



*Institute of Paper Science and Technology
Atlanta, Georgia*

IPST Technical Paper Series Number 725

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April 1998

Submitted to
11th International Drying Symposium
Thessaloniki, Greece
August 19–22, 1998

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LOW-VOC DRYING OF SOFTWOOD

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Keywords: radiofrequency, pinene, heating, collection

ABSTRACT

VOC emissions from drying softwood oriented strand board furnish or particle increase with decreasing particle size, and with increasing oven temperature and airflow rate. Particle size is related to surface area, an increase of which preferentially dries out the surface. Similarly, drying at high temperature or under high airflow depletes surface moisture. Hence, the wet line should be maintained at the surface for as long as possible in order to keep the furnish evenly moist during drying. Heating green OSB flakes in a low-headspace environment releases VOCs, but proportionately much less water. It is feasible to extract and potentially collect the VOCs from green wood prior to drying, and to then dry with lowered emissions. Heating wood with microwave leads to contrasting results. Water is released with very little VOC emissions if the flakes are microwaved in an open container. In contrast, the VOCs are efficiently extracted, but water is retained under low-headspace microwaving, suggesting that forcing hot water to remain in wet wood enhances VOC removal. The driving force is the entropy of mixing.

INTRODUCTION

The destruction of Volatile Organic Compounds (VOCs) released from drying oriented strand board (OSB) and other furnishes requires expensive controls. The problem is especially acute for softwood, whose emissions, principally terpenes (Flodin and Andersson, 1977; Cronn et al., 1983), exceed those from hardwood by an order of magnitude. Regenerative thermal oxidation units, or RTOs, are most often used as controls (Yeo, 1993; Grzanka, 1996; Matros et al., 1996), but they are expensive, use natural gas, and emit CO₂, a greenhouse gas. Attempts to extract VOCs out of dryer airstreams have been made (Slay et al., 1996) but have not advanced to commercialization. This paper develops two themes. In the first, some of the factors that influence VOC emissions are discussed, so that changes in *existing* drying practice can be made from an appreciation of the VOC release mechanisms involved. Some of these recommendations have recently been commercially implemented with major reductions in both VOCs and control costs.

Secondly, the basis of a process is described, where VOCs are withdrawn from wood *prior* to drying. The VOC-depleted wood is then conventionally dried with much-reduced emissions. The recovered chemicals represent a valuable feedstock, and the process, therefore, converts a problem into a product.

EXPERIMENTAL

Flakes for the manufacture of Oriented Strand Board (OSB) were obtained from Georgia-Pacific facilities at Grenada, MS, and Dudley, NC. Particle was obtained from the Weyerhaeuser Adel, GA, plant. These samples were wrapped and stored cold, and were generally used within a few days of receipt. The principal component of these furnishes was loblolly pine. The furnace used for drying was a 1.5-inch diameter ceramic tube whose midsection was electrically heated. The furnish was placed in a ceramic boat in the center of the tube, air was metered to the tube inlet at 2 lpm, and the entire furnace emissions were drawn into a JUM Model VE7 flame ionization analyzer (FIA) by its built-in pump. Unless otherwise indicated, the VOCs released from wood are expressed on a green basis.

RESULTS AND DISCUSSION

Effect of particle size on emissions

Since the surface area:volume ratio of wood changes with particle size, it follows that surface dry-out should increase with decreasing particle size. In order to establish this effect, green flakes were milled to different sizes, and dried at 130°C for 1 hour. The wood typically dries in about 30 minutes under these conditions, so the overall emissions reflect an over-dried situation. However, much of the residual VOCs in the dried flakes escape during the subsequent pressing operations, so that the 1-hour result reflects releases from some combination of drying and pressing.

Emissions increase dramatically with decreasing particle size as demonstrated by the data presented in Table 1. The only exception is the 75 μ value, but some VOC loss was probably induced by the heat generated during the extensive grinding required. A practical implication of the VOC-particle size relationship is that fines removal through green screening should reduce emissions. This has recently been confirmed in field trials. An OSB mill in the Northern US

	VOC ($\mu\text{g/g}$)
75 μ	508
425 μ	866
1 mm	425
3 mm	299
6 mm	308
20 mm	150
whole flake	1097

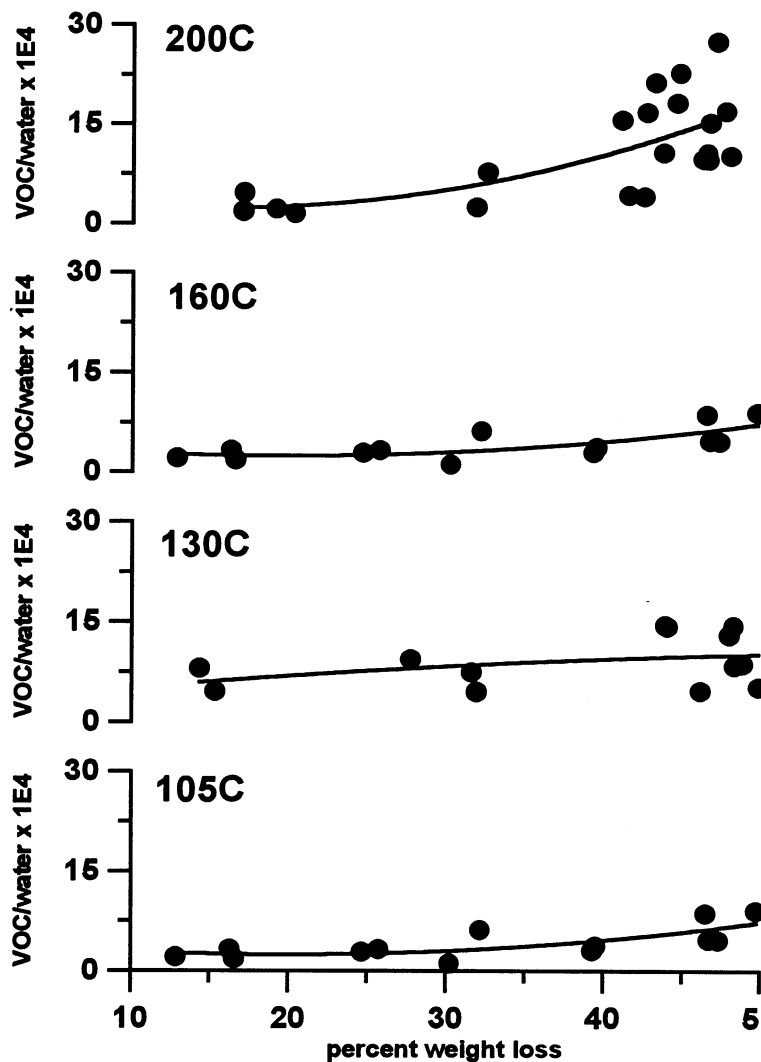


Figure 1. VOC:water ratios for OSB as a function of temperature and moisture content.

of VOC released per unit of water lost is higher at the higher temperatures, especially beyond about 30% weight loss, which corresponds to the onset of the falling rate period, where transport of water to the surface becomes rate-limiting (Banerjee et al., 1998a).

In order to develop the temperature-VOC relationship with a more uniform furnish, we dried particle at 130-180°C for 1 hour. As with OSB, two signals were observed. The first emerged rapidly and corresponds to the period during which the flake temperature was below 100°C, i.e., the furnish was evaporatively cooled. The second appeared after the furnish was substantially dry, and began to reach oven temperature. Consider the profiles in Figure 2, which represent VOC signals for particle between 130-180°C. Note that the maximum of the first signal remains at the same level, but that the intensity of the second increases with temperature.

now routinely green-screens its incoming furnish. In a related application, Georgia-Pacific's Holly Hill mill altered its refining operation so as to minimize the generation of fines, and were able to avoid the substantial cost of installing an RTO.

Effect of temperature on emissions

Softwood drying releases VOCs in two stages. There is an initial surge from surficial VOC, followed by a second burst when the surface water dries out, and the furnish temperature rises (Banerjee et al., 1995). In order to evaluate the effect of temperature on emissions, OSB flakes were homogenized by coarse-grinding in a Wiley Mill to about 1"x 3". They were then dried to various moisture end points under different temperatures and drying periods, and the VOC/water loss was determined for each charge. The results illustrated in Figure 1 show considerable scatter, but this is not unexpected given the variability in the furnish. However, it is clear that the amount

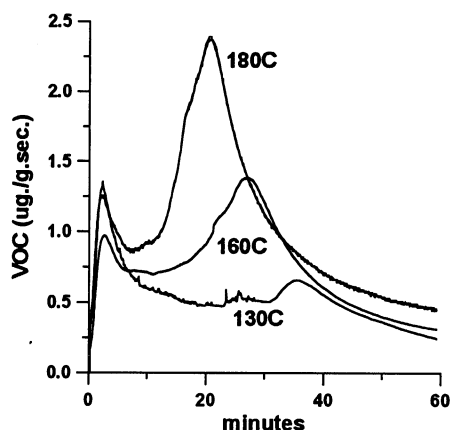


Figure 2. VOCs from particle.

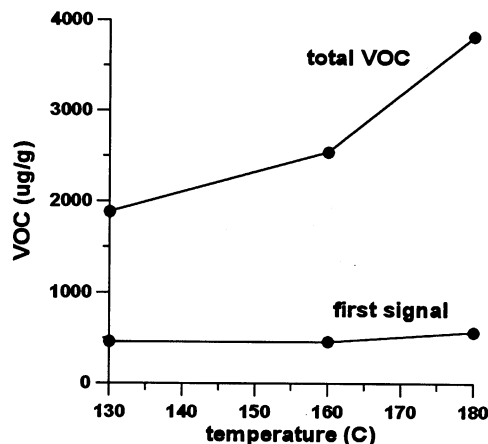


Figure 3. Dependence of VOC release on temperature for particle.

The first signal represents VOCs released while water is still being lost, i.e., the material is evaporatively cooled to or below 100°C regardless of the oven temperature. The second reflects VOCs given off after the furnish is much drier. The total VOC released over 1 hour increases with temperature as illustrated in Figure 3. The intensity of the first peak is not very temperature-dependent since the furnish temperature remains roughly constant because of evaporative cooling regardless of the oven set temperature.

Figure 3 demonstrates that VOCs emerge through different mechanisms *from the same furnish*. One pathway is temperature-dependent; the other is not. The initial signal reflects near-surface VOCs; the second peak emerges when the water is mostly gone and its temperature dependence implicates a vapor pressure-driven mechanism. As noted earlier, VOC emissions should be reduced if the furnish is dried just to the point of emergence of the second VOC signal.

Drying over a temperature gradient

Commercial drying is most often done in three-pass rotary dryers where flakes are blown through the dryer, whose inlet and outlet temperatures are maintained at about 500 and 120°C, respectively. In order to simulate the temperature gradients that exist in commercial dryers, we continuously moved the sample boat from the hot center of the furnace to the cooler region near the entrance over about 13 minutes. The oven was set at 500°C in our initial experiments. However, since the green flakes burned immediately, the temperature was reduced to 250-300°C; the outlet was kept at about 80°C. While this does not replicate field conditions, it does provide a measure of the effect of gradient drying on emissions.

The total VOC released is listed in Table 2. The “clean green” notation of the last two entries in Table 2 designate flakes where the fines were removed by gentle brushing. The average VOC is 739 µg/g at 300°C (initial temperature), and 587 µg/g at 250°C. Releases from the cleaned flakes are much lower at 356 µg/g at 250°C. It appears that the fines burn during drying, releasing a disproportionate amount of VOCs. Comparison of the gradient results to the isothermal work show that gradient drying releases *more* VOCs and *less* water than isothermal drying, especially for samples with attached fines. A possible explanation is that the surface of the flake

Table 2: VOCs from gradient drying			
sample	initial temperature (°C)	water loss (%)	VOC (µg/g)
green	300	34.54	748
green	300	38.98	729
green	250	35.02	402
green	250	35.76	601
green	250	37.14	254
green	250	35.24	687
green	250	32.50	992
clean green	250	32.44	417
clean green	250	35.01	296

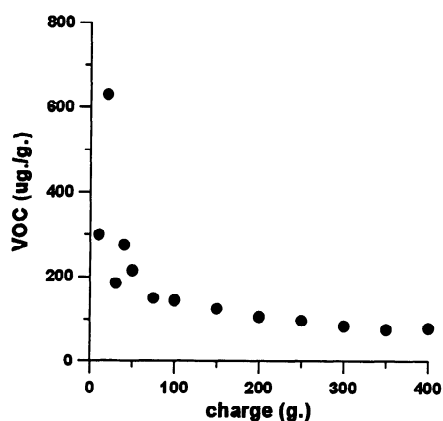


Figure 4. Dependence of VOC release on charge.

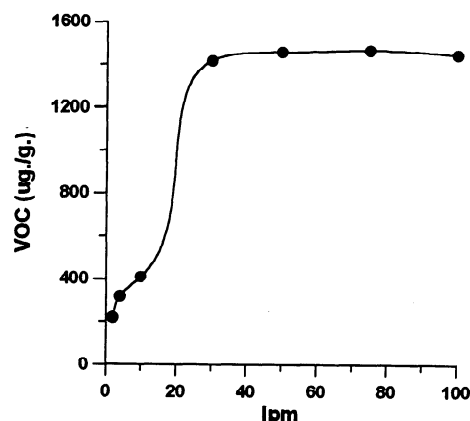


Figure 5. Dependence of emissions on flow rate.

hardens at the higher temperature involved in gradient drying, effectively sealing the moisture inside. Removing this moisture now requires more heat which drives off additional VOC.

Effect of flow rate on VOC emissions

OSB charges of different weights were dried under a 4 lpm airflow at 130°C, and VOCs were integrated over 1 hour. The results illustrated in Figure 4 show that smaller charges are associated with higher VOC. Except for the two highest weights in Figure 4, the furnish dried completely over the 1-hour period. Since the airflow in Figure 4 was constant, the smaller charge experienced a higher airflow per gram of furnish. In order to isolate the effect of airflow alone, the size of the charge was held constant and the airflow varied. Clearly, VOCs increase with airflow as shown in Figure 5, plateauing at about 30 lpm, which corresponds to 3 lpm/g. We attribute the phenomenon to partial dry-out of the surface at the higher flow rates. The local temperature in these dry regions rises and increased VOC loss occurs.

Relationship of the wet line to VOC emissions

The effects of furnish size, temperature, and flow rate were considered in this study. We hypothesize that smaller furnishes lead to higher VOCs because of surface dry-out. The tem-

perature of the dry surfaces is no longer regulated by evaporative cooling, and the higher temperature promotes VOC release. High temperature or gradient drying is similarly associated with high VOC since the surface dries out while the furnish interior still contains appreciable moisture. Likewise, high airflow depletes surface moisture, and promotes surface dry-out. Clearly, the key to low-VOC drying is to maximize surface moisture for as long as possible. This can only be done by enabling the transport of water to the surface to keep pace with the rate of evaporative loss. Hence, efforts to remove fines through green screening, or to minimize fines formation during processing and drying should reduce VOCs.

Low-temperature drying should assist surface saturation, since the rate of diffusion of water to the surface will then be able to better keep up with the evaporative loss. Support for this position comes from the temperature-dependence data. The VOC rise in Figure 1 corresponds to the beginning of the falling rate regime when the surface becomes progressively less saturated, i.e., dry regions develop. The contrast in the behavior of the two signals in Figure 3 is also quite compelling. The initial signal is independent of the oven set temperature because of evaporative cooling during constant rate drying. The intensity of the second signal, which is associated with late drying, increases with temperature and is responsible for the increase in overall VOCs. Again, VOCs increase when the furnish (or portions thereof) dry out.

Although the mechanism through which flow rate influences VOC release is less obvious, we hypothesize that dry regions develop on the surface at high flow rates. If so, then the temperature at these dry regions will rise owing to the loss of evaporative cooling, and will promote VOC release. From a practical viewpoint, it seems that a uniform reduction of moisture in the furnish during drying will reduce VOCs. Again, while the mechanism underlying these relationships is unknown, surface drying will impede the transport of interior moisture to the surface as seen in the gradient drying work. Hence, evaporative cooling of the surface will be diminished, and the surface temperature will rise, at least in certain regions. While the conditions that govern VOC loss are complex, we know that a VOC surge occurs when the flake is largely dry and the flake temperature rises. Thus, prolonging the onset of the temperature rise will retain the VOC in the flake and decrease the VOC:water loss ratio.

VOC emissions increase with decreasing particle size, increasing drying temperature, and increasing air flow. All these factors preferentially dry the surface. The optimum drying strategy should minimize temperature imbalances and moisture gradients within the flake in order to reduce "dry spots," since these regions will release a higher proportion of VOCs. Since surface dry-out will impede the movement of water to the surface, it should be avoided, or its onset delayed. The principal theme that emerges from this work is that the wet line should be maintained at the surface for as long as possible to keep the furnish evenly wet during drying. Practical observations support this position. For example, it appears that lower VOCs are associated with drying with a lower temperature conveyor system (Miller, 1996), or with superheated steam, both of which tend to extend the wet line at the flake surface.

VOC extraction from green flakes through low-headspace heating

Unlike thermal heating where the heat moves from the surface of the wood to the interior, microwave or radiofrequency (RF) heating transfers energy to the entire wood matrix. Paired sets of flakes (2-3 g) were prepared, and one set from each pair was microwaved in a Teflon

Table 3: VOC emissions at 130°C over 60 minutes	
microwave	VOC (µg/g)
control	857
1200 W, 1 min.	145
control	767
1200 W, 1 min.	266
control	536
600 W, 3 min.	329

cylinder (1¼" dia. x 4" length) fitted with a screw cap. Damp sponge inserts were positioned so as to inhibit moisture loss from the wood. Both microwaved and control flakes were dried, and the VOCs released during drying are compared in Table 3. Other control experiments were run to demonstrate that the VOC losses during microwaving are due to the effect of microwave itself on wood, and not indirectly to (a) the steam generated by the microwave, and (b) wood temperature differences during microwaving and heating. Hence, brief microwaving under low-headspace conditions extracts much of the VOCs that would otherwise emerge during drying, while retaining the water in the wood.

Microwaving under open conditions, i.e. without the low-headspace restriction leads to the opposite result in that water is lost, but the VOCs are mostly retained in the wood. Since the major difference between the low-headspace and the open experiments is the retention of water in wood in the former, water must assist VOC removal under low-headspace conditions. Simply put, the hot water forced to remain inside the wood during the low-headspace work promotes VOC release from wood. Water strongly absorbs microwave energy, whereas energy absorption by wood is much weaker, i.e. dry wood is not a lossy material. We hypothesize that without the headspace restriction, the water or steam moves quickly out of the flake before it has an opportunity to extract the VOCs from the wood.

Low-headspace drying does not necessarily require microwave; any form of heating that inhibits water loss from wood will suffice. The dimensions of the furnish dictate the optimal mode of heating. For dimension lumber, steam is impractical since the time required for VOC extraction is excessive (Boerner et al., 1997). We have found RF to be best for this application, and are developing a pilot unit that will allow VOC recovery (Banerjee et al., 1998b,c). Importantly, the high power costs of RF drying commonly associated with drying wood will not be incurred since no water is removed; the RF energy is only used to maintain temperature for a brief period in order to enable the VOC extraction to occur. In preliminary work, we have been able to dry the RF-treated lumber with an 80% reduction of VOCs (Banerjee et al., 1998b).

In summary, the interaction between hot water and the volatile organics in softwood promotes VOC loss from softwood. This is, at best, only partly the case during conventional drying where the water leaves the wood before it is able to fully extract the VOCs. In other words, the rate of water removal is greater than the rate of its interaction with the VOCs. This is especially evident during open-headspace microwaving, where very little VOC is lost. On the other hand, when the rate of water loss is suppressed by restricting the headspace, the extraction process predominates. Hence, either VOC or water release can be selected by adjusting the headspace. We do not imply that VOCs can only be removed through interaction with water; simple evaporation must also be a mechanism. However, water can play a pivotal role in extracting VOCs, and control of its residence time in wood provides options in VOC control.

ACKNOWLEDGMENTS

This work was funded by EPRI, Southern Co., Entergy, and Georgia-Pacific.

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