VOC Emissions
From the Drying of Red Alder Lumber

Report to

Cascade Hardwoods

Report by

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February 3, 2005

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I.   Results Summary

Two charges, containing 62.0 and 72.6 board feet of 1" random width red alder lumber, were dried from green in a small kiln at Oregon State University. The second charge was dried because data was not collected during the last 24 hours of the first charge. The kiln dry- and wet-bulb temperatures based on a schedule provided by Cascade Hardwoods. The maximum temperature was 170°F (76.7°C). The air velocity was 500 feet per minute (2.5 m/s). The kiln was indirectly heated with steam. There was no humidification. Regulating the amount of air entering the kiln controlled venting and the humidity.

A JUM 3-200 total hydrocarbon analyzer was used to measure organic emissions following EPA Method 25A. The results are shown in Table 1.

TABLE 1. Summary of results.

Run #	Initial MC	Final MC	Time[a]	VOC[b]
	%	%	hr:min	lb/mbf
1	103.0	10.2	99:57	3.44
2	106.2	7.6	123:46	4.18

II.   Lumber Source and Handling

Enough wood for the two charges of lumber was picked up by Oregon State University from the mill in Chehalis, WA on January 9, 2005. The wood was wrapped in plastic at the mill to prevent predying and loss of organic compounds during transit. Upon arrival at OSU, wood for the first charge was randomly selected. Half of the remaining wood was wrapped and stored in a freezer, the other half in a refrigerator. The frozen wood and some of the refrigerated wood was used for charge two. The charges were dried for five days each starting January 10 and January 19.

III.   Kiln Description and Operation

A schematic of the kiln is shown in Figure 1. The kiln box is approximately 4' by 4' by 4'. It is indirectly heated by steam. Four dry-bulb thermocouples and two wet-bulb thermocouples are located on the entering-air side of the load.   The dry-bulb

thermocouples are spaced in a grid. The two wet-bulb thermocouples are under a single sock at the center of the entering-air side of the load.

Humidity control

A 200 L/min MKS mass flow meter controlled and measured the amount of air entering the kiln. It was factory calibrated and checked using a bubble meter. The amount of air entering the kiln is based on the wet-bulb temperature - if it is above setpoint, the airflow is increased and if it is below setpoint the airflow is decreased. This is analogous to venting for a commercial kiln. A minimum of 6 L/min entered the kiln at all times, more than removed by the analyzer (2.6 L/min). Putting air into the kiln at a rate of 100 L/min causes the pressure in the kiln to be 60 to 130 Pa above ambient, depending on location in the kiln (high-pressure or low-pressure side). Thus, any fugitive leakage should be out of the kiln. Two additional flow meters can be manually set to provide additional airflow. These were not used in this study. The steam spray line is disabled, so no water vapor is added to the kiln atmosphere. The impinger train in Figure 1 was not used in this work.
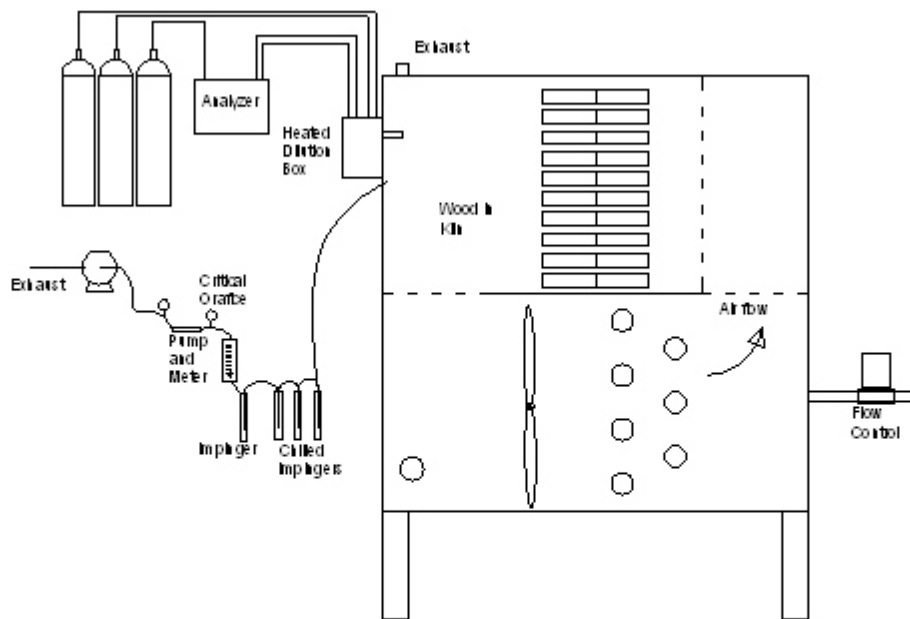

FIGURE 1. Schematic of kiln and sampling system.

Temperature control

Temperature in the kiln is controlled by indirect steam heating. When the average of the four dry-bulb thermocouples is below setpoint, the steam pressure in the coil is increased. When it is above setpoint, steam flow to the coil is reduced.

Schedules

The drying schedule used (Figure 2) was based on drying conditions supplied by the mill. The values in Figure 2 are based on the entering-air temperature. This represents the highest temperature the wood would experience in a commercial kiln.

Charge Sequence

The lumber was unwrapped and 2" were trimmed from each end of each board to give 44" samples. These were then weighed, placed in the kiln and dried according to the schedule in Figure 2. The actual temperatures are shown in Figure 3. Sampling for hydrocarbon was done as described in section IV. At the end of drying the wood was weighed, oven dried, and reweighed so initial and final moisture contents could be determined by ASTM D4442 (oven-dry method).
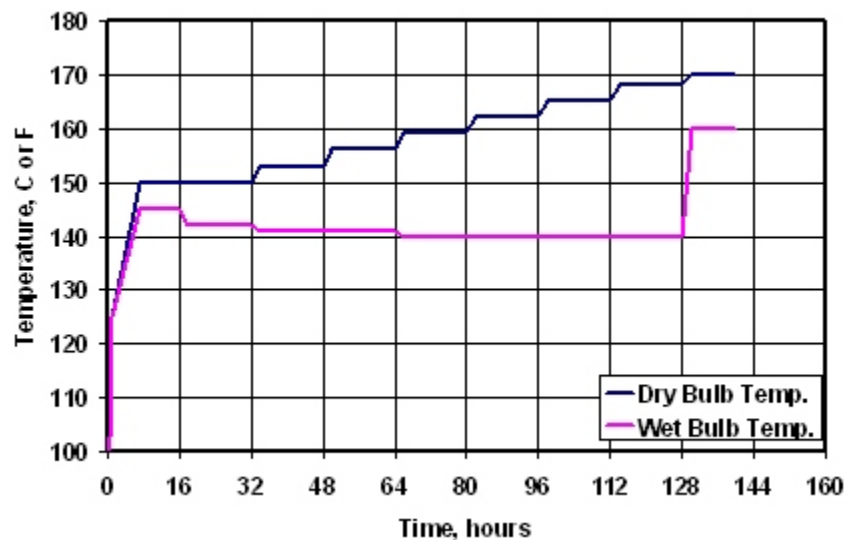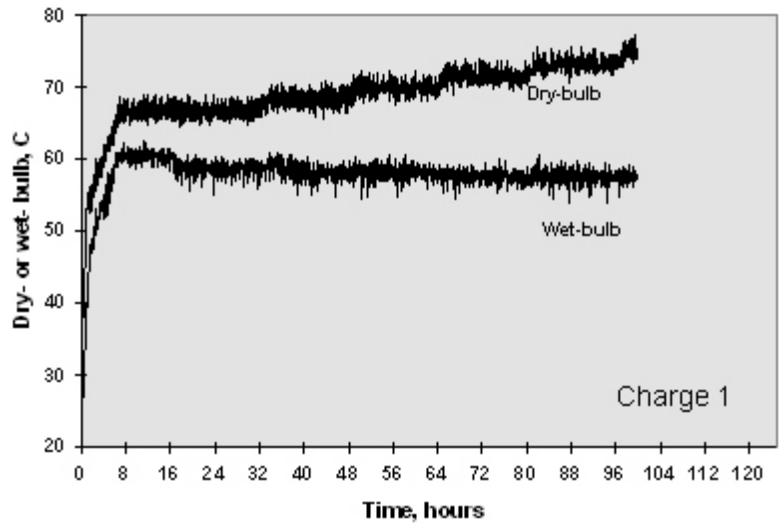

FIGURE 2. Drying schedule.

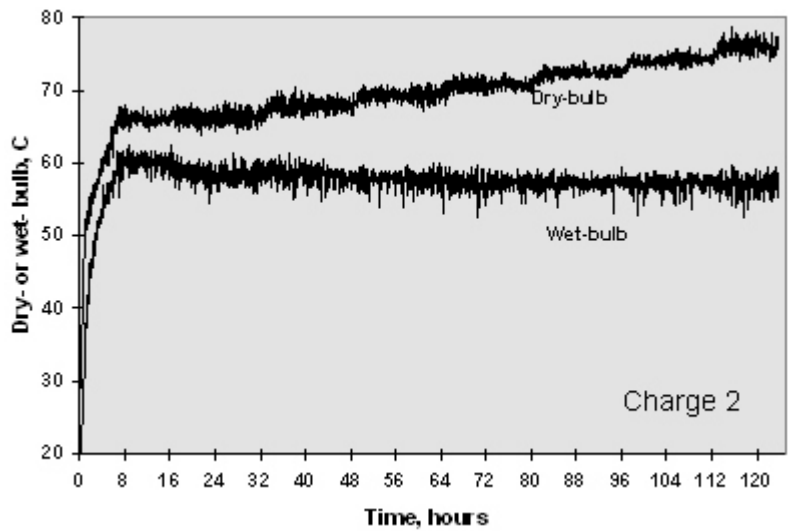**FIGURE 3A.** Dry- and wet-bulb temperatures for charge 1.

FIGURE 3B. Dry- and wet-bulb temperatures for charge 2.

IV.   Sampling Systems and Methodologies

Sampling for total hydrocarbon is done directly from the kiln as shown in Figure 1. The concentration obtained from the hydrocarbon analyzer and the amount of air entering the kiln allow the total hydrocarbon emissions to be calculated.

Figures 4a and 4b show the hydrocarbon sampling system. Unlike stack testing, all necessary equipment is permanently mounted on the kiln and flows are controlled with valves. The sample is withdrawn from the kiln under the assumption that the gas in the kiln is well-mixed and that the composition in the kiln near the exhaust is the same as the composition of the exhaust. The THC sample was drawn from the kiln directly into a heated dilution/filter box mounted on the side of the kiln. The box was heated to 125°C. Heated dilution gas can be added to the hydrocarbon sample gas to lower the gas moisture content to the detector. Dilution air was used when the gas moisture content in the kiln was greater than 15% so that the air moisture content to the detector remained less than 15%. The sample line from the box to the analyzer was heated to 133°C.   The valve at the back of the analyzer was heated to 145°C.

The fuel gas was hydrogen. The span gas was EPA Protocol 905 ppm propane in air, the mid-gas was certified 412 ppm propane. The zero gas was 0.1 ppm air. Detailed sampling procedures are in Appendix 1 and a summary is presented below.

Leak checks were conducted before and after the charge was dried. Valves are closed and all components from just behind the probe tip to the valve at the back of the analyzer are placed under a 18-20 inHg vacuum. Less than one inHg pressure change during two minutes is acceptable and this was met.

Total flow and sample flow to the analyzer were checked using an NIST-traceable flow meter. Total flow is measured with the dilution gas off. Sample flow is measured with it on. This was done at the beginning and end of each sampling interval. The meter was attached to the system near the probe tip within the heated box. The valves were repositioned so that the sample came from the flow meter rather than the kiln. Readings of flow were made with the dilution gas both off and on.   The flow readings were verified by observing the change in the analyzer reading for span gas with the dilution gas off and on. The dilution ratio calculated based on the analyzer readings was within 4% of that determined by the flow meter.
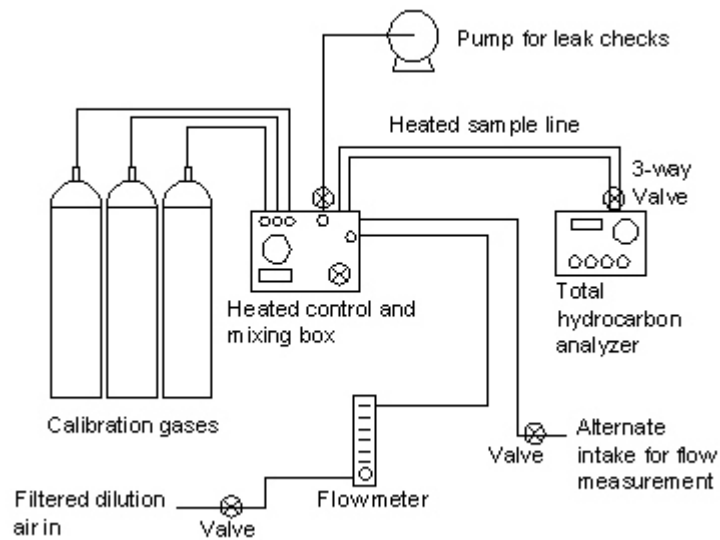
FIGURE 4A. Schematic of heated filter box with air dilution system, heated sample line, and analyzer. Sample enters heated box from back of drawing (box is attached to kiln).
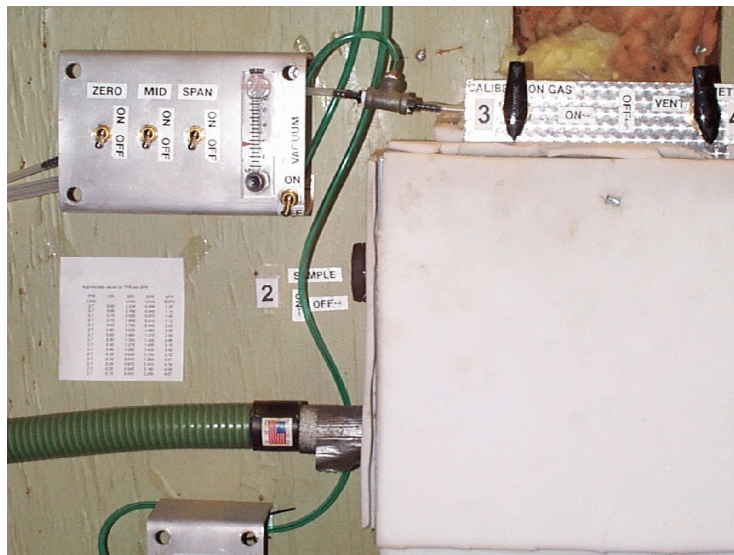
FIGURE 4B. Photo of VOC sampling system showing heated sample box (with white insulation), toggle valves and flow meter for calibration gases (upper left), on/off valve for calibration gas (3 at upper center right), heated sample line to analyzer (green tube, lower left), valve for sample (2 at center), toggle valve to vacuum pump (near calibration gas valves), and vent/flowmeter valve (4 at upper right).

Calibration of the zero and span of the detector was done at the beginning of each run (about every eight to ten hours). The calibration gas was introduced by setting the valves so the calibration gas entered the system near the probe tip at ambient pressure. The calibration was checked at the end of each run with no adjustments made to the zero or span during the run. The span drift was always less than two percent of full scale for a run and generally less than one percent. The zero drift was minimal during entire drying cycles.

V.   Data Reduction and Treatment

The "FlowCalc" worksheet in the Excel file "Kiln, Run1.XLS" (there's a set of files similarly named for Run 2) in Appendix 2 shows the calculations for each 3-minute interval during the charges. Column A is a reading number. Columns B and C are the clock and charge times, respectively. Columns D and E are the average dry- and wet-bulb temperatures. Column F is the vapor pressure of water at the wet-bulb temperature. The absolute humidity is shown in column G and the molal humidity in column H. These are calculated based on the dry-bulb temperature, wet-bulb temperature, vapor pressure.

Flow calculations

The volumetric dry gas flow rate in column I is the flowmeter reading adjusted for the meter calibrations and the molar humidity of the entering gas. This is in standard (at 0°C) liters per minute. In column J this has been converted to a mass flow rate in kg/min and in column K is the same information is expressed as a molal flow rate. These values are for the dry gas vented from the kiln.

Moisture calculations

The water removal rate in g/min (column L) is calculated from the humidity (column G) and the gas flow (column J). The and the total water (column M) is an integration of column L over time.

The moisture content of the wood at each time interval in the event (column N) was determined by reducing the MC of the wood from the previous value by accounting for the amount of water leaving the kiln during the interval. This amount has been adjusted by adjusting the wet-bulb temperature to make the ending moisture content match.

Total hydrocarbon calculations

The original total hydrocarbon analyzer reading is shown in column O. In column P this has been corrected to compensate for the range setting switch on the analyzer and scaling between the analyzer reading and the computer reading. Also in column P, the THA data between sampling runs has been adjusted to the average of the data during the 12-minute period before the analyzer testing and calibration time. The dilution THA (column Q) is the corrected THA reading divided by the dilution ratio (from column Y). In column R we have the opportunity to compensate for the effect of moisture on the JUM detector. This was not done so column R equals column Q. Finally in column S, the hydrocarbon concentration is converted to a dry gas basis concentration using the molar humidity (column H).

In column T, the hydrocarbon flow rate in g_{carbon}/min is calculated in a manner analogous to the water flow rate using the dry gas flow rate and the hydrocarbon concentration. Column U is the integral of column T over time, the cumulative hydrocarbon release up to that point in the schedule. Column V is the cumulative unit emissions, that is, column U divided by the oven-dry weight of the wood in the kiln.

Column X indicates the hydrocarbon sampling run and column Y is the dilution ratio during that run. The next two columns, Z and AA, are the cumulative dry gas and water during the kiln cycle. These are used obtain the average gas moisture contents. The uncorrected wood moisture content is shown in column AC. This is the MC in column N before adjustment of the wet-bulb to make the beginning and ending MCs match the oven-dry test. The kiln air and analyzer air moisture contents (based on volume) are shown in columns AD and AE.

At the end of the FlowCalc spreadsheet are summaries by run of the flow data for the total hydrocarbon run intervals. Further down are summaries by impinger interval. These are the tables that appear in the body of the report. The other pages in the files "Kiln.XLS" are graphs of the data in the FlowCalc page.

Moisture content and board weight data are in the files named "Board, Run 1.XLS."

VI.   Sampling Results

The hydrocarbon emissions are summarized graphically here. All emission data is presented in detail in electronic form in Appendix 2. A summary for each sampling interval is in Table 2.

Figure 5 shows total hydrocarbon concentration (left scale) and dry gas vent rate (right scale) versus time. The vent rate is low for approximately the few hours as the kiln

comes up to temperature and the wet-bulb depression is small. The venting then increases to a maximum during days two and three. The vent rate is higher during the second charge because there was more wood in the kiln. The vent rate decreases later in the schedules when the drying rate is low. The steps in the vent rate at approximately 12-hour intervals (most evident in charge 2) are due to the changes in the schedule.

The total hydrocarbon concentration is very dependent on the venting early in the schedule with a high vent rate resulting in a low hydrocarbon concentration and vice versa. When the venting increases at approximately 18 hours, the total hydrocarbon concentration decreases. Note that total hydrocarbon concentration is not indicative of the amount of hydrocarbon emissions unless one also considers the vent rate. These two factors combined determine the emissions.
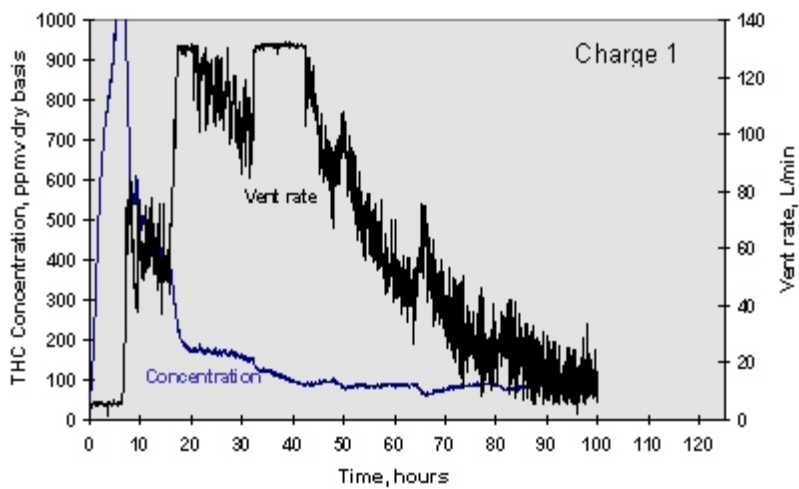
FIGURE 5a. Hydrocarbon concentration and vent rate versus time for charge 1.
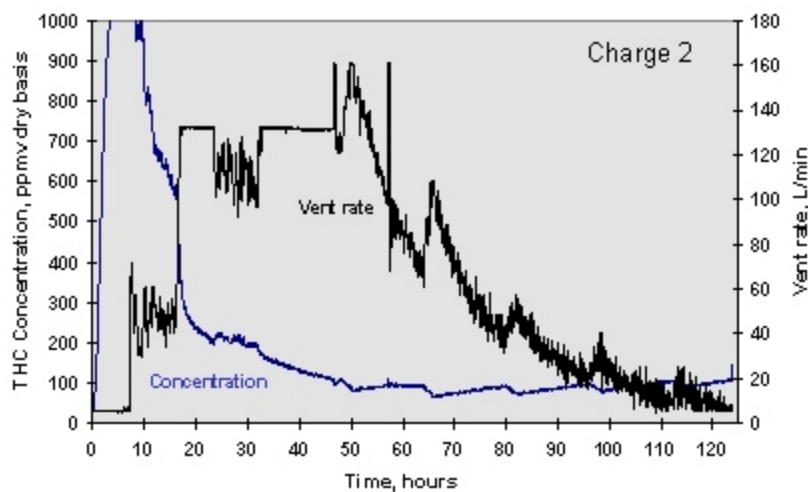
FIGURE 5b. Hydrocarbon concentration and vent rate versus time for charge 2.

Figure 6 shows the cumulative hydrocarbon emissions and the rate of emissions versus time. The cumulative emissions is the emissions up to any point in time in the schedule. The rate of emissions is how much is coming out per unit time. The maximum emission rates occur early in the schedules at less than 20 hours.
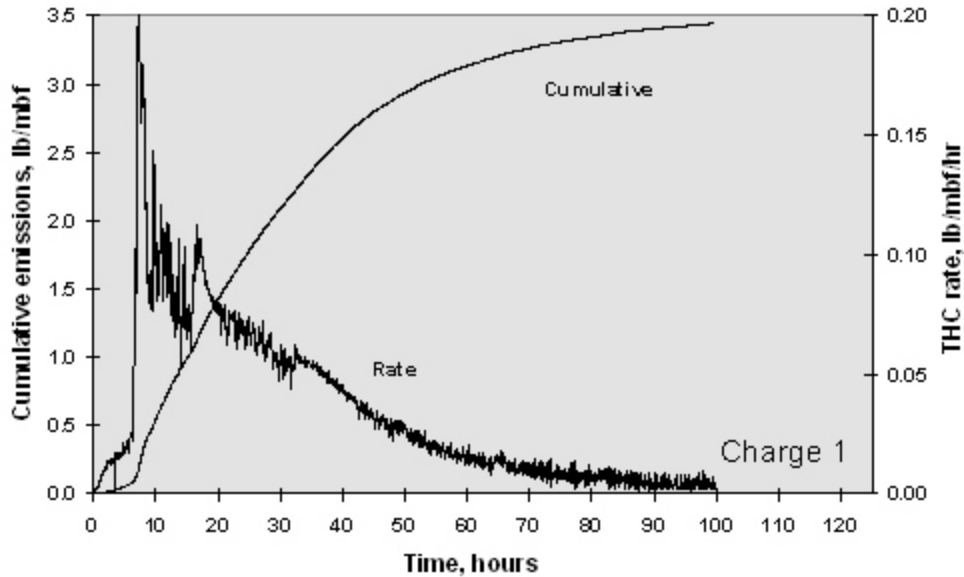
FIGURE 6a. Cumulative and rate of emissions versus time (as carbon) for charge 1.
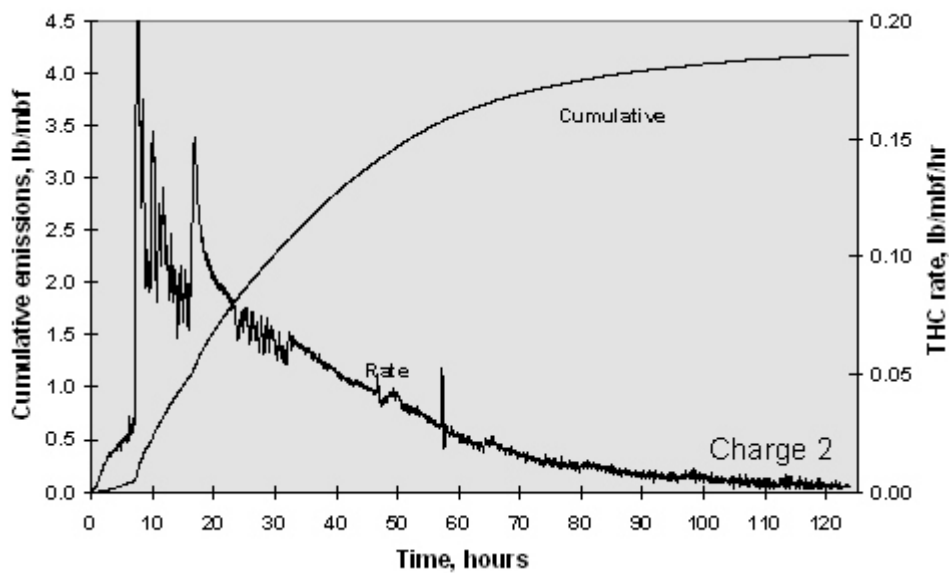
FIGURE 6b. Cumulative and rate of emissions versus time (as carbon) for charge 2.

The rate of emissions is very low at the end of the schedule. Approximately half of the emissions came out during the first 1.5 days of the 5-day schedule.

Figure 7 shows the wood moisture content versus time. The estimated moisture content should most accurately represent the MC-time relationship because the initial and final moisture contents match the oven-dry test. The initial moisture contents were 103 and 106% on a dry basis by ASTM D4442.
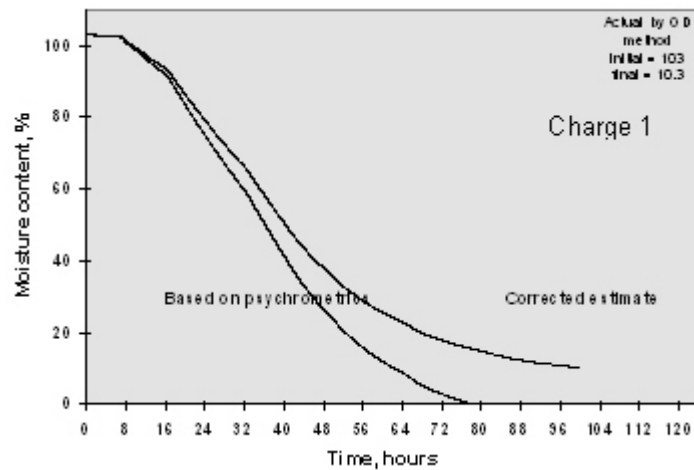
FIGURE 7a. Moisture content versus time for charge 1.
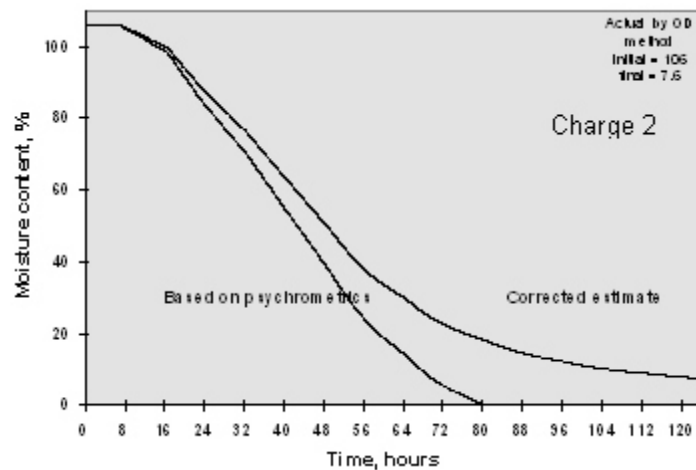
FIGURE 7b. Moisture content versus time for charge 2.

Figure 8 shows the cumulative hydrocarbon emissions versus moisture content. The hydrocarbon emissions for drying to any moisture content can be read from this graph. In agreement with past studies, there is a fairly linear relationship between the emissions and the decrease in moisture content, especially at lower moisture contents. Initially, the rate of emissions was quite high, possibly due to the storage of the logs (see "Anomolies" on page 14.
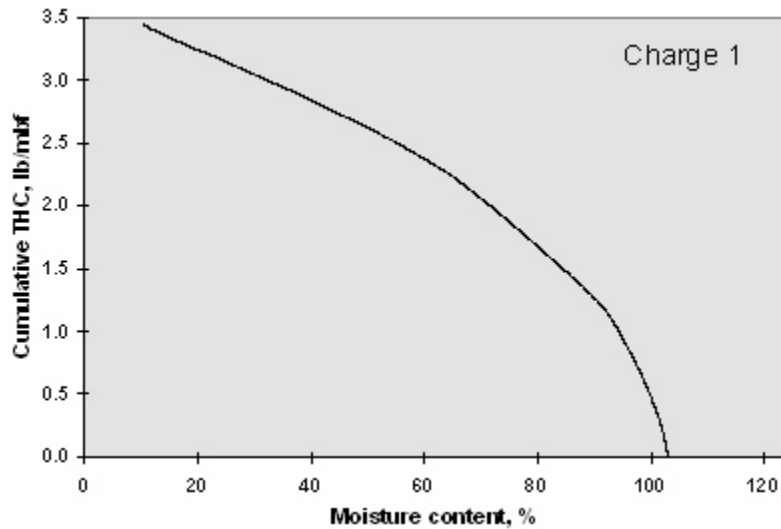
FIGURE 8a. Cumulative emissions (as carbon) versus moisture content for charge 1.
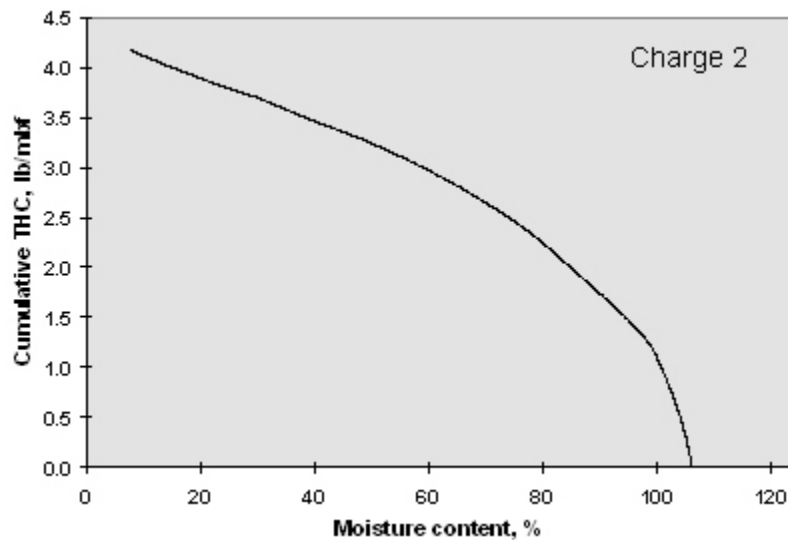
FIGURE 8b. Cumulative emissions (as carbon) versus moisture content for charge 2.

Table 2 shows the VOC results by run for the charges. A run is an interval between analyzer calibrations, about eight to ten hours of data. The interval time periods shown in the table include the times between sampling and mass calculations are adjusted to account for these. Sampling occurred for approximately 98% of the drying time. Samples of field sampling sheets, including dilution system and heated component data are given in Appendix 3 with full PDF format versions in Appendix 2.

TABLE 2a. Summary of sample runs for analysis of total hydrocarbon for charge 1.

| Sample Run	Time hrs	Average Humidity kg/kg	Dry Flow Rate @68 l/min	Wet Flow Rate @68 l/min	THC mass as C g	THC wet conc ppmv	THC dry conc ppmv	THC mass as C lbs/mbf	THC rate as C lb/hr/mbf	Average Wood MC %	Average Air MC %	Average Anal. MC %
1	5.35	0.072	5.9	6.6	1.75	526.9	606.9	0.062	0.0117	102.9	10.5	10.5
2	5.00	0.145	48.3	59.6	14.62	649.3	803.7	0.520	0.1040	101.3	19.0	19.0
3	9.95	0.137	92.1	112.4	24.30	271.4	336.8	0.865	0.0869	93.4	18.1	11.6
4	8.90	0.130	123.9	150.0	16.75	138.4	169.2	0.596	0.0670	77.9	17.4	11.1
5	4.25	0.130	118.8	143.7	6.58	119.8	146.4	0.234	0.0551	67.1	17.3	12.2
6	10.55	0.129	138.4	167.2	13.55	84.6	103.2	0.482	0.0457	53.2	17.2	12.1
7	9.90	0.125	96.1	115.4	7.54	72.8	88.3	0.268	0.0271	36.9	16.7	12.0
8	4.55	0.125	68.1	81.8	2.31	68.6	83.3	0.082	0.0181	28.8	16.8	12.1
9	10.05	0.122	54.6	65.3	3.83	65.0	78.6	0.136	0.0136	23.2	16.5	11.9
10	8.60	0.120	35.2	42.0	2.18	67.0	80.8	0.077	0.0090	17.6	16.2	11.6
11	4.80	0.119	26.1	31.1	0.95	70.4	84.8	0.034	0.0070	15.1	16.1	11.6
12	9.95	0.120	21.3	25.4	1.55	68.3	82.2	0.055	0.0055	12.8	16.2	11.6
13	8.10	0.118	13.8	16.4	0.90	75.2	90.4	0.032	0.0040	10.9	15.9	11.5
Sum	99.95				96.8				3.445			
Average		0.123	64.8	78.2		175.2	211.9		0.0350			

TABLE 2b. Summary of sample runs for analysis of total hydrocarbon for charge 2.

Sample Run	Time hrs	Average Humidity kg/kg	Dry Flow Rate @68 l/min	Wet Flow Rate @68 l/min	THC mass as C g	THC wet conc ppmv	THC dry conc ppmv	THC mass as C lbs/mbf	THC rate as C lb/hr/mbf	Average Wood MC %	Average Air MC %	Average Anal. MC %
1	4.30	0.055	6.0	6.6	1.52	574.1	648.0	0.046	0.0107	106.1	8.2	8.2
2	4.50	0.142	24.4	30.0	11.50	1065.6	1298.9	0.349	0.0776	105.7	18.6	18.6
3	10.00	0.138	71.1	86.9	33.83	504.5	625.9	1.027	0.1027	101.2	18.2	11.9
4	8.15	0.128	133.7	161.2	21.51	180.3	219.6	0.653	0.0801	89.4	17.0	10.9
5	6.00	0.128	119.5	144.2	12.59	161.0	196.3	0.382	0.0637	79.4	17.1	12.3
6	10.05	0.129	141.4	170.8	18.03	115.9	141.4	0.548	0.0545	67.0	17.2	12.4
7	8.55	0.124	148.8	178.5	11.72	85.4	103.5	0.356	0.0416	51.9	16.6	12.0
8	5.93	0.122	132.4	158.4	6.31	74.2	89.7	0.192	0.0324	40.2	16.4	11.6
9	8.00	0.121	88.8	106.1	5.83	75.9	91.6	0.177	0.0221	32.3	16.3	11.7
10	8.35	0.116	81.6	96.9	4.47	61.7	74.0	0.136	0.0163	24.6	15.8	11.4
11	7.05	0.117	49.2	58.5	2.72	72.8	87.4	0.082	0.0117	19.5	15.9	11.4
12	9.00	0.116	41.6	49.5	2.67	66.7	80.0	0.081	0.0090	15.7	15.8	11.4
13	5.90	0.116	26.4	31.3	1.28	76.5	91.7	0.039	0.0066	13.1	15.8	11.4
14	9.05	0.116	24.0	28.5	1.72	74.1	88.8	0.052	0.0058	11.1	15.7	11.3
15	10.15	0.116	14.8	17.6	1.31	81.3	97.5	0.040	0.0039	9.3	15.7	11.3
16	8.80	0.114	10.1	12.0	0.79	83.7	100.1	0.024	0.0027	8.0	15.5	11.2
Sum	123.78				137.8				4.184			
Average		0.119	69.6	83.6		209.6	252.2		0.0338			

VII. Quality Assurance

Leak checks

Leak checks were performed on the VOC system before and after drying and on the impinger sample train before each run.

Calibration

Data for the calibration gases are given in Appendix 4. The mid gas was not named because the analyzer was within tolerance without naming. The calibration sheet for the flow meter is also included is also included in Appendix 4 as is the thermocouple calibration check.

Anomalies

During the first charge, data collection ceased after 100 hours. We ran the second charge to remedy this.

During both charges the wood had a very strong odor during the first 24 to 36 hours. In our experience, this odor is not characteristic of red alder. The mill said this odor was typical for wood from rafted logs and the lumber tested did come from rafted logs. It is our belief that the high levels of VOC emissions measured are a reflection of this and that fresh wood would have significantly lower emissions.

There were no other anomalies during the work that would significantly affect the data.

Appendix 1. Detailed Sampling Procedures

INSTRUCTIONS FOR CHECKS OF EMISSIONS KILN

Purpose: Ensure kiln is operating correctly

Clock time: Record from computer

Run time: Record from computer. Check the box if the computer screen being refreshed and time is advancing.

Box temperature: Read from metal electrical box under desk, left controller. The top and bottom numbers should be similar on the box should be similar, about 126 C..

Valve temperature: Read from metal electrical box under desk, right controller. The top and bottom numbers should be similar on the box should be similar, about 154 C..

Dry-bulb temperature: Read from computer screen. Compare to graph to be sure it's correct. If it's not within a degree or two of the chart, check again in a few minutes. During startup (the first 3 or so hours), it may not be able to track. If it's too high, the heat valve should be closed, too low and the heat valve should be open. If it does not appear to be working correctly, call Mike or Mark.

Wet-bulb temperature: Read from computer screen. Compare to graph to be sure it's correct.

If it is too low, it means that the kiln atmosphere is too dry. Check the flow meters. If Flow1 is about 10 L/min (its lower limit), make sure that Flow2 and Flow3 are turned off

I*f it's too high,* then either the kiln atmosphere is too humid or the sock is not being wetted. If Flow 1 is near 200 L/min (its upper limit) add venting by opening Flow2 and/or Flow 3. The maximum for Flow2 is 50 L/min, if it reads over this value for several readings, reduce it to about 45 L/min. Don't change Flow3 often, rather set it and leave it for several hours if possible. Keep the Flow 3 reading constant by small adjustments. As Flow1 decreases or Flow2 turned down, there is more pressure behind Flow3 and the flow increased. Check for water in the wet-bulb reservoir (push the float down and make sure it's getting water).

Check both Wet-bulb1 and Wet-bulb2 and make sure they are reading about the same. If they differ by more than 2 C, call Mike or Mark.

If both wet-bulbs are reading the same as the dry-bulb, check the wet-bulb water.

If these procedures do not correct the wet-bulb temperature within 30 minutes, call Mike or Mark.

Line temperature: Read from gray box on wall above analyzer. It should read about 275°F.

Chiller temperature: Read the chiller temperature. It should be about -1°C.

Flow 1: Read from computer. The value of Flow1 changes depending on the wet-bulb. If Flow 1 is 10 L/min and the wet-bulb is too low, there's probably nothing we can do. If it's 200 L/min and the wet-bulb is too high, Flow2 and/or Flow3 can be opened. Flow2 and Flow3 should be adjusted so that Flow1 stays below 175 to 200 L/min.

Flow 2: Read from computer. The value of Flow2 is set by you. It will vary a little - as flow 1 goes down, flow 2 will go up. Do not set it to < 40 L/min if you think Flow1 is going to decrease or it will go off scale and not be read by the computer

Flow 3: Read from meter. The value of Flow3 is set by you. It will vary a little - as flow 1 goes down, flow 2 will go up. Be sure to clearly record this value and when you change it

Dilution flow: Read dilution flow meter. It should read the same setting as the red flag. Do not adjust. If significantly different, investigate.

F/M Flow: Read from rotometer. This should be about 400 to 500 cc/min.

Line vacuum: Read from the vacuum gauge. This should be about 20"Hg.

INSTRUCTIONS - FIELD DATA SHEET FOR TOTAL HYDROCARBON ANALYZER
PRE-SAMPLE PROCEDURE

BACKGROUND INFORMATION

Get the dry- and wet-bulb temperatures from the kiln schedule or off the computer. Use the highest expected values for the run.

Read absolute humidity off the psychrometric chart or table.
Calculate or read from tables -
Percent moisture = 100 / [1 + 1 / 1.61*AbHum]
Target Dilution Ratio (TDR) = 15 / Percent Moisture

Event = the name of the drying cycle.
Run = the number of the 3-hour interval.
Operator, that's you.
Date and time are now, as you start the data collection process.

AMBIENT DATA

Call 9-754-0081 and get altimeter setting.
Read the laboratory temperature from the thermometer.

ANALYZER CALIBRATION

Set valves so that 1, 2 = off; 3=on; 4=vent. This allows gas to flow out of the vents from the calibration tanks and shuts off all other sources. Only calibration gas should go through the detector.

Open the zero gas tank valve
zero toggle switch up (on), others down (off)
set flow to 3.5 L/min using regulator on tank
wait for a stable reading (about 30 to 60 seconds)
use the zero dial (pot) on THA to get a zero reading
read the analyzer
read computer
note pot setting
close valve on zero gas tank

Open span gas tank valve
span toggle switch up (on), others down (off)
set flow to 3.5 L/min using regulator on tank
set analyzer to range 3
wait for a stable reading (about 30 to 60 seconds)
use the span dial (pot) on THA to get a reading of 905 ppm

read the analyzer, record, for example, 9.05 or 900
read computer (should read about 905)
note pot setting

Open mid gas tank valve
mid toggle switch up (on), others down (off)
set flow to 3.5 L/min using regulator on tank
wait for a stable reading (about 30 to 60 seconds)
read analyzer (do not adjust pot settings), record, for example, 4.12 or 412
read computer (should about 412)
check for within tolerance
turn off mid gas
all toggle switches off

SET DILUTION FLOW BEFORE RUN

Set valves so that 1, 2, 3 = off; 4=meter. This allows gas to flow only from the meter to the detector.

Use the Gilibrator to take 4 readings of the total flow rate (TFR). This is the total flow drawn by the analyzer and should be about 2.6 L/min
Make sure the average does not include any "bad" readings
Record the average, L/min = cc/min / 1000
Write the Event, Run, and "Pre-TFR" on the Gilibrator printout.

Calculate the next two values -
Target dilution flow rate (TDFR)   is the TFR x (1 - DR)
Target sample flow rate (TSFR)   is the TFR x DR
Check that the sum of these is the Total Flow Rate

Set dilution flow
Set red pointer to desired dilution flow (on meter with valve 1)
Slowly open lower valve on dilution flow meter (1=on; 2, 3=off; 4=meter)
Use upper valve on dilution flow meter to adjust flow
Do not adjust this meter after this point
Read the meter that you just set and record the value

Use the Gilibrator to take 4 readings of the sample flow rate (SFR). This is the flow through the analyzer after dilution is set. It will vary, depending on the dilution setting.
Make sure the average does not include any "bad" readings
Record the average, L/min = cc/min / 1000
Write "Pre-SFR" on the Gilibrator printout.

CHECK DILUTION FLOW BEFORE RUN

Set valves so that 1, 3 = on; 2=off; 4=vent. This allows gas to flow out of the vent from the calibration tank and shuts off all other sources. Calibration gas and dilution air will go through the detector.

Open span gas tank valve
>span toggle switch up (on), others down (off)
>set flow to 3.5 L/min using regulator on tank
>set analyzer to range 3
>wait for a stable reading (about 30 to 60 seconds)   record
>turn off all calibration gas tank valves
>all toggle switches off

Calculate the dilution ratio based on gas flow by dividing the Sample Flow Rate by the Total Flow Rate.

Calculate the dilution ratio based on span gas by dividing the Diluted span by the undiluted span.

If the Dilution ratios do not agree within 5% - DO NOT PROCEED****. Use $100*(DR_{Span} - DR_{Flow})/DR_{Flow}$ to calculate the % difference.

**** check calculations, check that values for ppm and flows make sense, remeasure everything. If it still does not agree, call Mike or Mark

START RUN

Set valve so that 1, 2, 5 = on; 3, 4=off; all calibration tank valves off

Record the start time. Use the computer clock for all times or set your watch to the computer time.

Make sure analyzer is on appropriate range, usually range 3, to keep THC reading on computer between 60 and 750.

Monitor system, as needed. Record system condition at least hourly.

End time should be no more than 3 hours from start time.

POST-SAMPLE PROCEDURE

AT END OF RUN

Record your name as the operator.
Event = the drying cycle. Run = the 3-hour interval.
Operator, that's you. Date and time are now, as you start the data collection process.

AMBIENT DATA

Call 9-754-0081 and get temperature and altimeter
Local pressure = (Altimeter - 0.23) x 3.3867
Read the laboratory temperature from the thermometer.

Fill out appropriate information on Pre-sample side of data sheet for next run. This will save time in between runs.

END TIME

Record computer time.
DO NOT adjust dilution gas yet.

CHECK DILUTION FLOW AFTER RUN

Set valves so that 1, 3 = on; 2=off; 4=vent. This allows gas to flow out of the vent from the calibration tank and shuts off all other sources. Calibration gas and dilution air will go through the detector.

Open span gas tank valve
      span toggle switch up (on), others down (off)
      set flow to 3.5 L/min using regulator on tank
      wait for a stable reading (about 30 -60 seconds)
      record
      all toggle switches off

Sample flow rate. Set valves so that 1=on; 2, 3 = off; 4=meter. This allows gas to flow only from the meter and the dilution to the detector.

      Use the Gilibrator to take 5 readings of the sample flow rate (SFR). This is the
          flow through the analyzer with dilution on.
      Make sure the average does not include any "bad" readings
      Record the average, L/min = cc/min / 1000
      Write "Post-SFR" on the Gilibrator printout.

Read dilution flow meter
To calculate the L/min, divide scfh by 2.12
Turn off dilution flow meter using valve 1

Total flow rate. Set valves so that 1, 2, 3 = off; 4=meter. This allows gas to flow only from the meter to the detector.

Use the Gilibrator to take 5 readings of the total flow rate (TFR). This is the total flow drawn by the analyzer and should be about 2.6 L/min
Make sure the average does not include any "bad" readings
Record the average, L/min = cc/min / 1000
Write "Post-TFR" on the Gilibrator printout.

CHECK CALIBRATION OF ANALYZER

Set valves so that 1, 2 = off; 3=on; 4=vent. This allows gas to flow out of the vents from the calibration tanks and shuts off all other sources. Only calibration gas should go through the detector.

Span gas tank valve should be open
span toggle switch up (on), others down (off)
set flow to 3.5 L/min using regulator on tank
set analyzer to range 4
wait for a stable reading (about 30 -60 seconds)
read analyzer (do not adjust pot settings), record, for example, 1.50 as 1500
read computer (should read about 152 due to range 4 setting)
note pot setting
check for within tolerance - between 1483 and 1573

Open mid gas tank valve
mid toggle switch up (on), others down (off)
set flow to 3.5 L/min using regulator on tank
set analyzer to range 3
wait for a stable reading (about 30 -60 seconds)
read analyzer (do not adjust pot settings), record, for example, 8.50 as 850
read computer (should read same as analyzer)
check for within tolerance

Open the zero gas tank valve
zero toggle switch up (on), others down (off)
set flow to 3.5 L/min using regulator on tank
wait for a stable reading (about 30 -60 seconds)
read analyzer (do not adjust pot settings)

read computer
    note pot setting

Calculate the dilution ratio based on gas flow by dividing the Sample Flow Rate by the Total Flow Rate.

Calculate the dilution ratio based on gas flow by dividing the Sample Flow Rate by the Total Flow Rate.

Calculate % difference as $100 * \{$Absolute Value $(DR_{Span}-DR_{Flow})\} / DR_{Flow}$

Record the time now as the end time for check.

Tear off the four sets of Gilibrator readings (Pre-TFR, Pre-SFR, Post-SFR, Post-TFR) and staple to paper with other records.

Start Pre-Sample procedure for next run.

Appendix 2. Data in Electronic Form

Appendix 3. Samples of Field Data Sheets

Appendix 4. Calibration Data

Appended Information

Added by SWCAA

Total hydrocarbon emissions from red alder lumber during drying

Michael R. Milota*

Abstract

Hydrocarbon emissions can be precursors to low-level ozone formation and states may regulate them to maintain ambient air quality. Total hydrocarbon emissions were measured during the drying of red alder lumber. Fresh wood had low emissions, 0.2 pounds per 1,000 board feet. Wood that was stored for an extended period in salt water had emissions that were up to 40 times greater than this.

Red alder (*Alnus rubra*) is the major commercial hardwood species in the U.S. Pacific Northwest. It is often dried to moisture contents (MCs) of 6 to 8 percent and often used for furniture. Hydrocarbons are released as wood dries and their presence can cause atmospheric reactions to favor increased low-level ozone, a criteria pollutant subject to federal ambient air quality standards. States may limit hydrocarbon release to maintain ambient air quality and mills are required to report equipment or operational modifications that affect hydrocarbon emissions. The objective of this work was to measure the total hydrocarbon, or volatile organic compound (VOC), emissions from red alder lumber during drying.

Procedure

Raw material

Red alder lumber was supplied by three different mills in western Washington state. All was 4/4 nominal in thickness and random width. The actual thickness was 2.8 cm to 3.1 cm and the width ranged from 7 cm to 22 cm. Wood was cut at the mills to 1.2-m (4-ft) lengths, wrapped in plastic, and delivered to Oregon State University (OSU) within 2 days after sawing. Log storage times varied, however. Samples A and B, provided by two different mills, were both sawn from freshly harvested logs. The log storage time for sample C was unknown. The logs for sample D were stored in salt water for 6 to 9 months prior to sawing. Sample D had a sour odor when received, but the wood was not moldy and there were no obvious signs of fungal damage.

Upon arrival at OSU, the wood was placed in the kiln within 1 day. For sample D, the second charge dried was stored for 5 days wrapped in plastic at 5°C prior to drying. The dimensions of each board were measured. The boards were trimmed to 1.12 m by removing 5 cm from each end to reduce any effect from predrying. Each board was weighed before and after drying, then ovendried and reweighed so that MC could be determined.

Drying procedure

A schematic of the kiln is shown in **Figure 1**. The kiln box is approximately 1.2 m on each side. Dry- and wet-bulb temperatures are measured on the entering-air side of the load. The kiln is indirectly heated by steam to maintain the desired dry-bulb temperature. Humidity is controlled by metering the air entering the kiln to maintain the desired wet-bulb temperature. A minimum of 6 L/min of air entered the kiln at all times, more than removed by the analyzer (2.6 L/min).

The wood for each of the five charges was stacked in the kiln on 1.9-cm-thick stickers (3/4 in). The loads were 2 to 4 boards wide and 13 to 14 courses high (approximately 65 board feet). Drying schedules were provided by the mills supplying the wood. A typical drying schedule is shown in **Figure 2**. Among the three mills, all drying schedules started between 65° and 71°C with a 5°C wet-bulb depression and ended between 79° and 85°C with a 16° to 21°C wet-bulb depression. The air was circulated at 2.5 m/s (500 ft/min) through the lumber stack. The target MC was 7 percent and this was reached except on one charge. The drying times were approximately 4 to 5 days.

Hydrocarbon measurement

The system for sampling hydrocarbon concentration in the kiln exhaust is shown in **Figure 1**. It is assumed that the gas in the kiln is well mixed and that gas sampled near the exhaust has the same composition as the exhaust. The total hydrocarbon sample was drawn from the kiln directly into a dilution/filter box mounted on the side of the kiln. The box and all lines were heated to prevent condensation. Heated dilution gas was added to the sample so that the gas MC to the analyzer was less than 15 percent. Dilution gas flow was measured with a
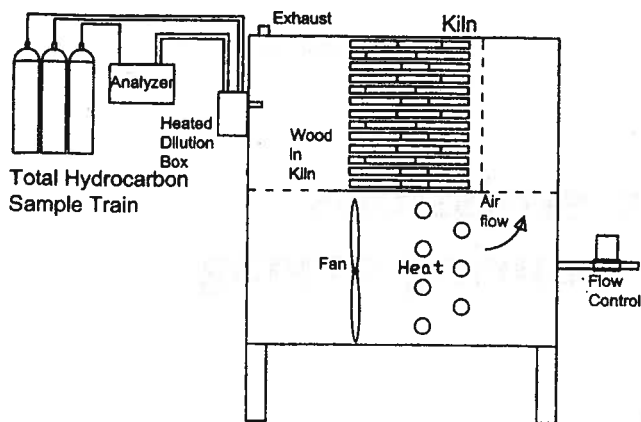
Figure 1. — Kiln and hydrocarbon sampling system.
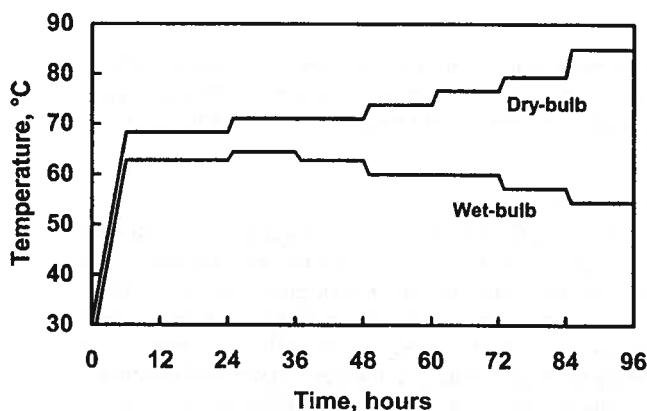
Figure 2. — Typical kiln schedule used in study for red alder.

Table 1. — Total hydrocarbon emissions released due to drying charges of red alder lumber to 7 percent MC. Values are reported "as carbon;" 0.2 lb/MBF is approximately 0.085 g per kg of ovendried wood.

Sample	Charge	Initial MC	Drying time	Emissions	Log storage
		(%)	(h)	(lb/MBF)	
A	1	103	125:48	0.21	Minimal
B	1	102	92:02	0.20	Minimal
C	1	105	93:15	0.59	Unknown
D[a]	1	103	99:59	3.44	Extended salt water storage
D	2	106	123.78	4.18	Extended salt water storage

[a]Dried to 10 percent MC.

Figure 3. — Concentration of total hydrocarbon emitted from kiln (left axis) and MC of the wood as a function of time (right axis). The drops in concentration correspond to venting increases at schedule changes.
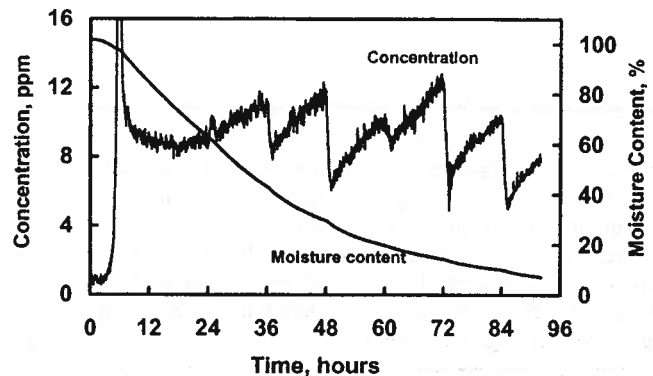
bubble meter. A reduction in the analyzer reading confirmed the dilution ratio.

The detector was calibrated at 4- to 10-hour intervals by introducing propane in air from gas cylinders (**Fig. 1**) to the probe tip. EPA Protocol gas was used to set the analyzer span, certified propane in air was used to test for linearity at the midrange, and the zero on the analyzer was set using air containing less than 0.1 ppm of hydrocarbon. The drift of the span value did not exceed 4 percent between calibrations. The zero drift was minimal. The methodology followed is similar to EPA Method 25A (Code of Federal Regulations 1991). It has been established that no scale up factor is needed between the emissions measured in the small-scale kiln and large-scale kilns (Lavery and Milota 2000, NCASI 2002).

Calculations

The concentration (ppm) detected by the analyzer is converted to a concentration (mass/volume) based on the dry gas. This times the dry gas flow rate is then integrated over time to give the total mass emitted. The total hydrocarbon values are expressed "as carbon," a standard way of expressing Method 25A results because individual compounds are not determined. This means that only the mass of the carbon atoms are included in the calculations. Also, oxygenation of the carbons and moisture in exhaust may also affect the readings. Emissions values were calculated to the time when the wood reached 7 percent MC. The full calculation procedure is described in Lavery and Milota (2000).

Results

The total hydrocarbon emissions released during the drying cycles are shown in **Table 1**. Samples A and B, although from different mills, have similar emissions values and are known to have been sawn from fresh logs. Sample C is from a third mill and the log history is unknown. Sample D is from the same mill as sample A, but the logs were stored in salt water for 6 to 9 months. This appears to have had a significant impact on the VOC emissions in both charges from that sample.

The concentration in the kiln and the MC as a function of time are shown in **Figure 3**. Initially, the concentration increases to a maximum as the kiln heats with minimal venting. The concentration then decreases and follows the sawtooth pattern shown in the figure. The decreases in concentration at regular intervals correspond to schedule changes. When the schedule calls for an increase in the wet-bulb depression, the venting increases and the concentration decreases. Then during each schedule step, as the wood dries and venting slowly decreases, the concentration increases. The MC changes slowly for the first few hours when the vent rate is low. The drying rate then increases when venting increases and decreases later in the schedule as the wood gets dry.

The profile of emissions released from the kiln is shown in **Figure 4**. The shape of this curve for total emissions, concave downward, is typical of all charges. Most of the emissions are released early in the schedule. The rate of emissions released shows a small spike at each schedule change corresponding to
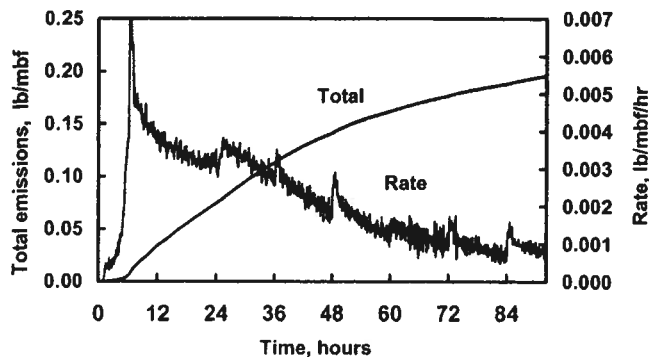
Figure 4. — *Total hydrocarbon emissions (left axis) and the rate of emissions (right axis) as a function of drying time.*

the increase in venting and perhaps some additional release from the wood as the drying rate increases due to the lower equilibrium MC in the kiln.

Sample D had emissions that were 40 times higher than samples A and B. This strongly suggests that log storage plays a role in the total hydrocarbon emissions during drying. Sample D had a very noticeable pungent odor during the first half of the drying schedule, possibly due to fatty acids produced by the activity of anaerobic bacteria in the wood. Singh and Kim (1997) indicate that bacteria may play a more important role than fungi in aquatic or waterlogged terrestrial environments and discuss tunneling, cavitation, or erosion of the cell wall by bacteria. Breakdown of the cell wall and stored sugars, proteins, and lipids may result in monosaccharides and other low molecular weight compounds that might contribute to VOC's. Schmidt and Liese (1994) indicate that bacteria can increase the pH of the wood by generation of ammonia or that wood can be acidified due to the production of organic acids. Acidic wood is prone to degradation.

The sodium chloride in the seawater may also play a role in the formation of VOCs. The sodium might exchange with the hydrogen of a carboxylic acid group such as the 4-O-methy-D-glucouronic substituent in the xylan of the hemicellulose.

DeGroot (1985) provides evidence for potassium, which has the same valence as sodium, complexing in this manner in cottonwood. The hydrogen ion then could pair with a chloride ion to form HCl. The HCl can react with acetate groups to form acetic acid, leaving an alcohol functional group on the wood. The increased pH of the wood from both the HCl and the acetic acid promotes further breakdown of the hemicellulose and increased emissions.

Conclusions

The total hydrocarbon emissions from fresh red alder are low, 0.2 pound per thousand board feet (lb/MBF) (0.085 g/kg), compared to non-resinous softwoods, which emit from 0.1 to 0.5 lb/MBF, and resinous softwoods, which might emit up to 1 to 3 lb/MBF.

Handling and storage of logs can significantly affect the emissions during drying as evidenced by the emissions from wood that had been stored in salt water for an extended period. If mills source test for permitting purposes, it is important to select material that is typical production material. If the handling practices change significantly, a mill may want to retest and update their permit to remain in compliance.

Literature cited

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