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RELEASE AND MEASUREMENT OF VOC EMISSIONS FROM LUMBER KILNS

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ABSTRACT

The release of turpentine and methanol from drying softwood lumber has been measured in full-scale experiments. VOC concentrations taken within the kiln headspace were very uniform, which allowed the total VOC release to be estimated without knowledge of the airflow. The mechanism proposed for turpentine emissions from lumber comprises three components: release of turpentine from the surface layer of water on the wood, water-mediated transport of turpentine from the wood interior to the surface, and evaporation during the falling rate period. Full-scale VOC releases from lumber can be predicted from laboratory work on sawdust, indicating that the mechanism is independent of the type of furnish.

INTRODUCTION

The measurement and control of VOC emissions are of current interest since regulatory compliance adds considerable cost. To date, the source of VOCs and the factors that govern their release have been addressed empirically, *e.g.* through study of the relationship between VOCs and operational parameters such as temperature and wood geometry. We have attempted to complement this approach through a more fundamental study with the hope of identifying principles that might be exploited to reduce emissions. In this paper we discuss the mechanism of VOC release from commercial drying of lumber, and establish a quantitative link to emissions from other types of furnish such as particle.

RESULTS AND DISCUSSION

Mechanism of VOC Emissions

VOCs are released from wood through a complex profile. There is an initial burst very early in the process after which they emerge with water in a near-constant ratio. A final burst occurs when the wood is almost dry. The profiles of water and VOC emissions are temperature-dependent. Consider the emissions from southern pine sawdust measured in a tube furnace in the laboratory (1) at two temperatures (105° and 200°C) as illustrated in Figure 1. Signals for the principal VOC component (pinene) and water closely track each other at 200°C. Both components are removed through heat. Had they behaved independently of each other, the profile for pinene would have lagged behind that of water on account of its higher boiling point. The similar profiles of the two components require a common mechanism to be responsible for their removal. Most likely, water transports the pinene through the wood matrix to the wet line.

Pinene:water ratios at various temperatures are plotted in Figure 2. The ratio in the central region (where the temperature remains steady at about 95°C because of evaporative cooling) is fairly constant at about 1,000 ppm across all temperatures. It is attractive to postulate that water dissolves the pinene and moves it to the surface, but the solubility of pinene in water is only 25 ppm. However, surfactants such as oleic acid are present in wood (2), and they can greatly elevate the solubility of organics in water (3, 4). Hence, it is plausible for surfactants to solubilize pinene in water to the 1,000 ppm level observed (1). The position of the early pinene peak is temperature-independent and remains constant at about 5 minutes, which suggests that it originates from the surface while the wood warms up. Pinene can be rapidly lost from surficial water; at 25°C, we estimate the loss from a 1 mm water film to occur with a half-life of only 100 seconds (1), a value that decreases at higher temperature. The differences between the water and pinene signals from sawdust at 105° and 200°C can now be reconciled through the following argument. At 105°C, the evaporation of water is initially slow, and pinene is lost from the surface layer of water. As a result, the pinene signal is high, while that of water is relatively low. At the higher oven temperature, the wood
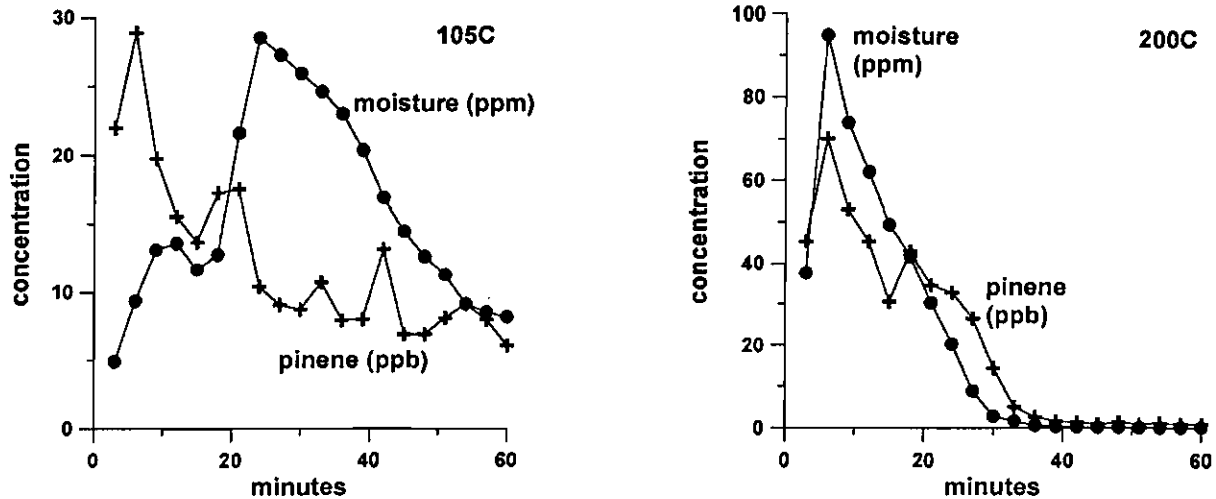
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Figure 1: Pinene emissions from southern pine sawdust at 105° and 200°C.
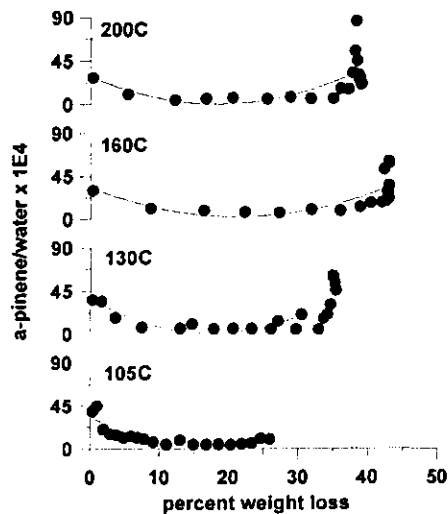

Figure 2: Pinene/water ratios for sawdust.

heats up faster, the interior water carrying its dissolved pinene load moves more quickly to the surface, and the two constituents are released together.

Finally, pinene can be lost through simple evaporation late in the drying process. It has been shown that the loss of VOCs from dry wood is vapor pressure driven; *e.g.*, the relationship between VOCs and dryer temperature breaks upwards at about 160°C, the boiling point of α-pinene. The increase in VOC emissions during late drying in Figure 2 reflects increasing pinene evaporation as the wood temperature climbs after the evaporative cooling effect of water is lost. Hence, there seems to be (at least) three mechanisms for the movement and release of pinene and other terpenes from wood. A burst occurs very early in the process, and this is ascribed to the loss of pinene dissolved in surface water. Pinene and water then tend to be released in a near-constant ratio, and this is attributed to water and surfactant mobilizing pinene from the interior of the wood matrix to the surface. Finally, when the wood is nearly dry, pinene is lost through evaporation. As shown below, VOCs are released from lumber in exactly the same manner.

Full-scale Lumber Drying Trials

VOC emissions were collected from a relatively new commercial southern pine dry kiln in the Southeastern US during July and November 2000. The wood is dried to a target MC of 14–14.5% through indirect heating with steam coils; the loads are mixed charges of 2 x 10's and 2 x 12's, with a volume of about 105,000 b.f. The dry bulb temperature is ramped up to about 100°C in three hours and then gradually increased reaching 115°C by the end of the run (about 17.5 hours). The vents are kept closed for the first four hours (*i.e.*, the warm-up period plus one additional hour), and then the exhaust vents are opened fully for the duration of the run to permit moisture to escape. The kiln manager for this particular company prefers not to open his intake vents during drying (except momentarily during fan reversal), hence the data collected generally represent actual changes in the kiln atmosphere resulting from lumber drying with minimal influence of external air infiltration. Method 25A emissions were measured (as propane) after diluting the kiln air sample with an equal amount of ambient air to minimize instrument problems caused by the high sample humidity.
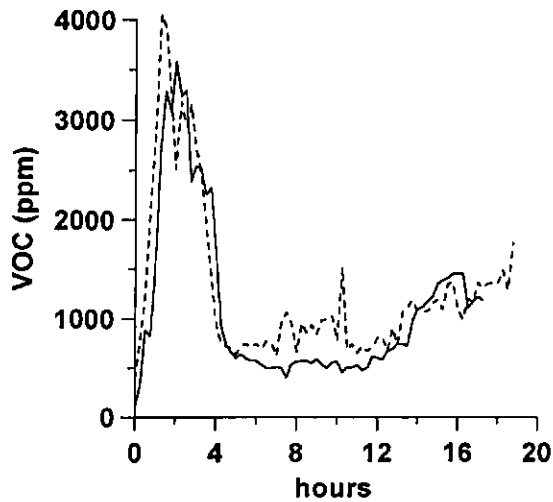
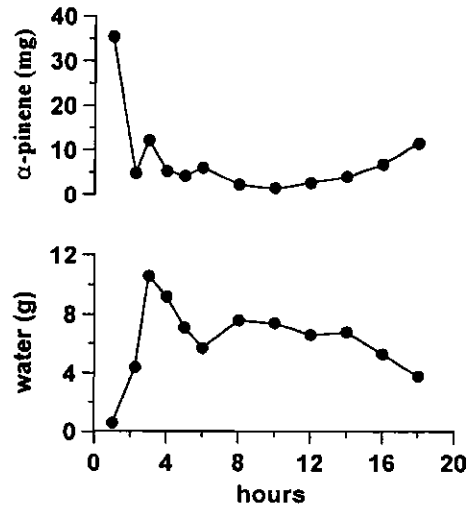**Figure 3: Method 25A profiles collected in July 2000 (bold) and November 2000 (dashed).**

Figure 4: Pinene and water profiles collected in July 2000.

A trailer from MSU was sited adjacent to the kiln to house instrumentation, and sampling probes were inserted at breast height through two gasketed holes in the kiln wall to determine whether the air flow and/or sampling location might affect the measurements: one was placed close to the door and the second was placed at the middle of the kiln. The probe was a 70-cm piece of 0.6 cm copper tubing tipped with a fine mesh filter. The line had been preheated to over 200°C to eliminate contaminants. Method 25A measurements were made continuously at both locations; kiln air was sampled through heated sample lines to avoid condensation problems. The values from the two probes were almost identical, confirming that the kiln volume was well-mixed. Air samples from within the kiln were also collected hourly in chilled water or methanol impingers. The water condensed was weighed, which allowed calculation of analyte:water ratios.

Representative profiles for the July and November emissions analyses are illustrated in Figure 3. All runs were replicated, and the replicates within each sampling event agreed very well. The November emissions are somewhat higher than those in July, possibly because of seasonal factors (5). Profiles of pinene and water are illustrated in Figure 4; there is a remarkable mirror-image relationship. As discussed earlier, the high initial pinene signal is believed to reflect loss of surficial material. Pinene is then lost along with water at an approximately constant ratio from 5-13 hours. Finally, local overdrying occurs and the VOCs rise as the water emissions taper off during the falling rate period. Note that the pinene:water ratio (in Figure 3) after the vents are opened after four hours approximates 1,000 ppm, the same value obtained in Figure 2.

For sawdust, the α-pinene:water ratio in the plateau region of Figure 2 is 1,000 ppm. If this value is applied to the water lost from drying lumber from a moisture content of 100 to 15%, then 2.1 lbs/Mbf of α-pinene would be released. This result does not consider the final uptick in Figure 3, which would increase the emissions by about 35%. α-Pinene was found to represent about 65% of the VOC emissions, which leads to a value of 4.4 lbs/Mbf of Method 25A emissions.

Emissions for the first four hours can be estimated through the following analysis. The emissions will principally occur through leaks as the air within the kiln expands from an ambient temperature to 100°C. The VOC concentration averages about 2,000 ppm during the first four hours. The kiln volume less the volume of the wood is approximately 52,000 cu ft. Heating this volume from ambient temperature (say 30°C) to 100°C expands it by 23%. The amount of VOC contained in this volume is 0.5 lbs/MBf. If this is added to the emissions estimated for the remainder of the kiln cycle, then an overall value of 4.9 lbs/MbF or 3.9 lbs/dry ton results, which compares well with results typically reported for lumber drying. Importantly, the calculation does not consider airflow at all. Except for
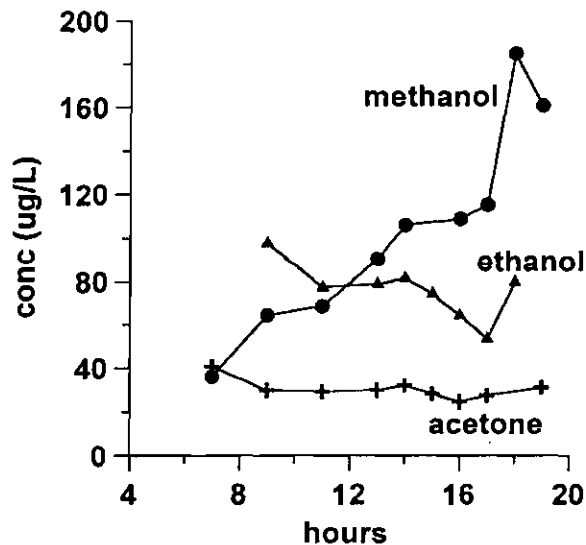
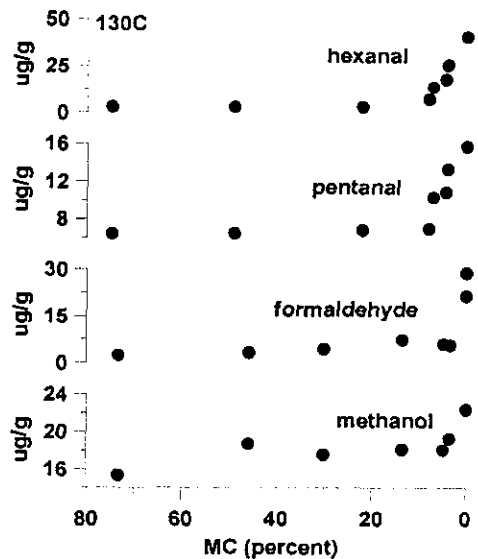Figure 5: Profiles of VOC constituents from drying lumber.

Figure 6: Profiles of VOC constituents from drying pine flakes at 130°C.

the initial spike, the emissions are normalized with respect to the water lost. Hence, the contribution of leaks is relatively unimportant, since the calculation does not consider *how* the emissions leave the kiln, only that they do so. Key features of the approach are that the VOCs and the water in the headspace are uniformly distributed, and that pinene is released as a constant fraction of water for most of the drying cycle. There are two major sources of variability. The 0.6 lbs/Mbf value for the initial closed-vent period is load-specific. It, and the 35% adjustment for the final uptick will depend on factors such the kiln layout and drying conditions. It is important to remember that the basis of the calculation, the α-pinene:water ratio of 1,000 ppm, was derived from laboratory work with sawdust and can also be applied to emissions from drying strand (1). Hence, the mechanism of VOC emissions from wood seems to be similar across furnish types.

Profiles of some water-soluble components collected in a chilled water impinger during the November 2000 run are provided in Figure 5. The results (reported as micrograms of analyte per liter of air) are to be interpreted only on a relative basis. Note that ethanol and acetone are released at almost a constant concentration, whereas methanol increases almost linearly with time throughout the run. This linearity was unexpected based on our previous experience with strand. We had found that methanol and formaldehyde emissions were level through most of the run, increasing dramatically when the wood tissue temperature climbed over 180°C. Typically, this happens when the moisture content dips below 6%, and the wood is no longer evaporatively cooled. An illustration is provided in Figure 6 (6).

The steady increase in methanol observed in Figure 5 is surprising in light of the Figure 6 results. The temperatures for lumber are much cooler, and we would have expected a low bleed of methanol, as observed during the early drying period in Figure 6. It is possible that the rise in methanol in Figure 5 originates from the furnish adjoining the steam coils, which could dry rapidly and whose surface temperatures could be atypically high. If so, then one route to methanol reduction might be to protect these regions from overheating. These and other options are presently being explored.

ACKNOWLEDGMENT

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