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Low VOC Drying of Lumber and Wood Panel Products

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Accomplishments

- Over 50% VOC is removed when OSB or particle is steamed at 170°C for 30 minutes. Much lower removal occurs at temperatures approximating 120°C.
- RF treatment of (2 in. x 4 in. x 48 in.) softwood lumber for 20 minutes results in a maximum of 68% VOC removal. The process has commercial potential.
- Transport of moisture in wood is greatest in the transverse surface, followed by the tangential and radial faces.
- Work on the seasonal influence of VOC components in wood has been initiated.

Apparatus for VOC extraction in a low head space environment

VOC extraction from particle and OSB with steam was conducted with the apparatus illustrated in Figure 1, constructed especially for this application. The unit is a 60 cm long by 10 cm diameter stainless steel pressure vessel. Different steam temperatures and treatment times were tested for both OSB and particle. Each experiment was conducted by loading 200 g. of flakes or 400 g. of particle into the vessel, which was then sealed. Thermocouples were positioned, and heating tapes activated in order to heat the exterior of the vessel to minimize steam condensation. Ambient pressure steam was injected into the vessel for 3 minutes, and the vessel was sealed by closing the needle valve. The temperature was brought up to the desired set point which was controlled by adjusting the current to the heating tapes. After steam treatment, the vapor inside the vessel was released into 100 mL of methanol for VOC analysis by gc, and the vessel flushed with fresh steam for 30 seconds.

Steam-induced extraction of VOC from OSB

The OSB steamed in the Figure 1 apparatus was heated in the tube furnace at 130°C and the VOCs measured. Two to four runs were made from each batch of steamed flakes. Results from flakes steamed at high temperature (>170°C) are presented in Table 1. The difference between the control (no steam) and sample runs reflects the VOC removed by steam. Over 50% VOC was removed after 30 minutes of steaming. Data are presented for both 30 and 60 minute treatments. The wood is dry at 30 minutes or less, and the 60-minute reflects an over-dried situation. The last column is the pinene recovered in the

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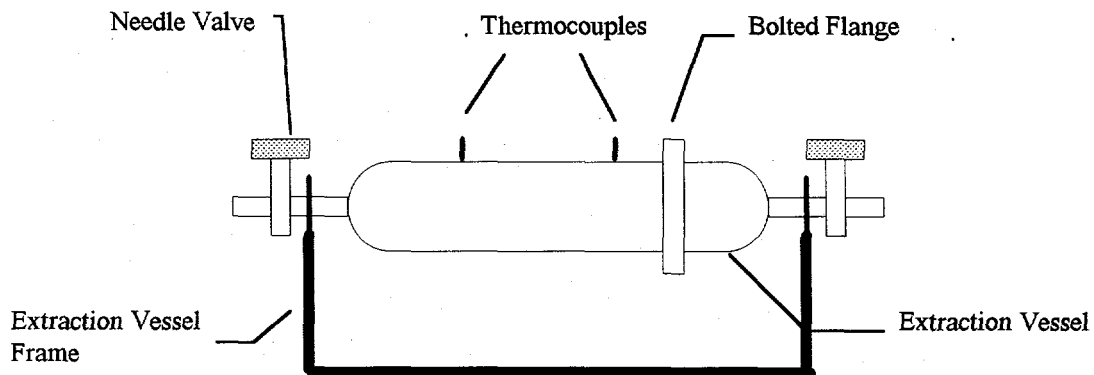


Figure 1: Schematic of a VOC extraction unit.

methanol trap (as measured by gc) as a percentage of total VOC (pinene and other components) lost from the wood. Despite the high variability, it is clear that a substantial fraction of the VOCs released can be recovered. One anomaly was noted: no VOC was lost from samples 151-5 through 151-8 in Table 1, and we are unable to explain this outcome. About 10-25% by weight of moisture was gained by the wood, but this is probably an artifact in that the moisture was deposited on the wood surface, as opposed to being absorbed by the furnish. The pressure within the cylinder was determined from steam tables using the temperature measured within the cylinder. Steaming at low temperature (116°C) removes much less VOC, if any, as shown in Table 2. Clearly, the steam must be at high temperature in order to effect VOC removal. We are presently working on a simple VOC collection system, after which we will explore commercial feasibility.

VOC profiles from steamed and control furnishes are compared in Figures 2 and 3. Signal intensities are much weaker for the latter, since VOC was removed during steaming. The delay in the second signal could well be an artifact, since the furnish picked up water during steaming, and the delay may reflect evaporation of this material.

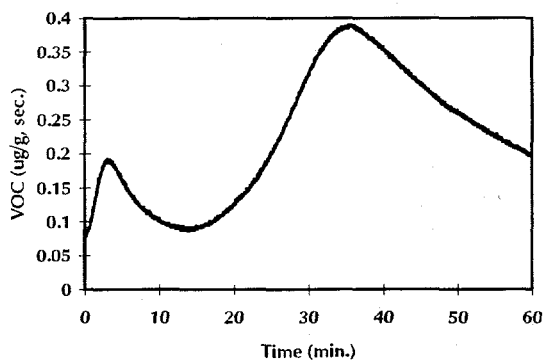


Figure 2: VOCs from run 140-1 (control)

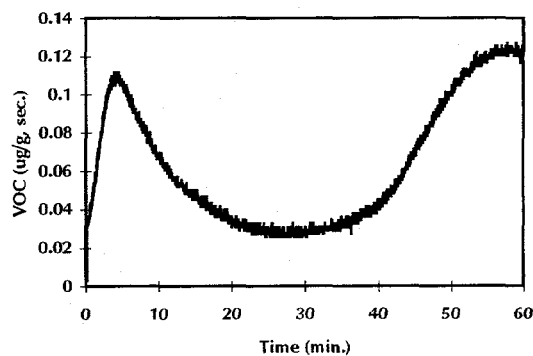


Figure 3: VOCs from run 140-3 (steamed at 171°C)

Table 1: VOC emissions from OSB after high temperature steaming

run	steam time (min)	steam temp (°C)	pressure (psi)	VOC (µg/g, dry basis), 60 min	VOC (µg/g, dry basis), 30 min	VOC re-covered (%)
OSB from G-P Grenada (11.13.96)						
140-1	control			805	267	
140-2	control			788	265	
140-3	30	171	118	227	95	
140-4	30		118	437	149	
OSB from G-P Grenada (11.21.96)						
150-1	control	NA		909	307	
150-2	control	NA		681	290	
150-3	control	NA		788	291	
150-4	control	NA		732	205	
avg.				778	273	
150-6	30	184	161	367	133	151
150-7	30	184		386	135	
150-8	30	184		436	143	
150-9	30	184		336	129	
avg.				381	135	
OSB from G-P Dudley (2.3.97)						
151-1	control	NA		418	245	
151-2	control	NA		375	175	
151-3	control	NA		490	263	
151-4	control	NA		667	349	
avg.				488	258	
151-5	30	181	151	556	338	123
151-6	30	181		340	216	
151-7	30	181		534	291	
151-8	30	181		467	244	
avg.				474	272	
152-1	30	172	121	315	161	47
152-2	30	172		191	116	
152-3	30	172		241	121	
152-4	30	172		144	87	
avg.				223	121	

Table 2: VOC emissions from OSB¹ at 130°C after low temperature steaming					
run	steam time (min)	steam temp (°C)	pressure (psi)	VOC (µg/g, dry basis), 60 min	VOC (µg/g, dry basis), 30 min
OSB from G-P Dudley (1.14.97)					
142-1	0 (control)			1078	490
142-2	0 (control)			1046	444
142-3	0 (control)			744	272
142-4	0 (control)			731	275
142-5	0 (control)			875	303
142-6	0 (control)			881	288
avg.				893	345
143-1	30	116	25	701	341
143-2	30			606	261
143-3	30			639	328
143-4	30			597	285
143-5	30			780	273
avg.				665	298
OSB from G-P Grenada (8.5.96)					
149-1	control	NA		1033	251
149-2	control	NA		1010	124
149-3	control	NA		263	45
149-4	control	NA		511	116
avg.				704	134
149-5	30	116	25	740	414
149-6	30	116		674	151
149-7	30	116		867	172
149-8	30	116		590	215
avg.				718	238

Steam-induced extraction of VOC from particle

Particle was first steamed, and then dried in the tube furnace at 130°C for 60 minutes, as above. Over 50% of the VOC was removed during steaming at high temperature as shown in Table 3. Decreasing steam treatment from 30 to 15 minutes decreased VOC removal by about 10%. On the other hand, increasing steaming time from 30 to 60 minutes did not increase the VOCs extracted to any substantial extent, but the furnish turned noticeably darker. As with OSB, much less VOC was lost during steaming at lower temperature as shown in Table 4. Typical VOC profiles are illustrated in Figures 4-6. Note that the intensity of the signals drops with increasing steaming temperature.

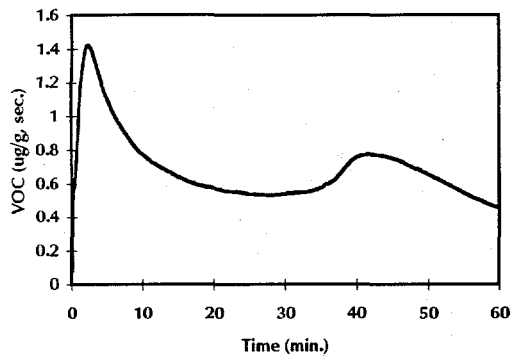


Figure 4: VOCs from run 153-3(control)

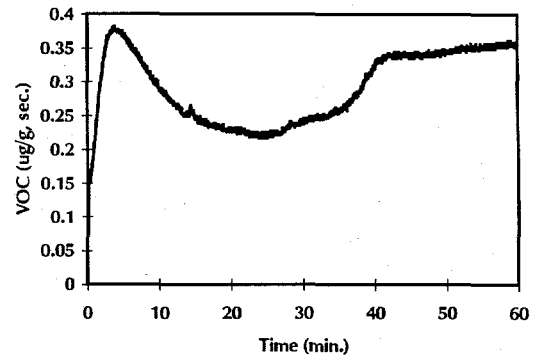


Figure 5: VOCs from run 153-5 (steamed at 179°C)

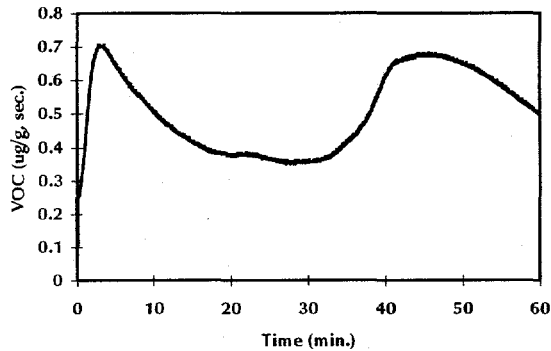


Figure 6: VOCs from run 160-3 (steamed at 119°C)

The effect of re-steaming once-steamed wood was determined by first steaming at 179°C for 30 minutes, allowing the sample to cool, and then steaming it again for another 30 minutes at 173°C. This wood was now dried in the tube furnace, and the VOCs measured are listed in Table 5. Although considerable additional VOC was lost, the wood particles darkened after the second steam treatment.

Table 3: VOC emissions from particle at 130°C after high temperature steaming

run	steam time (min)	steam temp (°C)	pressure (psi)	VOC (µg/g, dry basis), 60 min	VOC (µg/g, dry basis), 30 min	VOC recovered (%)
<i>particle from Weyerhaeuser, Adel (11.18.96)</i>						
153-1	control	NA		2351	1297	
153-2	control	NA		2463	1348	
153-3	control	NA		2462	1332	
153-4	control	NA		2581	1322	
155-5	control	NA		2646	1325	
155-6	control	NA		2723	1377	
160-1	control	NA		2403	1002	
160-2	control	NA		2274)	1000	
avg.				2488	1250	
153-5	30	179	142	1048	475	112
153-6	30	179		1183	488	
153-7	30	179		1412	504	
153-8	30	179		1096	472	
avg.				1185	485	
155-1	30	174	126	1175	502	89
155-2	30	174		1231	518	
155-3	30	174		1305	580	
155-4	30	174		1046	455	
avg.				1189	514	
157-1	15	174	142	1499	620	81
157-2	15	174		1492	598	
157-3	15	174		1325	533	
157-4	15	174		1427	586	
avg.				1436	584	
168-4	60	172	121	740	430	76
168-5	60	172		1363	634	
168-6	60	172		803	433	
168-7	60	172		874	471	
avg.				945	492	
170-1	60	178		879	464	
170-2	60	178		1021	556	
170-3	60	178		858	463	
170-4	60	178		931	548	
avg.				922	508	
173-1	30	178	69	1710	700	32
173-2	30	178		1620	722	
173-3	30	178		1570	656	
173-4	30	178		1560	673	
avg.				1610	688	
174-1	30	152		1760	813	
174-2	30	152		1818	739	
174-3	30	152		1537	612	

Table 4: VOC emissions from particle at 130°C after low temperature steaming						
run	steam time (min)	steam temp (°C)	pressure (psi)	VOC (µg/g, dry basis), 60 min	VOC (µg/g, dry basis), 30 min	VOC recovered (%)
<i>particle from Weyerhaeuser, Adel (11.18.96)</i>						
160-3	30	119	28	1820	815	18
160-4	30	119		1850	847	
160-5	30	119		2010	824	
160-6	30	119		2010	821	
avg.				1920	827	
161-1	30	122	30	1970	878	12
161-2	30	122		1690	762	
161-3	30	122		1860	848	
161-4	30	122		1704	752	
avg.				1807	810	

Table 5: VOC emissions from particle at 130°C after two steam treatments						
run	steam time (min)	steam temp (°C)	pressure (psi)	VOC (µg/g, dry basis), 60 min	VOC (µg/g, dry basis), 30 min	VOC recovered (%)
<i>particle from Weyerhaeuser, Adel (11.18.96)</i>						
control (Table 3) avg.				2490	1250	
156-1	30	173	125	351	292	14
156-2	30	173		350	306	
156-3	30	173		350	291	
156-4	30	173		395	300	
avg.				362	297	

VOC steam extraction of wood particles at atmospheric pressure

The previous experiments were conducted under pressure since the steam was introduced under atmospheric pressure, and the sealed unit was then heated. In order to separate the effects of temperature and pressure, a needle valve was attached to the vessel as shown in Figure 7. Particle was then steamed at about 167°C for 10 minutes under sealed conditions (with the valve closed), and then for 20 minutes with the needle valve slightly open. Vapor released during steaming was led to a methanol trap. The steamed wood was then heated in the tube furnace and the VOCs measured. The trap methanol was analyzed for pinene. The results of these experiments are designated in Table 6 as the series 177 measurements.

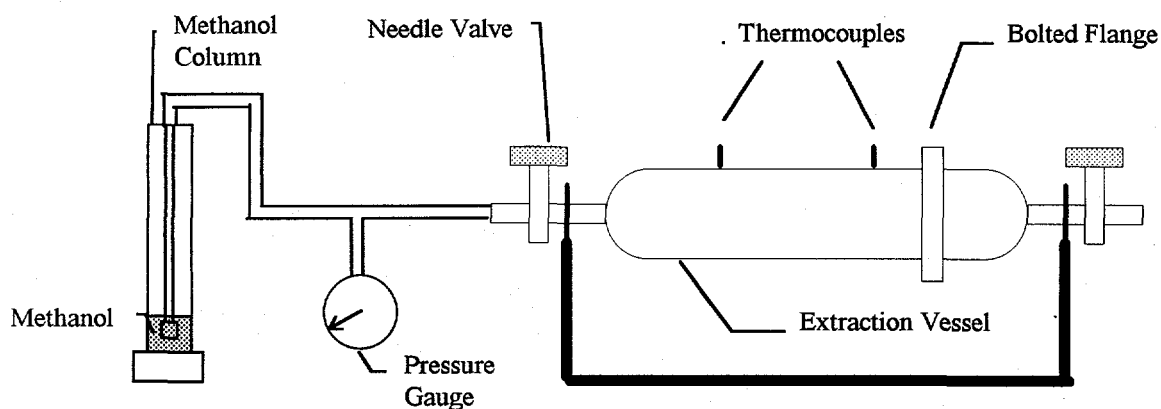


Figure 7: Modified VOC extraction vessel.

Table 6: VOC emissions from particle at 130°C at atmospheric pressure					
run	steam time (min)	steam temp (°C)	VOC ($\mu\text{g/g}$, dry basis), 60 min	VOC ($\mu\text{g/g}$, dry basis), 30 min	VOC recovered (%)
<i>particle from Weyerhaeuser, Adel (11.18.96)</i>					
control (Table 3) avg.			2490	1250	
177-1 ¹	30	167	903	346	25
177-2 ¹	30	167	899	351	
177-3 ¹	30	167	875	348	
177-4 ¹	30	167	907	346	
avg.			896	348	
178-1	30	168	1220	457	40
178-2	30	168	937	411	
178-3	30	168	1180	471	
178-4	30	168	923	366	
avg.			1070	426	
¹ sealed for the first 10 minutes					

Substantial VOC removal occurred during steaming. A possible mechanism for the low VOC recovery is condensation in the uninsulated, unheated viton tube stretching from the needle valve to the methanol trap. Runs were also made where the needle valve was opened partially immediately after steam-charging was complete, i.e. the material was steamed continuously at atmospheric pressure. The results, designated as the 178 series in Table 6 show VOC removal of about 60%. These results demonstrate that high temperature, and not high pressure, is key to VOC extraction.

RF treatment of lumber

In our previous report we showed that brief RF treatment of lumber in a low-headspace environment removed a large proportion of the VOC and very little water. However, Mississippi State University's kiln is too small to accommodate commercial 2 in x 4 in x 48 in sizes, and samples are split in half prior to drying. The question then arises as to whether VOC extraction with RF would also work with these larger samples. To simulate larger samples, freshly cut commercial 2 in x 4 in x 23 in pieces of lumber were dipped in melted paraffin to seal the end grain, and each piece was then wrapped in polyethylene film for RF treatment. One cut section was set aside as a control, and the other irradiated in a Strayfield unit at Georgia Power's Technology Application Center, at a power level of 0.8 amps for 6, 10, and 20 minutes. The irradiated samples were then dried at Mississippi State, and the emissions are provided in Table 7. The control (un-irradiated) samples were dried as a group, since no major differences were expected among them. The Table 7 results confirm our previous findings in that RF removes VOCs even from these partially sealed samples. Hence, low-headspace RF should be able to extract VOCs from commercial sizes of lumber. We are presently working on a simple collection system, and we expect the method to have commercial potential. We anticipate filing for a patent.

run	initial MC ¹	final MC ¹	RF treatment time (min)	VOC (lbs per dry ton)
011397-A-011397-D	108	6	0	3.08
011397-AA	105	0	6	2.11
011397-BB	88.9	0	10	2.19
011397-CC	60.9	0	20	0.97

¹MC: dry basis moisture content (percent)

Diffusion of water in wood

The relative drying rates of the transverse, tangential, and radial faces of wood were determined since work in our parallel EPRI project indicates that VOC release is related to the loss of water in wood. The tangential plane faces the outer portion of the wood (Figure 8). The radial face creates a plane reaching from the outer portion of the tree towards the inner core. The transverse, or cross section, is the face exhibiting growth rings. The sample cubes for the water diffusion in wood experiments were cut so all three faces were present in equal dimensions of 20 mm per side with faces appearing on the opposite sides of the cube. Five cubes and two moisture sections were taken from each of 3 boards, yielding a total of 15 sample cubes. An epoxy coating material was then applied to the cubes in the five groups to limit the transport of water through the epoxied face as shown in Table 8.

Table 8: Drying rates as a function of surface orientation					
treatment no.	transverse	radial	tangential	MC change, % / min (r^2)	proportional drying ratio
1	coated	coated	coated	0.588 (0.95)	0.31
2	open	coated	coated	1.459 (0.88)	0.78
3	coated	open	coated	0.715 (0.90)	0.38
4	coated	coated	open	0.929 (0.88)	0.49
5	open	open	open	1.881 (0.86)	1.00

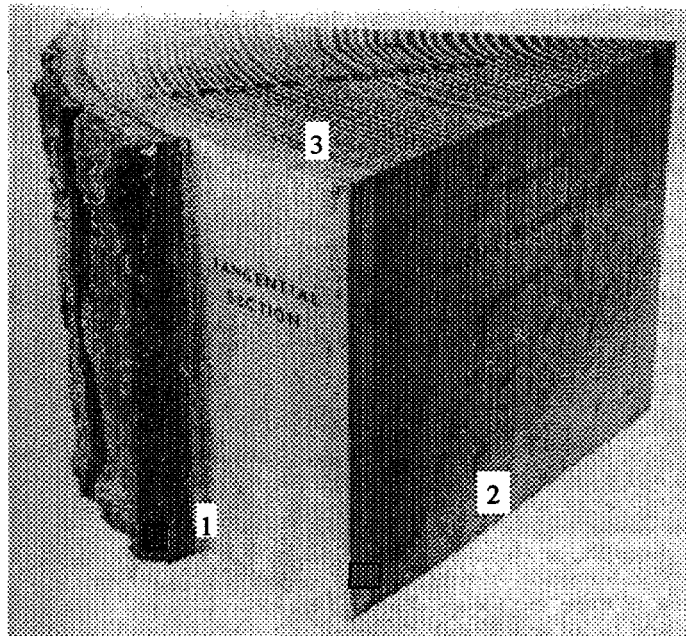


Figure: 8: Cross-section of tree naming the three planes; (1) tangential, (2) radial, and (3) transverse (cross section)

Treatment 1 was the control for the coating which indicated the resistance to water loss provided by the coating. The coating was applied to two faces of each cube for treatments 2-4; hence, water could only be lost through the open face. Finally, treatment 5 was left open. The coated cubes were reweighed and recorded as the adjusted green weight. The cubes were placed in a 120°C oven and weighed every 20 minutes until each cube reached its calculated weight at the fiber saturation point, or approximately 30% moisture content. Moisture contents were calculated for each interval, and linear regressions performed to determine drying rates for each treatment group. The results indicate that epoxy reduces the flow by a factor of 3.24; therefore the surfaces coated with epoxy emit vapor at 31% of normal flow.

Clearly, the high-temperature drying rates are different for the three primary wood

faces, with the transverse surface experiencing the greatest change in moisture content. At the start of a kiln cycle, there is a large drop in wood MC as the water near the ends moves out via capillary action. This phenomenon was demonstrated with the epoxy and cubes; the cubes with the transverse surface exposed dried quickly. At the start of a kiln cycle there is also a peak in the amount of VOC emissions observed from the wood.

Seasonal variation of monoterpenes and resin acids in Southern Yellow Pine

Samples were collected from twelve marked southern yellow pines (SYP) located in Moorehead Bottom on the MSU forest during February 1997. The circumference of the trees ranged between 44 and 57 inches, and increment cores were collected at a height of approximately 42 inches. A 12 inch increment borer with a core diameter of 0.200 inches was used for sample collection. The cores were divided into three four inch sections, with the first four inches being the inside sample, the second four inches being the middle sample and the last four inches being the outside sample.

Samples were prepared by adding 5 ml of methylene chloride to weighed cores and sonicating overnight. Diphenyl methane (internal standard) was added to each sample, which was analyzed for monoterpenes, 4-allylanisole, and resin acids on a Varian 3600 gas chromatograph equipped with a J&W DB-5 30 meter capillary column and a flame ionization detector. Table 9 contains preliminary results on a dry basis. Monthly sample collection will continue. The extraction procedure will be modified to prevent monoterpene loss during extraction.

Table 9. Monoterpenes from SYP (Loblolly) increment cores											
sample	a-pinene	camphene	b-pinene	myrcene	limonene	fenchyl alcohol	borneol	4-allyl anisole	total	core dry wt (g.)	total % monoterpene
	ug/mL										
1-inside	520	9.66	495	43.7	12.9	1.64	5.90	46.1	1140	0.804	1.41
1-middle	155	1.68	178	12.6	2.20	-----	-----	9.07	359	0.996	0.363
1-outside	91.7	1.65	105	9.10	1.44	-----	1.17	14.9	225	0.728	0.309
2-inside	298	-----	30.9	-----	-----	-----	-----	-----	329	0.904	0.363
2-middle	112	1.81	6.74	3.72	0.844	-----	-----	1.64	126	0.755	0.168
2-outside	104	1.55	6.74	2.83	0.905	-----	-----	4.25	120	0.700	0.172
3-inside*	361	6.45	191	7.79	7.59	11.4	17.0	120	721	0.812	0.888
3-middle*	4.14	-----	2.22	-----	-----	-----	-----	-----	6.37	0.893	0.007
3-outside*	-----	-----	-----	-----	-----	-----	-----	-----	-----	1.09	0
4-inside*	2.57	-----	1.93	-----	0.335	-----	-----	-----	4.84	0.607	0.008
4-middle	81.8	1.50	38.3	4.27	3.88	-----	-----	2.984	133	0.700	0.189
4-outside*	15.1	-----	8.47	-----	-----	-----	-----	5.648	29.2	0.751	0.039
5-inside	488	8.86	89.1	23.1	8.07	2.43	3.53	26.9	650	0.801	0.812
5-middle*	12.6	-----	3.66	0.958	-----	-----	-----	0.462	17.7	0.783	0.023
5-outside*	62.8	1.01	10.9	5.60	0.655	-----	-----	2.89	83.9	0.849	0.099
6-inside*	254	6.38	165	5.09	16.3	6.37	7.96	61.9	523	0.997	0.525
6-middle*	12.9	0.38	25.8	0.443	1.24	0.53	1.42	8.77	51.5	0.667	0.077
6-outside*	0.6	-----	-----	-----	-----	-----	-----	-----	0.632	0.714	0.001
7-inside	23.6	-----	-----	-----	-----	-----	-----	25.581	49.2	0.851	0.058
7-middle	116.9	2.03	22.8	3.64	6.65	-----	-----	3.18	155	0.647	0.24
7-outside*	11.8	0.163	3.02	-----	1.06	-----	-----	1.10	17.2	0.616	0.028
8-inside	437	9.66	179	3.58	12.8	3.34	5.77	32.8	684	0.897	0.763
8-middle	92.4	1.67	61.7	1.31	1.08	-----	0.870	2.21	161	0.826	0.195
8-outside*	1.7	-----	1.34	-----	-----	-----	-----	6.36	9.43	0.767	0.012
9-inside	1020	25.1	939	16.1	48.1	15.1	12.3	116	2190	0.779	2.81
9-middle	166	3.66	141	-----	9.05	-----	-----	26.33	346	0.678	0.511
9-outside	200	-----	203	-----	12.6	-----	-----	-----	416	0.764	0.545
10-inside	219	3.59	51.9	2.24	31.9	1.47	1.79	14.8	327	0.805	0.406
10-middle	224	3.35	68.3	3.70	29.8	-----	-----	4.61	334	0.799	0.418
10-outside	154	2.25	63.9	-----	17.4	-----	-----	3.09	240	0.870	0.276
11-inside	323	5.51	252	4.51	3.02	-----	-----	-----	588	1.10	0.534
11-middle	235	3.45	173	-----	2.41	-----	-----	-----	414	0.896	0.462
11-outside*	40.7	-----	29.4	-----	-----	-----	-----	-----	70.1	0.701	0.1
12-inside	183	-----	109	-----	2.26	-----	-----	-----	294	0.780	0.377
12-middle	241	4.21	140	4.12	3.44	-----	-----	-----	392	1.03	0.381
12-outside	179	2.66	84.6	3.84	3.79	-----	-----	7.10	280	0.814	0.344

*samples dried out during sonication