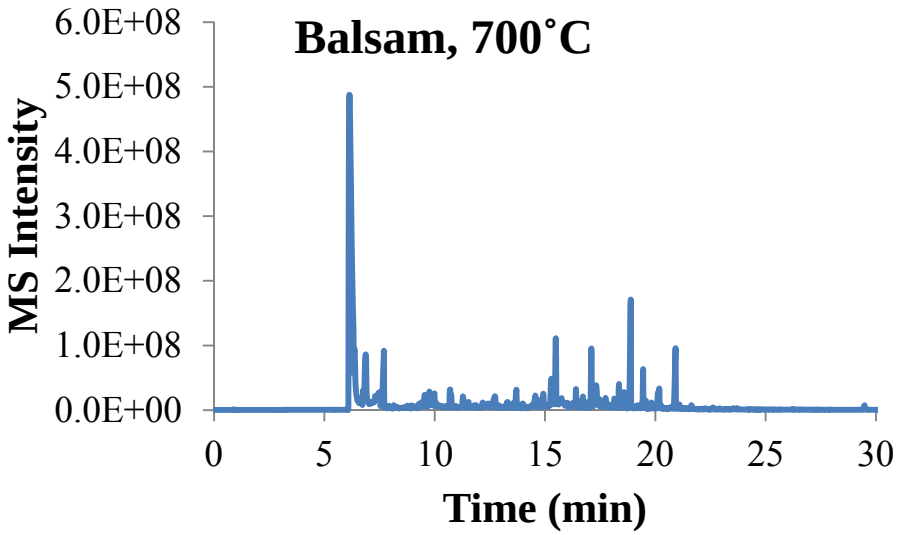

Figure 12: Chromatogram for balsam fast pyrolysis trial at 700˚C.

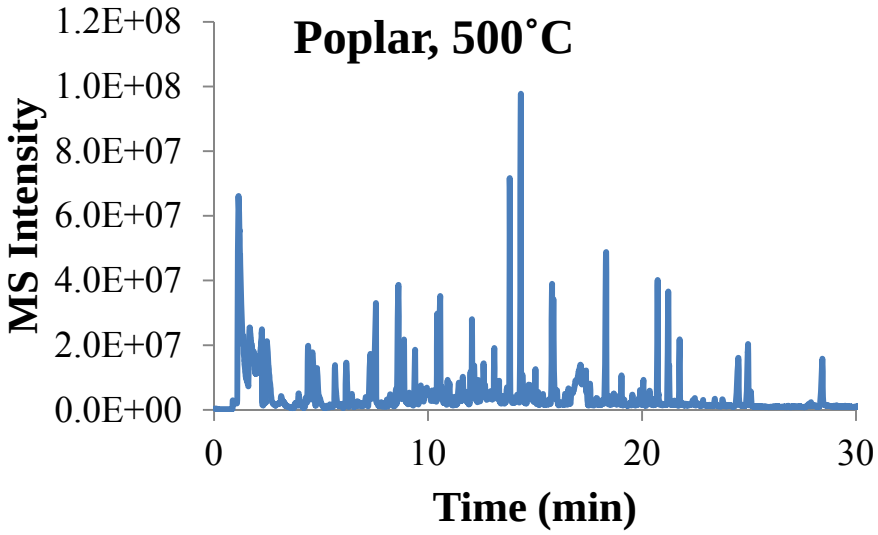

Figure 13: Chromatogram for poplar fast pyrolysis trial at 500˚C.

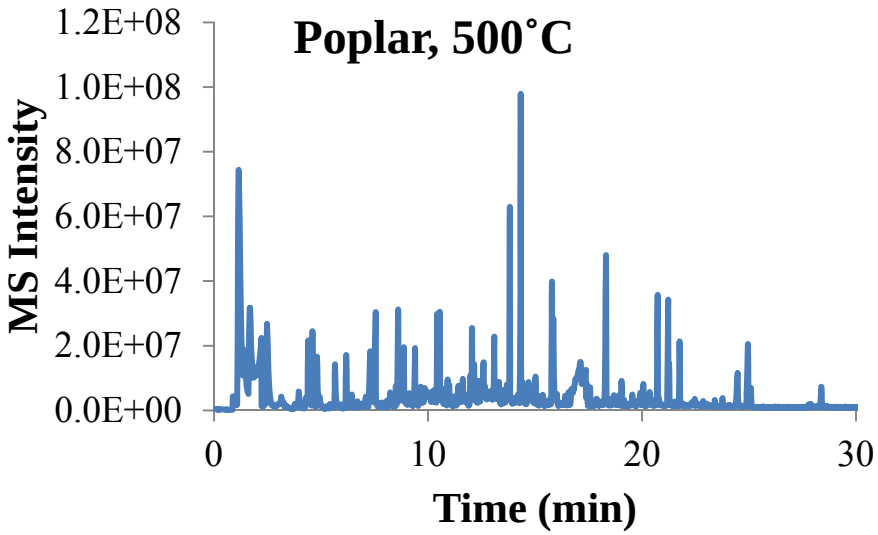

Figure 14: Chromatogram for poplar fast pyrolysis trial at 500˚C.

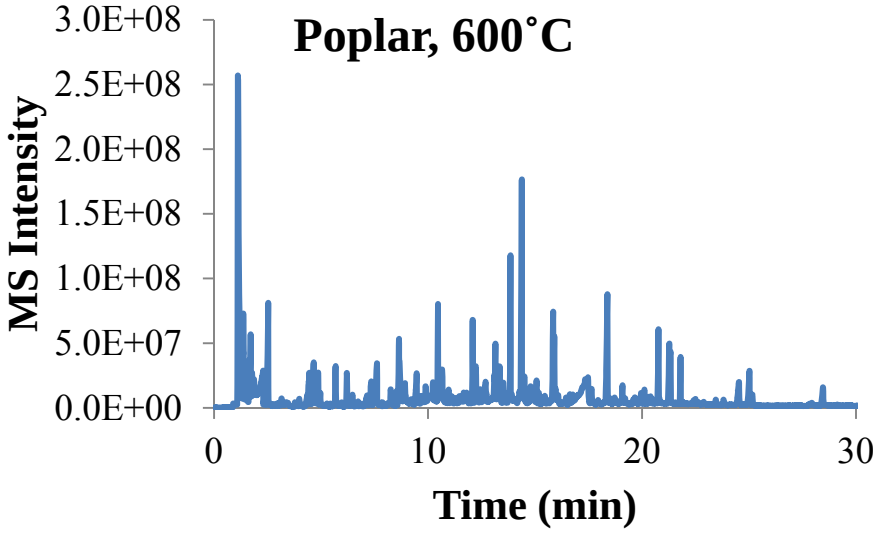

Figure 15: Chromatogram for poplar fast pyrolysis trial at 600˚C.

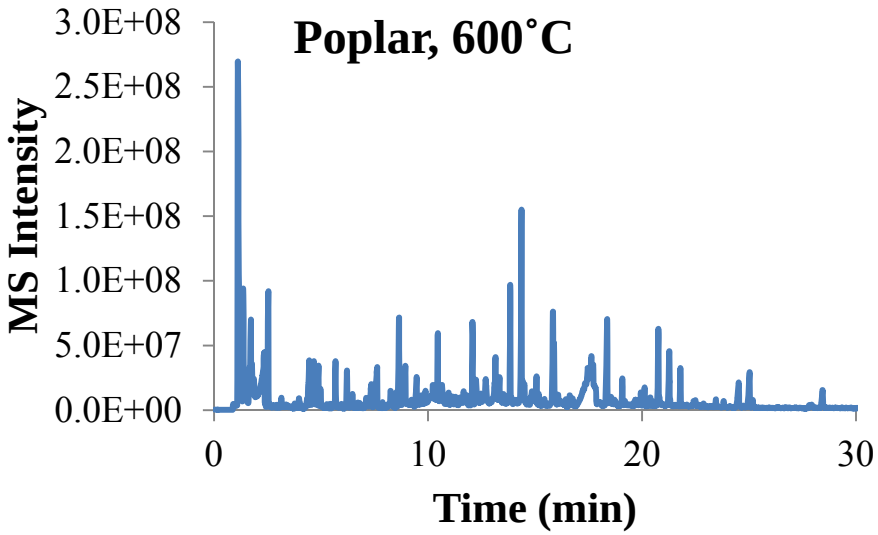

Figure 16: Chromatogram for poplar fast pyrolysis trial at 600˚C.

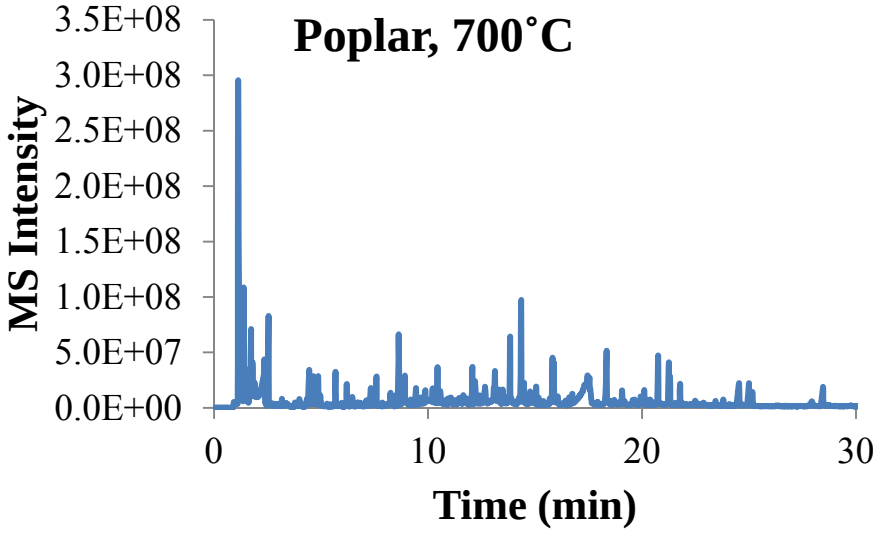

Figure 17: Chromatogram for poplar fast pyrolysis trial at 700˚C.

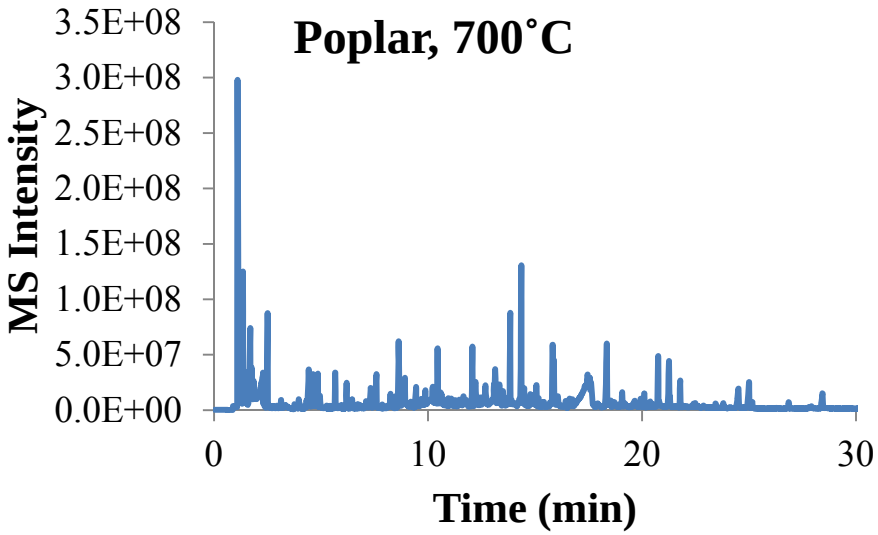

Figure 18: Chromatogram for poplar fast pyrolysis trial at 700˚C.

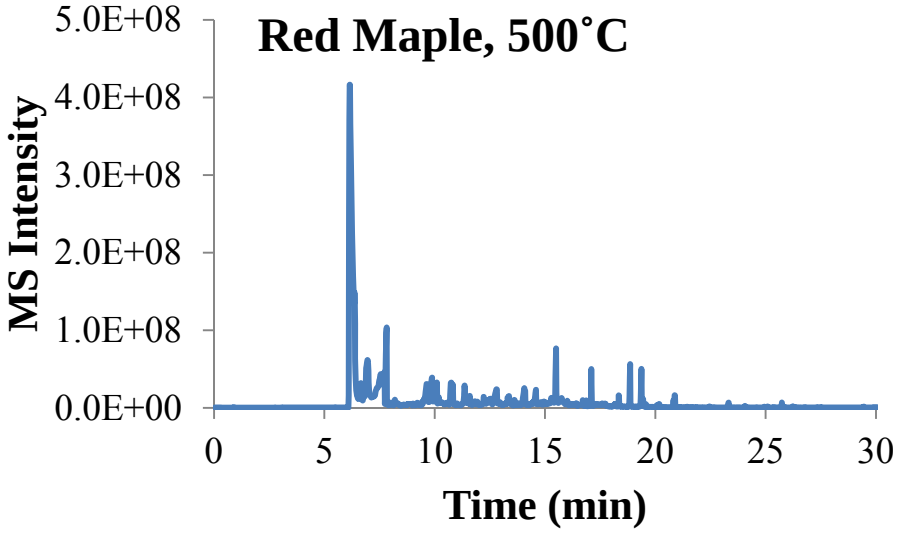

Figure 19: Chromatogram for red maple fast pyrolysis trial at 500˚C.

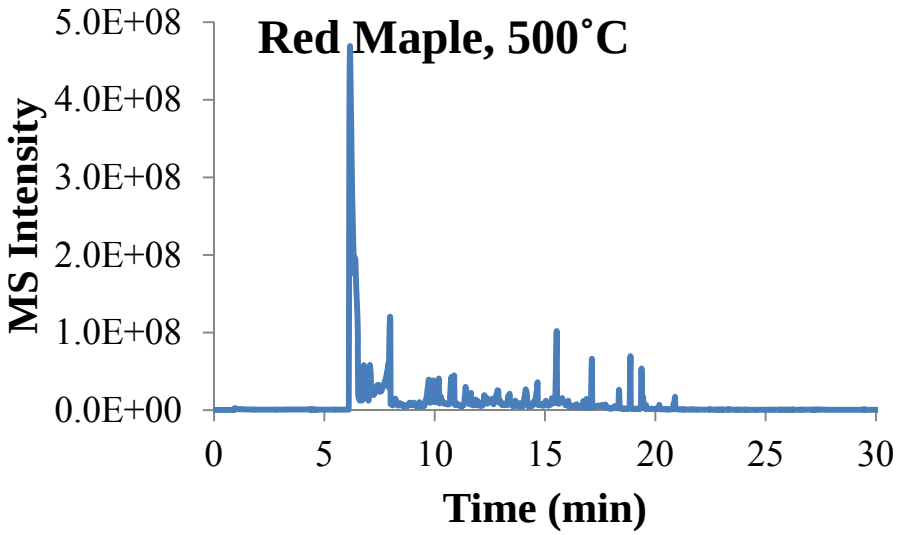

Figure 20: Chromatogram for red maple fast pyrolysis trial at 500˚C.

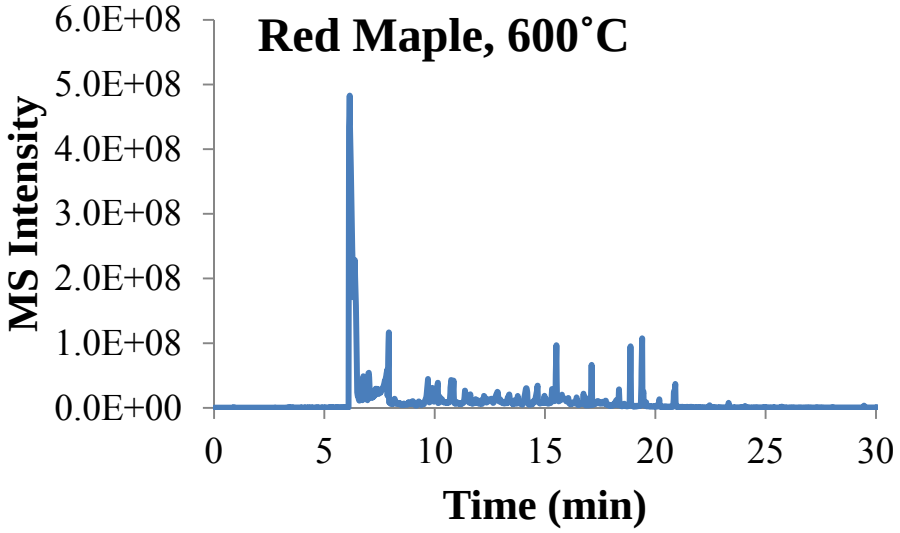

Figure 21: Chromatogram for red maple fast pyrolysis trial at 600˚C.

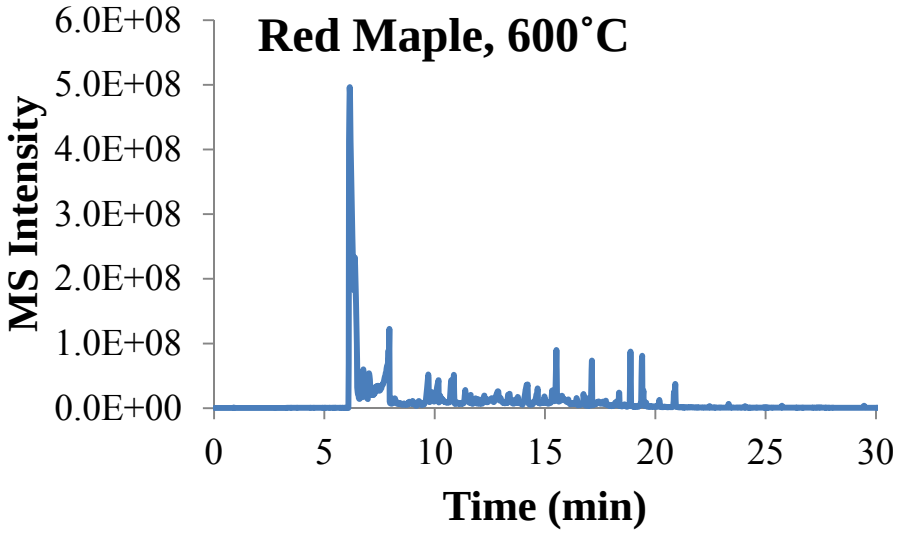

Figure 22: Chromatogram for red maple fast pyrolysis trial at 600˚C.

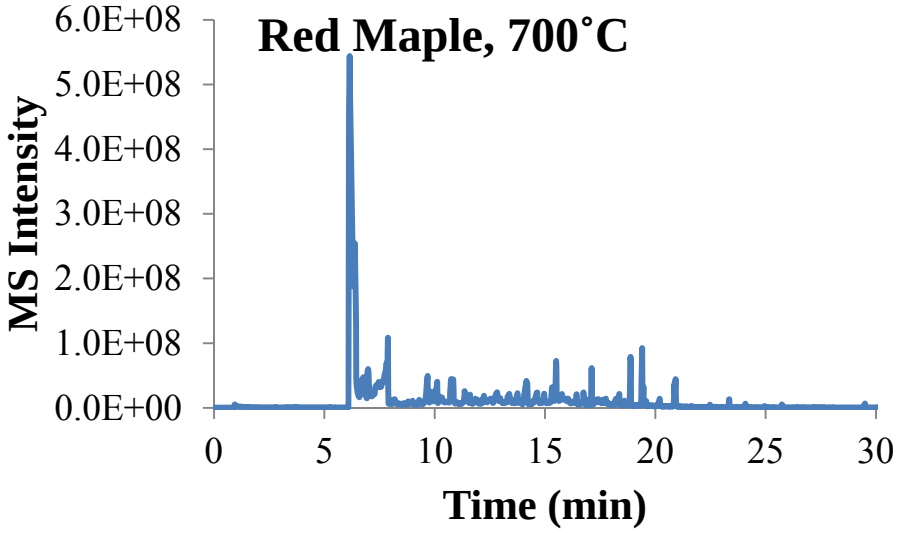

Figure 23: Chromatogram for red maple fast pyrolysis trial at 700˚C.

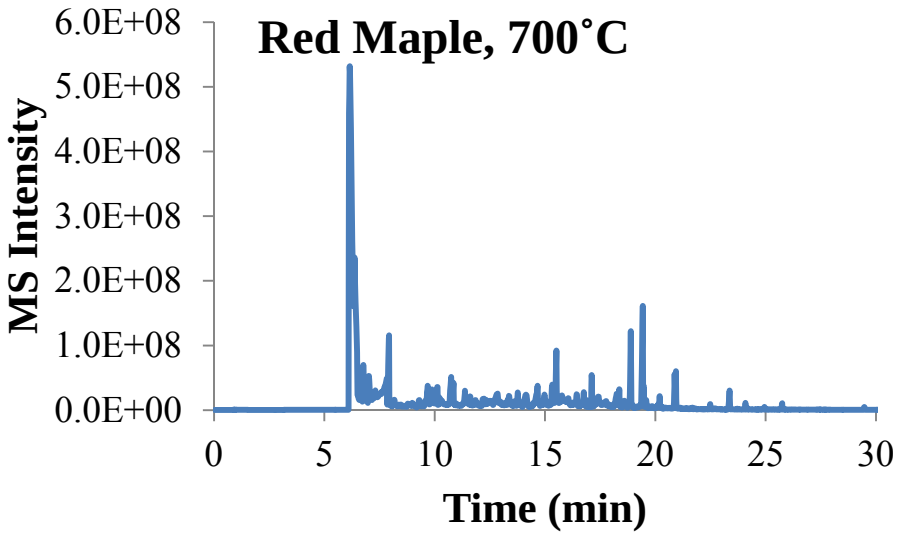

Figure 24: Chromatogram for red maple fast pyrolysis trial at 700˚C.

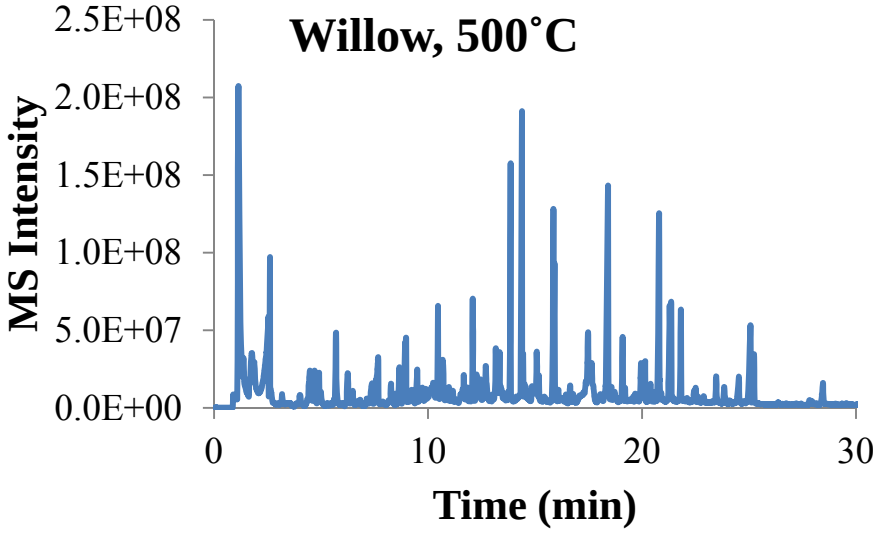

Figure 25: Chromatogram for willow fast pyrolysis trial at 500˚C.

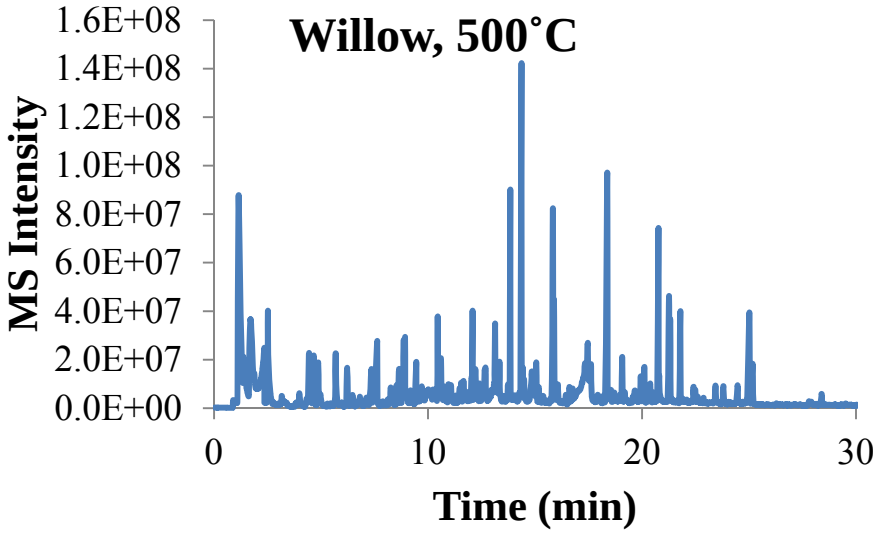

Figure 26: Chromatogram for willow fast pyrolysis trial at 500˚C.

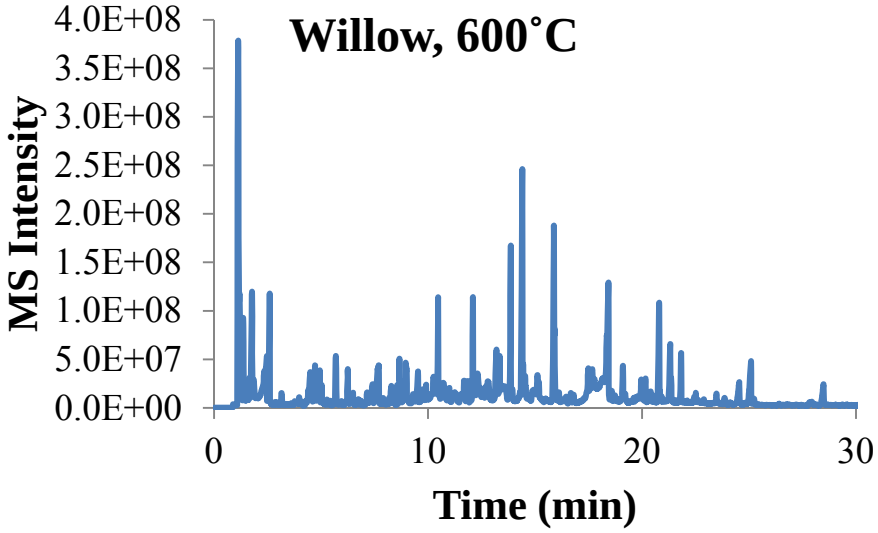

Figure 27: Chromatogram for willow fast pyrolysis trial at 600˚C.

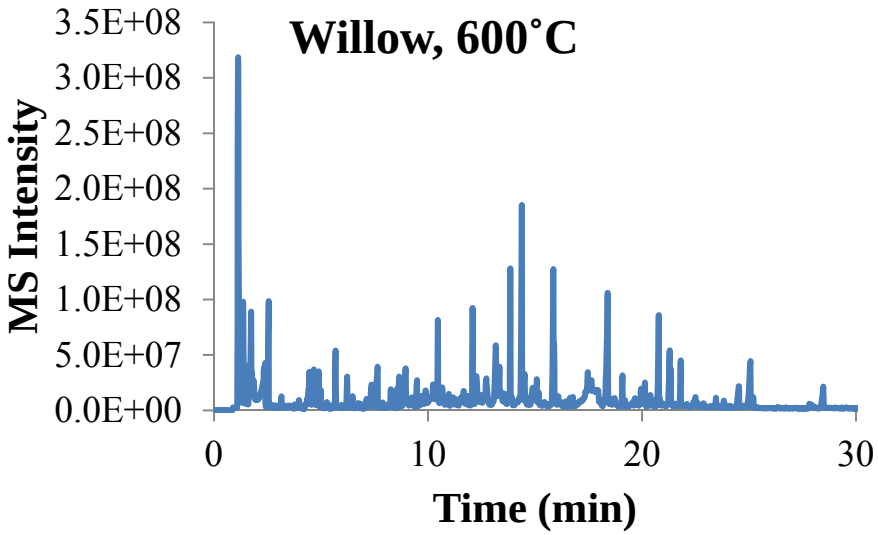

Figure 28: Chromatogram for willow fast pyrolysis trial at 600˚C.

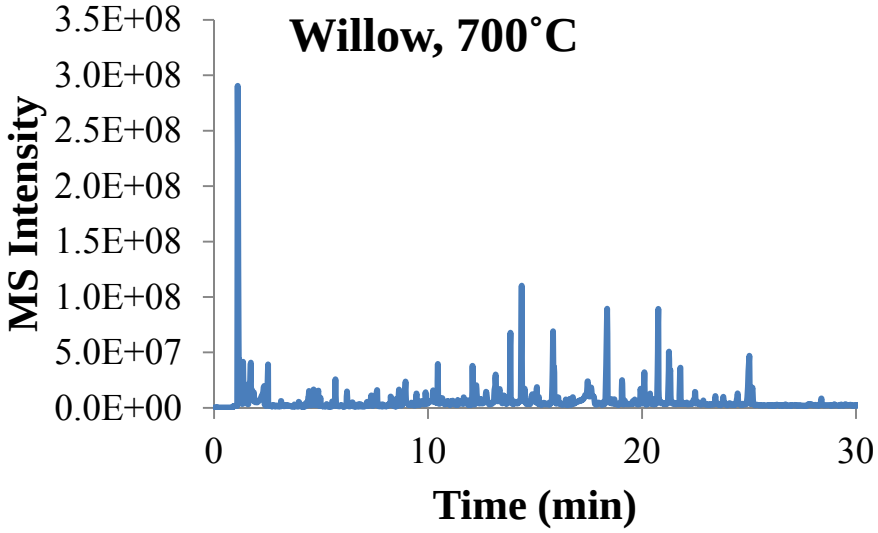

Figure 29: Chromatogram for willow fast pyrolysis trial at 700˚C.

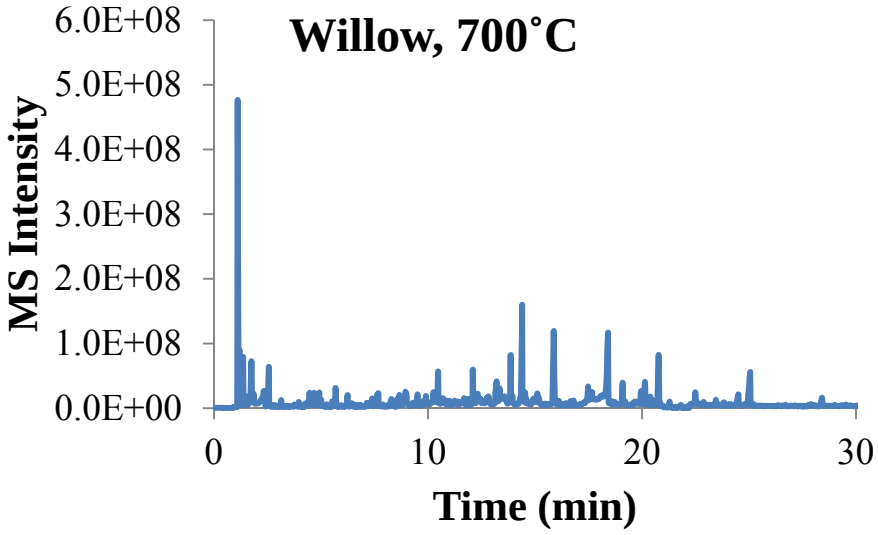

Figure 30: Chromatogram for willow fast pyrolysis trial at 700˚C.

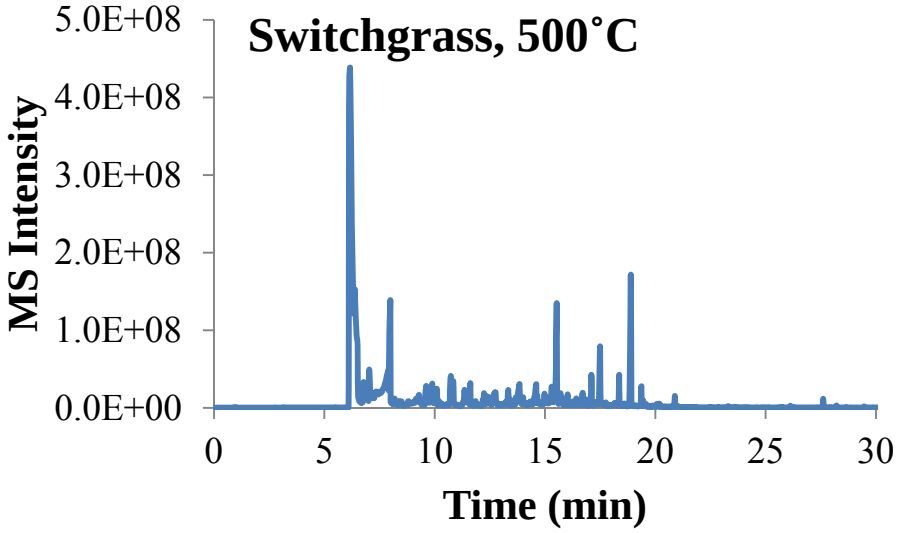

Figure 31: Chromatogram for switchgrass fast pyrolysis trial at 500˚C.

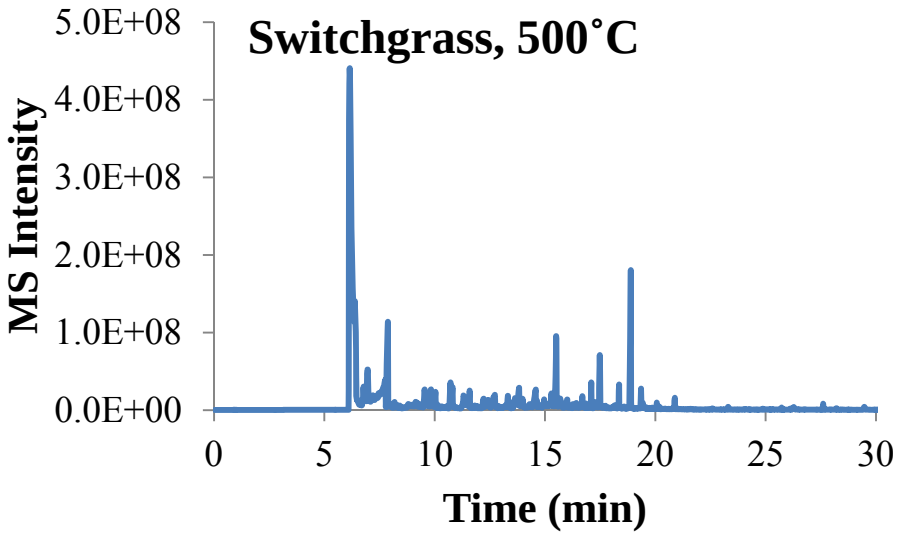

Figure 32: Chromatogram for switchgrass fast pyrolysis trial at 500˚C.

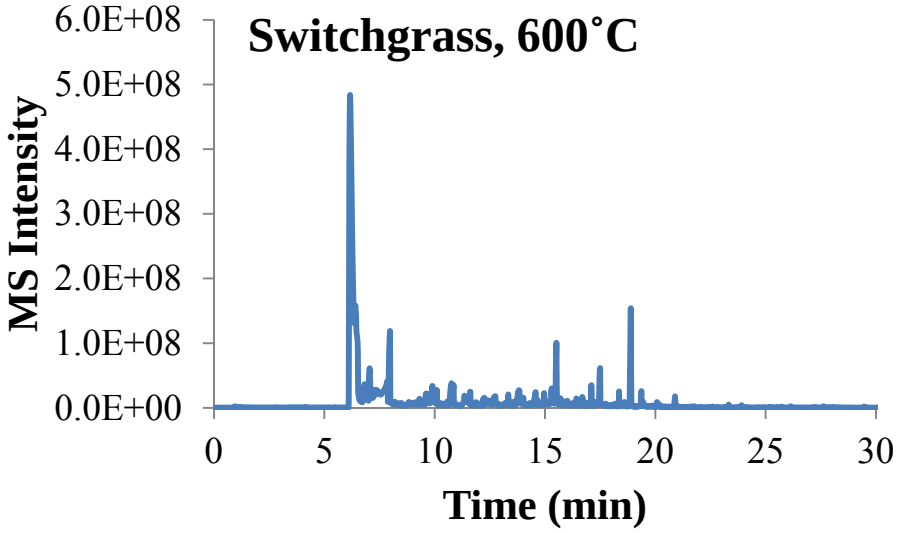

Figure 33: Chromatogram for switchgrass fast pyrolysis trial at 600˚C.

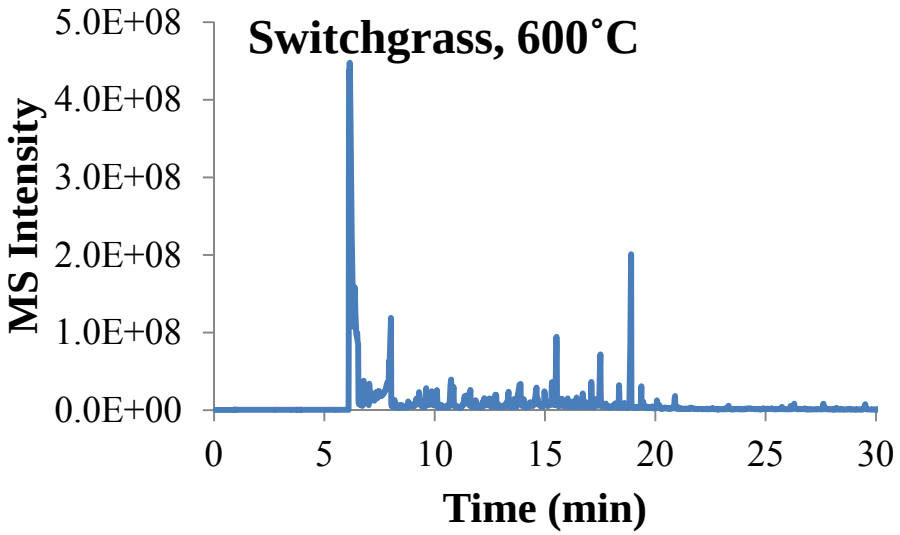

Figure 34: Chromatogram for switchgrass fast pyrolysis trial at 600˚C.

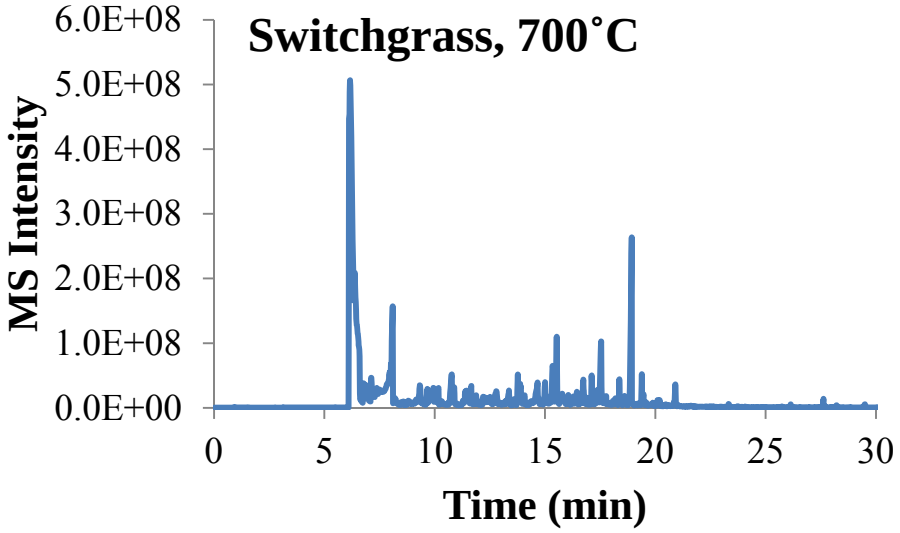

Figure 35: Chromatogram for switchgrass fast pyrolysis trial at 700˚C.

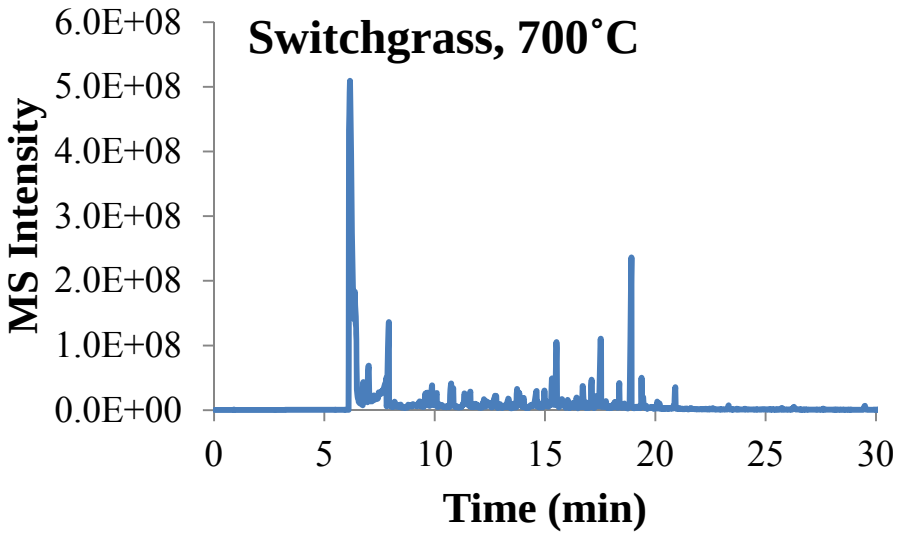

Figure 36: Chromatogram for switchgrass fast pyrolysis trial at 700˚C.

Table 2: NIST library matches for aspen fast pyrolysis trial at 500˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
2.421E+09	10.44	C8H19N	129	2-Octanamine	63.22	6.22
182263218	0.79	C3H6O3	90	Propanal, 2,3-dihydroxy-	41.72	6.68
766978582	3.31	C2H4O2	60	Acetaldehyde, hydroxy-	66.63	6.98
722778691	3.12	C2H4O2	60	Acetic acid	94.05	7.58
464023420	2	C3H6O2	74	2-Propanone, 1-hydroxy-	84.68	7.81
293658738	1.27	C3H6O2	74	2-Propanone, 1-hydroxy-	49.94	9.65
235259735	1.01	C7H14O	114	Pentanal, 2,3-dimethyl-	21.43	9.89
361385700	1.56	C4H6O3	102	Acetic anhydride	30.46	10.13
287057445	1.24	C5H4O2	96	3-Furaldehyde	63.18	10.76
224059115	0.97	C5H6O2	98	2-Furanmethanol	67.7	11.37
37978769	0.16	C6H10O4	146	1,2-Ethanediol, diacetate	55.22	11.6
96621139	0.42	C6H10O2	114	2-Pentenoic acid, 2-methyl-, (E)-	25.53	12.23
186046992	0.8	C6H12	84	2-Hexene	25.74	12.6
497921059	2.15	C6H10O	98	Cyclopentanone, 2-methyl-	33.23	12.9
291732915	1.26	C11H20O2	184	Undecanoic acid, hydroxy-, lactone	21.23	13.39
358087462	1.54	C6H10O2	114	2-Pentenoic acid, 2-methyl-, (E)-	38.8	13.66
218976334	0.94	C5H10N2O	114	Piperidine, 1-nitroso-	20.05	14.13
329423831	1.42	C6H8O2	112	1,2-Cyclopentanedione, 3-methyl-	45.27	14.67
66850727	0.29	C6H10O2	114	2-Pentenoic acid, 2-methyl-, (E)-	47.49	14.87
492924174	2.13	C7H8O2	124	Phenol, 2-methoxy-	43.36	15.52
373399262	1.61	C11H22O	170	Undecanal	43.26	15.89
169992443	0.73	C7H6O5	170	2,4,6-Trihydroxybenzoic acid	36.96	16.08
175849119	0.76	C11H20O2	184	Oxacyclododecan-2-one	52.55	16.42
302354630	1.3	C11H20O2	184	Undecanoic acid, hydroxy-, lactone	46.33	16.77
238909936	1.03	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	50.19	17.13
313141090	1.35	C6H6O4	142	4H-Pyran-4-one, 5-hydroxy-2-(hydroxymethyl)-	72.19	17.39
380335735	1.64	C12H22O2	198	ç Dodecalactone	22.86	17.76
349468704	1.51	C11H20O2	184	Undecanoic acid, hydroxy-, lactone	15.76	17.96

289691048	1.25	C9H12O2	152	2,4-Dimethoxytoluene	62.19	18.38
937488738	4.04	C10H14O	150	Phenol, 2,3,5,6-tetramethyl-	27.01	18.9
958942427	4.13	C10H18O	154	Eucalyptol	63.92	19.47
70658244	0.3	C11H20O2	184	Oxacyclododecan-2-one	32.01	19.63
381222346	1.64	C9H12O2	152	2,4-Dimethoxytoluene	15.93	20.21
1.061E+09	4.57	C9H12O3	168	1,2,3-Trimethoxybenzene	58.62	20.94
133584418	0.58	C8H8O4	168	Ethanone, 1-(2,3,4-trihydroxyphenyl)-	38.87	21.02
56922096	0.25	C9H10O3	166	Ethanone, 1-(4-hydroxy-3-methoxyphenyl)-	42.27	21.77
91196322	0.39	C9H10O3	166	Ethanone, 1-(4-hydroxy-3-methoxyphenyl)-	38.25	21.93
257760865	1.11	C9H10O4	182	3,4-Dimethoxy-5-hydroxybenzaldehyde	66.09	22.57
81543404	0.35	C10H14O2	166	Phenol, 2-methoxy-4-propyl-	48.22	22.77
295476133	1.27	C11H14O3	194	4-Butoxybenzoic acid	38.46	23.16
1.554E+09	6.7	C12H15NO4	237	3-Hydroxycarbofuran	78.25	23.51
672339033	2.9	C12H22O11	342	à-D-Glucopyranoside, à-D-glucopyranosyl	43.14	23.8
396042106	1.71	C15H15N	209	Acridine, 9,10-dihydro-9,9-dimethyl-	53.89	24.16
669617811	2.89	C11H21BrO2	264	11-Bromoundecanoic acid	31.94	24.27
532724377	2.3	C12H22O11	342	à-D-Glucopyranoside, à-D-glucopyranosyl	74.86	24.67
88546987	0.38	C15H15N	209	Acridine, 9,10-dihydro-9,9-dimethyl-	74.7	25.02
294763935	1.27	C9H10O4	182	Benzaldehyde, 4-hydroxy-3,5-dimethoxy-	87.64	25.24
107007434	0.46	C14H20O2	220	2,5-Cyclohexadiene-1,4-dione, 2,6-bis(1,1-dimethylethyl)-	40.26	25.46
963839214	4.16	C15H15N	209	Acridine, 9,10-dihydro-9,9-dimethyl-	70.87	25.87
306661642	1.32	C10H12O4	196	Benzaldehyde, 2,4,5-trimethoxy-	41.57	26.38
334205406	1.44	C12H8N2O	196	9H-Carbazole, 9-nitroso-	28.43	26.9
56787378	0.24	C41H64O13	764	Digitoxin	24.01	27.14
128838891	0.56	C9H10O4	182	Benzaldehyde, 4-hydroxy-3,5-dimethoxy-	53.35	27.57
158809433	0.68	C41H64O13	764	Digitoxin	37.92	27.92
92598277	0.4	C15H24O	220	4a,7-Methano-4aH-naphth[1,8a-b]oxirene, octahydro-4,4,8,8-tetramethyl-	29.19	28.57
147558072	0.64	C16H32O2	256	n-Hexadecanoic acid	70.69	29.56
318418096	1.37	C19H22O6	346	Gibberellic acid	32.9	30.16
110403927	0.48	C18H36O2	284	Octadecanoic acid	75.72	33.48
33376733	0.14	C13H17F3N4O4	350	1,3-Benzenediamine, 2,4-dinitro-N3,N3-dipropyl-6-(trifluoromethyl)-	31.73	34.61

Table 3: NIST library matches for aspen fast pyrolysis trial at 500˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
3.027E+09	29.46	C8H19N	129	2-Octanamine	68.42	6.19
132018407	1.28	C3H6O3	90	Propanal, 2,3-dihydroxy-	73.87	6.67
837493324	8.15	C2H4O2	60	Acetaldehyde, hydroxy-	62.83	6.92
1.774E+09	17.26	C3H6O2	74	2-Propanone, 1-hydroxy-	90.03	7.75
314375370	3.06	C3H6O2	74	2-Propanone, 1-hydroxy-	34.82	9.64
188424890	1.83	C7H14O	114	Pentanal, 2,3-dimethyl-	32.7	9.85
322793213	3.14	C4H6O3	102	Acetic anhydride	43.41	10.09
341301733	3.32	C5H4O2	96	3-Furaldehyde	78.59	10.75
178029651	1.73	C5H6O2	98	2-Furanmethanol	71.49	11.35
40775235	0.4	C6H10O4	146	1,2-Ethanediol, diacetate	65.01	11.59
74517177	0.73	C14H28O	212	9-Tetradecen-1-ol, (E)-	22.86	12.22
124173136	1.21	C6H12	84	2-Hexene	37.49	12.52
348558211	3.39	C5H6O2	98	2-Furanmethanol	30.12	12.82
156445242	1.52	C12H24O	184	Dodecanal	15.65	13.36
159672896	1.55	C6H7O4P	174	Phosphonic acid, (p-hydroxyphenyl)-	52.4	13.73
265999235	2.59	C5H10N2O	114	Piperidine, 1-nitroso-	52.26	14.07
165520210	1.61	C6H8O2	112	2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	56.4	14.61
134441325	1.31	C7H8O	108	Phenol, 3-methyl-	37.74	15.29
244735322	2.38	C7H8O2	124	Phenol, 2-methoxy-	52.64	15.5
169802687	1.65	C12H22O11	342	à-D-Glucopyranoside, à-D-glucopyranosyl	31.89	15.77
108720299	1.06	C9H10O3	166	Benzaldehyde, 3-ethoxy-2-hydroxy-	52.7	16.72
35805978	0.35	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	54.63	16.88
241341940	2.35	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	49.86	17.12
110682207	1.08	C9H12O2	152	2,4-Dimethoxytoluene	67.38	18.35
171365822	1.67	C10H14O	150	Phenol, 2-methyl-5-(1-methylethyl)-	22.06	18.87
316311626	3.08	C10H18O	154	Eucalyptol	46.44	19.39
40767854	0.4	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-	56.54	20.18
211028648	2.05	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-, (E)-	45.85	20.9
40006487	0.39	C12H15NO4	237	3-Hydroxycarbofuran	74.76	23.31

Table 4: NIST library matches for aspen fast pyrolysis trial at 600˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
4.867E+09	45.64	C8H19N	129	2-Octanamine	80.99	6.16
815538689	7.65	C2H4O2	60	Acetaldehyde, hydroxy-	68.05	6.94
1.291E+09	12.11	C2H4O2	60	Acetic acid	95.38	7.61
324475227	3.04	C3H6O2	74	2-Propanone, 1-hydroxy-	89.07	7.78
298380339	2.8	C3H6O2	74	Acetic acid, methyl ester	59.52	9.64
156235387	1.47	C7H14O	114	Pentanal, 2,3-dimethyl-	26.69	9.85
310087209	2.91	C4H6O3	102	Acetic anhydride	34.22	10.09
329036915	3.09	C5H4O2	96	3-Furaldehyde	72.86	10.8
138608447	1.3	C5H6O2	98	2-Furanmethanol	61.91	11.35
252874693	2.37	C5H6O2	98	2-Furanmethanol	34.13	12.8
139609640	1.31	C12H24O	184	Dodecanal	21.61	13.36
124771064	1.17	C6H7O4P	174	Phosphonic acid, (p-hydroxyphenyl)-	56	13.73
269933761	2.53	C5H10N2O	114	Piperidine, 1-nitroso-	47.63	14.1
188673447	1.77	C6H8O2	112	2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	64.05	14.59
126223901	1.18	C7H8O	108	Phenol, 3-methyl-	39.67	15.29
182106416	1.71	C7H8O2	124	Phenol, 2-methoxy-	44.83	15.49
83438570	0.78	C8H10O2	138	2-Methoxybenzyl alcohol	36.31	16.72
156836004	1.47	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	52.62	17.11
42541766	0.4	C9H12O2	152	2,4-Dimethoxytoluene	54.93	18.35
133967941	1.26	C12H17NO2	207	Phenol, 3-methyl-5-(1-methylethyl)-, methylcarbamate	32.12	18.86
246138093	2.31	C10H18O	154	Eucalyptol	45.32	19.38
185896071	1.74	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-, (E)-	46.13	20.89

Table 5: NIST library matches for aspen fast pyrolysis trial at 600˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
2.249E+09	32.03	CO2	44	Carbon dioxide	39.3	6.15
87835835	1.25	C3H6O3	90	Propanal, 2,3-dihydroxy-	22.41	6.64
543593169	7.74	C2H4O2	60	Acetaldehyde, hydroxy-	69.77	6.96
1.059E+09	15.08	C3H6O2	74	2-Propanone, 1-hydroxy-	90.64	7.81
190106995	2.71	C3H6O2	74	2-Propanone, 1-hydroxy-	41.09	9.65
104028998	1.48	C3H8O2	76	1,3-Propanediol	28.63	9.85
206892459	2.95	C3H6O2	74	2-Propanone, 1-hydroxy-	47.03	10.12
274432646	3.91	C5H4O2	96	3-Furaldehyde	74.78	10.81
120211066	1.71	C5H6O2	98	2-Furanmethanol	67.87	11.36
207839067	2.96	C5H6O2	98	2-Furanmethanol	26.33	12.82
122669459	1.75	C12H24O	184	Dodecanal	17.56	13.36
102565716	1.46	C6H7O4P	174	Phosphonic acid, (p-hydroxyphenyl)-	51.74	13.73
255439401	3.64	C4H6N2O2	114	2,4-Imidazolidinedione, 1-methyl-	27.17	14.11
150420193	2.14	C6H8O2	112	2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	66.8	14.59
84572472	1.2	C7H8O	108	Phenol, 3-methyl-	38.72	15.29
152185555	2.17	C7H8O2	124	Phenol, 2-methoxy-	50.99	15.49
163620627	2.33	C8H10O	122	Phenol, 2,6-dimethyl-	14.17	15.76
105398179	1.5	C9H10O3	166	Benzaldehyde, 3-ethoxy-2-hydroxy-	38.71	16.72
104874112	1.49	C8H10O2	138	2-Methoxy-5-methylphenol	48.39	17.11
114770217	1.63	C9H12O2	152	2,4-Dimethoxytoluene	71.1	18.35
124554110	1.77	C10H14O	150	Phenol, 2,3,5,6-tetramethyl-	26.57	18.86
242531372	3.45	C10H18O	154	Eucalyptol	45.05	19.38
199892166	2.85	C9H12O3	168	1,2,3-Trimethoxybenzene	75.61	20.83
55870648	0.8	C12H15NO4	237	3-Hydroxycarbofuran	75.67	23.31

Table 6: NIST library matches for aspen fast pyrolysis trial at 700˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
5.709E+09	53.07	C8H19N	129	2-Octanamine	80.6	6.15
186404247	1.73	C3H6O3	90	Propanal, 2,3-dihydroxy-	32.71	6.64
939672434	8.73	C2H4O2	60	Acetaldehyde, hydroxy-	72.22	6.96
1.521E+09	14.14	C3H6O2	74	2-Propanone, 1-hydroxy-	91.17	7.82
324706083	3.02	C3H6O2	74	Acetic acid, methyl ester	57.64	9.66
128296154	1.19	C3H8O2	76	1,3-Propanediol	26.66	9.85
305876705	2.84	C3H6O2	74	2-Propanone, 1-hydroxy-	44	10.11
272066014	2.53	C5H4O2	96	3-Furaldehyde	54.55	10.82
116179772	1.08	C5H6O2	98	2-Furanmethanol	30.87	11.35
177529694	1.65	C6H10O	98	Cyclopentanone, 2-methyl-	41.55	12.81
143378219	1.33	C6H6O	94	Phenol	51.56	13.74
226694978	2.11	C5H10N2O	114	Piperidine, 1-nitroso-	34.64	14.09
122514769	1.14	C7H8O	108	Phenol, 3-methyl-	50.27	15.29
130870875	1.22	C7H8O2	124	Phenol, 2-methoxy-	46.95	15.48
74049037	0.69	C8H10O2	138	2-Methoxy-5-methylphenol	48.07	17.1
103254706	0.96	C10H14O	150	Phenol, 2-methyl-5-(1-methylethyl)-	23.93	18.86
166434978	1.55	C10H18O	154	Eucalyptol	54.39	19.38
110002755	1.02	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-	51.6	20.9

Table 7: NIST library matches for aspen fast pyrolysis trial at 700˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
5.874E+09	53.75	C8H19N	129	2-Octanamine	78.78	6.15
1.304E+09	11.93	C2H4O2	60	Acetaldehyde, hydroxy-	78.87	7
568378848	5.2	C2H4O2	60	Acetic acid	91.59	7.54
1.064E+09	9.74	C3H6O2	74	2-Propanone, 1-hydroxy-	92.01	7.86
332760392	3.04	C3H6O2	74	Acetic acid, methyl ester	50.51	9.7
159053210	1.46	C3H8O2	76	1,3-Propanediol	29.19	9.89
255192230	2.33	C4H6O3	102	Acetic anhydride	38.19	10.15
295025329	2.7	C5H4O2	96	3-Furaldehyde	56.11	10.83
121537016	1.11	C5H6O2	98	2-Furanmethanol	38.07	11.38
170487887	1.56	C6H10O	98	Cyclopentanone, 2-methyl-	32.18	12.81
111690056	1.02	C6H6O	94	Phenol	49.23	13.74
185394535	1.7	C4H6N2O2	114	2,4-Imidazolidinedione, 1-methyl-	39.74	14.1
121551282	1.11	C7H8O	108	Phenol, 3-methyl-	43.38	15.29
165156058	1.51	C7H8O2	124	Phenol, 2-methoxy-	49.27	15.48
73158990	0.67	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	57.11	17.09
58266974	0.53	C10H14O	150	Phenol, p-tert-butyl-	26.05	18.85
69024289	0.63	C10H18O	154	Eucalyptol	48.72	19.36

Table 8: NIST library matches for balsam fast pyrolysis trial at 500˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
1.198E+09	42.68	C8H19N	129	2-Octanamine	45.81	6.17
367159206	13.08	C2H4O2	60	Acetaldehyde, hydroxy-	83.01	6.7
61194639	2.18	C2H4O2	60	Acetic acid	93.6	7.17
106907051	3.81	C3H6O2	74	2-Propanone, 1-hydroxy-	84.89	7.47
61155663	2.18	C3H6O2	74	Acetic acid, methyl ester	41.03	9.42
70595088	2.52	C3H8O2	76	1,3-Propanediol	32.75	9.62
58220253	2.07	C4H6O3	102	Acetic anhydride	39.95	9.85
46998976	1.67	C5H4O2	96	3-Furaldehyde	52.61	10.68
23918107	0.85	C5H6O2	98	2-Furanmethanol	68.82	11.2
50785147	1.81	C5H7ClO	118	Cyclobutanecarboxylic acid chloride	31.23	12.33
46723099	1.67	C6H10O	98	Cyclopentanone, 2-methyl-	71.65	12.57
35879216	1.28	C4H6N2O2	114	2,4-Imidazolidinedione, 1-methyl-	33.2	13.88
28277017	1.01	C6H8O2	112	2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	55.54	14.42
165875345	5.91	C7H8O2	124	Phenol, 2-methoxy-	54.71	15.47
123271329	4.39	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	51.87	17.09
32941976	1.17	C10H14O2	166	Phenol, 2-methoxy-4-propyl-	57.46	18.33
163685746	5.83	C12H17NO2	207	Phenol, 3-methyl-5-(1-methylethyl)-, methylcarbamate	32.18	18.85
39993398	1.43	C10H12O2	164	Eugenol	48.73	19.42
41896125	1.49	C8H8O3	152	Vanillin	52.1	20.03
82976049	2.96	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-, (E)-	49.79	20.88

Table 9: NIST library matches for balsam fast pyrolysis trial at 500˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
2.716E+09	46.4	C8H19N	129	2-Octanamine	91.77	6.17
505127836	8.63	C2H4O2	60	Acetaldehyde, hydroxy-	72.13	6.82
199428333	3.41	C2H4O2	60	Acetic acid	90.07	7.39
234758278	4.01	C3H6O2	74	2-Propanone, 1-hydroxy-	90.83	7.61
110500620	1.89	C3H6O2	74	2-Propanone, 1-hydroxy-	38.51	9.51
128134362	2.19	C3H6O	58	Propylene oxide	26.18	9.75
105140332	1.8	C3H6O2	74	2-Propanone, 1-hydroxy-	62	9.94
95762738	1.64	C5H4O2	96	3-Furaldehyde	59.11	10.71
64299198	1.1	C5H6O2	98	2-Furanmethanol	75.84	11.27
125488226	2.14	C6H10O	98	Cyclopentanone, 2-methyl-	68.14	12.68
83427819	1.43	C6H8O2	112	2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	55.44	14.52
70787168	1.21	C7H8O	108	Phenol, 3-methyl-	48.27	15.26
410294275	7.01	C7H8O2	124	Phenol, 2-methoxy-	47.18	15.51
21455864	0.37	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	43.37	16.86
286437083	4.89	C8H10O2	138	2-Methoxy-5-methylphenol	49.07	17.1
89740020	1.53	C10H14O2	166	Phenol, 2-methoxy-4-propyl-	77.44	18.34
339116015	5.79	C12H17NO2	207	Phenol, 3-methyl-5-(1-methylethyl)-, methylcarbamate	42.92	18.86
91122054	1.56	C10H12O2	164	Eugenol	46.71	19.43
49706521	0.85	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-	42.56	20.17
126185736	2.16	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-, (E)-	51.57	20.88

Table 10: NIST library matches for balsam fast pyrolysis trial at 600˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
3.974E+09	49.89	C8H19N	129	2-Octanamine	75.64	6.15
658061840	8.26	C2H4O2	60	Acetaldehyde, hydroxy-	68.76	6.86
312999189	3.93	C2H4O2	60	Acetic acid	91.13	7.46
267657110	3.36	C3H6O2	74	2-Propanone, 1-hydroxy-	91.62	7.67
145579688	1.83	C3H6O2	74	2-Propanone, 1-hydroxy-	42.71	9.53
113882969	1.43	C3H8O2	76	1,3-Propanediol	31.97	9.77
160281199	2.01	C3H6O2	74	2-Propanone, 1-hydroxy-	44.85	9.97
134688454	1.69	C5H4O2	96	3-Furaldehyde	56.57	10.69
67653926	0.85	C8H16O	128	2-Hexanone, 3,4-dimethyl-	36.85	11.27
146931220	1.84	C6H10O	98	Cyclopentanone, 2-methyl-	52.12	12.72
142461306	1.79	C6H8O2	112	2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	55.71	14.55
44472790	0.56	C7H8O	108	Phenol, 3-methyl-	37.67	14.92
129482093	1.63	C7H8O	108	Phenol, 3-methyl-	53.24	15.27
377038956	4.73	C7H8O2	124	Phenol, 2-methoxy-	64.46	15.49
44346416	0.56	C8H10O	122	Phenol, 3,4-dimethyl-	27.82	16.39
250597257	3.15	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	52.82	17.1
79398144	1	C6H6O2	110	1,2-Benzenediol	66.93	17.27
87244517	1.1	C10H14O2	166	Phenol, 2-methoxy-4-propyl-	75.92	18.34
417964503	5.25	C12H17NO2	207	Phenol, 3-methyl-5-(1-methylethyl)-, methylcarbamate	23.12	18.88
121594291	1.53	C10H12O2	164	Eugenol	50.47	19.43
85714259	1.08	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-	50.18	20.17
203195360	2.55	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-, (E)-	50.08	20.89

Table 11: NIST library matches for balsam fast pyrolysis trial at 600˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
3.502E+09	49.91	CO2	44	Carbon dioxide	44.09	6.14
732308060	10.44	C2H4O2	60	Acetaldehyde, hydroxy-	77.88	6.85
260657732	3.72	C2H4O2	60	Acetic acid	85.09	7.43
251288441	3.58	C3H6O2	74	2-Propanone, 1-hydroxy-	91.48	7.64
134324733	1.91	C3H6O2	74	2-Propanone, 1-hydroxy-	51.18	9.52
127977952	1.82	C3H6O	58	Propylene oxide	21.25	9.77
127166674	1.81	C3H6O2	74	2-Propanone, 1-hydroxy-	45.27	9.97
116906572	1.67	C5H4O2	96	3-Furaldehyde	69.52	10.69
66135651	0.94	C5H6O2	98	2-Furanmethanol	23.83	11.27
121800300	1.74	C6H10O	98	Cyclopentanone, 2-methyl-	63.83	12.68
69071959	0.98	C6H7O4P	174	Phosphonic acid, (p-hydroxyphenyl)-	49.81	13.67
63596404	0.91	C6H8O2	112	1,2-Cyclopentanedione, 3-methyl-	46.67	14.52
40016315	0.57	C7H8O	108	Phenol, 3-methyl-	40.32	14.91
119297697	1.7	C7H8O	108	Phenol, 3-methyl-	55.53	15.26
336731135	4.8	C7H8O2	124	Phenol, 2-methoxy-	73.88	15.49
302668925	4.31	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	57.42	17.1
63823648	0.91	C10H14O2	166	Phenol, 2-methoxy-4-propyl-	56.2	18.33
303644114	4.33	C12H17NO2	207	Phenol, 3-methyl-5-(1-methylethyl)-, methylcarbamate	24.3	18.86
90473173	1.29	C10H12O2	164	Eugenol	43.5	19.42
65758519	0.94	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-	47.86	20.16
120550444	1.72	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-, (E)-	55.24	20.88

Table 12: NIST library matches for balsam fast pyrolysis trial at 700˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
3.692E+09	51.06	C8H19N	129	2-Octanamine	69.04	6.15
691391323	9.56	C2H4O2	60	Acetaldehyde, hydroxy-	67.58	6.81
175890719	2.43	C2H4O2	60	Acetic acid	61.31	7.31
186973313	2.59	C3H6O2	74	2-Propanone, 1-hydroxy-	84.53	7.57
134993496	1.87	C3H6O2	74	Acetic acid, methyl ester	41.02	9.49
65130386	0.9	C3H6O	58	Propylene oxide	28.03	9.7
110913096	1.53	C3H6O2	74	2-Propanone, 1-hydroxy-	51.76	9.92
105571616	1.46	C5H4O2	96	3-Furaldehyde	59.01	10.69
47843969	0.66	C5H6O2	98	2-Furanmethanol	63.71	11.25
104450041	1.44	C6H10O	98	Cyclopentanone, 2-methyl-	63.61	12.64
71145737	0.98	C6H6O	94	Phenol	72.08	13.65
66667309	0.92	C2H2N4O2	114	1H-1,2,4-Triazole, 3-nitro-	54.8	13.95
40983155	0.57	C7H8O	108	Phenol, 3-methyl-	42.28	14.89
146111994	2.02	C7H8O	108	Phenol, 3-methyl-	49.95	15.25
168224464	2.33	C7H8O2	124	Phenol, 2-methoxy-	50.29	15.47
75457807	1.04	C8H10O	122	Phenol, 3,4-dimethyl-	27.98	16.39
171192368	2.37	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	45.56	17.09
152225264	2.11	C6H6O2	110	1,2-Benzenediol	84.44	17.27
71716266	0.99	C9H12O	136	Phenol, 2-ethyl-5-methyl-	28.11	17.73
60449063	0.84	C7H8O2	124	1,2-Benzenediol, 3-methyl-	90.95	18.11
51418707	0.71	C10H14O2	166	Phenol, 2-methoxy-4-propyl-	55.14	18.34
103650900	1.43	C7H8O2	124	1,2-Benzenediol, 3-methyl-	95.03	18.53
278022656	3.85	C12H17NO2	207	Phenol, 3-methyl-5-(1-methylethyl)-, methylcarbamate	39.81	18.86
142150703	1.97	C10H12O2	164	Eugenol	40.02	19.43
125468996	1.74	C8H8O3	152	Vanillin	52.46	20.09
190423480	2.63	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-, (E)-	46.3	20.89

Table 13: NIST library matches for balsam fast pyrolysis trial at 700˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
4.895E+09	48.3	C8H19N	129	2-Octanamine	68.11	6.14
1.04E+09	10.27	C2H4O2	60	Acetaldehyde, hydroxy-	75.97	6.87
316249895	3.12	C3H6O2	74	2-Propanone, 1-hydroxy-	90.9	7.71
163906773	1.62	C3H6O2	74	Acetic acid, methyl ester	43.61	9.55
125746362	1.24	C3H8O2	76	1,3-Propanediol	26.56	9.77
136455696	1.35	C3H6O2	74	2-Propanone, 1-hydroxy-	50.21	10
143519301	1.42	C5H4O2	96	3-Furaldehyde	54.17	10.71
101845729	1.01	C8H16O	128	2-Hexanone, 3,4-dimethyl-	36	11.28
130367006	1.29	C6H10O	98	Cyclopentanone, 2-methyl-	47.08	12.73
133205558	1.31	C6H6O	94	Phenol	55.58	13.71
127431986	1.26	C6H8O2	112	2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	51.45	14.57
162781735	1.61	C7H8O	108	Phenol, 3-methyl-	44.25	14.92
192667640	1.9	C7H8O	108	Phenol, 3-methyl-	56.97	15.29
352605035	3.48	C7H8O2	124	Phenol, 2-methoxy-	54.88	15.49
138560292	1.37	C8H10O	122	Phenol, 2,6-dimethyl-	13.06	15.75
81601572	0.81	C8H10O	122	Phenol, 3,4-dimethyl-	25.64	16.41
77511522	0.76	C8H10O	122	Phenol, 3,4-dimethyl-	23.86	16.72
207121996	2.04	C8H10O2	138	2-Methoxy-5-methylphenol	46.82	17.1
296280706	2.92	C6H6O2	110	1,2-Benzenediol	70.3	17.32
58590273	0.58	C9H12O	136	Phenol, 2-ethyl-5-methyl-	21.86	17.74
85638909	0.85	C10H14O2	166	Phenol, 2-methoxy-4-propyl-	69.07	18.36
113262983	1.12	C7H8O2	124	1,2-Benzenediol, 3-methyl-	93.89	18.57
472882121	4.67	C12H17NO2	207	Phenol, 3-methyl-5-(1-methylethyl)-, methylcarbamate	33.55	18.89
153864895	1.52	C10H12O2	164	Eugenol	37.52	19.45
143261354	1.41	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-	52.72	20.18
283030681	2.79	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-, (E)-	65.77	20.92

Table 14: NIST library matches for poplar fast pyrolysis trial at 500˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
626606150	12.69	CO2	44	Carbon dioxide	71.86	1.15
187958462	3.81	C2H4O2	60	Acetaldehyde, hydroxy-	77.37	1.67
62731538	1.27	C4H6O3	102	Butanoic acid, 2-oxo-	44.71	1.86
221409507	4.48	C2H4O2	60	Acetic acid	95.21	2.24
172284329	3.49	C3H6O2	74	2-Propanone, 1-hydroxy-	81.5	2.47
34194148	0.69	C4H9NO5	151	1,3-Propanediol, 2-(hydroxymethyl)-2-nitro-	21.63	3.14
24384797	0.49	C5H8O	84	1-Pentyn-3-ol	47.92	3.95
12067038	0.24	C4H6O3	102	Butanoic acid, 2-oxo-	17.24	4.3
99623496	2.02	C4H6O3	102	Acetic anhydride	30.48	4.4
103879088	2.1	C7H14O	114	Pentanal, 2,3-dimethyl-	15.4	4.6
75184721	1.52	C4H6O3	102	Acetic anhydride	62.85	4.82
56349596	1.14	C5H4O2	96	3-Furaldehyde	69.69	5.65
62593621	1.27	C5H6O2	98	2-Furanmethanol	64.06	6.19
19669473	0.4	C6H10O4	146	1,2-Ethanediol, diacetate	44.09	6.44
17793820	0.36	C5H8O2	100	2-Butenoic acid, methyl ester, (E)-	52.87	7.09
62960590	1.28	C6H12	84	2-Hexene	27.95	7.31
22853409	0.46	C5H6O2	98	1,3-Butadiene-1-carboxylic acid	40.04	7.41
133888120	2.71	C6H10O	98	Cyclohexanone	58.1	7.57
27058001	0.55	C14H28O	212	9-Tetradecen-1-ol, (E)-	19.96	8.24
167257559	3.39	C6H7O4P	174	Phosphonic acid, (p-hydroxyphenyl)-	48.38	8.62
83319583	1.69	C4H6N2O2	114	2,4-Imidazolidinedione, 1-methyl-	35.14	8.88
11227308	0.23	C6H8O2	112	2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	35.73	9.13
47860666	0.97	C6H8O2	112	2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	52.41	9.4
27414178	0.56	C6H10O2	114	2-Pentenoic acid, 2-methyl-, (E)-	67.97	9.66
15720173	0.32	C9H16O2	156	2(3H)-Furanone, dihydro-5-pentyl-	14.49	9.86
56502943	1.14	C9H16O2	156	2(3H)-Furanone, dihydro-5-pentyl-	31.99	9.95
12847627	0.26	C11H20O2	184	Undecanoic acid, hydroxy-, lactone	32.48	10.19
18444260	0.37	C6H6O3	126	Methyl 2-furoate	89.59	10.31
45104823	0.91	C7H8O2	124	Phenol, 2-methoxy-	54.57	10.43

182363209	3.69	C4H8O	72	Butanal	29.66	10.57
11188603	0.23	C6H6O3	126	1,3,5-Benzenetriol	43.38	10.81
14752011	0.3	C11H20O2	184	Undecanoic acid, hydroxy-, lactone	14.29	10.92
26373877	0.53	C5H10N2O	114	Piperidine, 1-nitroso-	69.77	11.01
42197843	0.85	C6H10O	98	Cyclopentanone, 2-methyl-	12.81	11.44
27259678	0.55	C8H10O2	138	2-Methoxybenzyl alcohol	49.3	11.63
21904408	0.44	C7H6O2	122	Benzenecarboxylic acid	88.59	11.74
67151246	1.36	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	53.4	12.06
37160987	0.75	C6H6O2	110	1,2-Benzenediol	70.63	12.16
14685102	0.3	C6H10O2	114	2-Pentenoic acid, 2-methyl-, (E)-	20.49	12.36
18492694	0.37	C12H22O2	198	ç Dodecalactone	22.83	12.47
51763336	1.05	C5H6O2	98	2-Furanmethanol	11.84	12.6
14522437	0.29	C12H22O11	342	à-D-Glucopyranoside, à-D-glucopyranosyl	23.96	12.93
58023557	1.18	C7H8O3	140	Flamenol	71.4	13.1
25760457	0.52	C9H12O2	152	2,4-Dimethoxytoluene	62.17	13.32
19456338	0.39	C7H6O2	122	Benzaldehyde, 3-hydroxy-	16.9	13.69
121295203	2.46	C12H17NO2	207	Phenol, 3-methyl-5-(1-methylethyl)-, methylcarbamate	22.72	13.82
193122531	3.91	C10H18O	154	Eucalyptol	44.12	14.34
34058823	0.69	C6H6O3	126	1,3,5-Benzenetriol	48.34	14.7
23571101	0.48	C11H20O2	184	Undecanoic acid, hydroxy-, lactone	28.87	14.81
22876913	0.46	C8H8O3	152	Vanillin	48.25	15.03
7177652.4	0.15	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-	68.62	15.15
21528609	0.44	C9H12O2	152	2,4-Dimethoxytoluene	23.49	15.38
176037226	3.57	C9H12O3	168	1,2,3-Trimethoxybenzene	70.84	15.8
12687750	0.26	C10H14O2	166	Phenol, 2-methoxy-4-propyl-	95.14	16.03
8370636.1	0.17	C12H18	162	Benzene, 1,3-bis(1-methylethyl)-	28.8	16.41
13346056	0.27	C11H12O4	208	4-Acetoxy-3-methoxyacetophenone	54.58	16.56
13246080	0.27	C9H10O3	166	Ethanone, 1-(4-hydroxy-3-methoxyphenyl)-	17.92	16.71
204734933	4.15	C12H22O11	342	à-D-Glucopyranoside, à-D-glucopyranosyl	51.53	17.12
59581105	1.21	C10H12O3	180	Propylparaben	49.45	17.28
56200167	1.14	C10H12O3	180	Propylparaben	60.01	17.39
19852793	0.4	C10H14O2	166	Phenol, 2-methoxy-4-propyl-	82.75	17.57

148827195	3.01	C12H15NO4	237	3-Hydroxycarbofuran	56.09	18.33
17997740	0.36	C20H22N8O5	454	Methotrexate	34.71	18.69
12197467	0.25	C11H21BrO2	264	11-Bromoundecanoic acid	38.38	18.92
20224846	0.41	C10H10O2	162	4-Methoxycinnamaldehyde	18.43	19.04
21480463	0.44	C41H64O13	764	Digitoxin	25.6	19.55
18603136	0.38	C20H28O	284	Vitamin A aldehyde	16.44	19.92
20735348	0.42	C9H10O4	182	3,4-Dimethoxy-5-hydroxybenzaldehyde	49.1	20.07
12280298	0.25	C20H28O	284	Vitamin A aldehyde	21.44	20.36
96497614	1.95	C10H10O2	162	4-Methoxycinnamaldehyde	22.69	20.74
111638188	2.26	C12H18O	178	6-tert-Butyl-2,4-dimethylphenol	19.74	21.23
41026101	0.83	C13H11Br	246	Benzene, 1,1'-(bromomethylene)bis-	38.52	21.76
80146276	1.62	C12H24O2	200	Dodecanoic acid	30.2	24.51
70448569	1.43	C12H15NO4	237	3-Hydroxycarbofuran	27.91	24.96
13568626	0.27	C19H22O6	346	Gibberellic acid	19.49	25.08
70946794	1.44	C16H32O2	256	n-Hexadecanoic acid	37.89	28.43
17896360	0.36	C16H34	226	Hexadecane	20.88	35.54
16464753	0.33	C20H42	282	Eicosane	23.51	37.63
16013793	0.32	C16H34	226	Hexadecane	27.58	39.6

Table 15: NIST library matches for poplar fast pyrolysis trial at 500˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
11116331	0.24	CO2	44	Carbon dioxide	78.17	0.88
574375604	12.34	CO2	44	Carbon dioxide	71.61	1.16
107326292	2.31	C3H4O3	88	Propanoic acid, 2-oxo-	29.02	1.38
202795352	4.36	C2H4O2	60	Acetaldehyde, hydroxy-	78.08	1.69
58817262	1.26	C4H6O3	102	Butanoic acid, 2-oxo-	52.7	1.87
198450510	4.26	C2H4O2	60	Acetic acid	95.16	2.22
154008465	3.31	C3H6O2	74	2-Propanone, 1-hydroxy-	79.21	2.48
29492392	0.63	C4H9NO5	151	1,3-Propanediol, 2-(hydroxymethyl)-2-nitro-	33.87	3.14
22022694	0.47	C5H7ClO	118	Cyclobutanecarboxylic acid chloride	27.52	3.96
12787905	0.27	C4H6O3	102	Butanoic acid, 2-oxo-	29.78	4.3
91758111	1.97	C3H6O2	74	2-Propanone, 1-hydroxy-	34.43	4.41
100242616	2.15	C7H14O	114	Pentanal, 2,3-dimethyl-	30.48	4.6
53170005	1.14	C4H6O3	102	Acetic anhydride	65.4	4.82
16254221	0.35	C6H8N2O	124	Propanenitrile, 3,3'-oxybis-	73.73	4.93
57606691	1.24	C5H4O2	96	3-Furaldehyde	75.5	5.66
55376691	1.19	C5H6O2	98	2-Furanmethanol	72.43	6.18
18034188	0.39	C6H10O4	146	1,2-Ethanediol, diacetate	63.03	6.44
14832023	0.32	C5H8O2	100	2-Butenoic acid, methyl ester, (E)-	58.67	7.09
57053450	1.23	C6H12	84	2-Hexene	25.02	7.3
19525026	0.42	C5H6O2	98	1,3-Butadiene-1-carboxylic acid	38.61	7.4
117850753	2.53	C6H10O	98	Cyclohexanone	49.91	7.56
22531048	0.48	C14H28O	212	9-Tetradecen-1-ol, (E)-	25.6	8.23
11545913	0.25	C6H6O2	110	Resorcinol	62.27	8.5
104947665	2.25	C6H6O	94	Phenol	48.13	8.61
71157688	1.53	C4H6N2O2	114	2,4-Imidazolidinedione, 1-methyl-	24.47	8.87
11532067	0.25	C6H8O2	112	2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	45.25	9.13
47540245	1.02	C6H8O2	112	2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	54.96	9.4
27025908	0.58	C6H10O2	114	2-Pentenoic acid, 2-methyl-, (E)-	66.05	9.66
73662172	1.58	C7H8O	108	Phenol, 3-methyl-	18.18	9.85

12519574	0.27	C7H8O2	124	Benzenemethanol, 4-hydroxy-	21.46	10.19
19662111	0.42	C6H6O3	126	Methyl 2-furoate	92.43	10.31
45667393	0.98	C7H8O2	124	Phenol, 2-methoxy-	51.74	10.43
142911487	3.07	C4H8O	72	Butanal	32.25	10.55
10578578	0.23	C6H6O3	126	1,3,5-Benzenetriol	46.22	10.81
14814428	0.32	C11H20O2	184	Undecanoic acid, hydroxy-, lactone	14.76	10.92
24715473	0.53	C5H10N2O	114	Piperidine, 1-nitroso-	70.25	11
8885350.2	0.19	C14H28O	212	9-Tetradecen-1-ol, (E)-	28.58	11.24
35515688	0.76	C19H37NO	295	Octadecane, 1-isocyanato-	30.65	11.49
28766865	0.62	C8H10O2	138	2-Methoxybenzyl alcohol	51.36	11.63
20474323	0.44	C7H6O2	122	Benzenecarboxylic acid	87.33	11.73
24931932	0.54	C6H6O4	142	4H-Pyran-4-one, 5-hydroxy-2-(hydroxymethyl)-	37.15	11.98
40367854	0.87	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	51.49	12.06
37552277	0.81	C6H6O2	110	1,2-Benzenediol	78.99	12.16
13296236	0.29	C6H10O2	114	2-Pentenoic acid, 2-methyl-, (E)-	15.1	12.36
21187675	0.46	C12H24O	184	Dodecanal	27.48	12.51
51606117	1.11	C5H6O2	98	2-Furanmethanol	14.66	12.6
17432786	0.37	C11H20O2	184	Undecanoic acid, hydroxy-, lactone	24.2	12.93
64604667	1.39	C7H8O3	140	Flamenol	75.68	13.1
28253482	0.61	C9H12O2	152	2,4-Dimethoxytoluene	73.61	13.32
19161978	0.41	C8H10O2	138	1,3-Benzenediol, 4-ethyl-	39.38	13.47
6425480.8	0.14	C12H22O11	342	à-D-Glucopyranoside, à-D-glucopyranosyl	36.42	13.6
19684173	0.42	C7H6O2	122	Benzaldehyde, 3-hydroxy-	14.38	13.69
106283936	2.28	C12H17NO2	207	Phenol, 3-methyl-5-(1-methylethyl)-, methylcarbamate	24.11	13.83
22643970	0.49	C9H11NO4	197	Levodopa	22.95	14.22
167510775	3.6	C10H18O	154	Eucalyptol	43.24	14.34
20617062	0.44	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-	42.54	14.42
40129448	0.86	C6H6O3	126	1,3,5-Benzenetriol	62.73	14.7
20662334	0.44	C11H20O2	184	Undecanoic acid, hydroxy-, lactone	32.88	14.81
19350336	0.42	C8H8O3	152	Vanillin	50.46	15.03
5501583.5	0.12	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-	64.7	15.15
20451270	0.44	C9H12O2	152	2,4-Dimethoxytoluene	31.88	15.36

161070353	3.46	C9H12O3	168	1,2,3-Trimethoxybenzene	60.33	15.8
9054806	0.19	C10H14O2	166	Phenol, 2-methoxy-4-propyl-	94.71	16.03
8343685.2	0.18	C11H14O	162	Ethanone, 1-(2,4,6-trimethylphenyl)-	28	16.41
10354162	0.22	C11H12O4	208	4-Acetoxy-3-methoxyacetophenone	55.8	16.56
14984543	0.32	C9H10O3	166	Ethanone, 1-(4-hydroxy-3-methoxyphenyl)-	41.86	16.71
222533417	4.78	C12H22O11	342	à-D-Glucopyranoside, à-D-glucopyranosyl	49.8	17.11
55706641	1.2	C10H12O3	180	Propylparaben	53.78	17.28
62056313	1.33	C10H12O3	180	Propylparaben	66.36	17.38
17550363	0.38	C10H14O2	166	Phenol, 2-methoxy-4-propyl-	79.42	17.57
135241359	2.91	C12H15NO4	237	3-Hydroxycarbofuran	54.12	18.32
16619272	0.36	C20H22N8O5	454	Methotrexate	57.15	18.69
12701919	0.27	C12H22O11	342	à-D-Glucopyranoside, à-D-glucopyranosyl	31.89	18.92
16205589	0.35	C15H24O	220	1,4-Methanoazulen-7(1H)-one, octahydro-1,5,5,8a-tetramethyl-	17.64	19.05
21333354	0.46	C41H64O13	764	Digitoxin	21	19.55
17002628	0.37	C20H28O	284	Vitamin A aldehyde	20.71	19.92
15719581	0.34	C9H10O4	182	3,4-Dimethoxy-5-hydroxybenzaldehyde	51.01	20.06
10998122	0.24	C20H28O	284	Vitamin A aldehyde	22.86	20.36
77962999	1.67	C10H10O2	162	4-Methoxycinnamaldehyde	29.2	20.73
100984722	2.17	C12H18O	178	6-tert-Butyl-2,4-dimethylphenol	18.48	21.23
39930514	0.86	C13H11Br	246	Benzene, 1,1'-(bromomethylene)bis-	39.15	21.76
44985748	0.97	C12H24O2	200	Dodecanoic acid	28.99	24.47
67301385	1.45	C12H15NO4	237	3-Hydroxycarbofuran	34.49	24.95
17513997	0.38	C19H22O6	346	Gibberellic acid	13.6	25.09
23838396	0.51	C16H32O2	256	n-Hexadecanoic acid	29.17	28.38

Table 16: NIST library matches for poplar fast pyrolysis trial at 600˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
1.086E+09	15.3	CO2	44	Carbon dioxide	89.51	1.12
163700348	2.31	C5H8O2	100	1-Propen-2-ol, acetate	30.86	1.37
183324727	2.58	C2H4O2	60	Acetaldehyde, hydroxy-	80.22	1.72
155518911	2.19	C4H6O2	86	2,3-Butanedione	44.66	1.78
254491730	3.58	C2H4O2	60	Acetic acid	96.57	2.3
219749090	3.09	C3H6O2	74	2-Propanone, 1-hydroxy-	79.14	2.54
128677403	1.81	C3H6O2	74	Acetic acid, methyl ester	28.28	4.45
128872384	1.81	C7H14O	114	Pentanal, 2,3-dimethyl-	23.44	4.66
84947118	1.2	C4H6O3	102	Acetic anhydride	66.96	4.87
24926286	0.35	C6H8N2O	124	Propanenitrile, 3,3'-oxybis-	71.06	4.97
85602055	1.21	C5H4O2	96	3-Furaldehyde	63.85	5.68
67178104	0.95	C5H6O2	98	2-Furanmethanol	67.45	6.21
31288315	0.44	C6H10O4	146	1,2-Ethanediol, diacetate	70.83	6.47
36191139	0.51	C5H8	68	1,3-Butadiene, 2-methyl-	31.97	7.15
78235358	1.1	C6H12	84	2-Hexene	23.63	7.34
186211270	2.62	C6H10O	98	Cyclopentanone, 2-methyl-	49.18	7.61
50757978	0.71	C14H28O	212	9-Tetradecen-1-ol, (E)-	43.44	8.26
16780021	0.24	C6H6O2	110	Resorcinol	38.43	8.52
248060703	3.49	C6H6O	94	Phenol	50.29	8.64
73028681	1.03	C4H6N2O2	114	2,4-Imidazolidinedione, 1-methyl-	20.8	8.93
80171159	1.13	C6H8O2	112	2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	67.56	9.47
24174617	0.34	C7H8O	108	Phenol, 3-methyl-	43.67	9.89
40155912	0.57	C7H8O	108	Phenol, 3-methyl-	45.52	10.23
128611449	1.81	C7H8O2	124	Phenol, 2-methoxy-	58.47	10.47
168407256	2.37	C9H18O	142	Nonanal	22.6	10.66
18175370	0.26	C14H30O	214	1-Tetradecanol	14.46	10.96
24268989	0.34	C8H10O2	138	2-Methoxybenzyl alcohol	60.14	11.67
42495006	0.6	C7H6O2	122	Benzenecarboxylic acid	52.79	11.8
116795673	1.64	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	44.65	12.09

120562567	1.7	C6H6O2	110	1,2-Benzenediol	72.6	12.23
22834510	0.32	C6H10O2	114	2-Pentenoic acid, 2-methyl-, (E)-	21.85	12.45
23840911	0.34	C11H20O2	184	Undecanoic acid, hydroxy-, lactone	17.45	12.59
57340781	0.81	C11H20O2	184	Undecanoic acid, hydroxy-, lactone	13.24	12.69
181214864	2.55	C7H8O3	140	Flamenol	76.06	13.15
94715119	1.33	C9H12O2	152	2,4-Dimethoxytoluene	71.59	13.35
46684840	0.66	C7H8O2	124	1,2-Benzenediol, 3-methyl-	87.47	13.51
214178519	3.02	C10H14O	150	Phenol, 2,3,5,6-tetramethyl-	23.14	13.86
469412221	6.61	C10H18O	154	Eucalyptol	46.92	14.39
47838500	0.67	C7H6O4	154	2,4,6-Trihydroxybenzaldehyde	27.57	14.51
72881405	1.03	C8H10O2	138	1,3-Benzenediol, 4-ethyl-	64.75	14.8
38280819	0.54	C8H8O3	152	Vanillin	48.78	15.07
17016251	0.24	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-	49.78	15.18
312006659	4.39	C9H12O3	168	1,2,3-Trimethoxybenzene	73.45	15.85
211975228	2.99	C11H14O3	194	4-Butoxybenzoic acid	14.74	17.35
51654988	0.73	C13H11Br	246	Benzene, 1,1'-(bromomethylene)bis-	30.83	17.48
34653424	0.49	C10H14O2	166	Phenol, 2-methoxy-4-propyl-	86.5	17.64
284659890	4.01	C12H15NO4	237	3-Hydroxycarbofuran	66.86	18.39
47479858	0.67	C15H24O	220	1,4-Methanoazulen-7(1H)-one, octahydro-1,5,5,8a-tetramethyl-	12.15	19.09
33332222	0.47	C20H28O	284	Vitamin A aldehyde	13.85	19.96
29640568	0.42	C9H10O4	182	3,4-Dimethoxy-5-hydroxybenzaldehyde	36.47	20.11
141634497	1.99	C10H10O2	162	4-Methoxycinnamaldehyde	19.61	20.78
230179799	3.24	C12H18O	178	6-tert-Butyl-2,4-dimethylphenol	17.59	21.28
77017481	1.08	C13H11Br	246	Benzene, 1,1'-(bromomethylene)bis-	33.05	21.81
91878916	1.29	C16H32O2	256	n-Hexadecanoic acid	29.28	24.53
105930086	1.49	C12H15NO4	237	3-Hydroxycarbofuran	38.07	25.03
26661390	0.38	C19H22O6	346	Gibberellic acid	18.67	25.16
68192103	0.96	C16H32O2	256	n-Hexadecanoic acid	41.35	28.45

Table 17: NIST library matches for poplar fast pyrolysis trial at 600˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
1.114E+09	14.55	CO2	44	Carbon dioxide	86.61	1.12
203932668	2.66	C4H6O3	102	Acetic anhydride	34.85	1.37
314530892	4.11	C2H4O2	60	Acetaldehyde, hydroxy-	75.7	1.73
64623778	0.84	C4H6O3	102	Butanoic acid, 2-oxo-	60.99	1.87
32149033	0.42	C2H4O2	60	Acetic acid	63.04	1.96
423590268	5.53	C2H4O2	60	Acetic acid	92.71	2.37
232080707	3.03	C3H6O2	74	2-Propanone, 1-hydroxy-	80.57	2.55
32450887	0.42	C5H8O	84	1-Pentyn-3-ol	32.73	3.97
167390831	2.19	C3H6O2	74	Acetic acid, methyl ester	35.48	4.45
142106265	1.86	C7H14O	114	Pentanal, 2,3-dimethyl-	25.22	4.67
109221985	1.43	C4H6O3	102	Acetic anhydride	64.26	4.89
33886389	0.44	C6H8N2O	124	Propanenitrile, 3,3'-oxybis-	69.28	4.98
104931639	1.37	C5H4O2	96	3-Furaldehyde	73.01	5.68
77292570	1.01	C5H6O2	98	2-Furanmethanol	53.24	6.22
36087762	0.47	C6H10O4	146	1,2-Ethanediol, diacetate	70.51	6.47
85499149	1.12	C6H12	84	2-Hexene	27.92	7.35
186537039	2.44	C6H10O	98	Cyclopentanone, 2-methyl-	61.1	7.63
69175360	0.9	C12H24O	184	Dodecanal	23.09	8.25
21165980	0.28	C6H6O2	110	Resorcinol	35.09	8.53
219585636	2.87	C6H7O4P	174	Phosphonic acid, (p-hydroxyphenyl)-	48.27	8.65
141351435	1.85	C2H2N4O2	114	1H-1,2,4-Triazole, 3-nitro-	45.94	8.95
71992339	0.94	C6H8O2	112	2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	67.77	9.47
19696568	0.26	C7H8O	108	Phenol, 3-methyl-	46.88	9.88
103154198	1.35	C7H8O	108	Phenol, 3-methyl-	32.32	10.23
97627282	1.27	C7H8O2	124	Phenol, 2-methoxy-	53.58	10.46
103321580	1.35	C11H22O	170	Undecanal	30.62	10.65
17236455	0.23	C11H20O2	184	Undecanoic acid, hydroxy-, lactone	22.03	10.96
31425616	0.41	C9H10O3	166	Benzaldehyde, 3-ethoxy-2-hydroxy-	42.65	11.67
129727294	1.69	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	46.78	12.08

100978935	1.32	C6H6O2	110	1,2-Benzenediol	48.12	12.24
28287761	0.37	C6H10O2	114	2-Pentenoic acid, 2-methyl-, (E)-	16.8	12.47
85848085	1.12	C11H22O	170	Undecanal	14.1	12.7
174165772	2.27	C7H8O3	140	Flamenol	67.7	13.16
70848617	0.93	C9H12O2	152	2,4-Dimethoxytoluene	76.66	13.34
196215970	2.56	C12H17NO2	207	Phenol, 3-methyl-5-(1-methylethyl)-, methylcarbamate	24.78	13.85
364888594	4.77	C10H18O	154	Eucalyptol	49.39	14.38
43823158	0.57	C10H18O	154	3-Cyclohexen-1-ol, 4-methyl-1-(1-methylethyl)-	26.4	14.51
63439727	0.83	C7H6O5	170	2,4,6-Trihydroxybenzoic acid	34.11	14.86
50456558	0.66	C8H8O3	152	Vanillin	52.84	15.07
15964553	0.21	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-	59.29	15.17
316494455	4.13	C9H12O3	168	1,2,3-Trimethoxybenzene	69.79	15.84
28880596	0.38	C10H14O2	166	Phenol, 2-methoxy-4-propyl-	93.73	16.08
32781047	0.43	C9H10O3	166	Ethanone, 1-(4-hydroxy-3-methoxyphenyl)-	54.64	16.63
259033288	3.38	C11H14O3	194	4-Butoxybenzoic acid	33.61	17.46
264856149	3.46	C10H12O3	180	Propylparaben	25.19	17.63
185570208	2.42	C10H12O3	180	Propylparaben	27.96	17.72
231955538	3.03	C12H15NO4	237	3-Hydroxycarbofuran	60.27	18.37
55649105	0.73	C20H28O	284	Vitamin A aldehyde	23.18	19.08
38668743	0.5	C12H15NO4	237	3-Hydroxycarbofuran	24.72	19.94
40222274	0.53	C9H10O4	182	3,4-Dimethoxy-5-hydroxybenzaldehyde	38.35	20.12
158615065	2.07	C10H10O2	162	4-Methoxycinnamaldehyde	22.9	20.77
138544758	1.81	C12H18O	178	6-tert-Butyl-2,4-dimethylphenol	18.94	21.28
62212662	0.81	C12H8N2O	196	9H-Carbazole, 9-nitroso-	30.17	21.8
91967103	1.2	C16H32O2	256	n-Hexadecanoic acid	30.91	24.52
110572930	1.44	C12H15NO4	237	3-Hydroxycarbofuran	34.83	25.03
60988621	0.8	C16H32O2	256	n-Hexadecanoic acid	42.88	28.44

Table 18: NIST library matches for poplar fast pyrolysis trial at 700˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
1.046E+09	18.42	CO2	44	Carbon dioxide	87.93	1.13
207624810	3.66	C5H8O2	100	1-Propen-2-ol, acetate	29.63	1.38
291870423	5.14	C2H4O2	60	Acetaldehyde, hydroxy-	79.59	1.73
61379984	1.08	C4H6O3	102	Butanoic acid, 2-oxo-	53.49	1.9
347563155	6.12	C2H4O2	60	Acetic acid	85.04	2.36
154091013	2.71	C3H6O2	74	2-Propanone, 1-hydroxy-	86.01	2.55
140972292	2.48	C3H6O2	74	Acetic acid, methyl ester	39.63	4.46
92984386	1.64	C7H14O	114	Pentanal, 2,3-dimethyl-	33.63	4.65
86879296	1.53	C4H6O3	102	Acetic anhydride	65.53	4.87
24662558	0.43	C6H8N2O	124	Propanenitrile, 3,3'-oxybis-	75.03	4.97
74770256	1.32	C5H4O2	96	3-Furaldehyde	68.42	5.68
52547302	0.93	C5H6O2	98	2-Furanmethanol	63.92	6.21
54904277	0.97	C6H12	84	2-Hexene	33.95	7.33
128278265	2.26	C6H10O	98	Cyclopentanone, 2-methyl-	44.85	7.6
52315494	0.92	C14H28O	212	9-Tetradecen-1-ol, (E)-	45.13	8.25
16029497	0.28	C6H6O2	110	Resorcinol	22.27	8.52
175757228	3.1	C6H6O	94	Phenol	49.34	8.63
123071609	2.17	C4H6N2O2	114	2,4-Imidazolidinedione, 1-methyl-	20.83	8.92
46399995	0.82	C6H8O2	112	1,2-Cyclopentanedione, 3-methyl-	47.65	9.44
23486951	0.41	C7H8O	108	Phenol, 2-methyl-	36.1	9.88
29021650	0.51	C7H8O	108	Phenol, 3-methyl-	41.6	10.22
50280064	0.89	C7H8O2	124	Phenol, 2-methoxy-	55.05	10.44
53718647	0.95	C5H10O	86	2-Penten-1-ol, (Z)-	11.64	10.57
78982701	1.39	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	52.96	12.08
83370415	1.47	C6H6O2	110	1,2-Benzenediol	72.52	12.2
60321500	1.06	C11H20O2	184	Undecanoic acid, hydroxy-, lactone	11.99	12.67
119300653	2.1	C7H8O3	140	Flamenol	70.69	13.13
37704480	0.66	C9H12O2	152	2,4-Dimethoxytoluene	70.81	13.33
44541354	0.78	C7H8O2	124	1,2-Benzenediol, 3-methyl-	88.49	13.5

114125255	2.01	C10H14O	150	Phenol, p-tert-butyl-	26.06	13.84
225571785	3.97	C10H18O	154	Eucalyptol	50.7	14.36
43183836	0.76	C10H18O	154	3-Cyclohexen-1-ol, 4-methyl-1-(1-methylethyl)-	26.64	14.49
65720531	1.16	C8H10O2	138	1,3-Benzenediol, 4-ethyl-	58.09	14.78
34991085	0.62	C8H8O3	152	Vanillin	48.66	15.06
186967060	3.29	C9H12O3	168	1,2,3-Trimethoxybenzene	70.88	15.82
22627245	0.4	C11H12O4	208	4-Acetoxy-3-methoxyacetophenone	68.22	16.74
240399527	4.23	C11H14O3	194	4-Butoxybenzoic acid	38.31	17.45
100720773	1.77	C10H12O3	180	Propylparaben	27.66	17.54
176027956	3.1	C12H15NO4	237	3-Hydroxycarbofuran	72.29	18.35
46242895	0.81	C10H10O2	162	4-Methoxycinnamaldehyde	12.26	19.07
35334714	0.62	C9H10O4	182	3,4-Dimethoxy-5-hydroxybenzaldehyde	38.84	20.11
99537686	1.75	C10H10O2	162	4-Methoxycinnamaldehyde	15.72	20.76
165401087	2.91	C12H18O	178	6-tert-Butyl-2,4-dimethylphenol	17.57	21.26
41331507	0.73	C13H11Br	246	Benzene, 1,1'-(bromomethylene)bis-	28.41	21.78
114588851	2.02	C16H32O2	256	n-Hexadecanoic acid	28.56	24.53
80744811	1.42	C12H15NO4	237	3-Hydroxycarbofuran	39.37	25
43370892	0.76	C19H22O6	346	Gibberellic acid	22.83	25.16
81729775	1.44	C16H32O2	256	n-Hexadecanoic acid	29	28.46

Table 19: NIST library matches for poplar fast pyrolysis trial at 700˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
1.005E+09	16.25	CO2	44	Carbon dioxide	87.78	1.1
202366997	3.27	C4H6O3	102	Acetic anhydride	30.25	1.35
288370477	4.66	C2H4O2	60	Acetaldehyde, hydroxy-	79.35	1.7
97424251	1.57	C4H6O3	102	Butanoic acid, 2-oxo-	59.1	1.85
317247881	5.13	C2H4O2	60	Acetic acid	96.09	2.29
185019501	2.99	C3H6O2	74	2-Propanone, 1-hydroxy-	78.97	2.51
149397983	2.42	C3H6O2	74	Acetic acid, methyl ester	55.38	4.43
111496711	1.8	C7H14O	114	Pentanal, 2,3-dimethyl-	38.18	4.63
88758408	1.43	C4H6O3	102	Acetic anhydride	66.24	4.86
26581353	0.43	C6H8N2O	124	Propanenitrile, 3,3'-oxybis-	72.68	4.95
83660357	1.35	C5H4O2	96	3-Furaldehyde	73.77	5.66
58004130	0.94	C5H6O2	98	2-Furanmethanol	47.73	6.2
63761916	1.03	C6H12	84	2-Hexene	43.8	7.33
150948823	2.44	C6H10O	98	Cyclopentanone, 2-methyl-	44.27	7.59
49199229	0.8	C14H28O	212	9-Tetradecen-1-ol, (E)-	34.2	8.25
16573697	0.27	C6H6O2	110	Resorcinol	38.57	8.52
181115367	2.93	C6H6O	94	Phenol	50.24	8.63
132772657	2.15	C2H2N4O2	114	1H-1,2,4-Triazole, 3-nitro-	23.12	8.92
57645778	0.93	C6H8O2	112	2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	72.64	9.44
26714934	0.43	C7H8O	108	Phenol, 3-methyl-	41.88	9.88
42447032	0.69	C7H8O	108	Phenol, 3-methyl-	55.58	10.22
77524109	1.25	C7H8O2	124	Phenol, 2-methoxy-	52.27	10.45
75773162	1.22	C5H10O	86	2-Penten-1-ol, (Z)-	8.57	10.58
28255843	0.46	C9H10O3	166	Benzaldehyde, 3-ethoxy-2-hydroxy-	35.65	11.66
106511468	1.72	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	48.3	12.08
89032168	1.44	C6H6O2	110	1,2-Benzenediol	62.21	12.22
69877644	1.13	C11H20O2	184	Undecanoic acid, hydroxy-, lactone	15.03	12.68
167747835	2.71	C7H8O3	140	Flamenol	70.44	13.14
75445188	1.22	C9H12O2	152	2,4-Dimethoxytoluene	69.5	13.34

38956310	0.63	C7H8O2	124	1,2-Benzenediol, 3-methyl-	88.68	13.51
169155076	2.73	C10H14O	150	Phenol, 2-methyl-5-(1-methylethyl)-	21.05	13.85
301835306	4.88	C10H18O	154	Eucalyptol	50.48	14.36
38300167	0.62	C10H18O	154	3-Cyclohexen-1-ol, 4-methyl-1-(1-methylethyl)-	25.83	14.5
68698470	1.11	C8H10O2	138	1,3-Benzenediol, 4-ethyl-	58.12	14.79
41543622	0.67	C8H8O3	152	Vanillin	45.84	15.07
237010034	3.83	C9H12O3	168	1,2,3-Trimethoxybenzene	49.5	15.83
39237950	0.63	C10H14O2	166	Phenol, 2-methoxy-4-propyl-	93	16.07
241985020	3.91	C11H14O3	194	4-Butoxybenzoic acid	32.73	17.46
166611844	2.69	C10H12O3	180	Propylparaben	31.92	17.57
200125487	3.24	C12H15NO4	237	3-Hydroxycarbofuran	58.71	18.36
41693644	0.67	C20H28O	284	Vitamin A aldehyde	14.01	19.07
31358133	0.51	C9H10O4	182	3,4-Dimethoxy-5-hydroxybenzaldehyde	42.83	20.11
118402464	1.91	C10H10O2	162	4-Methoxycinnamaldehyde	21.02	20.76
134162081	2.17	C12H18O	178	6-tert-Butyl-2,4-dimethylphenol	22	21.26
50311274	0.81	C13H11Br	246	Benzene, 1,1'-(bromomethylene)bis-	27.41	21.79
82294487	1.33	C16H32O2	256	n-Hexadecanoic acid	33.02	24.51
94185161	1.52	C12H15NO4	237	3-Hydroxycarbofuran	35.98	25
65325222	1.06	C16H32O2	256	n-Hexadecanoic acid	34.67	28.43

Table 20: NIST library matches for red maple fast pyrolysis trial at 500˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
4.281E+09	51.87	C9H13N	135	Dextroamphetamine	42.43	6.15
133581622	1.62	CH6N2	46	Hydrazine, methyl-	53.83	6.66
643511098	7.8	C2H4O2	60	Acetaldehyde, hydroxy-	70.91	6.96
523703814	6.34	C2H4O2	60	Acetic acid	93.68	7.56
332178914	4.02	C2H4O2	60	Acetic acid	94.33	7.73
322341008	3.91	C3H6O2	74	2-Propanone, 1-hydroxy-	93.16	7.83
205009768	2.48	C3H6O2	74	Acetic acid, methyl ester	42.26	9.63
211912636	2.57	C3H6O	58	Propylene oxide	27.6	9.89
200216919	2.43	C3H6O2	74	2-Propanone, 1-hydroxy-	39.95	10.11
200789284	2.43	C5H4O2	96	3-Furaldehyde	59.31	10.75
130632104	1.58	C5H6O2	98	2-Furanmethanol	61.12	11.36
175019671	2.12	C6H10O	98	Cyclopentanone, 2-methyl-	50.93	12.81
149413023	1.81	C5H10N2O	114	Piperidine, 1-nitroso-	31.06	14.06
107096894	1.3	C6H8O2	112	2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	56.42	14.59
194314964	2.35	C7H8O2	124	Phenol, 2-methoxy-	59.95	15.51
97215940	1.18	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	52.62	17.1
35585162	0.43	C9H12O2	152	2,4-Dimethoxytoluene	57.76	18.34
101249627	1.23	C12H17NO2	207	Phenol, 3-methyl-5-(1-methylethyl)-, methylcarbamate	23.81	18.86
151241737	1.83	C10H18O	154	Eucalyptol	46.54	19.37
57494461	0.7	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-, (E)-	46.8	20.88

Table 21: NIST library matches for red maple fast pyrolysis trial at 500˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
5.995E+09	55.89	C8H19N	129	2-Octanamine	54.51	6.17
244179132	2.28	C4H8O	72	Oxirane, 2,3-dimethyl-, trans-	33.94	6.79
275423016	2.57	C2H4O2	60	Acetaldehyde, hydroxy-	72.93	7.07
310649423	2.9	C2H4O2	60	Acetic acid	80.62	7.45
1.08E+09	10.07	C3H6O2	74	2-Propanone, 1-hydroxy-	90.85	7.98
233512250	2.18	C3H6O2	74	Acetic acid, methyl ester	38.07	9.72
201324647	1.88	C3H8O2	76	1,3-Propanediol	36.68	9.94
338056080	3.15	C3H6O2	74	2-Propanone, 1-hydroxy-	47.66	10.19
328877633	3.07	C6H8O	96	Furan, 2,5-dimethyl-	36.2	10.88
153477486	1.43	C6H12O	100	Butanal, 2-ethyl-	39.49	11.4
50418743	0.47	C4H6O2	86	Acetic acid ethenyl ester	50.48	11.65
228173756	2.13	C6H10O	98	Cyclopentanone, 2-methyl-	44.61	12.86
111791027	1.04	C12H24O	184	Dodecanal	25.62	13.39
175192558	1.63	C5H10N2O	114	Piperidine, 1-nitroso-	27.68	14.13
176197295	1.64	C6H8O2	112	1,2-Cyclopentanedione, 3-methyl-	44.52	14.66
287747448	2.68	C7H8O2	124	Phenol, 2-methoxy-	60.08	15.53
141046515	1.31	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	56.65	17.13
55273899	0.52	C10H14O2	166	Phenol, 2-methoxy-4-propyl-	46.37	18.36
131910879	1.23	C10H14O	150	Phenol, p-tert-butyl-	26.27	18.88
154948604	1.44	C10H18O	154	Eucalyptol	35.73	19.38
52853459	0.49	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-	50.92	20.89

Table 22: NIST library matches for red maple fast pyrolysis trial at 600˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
5.869E+09	53.44	C8H19N	129	2-Octanamine	55.36	6.15
215044035	1.96	C3H4O2	72	Methylglyoxal	30.87	6.77
237095788	2.16	C2H4O2	60	Acetaldehyde, hydroxy-	71.99	7.01
906234942	8.25	C2H4O2	60	Acetic acid	91.11	7.86
269171154	2.45	C3H6O2	74	2-Propanone, 1-hydroxy-	92.04	7.93
231763792	2.11	C3H6O2	74	Acetic acid, methyl ester	48.96	9.7
152413410	1.39	C3H6O	58	Propylene oxide	38.83	9.89
332963224	3.03	C3H6O2	74	2-Propanone, 1-hydroxy-	38.55	10.15
306205617	2.79	C5H4O2	96	3-Furaldehyde	58.85	10.75
134502082	1.22	C6H12O	100	Butanal, 2-ethyl-	35.31	11.38
40014116	0.36	C4H6O2	86	Acetic acid ethenyl ester	35.9	11.62
213914134	1.95	C6H10O	98	Cyclopentanone, 2-methyl-	39.46	12.85
110893433	1.01	C12H24O	184	Dodecanal	21.07	13.38
213961377	1.95	C2H2N4O2	114	1H-1,2,4-Triazole, 3-nitro-	32.43	14.16
173033120	1.58	C6H8O2	112	1,2-Cyclopentanedione, 3-methyl-	35.49	14.66
111342226	1.01	C7H8O	108	Phenol, 3-methyl-	60.03	15.33
273059898	2.49	C7H8O2	124	Phenol, 2-methoxy-	55.77	15.52
156375505	1.42	C8H10O	122	Phenol, 2,6-dimethyl-	21.38	15.77
74429694	0.68	C8H10O2	138	2-Methoxybenzyl alcohol	61.27	16.75
126733827	1.15	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	50.63	17.12
121759124	1.11	C10H14O2	166	Phenol, 2-methoxy-4-propyl-	66.57	18.36
216521200	1.97	C12H17NO2	207	Phenol, 3-methyl-5-(1-methylethyl)-, methylcarbamate	23.93	18.88
351711691	3.2	C10H18O	154	Eucalyptol	36.27	19.41
143800000	1.31	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-, (E)-	43.46	20.91

Table 23: NIST library matches for red maple fast pyrolysis trial at 600˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
6.151E+09	52.95	C8H19N	129	2-Octanamine	70.11	6.15
327364676	2.82	C4H8O	72	Oxirane, 2,3-dimethyl-, trans-	34.63	6.77
267282407	2.3	C2H4O2	60	Acetaldehyde, hydroxy-	69.96	7.02
281210352	2.42	C2H4O2	60	Acetic acid	74.86	7.43
1.196E+09	10.29	C3H6O2	74	2-Propanone, 1-hydroxy-	89.53	7.95
294776004	2.54	C3H6O2	74	Acetic acid, methyl ester	42.06	9.71
127846360	1.1	C3H6O	58	Propylene oxide	24.81	9.88
395791757	3.41	C3H6O2	74	2-Propanone, 1-hydroxy-	46.6	10.18
308975648	2.66	C6H8O	96	Furan, 2,5-dimethyl-	33.91	10.87
138744847	1.19	C6H12O	100	Butanal, 2-ethyl-	25.93	11.39
260012882	2.24	C6H10O	98	Cyclopentanone, 2-methyl-	37.6	12.88
143310395	1.23	C12H24O	184	Dodecanal	29.15	13.39
275967737	2.38	C4H6N2O2	114	2,4-Imidazolidinedione, 1-methyl-	45.58	14.21
151491056	1.3	C6H8O2	112	2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	36.26	14.66
101173958	0.87	C7H8O	108	Phenol, 3-methyl-	44.51	15.33
255650338	2.2	C7H8O2	124	Phenol, 2-methoxy-	52.78	15.52
71689943	0.62	C8H10O2	138	2-Methoxybenzyl alcohol	58.52	16.75
137384214	1.18	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	57.75	17.13
109690598	0.94	C10H14O2	166	Phenol, 2-methoxy-4-propyl-	53.16	18.36
190815340	1.64	C12H17NO2	207	Phenol, 3-methyl-5-(1-methylethyl)-, methylcarbamate	30.1	18.88
287341295	2.47	C10H18O	154	Eucalyptol	44.65	19.41
144179531	1.24	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-	57.59	20.91

Table 24: NIST library matches for red maple fast pyrolysis trial at 700˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
6.287E+09	54.59	C8H19N	129	2-Octanamine	83	6.15
307103141	2.67	C4H6O	70	Methyl vinyl ketone	20.97	6.77
260654127	2.26	C2H4O2	60	Acetaldehyde, hydroxy-	72.39	6.98
384551369	3.34	C2H4O2	60	Acetic acid	86.3	7.46
934319438	8.11	C3H6O2	74	2-Propanone, 1-hydroxy-	92.25	7.88
269874135	2.34	C3H6O2	74	2-Propanone, 1-hydroxy-	51.88	9.68
119219383	1.04	C3H6O	58	Propylene oxide	25.34	9.85
374922204	3.26	C3H6O2	74	2-Propanone, 1-hydroxy-	40.02	10.12
306088198	2.66	C5H4O2	96	3-Furaldehyde	60.63	10.75
127397918	1.11	C6H12O	100	Butanal, 2-ethyl-	32.73	11.36
179911145	1.56	C6H10O	98	Cyclopentanone, 2-methyl-	40.35	12.82
108860505	0.95	C6H7O4P	174	Phosphonic acid, (p-hydroxyphenyl)-	33.98	13.75
300287071	2.61	C2H2N4O2	114	1H-1,2,4-Triazole, 3-nitro-	24.92	14.16
135242855	1.17	C6H8O2	112	1,2-Cyclopentanedione, 3-methyl-	46.4	14.65
118829358	1.03	C7H8O	108	Phenol, 3-methyl-	43.51	15.32
211143243	1.83	C7H8O2	124	Phenol, 2-methoxy-	45.32	15.51
88262934	0.77	C8H10O	122	Phenol, 3,4-dimethyl-	26.15	16.43
81452027	0.71	C8H10O2	138	2-Methoxybenzyl alcohol	53.95	16.75
103460954	0.9	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	54.2	17.12
129080255	1.12	C9H12O2	152	2,4-Dimethoxytoluene	48.12	18.37
196371094	1.71	C10H14O	150	Phenol, 2,3,5,6-tetramethyl-	30.78	18.88
310621730	2.7	C10H18O	154	Eucalyptol	43.75	19.41
181574122	1.58	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-	49.46	20.92

Table 25: NIST library matches for red maple fast pyrolysis trial at 700˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
6.53E+09	51.73	C8H19N	129	2-Octanamine	80.68	6.15
267609492	2.12	C3H4O2	72	Methylglyoxal	16.81	6.77
208629596	1.65	C2H4O2	60	Acetaldehyde, hydroxy-	75.26	7.01
790130193	6.26	C2H4O2	60	Acetic acid	90.72	7.84
342831911	2.72	C3H6O2	74	2-Propanone, 1-hydroxy-	88	7.94
178559520	1.41	C3H6O2	74	Acetic acid, methyl ester	46.73	9.68
158152417	1.25	C3H8O2	76	1,3-Propanediol	35.38	9.88
291904587	2.31	C3H6O2	74	2-Propanone, 1-hydroxy-	52.05	10.13
311602280	2.47	C5H4O2	96	3-Furaldehyde	65.51	10.75
144227129	1.14	C6H12O	100	Butanal, 2-ethyl-	27.96	11.38
236120736	1.87	C6H10O	98	Cyclopentanone, 2-methyl-	60.29	12.85
145789196	1.15	C14H28O	212	9-Tetradecen-1-ol, (E)-	46.31	13.37
155338156	1.23	C6H6O	94	Phenol	40.9	13.76
159452362	1.26	C4H6N2O2	114	2,4-Imidazolidinedione, 1-methyl-	35.44	14.14
204565223	1.62	C6H8O2	112	1,2-Cyclopentanedione, 3-methyl-	36.18	14.66
95645519	0.76	C7H8O	108	Phenol, 3-methyl-	47	14.98
143879368	1.14	C7H8O	108	Phenol, 3-methyl-	50	15.33
249836672	1.98	C7H8O2	124	Phenol, 2-methoxy-	50.37	15.52
95135197	0.75	C8H10O	122	Phenol, 3,4-dimethyl-	24.67	16.44
120541138	0.95	C8H10O2	138	2-Methoxybenzyl alcohol	48.57	16.76
101850918	0.81	C8H10O2	138	2-Methoxy-5-methylphenol	49.16	17.12
169981204	1.35	C6H6O2	110	1,2-Benzenediol	54.57	17.4
201757653	1.6	C9H12O2	152	2,4-Dimethoxytoluene	65.59	18.37
298340549	2.36	C12H17NO2	207	Phenol, 3-methyl-5-(1-methylethyl)-, methylcarbamate	38.75	18.89
577569606	4.58	C10H18O	154	Eucalyptol	31.38	19.44
84428425	0.67	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-	42.43	20.2
274334537	2.17	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-	50.41	20.94
84533331	0.67	C12H15NO4	237	3-Hydroxycarbofuran	72.73	23.36

Table 26: NIST library matches for willow fast pyrolysis trial at 500˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
49540528	0.5	CO2	44	Carbon dioxide	97.98	0.9
1.21E+09	12.14	C9H13N	135	Dextroamphetamine	46.74	1.14
97497501	0.98	C3H4O3	88	Propanoic acid, 2-oxo-	30.62	1.38
224376591	2.25	C2H4O2	60	Acetaldehyde, hydroxy-	42.46	1.77
106157459	1.07	C4H6O3	102	Butanoic acid, 2-oxo-	41.78	1.88
596446525	5.98	C3H6O2	74	2-Propanone, 1-hydroxy-	89.77	2.62
30759897	0.31	C15H22N2O3	278	Tolycaine	55.85	3.18
44759718	0.45	C4H6O2	86	2,2'-Bioxirane, (R*,R*)-(ñ)-	26.65	4.02
158030251	1.59	C3H6O2	74	Acetic acid, methyl ester	36	4.48
112658205	1.13	C7H14O	114	Pentanal, 2,3-dimethyl-	29.26	4.7
78680622	0.79	C4H6O3	102	Acetic anhydride	46.23	4.91
24467885	0.25	C5H7NO3	129	Pidolic Acid	67.55	5
174476638	1.75	C5H4O2	96	3-Furaldehyde	78.99	5.71
99480707	1	C5H6O2	98	2-Furanmethanol	58.1	6.25
38061163	0.38	C6H10O4	146	1,2-Ethanediol, diacetate	62.86	6.49
80086662	0.8	C6H12	84	2-Hexene	33.94	7.39
190473367	1.91	C6H10O	98	Cyclopentanone, 2-methyl-	69.95	7.68
70870190	0.71	C12H24O	184	Dodecanal	20.44	8.27
18744479	0.19	C6H6O2	110	Resorcinol	57.42	8.55
93175653	0.93	C6H7O4P	174	Phosphonic acid, (p-hydroxyphenyl)-	58.13	8.67
231066061	2.32	C2H2N4O2	114	1H-1,2,4-Triazole, 3-nitro-	40.41	8.97
42727845	0.43	C6H8O2	112	2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	41.38	9.24
67678132	0.68	C6H8O2	112	1,2-Cyclopentanedione, 3-methyl-	57.24	9.5
26391531	0.26	C7H6O2	122	Benzaldehyde, 2-hydroxy-	36.81	9.67
21468921	0.22	C6H10O2	114	2-Pentenoic acid, 2-methyl-, (E)-	62.83	9.74
21971808	0.22	C7H8O	108	Phenol, 3-methyl-	40.19	9.9
75017349	0.75	C9H16O2	156	2(3H)-Furanone, dihydro-5-pentyl-	32.78	10.16
44566953	0.45	C7H8O	108	Phenol, 3-methyl-	20	10.24

108196002	1.09	C7H8O2	124	Phenol, 2-methoxy-	52.76	10.47
158680247	1.59	C9H18O	142	Nonanal	36.85	10.68
15574982	0.16	C6H6O3	126	1,3,5-Benzenetriol	33.04	10.98
33197951	0.33	C5H10N2O	114	Piperidine, 1-nitroso-	34.97	11.16
93846445	0.94	C9H10O3	166	Benzaldehyde, 3-ethoxy-2-hydroxy-	57.75	11.68
37450959	0.38	C7H6O2	122	Benzenecarboxylic acid	45.22	11.83
133429811	1.34	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	51.75	12.09
117481216	1.18	C6H6O2	110	1,2-Benzenediol	47.87	12.27
40898617	0.41	C8H8O	120	Phthalan	28.98	12.46
100506273	1.01	C11H22O	170	Undecanal	14.31	12.7
94459299	0.95	C7H8O3	140	Flamenol	71.2	13.17
110902745	1.11	C9H12O2	152	2,4-Dimethoxytoluene	68.77	13.35
312751130	3.14	C10H14O	150	Phenol, 2-methyl-5-(1-methylethyl)-	24.83	13.86
576844517	5.79	C10H18O	154	Eucalyptol	47.32	14.39
45599846	0.46	C11H20O2	184	Oxacyclododecan-2-one	30.5	14.87
34052344	0.34	C15H24O	220	4a,7-Methano-4aH-naphth[1,8a-b]oxirene, octahydro-4,4,8,8-tetramethyl-	25.37	14.98
86062650	0.86	C8H8O3	152	Vanillin	48.21	15.09
33397836	0.34	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-	61.95	15.18
513952366	5.16	C9H12O3	168	1,2,3-Trimethoxybenzene	70.54	15.86
26874945	0.27	C10H14O2	166	Phenol, 2-methoxy-4-propyl-	93.9	16.09
41871391	0.42	C11H12O4	208	4-Acetoxy-3-methoxyacetophenone	63.68	16.65
175382724	1.76	C13H11Br	246	Benzene, 1,1'-(bromomethylene)bis-	27.95	17.48
180481207	1.81	C10H14O2	166	Phenol, 2-methoxy-4-propyl-	71.24	17.65
611730069	6.14	C12H15NO4	237	3-Hydroxycarbofuran	65.39	18.42
27875890	0.28	C12H15NO4	237	3-Hydroxycarbofuran	80.45	18.57
41069267	0.41	C18H22O4	302	3,4-Hexanediol, 3,4-bis(4-hydroxyphenyl)-	25.96	18.72
117967726	1.18	C12H15NO4	237	3-Hydroxycarbofuran	16.57	19.1
23435330	0.24	C13H11Br	246	Benzene, 1,1'-(bromomethylene)bis-	30.03	19.21
84210004	0.84	C12H15NO4	237	3-Hydroxycarbofuran	46.14	19.96
87934164	0.88	C9H10O4	182	3,4-Dimethoxy-5-hydroxybenzaldehyde	49.33	20.15
27099225	0.27	C12H15NO4	237	3-Hydroxycarbofuran	85.6	20.32

26305910	0.26	C20H28O	284	Vitamin A aldehyde	21.14	20.4
14450542	0.14	C15H24O	220	4a,7-Methano-4aH-naphth[1,8a-b]oxirene, octahydro-4,4,8,8-tetramethyl-	25.61	20.52
416738924	4.18	C10H10O2	162	4-Methoxycinnamaldehyde	22.93	20.81
202818658	2.04	C12H18O	178	6-tert-Butyl-2,4-dimethylphenol	18.4	21.3
178131411	1.79	C12H15NO4	237	3-Hydroxycarbofuran	90.33	21.37
147633183	1.48	C13H11Br	246	Benzene, 1,1'-(bromomethylene)bis-	30.43	21.82
24747962	0.25	C15H24O	220	4a,7-Methano-4aH-naphth[1,8a-b]oxirene, octahydro-4,4,8,8-tetramethyl-	38.63	22.43
22835572	0.23	C8H11NO2	153	3-Pyridinemethanol, 5-hydroxy-4,6-dimethyl-	28.08	22.51
59572838	0.6	C13H12	168	Diphenylmethane	32.65	23.47
47125528	0.47	C19H22O6	346	Gibberellic acid	18.15	23.84
84110646	0.84	C16H32O2	256	n-Hexadecanoic acid	31.93	24.53
229741690	2.31	C12H15NO4	237	3-Hydroxycarbofuran	37.55	25.07
122125902	1.23	C15H24O	220	4a,7-Methano-4aH-naphth[1,8a-b]oxirene, octahydro-4,4,8,8-tetramethyl-	16.55	25.24
65343711	0.66	C16H32O2	256	n-Hexadecanoic acid	40.89	28.46
32636414	0.33	C10H10O2	162	Benzene, 1,2-(methylenedioxy)-4-propenyl-, (E)-	12.01	36.24
41806549	0.42	C12H11N	169	[1,1'-Biphenyl]-4-amine	49.11	38.56
29900162	0.3	C17H36	240	Heptadecane	18.46	43.29
28739500	0.29	C13H14	170	Naphthalene, 1-(1-methylethyl)-	54.71	43.42
68760146	0.69	C41H72O2	596	Cholest-5-en-3-ol (3á)-, tetradecanoate	39.04	50.25

Table 27: NIST library matches for willow fast pyrolysis trial at 500˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
634745062	10.52	CO2	44	Carbon dioxide	49.71	1.15
102642018	1.7	C5H8O2	100	1-Propen-2-ol, acetate	18.2	1.39
335592094	5.56	C2H4O2	60	Acetaldehyde, hydroxy-	76.5	1.72
223525764	3.7	C2H4O2	60	Acetic acid	94.12	2.35
143541556	2.38	C3H6O2	74	2-Propanone, 1-hydroxy-	86.36	2.52
25736446	0.43	C4H6O2	86	2,2'-Bioxirane, (R*,R*)-(ñ)-	30.96	3.99
101816669	1.69	C3H6O2	74	2-Propanone, 1-hydroxy-	37.93	4.44
100000249	1.66	C3H6O	58	Propylene oxide	20.53	4.66
66627282	1.1	C4H6O3	102	Acetic anhydride	35.02	4.87
19323208	0.32	C5H7NO3	129	Pidolic Acid	75.26	4.97
73886923	1.22	C5H4O2	96	3-Furaldehyde	75.7	5.68
61701453	1.02	C5H6O2	98	2-Furanmethanol	72.34	6.22
21731655	0.36	C6H10O4	146	1,2-Ethanediol, diacetate	71.77	6.47
58611512	0.97	C6H12	84	2-Hexene	41.36	7.36
139440118	2.31	C6H10O	98	Cyclopentanone, 2-methyl-	52.96	7.63
41250146	0.68	C12H24O	184	Dodecanal	19.06	8.25
16858947	0.28	C6H6O2	110	Resorcinol	63.82	8.53
48849969	0.81	C6H6O	94	Phenol	53.29	8.65
162833923	2.7	C4H6N2O2	114	2,4-Imidazolidinedione, 1-methyl-	35.53	8.93
15704540	0.26	C6H8O2	112	2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	35.31	9.18
54900794	0.91	C6H8O2	112	2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	72.84	9.45
34196068	0.57	C6H10O2	114	2-Pentenoic acid, 2-methyl-, (E)-	72.31	9.71
14243159	0.24	C7H8O	108	Phenol, 3-methyl-	36.89	9.89
41472822	0.69	C9H16O2	156	2(3H)-Furanone, dihydro-5-pentyl-	63.22	10.01
14984883	0.25	C12H24O	184	Dodecanal	26.82	10.14
16500044	0.27	C11H20O2	184	Oxacyclododecan-2-one	18.09	10.22
11111834	0.18	C6H6O3	126	Methyl 2-furoate	93.59	10.34
54053084	0.9	C7H8O2	124	Phenol, 2-methoxy-	66.22	10.46

105637878	1.75	C5H10O	86	Cyclobutanemethanol	18.41	10.61
13650569	0.23	C6H6O3	126	1,3,5-Benzenetriol	49.14	10.86
12785107	0.21	C11H20O2	184	Undecanoic acid, hydroxy-, lactone	17.55	10.96
32167074	0.53	C5H10N2O	114	Piperidine, 1-nitroso-	31.13	11.08
44627861	0.74	C19H37NO	295	Octadecane, 1-isocyanato-	32.07	11.55
24894901	0.41	C9H10O3	166	Benzaldehyde, 3-ethoxy-2-hydroxy-	40.51	11.66
85168709	1.41	C8H10O2	138	2-Methoxy-5-methylphenol	52.73	12.08
60455525	1	C6H6O2	110	1,2-Benzenediol	52.91	12.22
20422318	0.34	C11H20O2	184	Undecanoic acid, hydroxy-, lactone	17.71	12.42
23798649	0.39	C12H22O2	198	ç Dodecalactone	13.9	12.56
66612151	1.1	C14H30O	214	1-Tetradecanol	14.07	12.69
23444037	0.39	C11H20O2	184	Oxacyclododecan-2-one	36.08	12.98
126018349	2.09	C7H8O3	140	Flamenol	73.25	13.14
50056612	0.83	C9H12O2	152	2,4-Dimethoxytoluene	50.96	13.34
30539931	0.51	C12H22O11	342	à-D-Glucopyranoside, à-D-glucopyranosyl	28.87	13.74
132024546	2.19	C12H17NO2	207	Phenol, 3-methyl-5-(1-methylethyl)-, methylcarbamate	28.31	13.85
338906697	5.61	C10H18O	154	Eucalyptol	45.66	14.37
66851999	1.11	C11H20O2	184	Oxacyclododecan-2-one	20.86	14.85
18453668	0.31	C15H24O	220	4a,7-Methano-4aH-naphth[1,8a-b]oxirene, octahydro-4,4,8,8-tetramethyl-	31.73	14.97
36717594	0.61	C8H8O3	152	Vanillin	44.9	15.06
11170250	0.19	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-	59.38	15.18
291216707	4.82	C9H12O3	168	1,2,3-Trimethoxybenzene	70.29	15.84
29885305	0.5	C10H14O2	166	Phenol, 2-methoxy-4-propyl-	93.57	16.07
19656052	0.33	C11H12O4	208	4-Acetoxy-3-methoxyacetophenone	60.29	16.61
11170976	0.19	C11H12O4	208	4-Acetoxy-3-methoxyacetophenone	74.68	16.76
125606806	2.08	C10H12O3	180	Propylparaben	20.49	17.35
77356235	1.28	C13H11Br	246	Benzene, 1,1'-(bromomethylene)bis-	32.99	17.47
68306380	1.13	C10H14O2	166	Phenol, 2-methoxy-4-propyl-	49.39	17.61
328569239	5.44	C12H15NO4	237	3-Hydroxycarbofuran	71	18.38
12910660	0.21	C12H15NO4	237	3-Hydroxycarbofuran	78	18.54
57870949	0.96	C10H10O2	162	4-Methoxycinnamaldehyde	18.61	19.08

20820109	0.34	C13H11Br	246	Benzene, 1,1'-(bromomethylene)bis-	44.88	19.2
32916149	0.55	C15H24O	220	4a,7-Methano-4aH-naphth[1,8a-b]oxirene, octahydro-4,4,8,8-tetramethyl-	20.19	19.66
36343604	0.6	C20H28O	284	Vitamin A aldehyde	12.42	19.95
46289144	0.77	C9H10O4	182	3,4-Dimethoxy-5-hydroxybenzaldehyde	43.08	20.12
18744152	0.31	C20H28O	284	Vitamin A aldehyde	18.94	20.39
200916063	3.33	C10H10O2	162	4-Methoxycinnamaldehyde	28.52	20.77
194235973	3.22	C12H18O	178	6-tert-Butyl-2,4-dimethylphenol	16.82	21.27
82212739	1.36	C13H11Cl	202	Benzene, 1,1'-(chloromethylene)bis-	29.73	21.8
18740579	0.31	C15H24O	220	4a,7-Methano-4aH-naphth[1,8a-b]oxirene, octahydro-4,4,8,8-tetramethyl-	44.43	22.41
11936482	0.2	C8H11NO2	153	3-Pyridinemethanol, 5-hydroxy-4,6-dimethyl-	24.73	22.49
29296140	0.49	C13H12	168	Naphthalene, 1-(2-propenyl)-	35.01	23.44
27556303	0.46	C19H22O6	346	Gibberellic acid	19.35	23.8
32229131	0.53	C16H32O2	256	n-Hexadecanoic acid	30.2	24.47
168732200	2.8	C12H15NO4	237	3-Hydroxycarbofuran	36.4	25.02
58060380	0.96	C15H24O	220	4a,7-Methano-4aH-naphth[1,8a-b]oxirene, octahydro-4,4,8,8-tetramethyl-	22.28	25.17
19084367	0.32	C16H32O2	256	n-Hexadecanoic acid	37.69	28.39
22659839	0.38	C12H11N	169	[1,1'-Biphenyl]-4-amine	43	38.52
32676798	0.54	C41H72O2	596	Cholest-5-en-3-ol (3á)-, tetradecanoate	36.13	50.23

Table 28: NIST library matches for willow fast pyrolysis trial at 600˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
1.632E+09	13.91	C8H19N	129	2-Octanamine	62.76	1.13
204663674	1.74	C5H8O2	100	1-Propen-2-ol, acetate	47.88	1.37
37529006	0.32	C2H4O2	60	Acetaldehyde, hydroxy-	77.18	1.63
353079954	3.01	C2H4O2	60	Acetaldehyde, hydroxy-	55.52	1.78
62402144	0.53	C4H6O3	102	Butanoic acid, 2-oxo-	43.33	1.87
412584221	3.51	C2H4O2	60	Acetic acid	94.48	2.47
292869922	2.49	C3H6O2	74	2-Propanone, 1-hydroxy-	89.26	2.61
38489119	0.33	C5H10O	86	3-Pentanone	19.76	3.16
204256894	1.74	C3H6O2	74	2-Propanone, 1-hydroxy-	30.64	4.5
178317532	1.52	C6H12O	100	Pentanal, 2-methyl-	25.6	4.72
166885591	1.42	C4H6O3	102	Acetic anhydride	49.71	4.95
57117279	0.49	C5H7NO3	129	Pidolic Acid	45.28	5.03
178906174	1.52	C5H4O2	96	3-Furaldehyde	76.83	5.69
110689468	0.94	C5H6O2	98	2-Furanmethanol	56.47	6.25
23882354	0.2	C6H10O4	146	1,2-Ethanediol, diacetate	74.62	6.5
43446287	0.37	C14H28O	212	9-Tetradecen-1-ol, (E)-	34.71	7.16
111707285	0.95	C6H12	84	2-Hexene	39.32	7.41
306945180	2.61	C6H10O	98	Cyclopentanone, 2-methyl-	72.45	7.69
98565463	0.84	C14H28O	212	9-Tetradecen-1-ol, (E)-	35.68	8.29
39412644	0.34	C6H6O2	110	Resorcinol	60.28	8.55
161415897	1.38	C6H6O	94	Phenol	48.41	8.67
211061286	1.8	C5H10N2O	114	Piperidine, 1-nitroso-	28.21	8.96
119448615	1.02	C6H8O2	112	1,2-Cyclopentanedione, 3-methyl-	44.96	9.54
50093742	0.43	C6H10O2	114	2-Pentenoic acid, 2-methyl-, (E)-	67.64	9.76
41087478	0.35	C7H8O	108	Phenol, 3-methyl-	49.7	9.91
134742735	1.15	C7H8O	108	Phenol, 3-methyl-	46.52	10.26
253915348	2.16	C7H8O2	124	Phenol, 2-methoxy-	46.82	10.48
151199390	1.29	C9H18O	142	Nonanal	28.02	10.71
57748046	0.49	C11H20O2	184	Undecanoic acid, hydroxy-, lactone	32.17	11

81151873	0.69	C9H10O3	166	Benzaldehyde, 3-ethoxy-2-hydroxy-	36.89	11.68
75903448	0.65	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	51.6	11.86
182462512	1.55	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	55.97	12.1
67232148	0.57	C6H6O4	142	4H-Pyran-4-one, 5-hydroxy-2-(hydroxymethyl)-	86.41	12.19
167170943	1.42	C6H6O2	110	1,2-Benzenediol	64.09	12.31
170756860	1.45	C6H6O3	126	1,3,5-Benzenetriol	27.79	12.8
257861282	2.2	C7H8O3	140	Flamenol	66.92	13.2
110865086	0.94	C9H12O2	152	2,4-Dimethoxytoluene	51.94	13.35
129567872	1.1	C11H20O2	184	Undecylenic Acid	24.02	13.45
81917980	0.7	C7H8O2	124	1,2-Benzenediol, 3-methyl-	51.37	13.6
367565071	3.13	C12H17NO2	207	Phenol, 3-methyl-5-(1-methylethyl)-, methylcarbamate	27.76	13.87
751014935	6.4	C10H18O	154	Eucalyptol	53.07	14.41
95091374	0.81	C8H11NO3	169	dl-Noradrenaline	24.21	14.54
144262418	1.23	C8H8O3	152	Vanillin	47.55	15.12
658663255	5.61	C9H12O3	168	1,2,3-Trimethoxybenzene	55.08	15.89
104329200	0.89	C13H11Br	246	Benzene, 1,1'-(bromomethylene)bis-	31.44	17.49
154576285	1.32	C10H14O2	166	Phenol, 2-methoxy-4-propyl-	62.06	17.68
46358397	0.39	C11H14O3	194	4-Butoxybenzoic acid	55.32	17.78
133166349	1.13	C12H22O11	342	à-D-Glucopyranoside, à-D-glucopyranosyl	71.11	18.17
668967838	5.7	C12H15NO4	237	3-Hydroxycarbofuran	76.36	18.43
122491325	1.04	C12H15NO4	237	3-Hydroxycarbofuran	16.35	19.11
89626190	0.76	C12H15NO4	237	3-Hydroxycarbofuran	34.16	19.97
76796675	0.65	C9H10O4	182	3,4-Dimethoxy-5-hydroxybenzaldehyde	21.84	20.17
342367658	2.92	C10H10O2	162	4-Methoxycinnamaldehyde	18.86	20.81
271965113	2.32	C12H18O	178	6-tert-Butyl-2,4-dimethylphenol	17.83	21.32
136047232	1.16	C12H8N2O	196	9H-Carbazole, 9-nitroso-	48.34	21.83
124315108	1.06	C16H32O2	256	n-Hexadecanoic acid	30.09	24.55
237717472	2.02	C12H15NO4	237	3-Hydroxycarbofuran	37.18	25.09
112303758	0.96	C16H32O2	256	n-Hexadecanoic acid	41.35	28.48
41889024	0.36	C17H36	240	Heptadecane	18.93	43.28

Table 29: NIST library matches for willow fast pyrolysis trial at 600˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
1.303E+09	14.3	CO2	44	Carbon dioxide	42.64	1.13
210060338	2.31	C5H8O2	100	1-Propen-2-ol, acetate	36.94	1.37
63101425	0.69	C2H4O2	60	Acetaldehyde, hydroxy-	77.9	1.64
295310920	3.24	C2H4O2	60	Acetaldehyde, hydroxy-	80.07	1.74
58085982	0.64	C4H6O3	102	Butanoic acid, 2-oxo-	48.31	1.87
332837821	3.65	C2H4O2	60	Acetic acid	93.8	2.4
240098896	2.64	C3H6O2	74	2-Propanone, 1-hydroxy-	88.88	2.56
32808909	0.36	C4H6O2	86	2-Propenoic acid, 2-methyl-	26.82	3.15
179886160	1.97	C3H6O2	74	Acetic acid, methyl ester	42.74	4.46
145362814	1.6	C7H14O	114	Pentanal, 2,3-dimethyl-	23.85	4.67
124762892	1.37	C4H6O3	102	Acetic anhydride	59.84	4.9
42452078	0.47	C5H7NO3	129	Pidolic Acid	50.71	4.99
142408900	1.56	C5H4O2	96	3-Furaldehyde	73.87	5.68
76052150	0.83	C5H6O2	98	2-Furanmethanol	70.98	6.22
42184067	0.46	C6H10O4	146	1,2-Ethanediol, diacetate	63.41	6.48
89893496	0.99	C6H12	84	2-Hexene	43.41	7.36
205144257	2.25	C6H10O	98	Cyclopentanone, 2-methyl-	66.2	7.65
93206626	1.02	C14H28O	212	9-Tetradecen-1-ol, (E)-	39.9	8.27
28095076	0.31	C6H6O2	110	Resorcinol	56.86	8.53
96691418	1.06	C6H7O4P	174	Phosphonic acid, (p-hydroxyphenyl)-	54.6	8.65
232665237	2.55	C2H2N4O2	114	1H-1,2,4-Triazole, 3-nitro-	31.26	8.96
80391204	0.88	C6H8O2	112	1,2-Cyclopentanedione, 3-methyl-	50.82	9.49
26757335	0.29	C7H8O	108	Phenol, 3-methyl-	38.5	9.89
112561956	1.24	C7H8O	108	Phenol, 3-methyl-	35.58	10.24
122203383	1.34	C7H8O2	124	Phenol, 2-methoxy-	54.74	10.46
97376424	1.07	C11H22O	170	Undecanal	42.83	10.67
20510172	0.23	C11H20O2	184	Undecanoic acid, hydroxy-, lactone	25.06	10.97
33437698	0.37	C9H10O3	166	Benzaldehyde, 3-ethoxy-2-hydroxy-	36.74	11.67
189948840	2.09	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	52.94	12.09

156222962	1.72	C6H6O2	110	1,2-Benzenediol	69.3	12.26
174597943	1.92	C11H20O2	184	Undecanoic acid, hydroxy-, lactone	14.47	12.73
235696232	2.59	C7H8O3	140	Flamenol	69.86	13.17
138333025	1.52	C9H12O2	152	2,4-Dimethoxytoluene	55.63	13.34
262154249	2.88	C10H14O	150	Phenol, 2-methyl-5-(1-methylethyl)-	32.08	13.85
511459358	5.62	C10H18O	154	Eucalyptol	52.08	14.39
83339369	0.91	C10H18O	154	3-Cyclohexen-1-ol, 4-methyl-1-(1-methylethyl)-	26.5	14.51
111827289	1.23	C11H20O2	184	Oxacyclododecan-2-one	19.13	14.89
64514385	0.71	C8H8O3	152	Vanillin	45.73	15.09
24334659	0.27	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-	60.45	15.18
455418867	5	C9H12O3	168	1,2,3-Trimethoxybenzene	68.35	15.86
141862269	1.56	C12H8N2O	196	9H-Carbazole, 9-nitroso-	14.37	17.47
134105648	1.47	C10H14O2	166	Phenol, 2-methoxy-4-propyl-	64.96	17.64
81765635	0.9	C12H22O11	342	à-D-Glucopyranoside, à-D-glucopyranosyl	57.67	17.76
88821583	0.98	C12H22O11	342	à-D-Glucopyranoside, à-D-glucopyranosyl	72.5	17.93
447545359	4.91	C12H15NO4	237	3-Hydroxycarbofuran	77.36	18.4
72723001	0.8	C20H28O	284	Vitamin A aldehyde	27.81	19.09
51845612	0.57	C12H15NO4	237	3-Hydroxycarbofuran	32.84	19.95
79923346	0.88	C9H10O4	182	3,4-Dimethoxy-5-hydroxybenzaldehyde	35.63	20.14
23904255	0.26	C20H28O	284	Vitamin A aldehyde	35.74	20.39
248447351	2.73	C10H10O2	162	4-Methoxycinnamaldehyde	19.83	20.79
236095281	2.59	C12H18O	178	6-tert-Butyl-2,4-dimethylphenol	13.88	21.29
95213950	1.05	C12H8N2O	196	9H-Carbazole, 9-nitroso-	29.17	21.81
102112780	1.12	C16H32O2	256	n-Hexadecanoic acid	33.17	24.53
204620344	2.25	C12H15NO4	237	3-Hydroxycarbofuran	34.75	25.07
35143769	0.39	C19H22O6	346	Gibberellic acid	25.88	25.2
97236759	1.07	C16H32O2	256	n-Hexadecanoic acid	37.54	28.47
32146492	0.35	C16H34	226	Hexadecane	19.8	43.28

Table 30: NIST library matches for willow fast pyrolysis trial at 700˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
812121676	13.95	CO2	44	Carbon dioxide	92.59	1.11
141418407	2.43	C4H10	58	Butane	19.85	1.35
274929607	4.72	C2H4O2	60	Acetaldehyde, hydroxy-	81.62	1.73
186727785	3.21	C2H4O2	60	Acetic acid	89.63	2.35
85544517	1.47	C3H6O2	74	2-Propanone, 1-hydroxy-	89.82	2.53
79672976	1.37	C3H6O2	74	2-Propanone, 1-hydroxy-	21.79	4.44
66714948	1.15	C7H14O	114	Pentanal, 2,3-dimethyl-	22.51	4.65
68188437	1.17	C4H6O3	102	Acetic anhydride	58.82	4.88
78808706	1.35	C5H4O2	96	3-Furaldehyde	76.84	5.68
37370243	0.64	C5H6O2	98	2-Furanmethanol	61.34	6.22
41778121	0.72	C6H12	84	2-Hexene	25.12	7.35
88242428	1.52	C6H10O	98	Cyclopentanone, 2-methyl-	41.27	7.62
48949746	0.84	C14H28O	212	9-Tetradecen-1-ol, (E)-	28.07	8.26
58760286	1.01	C6H6O	94	Phenol	51.83	8.65
125565118	2.16	C2H2N4O2	114	1H-1,2,4-Triazole, 3-nitro-	43.47	8.95
43684211	0.75	C6H8O2	112	1,2-Cyclopentanedione, 3-methyl-	46.53	9.46
27589088	0.47	C7H8O	108	Phenol, 2-methyl-	40.49	9.89
109883159	1.89	C7H8O	108	Phenol, 3-methyl-	41.18	10.24
63124417	1.08	C7H8O2	124	Phenol, 2-methoxy-	54.35	10.46
83010657	1.43	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	57.48	12.08
88157681	1.51	C6H6O2	110	1,2-Benzenediol	68.28	12.26
81268408	1.4	C11H22O	170	Undecanal	15.11	12.71
132810189	2.28	C7H8O3	140	Flamenol	69.88	13.16
65684557	1.13	C9H12O2	152	2,4-Dimethoxytoluene	59.56	13.35
156732904	2.69	C10H14O	150	Phenol, 2,3,5,6-tetramethyl-	28.52	13.86
323550806	5.56	C10H18O	154	Eucalyptol	45.81	14.38
80085979	1.38	C11H20O2	184	Oxacyclododecan-2-one	21.57	14.87
56814046	0.98	C8H8O3	152	Vanillin	40.35	15.09
264244813	4.54	C9H12O3	168	1,2,3-Trimethoxybenzene	73.68	15.85

236286854	4.06	C9H10O4	182	3,4-Dimethoxy-5-hydroxybenzaldehyde	58.23	17.47
120373266	2.07	C12H15NO4	237	3-Hydroxycarbofuran	63.66	17.63
340686427	5.85	C12H15NO4	237	3-Hydroxycarbofuran	73.42	18.38
63178469	1.08	C15H15N	209	Acridine, 9,10-dihydro-9,9-dimethyl-	62.08	19.07
43235961	0.74	C15H15N	209	Acridine, 9,10-dihydro-9,9-dimethyl-	70.75	19.94
85852435	1.47	C9H10O4	182	Benzaldehyde, 4-hydroxy-3,5-dimethoxy-	91.88	20.11
48628211	0.84	C14H20O2	220	2,5-Cyclohexadiene-1,4-dione, 2,6-bis(1,1-dimethylethyl)-	40.89	20.38
242802220	4.17	C15H15N	209	Acridine, 9,10-dihydro-9,9-dimethyl-	69.14	20.77
223927589	3.85	C10H12O4	196	Benzaldehyde, 2,3,4-trimethoxy-	74.08	21.26
93753515	1.61	C12H8N2O	196	9H-Carbazole, 9-nitroso-	27.76	21.8
67128398	1.15	C9H10O4	182	Benzaldehyde, 4-hydroxy-3,5-dimethoxy-	37.83	22.48
57700018	0.99	C16H32O2	256	n-Hexadecanoic acid	67.66	24.47
279485542	4.8	C12H15NO4	237	3-Hydroxycarbofuran	27.74	25.02
61111039	1.05	C17H21NO2	271	Desomorphine	56.95	38.49
87519512	1.5	C23H32O6	404	Hydrocortisone Acetate	56.53	43.38

Table 31: NIST library matches for willow fast pyrolysis trial at 700˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
1.122E+09	13.79	CO2	44	Carbon dioxide	86.32	1.11
158978057	1.95	C5H8O2	100	1-Propen-2-ol, acetate	36.86	1.37
390818883	4.8	C2H4O2	60	Acetaldehyde, hydroxy-	57.04	1.75
302481575	3.72	C2H4O2	60	Acetic acid	67.04	2.33
167984608	2.06	C3H6O2	74	2-Propanone, 1-hydroxy-	90.27	2.57
133596433	1.64	C3H6O2	74	2-Propanone, 1-hydroxy-	32.36	4.47
98073789	1.21	C3H8O2	76	1,3-Propanediol	19.58	4.68
144122116	1.77	C4H6O3	102	Acetic anhydride	61.99	4.92
89168507	1.1	C5H4O2	96	3-Furaldehyde	75.71	5.68
58322604	0.72	C5H6O2	98	2-Furanmethanol	68.19	6.24
156197232	1.92	C6H10O	98	Cyclopentanone, 2-methyl-	70.06	7.67
78972622	0.97	C6H7O4P	174	Phosphonic acid, (p-hydroxyphenyl)-	50.26	8.66
174347058	2.14	C5H10N2O	114	Piperidine, 1-nitroso-	13.93	8.94
56842683	0.7	C6H8O2	112	2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	58.21	9.52
44393065	0.55	C7H8O	108	Phenol, 2-methyl-	42.15	9.9
136153231	1.67	C7H8O	108	Phenol, 3-methyl-	46.5	10.26
163004881	2	C7H8O2	124	Phenol, 2-methoxy-	56.39	10.48
175204353	2.15	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	51.66	12.1
181507584	2.23	C6H6O2	110	1,2-Benzenediol	55.25	12.32
176462402	2.17	C7H8O3	140	Flamenol	66.9	13.2
248934111	3.06	C10H14O	150	Phenol, 2-methyl-5-(1-methylethyl)-	24.56	13.87
565568716	6.95	C10H18O	154	Eucalyptol	44.06	14.41
101424312	1.25	C8H8O3	152	Vanillin	42.47	15.12
454219065	5.58	C9H12O3	168	1,2,3-Trimethoxybenzene	69.13	15.88
135859003	1.67	C9H10O4	182	3,4-Dimethoxy-5-hydroxybenzaldehyde	69.39	17.48
226763709	2.79	C12H15NO4	237	3-Hydroxycarbofuran	65.39	17.65
797277289	9.8	C12H15NO4	237	3-Hydroxycarbofuran	74.91	18.42
128619891	1.58	C15H15N	209	Acridine, 9,10-dihydro-9,9-dimethyl-	56.24	19.1
81313397	1	C15H15N	209	Acridine, 9,10-dihydro-9,9-dimethyl-	68.33	19.95

128678034	1.58	C9H10O4	182	Benzaldehyde, 4-hydroxy-3,5-dimethoxy-	91.6	20.14
75104543	0.92	C14H20O2	220	2,5-Cyclohexadiene-1,4-dione, 2,6-bis(1,1-dimethylethyl)-	42.11	20.39
347354584	4.27	C15H15N	209	Acridine, 9,10-dihydro-9,9-dimethyl-	80.67	20.78
198551822	2.44	C13H10O2	198	2-Biphenylcarboxylic acid	47.71	22.49
97736869	1.2	C16H32O2	256	n-Hexadecanoic acid	70.22	24.5
309493127	3.8	C12H15NO4	237	3-Hydroxycarbofuran	27.08	25.06
87182978	1.07	C17H21NO2	271	Desomorphine	56.69	38.5
143017297	1.76	C23H32O6	404	Hydrocortisone Acetate	50.32	43.39

Table 32: NIST library matches for switchgrass fast pyrolysis trial at 500˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
5.073E+09	49.3	C9H13N	135	Dextroamphetamine	40.59	6.17
173915948	1.69	C4H6O2	86	2,3-Butanedione	45.3	6.78
190556691	1.85	C2H4O2	60	Acetaldehyde, hydroxy-	72.75	7.04
1.209E+09	11.75	C3H6O2	74	2-Propanone, 1-hydroxy-	92.11	7.99
154190551	1.5	C8H10N2O2	166	Hydrazinecarboxylic acid, phenylmethyl ester	46.29	9.29
153930552	1.5	C4H6O3	102	Butanoic acid, 2-oxo-	47.3	9.62
125572129	1.22	C7H14O	114	Pentanal, 2,3-dimethyl-	27.65	9.89
86198542	0.84	C3H6O2	74	2-Propanone, 1-hydroxy-	38.37	10.09
280209437	2.72	C5H4O2	96	3-Furaldehyde	64.79	10.74
157544272	1.53	C6H12O	100	Butanal, 2-ethyl-	35.93	11.35
76274722	0.74	C6H10O4	146	1,2-Ethanediol, diacetate	70.21	11.62
167406357	1.63	C14H28O	212	9-Tetradecen-1-ol, (E)-	33.18	12.24
149196596	1.45	C6H10O	98	Cyclopentanone, 2-methyl-	65.93	12.74
112491820	1.09	C14H28O	212	9-Tetradecen-1-ol, (E)-	48.23	13.34
232622624	2.26	C6H7O4P	174	Phosphonic acid, (p-hydroxyphenyl)-	42.07	13.84
223694238	2.17	C6H8O2	112	2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	46.86	14.61
68798892	0.67	C7H8O	108	Phenol, 3-methyl-	42.88	14.98
111648624	1.08	C7H8O	108	Phenol, 3-methyl-	52.69	15.3
392067923	3.81	C7H8O2	124	Phenol, 2-methoxy-	54.13	15.54
76012954	0.74	C14H28O	212	9-Tetradecen-1-ol, (E)-	21.14	15.7
48078009	0.47	C6H6O3	126	1,3,5-Benzenetriol	55.15	16.03
58908140	0.57	C8H10O	122	Phenol, 4-ethyl-	30.07	16.71
96473212	0.94	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	51.28	17.1
200682327	1.95	C8H8O	120	Phthalan	37.8	17.5
81605466	0.79	C9H12O2	152	2,4-Dimethoxytoluene	52.78	18.36
452489188	4.4	C12H17NO2	207	Phenol, 3-methyl-5-(1-methylethyl)-, methylcarbamate	31.46	18.89
94269589	0.92	C10H18O	154	Eucalyptol	61.31	19.37
44393532	0.43	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-, (E)-	40.99	20.88

Table 33: NIST library matches for switchgrass fast pyrolysis trial at 500˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
4.346E+09	51.83	C8H19N	129	2-Octanamine	40.14	6.15
138781066	1.66	C4H6O2	86	Acetic acid ethenyl ester	35.84	6.78
204315241	2.44	C2H4O2	60	Acetaldehyde, hydroxy-	71.58	6.96
112521273	1.34	C2H8N2	60	Hydrazine, ethyl-	71.39	7.2
566298076	6.75	C2H4O2	60	Acetic acid	93.44	7.78
404767861	4.83	C3H6O2	74	2-Propanone, 1-hydroxy-	92.26	7.88
143998236	1.72	C4H6O3	102	Butanoic acid, 2-oxo-	49.75	9.55
103137964	1.23	C7H14O	114	Pentanal, 2,3-dimethyl-	22.07	9.84
67864489	0.81	C3H6O2	74	2-Propanone, 1-hydroxy-	30.85	10.04
218852017	2.61	C5H4O2	96	3-Furaldehyde	63.48	10.72
141540340	1.69	C8H16O	128	2-Hexanone, 3,4-dimethyl-	41.37	11.31
61126772	0.73	C6H10O4	146	1,2-Ethanediol, diacetate	75.09	11.58
129135148	1.54	C6H10O	98	Cyclopentanone, 2-methyl-	66.87	12.73
84597769	1.01	C14H28O	212	9-Tetradecen-1-ol, (E)-	53.66	13.31
202718075	2.42	C6H7O4P	174	Phosphonic acid, (p-hydroxyphenyl)-	39.35	13.83
153897785	1.84	C6H8O2	112	1,2-Cyclopentanedione, 3-methyl-	48.85	14.58
92308519	1.1	C7H8O	108	Phenol, 3-methyl-	40.09	15.29
290798661	3.47	C7H8O2	124	Phenol, 2-methoxy-	62.53	15.51
54857443	0.65	C8H10O	122	Phenol, 4-ethyl-	26.73	16.69
70942708	0.85	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	54.5	17.1
182517294	2.18	C8H8O	120	Phthalan	41.06	17.49
69170149	0.82	C9H12O2	152	2,4-Dimethoxytoluene	49.77	18.36
424513641	5.06	C12H17NO2	207	Phenol, 3-methyl-5-(1-methylethyl)-, methylcarbamate	30.77	18.89
74862775	0.89	C10H18O	154	Eucalyptol	47.9	19.35
45181190	0.54	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-	61.05	20.88

Table 34: NIST library matches for switchgrass fast pyrolysis trial at 600˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
5.677E+09	57.15	C8H19N	129	2-Octanamine	31.17	6.17
184509312	1.86	C4H6O2	86	Acetic acid ethenyl ester	18.07	6.82
207797365	2.09	C2H4O2	60	Acetaldehyde, hydroxy-	73.37	7.05
731850337	7.37	C2H4O2	60	Acetic acid	86.89	7.86
410020441	4.13	C3H6O2	74	2-Propanone, 1-hydroxy-	91.45	7.98
63704232	0.64	C4H6O3	102	Butanoic acid, 2-oxo-	44.14	9.6
230705288	2.32	C7H14O	114	Pentanal, 2,3-dimethyl-	19.09	9.9
76507254	0.77	C3H6O2	74	2-Propanone, 1-hydroxy-	33.49	10.11
306872839	3.09	C5H4O2	96	3-Furaldehyde	66.71	10.76
144646584	1.46	C8H16O	128	2-Hexanone, 3,4-dimethyl-	30.33	11.35
72963203	0.73	C6H10O4	146	1,2-Ethanediol, diacetate	76.4	11.61
124694504	1.26	C6H10O	98	Cyclopentanone, 2-methyl-	36.35	12.74
101488485	1.02	C14H28O	212	9-Tetradecen-1-ol, (E)-	46.31	13.34
218007614	2.19	C6H7O4P	174	Phosphonic acid, (p-hydroxyphenyl)-	39.04	13.82
137773515	1.39	C6H8O2	112	1,2-Cyclopentanedione, 3-methyl-	52.88	14.58
71318954	0.72	C7H8O	108	Phenol, 3-methyl-	41.56	14.96
109835632	1.11	C7H8O	108	Phenol, 3-methyl-	55.48	15.3
279384974	2.81	C7H8O2	124	Phenol, 2-methoxy-	55.97	15.52
73935136	0.74	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	53.13	17.1
166117373	1.67	C8H8O	120	Phthalan	45.66	17.5
49398050	0.5	C9H12O2	152	2,4-Dimethoxytoluene	48.47	18.36
372121136	3.75	C10H14O	150	Phenol, 2,3,5,6-tetramethyl-	29.81	18.89
74130869	0.75	C10H18O	154	Eucalyptol	56.74	19.37
48227993	0.49	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-	48.08	20.89

Table 35: NIST library matches for switchgrass fast pyrolysis trial at 600˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
5.079E+09	50.95	CO2	44	Carbon dioxide	36.45	6.15
186776355	1.87	C4H6O2	86	Acetic acid ethenyl ester	43.83	6.78
112677497	1.13	C2H4O2	60	Acetaldehyde, hydroxy-	71.87	7.04
310541753	3.12	C4H9NO2	103	sec-Butyl nitrite	7.86	7.46
928373066	9.31	C3H6O2	74	2-Propanone, 1-hydroxy-	91.43	8.02
188829939	1.89	C7H8	92	1,3,5-Cycloheptatriene	51.57	9.29
73250289	0.73	C4H6O3	102	Butanoic acid, 2-oxo-	45.73	9.62
147110446	1.48	C7H14O	114	Pentanal, 2,3-dimethyl-	32.69	9.88
97034700	0.97	C3H6O2	74	2-Propanone, 1-hydroxy-	38.36	10.11
263745133	2.65	C5H4O2	96	3-Furaldehyde	61.4	10.75
167141613	1.68	C5H6O2	98	2-Furanmethanol	21.03	11.44
74630686	0.75	C6H10O4	146	1,2-Ethanediol, diacetate	71.65	11.62
121835198	1.22	C6H10O	98	Cyclopentanone, 2-methyl-	54.51	12.75
124875504	1.25	C14H28O	212	9-Tetradecen-1-ol, (E)-	47.29	13.35
313696559	3.15	C7H7NO2	137	Carbamic acid, phenyl ester	33.88	13.9
184091646	1.85	C6H8O2	112	1,2-Cyclopentanedione, 3-methyl-	54.36	14.62
78700545	0.79	C7H8O	108	Phenol, 3-methyl-	39.32	14.98
125994564	1.26	C7H8O	108	Phenol, 3-methyl-	43.98	15.32
292420488	2.93	C7H8O2	124	Phenol, 2-methoxy-	55.19	15.52
70835994	0.71	C8H10O	122	Phenol, 4-ethyl-	34.9	16.71
82983132	0.83	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	54.79	17.1
192441203	1.93	C8H8O	120	Phthalan	41.73	17.51
71957558	0.72	C9H12O2	152	2,4-Dimethoxytoluene	51.05	18.36
521874738	5.24	C12H17NO2	207	Phenol, 3-methyl-5-(1-methylethyl)-, methylcarbamate	38.34	18.9
94434185	0.95	C10H18O	154	Eucalyptol	53.34	19.37
62534030	0.63	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-	56.49	20.89
310541753	3.12	C4H9NO2	103	sec-Butyl nitrite	7.86	7.46

Table 36: NIST library matches for switchgrass fast pyrolysis trial at 700˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
7.191E+09	49.16	C8H19N	129	2-Octanamine	84.07	6.17
278510533	1.9	C4H6O2	86	Acetic acid ethenyl ester	37.13	6.77
180502674	1.23	C2H4O2	60	Acetaldehyde, hydroxy-	65.76	7.12
134821331	0.92	C5H12O	88	1-Butanol, 3-methyl-	21.31	7.38
1.416E+09	9.68	C3H6O2	74	2-Propanone, 1-hydroxy-	93.86	8.1
236669683	1.62	C7H8	92	1,3,5-Cycloheptatriene	29.25	9.33
73864256	0.5	C4H6O3	102	Butanoic acid, 2-oxo-	44.3	9.67
198234400	1.36	C3H8O2	76	1,3-Propanediol	23.67	9.94
198856759	1.36	C3H6O2	74	2-Propanone, 1-hydroxy-	44.01	10.18
326331578	2.23	C5H4O2	96	3-Furaldehyde	54.97	10.78
211558250	1.45	C8H10	106	Benzene, 1,3-dimethyl-	31.86	11.44
89899768	0.61	C6H10O4	146	1,2-Ethanediol, diacetate	70.45	11.66
71436015	0.49	C8H8	104	1,3,5,7-Cyclooctatetraene	53.94	11.88
177487390	1.21	C5H6O2	98	2-Furanmethanol	24.05	12.79
133800913	0.91	C14H28O	212	9-Tetradecen-1-ol, (E)-	42.97	13.37
388066580	2.65	C6H6O	94	Phenol	50.68	13.78
288273223	1.97	C6H8O2	112	1,2-Cyclopentanedione, 3-methyl-	43.12	14.66
124165974	0.85	C7H8O	108	Phenol, 3-methyl-	45.51	15
232454269	1.59	C7H8O	108	Phenol, 3-methyl-	53.55	15.34
330708539	2.26	C7H8O2	124	Phenol, 2-methoxy-	60.46	15.54
128465819	0.88	C8H10O	122	Phenol, 2,6-dimethyl-	25.61	15.78
55473566	0.38	C6H6O3	126	1,3,5-Benzenetriol	42.53	16.05
78995069	0.54	C8H10O	122	Phenol, 2,3-dimethyl-	22.15	16.45
183518096	1.25	C8H10O	122	Phenol, 4-ethyl-	42.84	16.74
120179429	0.82	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	51.98	17.12
521073684	3.56	C8H8O	120	Phthalan	50.08	17.55
95766726	0.65	C9H12O2	152	2,4-Dimethoxytoluene	51.76	18.37
846571105	5.79	C12H17NO2	207	Phenol, 3-methyl-5-(1-methylethyl)-, methylcarbamate	35.59	18.93
190063916	1.3	C10H18O	154	Eucalyptol	57.38	19.4

125044523	0.85	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-	46.11	20.91

Table 37: NIST library matches for switchgrass fast pyrolysis trial at 700˚C.

Area	Area %	Molecular Formula	MolecularWeight	Name	Probability	RT
5.739E+09	49.42	C8H19N	129	2-Octanamine	77.24	6.17
210838192	1.82	C4H6O2	86	2,3-Butanedione	37.4	6.77
262298543	2.26	C2H4O2	60	Acetaldehyde, hydroxy-	74.03	7.01
95825130	0.83	C2H8N2	60	Hydrazine, ethyl-	38.46	7.24
711753827	6.13	C2H4O2	60	Acetic acid	87.22	7.82
451419953	3.89	C3H6O2	74	2-Propanone, 1-hydroxy-	92.5	7.93
157351840	1.35	C3H6O2	74	2-Propanone, 1-hydroxy-	50.99	9.67
170549400	1.47	C3H8O2	76	1,3-Propanediol	26.07	9.89
128418732	1.11	C3H6O2	74	2-Propanone, 1-hydroxy-	47.09	10.09
248426790	2.14	C5H4O2	96	3-Furaldehyde	62.87	10.75
163435641	1.41	C8H16O	128	2-Hexanone, 3,4-dimethyl-	31.77	11.35
64907799	0.56	C6H10O4	146	1,2-Ethanediol, diacetate	48.53	11.62
153589245	1.32	C6H10O	98	Cyclopentanone, 2-methyl-	36.22	12.74
264533129	2.28	C6H6O	94	Phenol	55.63	13.73
62980827	0.54	C2H2N4O2	114	1H-1,2,4-Triazole, 3-nitro-	43.7	14.03
215689616	1.86	C6H8O2	112	2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	58.68	14.62
128069551	1.1	C7H8O	108	Phenol, 3-methyl-	46.65	14.98
184547192	1.59	C7H8O	108	Phenol, 3-methyl-	51.29	15.32
332756532	2.87	C7H8O2	124	Phenol, 2-methoxy-	56.55	15.52
59583270	0.51	C8H10O	122	Phenol, 3,4-dimethyl-	21.22	16.44
129822265	1.12	C8H10O	122	Phenol, 4-ethyl-	41.55	16.71
109126842	0.94	C8H10O2	138	Phenol, 2-methoxy-4-methyl-	53.18	17.12
100472508	0.87	C6H6O2	110	1,2-Benzenediol	64.5	17.32
402514332	3.47	C8H8O	120	Phthalan	39.96	17.53
94212069	0.81	C9H12O2	152	2,4-Dimethoxytoluene	50.96	18.37
699365197	6.02	C12H17NO2	207	Phenol, 3-methyl-5-(1-methylethyl)-, methylcarbamate	33.51	18.92
174354948	1.5	C10H18O	154	Eucalyptol	53.74	19.38
97394229	0.84	C10H12O2	164	Phenol, 2-methoxy-4-(1-propenyl)-	53.51	20.91