Characterization of Odorants in Particleboard Coated with Nitrocellulose Lacquer under Different Environment Conditions

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Abstract

It is well known that the release of volatile organic compounds (VOCs) and odors from wood-based panels is harmful to human health. The VOCs emitted from decorative wood-based panels have been investigated generally, but information is limited regarding the key odor compounds that people find most irritating. In this experiment, particleboard coated with nitrocellulose lacquer was analyzed by gas chromatography coupled with mass spectrometry and olfactometry. Twenty odors were identified, which arose between 5 and 25 minutes. Most odorants from nitrocellulose lacquer–coated particleboard were aromatics, esters, and alcohols, whereas those from control (unvarnished) particleboard were aromatics, aldehydes, and esters. With an increasing ratio of air exchange rate to loading factor, the total VOCs concentration and the total value of odor intensity from nitrocellulose lacquer–coated particleboard declined. However, both increased as temperature and relative humidity rose. The fluctuation of total VOCs between different days tended to fluctuate more sharply when the temperature and relative humidity rose and when the ratio of air exchange rate to loading factor dropped. To accelerate the release of VOCs and odors and reduce their effects on humans, the optimum storing conditions for particleboard with a nitrocellulose lacquer after-production were 40°C, 60 percent relative humidity, and a 1.0-$m^3 \cdot h^{-1} \cdot m^{-2}$ ratio of air exchange rate to loading factor.

The topic of indoor air pollution has been increasingly attracting attention (Yang and Zhang 2014). Recently, the odor problem has become a growing topic of complaint (Kasper et al. 2017). Worrisome odors can affect human emotions, the mind, the state of the human spirit (Brattoli et al. 2013), and even health (Jones 1999, Rosenkranz and Cunningham 2003). Some researchers have found that the most worrisome odors come from volatile organic compounds (VOCs) (Tang 2008, Peng et al. 2009, Bitter et al. 2010, Du and Shen 2015, Shen et al. 2006, Deng et al. 2016). However, in some cases, people are even troubled by indoor odors with VOCs concentrations within the safety limits. Therefore, it is necessary to identify the composition of the odor and explore the relationship between odor and VOCs.

Many studies have examined the volatile compound compositions of woodwork (Shen and Jiang 2018). More recently, studies are focused on testing methods, decorative wood, and the effects of environmental factors. Liu et al. (2017b) detected VOCs emissions from three-layer parquet using a rapid test method and found that the VOCs comprised aromatic hydrocarbons and esters, and that the optimum conditions when sampling VOCs emitted from three-layer parquet using the rapid test method were 80°C, 60 percent relative humidity, and area specific air flow rate of 0.2 $m^2 \cdot m^{-3}$. Some research studied the effects of VOCs released from unfinished, polyvinyl chloride–faced (PVC-faced), and melamine-finished particleboards on indoor air quality. They found that maximum loading rates of the unfinished, PVC-faced, and melamine-finished particle-

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Table 1.—Detailed parameters of the particleboard.

Option	Parameters
Tree species	*Eucalyptus robusta Smith*
Place of origin	Guangdong, China
Thickness	12 mm
Hot-pressing temperature	225°C
Hot-pressing time	85 s
Pressing pressure	1.4 MPa
Moisture content	5.94%
Density	0.64–0.65 $g \cdot cm^{-3}$
Adhesive	melamine-modified UF resin
Resin content	180-220 $g \cdot m^{-2}$
Adhesive molar ratio	1:1.6
Adhesive pH	7.0–7.5
Solid content of colloid	55%–60%
Adhesive viscosity (Pa.s)	0.35–0.4
Adhesive curing time (s)	55-60

boards were 2.0 $m^2 \cdot m^{-3}$, 3.8 $m^2 \cdot m^{-3}$, and 3.8 $m^2 \cdot m^{-3}$, respectively (Jiang et al. 2018). Shao et al (2018) studied the effect of panel area:volume ratio on the release of various substances from different types of decorative particleboards and found that an increase of panel area:volume ratio could cause the VOCs concentration to increase, but the panel area:volume ratio does not have a linear relationship with VOCs concentration. Wang et al. (2017b) found that temperature had a greater effect on the release of VOCs from three-layer plywood than did relative humidity or the air-exchange rate. However, few reports have focused on the odors from wooden panels. Wang et al. (2018) discussed the alkyd resin enamel-coated particleboards via gas chromatography mass spectroscopy–olfactometry and found that the main odor substances released from the panels were aromatic compounds, aldehydes, and alkanes. Similar odor studies were performed on American, French, Hungarian, and Russian oak by Díaz-Maroto et al. (2008), poplar (*Populus* L. spp.), pine (*Pinus* L. spp.), and basswood (*Tilia* L. spp.) by Wang et al. (2017a), and on incense-cedar (*Calocedrus decurrens* (Torr.) Florin) by Schreiner et al. (2017).

The use of gas chromatography coupled with mass spectrometry and olfactometry technology (GC-MS/O) was proposed by Fuller et al. (1964) and improved by Acree et al. (1976, 1984) and Ullrich and Grosch (1987). There are four major detection methods for GC-MS/O (Maarse and Van der Heij 1994): dilution analysis, time–intensity analysis, detection frequency, and posterior intensity evaluations. GC-MS/O has the feature of being accurate both qualitatively and quantitatively (Hsu and Shi 2013), and it provides high sensitivity (Xia and Song 2006). It has been widely used in fields such as food (Frank et al. 2004, Sehieberle and Schuh 2006), tobacco (Cotte et al. 2010), mephitis (Bulliner et al. 2006, Chen et al. 2008), and interior decorating (Knudsen et al. 2007, Clausen et al. 2008, Burdack-Freitag et al. 2009).

As a kind of new timber, decorative wood-based panels have become widely used in furniture and interiors, thus, the VOCs and odor therein should be studied. Therefore, in this study, particleboard coated with nitrocellulose lacquer, which is commonly used for the veneer of furniture, was selected for odor identification. Different from the previous research, time and environmental factors were in the focuses of this research. The study applied a combined human-sensory and odorant-analytical method to identify the main odorants in the sampled decorative wood-based panels. The aims of this study were to identify the key odorant compounds and to explore the appropriate environmental conditions for the storage of particleboard with a nitrocellulose lacquer after-production finish. The data obtained can be used to perfect the odor library of decorative wood-based panels.

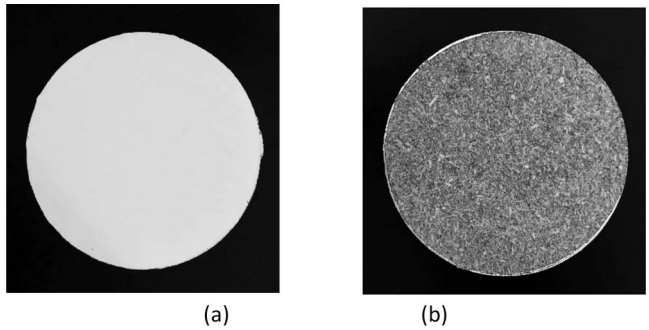


Figure 1.—Images of samples of the two kinds of boards: (a) nitrocellulose lacquer–coated particleboard, (b) particleboard.

Materials and Methods

Materials

The wood-based composite panels used in this study were Grade E1 particleboards from a furniture company in China. Table 1 lists the detailed parameters of the particleboards. After being overlaid with *Fraxinus mandshurica* veneer (0.25-mm thickness; urea formaldehyde resin and white latex with the ratio of 6:4; coating amount, 100 $g \cdot m^{-2}$; hot pressing time, 3 min; hot pressing temperature, 100°C), the nitrocellulose lacquer was applied (Bauhinia flower transparent sealer, white barrier coat, and diluent with the ratio of 3:1). A series of processes occurred: sanding (320 mesh sandpaper), brushing two times with sealer (10 $m^2 \cdot kg^{-1}$ per time), sanding (800 mesh sandpaper), and brushing two times with the barrier coat (10 $m^2 \cdot kg^{-1}$ per time). The images of the two kinds of samples are shown in Figure 1. The samples were cut into round pieces (60-mm diameter) with an exposed area of 5.65×10^{-3} m^2. After the edges of the specimens were wrapped with aluminum foil to prevent the release of compounds, the samples were stored in polytetrafluoroethylene bags and refrigerated until needed.

Sample preparation

Two liters of VOCs from nitrocellulose lacquer–coated particleboard were adsorbed by a Micro-Chamber/Thermal Extractor M-CTE250 (Markes International Inc., UK) and connected with a cylindrical volumetric flask to provide moisture and regulate the carrier gas humidity; a handheld hygrometer was also used. The temperature could be adjusted between 0°C and 250°C and the relative humidity between 30 and 80 percent. Clean and humidified nitrogen was used as the carrier gas. The cell volume was 1.35×10^{-4} per m^3, and the loading rate was 41.85 $m^2 \cdot m^{-3}$. Four replicate samples were made and subjected to different conditions during a sampling cycle of 8 hours. The experimental schemes are detailed in Table 2. After sampling, the Tenax TA sampling tubes were wrapped in polytetrafluoroethylene bags until needed.

Table 2.—Experimental scheme.

Experimental scheme	Research direction	Temperature (°C)	Relative humidity (%)	Ratio of air exchange rate and loading factor ($m^3 \cdot h^{-1} \cdot m^{-2}$)
A	Standard environment	23	40	0.5
B	Influence of temperature	23/30/40	40	0.5
C	Influence of relative humidity	23	40/60	0.5
D	Influence of ratio of air exchange rate and loading factor/($m^3 \cdot m^{-2} \cdot h^{-1}$)	23	40	0.2/0.5/1.0

Methods

Analysis of VOCs.—A unity thermal analysis desorption unit (Markes International) was used with nitrogen as the carrier gas, set at the following parameters: thermal desorption temperature, 280°C; cold-trap adsorption temperature, −15°C; thermal analysis time, 10 minutes; and injection time, 1 minute. The DSQ II series quadrupole GC-MS unit came from Thermo Fisher Scientific (Schwerte, Germany). Chromatography was performed with a DB-5 quartz capillary column (3,000 mm [length] × 0.26 mm [inner diameter] × 0.25 μm [particle sizes]; Agilent Technologies, USA). Helium was used as the carrier gas, with a constant velocity of 1.0 $mL \cdot min^{-1}$ by splitless injection. The chromatographic column was initially kept at 40°C for 2 minutes; then, the temperature was increased to 50°C (in $2°C \cdot min^{-1}$ increments) and was held at that temperature for 4 minutes. Finally, the temperature was increased to 250°C in $10°C \cdot min^{-1}$ increments and held there for 8 minutes, with the injection port temperature also at 250°C. The following GC-MS conditions were used: ionization mode, electron ionization; ion energy, 70 eV; transmission line temperature, 270°C; ion source temperature, 230°C; and mass scan range, 50 to 650 atomic mass units.

Identification of odor.—The Sniffer 9100 Olfactory Detector came from Brechbühler AG (Echallens, Switzerland). The photograph of the GC-MS/O test set-up is shown in Figure 2. The transmission line temperature was 150°C, and nitrogen was used as the carrier gas through a purge valve. Moist air was added to prevent dehydration of the nasal mucosa of the odor assessors. Direct-intensity methods were chosen for analysis of the compounds. After specific training, four assessors (between 20 and 30 y old, with no history of smoking and no olfactory organ disease) formed an odor-analysis evaluation group, and the experimental environment was set to reference standard EN 13725-2003 (NSAI 2003). The room was well ventilated, and there were no peculiar smells within the room. The temperature was kept at 23°C ± 2°C throughout the entire experiment. Activities such as eating, which might have an effect on indoor odors, were forbidden for 5 hours before the experiment. During a GC run described above, the human sensory-evaluation assessors recorded the odorant's characteristic and intensity value as well as retention time. A six-point Likert-type scale, ranging from 0 to 5, was used for intensity judgment, according to Japanese standards (Ministry of the Environment 1971): 0 = none, 1 = very weak, 2 = weak, 3 = moderate, 4 = strong, and 5 = very strong. The method of fingerprint span was used simultaneously to further verify the results. Experimental results were finally recorded when the same odor characteristics were described by at least two assessors. The intensity value was based on the average value from the assessors.

The odorants were identified by comparing the MS spectra to the National Institute of Standards and Technology and Wiley (Hoboken, New Jersey, USA) MS libraries, which matched degrees up to 800 or more. An internal-standard method was used in this experiment, with deuterium substituted for toluene at a concentration of 200 $ng \cdot \mu L^{-1}$, which added 2 μL. The internal-standard quantitative-analysis method used the following equation:

$$M_i = A_i \times \left(\frac{M_s}{A_s}\right) \quad (1)$$

where M_s is the mass of the internal standard added to the calibration standard; A_i and A_s are the peak areas of the products tested and the internal standard, respectively; and

Figure 2.—Photograph of the gas chromatography coupled with mass spectrometry and olfactometry (GC-MS/O) test set-up.

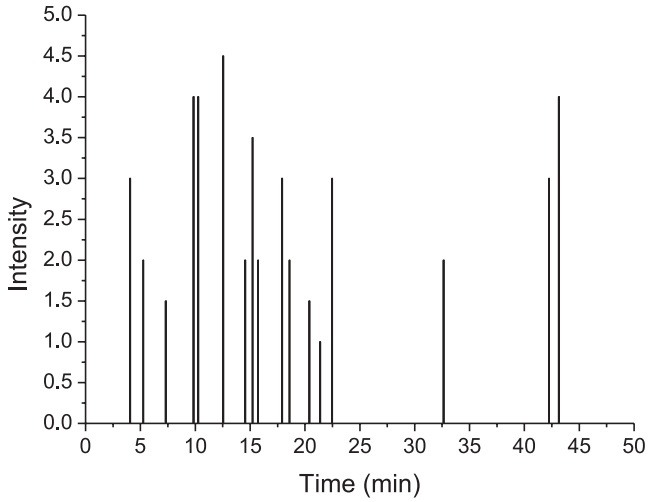


Figure 3.—Odor-time intensity spectrum of the nitrocellulose lacquer–coated particleboard.

M_i is the mass of the sample to which the internal standard is added. The refractive index values for the compounds were calculated by the retention time of *n*-alkane under the same conditions (Van Den Dool and Katz 1963).

Results and Discussion

Characterization of odor-active compounds

The GC total ion flowchart and the odor time–intensity spectrum under scheme A (a standard environment) of particleboard coated with nitrocellulose lacquer tested by GC-MS/O are shown in Figure 3. Approximately 20 kinds of odors were identified. The time during which they were noticeable was concentrated from 5 to 25 minutes, with a few appearing from 30 to 45 minutes. Referring to the acute toxicity classification of compounds given by the World Health Organization (WHO/IPCS 1996) (Table 3), the odor compound characteristics and relevant parameters of the nitrocellulose lacquer–coated particleboard and control particleboard can be determined (Tables 4 and 5). Most odorants from nitrocellulose lacquer–coated particleboard were aromatics, followed by esters and alcohol, whereas the control particleboard was found to contain more aromatics, aldehydes, and esters. Among the odorants of nitrocellulose lacquer–coated particleboard, aromatics and alcohols have greater toxicities than ketones and esters. According to the UL 2821-2013 standard (Greenguard Environmental Institute 2006), ethylbenzene, *o*-xylene, butanoic acid ethyl ester, 2-butanol, and 2-butoxy-ethanol should be given greater attention.

Referring to the relevant research literature (Schreiner et al. 2017), the odor profiles of two categories of particleboard were drawn to show the odor characteristics (Fig. 4). According to the results of the odor profile analysis, for particleboard coated with nitrocellulose lacquer, the sweet fruit smell was the most dominant odor impression, with a rating of 5.0, followed by leather and mixed smell (3.0), and then aromatic (2.25). The attributes bitter almonds, cream, banana, burned leather, grape, grass, and sweet orange were rated with low intensity (2.0), whereas the attributes minty and wine were rated with even lower intensity (1.5). Consequently, the odor profile of the particleboard coated with nitrocellulose lacquer can be described as being mainly sweet fruit, leather, and mixed smell. At the initial stage, the overall evaluation of the sample was rated as 4.5, corresponding to an intense perception. For particleboard, charcoal and cream were the strongest perception (3.0), followed by sweet and bitter (2.0), and then oil (1.5). The attributes wheat, fresh, flower, and sweet fruit were rated with only minor intensity (1.0). The overall evaluation of the particleboard's sample was rated as 3.5, corresponding to a medium perception.

There was no direct correlation between the odor intensity and concentration of the different odorant compounds. However, the concentration can affect the odor intensity for certain types of compounds. Both et al. (2004) also found that odor intensity is logarithmically related to odorant concentration (Stevens's law or the power law) which can be calculated with the following equation:

$$I = K \log C \tag{2}$$

where I is the odor intensity, K is a constant, and C is the mass concentration of the odorant.

Effects of temperature on odor and TVOCs emissions

It can be seen from Figure 5 that the total VOCs (TVOC) and the total value of odor intensity under higher temperature was consistently higher than the lower temperature over the 35-day period. Aromatics, esters, and alcohols were the main odorant substances released from nitrocellulose lacquer–coated particleboard. In equilibrium, the proportion of the odorant compounds from TVOCs increased with the raise of temperature. At 23°C, 30°C, and 40°C, the proportions were 55.11, 67.76, and 70.56 percent, respectively. The mass concentrations of odorant aromatics, esters, and alcohols all grow with an increase in temperature.

TVOCs and odor intensities of nitrocellulose lacquer–coated particleboard at 23°C, 30°C, and 40°C all decreased from day 1 to day 35. The TVOCs and odor intensities of

Table 3.—Acute toxicity classification of compounds by the World Health Organization.

Toxicity classification	Rats orally LD_{50} ($mg \cdot kg^{-1}$)[a]	Rats inhaled and dead (1/3–2/3 in 4 h)	Rabbit transdermal LD_{50} ($mg \cdot kg^{-1}$)
Severe toxicity	<1	<10	<5
Highly toxicity	1–50	10–100	5–43
Moderate toxicity	51–500	101–1,000	44–350
Low toxicity	501–5,000	1,001–10,000	351–2,180
Slight toxicity	5,001–15,000	10,001–100,000	2,181–22,590
Nontoxic	>15,000	>100,000	>22,600

[a] LD_{50} = 50 percent lethal dose.

Table 4.—Composition of odorant compounds from nitrocellulose lacquer-coated particleboard.

Compounds	Retention index	Mass concentration ($\mu g \cdot m^{-3}$)	Toxicity classification	Odor character	Odor intensity	Possible sources
Aromatic compounds						
Ethylbenzene	853	11,147.52	Low	Aromatic	3.5	Particleboard emission, paint solvent
O-xylene	862	5,326.01	Low	Bitter almonds	2	Paint solvent
1,2,4-trimethyl-benzene	981	48.06	Low	Aromatic	1	Naphtha cracking in paint solvent
1,3,5-trimethyl-benzene	1,006	16.11	Low	Mixed smell	3	Naphtha cracking in paint solvent
Cyclohexyl-benzene	1,404	11.58	Low	Cream	2	Paint solvent
1,2,4,5-tetramethyl-benzene	1,108	24.99	Slight	Camphor	0	Plasticizer in coating
Ketones						
2,6-dimethyl-4-heptanone	959	302.02	Slight	Minty note	1.5	Paint solvent
Esters						
Acetic acid 1-methylpropyl ester	737	3,753.36	Slight	Sweet fruit	4	Paint solvent, diluent, spice
Acetic acid 2-methylpropyl ester	755	1,111.47	Slight	Sweet fruit	4	Paint solvent, diluent, spice
Butyl acetate	801	4,358.35	Slight	Sweet fruit	4.5	Particleboard emission, paint solvent, diluent
3-methyl-acetate 2-butanol	840	2,446.25	Slight	Banana, burned leather	2	Paint solvent, diluent
Ethyl butyrate	787	20.06	Slight	Sweet fruit	0	Paint solvent
Alcohols						
2-butanol	<600	285.72	Low	Grass, grape	2	Paint co-solvent
2-pentanol	683	336.45	Low	Sour grape wine	1.5	Paint solvent, spice
2-butoxy-ethanol	904	23.54	Low	Leather	3	Paint solvent
(E)-6-nonen-1-ol	919	2,327.82	Low	Sweet orange	2	spice

nitrocellulose lacquer–coated particleboard reached their maximum values on Day 1 (initial stage) and gradually decreased until a stable phase was achieved. The decreasing trend was due to a concentration difference between the interior and external environments. According to the theory of mass transfer, the VOCs inside the particleboards will continue to release until the concentration difference disappears (Liu et al. 2017a). Jia and Chai (2001) also found that the material order of the magnitude of the diffusion coefficient in liquid and solid zones, in general, was from 10^{-9} $m^2 \cdot s^{-1}$ to 10^{-12} $m^2 \cdot s^{-1}$, whereas the material order of the magnitude for the diffusion coefficient in the solid zone can drop to 10^{-6} $m^2 \cdot s^{-1}$. So, the mass transfer resistance of the VOCs in the gas-phase boundary layer is far less than it is within particleboard. As time goes on, the VOCs mass transfer resistance within the material increases, and, at the same time, the release coefficient decreases, so the release of VOCs lessens.

The TVOCs between different temperatures gradually narrowed as time went on, but for the total value of odor intensity, there was a great difference under different temperatures during the release process. The standard deviations of 30°C and 40°C were around 1.1 and 1.2 times larger than 23°C, which indicated that when the temperature increased, the TVOCs between different days tended to fluctuate more sharply. On the first day, 54,962.01 $\mu g \cdot m^{-3}$ TVOCs was detected at 23°C, while the TVOCs at 30°C and 40°C stood at 60,198.36 $\mu g \cdot m^{-3}$ and 65,156.33 $\mu g \cdot m^{-3}$. In a state of equilibrium, TVOCs at 23°C dropped to 504.77$\mu g \cdot m^{-3}$. By contrast, the TVOCs at 30°C fell by around 1.8 times TVOCs at 23°C, and TVOCs at 40°C declined by around 2.4 times compared to TVOCs at 23°C. On the first day, the total values of odor intensity were respectively 36, 40, and 43.25 at 23°C, 30°C, and 40°C, and then declined to 7.75, 13, and 14.75 in equilibrium.

Table 5.—Composition of odorant compounds from particleboard.

Compounds	Retention index	Mass concentration ($\mu g \cdot m^{-3}$)	Toxicity	Odor character	Odor intensity
Aromatic compounds					
Benzene	642	4.56	Low	Burnt	1
Ethylbenzene	849	187.25	Low	Aromatic	1
1,3-dimethyl-benzene	858	152.56	Low	Aromatic, sweet	2
Styrene	875	101.16	Low	Charcoal, cream	3
1-ethyl-2-methyl-benzene	912	2.42	Low	Mixed smell	0
1,2,4-trimethyl-benzene	981	4.15	Low	Aromatic	0
1-methylene-1h-indene	1165	75.60	Low	Bitter, oil	2
1-methyl-naphthalene	1340	9.44	Low	Wheat	1
Aldehyde					
Hexanal	775	6.25	Low	Sweet	2
Nonanal	1085	3.31	Low	Oil, flower, fresh	1
Esters					
Acetic acid, butyl ester	800	20.47	Slight	Fresh and sweet fruit	1
Alkenes					
D-limonene	1023	3.36	Low	Lemon	0

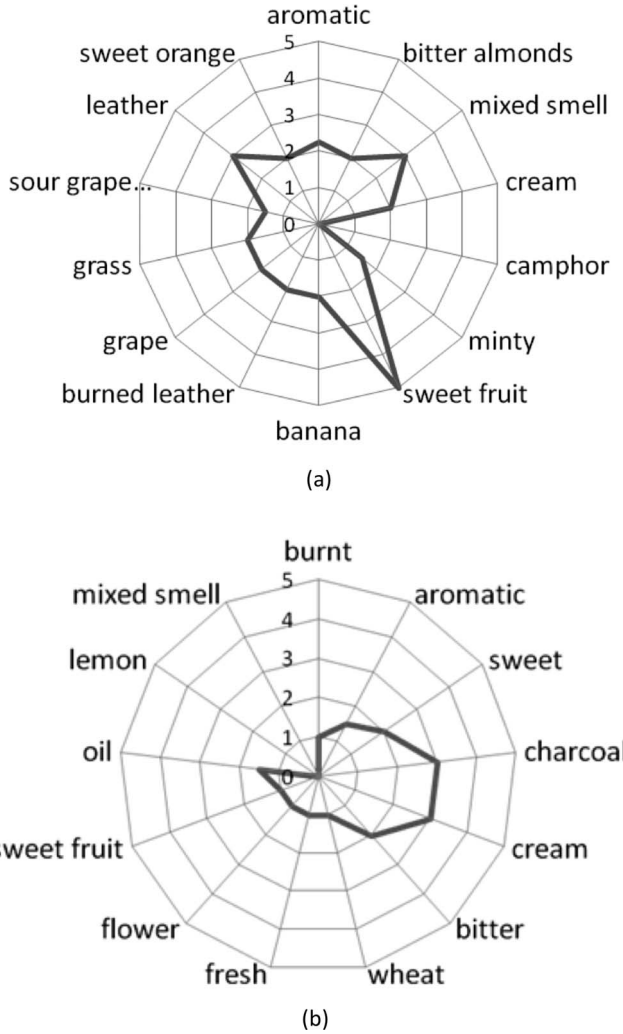


Figure 4.—Odor profiles of two particleboards: (a) nitrocellulose lacquer–coated particleboard, (b) particleboard.

An increase in temperature promoted the release of VOCs and odor from the untreated particleboard and nitrocellulose lacquer–coated particleboard. When the temperature increased, the release of VOCs molecules within the interior of the particleboards and the surface lacquer were accelerated. At the same time, the material diffusion, desorption, evaporation, and chemical reactions also increased, which can cause a rapid emission of TVOCs (Wang et al. 2017b). The relationship between temperature and the VOCs diffusion coefficient within a material is simplified in the following equation (Li et al. 2013):

$$D = D_{ref} \exp\left| -E\left|\frac{1}{T} - \frac{1}{296}\right|\right| \quad (3)$$

where D is the internal diffusion coefficient of the material (in $m^2 \cdot h^{-1}$), D_{ref} is the internal diffusion coefficient of the material at 23°C (926 K), E is determined by the test coefficient (generally valued at 9,000 K), and T is the thermodynamic temperature (in K). Temperature influences VOCs emissions through its effect on the diffusion coefficient. Conversely, with an increase in temperature, the mass transfer resistance decreases, which promotes the release of the VOCs within the material.

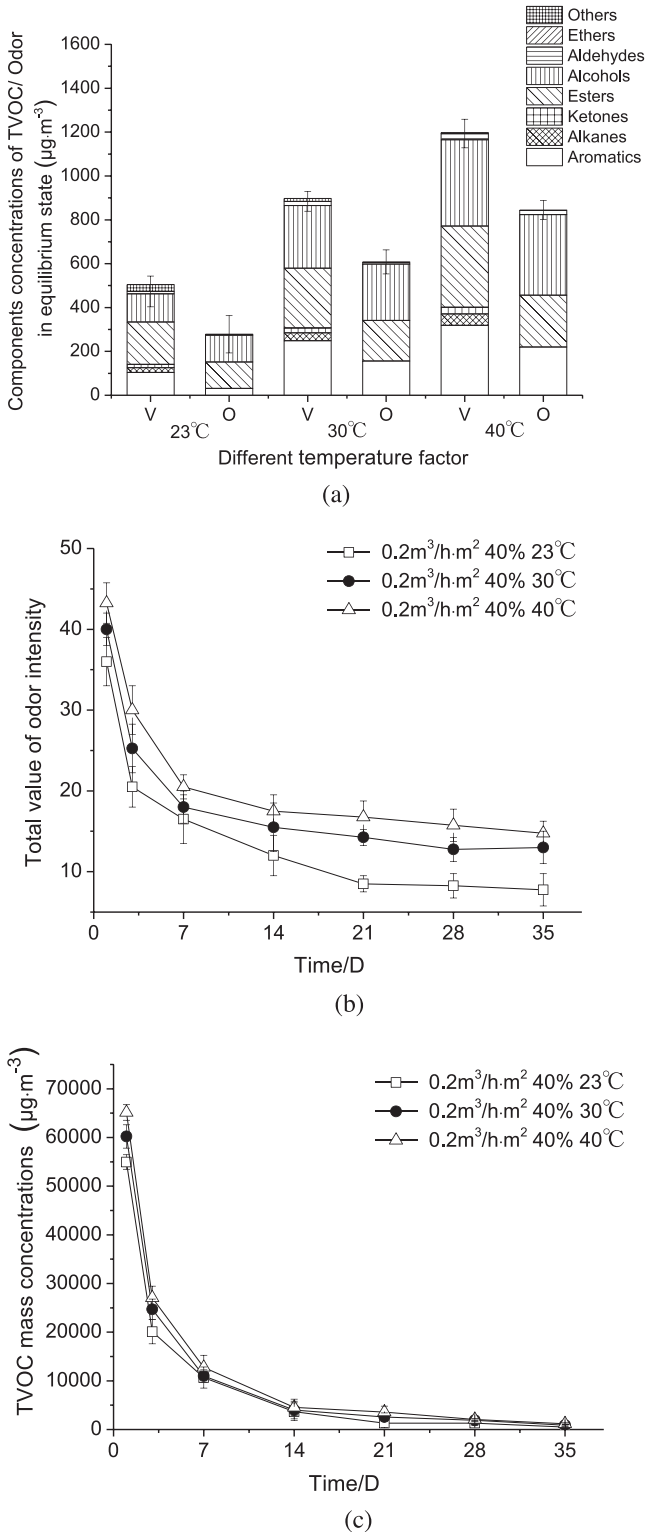
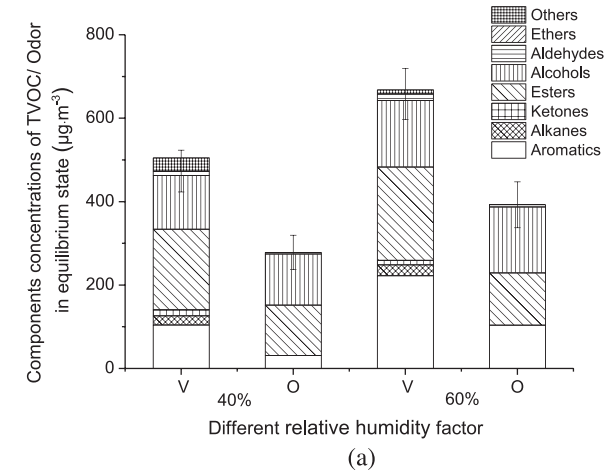


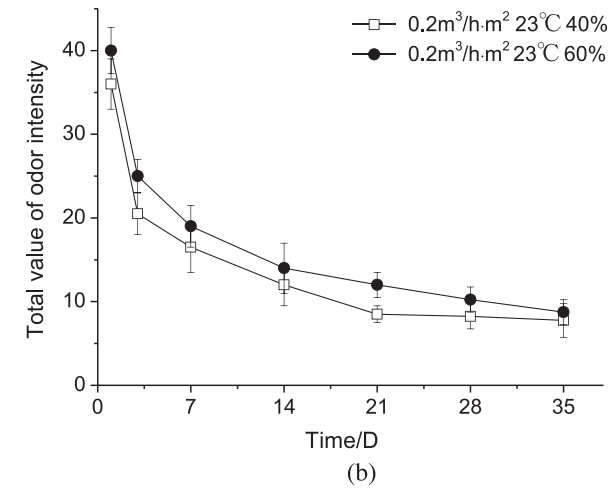
Figure 5.—The effect of temperature on total odor intensity and total volatile organic compound (TVOC) mass concentration: (a) TVOC and odor component concentrations, (b) total value of odor intensity, and (c) TVOC mass concentration.

Effects of relative humidity on odor and TVOCs emissions

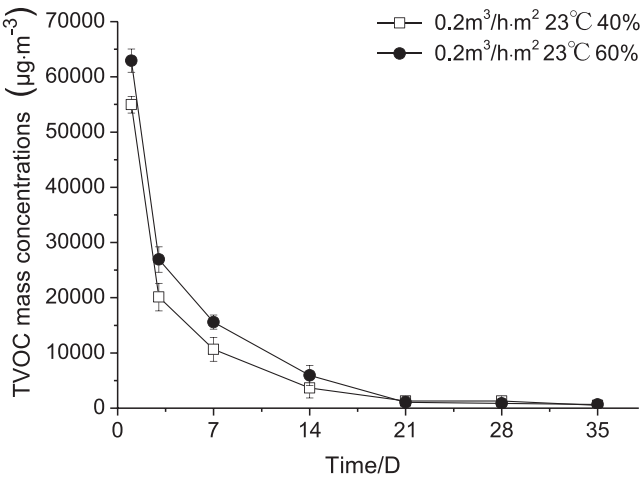
Figure 6 shows the total odor intensity and TVOCs mass concentration under various relative humidity levels. In



(a)



(b)



(c)

Figure 6.—The effect of relative humidity on total odor intensity and total volatile organic compound (TVOC) mass concentration: (a) TVOC and odor component concentrations, (b) total value of odor intensity, and (c) TVOC mass concentration.

equilibrium, at relative humidities of 40 and 60 percent, the proportion of the odorant compounds within the TVOCs were, respectively, 55.11 and 58.76 percent. For the nitrocellulose lacquer–coated particleboard, the mass concentrations of major odorants, such as aromatics, esters, and aldehydes, were also positively correlated with the relative humidity.

The TVOCs and total value of the odor intensity from nitrocellulose lacquer–coated particleboard increased with the rise of relative humidity, which may be explained by a change in pore structure from an increase in hydrolysis. The expansion of pores in the drying layer and the hygroscopicity of the particleboard favor the release of VOCs (Shan et al. 2013, Zhu et al. 2013). In addition, the moisture content of the oil coating increased with an increase in relative humidity, which might be caused by a decrease in the mass transfer resistance as the release coefficient increased, which, thereby, led to an acceleration in VOCs emissions. Similar to the tendency of temperature, the standard deviation of relative humidity of 60 percent was around 1.15 times larger than relative humidity of 40 percent, which indicated that when the relative humidity increased, there tended to be a high dispersion degree, and the TVOCs between different days fluctuated sharply. The TVOCs between different relative humidities gradually narrowed as time went on.

Effects of the air exchange–loading factor ratio on odor and TVOCs emissions

Figure 7 shows the total odor intensity and the TVOCs mass concentration under various air exchange–loading factor ratios. The air exchange–loading factor ratio appeared to have little effect on the proportion of odorant compounds composing the TVOCs. Under air exchange rates and loading factors of 0.2, 0.5, and 1.0 $m^3 \cdot h^{-1} \cdot m^{-2}$, the proportions of the odorant compounds in the TVOCs of the nitrocellulose lacquer–coated particleboard were 55.30, 55.11, and 57.12 percent, respectively. However, with an increase in the air exchange rates and loading factors, the mass concentration of odorant components decreased.

When the ratio of the air exchange rate to the loading factor increased, the TVOCs and total value of the odor intensity of nitrocellulose lacquer–coated particleboard decreased. In the early stages, the effects on the TVOCs and odor release were more significant. As time went on, the distinction between TVOCs and total odor intensity under various ratios gradually diminished. The higher ratios of air exchange to loading factor tended to accelerate the release of VOCs. Yu et al. (2006) and Yang et al. (2007), who studied the influence of natural ventilation on VOCs emissions from interior furnishings, also found that increased ventilation reduced VOCs concentrations. Large amounts of fresh carrier gas can dilute VOCs emissions within the microcell extraction, which then enlarges the concentration gradient between the microcell extraction and particleboard panels, thereby promoting the release of VOCs and reducing their concentration while, at same time, reducing the total value of the odor intensity. The standard deviations of 0.2 and 0.5 $m^3 \cdot h^{-1} \cdot m^{-2}$ were around 27 and 14 percent higher than that of 1.0 $m^3 \cdot h^{-1} \cdot m^{-2}$. When the ratios of air exchange to loading factor declined, the standard deviation rose, and the TVOCs tended to fluctuate more sharply.

Conclusion

Approximately 20 kinds of odors from nitrocellulose lacquer–coated particleboard were identified in this experiment. The time of odor detection was concentrated from 5

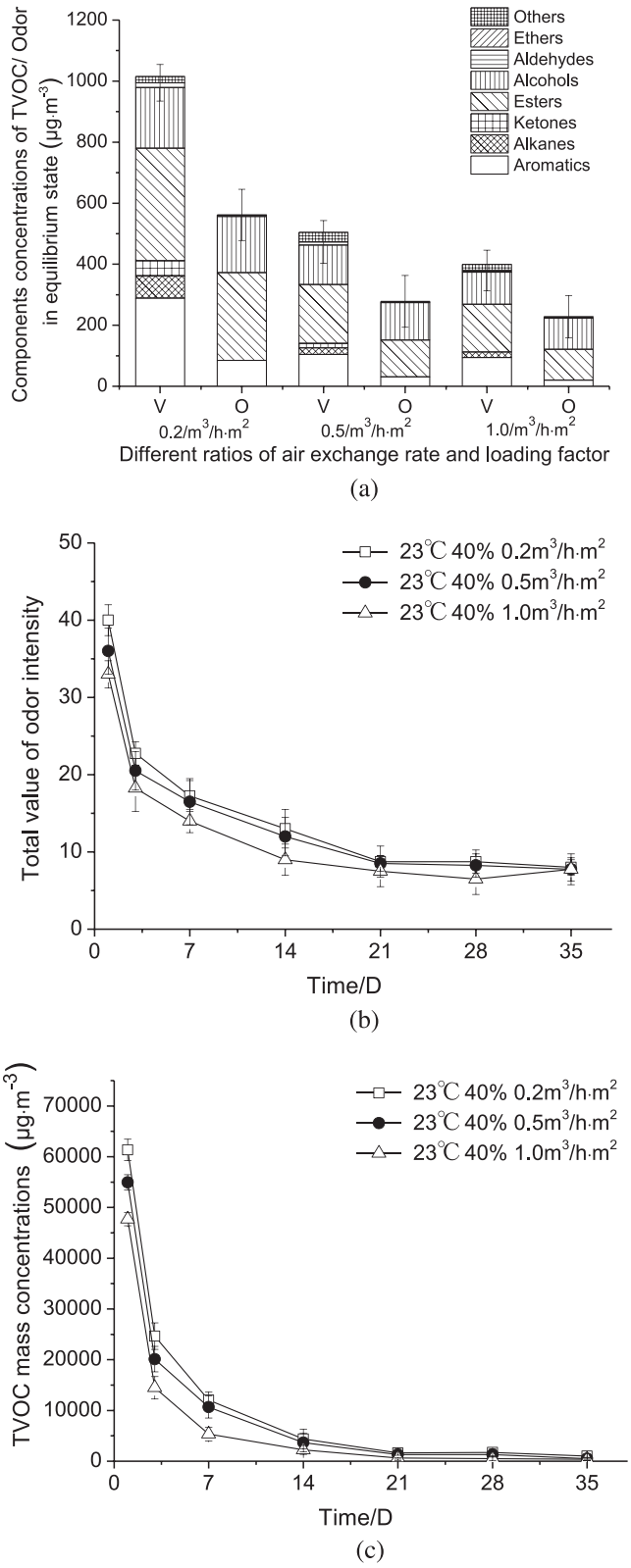


Figure 7. —The effect of ratios of air exchange rate and loading on total odor intensity and total volatile organic compound (TVOC) mass concentration: (a) TVOC and odor component concentrations, (b) total value of odor intensity, and (c) TVOC mass concentration.

to 25 minutes, and a few appeared from 30 to 45 minutes. The odor profile of the particleboard coated with nitrocellulose lacquer can be described as mainly sweet fruit, leather, and mixed smell. Aromatics, esters, and alcohols were the main odorant substances released from nitrocellulose lacquer–coated particleboard, whereas those from control particleboard were primarily aromatics, aldehydes, and esters.

The TVOCs and odor intensities of nitrocellulose lacquer–coated particleboard reached their maximum values on the initial stage and gradually decreased until a stable phase was achieved.

The TVOCs concentration and the total value of odor intensity increased as temperature and relative humidity rose. The fluctuation of TVOCs between different days presented a similar trend. The standard deviations of 30°C and 40°C were around 1.1 and 1.2 times larger than at 23°C, and the standard deviation of relative humidity of 60 percent was around 1.15 times larger than relative humidity of 40 percent. However, with a decrease in the ratio of air exchange rate to loading factor, the TVOCs concentration and the total value of odor intensity from the nitrocellulose lacquer coating increased, at the same time the TVOCs between different days tended to fluctuate more sharply. The standard deviations of 0.2 and 0.5 $m^3 \cdot h^{-1} \cdot m^{-2}$ were around 27 and 14 percent higher than that of 1.0 $m^3 \cdot h^{-1} \cdot m^{-2}$. The proportion of the odor substance in the TVOCs increased with an increase in temperature and relative humidity, while the ratio of air exchange rate to loading factor had little effect on the concentrations.

These results suggest that a storage environment which has higher temperature, relative humidity, and air exchange rate to loading factor ratio will accelerate the VOC and odor emissions of nitrocellulose lacquer–coated particleboard. The optimum conditions of storing particleboard with a nitrocellulose lacquer after-production were 40°C, 60 percent relative humidity, and a 1.0-$m^3 \cdot h^{-1} \cdot m^{-2}$ ratio of air exchange rate to loading factor.

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