Long-term development of VOC emissions from OSB after hot-pressing

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Abstract

An oriented strand board (OSB) made of Scots pine (*Pinus sylvestris* L.) was tested for volatile organic compound (VOC) emissions 24 h after the hot-pressing process over a period of 2 months. The predominant emissions from the OSB were monoterpenes and aldehydes. Terpene emissions decreased continuously, whereas aldehyde concentrations initially increased and subsequently decayed. Aldehydes are formed by the autoxidative splitting of unsaturated fatty acids contained in the wood. Due to the delayed release of aldehydes, a comparison of different emission test results is only possible if age and storage conditions are clearly specified. For a reduction in VOC emissions from wood-based materials, wood properties, manufacturing process, and storage conditions have to be considered.

Keywords: aldehydes; emissions; oriented strand board (OSB); *Pinus sylvestris*; terpenes; volatile organic compounds (VOCs).

Introduction

Oriented strand board (OSB) made of pine (*Pinus* spp.) emits several volatile organic compounds (VOCs), mainly terpenes and aldehydes. Pine contains a number of terpenes, such as α-pinene, β-pinene and 3-carene. Aldehydes arise from the degradation of unsaturated fatty acids. Back and Allan (2000) suggested that aldehydes are formed by the autoxidation of unsaturated fatty acids after the manufacturing of the wood-based panels, for example. However, this theory cannot be confirmed on the basis of actual studies. A "freshly produced" OSB investigated by Salthammer et al. (2003) showed continuously decreasing aldehyde emissions.

Wood-based panels, especially OSBs, are frequently used in the construction of houses. Terpenes and aldehydes can often be identified as major sources of VOCs in indoor air (Hodgsen et al. 2002). To reduce and control potential indoor emission sources, several national and European activities have been launched, including the German Committee for Health-related Evaluation of Building Products (Ausschuss zur gesundheitlichen Bewertung von Bauprodukten, AgBB). Its main task is the establishment of a uniform health-related assessment scheme (AgBB 2003). Thus, control and reduction of VOC emissions are relevant for manufacturers of wood-based materials.

Usually, assessment schemes are based on a 28-day test period (AgBB 2003; ECA 1997; RAL-UZ 1999). The development of VOC emissions from OSBs for longer than 28 days after hot-pressing is still unknown. The aim of this work is a long-term (2 months) analysis of VOC emissions from OSB with a focus on the formation and release of aldehydes, taking into consideration the suggestions of Back and Allan (2000). Possible factors affecting the emissions from OSB are discussed.

Materials and methods

Materials

An OSB of 25 mm in thickness produced from Scots pine (*Pinus sylvestris* L.) and bonded with polymeric methylene di(phenylisocyanate) (pMDI) was obtained from an industrial mill. A panel was taken directly after leaving the continuous hot press. After a cooling period (approx. 30 min) samples (30 cm×30 cm) were cut from the centre of the panel. To prevent exposure to or loss of VOCs during transport, the sample was placed between two panels and wrapped in aluminium foil. After transportation to the laboratory, it was cut into its final dimensions (21 cm×21 cm). To exclude any edge effects, the edges were sealed with aluminium-coated adhesive tape, with an overlap of 1 cm. The emitting area was 722 cm^2.

Approximately 24 h after leaving the hot press, the OSB was placed into an environmental testing chamber to commence the testing period (t_0). VOC emissions were determined over a period of 59 days; the samples remained inside the chamber for the whole testing period.

Only results for one sample are presented here. However, tests on other OSBs proved the emission patterns described in this work.

Methods

The sampling and analytical procedures, as well as the equipment, were in accordance with prEN 13419-1 (2003) and ISO/DIS 16000-6 (2002). Tests were performed in environmental test chambers (glass desiccators) with a volume of 23 l. Jann et al. (1999) showed good comparability of these chambers with 1 m^3 chambers constructed for measurement of VOCs and semivolatile organic compounds (SVOCs). A constant and adjustable airflow (1.200 l min^{-1}) was flowed through the chamber, corresponding to 3.1 air exchanges h^{-1}. The loading factor was $n=3.1$ m^2 m^{-3} and the resulting area-specific airflow rate was $q=1.0$ m^3 m^{-2} h^{-1}. The airflow was conditioned for temperature ($23\pm0.5°C$) and relative humidity ($50\pm3\%$). Temperature and humidity, both were measured at the inlet port.

Table 1   Development and composition of VOC emissions from OSB.

	Area-specific emission rate SER_a ($\mu g\ m^{-2}\ h^{-1}$ TE)							
	1 day	3 days	9 days	13 days	17 days	21 days	28 days	59 days
Terpenes								
α-Pinene	5758	4371	3506	2606	1613	1257	687	143
Camphene	44	36	25	27	17	14	9	0
β-Pinene	448	355	238	188	140	116	71	13
Myrcene	46	37	17	9	7	ND	ND	ND
3-Carene	2105	1520	1023	628	414	331	220	74
Limonene	59	45	42	33	33	28	18	3
Other terpenes	46	25	26	8	5	3	ND	ND
Terpinolene	29	12	ND	ND	ND	ND	ND	ND
C3/C4-Benzenes	32	29	71	78	87	74	56	14
Terpenoids	ND	ND	8	9	8	8	7	ND
Sum	8567	6430	4956	3586	2323	1831	1068	246
Aldehydes and ketones								
Pentanal	8	14	59	82	94	106	110	49
Hexanal	57	185	436	540	636	727	708	375
2-Octenal	ND	ND	12	14	23	18	12	ND
Benzaldehyde	ND	ND	8	8	12	10	9	1
Octanal	ND	ND	4	3	7	6	7	4
Nonanal	ND	ND	ND	ND	6	5	4	1
2-Heptenal	ND	ND	ND	ND	12	11	9	ND
2-Heptanone	ND	ND	ND	ND	7	8	8	5
Sum	66	199	519	647	798	891	867	435
Total	8632	6630	5476	4234	3121	2723	1935	681

ND, not detectable.

Air samples were collected on Tenax TA sorbent (200 mg, 60–80 mesh) using an air sample pump with an electronic flow controller. A sample flow rate of 100 ± 1 ml min^{-1} was used for a period of 5–40 min, giving a total air volume of 0.5–4 l. Before sampling, each tube was spiked with 199.4 ng of toluene dissolved in methanol as an internal standard.

After air sampling, the tubes were thermally desorbed using PAL/TDAS 2000 equipment (Chromtech, Germany), and compounds were then characterised and quantified by gas chromatography (HP 6895) and mass spectrometry (HP MSD 5972A). Compounds were quantitatively assessed by multiplying the chromatogram peak area for each compound by the response factor for the internal standard. Hence, all concentrations reported are toluene equivalents (TE). Such a semi-quantitative assessment describes the development of the emissions, rather than exact concentrations. Depending on the concentrations and properties of individual compounds, results deviate by approximately $\pm30\%$ from actual concentrations.

The thermodesorption conditions were as follows: desorption temperature, 250°C; desorption time, 5 min; cryofocussing, –30°C; and split ratio, 1:40. For separation, a 60 m analytical column (Zebron 1701, film 0.25 μm, i.d. 0.25 mm) was used. The GC temperature program was: 45°C hold for 10 min, increase at 5°C min^{-1} to 140°C, increase at 10°C min^{-1} to 240°C, increase at 25°C min^{-1} to 290°C, hold for 5 min. The MSD was operated in scan mode (25–40 amu) with 2.2 scans s^{-1} at an interface temperature of 280°C.

Results and discussion

Table 1 summarises the composition of the VOC emissions from the OSB. Terpenes, aldehydes and ketones were present, with terpenoids also present at relatively low concentrations.

VOC emissions decreased from 8632 (24 h) to 681 μg m^{-2} h^{-1} TE (59 days). Day one after the OSB was placed into the environmental test chamber, mainly terpenes (99.2%) were emitted. The terpene emission rate diminished constantly over the test period. Aldehyde concentrations showed a different behaviour: they increased in the first 3 weeks and decreased subsequently. At 24 h after loading the test chamber, the aldehyde emission rate was 66 μg m^{-2} h^{-1} TE; a maximum of 891 μg m^{-2} h^{-1} TE was reached after 21 days. After 59 days, the aldehyde emission rate was 435 μg m^{-2} h^{-1} TE. In contrast to the decreasing emission of terpenes, the concentration of aldehydes increased as a proportion of total VOC emissions from 0.8% (first day) to 64%.

Terpenes

Terpenes naturally occur in the oleoresin of softwoods and are important components in the defence against insects and fungi. Due to their relatively high vapour pressure at ambient temperatures, terpenes are volatile and contribute to the characteristic odours of different wood species.

The composition of the terpenes emitted in this investigation is similar to that established by several authors. It corresponds mainly with the terpene content of *Pinus sylvestris*, the principal raw material of the OSB tested (Sundin et al. 1992; Risholm-Sundman et al. 1998; Baumann et al. 1999). The composition of the terpenes emitted is shown in Table 1 and Figure 1. α-Pinene, 3-carene and β-pinene are most abundant, accounting for up to 96% of the total terpene emission at the beginning of the
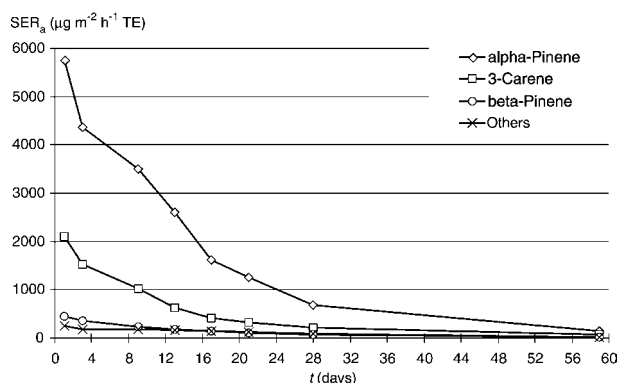
Figure 1 Terpene emission rates over 59 days.

study; after 28 days they accounted for up to 91%. Together with C3/C4-benzenes, they were the only detectable terpenes after 59 days. Moreover, camphene, myrcene and limonene were detected in amounts of 2% of all terpenes, as well as tricyclene, thujene and phellandrene. With the exception of C3/C4-benzenes, all terpenes exhibited a significant decrease over the whole testing period. On the first day, the terpene emission rate was 8567 μg m^{-2} h^{-1} TE (100%); after 28 days, this decreased to 106 μg m^{-2} h^{-1} TE (12%). The compounds *p*-, *m*- and *o*-cymene could not be distinguished due to similar mass spectra and a lack of corresponding standards. These compounds are therefore summarised as C3/C4-benzenes. After increasing until day 17 to 87 μg m^{-2} h^{-1} TE, the cymene emission rate decreased to 56 (28 days) and 14 μg m^{-2} h^{-1} TE (59 days). Cymenes can be formed by the thermal rearrangement of camphene, 3-carene and limonene (McGraw et al. 1999). In this context, it is conceivable that terpene reactions and the formation of cymene continue after exposure to elevated temperatures. Terpenoids, observed in low amounts, are oxidation products. For example, limonene oxide was detectable from the day 13 on and its amount remained constant until the day 28. This substance class could not be detected at all by day 59.

Terpene emissions depend on the extractive content of the wood and the manufacturing conditions. Salthammer et al. (2003) showed that increasing drying temperatures lead to decreasing terpene emissions from pine wood chips.
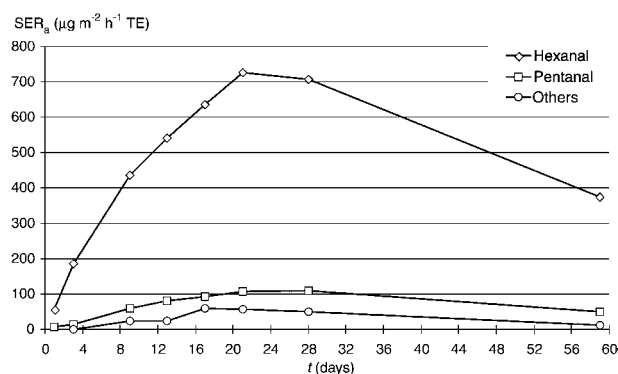
Aldehydes and ketones

Table 1 and Figure 2 illustrate the composition and development of aldehyde emissions. Such compounds do not occur naturally in wood and it is obvious that they are formed during the OSB manufacturing process. Due to low odour thresholds, some of these aldehydes contribute to the odour of OSB. Hexanal and pentanal are the most abundant; these compounds accounted for 100% (24 h), 94% (28 days), and 97% (59 days) of all aldehydes. After 28 days, 708 μg m^{-2} h^{-1} TE of hexanal and 110 μg m^{-2} h^{-1} TE of pentanal were emitted. After 59 days these concentrations decreased to 375 (hexanal) and 49 μg m^{-2} h^{-1} TE (pentanal). Octanal and nonanal were also detected. In addition, benzaldehyde and lower concentrations of the unsaturated aldehydes 2-octenal and 2-heptenal occurred. 2-Heptanone was the only ketone detected.

All aldehyde emissions seemed to behave similarly: the concentration increased significantly at the beginning and decreased slowly over the course of time. On the first day only hexanal and pentanal were detectable; other aldehydes appeared later at lower concentrations (Figure 3). Nonanal, benzaldehyde and octanal appeared on the day 9, and 2-heptenal, 2-heptanone and 2-octenal on day 17. After 28 days the emission rates of other aldehydes fluctuated between 4 (nonanal) and 12 μg m^{-2} h^{-1} TE (2-octenal). Beside hexanal and pentanal, only octanal and 2-heptanone, as well as traces of benzaldehyde and nonanal, were detectable after 59 days.

Baumann et al. (2000) investigated aldehyde emissions from particleboards and medium-density fibreboard (MDF); Salthammer et al. (2003) studied VOC emissions from OSB. Both research groups reported on numerous aldehydes similar to the compounds found here. However, in contrast to the results presented here, Salthammer et al. (2003) did not report on increasing aldehyde concentrations at the beginning of their tests. All substance classes revealed a decreasing tendency. A probable reason for the differing emission behaviour is the age of the samples tested. The OSB in this work was tested 24 h after leaving the hot press. Salthammer et al. (2003) neither specified the exact age of the sample nor the storage conditions prior to the emission test. Baumann et al. (2000) analysed emissions only after 48 h in the environmental test chamber and did not specify the age of the tested samples either.
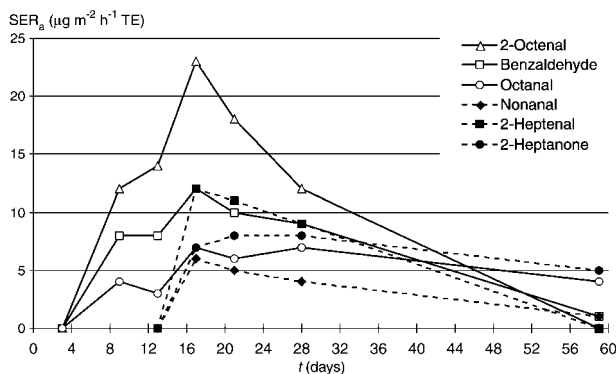

Figure 2 Emissions of aldehydes over 28 days.

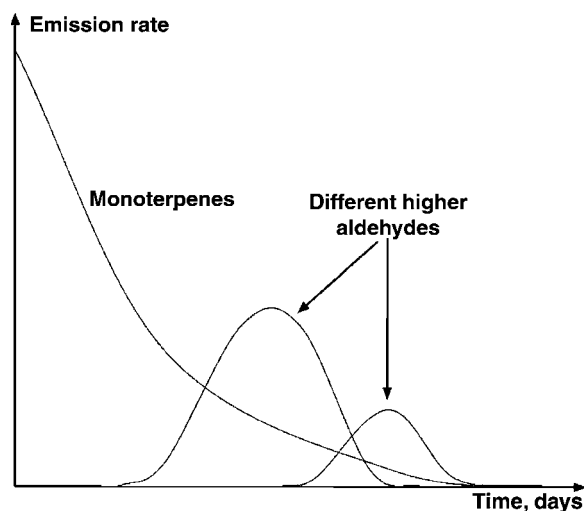**Figure 3** Emissions of other aldehydes over 28 days.

Figure 4 Expected emission rate versus time from wood-based panels (Back and Allan 2000).

Back and Allan (2000) suggested a delayed increase in aldehyde emission rates based on data for autoxidation of unsaturated fatty acids (Figure 4). These authors suggested that aldehyde emission rates plotted versus time pass through a maximum. Aldehydes are probably formed by the oxidative degradation of unsaturated lipids present in *Pinus sylvestris*. It contains mainly unsaturated fatty acids (96%), of which mono-unsaturated oleic acid (35.5%) and double unsaturated linoleic acid (40.5%) predominate (Holmbom and Ekman 1978). The dry wood of Scots pine and Norway spruce contains 3–5% triglycerides (predominantly in the sapwood) and free fatty acids (mainly in the heartwood), which can be decomposed to aldehydes (Back and Allan 2000; Piispanen and Saranpää 2002; Svedberg et al. 2004). Such reactions can be either enzyme-catalysed or occur through autoxidative reactions (Chan 1987; Noordermeer et al. 2001). High temperatures involved in the production of OSB certainly denature enzymes, so that the autoxidative path is more probable. Unsaturated fatty acids form radical-induced hydroperoxides, which split and form volatile compounds. Double unsaturated linoleic acids are supposed to be the source of 2-octenal, 2-heptenal, and 2-heptanone, as well as the predominant compounds pentanal and hexanal. Octanal and nonanal are formed through splitting of the mono-unsaturated oleic acid (Chan 1987). The origin of benzaldehyde is unknown.

One reason for the delayed occurrence of these aldehydes is the different oxidation speed of fatty acids and their esters. It is lower for fats and their esters compared to free fatty acids (Back and Allan 2000). Due to a decrease in activation energy from a monoene to a 1,4-diene, polyunsaturated fatty acids also react faster than mono-unsaturated notes (Chan 1987). This, however, does not explain the delayed occurrence of nonanal, 2-heptenal and 2-heptanone. Their initial concentrations were probably below detection limits. Autoxidation can also lead to the formation of organic acids via aldehydes (Chan 1987). Thus, due to a high hexanal concentration, the occurrence of hexanoic acid could be expected. Under the conditions of this investigation, no organic acids were detectable.

It is plausible that the inherent wood properties and the manufacturing process are the main factors influencing aldehyde emission. An autoxidative chain reaction can be initiated by transition metals contained in wood (mainly Fe, Mn and Cu) or high-energy irradiation. The high temperatures of drying and hot pressing are probably sufficient for initiation. It is also obvious that drying and pressing conditions are suited for the control of VOC emissions. Thus, Jiang et al. (2002) concluded that the press time and temperature mainly affected VOC emissions from particleboard made of hardwoods.

Definite correlations between these parameters and the resulting emissions have not been identified. Substitution of the resinous and fat-containing raw material, such as pine, could certainly reduce emissions, but this option is limited due to the regional availability of wood species. Ohlmeyer (2002) demonstrated that hot stacking significantly reduces formaldehyde emissions from wood-based panels. Formaldehyde belongs to the very volatile organic components (VVOCs) originating mainly from adhesives. It is possible that a similar effect on the aldehydes mentioned here could be achieved. With respect to limited oxygen availability inside the stack of panels, it is probable that hot stacking of panels would alter the emission development. Even though long-term storage may reduce all emissions significantly, the economic and logistical efficiency of this procedure is questionable.

Conclusions

It was demonstrated that aldehyde emission occurs after a delay. This observation supports the hypothesis of Back and Allan (2000) that aldehyde emissions from wood-based panels are not formed during the manufacturing process. Accordingly, the general comparability of test results from different laboratories is questionable as long as the start time of the emission tests is not accurately defined. Furthermore, the elapsed time between production and measurement and the storage conditions should be stated. Not only the properties of the wood species, but also the manufacturing conditions have to be considered for successful control and reduction of VOC emissions.

Acknowledgements

References

AgBB (2003) Vorgehensweise bei der gesundheitlichen Bewertung der Emissionen von flüchtigen organischen Verbindungen (VOC) aus Bauprodukten – mit aktualisierten NIK-Werten. Ausschuss zur gesundheitlichen Bewertung von Bauprodukten. pp. 2–17.

Back, E.L., Allan, L.H. Pitch Control, Wood Resin and Deresination. Tappi Press, Atlanta, GA, 2000.

Baumann, M., Battermann, A., Zhang, G.-Z. (1999) Terpene emissions from particleboard and medium-density fibreboard products. For. Prod. J. 49:49–56.

Baumann, M., Lorenz, L., Batterman, S., Zhang, G.-Z. (2000) Aldehyde emissions from particleboard and medium fibreboard products. For. Prod. J. 50:75–82.

Chan, H.W.-S. Autoxidation of Unsaturated Lipids. Academic Press, London, 1987.

ECA (1997) ECA Report No. 18. VOC emissions from building products. Solid flooring materials. European Collaborative Action: Indoor Air Quality and its Impact on Man.

Hodgsen, A.T., Beal, D., McIlvaine, J.E.R. (2002) Sources of formaldehyde, other aldehydes and terpenes in a new manufactured house. Indoor Air 12:235–242.

Holmbom, B., Ekman, R. (1978) Tall oil precursors of Scots pine and common spruce and their change during sulphate pulping. Acta Acad. Abo., Ser. B 38:1–11.

ISO/DIS 16.000-6 (2002) Determination of volatile organic compounds in indoor air and chamber air by active sampling on TENAX TA sorbent, thermal desorption and gas chromatography using MSD/FID.

Jann, O., Wilke, O., Brödner, D. (1999) Entwicklung eines Prüfverfahrens zur Ermittlung der Emissionen flüchtiger organischer Verbindungen aus beschichteten Holzwerkstoffen und Möbeln.

Jiang, T., Gardner, D.J., Baumann, M. (2002) Volatile organic emissions arising from the hot-pressing of mixed-hardwood particleboard. For. Prod. J. 52:66–77.

McGraw, G.W., Hemingway, R.W., Ingram, L.L., Canady, C.S., McGraw, W.B. (1999) Thermal degradation of terpenes: camphene, D-3-aarene, limonene and α-terpinene. Environ. Sci. Technol. 33:4029–4033.

Noordermeer, M.A., Veldink, G.A., Vliegenthart, J.F.G. (2001) Fatty acid hydroperoxide lyase: A plant cytochrome P450 enzyme involved in wound healing and pest resistance. Chem. Bio. Chem 2:494–504.

Ohlmeyer, M. (2002) Untersuchung über die Eigenschaftsentwicklung von Holzwerkstoffen nach dem Heißpressen. Dissertation Universität Hamburg 203S.

Piispanen, R., Saranpää, P. (2002) Neutral lipids and phospholipids in Scots pine (*Pinus sylvestris*) sapwood and heartwood. Tree Physiol. 22:661–666.

prEN 13419-1 (2003) Bauprodukte – Bestimmung der Emission von flüchtigen organischen Verbindungen – Teil 1: Emissionsprüfkammer-Verfahren.

RAL-UZ (1999) RAL-UZ 38: Grundlage für Umweltzeichenvergabe. Emissionsarme Produkte aus Holz und Holzwerkstoffen. RAL Sankt Augustin.

Risholm-Sundman, M., Herder, P., Lundgren, M., Vestin, E. (1998) Emissions of acetic acid and other volatile organic compounds from different species of solid wood. Holz Roh-Werkstoff 56:125–129.

Salthammer, T., Boehme, B., Meyer, B., Siwinski, N. (2003). Release of primary compounds and reaction products from oriented strand board (OSB). In: Healthy Buildings 2003, Singapore.

Sundin, E.B., Risholm-Sundman, M., Edenholm, K. (1992). Emission of formaldehyde and other volatile organic compounds from sawdust and lumber, different wood-based panels, and other building materials: A comparative study. In: 26th International Particleboard/Composite Materials Symposium, Washington State University, Pullmann, Washington. Forest Products Society, Madison, WI, USA.

Svedberg, U.R.A., Högberg, H.-E., Högberg, J., Galle, B. (2004) Emission of hexanal and carbon monoxide from storage of wood pellets, a potential occupational and domestic hazard. Ann. Occupational Hyg. 48:339–349.