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Wet Line Extension Reduces VOCs From Softwood Drying

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Abstract

VOC emissions from drying softwood oriented strand board (OSB) or sawdust 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. The optimum drying strategy from the perspective of reducing VOCs should minimize temperature imbalances and moisture gradients within the flake in order to reduce dry spots. Since surface dry-out will impede the movement of water to the surface, its onset should be delayed. Hence, the wet line should be maintained at the surface for as long as possible to keep the furnish evenly wet during drying.

Introduction

Volatile organics released from drying oriented strand board and other furnishes require expensive controls. The problem is especially acute for softwood, whose emissions, principally terpenes (1,2), exceed those from hardwood by an order of magnitude. To some extent, the water:VOC release ratio depends upon the drying strategy employed, so that options exist for lowering emissions without installing major additional capital. Our objective is to understand some of the factors that influence VOC emissions, so that reductions can be pursued from an appreciation of the mechanisms involved.

Moisture in wood occurs in two forms: bound and free (3-6). Bound water is adsorbed to cell walls, and ranges between 25-32% of dry weight at the fiber saturation point. Moisture in excess of this amount is called free water, and its quantity is limited by wood porosity. At moderate temperatures (35-180°C), the drying period can be divided into (a) a heat-transfer-controlled regime, where the drying rate is virtually constant, and free water evaporates from the surface; (b) a moisture-controlled regime where both free and bound water migrate to the surface and then evaporate; and (c) a diffusion-controlled regime, where the drying rate decreases, since only the bound water is removed by diffusion and evaporation (3,6). In the initial constant rate regime, the surface moisture evaporates as if from a free liquid surface, and the moisture in the pores migrates to the surface to maintain surface saturation. At the critical moisture content, the rate of moisture migration to the surface becomes too slow for the surface to remain saturated, heat-transfer controlled drying predominates, and the drying rate progressively decreases (3,6). The surface now becomes drier and hotter, as compared to the bulk. At a moisture content of 20% or less, diffusion-controlled drying predominates. Here, the drying rate is determined by the diffusion coefficient, the distance across which diffusion occurs, and the moisture content. Evaporation takes place from a very narrow front at the juncture of the outer and inner layers (6). This front, the wet line, moves deeper into the material as the flake dries. In this paper, we will demonstrate that VOC release can be minimized if the wet line is maintained at the surface for as long as possible.

Experimental

OSB flakes were obtained from Georgia-Pacific facilities at Grenada, MS, and Dudley, NC. Sawdust 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. Two furnaces were used in this study. A 1.5-inch diameter ceramic tube furnace was utilized for small (<8 g.) samples, which were placed in a ceramic boat in the center of the tube. A 1.5-inch midsection of the tube was electrically heated. 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), with its built-in pump. This unit is used in EPA Method 25A for monitoring total gaseous non-methane emissions (7). A 2,750-cu in. furnace was used to dry up to 5 lbs. of furnish. Here, air was injected through a manifold at the base of the furnace, and a sidestream from the emissions was directed to the FIA through heated lines. The two units are referred to in this study as the small and large furnaces, respectively. Unless otherwise indicated, the VOCs released from wood are expressed on a green basis.

Results

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 particle sizes and dried in our small furnace at 130°C for 1 hour. The wood typically dries in about 30 minutes under these conditions, so the overall emissions reflect an overdried 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. It is difficult to directly relate laboratory measurements to field situations since the temperatures, airflow, humidity, etc., of a commercial dryer are variable, and these parameters all have an appreciable influence on emissions.

Emissions increase dramatically with decreasing particle size as demonstrated by the data presented in Table 1. The only exception is the 200 mesh value, but some VOC loss was probably induced by the heat generated during the extensive grinding required. These trends were confirmed with larger (50 g.) batches of flakes processed in our large oven. Hence, increasing the surface area: volume ratio greatly increases emissions. A practical outcome of this finding is that screening of the green furnish to remove fines should reduce emissions, and a field trial is presently underway.

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 (8). In order to measure the flake surface temperature, a thermocouple was attached to the surface of a flake placed in our small furnace at 160°C. The thermocouple consists of a bimetallic interface sandwiched between an adhesive strip that attaches to the flake and a fiberglass cover. Duplicate temperature measurements made from separate green and dry flakes are averaged in Figure 1. Clearly, evaporative cooling retards the temperature rise of the green flake. A less pronounced but similar difference occurs at 130°C.

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 in the small furnace to various moisture end points under different conditions of temperatures and drying periods, and the VOC/water loss was determined for each charge. The results illustrated in Figure 2 show considerable scatter, but this is not unexpected given the variability in the furnish. However, it is clear that the amount of VOC released per unit of water lost is much higher at the higher temperatures, particularly after about 30% weight loss, which corresponds to the onset of the falling rate period, where transport of water to the surface becomes rate-limiting (5,6).

In order to further develop the temperature-VOC relationship with a more uniform furnish, we dried sawdust in our small oven 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 (8). Consider the profiles in Figure 3, which represent VOC signals for sawdust 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. 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 correlates with temperature as illustrated in Figure 4. The intensity of the first peak is not temperature-dependent since the furnish temperature remains roughly constant regardless of the oven set temperature.

Figure 4 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 previously (8), VOC emissions should be reduced if the furnish is dried just to the point of emergence of the second VOC signal.

Commercial drying is most often done in three-pass rotary dryers where flakes are blown into the dryer whose inlet and outlet temperatures are at about 500 and 120°C. In order to better simulate field conditions, we measured VOCs as flakes were dried across a temperature gradient in our small furnace. We achieved this by continuously moving the sample from the hot center of the furnace to the cooler region near the entrance over about 13 minutes. The inlet temperature was 250-300°C; the outlet was 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 represents 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. The fines overdry as discussed above, and release a disproportionate amount of VOC. Comparison of the gradient results with the isothermal work shows 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 hardens at the higher temperature involved in gradient drying, partially sealing the moisture inside. Removing this moisture now requires more heat, which drives off additional VOCs.

Effect of flow rate on VOC emissions

OSB charges of different weights were dried under a 4 lpm airflow in our large furnace at 130°C, and VOCs were integrated over 1 hour. The results illustrated in Figure 5 show that smaller charges are associated with higher VOC. Except for the two highest weights in Figure 5, the furnish dried completely over the 1-hour period. Since the airflow in Figure 5 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. VOCs from drying 10 g. of OSB at 130°C for 1 hour are plotted against airflow in Figure 6. Clearly, VOCs increase with airflow, plateauing at about 30 lpm, which corresponds to 3 lpm/g. Flow rate affects water loss to a lesser degree as shown in Figure 7, where 50 g. of OSB were dried at flow rates of 1-50 lpm. Hence, we have the curious situation where increasing airflow dramatically increases VOC loss, but affects the drying rate to a much smaller extent. 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.

Discussion

The effects of three parameters on VOC release, namely 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 temperature 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 keep up with the evaporative loss. Support for this position comes from the temperature dependence data. The VOC rise in Figure 2 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 4 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 therein) 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 experiments. 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 (8). Thus, prolonging the onset of the temperature rise will retain the VOC in the flake and decrease the VOC:water loss ratio. We note that this is not necessarily a panacea, since the retained VOCs may well increase press vent emissions, a possibility that we plan to explore.

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 (9) or with superheated steam (10, 11), both of which tend to extend the wet line at the flake surface.

Acknowledgments

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Table 1: Particle size effects on emissions during drying at 60 minutes at 130°C

	VOC (μg/g)
75μ	508
425μ	866
1 mm	425
3 mm	299
6 mm	308
20 mm	150
whole chip	109

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

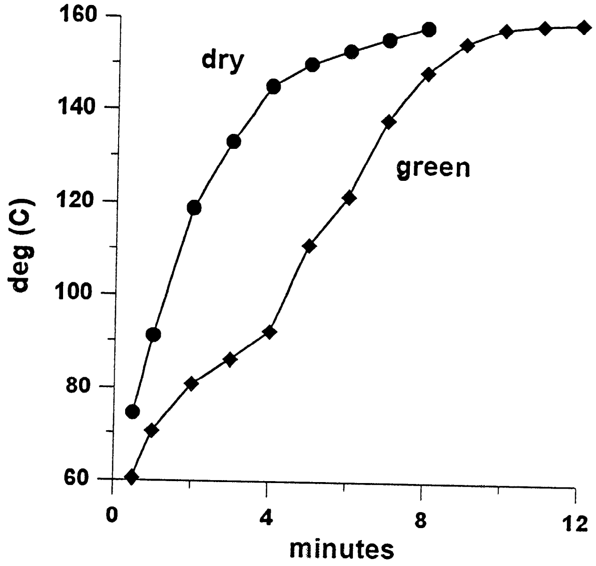

Figure 1: Surface temperatures of OSB during 160°C drying.

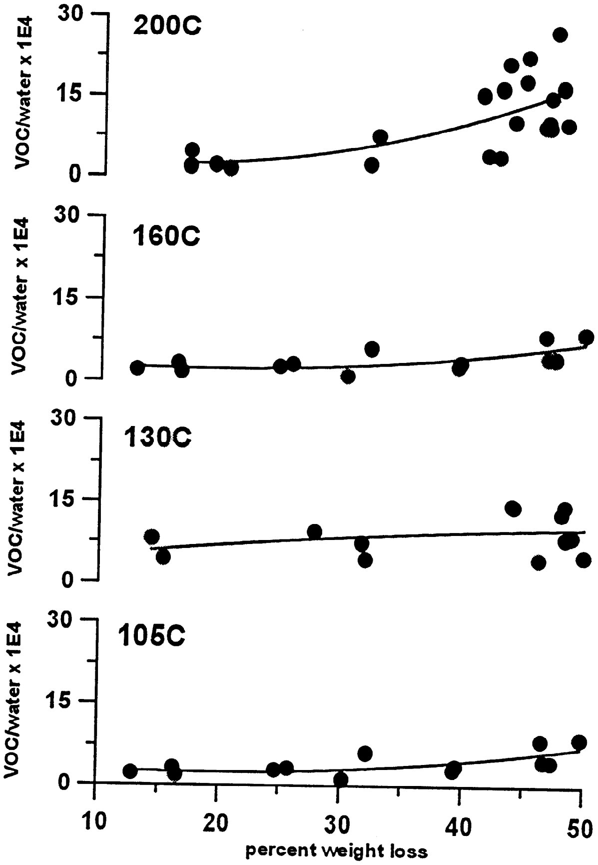

Figure 2: VOC/water ratios for OSB as a function of temperature and moisture content (initial wet basis moisture ≈ 50%).

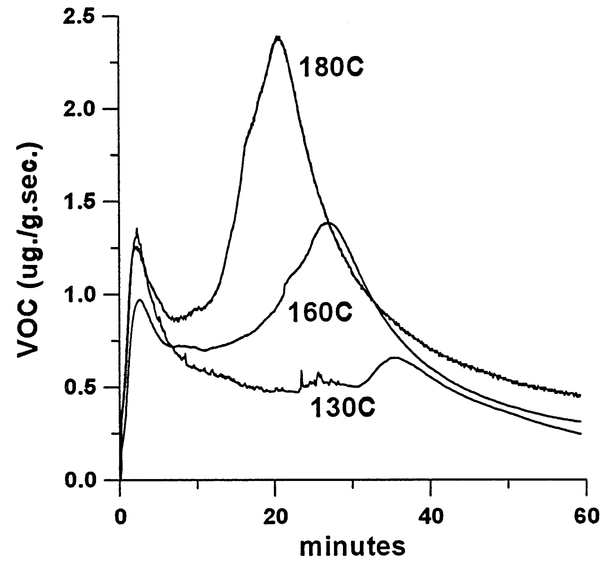

Figure 3: VOCs from sawdust.

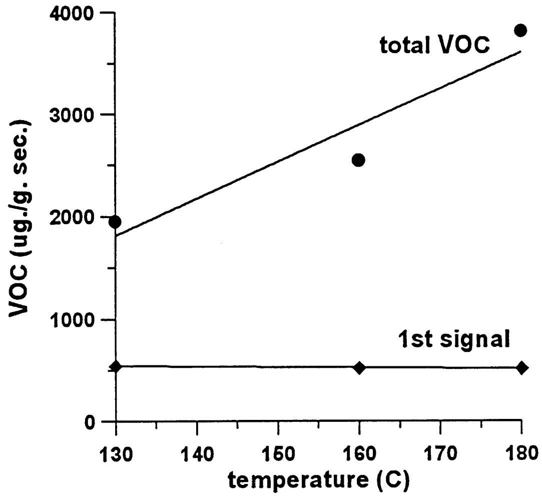

Figure 4: Dependence of VOC release on temperature for sawdust.

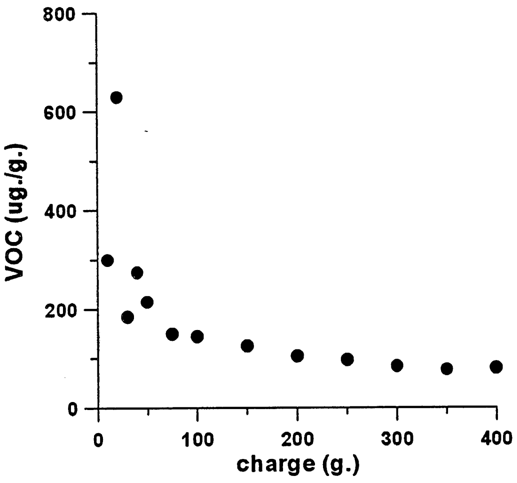

Figure 5: Dependence of VOC release on charge (wet basis).

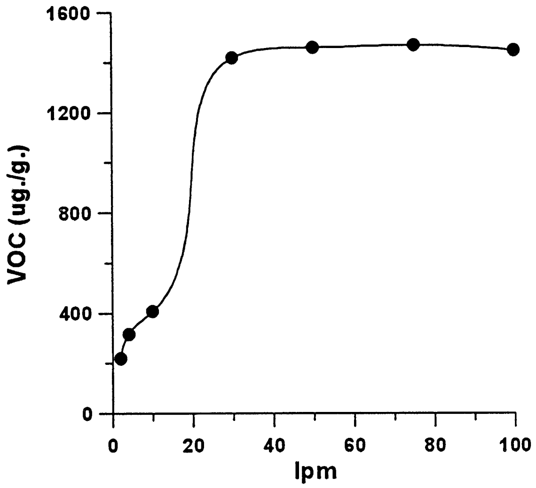

Figure 6: Dependence of emissions on flow rate (wet basis).

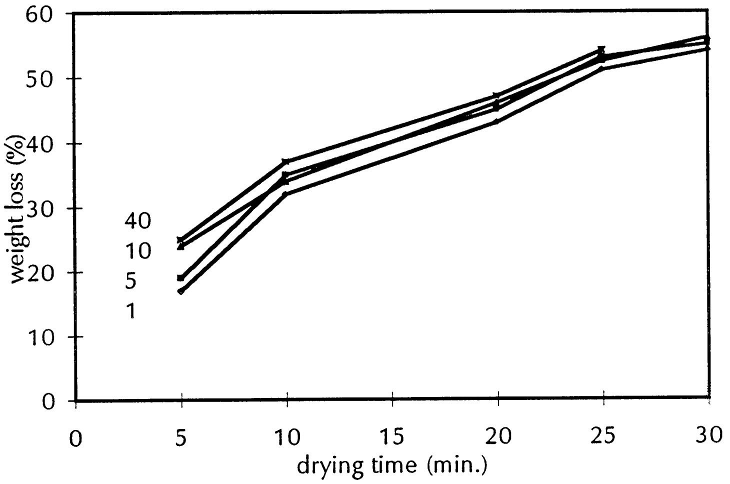

Figure 7: Effect of flow rate (1, 5, 10,and 40 lpm) on drying rate (wet basis).