Release of primary compounds and reaction products from oriented strand board (OSB)

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ABSTRACT
Wood chips, strands and oriented strand boards (OSBs) were tested for release of VOCs in 1 m^3 test chambers. The dominant compounds monitored in the chamber air were terpenes and aliphatic aldehydes. The chamber concentrations of the compounds were strongly dependent on the processing parameters. It was shown that OSBs are major sources of these air contaminants. This was demonstrated by measuring indoor air pollutants in newly manufactured houses.

INDEX TERMS
Terpenes; Aldehydes; Wood-based products; Processing; Chamber testing

INTRODUCTION
Oriented strand boards (OSBs) in the European context are defined as 'boards of long, thin, directional strands or chips of wood' (Boehme, 1999). The softwoods used for the production of OSBs—apart from the water portion—consist of non-volatile polymers, mainly of cellulose, lignin and the hemi-celluloses. Besides that they also contain, mostly in comparably low quantities, volatile and semi-volatile organic components (Fengel and Wegener, 1989). As for the VOCs, in principle, two groups may be distinguished: (1) volatile ingredients of wood; (2) VOCs that are released by hydrolytic, thermal and/or oxidizing reactions from non-volatile wood components.

In the fresh state softwood species contain between approximately 0.5 and 2% of monoterpenes, above all α- and β-pinene, 3-carene and limonene. Therefore, terpene emissions are found in all natural construction elements made of softwood (Salthammer and Fuhrmann, 1996; Baumann *et al*., 1999). The monoterpene content is decreased because of natural or artificial drying, but in the decreasing characteristics there are differences depending on the wood species. Carboxylic acids and aldehydes belong to the reactively formed VOCs. These compounds have a low odour level and, like the terpenes, contribute to the odour impression of the dry wood. Detectable emissions in carboxylic acids concern formic acid and above all acetic acid (Risholm-Sundman *et al*., 1998) and in certain cases also higher acids like hexananoic acid. Many wood-based materials also show a considerable release of aliphatic aldehydes like pentanal, hexanal, nonanal and others (Baumann *et al*., 2000). The high emission rates of organic acids and aldehydes are due to the thermal–hydrolytic disintegration process during the manufacturing process.

Wood-based products are frequently used for the construction of houses. Therefore, terpenes and aldehydes are often monitored as major pollutants of indoor air (Hodgson *et al*., 2002). High indoor concentrations of terpenes may have adverse effects on human health, as limonene and 3-carene are known to be skin irritants. In addition, ultrafine particles and sensory irritants are formed from terpene–ozone reactions (Weschler and Shields, 1999; Wolkoff *et al*., 2000). In order to identify the reasons for emissions of VOCs from OSBs,

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chips, strands and manufactured boards were studied in test chambers. Additional measurements were conducted in newly manufactured houses.

METHODS

The first experiment related to chips made of freshly felled pine that was stored under normal climatic conditions until testing. The temperatures for drying of chips were 30, 120 and 220°C. For the second experiment industrial dried strands were used. The individual process stages like disintegration, drying and board manufacture were carried out at WKI. In the manufacture of OSB board MUPF was used as the binder. Additionally, OSBs bonded with PMDI from industrial manufacture were included in a third investigation.

All emission experiments were carried out in self-constructed 1 m^3 glass chambers in accordance with ENV 13419-1. Details of the chamber design have been described earlier (Salthammer 1997). The following test conditions were applied: temperature = 23°C, relative humidity = 45% and air exchange rate n = 1.0 h^{-1}. For OSBs, the loading factor was n = 1.0 m^2/m^3. Wood chips and strands (300 g) were evenly spread on a grid of 40 cm × 60 cm. Prior to each test, the chamber was heated to 70°C for 48 h to reduce memory effects and keep the chamber blank low. The effectiveness of thermal cleaning process was controlled by measuring a blank value before each experiment.

Air samples were collected on Tenax TA (2–4 l total volume at a flow rate of 100 ml/min). The analysis of the Tenax tubes was carried out using a GC/MS system (Agilent 6890/5973N) equipped with a thermal desorption-cold trap injector (Perkin Elmer ATD 400). Identification of the compounds was based on a PBM library search. Moreover, mass spectra and retention data were compared with those of reference compounds. All commercially available chemicals were purchased in GC quality from Aldrich, Germany. It was not possible to calculate surface-related emission rates for the chips and strands. The results are therefore expressed in terms of chamber concentrations.

RESULTS

For the first experiment, chips were produced from the fresh pine wood. The chips were partitioned and separately dried at 30°C (24 h), 120°C (6 h) and 220°C (2 h) in drying cabinets.

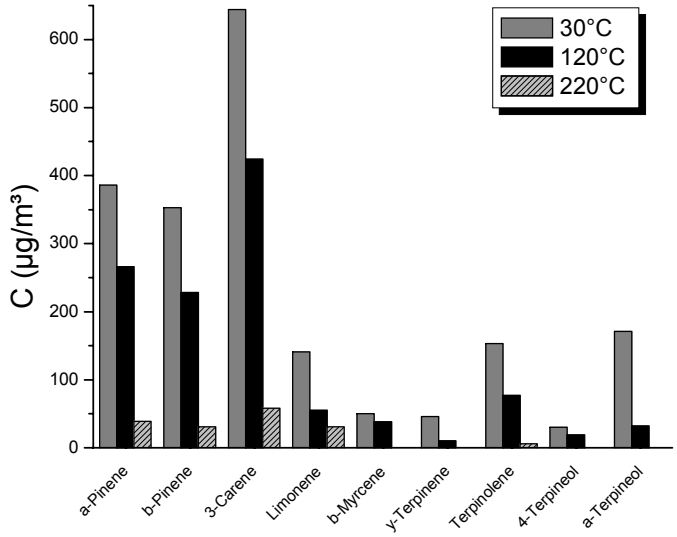

Figure 1 Dependence of chamber concentrations for terpenes emitted from wood chips (pine) on the drying temperature 24 h after loading (see text for test conditions).

After cooling to 23°C in a climate room the chips (300 g) were transferred to the test chamber and VOC concentrations were measured after 24 h. The results are presented in Figure 1. As expected, the highest concentrations were measured for 3-carene, α-pinene and β-pinene (Salthammer and Fuhrmann, 1996). For 30°C, the sum value was Σ(VOC) = 1974 µg/m^3. The nine quantified terpenes and terpene alcohols contributed to more than 95% with *C*(3-carene) = 644 µg/m^3, *C*(α-pinene) = 386 µg/m^3 and *C*(β-pinene) = 353 µg/m^3. The concentrations of limonene, α-terpinolene and α-terpineol were between 141 and 171 µg/m^3. The lowest values (<50 µg/m^3) were measured for β-myrcene, γ-terpinene and 4-terpineol. The drying process at 120°C caused a reduction in the terpene concentrations of more than 40%, with Σ(VOC) = 1149 µg/m^3. A significant reduction of emissions could be observed with Σ(VOC) = 193 µg/m^3 and *C*(3-carene) = 58 µg/m^3 after drying the strands for 2 h at 220°C. In this experiment, hexanal was detected in the chamber air with a concentration of *C*(hexanal) = 28 µg/m³. It should, however, be mentioned, that a temperature of 220°C is used for the pressing step of OSBs (see below) but is definitely too high for the drying of wood.

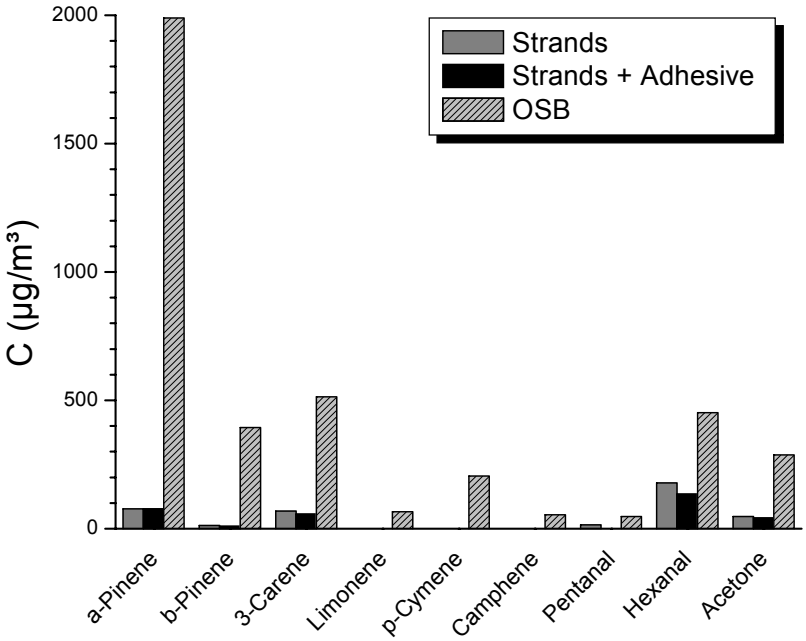

Figure 2 Chamber concentrations for terpenes emitted from dried strands, strand + adhesive and MUPF-bonded OSB 24 h after loading (see text for test conditions).

In the second experiment, the release of VOCs from industrial dried strands, strands + MUPF adhesive (= melamine–urea–phenol formaldehyde adhesive) and a MUPF-bonded OSB manufactured in WKI were compared. The chamber concentrations 24 h after loading are shown in Figure 2. In contrast to the pine chips dried under laboratory conditions in a cabinet (see Figure 1), the material used in this experiment showed a different emission behaviour. The main VOC components detected in the chamber air were terpenes, aliphatic aldehydes and acetone. The highest concentrations were monitored for *C*(hexanal) = 179 µg/m^3, *C*(α-pinene) = 78 µg/m^3 and *C*(3-carene) = 68 µg/m^3, with Σ(VOC) = 547 µg/m^3. Strands with MUPF adhesive (before pressing) showed a very similar emission pattern with *C*(hexanal) = 135 µg/m^3, *C*(α-pinene) = 78 µg/m^3, *C*(3-carene) = 57 µg/m^3 and Σ(VOC) = 321 µg/m^3. The influence of the industrial drying process, which is often carried out in a

rotating drum, is clearly visible. Hexanal, pentanal, acetone and other aldehydes and ketones are typical degradation products of wood ingredients formed under thermal stress. The dwell time of strands in a rotating drum is about 20 min. The exhaust gas from a combustor used for drying enters the drum with a temperature of more than 400°C. Therefore, the surface of the wet strands might be exposed to high temperatures (>120°C), which trigger the degradation reactions of hemi-celluloses and lignins. The temperature of the dried strands (humidity < 2%) leaving the drum is 70–80°C.

It is also obvious from Figure 2 that the pressing step has a significant influence on the emission strength. The temperature for industrial pressing is 200–225°C and the press time is 10–16 s per mm thickness. Therefore, the OSB surface can be directly exposed to temperatures >200°C for 1–3 min. Such conditions cause high VOC emissions. The OSB investigated here yielded a chamber concentration 24 h after loading of Σ(VOC) = 4061 μg/m^3 with the main components *C*(hexanal) = 453 μg/m^3, *C*(α-pinene) = 1989 μg/m^3, *C*(3-carene) = 514 μg/m^3, C(β-pinene) = 394 μg/m^3 and C(acetone) = 288 μg/m^3.

Jiang *et al*. (2002) have investigated VOC emissions from particleboard as a function of the five press variables temperature, time, resin content, moisture content and board density. In accordance with the results reported here for OSB, press time and press temperature were the most significant parameters for increased VOC values. Terpene and aldehyde emissions from particleboard and medium-density fibreboard were studied by Baumann *et al*. (1999, 2000) in test chambers (48 h values). The spectrum of detected terpenes was similar to that found for OSB, but the terpenes accounted for only 7–21% of the total VOC emission. Detected aldehydes were hexanal, heptanal, octanal, nonanal, benzaldehyde and 2-octenal, which accounted for up to 92% of the total emission of VOCs.

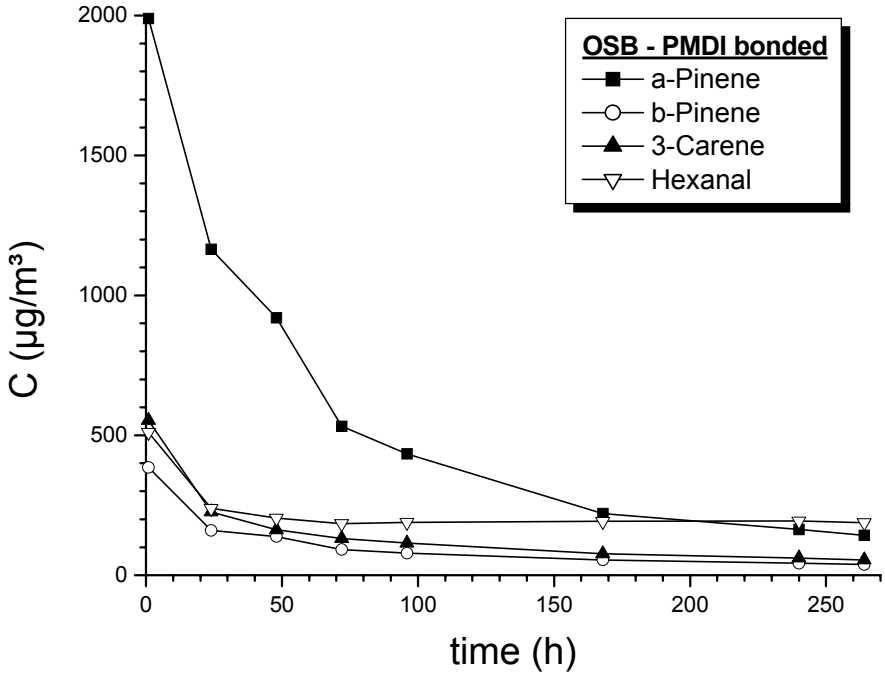

Figure 3 Concentration versus time profile for the emission of α-pinene, β-pinene, 3-carene and hexanal from PMDI-bonded OSB (see text for test conditions).

It is of interest to estimate the decay of the VOC emission profile of OSB. Therefore, a freshly produced board bonded with PMDI (= polymeric 4,4′-methylene-bis(phenyl-isocyanate)) was tested for 264 h (11 days) in a 1 m^3 chamber. The concentration versus time

profiles of the main components in the chamber air are shown in Figure 3. The highest concentration was found for α-pinene with 1990 μg/m^3 (1 h), which decayed to 143 μg/m^3 (7%) within 263 h. Similar results were obtained for β-pinene (10%) and 3-carene (10%). The initial concentration of hexanal was 511 μg/m^3 (1 h), but after 72 h the concentration remained constant at a level of 180–190 μg/m^3. This observation is typical for aliphatic aldehydes, which are released from building products on a long-term scale (Salthammer *et al*. 1999).

Table 1 Concentrations of terpenes and aldehydes in newly manufactured houses

Compound	House 1 (μg/m^3)	House 2 (μg/m^3)	House 3 (μg/m^3)
α-Pinene	448	216	319
β-Pinene	62	36	50
Limonene	71	29	36
3-Carene	66	80	154
Pentanal	45	–	17
Hexanal	156	469	80
Octanal	15	29	11
Nonanal	35	23	17
Σ(VOC)	1356	1591	Not determined

Finally, the indoor air concentrations of terpenes and aldehydes were determined in the living rooms of three newly manufactured houses with constructional elements made of OSB. The results are shown in Table 1. All objects showed similar emission characteristics, with terpenes and aldehydes being the dominant compounds. More than 20 different substances belonging to these groups could be detected, which accounted for more than 80% of the total emission. The highest concentrations were measured for α-pinene with 448 μg/m^3 in House 1 and for hexanal with 469 μg/m^3 in House 2. As the houses are new, a significant reduction of VOC concentrations can be expected within several weeks. Nevertheless, with respect to their potential for sensory irritation and low odour thresholds, elevated concentrations of terpenes and aldehydes in indoor air cause a number of problems (Hodgson *et al*., 2002). From principles of precaution it is therefore recommended that exposure to VOCs should be generally kept 'as low as reasonably achievable' (ALARA) (Mølhave, 2003). In Germany, an *ad hoc* working group has recently introduced an indoor air guideline value of 0.2 mg/m^3 for bicyclic terpenes (α-pinene) (Sagunski and Heinzow, 2003). Low VOC indoor concentrations require low VOC emissions from building materials. Strategies for VOC emission testing should therefore include measurements on a longer time-scale (Wolkoff, 2003).

CONCLUSIONS

The investigations carried out on OSBs showed that in addition to the wood species, pine, and the drying process, hot pressing is particularly responsible for the later release of VOCs. Freshly manufactured OSBs of pine strands show, besides the emission of monoterpenenes, a considerable emission of the very odorous aliphatic aldehydes pentanal, hexanal, heptanal, octanal and nonanal. These compounds are generated by thermal and oxidative degradation processes of the wood substances during the drying process and then during the pressing process in the surface layers of the OSB.

Baumann *et al*. (1999, 2000) have studied the emission behaviour of wood-based materials in test chambers and as a function of the processing parameters (Jiang *et al*., 2002). The

results showed that for many wood-based materials a reduction in the VOC emission is necessary when used for structural applications. Basic strategies leading to a reduction of the VOC emissions from (freshly manufactured) wood-based materials, like OSBs, are selection of the wood species, the pre-treatment of the raw material, the drying and pressing conditions, the sanding of the surface layers and the storage period between manufacture and processing. Nevertheless, it can be seen that for the manufacturer of OSBs and other wood-based materials the efficiency of the measures, the observation of technical parameters and the regional availability of the wood species represent decision-making reasons, the consideration of which is compulsorily required. Thus, the reduction of emission by adjustment of the pressing temperature is supposed to show the best effect.

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