

Total hydrocarbon and HAP emissions from the drying of red alder lumber

Report to
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Report by
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April 15, 2014

Wess Safford

From: Milota, Mike [mike.milota@oregonstate.edu]
Sent: Wednesday, May 07, 2014 3:16 PM
To: Wess Safford
Cc: 'Jacobson, Jerad'
Subject: RE: Lumber Drying Test Results
Attachments: Milota, 1999, EffectOfMCOAnalyzer.pdf

Wess,

Offhand there are three contributing factors. First VOCs are reported as carbon. 7.89 is based on the actual molecular weight of ethanol. If reported as carbon it would be 4.11. Second, the ethanol response on the hydrocarbon detector is less than that of propane, I'm not sure by how much (about 60% for methanol). Suppose it's 80%. The 4.11 then becomes 3.29 lb/mbf. The other factor is the moisture effect on the analyzer (see attached) which might take it down another 10% to 2.96. I know this is still not enough to make total sense of the numbers, but it does bring them a lot closer.

Note that all the compounds (mainly AA, EtOH, and MeOH) on page 9 total about 8.4 lb/mbf. If you apply the same logic (acetic as carbon would be reduced to 39% compared to 52% for EtOH for "as carbon" and the GC response will be lower) to all the compounds, you would still come out around 3 lb/mbf.

The ethanol was definitely there. The high number is not a typo. It surprised me enough that I did not have standards made to high enough concentration to measure it at first. I had to dilute several samples, then run again on the GC. We ran the first few samples (from early in drying) in one batch on the GC, then later remade these (with dilution) and ran all the samples in a single batch which is what we reported. There wasn't much, if any difference between these. Even with no standards it would have been clear there was a lot of ethanol compared to the other compounds.

We have seen this lack of agreement before where the HAPs exceed the VOCs especially in hardwoods. In softwoods there are a lot of other compounds (such as pinenes) and less EtOH and AA so we don't see the aldehydes and alcohols exceed the total hydrocarbon measurement. Beyond this, I don't have any more reasons. There is more hemicellulose in hardwoods and the hemicellulose has 2-carbon acetyls that are cleaved during heating. This gives the ethanol.

Hope this helps. If you have other questions, please let me know.

Mike M.

From: Wess Safford [mailto:Wess@swcleanair.org]
Sent: Wednesday, May 07, 2014 1:40 PM
To: Milota, Mike
Cc: Jacobson, Jerad
Subject: Lumber Drying Test Results

Mike / Jerad –

SWCAA received the test report for the recently conducted 'water wood' lumber drying test. I have done a quick review of the results, and one item appears a bit odd.

A total VOC emission value of 2.34 lb/mbf is presented on page 1. An ethanol emission value of 7.89 lb/mbf is presented on page 9. My expectation is that ethanol would be a moderate fraction of overall VOC, and at the very least, the

ethanol value should be smaller than the total VOC value. Am I reading the report correctly? If so, do you have any suggestions for why the ethanol value is higher?

- Wess

Wess Safford, AQ Engineer
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Summary

One charge of red alder 5/4 lumber was dried in a small kiln at Oregon State University. The kiln dry- and wet-bulb temperatures were based on a schedule provided by Northwest Hardwoods. The maximum temperature was 170°F (77°C). The air velocity was 750 feet per minute (3.7 m/s). The kiln was indirectly heated with steam. The amount of air entering the kiln was regulated to control humidity.

A JUM VE-7 total hydrocarbon analyzer was used to measure organic emissions following EPA Method 25A. The results are shown in Table 1.

Table 1. Summary of total hydrocarbon results to 15% moisture content. VOC units are pounds per thousand board feet as carbon.

Charge	Initial MC	Final MC	Time to 8%	VOC ^B
	%	%	hr:min	lb/mbf
Red alder	112	8.0 ^A	96:08	2.34

^A actual time to 7% MC was 101:32 hours

^B VOCs are reported at 8% moisture content

NCASI Method ISS/FP-A105.01 was used to measure the MACT HAP emissions. The results are shown in Table 2. The sum of the HAPs emitted was 0.18 lb/mbf for the red alder.

Table 2. Summary of HAP results for moisture content and time shown in Table 1. Emissions units are pounds per thousand board feet.

	Methanol	Phenol ^A	Form-aldehyde	Acet-aldehyde	Propion-aldehyde	Acrolein
Red alder	0.114	0.000	0.0005	0.064	0.0009	0.0007

^A None detected

1. Description of source

The tested source is a lumber dry kiln. Lumber destined for the mill's kiln was sampled and tested in a small-scale kiln at Oregon State University.

Mill personnel reported that the logs were harvested during August of 2013. The harvest location was Homfray Creek, BC, Canada. The logs were stored on land from August to October 23, 2013. They were then in water from October 23, 2013 to March 20, 2014. At the mill the logs were sawed on March 26, 2014, wrapped, and loaded to be delivered to OSU on March 27, 2014.

Enough wood for three charges of lumber was delivered to Oregon State by an employee of Northwest Hardwoods on March 27, 2014. The wood was wrapped in plastic and lumber wrap at the mill to prevent moisture loss during transport. The wood appeared to be fresh.

At OSU, the 4-foot pieces were sorted March 28. One third was randomly pulled from the pile and used for the charge. It was wrapped and stored outside out of the sun (temperature in the 40°F range). The remaining wood was wrapped in plastic and placed in a refrigerator at 35°F.

2. Date and time of test

The charge was dried from March 31, 2014 at 8 am until 13:32 am on April 4, 2014. Drying was done under the supervision of Mike Milota at Oregon State University. Students were used to monitor parts of the test.

3. Results

Total hydrocarbon

See Table 1, page 1, for a summary of the hydrocarbon results. Details for each sampling interval are tabulated and the hydrocarbon emissions are summarized graphically here. All emission data is presented in detail in electronic form in Appendix 2.

An interval is the period between analyzer calibrations, about three to six hours of data. The interval time periods shown in the table include the calibration times and mass calculations are adjusted to account for these. Sampling occurred for approximately 95% of the drying time.

Figure 1 shows total hydrocarbon concentration (left scale) and dry gas vent rate (right scale) versus time. Concentration has a large peak at 8 hours during the period when venting is low. It is low at 10 hours when venting is high. In general, the concentration decreases though the schedule. The vent rate is quite

variable in the beginning of the schedule. Up to six hours the venting is at a maximum as the control system tries to keep the wet-bulb at setpoint. At about 6 hours the wet-bulb temperature went below the set point and we tried to help the control by turning down the air manually. This caused the large drop in venting. It was turned back up at about 10 hours.

Figure 2 shows the cumulative hydrocarbon emissions (left scale, smooth line) and the rate of emissions (right scale, jagged line) versus time. The cumulative value is the emissions up to any point in time in the schedule. The rate is how much is coming out per unit time. The maximum emission rates occurred between 5 and 20 hours, after which it steadily decreases as the moisture loss from the wood slows.

Figure 3 shows the total hydrocarbon emissions as a function of wood moisture content. This graph would be useful for predicting emissions at various final moisture content levels. Note that there are only small differences in emissions

for final moisture contents between 7 and 10%.

Table 3. Summary of results for each sampling interval for total hydrocarbon.

Sample Run	Time hrs	Average Humidity kg/kg	Flow rate		THC mass as C g	THC concentration		THC rate as C g/hr	THC mass as C lbs/mbf	THC rate as C lb/hr/mbf	Average			
			Dry @68 l/min	Wet @68 l/min		wet ppmv	dry ppmv				Wood MC %	Air MC %	Anal. MC %	
1	2.60	0.028	207.7	217.0	6.27	121.2	126.8	2.41	0.126	0.0483	111.4	4.3	4.3	
2	8.41	0.118	115.1	137.1	26.98	429.3	545.9	3.21	0.541	0.0643	106.6	16.0	9.0	
3	6.11	0.176	113.9	146.3	18.21	241.4	309.9	2.98	0.365	0.0597	95.5	22.1	12.4	
4	4.76	0.179	126.4	162.9	11.95	182.5	235.2	2.51	0.239	0.0503	86.1	22.4	12.5	
5	4.21	0.185	165.1	214.5	10.25	126.7	164.5	2.44	0.205	0.0488	75.5	23.0	13.0	
6	5.96	0.190	177.4	231.8	13.09	106.1	138.8	2.20	0.262	0.0440	61.3	23.5	13.1	
7	3.05	0.188	145.6	189.8	5.34	103.3	134.6	1.75	0.107	0.0351	49.1	23.3	13.0	
8	6.21	0.189	116.5	151.9	8.45	99.8	130.2	1.36	0.169	0.0273	39.6	23.3	13.1	
9	7.11	0.185	87.5	113.6	6.33	88.8	115.3	0.89	0.127	0.0178	29.3	23.0	13.0	
10	5.76	0.179	58.2	75.0	3.13	82.3	106.0	0.54	0.063	0.0109	21.8	22.4	12.8	
11	5.06	0.181	41.1	53.1	1.94	80.4	103.9	0.38	0.039	0.0077	17.7	22.6	12.9	
12	10.31	0.177	29.5	37.9	2.64	79.5	102.6	0.26	0.053	0.0051	13.9	22.2	12.4	
13	5.21	0.163	27.1	34.2	0.94	59.2	74.7	0.18	0.019	0.0036	10.5	20.8	11.7	
14	3.40	0.163	14.4	18.2	0.36	65.2	82.4	0.11	0.007	0.0021	9.3	20.8	12.5	
15	6.91	0.162	7.3	9.2	0.40	69.5	87.6	0.06	0.008	0.0011	8.6	20.7	12.4	
16	4.36	0.150	6.6	8.2	0.20	62.0	77.0	0.05	0.004	0.0009	8.1	19.5	11.7	
17	6.66	0.143	7.5	9.2	0.30	54.2	66.7	0.04	0.006	0.0009	7.7	18.8	11.3	
Sum	96.08				116.8				2.340					
Average		0.162	85.1	106.5		120.7	153.1	1.26		0.0252				

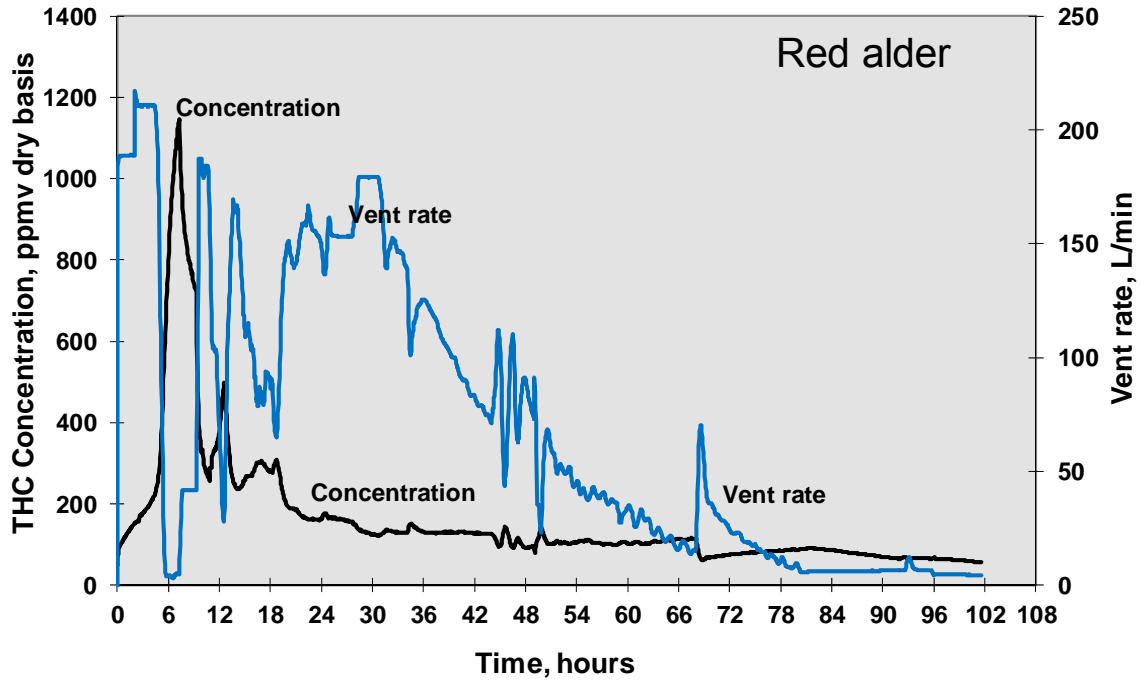


Figure 1. Hydrocarbon concentration and vent rate versus time 1.

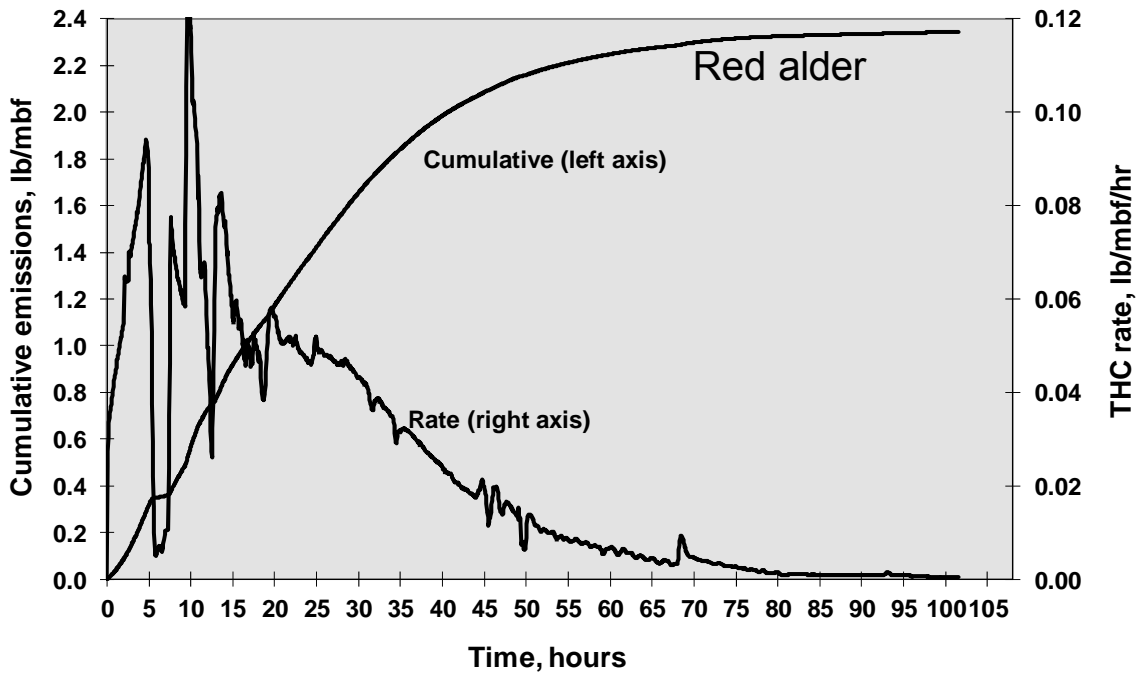


Figure 2. Cumulative hydrocarbon emissions (left scale, smooth line) and the rate of emissions (right scale, jagged line) versus time.

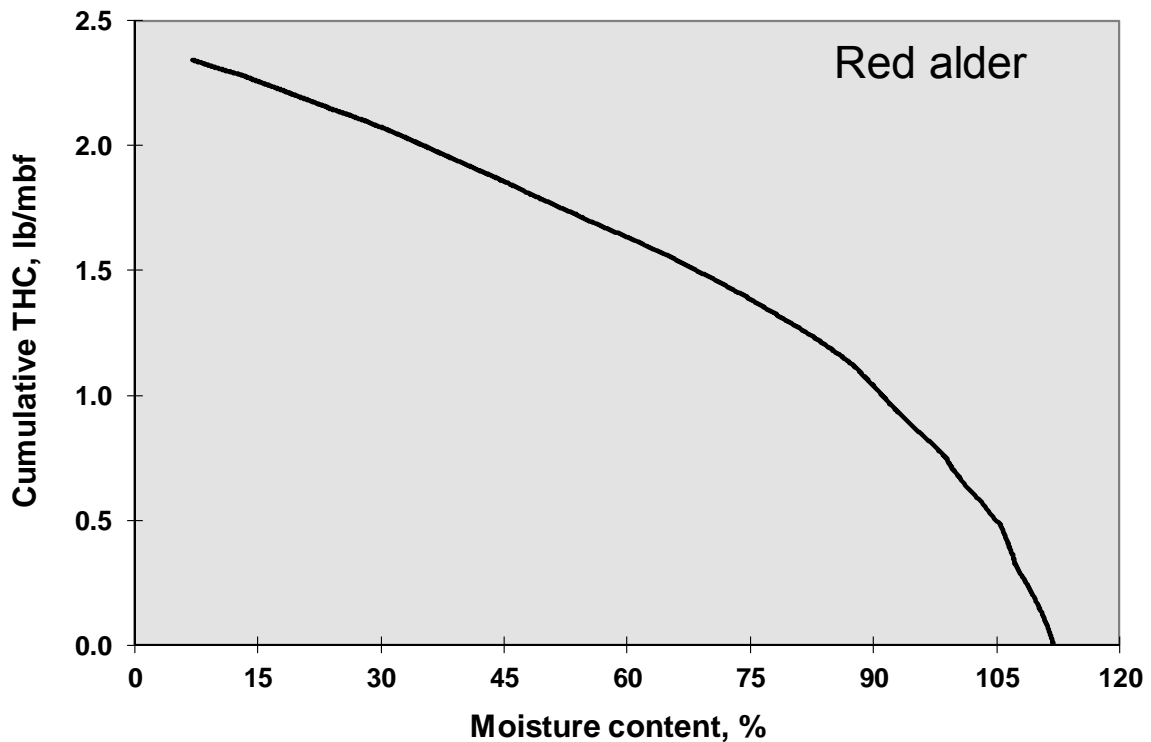


Figure 3. Total hydrocarbon emissions as a function of wood moisture content.

HAPs

See Table 2, page 1, for a summary of the HAP results. Details for each sampling interval are tabulated and the HAP emissions are summarized graphically here. All emission data is presented in detail in electronic form in Appendix 2.

A summary of the kiln conditions for each sampling interval is in Table 4. A collection interval is the time the impingers were on and sampling occurred, approximately 90 minutes. An adjusted interval is the period spanning the midpoints between collection intervals, about six hours. For example, if the impingers were on from 12:00 to 13:30, 18:00 to 19:30, and 00:00 to 1:30, the 18:00 to 19:30 impinger set represents the adjusted interval from 15:45 to 21:45. The mass calculations are adjusted proportionally to represent emissions during the adjusted interval. For example, if a collection interval was 90 minutes and the adjusted interval was six hours, the amount of HAPs in the impinger is multiplied by four. Sampling occurred for approximately 25% of the drying time.

The MACT HAP emissions and the emissions of ethanol and acetic acid are shown in Table 5. The total HAP emissions were 0.18 lb/mbf for the red alder (does not include the non-HAPs, ethanol and acetic acid). Methanol is the HAP emitted in the greatest quantity (0.114 lb/mbf) followed by acetaldehyde (0.064 lb/mbf). Other HAPs (formaldehyde, propionaldehyde, and acrolein) are present and comprise only 1.2% of all the HAPs. Phenol was not detected in any sample.

The HAP emissions as a function of time and wood moisture content during the cycle are shown in Figures 4 and 5, respectively. The rate of HAP emissions decreases with time throughout the schedule (lines are concave downward in Figure 4). The rate of HAP emissions per percent moisture content change are greatest (lines in Figure 5 are concave upward) at low moisture content (even though they are lowest per unit of time because of the slow drying rate at low moisture content). The rate of HAP emissions is also a little greater at high moisture content.

Table 4. Summary of HAP sampling intervals.

Sample Run ID	Collection Interval	Adjusted Interval	Dry gas mass	Average Dry gas flow rate	Molar Humidity	Moisture Content	
	hours	hours	kg	kg/min	mol/mol	Mid %	End %
1	1.60	3.15	48.127	0.254	0.050	111.7	110.0
2	2.00	5.81	37.546	0.108	0.231	107.1	105.7
3	1.43	5.26	49.772	0.158	0.291	99.5	95.0
4	1.50	5.51	42.893	0.130	0.285	90.8	86.1
5	1.52	6.01	70.716	0.196	0.293	78.6	70.9
6	1.50	6.01	77.230	0.214	0.308	62.3	53.6
7	1.50	6.01	60.570	0.168	0.303	46.4	40.2
8	1.50	6.11	42.992	0.117	0.304	35.0	30.8
9	1.52	5.96	35.870	0.100	0.289	26.4	23.2
10	1.50	5.96	22.673	0.063	0.293	20.5	18.3
11	1.50	5.96	16.041	0.045	0.292	16.4	14.9
12	1.50	6.01	9.754	0.027	0.293	13.7	12.9
13	1.50	6.01	15.015	0.042	0.266	11.0	9.9
14	1.50	6.01	6.060	0.017	0.263	9.2	8.8
15	1.50	6.01	2.906	0.008	0.259	8.5	8.3
16	1.50	6.01	2.931	0.008	0.235	8.0	7.8
17	1.50	6.01	3.053	0.008	0.231	7.5	7.2
SUM		97.78					

Table 5. Summary of the HAP, acetic acid, and ethanol emissions.

Sample Run ID	Interval Endpoint	Wood Moisture Content	Unit mass leaving kiln							
			Methanol	Phenol	Ethanol	Acetic acid	Formaldehyde	Acetaldehyde	Propionaldehyde	Acrolein
			lb/mbf	lb/mbf	lb/mbf	lb/mbf	lb/mbf	lb/mbf	lb/mbf	lb/mbf
1	3.15	110.0	0.0015	0.0000	0.3988	0.0034	0.00002	0.0109	0.00000	0.00000
2	8.96	105.7	0.0035	0.0000	1.5687	0.0134	0.00000	0.0061	0.00001	0.00000
3	14.22	95.0	0.0132	0.0000	1.3010	0.0308	0.00004	0.0096	0.00008	0.00013
4	19.73	86.1	0.0067	0.0000	0.9147	0.0143	0.00002	0.0071	0.00005	0.00007
5	25.74	70.9	0.0120	0.0000	1.6442	0.0258	0.00004	0.0051	0.00008	0.00008
6	31.74	53.6	0.0109	0.0000	0.6105	0.0643	0.00006	0.0051	0.00007	0.00010
7	37.75	40.2	0.0133	0.0000	0.5719	0.0617	0.00003	0.0034	0.00005	0.00006
8	43.86	30.8	0.0105	0.0000	0.3625	0.0498	0.00002	0.0022	0.00004	0.00004
9	49.82	23.2	0.0090	0.0000	0.1964	0.0346	0.00002	0.0020	0.00005	0.00004
10	55.77	18.3	0.0080	0.0000	0.1339	0.0299	0.00005	0.0039	0.00010	0.00006
11	61.73	14.9	0.0038	0.0000	0.0451	0.0130	0.00003	0.0022	0.00006	0.00003
12	67.74	12.9	0.0054	0.0000	0.0496	0.0121	0.00003	0.0020	0.00007	0.00003
13	73.75	9.9	0.0052	0.0000	0.0360	0.0131	0.00006	0.0024	0.00009	0.00004
14	79.76	8.8	0.0049	0.0000	0.0300	0.0092	0.00002	0.0009	0.00004	0.00002
15	85.76	8.3	0.0021	0.0000	0.0111	0.0030	0.00001	0.0005	0.00002	0.00001
16	91.77	7.8	0.0022	0.0000	0.0092	0.0031	0.00001	0.0004	0.00002	0.00001
17	97.78	7.2	0.0015	0.0000	0.0059	0.0029	0.00002	0.0005	0.00002	0.00001
		Sums:	0.114	0.000	7.890	0.384	0.0005	0.064	0.0009	0.0007

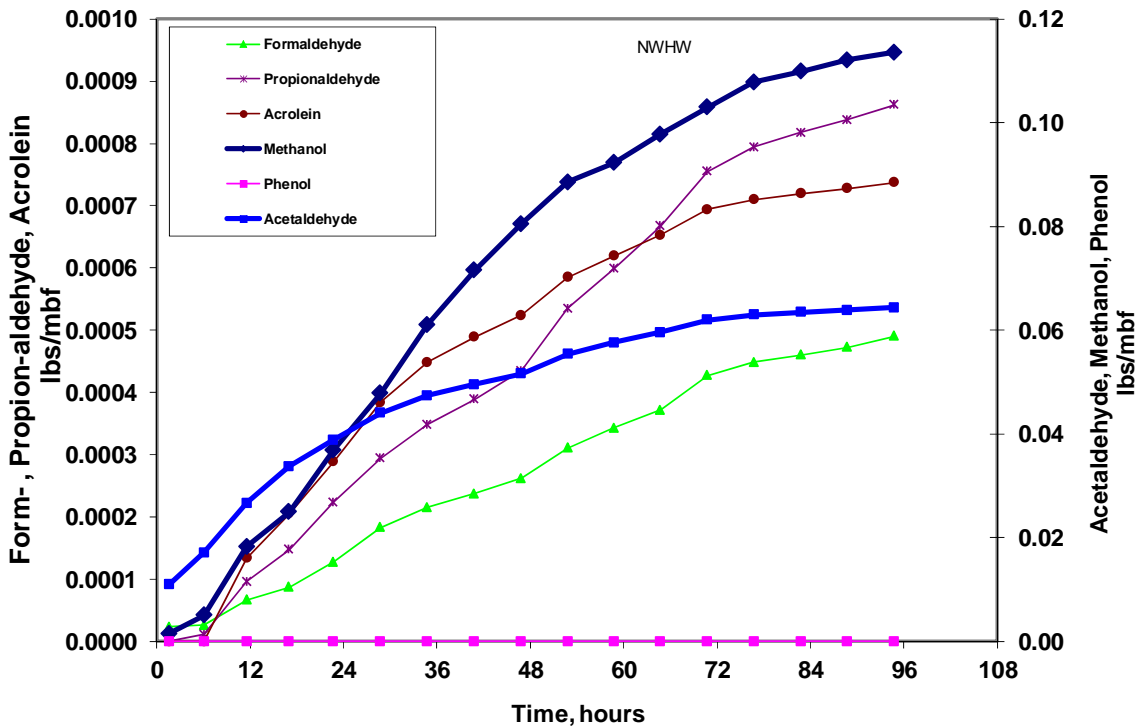


Figure 4. HAP emissions as a function of time.

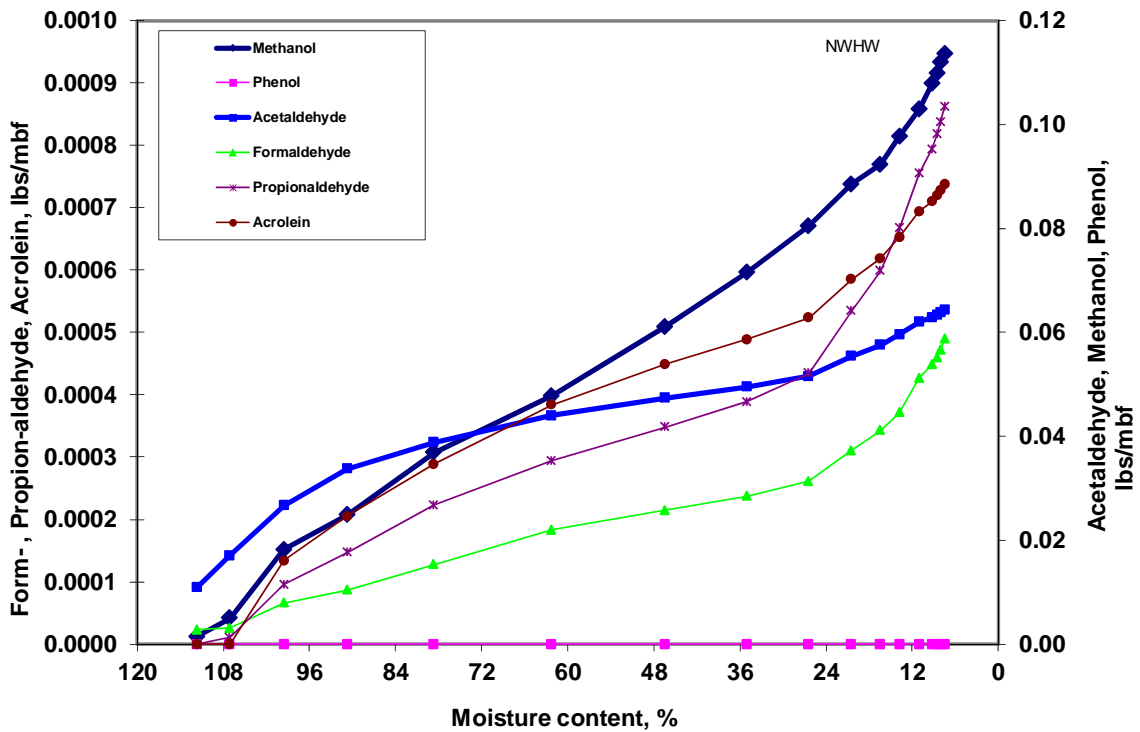


Figure 5. HAP emissions as a function of moisture content.

The detection limits for the GC instrument were

- Methanol – 0.65 µg/mL in the aqueous phase
- Phenol – 0.14 µg/mL in the aqueous phase
- Ethanol – 0.92 µg/mL in the aqueous phase
- Acetic acid – 0.98 µg/mL in the aqueous phase
- Formaldehyde - 0.05 µg/mL in the hexane phase
- Acetaldehyde – 0.05 µg/mL in the hexane phase
- Propionaldehyde – 0.04 µg/mL in the hexane phase
- Acrolein – 0.05 µg/mL in the hexane phase

The method detection limit varies with gas flow through the impingers and the amount of solution in the impingers. Typical (based on the average flow conditions and impinger volumes for the 18 impinger samples) method detection limits in the sampled gas (wet kiln exhaust) are

- Methanol - 0.48 ppm
- Phenol - 0.04 ppm
- Ethanol – 0.46 ppm

Acetic acid – 0.38 ppm
 Formaldehyde - 0.014 ppm
 Acetaldehyde - 0.009 ppm
 Propionaldehyde - 0.006 ppm
 Acrolein - mean = 0.008 ppm

All samples were above the detection limits except for phenol in all samples (not detected), propionaldehyde in sample 1, and acrolein in samples 1 and 2. The table below shows the amounts emitted if one-half the detection limit is substituted for all samples below the detection limit, the total HAPs remain unchanged (with rounding) at 0.180 lb/mbf.

Unit mass leaving kiln							
Methanol	Phenol	Ethanol	Acetic acid	Form-aldehyde	Acet-aldehyde	Propion-aldehyde	Acrolein
lb/mbf	lb/mbf	lb/mbf	lb/mbf	lb/mbf	lb/mbf	lb/mbf	lb/mbf
0.114	0.000	7.890	0.384	0.0005	0.064	0.0009	0.0008

Field spikes were run by operating two impinger trains simultaneously. An aliquot of the compounds was added to one impinger train. Spike recovery percentage is the mass of a compound detected in the lab compared to mass added to the impinger. Table 6 shows the field spike recoveries. The method requires between 70% and 130% recovery if the concentration of the compound in the gas phase is greater than 1.5 ppm in the dry gas. All spike recoveries were within +/- 30%. For acetic acid the range was 74 to 124%. The range was 83 to 115% for the other compounds. We did not have acrolein in the lab until late on the fourth day of testing, so two spikes (a high and a low) were done for the last two impinger sets. The spike levels (the amount in the spiked impinger should be between three to five times that in the unspiked impinger) were correct for methanol in the run 17 spike, and for all other compounds in run 18 spike.

The results for a field blank collected are shown in Table 7. None of the target compounds were detected in the blank above the detection limits. Formaldehyde was the only compound detected at approximately 10% of the detection limit and 40x lower than the typical sample concentration.

Duplicate samples were run by operating two impinger trains simultaneously. The results of duplicates are shown in Table 8. The percentage is the difference between the gas concentrations detected by each impinger. Phenol was not detected so duplicates could not be compared. Differences ranged from 1.4 to 15.5%, all within the limits of the method.

Table 6. Example of spike test results.

Alcohol Spike									
Run	Mass in impinger				Impinger flow mL/min	Mass corrected for flow			
	Methanol	Phenol	Ethanol	Acetic		Methanol	Phenol	Ethanol	Acetic
	µg	µg	µg	µg		µg	µg	µg	µg
17	1168.2	0.0	4551.0	2192.2	402.5	600.7	0.0	2340.2	1127.3
1703	1601.0	190.5	13660.7	7519.7	207.0	1601.0	190.5	13660.7	7519.7
Spike mass g	Spike concentrations					Spike recoveries			
	Methanol	Phenol	Ethanol	Acetic		Methanol	Phenol	Ethanol	Acetic
	µg/mL	µg/mL	µg/mL	µg/mL		%	%	%	%
1.74	524.8	97.7	6186.6	3452.6		109.6	112.1	105.2	106.4

Aldehyde Spike									
Run	Mass in impinger				Impinger flow mL/min	Mass corrected for flow			
	Form-aldehyde	Acet-aldehyde	Propion-aldehyde	Acrolein		Form-aldehyde	Acet-aldehyde	Propion-aldehyde	Acrolein
	µg	µg	µg	µg		µg	µg	µg	µg
17	13.9	362.8	18.5	7.3	402.5	15.5	405.6	20.7	8.2
1702	49.5	1115.2	68.7	25.0	450.0	49.5	1115.2	68.7	25.0
Spike mass g	Spike concentrations					Spike recoveries			
	Form-aldehyde	Acet-aldehyde	Propion-aldehyde	Acrolein		Form-aldehyde	Acet-aldehyde	Propion-aldehyde	Acrolein
	µg/mL	µg/mL	µg/mL	µg/mL		%	%	%	%
1.69	15.9	373.1	19.9	7.4		83.2	74.2	94.2	88.3

Alcohol Spike									
Run	Mass in impinger				Impinger flow mL/min	Mass corrected for flow			
	Methanol	Phenol	Ethanol	Acetic		Methanol	Phenol	Ethanol	Acetic
	µg	µg	µg	µg		µg	µg	µg	µg
18	1196.4	0.0	3718.5	1577.7	405.0	1319.8	0.0	4101.8	1740.4
1802	1654.9	57.7	7477.4	3707.3	446.8	1654.9	57.7	7477.4	3707.3
Spike mass g	Spike concentrations					Spike recoveries			
	Methanol	Phenol	Ethanol	Acetic		Methanol	Phenol	Ethanol	Acetic
	µg/mL	µg/mL	µg/mL	µg/mL		%	%	%	%
0.52	559.8	98.9	6429.1	3449.1		115.1	112.2	101.0	109.7

Aldehyde Spike									
Run	Mass in impinger				Impinger flow mL/min	Mass corrected for flow			
	Form-aldehyde	Acet-aldehyde	Propion-aldehyde	Acrolein		Form-aldehyde	Acet-aldehyde	Propion-aldehyde	Acrolein
	µg	µg	µg	µg		µg	µg	µg	µg
18	16.7	383.4	21.2	7.7	405.0	8.4	193.8	10.7	3.9
1803	22.3	573.7	28.7	10.4	204.7	22.3	573.7	28.7	10.4
Spike mass g	Spike concentrations					Spike recoveries			
	Form-aldehyde	Acet-aldehyde	Propion-aldehyde	Acrolein		Form-aldehyde	Acet-aldehyde	Propion-aldehyde	Acrolein
	µg/mL	µg/mL	µg/mL	µg/mL		%	%	%	%
0.54	15.9	373.1	19.9	7.4		106.6	124.3	110.6	107.3

Table 7. Results for the field blank.

Field blank							FB
Methanol	Phenol	Ethanol	Acetic acid	Form-aldehyde	Acet-aldehyde	Propion-aldehyde	Acrolein
ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000

Table 8. Results for duplicate runs.

Duplicate									
Run	Mass in impinger								Impinger flow
	Methanol	Phenol	Ethanol	Acetic acid	Form-aldehyde	Acet-aldehyde	Propion-aldehyde	Acrolein	
	µg	µg	µg	µg	µg	µg	µg	µg	
2	287.1	0.0	128118	1092.3	0.2	500.6	0.9	0.0	396.0
202	350.7	0.0	122690	1441.5	0.2	477.4	0.8	0.0	441.3
Difference, %	9.2	#DIV/0!	15.1	16.9	15.5	15.5	15.5	#DIV/0!	
Duplicate									
Run	Mass in impinger								Impinger flow
	Methanol	Phenol	Ethanol	Acetic acid	Form-aldehyde	Acet-aldehyde	Propion-aldehyde	Acrolein	
	µg	µg	µg	µg	µg	µg	µg	µg	
10	822.2	0.0	13748.1	3065.3	5.0	395.7	10.3	6.3	400.8
1002	898.4	0.0	15016.0	3299.6	5.8	436.3	11.6	6.6	443.7
Difference, %	1.3	#DIV/0!	1.4	2.8	4.0	0.4	2.1	6.0	

4. Control system and operating conditions

A schematic of the kiln is shown in Figure 6(top). 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 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 4 L/min entered the kiln at all times, more than removed by the analyzer (1.6 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.

Temperature control

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

The dry- and wet-bulb temperatures recorded for each charge are shown in Figure 7. The schedule provided by the mill is also shown. There was some difficulty in maintaining the wet-bulb temperature early in the schedule.

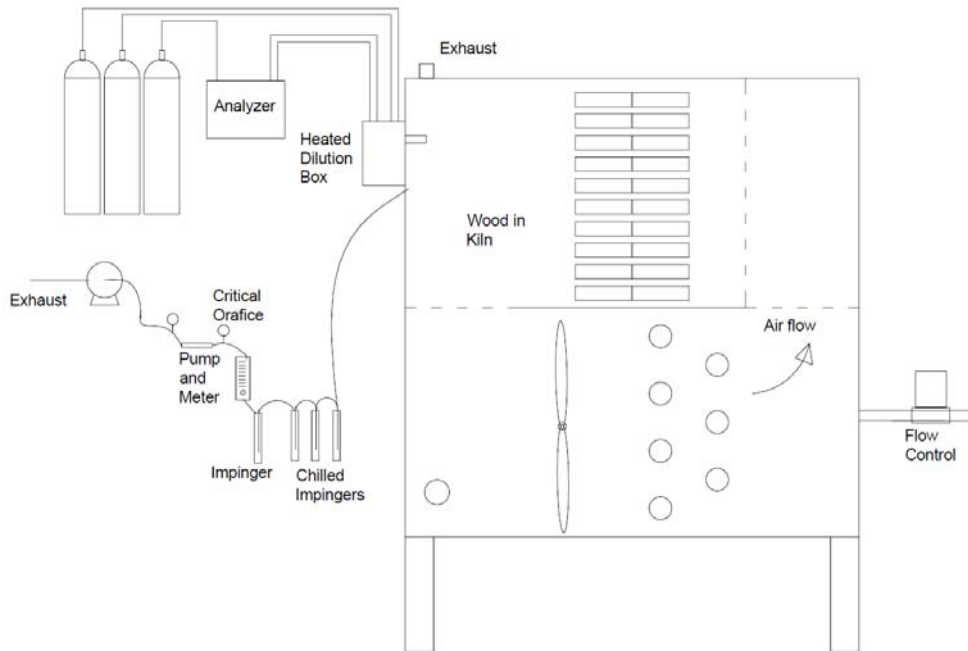


Figure 6. Schematic of kiln and sampling system (top) and photo of charge in kiln (bottom).

5. Production-related parameters

Wood quantity

The wood properties were determined using the nominal wood dimensions (5/4 in this case) which provides for 1.25 board feet per square foot of board face. There were 42 pieces in the kiln at 44" in length. The sum of the 42 board widths was 288 inches. The board footage was therefore 110 board feet. This quantity was used to express the emissions from the drying cycle on a production basis of lb/mbf (pounds per thousand board feet).

Wood properties

The wood property measurements are shown in Table 9. Individual measurements can be found in the Excel file "Weights, NWHW.XLS" in Appendix 2.

Occasional tension wood was noted, particularly in board #18. The amount seemed typical for red alder.

Heartwood percentage was not determined because it cannot be easily distinguished from sapwood in red alder.

The average ring count was determined by counting the rings over a 1" radial distance and averaging for all boards.

The number of knots were counted on the top face of each board and averaged. Knot diameter is an average of the knots present. The knots occupied approximately 0.8% of the boards' faces.

Table 9. Wood properties.

Charge	Knots		Heartwood	Ring count	Pith In
	Number	Size			
	#	In.			
Red alder	1.8	1.3	N/D	5.6	4 of 42

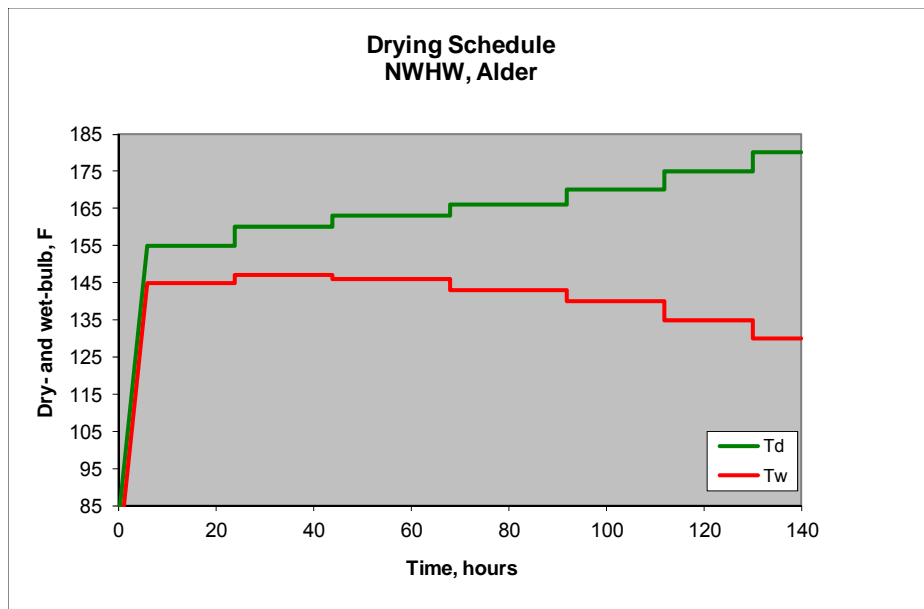
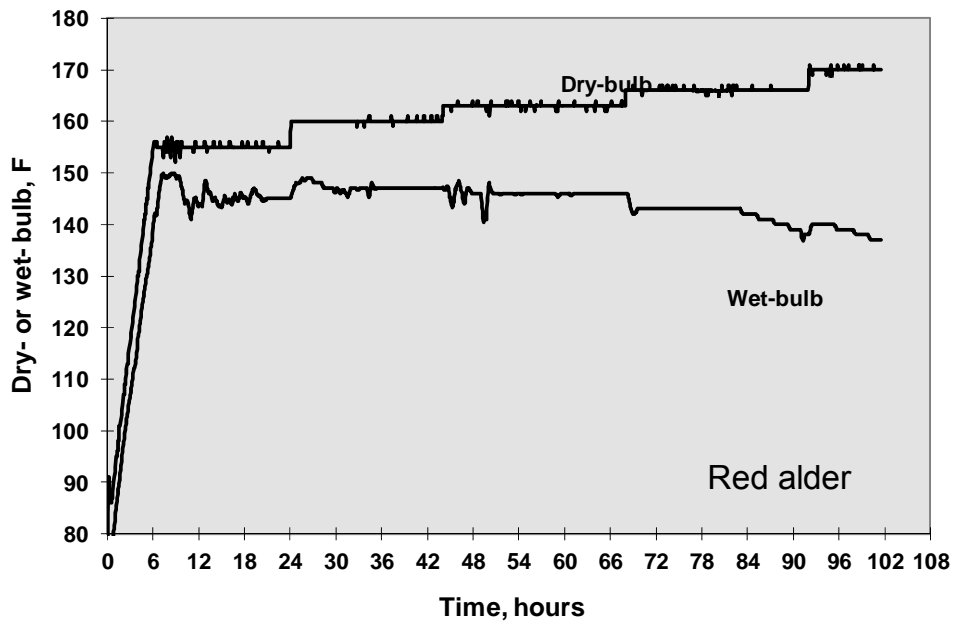


Figure 7. Schedules followed (top) and schedule provided by mill (bottom).

6. Test methods

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. 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).

Sampling Methodologies

Hydrocarbon

Sampling for total hydrocarbon is done directly from the kiln as shown in Figure 6 (top). The concentration obtained from the hydrocarbon analyzer and the amount of air entering the kiln allow the total hydrocarbon emissions to be calculated.

Figure 8 shows the hydrocarbon sampling system. Unlike stack testing, all necessary equipment is located in a lab 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 into a heated dilution/filter box. The box was heated to 235-245°F. Heated dilution gas was added to the hydrocarbon sample gas to lower the gas moisture content to the detector (except for run 1) 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 245°F. The 3-way valve at the back of the analyzer was heated to 250°F.

The fuel gas was hydrogen. The span gas was EPA Protocol 197 ppm propane in air, the mid-gas was EPA Protocol 50 ppm propane in air. The zero gas was <0.1 ppm air. Detailed sampling procedures are in Appendix 1.

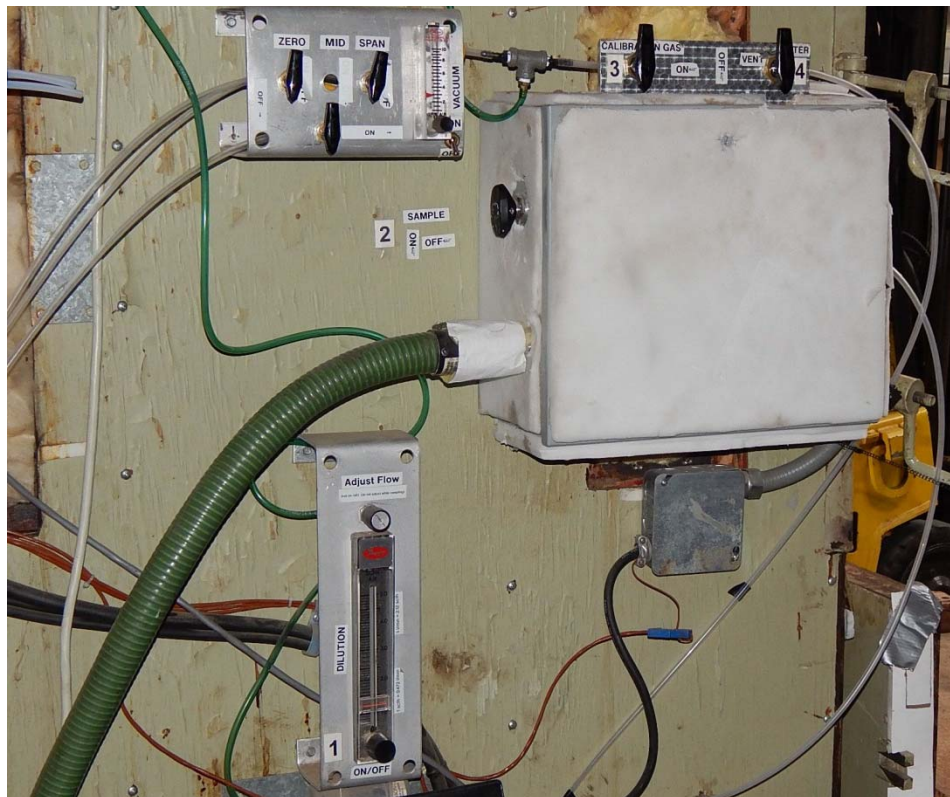
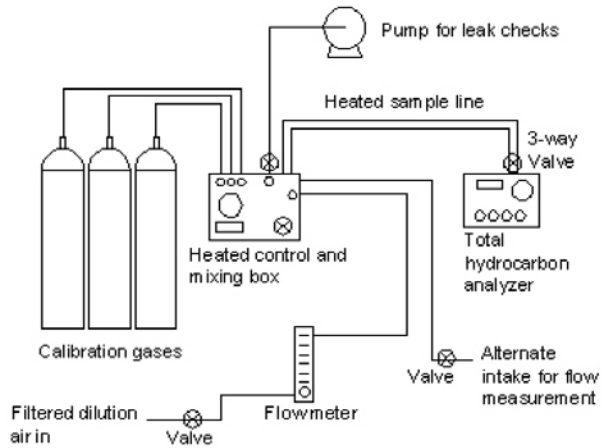


Figure 8. Schematic of heated filter box with air dilution system, heated sample line, and analyzer (top). Sample enters heated box from back of drawing through a heated sampling line. Calibration gas valves and dilution air valves are to left. Line to analyzer is the green line on the left in the left photo.

HAPs

The sampling train for NCASI Method 105 is shown in Figure 9. The impingers were in a glycol solution maintained at -1 C. Prior to each sampling interval, the impingers were laboratory-washed and 10 to 15 mL of BHA solution were added to the first and second impingers. The third impinger was left empty. The fourth impinger was present in the system to prevent any overflow from reaching the critical orifice. The system was then assembled and a vacuum check was performed with the valves at each end closed. Less than 1" Hg of pressure change over 2 minutes was acceptable. This was met for each interval. The flow rate through the system was then measured using a Gilibrator flow meter to take four flow readings at the probe tip. This was approximately 240-500 mL/min, depending on the sampling train. A valve at the probe tip was then turned to sample from the kiln and the sampling interval begun. The collection interval time was approximately 1:30 and an interval was started approximately every six hours.

The flow rate was measured after each sampling interval. The fluid in the three impingers was weighed and placed in a glass bottle. The impingers were then rinsed with 10 mL of water followed by 3 to 5 mL of hexane. The rinses were also placed in the bottle and it was sealed. Samples were kept refrigerated and in the dark until lab analysis was done. Lab analysis was done within one week of sample collection.

The local airport altimeter setting and the lab temperature were recorded at the beginning and end of each interval so the flow rates could be adjusted to standard conditions.

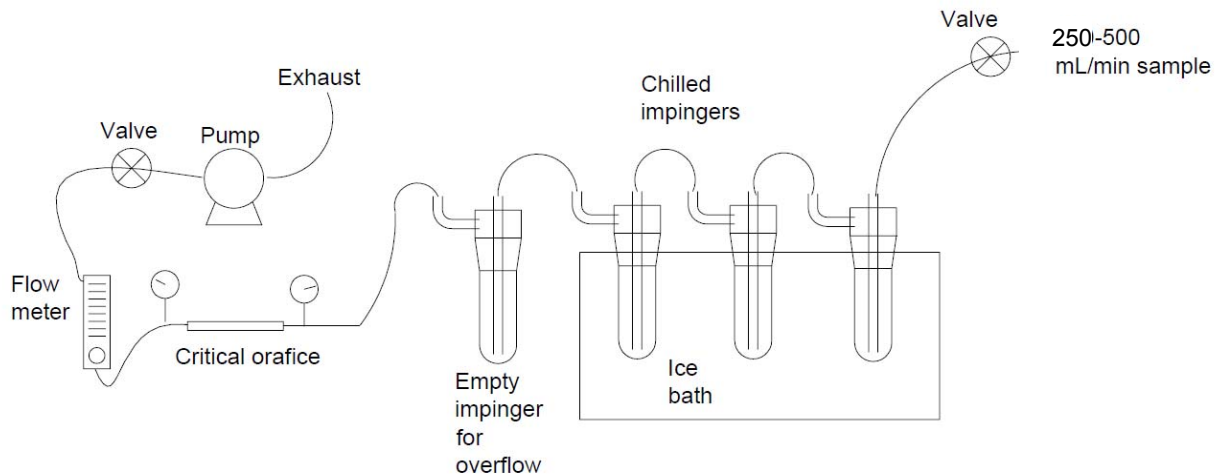


Figure 9. HAPs sampling train.

7. Analytical procedures

Hydrocarbon

Leak checks of the VOC sampling train were conducted before and after the charge was dried. A valve was closed at the probe tip and a 3-way valve was closed at the back of the analyzer. All components from just behind the probe tip to the valve at the back of the analyzer were placed under a 15-20 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 and is equal to both the sample flow from the kiln when the dilution is off and the total volume drawn by the analyzer. Sample flow is measured with dilution gas on (if used for that interval) and is the volume of gas sampled from the kiln when the dilution gas is 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 analyzer reading for span gas with the dilution gas off and on. The dilution ratio calculated based on the analyzer readings was always within 5% of that determined by the flow meter and almost always within 2%. Note that dilution was not actually used for run 1 because the kiln wet-bulb was low enough initially that the gas moisture content was less than 15% until the wet-bulb temperature was greater than 130-135°F.

Calibration of the zero and span of the detector was done at the beginning of each run (about every six hours). The calibration gas was introduced by setting the valves so the calibration gas entered the system in the white heated mixing box at ambient pressure. The calibration was checked at the end of each run with no adjustments made to the instrument's zero or span during the run. A span drift less than 10% of the span value was acceptable. A zero drift of less than 3% of the span value was acceptable. A total calibration drift less than 10% was acceptable for a sampling run. These criteria were met.

HAPs

Lab analysis for aldehydes

Aldehyde standards were prepared by the volumetric dilution of neat aldehydes in water (to 250 ppm for formaldehyde, propionaldehyde, acrolein and acetaldehyde). This stock solution was mixed a BHA solution [from ortho-benzylhydroxylamine hydrochloride (BHA) and deionized water (30g BHA per

liter of water)]. The stock solution-BHA mixture was vigorously agitated and allowed to sit for six hours to allow for derivatization of the aldehydes into aldoximes. The derivatized aldehyde solution was extracted with three aliquots of hexane to create a 400 ppm stock solution in hexane. This was volumetrically (but calculations based on mass) diluted to make standards down to 0.8 ppm. 1.8 mL aliquots were placed in GC autosampler vials with 10 μ L of 8800 ppm nitrobenzene added to each as an internal standard.

The samples (from the bottles collected in field) were prepared by performing three extractions in a separatory funnel. The first extraction was with the hexane added in the field. The second extraction was with a 7-mL aliquot of hexane after using it to rinse the sample bottle. The final extraction was done with 7 mL of clean hexane. The total hexane volume was approximately 18-20 mL. The volumes of the two phases were calculated from their weights. A 1.8 mL aliquot of the hexane fraction was transferred to an autosampler vial and spiked with internal standard.

The analytical instrument was a Shimadzu GC model 2010 with a flame thermionic detector (FTD), the Shimadzu equivalent of a nitrogen phosphorous detector (NPD). The column was a 105-meter Restek RTX-5 capillary with a 0.25 mm outside diameter and a stationary phase thickness of 0.25 μ m. The oven schedule was: 2 minutes at 120°C, 2°C/min ramp to 160°C, 40°C/min ramp to 220°C and 6.5 minutes at 220°C. The column flow was 25 cm/sec, with 3 mL/min septum purge, and a 1:10 split ratio with a glass wool packed split injection liner. The detector make up He was set to 20 mL/min and the H₂ was set to 3 mL/min. The air was set to 140 mL/min, and the source current was set to 2 pA. The He and H₂ gases were grade 5 and the air was grade 0.1. The injector temperature was 200°C and the detector temperature 280°C. An AOC-20i autosampler was used to perform 1 μ L injections using a 10 μ L syringe with a steel plunger.

Lab analysis for alcohols

Standards for methanol, phenol, ethanol, and acetic acid were prepared by the volumetric dilution of neat reagents in water. The mixed standard was prepared at a concentration of 900 milligrams per liter (mg/L). Additional standards were prepared by the volumetric dilution of the mixed standard at a range from 0.5 mg/L to 500 mg/L. Aliquots of these were placed into autosampler vials with 10 μ L of 20,000 ppm cyclohexanol internal standard.

Samples were prepared by transferring aliquots of the previously hexane-extracted aqueous fractions into autosampler vials and adding internal standard. The analytical instrument was a Shimadzu GC model 2010 with a FID detector. The column was a 60-meter Restek Stabilwax capillary with a 0.53 mm outside diameter and a stationary phase thickness of 1.5 μ m. The oven schedule was: 3 minutes at 60°C, 10°C/min ramp to 80°C, 3 minutes at 80°C, 10°C/min ramp to 230°C, and 10 minutes at 230°C. The column flow was 30 cm/sec, with 3 mL/min septum purge, and a 1:10 split ratio with a glass wool packed split injection liner.

The detector make up He was set to 25 mL/min and the H₂ was set to 50 mL/min. The air was set to 500 mL/min. The He and H₂ gases were grade 5 and the air was grade 0.1. The injector temperature was 175°C and the detector temperature 250°C. An AOC-20i autosampler was used to perform 1 µL injections using a 10 µL syringe with a PTFE plunger.

8. Field data sheets and sample calculations

Field data sheets

Samples of field data sheets are shown in Figures 10 to 13. All field data sheets are in Appendix 2 this report in electronic format (pdf).

FIELD DATA SHEET FOR TOTAL HYDROCARBON ANALYZER - BEFORE

BACKGROUND INFORMATION

Event (kiln charge): NWHW - 1 Dry-bulb temperature: 155
 Run: 2.5 Wet-bulb temperature: 145
 Operator: MRR Target Dilution Ratio (TDR): 0.2
 Date: 4-1-14 Laboratory temperature: 73 °F

ANALYZER CALIBRATION (change pots to calibrate) [R to L: 5=off 4=vent; 3=on; 2,1= off]

	Range	Analyzer, reading	Computer, ppm	Within range	Pot settings
zero	3	0.00 (0)	0.00 (0)		486
span	3	1.97 (1.97)	1.97 (196.6)		285
mid	3	0.50 (0.50)	0.50 (50.3)	45 to 55	
mid	2	5.00 (5.00)			

Reset range to 3. Range: 3 [tanks on]

SET DILUTION FLOW BEFORE RUN (do not change pots)

Total flow rate (TFR): 1501 mL/min [Valves 3 = off; 4=meter (5.2,1=off)]
 Target dilution flow rate (TDFR) _____ mL/min [TFR x (1 - DR)]
 Set and read dilution meter: 1.5 scfh [scfh = mL/min * 0.00212]
 Sample flow rate (SFR): 838.4 mL/min [1 and 5 = on]

CHECK DILUTION FLOW BEFORE RUN (do not change pots) [4=vent; 3=on (2=off, 1,5=on)]

	Analyzer	DR _{span} [Span _{total} /Span]	DR _{flow} [SFR / TFR]	Difference, % 100*(DR _{span} - DR _{flow})/DR _{flow}
Span _{total}	110	0.56	0.56	0

START TIME: 6:54 (clock) [L to R: 1, 2= on; 3, 4 = off; 5=on]

ANALYZER RANGE: 3 [0.6 < reading < 7.5; All valves vertical, tanks off]

ANALYZER RANGE ON COMPUTER (set to match analyzer): 3

FIELD DATA SHEET FOR TOTAL HYDROCARBON ANALYZER - AFTER

Operator: Jey Event (kiln charge): NWHW - 1
 Run (sample): 50 Laboratory temperature: 75 °F
 END TIME: 9:50
 Range setting on Analyzer: 3 on Computer: 3
 Reset range to 3. Range: 3 [tanks on]

CHECK DILUTION FLOW AFTER RUN (do not change pots) [4=vent; 3=on; 2=off; (1,5=on)]

	Analyzer reading	Computer, ppm
Span _{total}	1.11	1.10

Sample flow rate (SFR): 838.6 mL/min [3 = off, 4=meter (2=off 1,5=on)]
 Read dilution meter: 8.15 scfh
 Total flow rate (TFR): 1495 mL/min [1, 5 = off; 4=meter 2,3 = off]
 Dilution ratio (DR_{flow}): .56 [SFR / TFR]

CHECK OF ANALYZER CALIBRATION (do not change pots) [3=on, 4=vent (1,2,5=off)]

	Analyzer reading	Computer, ppm	Within range	Pot settings
span	1.97	1.97	187 to 206	285
mid	.50	.50	45 to 55	
zero	0	0	-5 to +5	285

Dilution ratio (DR_{span}): .56 [Span_{total} / Span]
 Dilution ratio difference: 0 % [100*(Abs(DR_{span} - DR_{flow}))/DR_{flow}]
 End time for check: 10:06
 Comments: _____

Figure 10. Sample of field data sheet for hydrocarbon analyzer.

FIELD DATA SHEET, 105 HAPS MEASUREMENT
TRAIN #1 - BEFORE SAMPLE

Operator: MRI Event (kiln charge): NWHW-1
Date: 4-2-14 Run (sample): 9-A

Altimeter setting: 30.01 inHg
Isopropanol rinse or lab wash: Y

IMPINGER WEIGHTS (add BHA to impingers)

	Dry Weight, g	Wet Weight, g	BHA added, g
Impinger #1A	41.54	<u>5743</u>	(-15 mL)
Impinger #1B	47.31	<u>6213</u>	(-15 mL)
Impinger #1C	42.33	-----	-----
Total BHA added: _____			

Optional Spike: _____ g Spike type: Alcohol Aldehyde

(take impingers to lab from scale)
Lab (ambient) temperature 73 °F

Leak check: Vacuum 16 inHg Vacuum check ok
Sample flow rate: 451.3 mL/min (Average of 4. Label printout)
Set probe valve to sample from kiln CLOCK TIME: 6:11A
ELAPSED TIME: 46:11

Is the probe valve set to sample?
Is gas flowing (look at flow meters)?

FLOW METER READINGS DURING TEST (every 20 minutes)

Clock time	6:14	6:31	7:39
Vacuum, inHg	<u>27</u>	<u>27</u>	<u>27</u>
Flow rate, mL/min	<u>425</u>	<u>425</u>	<u>425</u>

FIELD DATA SHEET, 105 HAPS MEASUREMENT
TRAIN #1 - AFTER SAMPLE

Operator: MRI Event (kiln charge): NWHW-1
Run (sample): 9-A

Altimeter setting: 30.04 inHg
Sample line rinse vial: 2046 g (with 5 mL DIW)
Lab (ambient) temperature: 73 °F
Change position of valve at the kiln Clock time: 7:42
Elapsed time: 47:42

(take sample line then measure flow rate)
Set probe valve to measure sample flow rate. Shut off other flows using lower valves.
Sample flow rate: 452.0 mL/min [Average of 4. Label printout]
(take impingers to scale from lab)
Sample line rinse vial: 13.65 g (empty)
Empty bottle weight: 132.34 g (with lid)

IMPINGER WEIGHTS (transfer sample to bottle)

	Wet Weight, g	Dry Weight, g	Water removed, g
Impinger #1A	<u>21.31</u>		
Impinger #1B	<u>63.18</u>		
Impinger #1C	<u>42.55</u>		

Bottle weight without impinger rinse: 172.80 g (with lid)
(take impingers with 10 mL DIW water)
Bottle weight with impinger rinse: 182.42 g (with lid)
(take impingers with 5 mL DIW water)
Filled bottle weight: 193.14 g (with lid)

Fluids lost during handling: _____ mL (estimate)
Comments: _____

Figure 11. Sample of field data sheet for HAPs collection.

Charge: NWHW-1 Date: _____ Time: _____ Page: 2

Clock time	Elapsed time	Run #	Temperatures					Flows					Vacuum					
			T dry °F	T wet °F	Valve °F	G. line °F	Box °F	Chiller °C	Flow 1 L/min	Flow 2 L/min	Flow 3 L/min	Dilution SCFM	Line 1 ml/min	Line 2 ml/min	Line 3 ml/min	Line 1 inHG	Line 2 inHG	Line 3 inHG
00:00	16:31	3	155	146	250	245	245	-1	92	-	-	1.5	-	425	-	-	28	-
00:56	16:56	3	155	144	250	245	244	-1	74	0	0	1.5	-	425	-	-	28	-
1:55	17:55	4	155	144	250	245	244	-1	83	0	0	1.5	-	-	-	-	-	-
5:15	21:16	4	155	145	250	245	235	-1	151	0	0	1.5	-	-	-	-	-	-
6:01	22:01	4	155	145	250	245	234	-1	160	0	0	1.5	425	450	-	27	27	-
7:51	23:51	5	155	145	250	245	247	-1	150	0	0	1.5	-	-	-	-	-	-
8:51	24:51	5	160	147	250	245	245	-1	160	0	0	1.5	-	-	-	-	-	-
10:03	26:03	5	160	149	250	245	244	-1	153	-	-	0	-	-	-	-	-	-
10:20	26:20	6	160	149	250	245	242	-1	153	0	0	1.5	-	-	-	-	-	-
11:39	27:39	6	160	148	250	245	245	-1	153	0	0	1.5	-	-	-	-	-	-
12:04	28:04	6	160	148	250	245	244	-1	163	-	-	1.5	400	425	280	27	27	29
12:49	28:49	6	160	147	250	245	242	-1	171	0	0	1.5	425	450	325	27	27	29
14:45	30:45	6	160	146	250	245	242	-1	176	0	0	1.5	-	-	-	-	-	-
16:30	32:30	7	160	147	250	245	244	-1	151	0	0	1.5	-	-	-	-	-	-
18:51	33:51	7	160	147	250	245	243	-1	141	0	0	1.5	-	-	-	-	-	-
19:55	35:55	8	160	147	250	245	254	-1	175	0	0	1.5	-	-	-	-	-	-
20:59	36:59	8	160	147	250	245	244	-1	119	0	0	1.5	-	-	-	-	-	-

Figure 12. Sample of kiln log data sheet.

PUMP S/N	ID	FLOW	AVERAGE	# SAMPLES
1495	01	834.4	451.0	01
1496	02	837.2	452.0	02
1497	03	838.9	453.6	03
1498	04	842.9	454.3	04

Figure 13. Sample of flow measurement record.

Calculations

The “FlowCalc” worksheet in the Excel files “Kiln, NHHW.XLS” 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/E and F/G are the average dry- and wet-bulb temperatures.

Humidity

Column H is the vapor pressure (P_{vp} , Pa) of water at the wet-bulb temperature. The absolute humidity ($AbHum$, $kg_{water} \cdot kg_{air}^{-1}$) is shown in column I and the molal humidity ($MolHum$, $mol_{water} \cdot mol_{air}^{-1}$) in column J. These are calculated based on the dry-bulb temperature (T_d , °C) and wet-bulb temperature (T_w , °C),

$$P_{vp} = P_{ambient} * 10^{(16.373 - 2818.6/(T_d+273.16) - 1.6908 * \text{LOG}_{10}(T_d + 273.16) - 0.0057546 * (T_d + 273.16) + 0.0000040073 * (T_d + 273.16)**2)}$$

$$AbHum = (MW_{water} / MW_{air}) * (1 / (P_{kiln}/P_{vp}-1)) - ((T_d-T_w) * R_{psy}) / \lambda$$

$$MolHum = AbHum * MW_{air} / MW_{water}$$

where MW are molecular weights ($kg \cdot kmol^{-1}$), R_{psy} is the psychrometric ratio ($0.95 \text{ kJ} \cdot \text{kg}^{-1} \cdot \text{K}^{-1}$), and λ is the latent heat ($2419 \text{ kJ} \cdot \text{kg}^{-1}$).

Flows

The volumetric dry gas flow rate (DryGasV, L•min⁻¹) in column K 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 L this has been converted to a mass flow rate (DryGasM, kg•min⁻¹) and in column M is the same information is expressed as a molal flow rate (DryGas, kgmol•min⁻¹). These values are for the dry gas vented from the kiln.

$$\text{DryGasV} = (\text{FlowMeter1} + \text{FlowMeter2} + \text{FlowMeter3}) * (1/(1+\text{MolHum}_{\text{In}}))$$

$$\text{DryGasM} = (\text{DryGasV L}\cdot\text{min}^{-1}) * 1/(22.4 \text{ m}^3\cdot\text{kgmol}^{-1}) * \text{MW}_{\text{air}} / (1000 \text{ L}\cdot\text{m}^{-3})$$

$$\text{DryGas (kgmol/min)} = \text{DryGasM} / \text{MW}_{\text{air}}$$

The water removal rate (WaterVented, g•min⁻¹) (column N) is calculated from the humidity (column I) and the gas flow (column L). The total water (column O) is an integration of column N over time.

$$\text{WaterVented} = (\text{AbHum} - \text{AbHum}_{\text{In}}) * (\text{DryGasM} * 1000 \text{ g}\cdot\text{kg}^{-1})$$

Moisture content

The moisture content of the wood at each three-minute interval (column P) was determined by reducing the moisture content of the wood from the previous value by accounting for the amount of water leaving the kiln during the interval.

$$\text{MC} = \text{MC}_{\text{Previous}} - 100 * (\text{WaterVented} / (1000 \text{ g}\cdot\text{kg}^{-1}) / \text{ODWoodWt})$$

This amount is then adjusted by adjusting the wet-bulb temperature to make the ending moisture content match that measured by ASTM D4222.

Hydrocarbon

The original total hydrocarbon analyzer reading is shown in column Q. In column R this has been corrected to compensate for the range setting switch on the analyzer. Also in column R, the THA data between sampling runs (rows labeled “test” in column AA) has been adjusted to the average of the data during the 9-minute period before and the 9-minute period after the analyzer testing and calibration time.

The dilution THA (column S) is the corrected THA reading divided by the dilution ratio (from column AA). In column T we have the opportunity to compensate for the effect of moisture on the JUM detector. Column T equals column S because dilution was used and no compensation was made. Finally in column U, the hydrocarbon concentration is converted to a dry gas basis concentration using the molar humidity (column J).

$$\text{THC}_{\text{Dry, ppm}} = \text{THC} * (1 + \text{MolHum})$$

In column V, the hydrocarbon flow rate ($\text{THC}_{\text{Vented}}$, $\text{g}_{\text{Carbon}} \cdot \text{min}^{-1}$) is calculated in a manner analogous to the water flow rate using the dry gas flow rate and the hydrocarbon concentration.

$$\text{THC}_{\text{Vented}} = \text{DryGas} * (\text{THC}_{\text{Dry}} / 10^6) * \text{MW}_{\text{Propane}} * (1000 \text{ g} \cdot \text{kg}^{-1}) * (0.81818 \text{ g}_{\text{Carbon}} \cdot \text{g}_{\text{Propane}}^{-1})$$

Column W is the integral of column V over time, the cumulative hydrocarbon released up to that point in the schedule (in grams). Column X is the cumulative unit emissions, that is, column W divided by the oven-dry weight of the wood in the kiln. Column AI is the cumulative emissions in pounds per thousand board feet and column AH is the rate of emissions release ($\text{lb} \cdot \text{mbf}^{-1} \cdot \text{hr}^{-1}$)

Column Z indicates the hydrocarbon sampling run and column AA is the dilution ratio during that run.

The remaining columns are used not used in the hydrocarbon calculations. They are for graphing shown on other worksheets in the workbook.

At the end of the FlowCalc spreadsheet (at the bottom) are summaries by run of the flow data for the total hydrocarbon run intervals (interval summary button will reposition spreadsheet).

Moisture content and board weight data are on the “Define” worksheet and the original data are in the files named “Weights, NWHW.XLS”.

HAPs

Within the file “HAPs, NWHW.xls”, the summary page presents the data by run interval. The data is copied from the other pages to provide a concise summary.

The “Field Data” page is data transcribed from the field data sheets (copies of the sheets are included in Appendix 2 in PDF format) and includes the ambient pressure, lab temperature, flow rate through the impingers, and run start and stop times.

The “Laboratory Data” page contains results from the lab analysis for HAPs. These values come from the files “AQU, GC Sheet, NWHW.xls” and “ALD, GC Sheet, NWHW.xls” in the “Lab Data” directory. The GC retention times and peak areas and the GC calibrations are in these files.

On the “Impinger Calculations” page, the field data and laboratory data are used to give a dry gas flow rate through the impingers (columns J and K) and the mass of target compounds in the impingers (columns L to Q). Flow rates were adjusted to standard conditions in columns F and G.

$$\text{ImpgrFlow}_{\text{Std}_m\text{L}} = \text{ImpgrFlow} * (273.16\text{K} / T_{\text{meter}}) / (P_{\text{meter}} / 101.33 \text{ kPa})$$

A dry gas flow rate is calculated in columns H and I

$$\text{ImpgrFlow}_{\text{Dry}_m\text{L}} = \text{ImpgrFlow}_{\text{Std}_m\text{L}} / (1 + \text{MolHum})$$

The average of the before and after gas flow measurements through the impingers (column J) is then converted to a mass basis in column K.

$$\text{ImpgrFlow}_{\text{Dry}_g} = \text{MWair} * \text{ImpgrFlw}_{\text{Dry}_mL} * P / (T * R)$$

Finally, the mass of each compound recovered from the impinger is calculated in columns L to S.

$$\text{Mass}_i = (\text{Concentration}_i) / (\text{DenSolvent}) * (\text{Mass solvent})$$

The “Kiln Calculations” page uses a ratio of the dry gas flow through the kiln (calculated in the spreadsheets named “Kiln, NWHW.xls” and copied to column D) to the dry gas flow rate through the impinger to scale up the quantities and obtain the mass of each compound leaving the kiln (columns I to P).

On the “Emission” page, the amount of a HAP leaving the kiln is divided by the mass (in kg) or volume of wood (in mbf) to express the emissions on a per kg of wood (columns B-I) or per mbf basis (columns J-Q). Concentrations leaving the kiln are given in columns R to AG.

The “Quality Assurance” page presents information on the spikes, duplicates and blanks. For each spike a % recovery is calculated based on the mass of a HAP recovered divided by the amount added. The difference for each duplicate is calculated as a percentage from the difference between the impingers divided by the average mass collected after adjusting for impinger flow.

The remaining pages in “HAPs, NWHW.xls” are for graphing purposes.

9. Chain of custody information

Wood was collected by mill personnel and delivered to Oregon State by Northwest Hardwoods. The wood was retained by Oregon State after delivery as documented in section 1. Field samples remained at Oregon State University.

10. Calibration documentation

Sensidyne, LP
CALIBRATION CERTIFICATE

Cell S/N: 1302015-S Date: February 07, 2013

This is to certify that the above referenced Gilibrator Flow Cell was calibrated using film flowmeter MCS-102, which has been calibrated by instruments directly traceable to the National Institute of Standards and Technology, NIST Report 8361604.

Results:

REFERENCE MCS-102 cc/min	S/N 1302015-S cc/min	RELATIVE DIFF. cc/min	PERCENT DIFF.
1998	2001	3	0.15
2002	2001	-1	-0.05
1996	2004	8	0.40
2004	2005	1	0.05
1996	2004	8	0.40
2001	2002	1	0.05
2000	2004	4	0.20
2001	2002	1	0.05
1994	2004	10	0.50
2001	2004	3	0.15

MAX 10.0 0.5

MEAN 1999.3 2003.1

Calibrated by Eric N. Pez Date: February 07, 2013
CODE 100

Figure 14. Flow meter calibration.

CERTIFICATE OF ANALYSIS Grade of Product: EPA Protocol

Part Number: E02AI99E15A0456 Reference Number: 48-124285462-2
 Cylinder Number: CC172274 Cylinder Volume: 146 Cu.Ft.
 Laboratory: ASG - Los Angeles - CA Cylinder Pressure: 2015 PSIG
 PGVP Number: B32011 Valve Outlet: 590
 Gas Code: APPVD Analysis Date: Oct 13, 2011

Expiration Date: Oct 13, 2014

Certification performed in accordance with "EPA Traceability Protocol (Sept. 1997)" using the assay procedures listed. Analytical Methodology does not require correction for analytical interferences. This cylinder has a total analytical uncertainty as stated below with a confidence level of 95%. There are no significant impurities which affect the use of this calibration mixture. All concentrations are on a volume/volume basis unless otherwise noted.
 Do Not Use This Cylinder below 150 psig i.e. 1 Mega Pascal

ANALYTICAL RESULTS				
Component	Requested Concentration	Actual Concentration	Protocol Method	Total Relative Uncertainty
PROPANE	50.00 PPM	50.33 PPM	G1	+/- 1% NIST Traceable
Air	Balance			

CALIBRATION STANDARDS				
Type	Lot ID	Cylinder No	Concentration	Expiration Date
NTRM	080610	CC263076	49.62PPM PROPANE/AIR	Jul 15, 2012

ANALYTICAL EQUIPMENT		
Instrument/Make/Model	Analytical Principle	Last Multipoint Calibration
Nicolet 6700 AHR0801551 C3H8	FTIR	Sep 21, 2011

Triad Data Available Upon Request

Notes:

Signature on file

Approved for Release

Airgas Specialty Gases
 11711 South Alameda Street
 Los Angeles, CA 90059
 (323) 568-2293 Fax: (323) 567-3686
 www.airgas.com

CERTIFICATE OF ANALYSIS Grade of Product: EPA Protocol

Part Number: E02AI99E15A1511 Reference Number: 48-124370716-1
 Cylinder Number: SG9115185BAL Cylinder Volume: 146.2 CF
 Laboratory: ASG - Los Angeles - CA Cylinder Pressure: 2015 PSIG
 PGVP Number: B32013 Valve Outlet: 590
 Gas Code: PPN,BALA Certification Date: Apr 23, 2013

Expiration Date: Apr 23, 2021

Certification performed in accordance with "EPA Traceability Protocol for Assay and Certification of Gaseous Calibration Standards (May 2012)" document: EPA 600/R-12/531, using the assay procedures listed. Analytical Methodology does not require correction for analytical interference. This cylinder has a total analytical uncertainty as stated below with a confidence level of 95%. There are no significant impurities which affect the use of this calibration mixture. All concentrations are on a volume/volume basis unless otherwise noted.
 Do Not Use This Cylinder below 100 psig i.e. 0.7 megapascals.

ANALYTICAL RESULTS					
Component	Requested Concentration	Actual Concentration	Protocol Method	Total Relative Uncertainty	Assay Dates
PROPANE	200.0 PPM	199.3 PPM	G1	+/- 0.3% NIST Traceable	04/23/2013
AIR	Balance				

CALIBRATION STANDARDS					
Type	Lot ID	Cylinder No	Concentration	Uncertainty	Expiration Date
NTRM	08061123	CC263016	249.1 PPM PROPANE NITROGEN	+/- 0.6%	Jun 22, 2018

ANALYTICAL EQUIPMENT		
Instrument/Make/Model	Analytical Principle	Last Multipoint Calibration
Nicolet 6700 AHR0801551 C3H8	FTIR	Apr 11, 2013

Triad Data Available Upon Request

Notes:

Approved for Release

Figure 15. Certificates for calibration gases.

11. Anomalies

The wet bulb was

We had no acrolein for spikes until April 3, despite having ordered it in January. Thus the spikes were done toward the end of the run

There was a 2 g (out of 57 g) difference between the water measured in the impingers and what was measured in the sample bottle.

12. Statement of validity

The statements in this report accurately represent the testing that occurred.



Michael R. Milota

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Appendix 1. Detailed sampling procedures

Checks of kiln to record on log

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 plastic electrical enclosure on wall or on computer screen. The top and bottom numbers on controller should be similar and greater than the kiln temperature, 240°F.

Line temperature: Read from plastic electrical enclosure on wall or on computer screen. The top and bottom numbers on controller should be similar and greater than the box temperature, 245°F.

Valve temperature: Read from plastic electrical enclosure on wall or on computer screen. The top and bottom numbers on controller should be similar and greater than the line temperature, 250°F.

Dry-bulb temperature: Read from computer screen. Compare to paper 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.

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

If the wet-bulb is too low, it means that the kiln atmosphere is too dry. Check the flow meters. If Flow1 is about 6 L/min (its lower limit), make sure that Flow2 and Flow3 are turned off. Flow2 records automatically. Enter any Flow3 change into the computer. Otherwise, call Mike.

If 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. Enter any Flow3 change into the computer. 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°F, call Mike

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.

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 6 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. Change it on the computer screen (click on it and type the new value).

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

Impinger flows: Read from rotometers. This should be about 250 to 500 cc/min.

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

Total hydrocarbon analyzer

BACKGROUND INFORMATION

Get the dry- and wet-bulb temperatures from the kiln schedule or off the computer. Use the highest expected values for the next three to six hours.

Read absolute humidity off the psychrometric chart or table.
Calculate or read from tables -

$$\text{Percent moisture} = 100 / [1 + 1 / 1.61 \cdot \text{AbHum}]$$

$$\text{Target Dilution Ratio (TDR)} = 15 / \text{Percent Moisture}$$

Event = the name of the drying cycle.

Run = the number of the 3-hour interval.

Operator, that's you.

Date – use date VOC run will start if close to midnight

AMBIENT DATA

Read the laboratory temperature from the computer or thermometer.

ANALYZER CALIBRATION (BEFORE SIDE OF SHEET)

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

set analyzer to range 3

zero valve on, others off

set flow to 3 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 (may be 197 or 794 ppm gas)

span valve on, others off

set flow to 3 L/min using regulator on tank

wait for a stable reading (about 30 to 60 seconds)

use the span dial (pot) on THA to get a reading of 610ppm

read the analyzer and record, eg, record 7.96

read computer (should read about 794)

record pot setting
Leave span tank valve open

Open mid gas tank valve (197 or 50 ppm gas)
mid valve right on, others off
set flow to 3 L/min using regulator on tank
wait for a stable reading (about 30 to 60 seconds)
read and record analyzer and computer (do not adjust pot settings)
check for within tolerance
switch analyzer to range 2
read analyzer and computer
check for within tolerance
switch analyzer back to range 3
Turn off mid gas tank valve

SET DILUTION FLOW BEFORE RUN (BEFORE SIDE OF SHEET)

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 1.6 L/min
Make sure the average does not include any "bad" readings
Record the average in mL/min; It should be 1500-1600 mL/min
Write the Run # and "Pre-TFR" on the Gilibrator printout.

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

Set dilution flow
Set red pointer to desired dilution flow
Slowly open lower valve on dilution flow meter (1=ON)
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 in SCFH
Calculate and record L/min

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 in mL/min
Write "Pre-SFR" on the Gilibrator printout.

CHECK DILUTION FLOW BEFORE RUN (BEFORE SIDE OF SHEET)

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 (should already be open)
span panel valve right (on), others down (off)
set flow to 3 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 calibration gas panel valves off
All tank valves off

Calculate the dilution ratio based on gas flow by dividing the Sample Flow Rate by the Total Flow Rate. $DR = \text{Absolute value of } [100 * (DR \text{ Span} - DR \text{ Flow}) / DR \text{ Flow}]$

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

If the dilution ratio calculated from the span gas and the dilution ratio calculated from the flow do not agree within 5% - DO NOT PROCEED****. Check the calculations, then redo the measurements.

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

START RUN (BOTTOM OF BEFORE SIDE OF SHEET)

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

Record the start time. Use the computer clock or stopwatch time.

Make sure analyzer is on appropriate range, usually range 3, to keep THC reading on computer between 60 and 600.

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

End time should be no more than 3-6 hours from start time.

POST-SAMPLE PROCEDURE - AT END OF RUN (AFTER SIDE OF SHEET)

Record your name as the operator.

Event = the drying cycle.
Run = number of the 3-hour interval.
Operator, that's you.

AMBIENT DATA

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 or analyzer pots until the instructions tell you to.

CHECK DILUTION FLOW AFTER RUN (AFTER SIDE OF SHEET)

Measure diluted span gas: 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 panel valve ON, others OFF
set flow to 3 L/min using regulator on tank
set analyzer to range 3
wait for a stable reading (about 30 -60 seconds)
record

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 4 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 in L/min

Write Run # and "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 (lower dilution valve)

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 4 readings of the total flow rate (TFR). This is the total flow drawn by the analyzer and should be about 1.6 L/min
Make sure the average does not include any "bad" readings
Record the average
Write Run # and "Post-TFR" on the Gilibrator printout.

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

CHECK CALIBRATION OF ANALYZER (AFTER SIDE OF SHEET)

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 panel valve ON, others down OFF
set flow to 3 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, 7.94 as 794
read computer (should read about the same)
note pot setting
check for within tolerance

Open mid gas tank valve
mid panel valve = ON, others OFF
set flow to 3 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, 1.97 as 197
read computer (should read same as analyzer)
check for within tolerance

Open the zero gas tank valve
zero panel valve = ON, others OFF
set flow to 3 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

Close all tank valves if charge is ending

Calculate the dilution ratio based on gas concentration by dividing the Diluted span by the Span

Calculate % difference in the two dilution ratios as $100 * \frac{\text{Absolute Value (DRSpan-DRFlow)}}{\text{DRFlow}}$

Record the time now as the end time for check.

Start Pre-Sample procedure for next run.

HAP 105 Collection

BACKGROUND DATA

Begin about 15 minutes before run should start
Operator, that's you.
Date, today or tomorrow if sample will start after midnight
Event = Kiln Charge
Run = sequence of M/F measurement (1-A, or 5-C, etc)

PRE RUN DATA

Call 9-541-754-0081 and get altimeter setting.

IMPINGER WEIGHTS

Verify that the impinger weights match the prerecorded weights on the data sheet.

Put 15 mL of BHA solution in impinger #1.
Put 10 mL of BHA solution in impinger #2.
Impinger #3 is not filled. It is for overflow.

Reweigh the impingers with the BHA solution.
Place BHA stock back into cooler
Install impingers and lower into chiller

LEAK CHECK

Read the laboratory temperature.
Close valve to sample probe.
Turn on pump (it may already be on)
Evacuate to 15 to 18 " Hg, record
Close valve that is near pump
Note pressure and start timer
Allowable pressure change is 1" Hg in 2 minutes, if it is more than this, find the source of the leak. Record change.
Slowly open valve near probe tip so that pressure is slowly relieved.
Completely open valve near probe tip
Open valve near pump

SAMPLE FLOW RATE

Attach probe tip to Gilibrator
Take 4 readings
Make sure all readings in average are "good" readings

Record the average

START TIME

Put probe into kiln (or turn valve to sample kiln) and record time.
Check meters to make sure gas is flowing

FLOW READINGS DURING TEST

Note flow meter reading at intervals of at least 20-30 minutes
Run test for 1:30 or less if impingers fill

POST RUN DATA

Begin about 10 minutes before run should end
Label a sample bottle with the Event and Run numbers and record the weight.
Call 9-541-754-0081 and get altimeter setting.

END TIME

Remove probe (or turn valve to meter setting) from kiln
Record time

SAMPLE FLOW RATE

Rinse probe with 5 mL of DI water
Read the laboratory.
Attach probe tip to Gilibrator
Take 5 readings
Make sure all readings in average are "good" readings
Record the average

IMPINGER WEIGHTS

Lift impingers from chiller, take to scale, and place onto rack
Dry the outside of the impingers
Remove U tubes connecting the impingers together
Weigh sample bottle with lid
Weigh the impingers (without stoppers) with the catch and record
Transfer the impinger contents to the sample bottle
Weigh the sample bottle with lid and record
Rinse impingers (last to first) with 10 mL DIW (save in the sample bottle)
Weigh the sample bottle with lid and record
Rinse impingers (last to first) with 5 mL hexane (save in the sample bottle)
Weigh the sample bottle with lid and record
Place the sample bottle into cold storage
Record the volume of any liquids lost during this procedure.
Wash glassware with phosphate-free detergent and set out to dry.

Appendix 2. Electronic copy of data and calculations