Emission Characteristics and Health Risks of Volatile Organic Compounds and Odor from PVC-overlaid Particleboard

Qifan Wang,[a] Jun Shen,[a,*] Tianyu Cao,[a] Jianhui Du,[b] Huajun Dong,[a,c] and Xiwei Shen [d]

Indoor air quality has become a focus of people's attention. The emission characteristics and health risks of volatile organic compounds (VOCs) and the odor emitted from polyvinyl chloride (PVC) overlaid particleboard were investigated. A synthetic index-olfactory evaluation method was used to estimate the health risks of PVC, caused by VOCs and odor based on the technology of gas chromatography-mass spectroscopy/olfactometry. Olfactory analyses and instrument detection were implemented to indentify the crucial odor-active compounds. The results demonstrated that the highest concentration of VOCs and highest odor intensity occurred in the initial stage. Overall, a total of 17 odor-active compounds, including aromatic hydrocarbons, ketones, esters, alcohols, and aldehydes, were identified from PVC, while aldehydes, ketones, and esters were the most harmful constituents. Pleasant, sweet, and spicy fragrances were the key odor characteristics. It was shown that covering of the surface could effectively prevent the release of VOCs and odors, and the increased thickness would raise the emission of VOCs when the change of the total odor intensities was low. Based on the evaluation, at room temperature of 23 °C ± 1 °C, it was suggested that PVC should be stored in a well-ventilated place (more than 0.5 $m^3m^{-2}h^{-1}$) for at least 28 days before it is used indoors.

Keywords: PVC-overlaid; Particleboard; Odorant; GC-MS/O; Sensory analysis; Synthetic index-olfactory evaluation method

Contact information: a: Northeast Forestry University, Harbin, China; b: Sichuan University, Chengdu, China; c: Harbin University of Commerce, Harbin, China; d: Harvard University, Boston, MA, USA;
** Corresponding author: shenjunr@126.com*

INTRODUCTION

Volatile organic compounds (VOCs), which are harmful to the human body (Shen *et al*. 2001), are considered as crucial parameters for testing air quality both indoors and outdoors (Kumar *et al*. 2014). Research has shown that direct exposure to VOCs may affect the respiratory system, hematopoietic system, and nervous system (Tong *et al*. 2019), causing sensory irritation (Daisey *et al*. 2003), allergies (Tagiyeva and Sheikh 2014), airway inflammation (Kwon *et al*. 2018), and leukemia (Gao *et al*. 2014). According to the World Health Organization (WHO), more than two million premature deaths per year are due to the effects of air pollution. The qualified indoor air quality has been defined by the institution of American heating, refrigerating, and air conditioning engineers (ANSI/ ASHRAE Standard 62-2001 (2003)), where a qualified environment is defined as the concentration of harmful substances below the limit. At the same time, the people in the surrounding environment must feel comfortable. However, limited information is available on the odor-active substances contained in the material that affect the environment. It contradicts the increasing attention of the odorant problem from furniture and interior decorations (Nibbe 2017). Related research shows that even though the concentration of VOCs is below the limit, the odor also can affect people's state of mind, spirit, and overall health (Aatamila *et al*. 2011).

In an indoor environment, the emission of VOCs and odor are mainly from furniture and flooring, which are made from wood-based panels. The VOCs emissions from wood-based panels have been investigated in recent years. Most studies have focused on emission components, testing methods, and effects of environmental factors (Liu *et al*. 2017; Wang *et al*. 2017). However, there are reports that pay attention to the odor problem from wood-based panels. Some scholars have investigated odor emissions from solid wood (Schreiner *et al*. 2018) and lacquered wood-based panels (Wang *et al*. 2018). They identified the odor-causing compounds and explored the effects of environmental factors on the volatile organic compounds (VOCs) and odor emissions, while the health effects in wooden boards have not been studied. In addition, characteristics of VOCs and their impacts on the indoor air of wood-based panels have been reported, while the effects of odor were not evaluated (Liu and Zhu 2012; Jiang *et al*. 2018a). Therefore, it is of great significance to clarify the odor and levels of VOCs during the use, which could contrast the data between VOCs and odor and provide more odor analyses, increasing the ability to control it.

As an effective method, the gas chromatography-mass spectroscopy/olfactometry technology (GC-MS/O) was used in this experiment. The GC-MS/O not only combined the excellent separation techniques of gas chromatography and the abundant structural information produced by a mass spectrometer (Hsu and Shi 2013), but also the human sense of smell, which may exceed many chemical detectors (Xia and Song 2006). There are four major GC-MS/O detection methods (Maarse and Van der Heij 1993): dilution analysis, time-intensity analysis, detection-frequency method, and posterior-intensity evaluation. The GC-MS/O has been widely used to select and evaluate active odor substances from complex mixtures (Zhang *et al*. 2009), such as tobacco (Cotte *et al*. 2010), food (Machiels *et al*. 2003; Frank *et al*. 2004; Gómez-Miguez *et al*. 2007), flavorings and spice (Choi 2005; Dharmawan *et al*. 2009), building materials (Huang *et al*. 2016), and environmental monitoring (Rabaud *et al*. 2002; Bulliner *et al*. 2006). However, GC-MS/O has not been widely used in the wood and furniture industry.

Wood-based panels, such as particleboards, are widely used in interior decoration and furniture for the decreasing forest area (Shen and Jiang 2018; Wu *et al*. 2016). After covering the surface with a decorative layer, particleboards present a beautiful appearance; however its problems of VOCs and odor should not be overlooked. To reduce the harm caused by VOCs and odor to human health, TVOC and odor from two different types of decorative particleboards were studied in this article. The characteristics of the odor compounds were identified, and the release trends have been obtained. The synthetic index-olfactory evaluation method was established to evaluate the panel and then explore the suitable storage time.

EXPERIMENTAL

Materials

The wood-based composite panels used in this study were E1 grade particleboards (PB) from a furniture company in China (Suofeiya Home Collection Co., Ltd, Guangdong, China). Table 1 lists the detailed parameters of the particleboards and overlaying process.

The experimental panels were either particleboards with no surface lamination or panels that were overlaid with polyvinyl chloride (PVC) (the main components include PVC resins, plasticizers, stabilizers, fillers, *etc*.). The samples were cut into round pieces (60-mm diameter) for the micro chamber/thermal extractor apparatus, and the exposed surface area was 5.65×10^{-3} m^{-2}. The images of the two kinds of samples are shown in Fig. 1. After the edges of the specimens were sealed with aluminum foil to prevent the release of compounds, the samples were stored in polytetrafluoroethylene (PTFE) bags and refrigerated until needed.

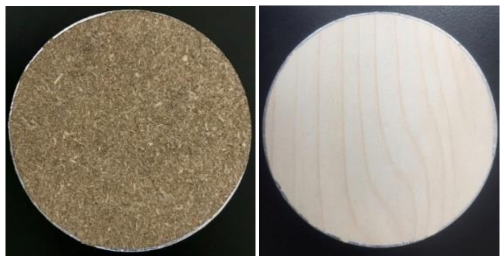

Fig. 1. Experimental samples: (a) PB and (b) PVC

Table 1. Detail Parameters of the Particleboard and Overlaying Process

Option	Parameters of PB	Parameters of Overlaying Process
Tree species	*Eucalyptus robusta* Smith	-
Thickness (mm)	8/18	-
Hot-pressing temperature (°C)	225	185
Hot-pressing time (s)	8 to 50 / 18 to 120	60
Pressing pressure (MPa)	1.4	19.5
MC (%)	5.94	-
Density (g/cm³)	0.64 to 0.65	-
Adhesive	Melamine-modified UF resin	Melamine-modified UF resin
Resin content (g/m²)	180 to 220	180 to 220
Adhesive molar ratio	1:1.6	1:1.6
Adhesive pH	7.0 to 7.5	7.0 to 7.5
Solid content of colloid (%)	55 to 60	55 to 60
Adhesive viscosity (Pa.s)	0.35 to 0.4	0.35 to 0.4
Adhesive curing time (s)	55 to 60	55 to 60

Sample preparation

The micro-chamber/thermal extractor (μ-CTE 250; Markes International Inc., Llantrisant, UK), consisted of four cylindrical microchambers (each with a microcell diameter of 64 mm wide × 36 mm deep). The Tenax TA tube (Markes International Inc., Llantrisant, UK) used in this experiment had a stainless steel pipe body and contained 200 mg of 2,6 dibenzofurans porous polymer, which could adsorb or desorb the VOCs efficiently.

A total of 2 litres of air containing VOCs for each sample from the materials was collected using the Tenax TA tubes. The main experimental conditions were set to a suitable living condition for humans (temperature 23 °C ± 1 °C, relative humidity 40% ± 5%, and an air exchange rate to loading factor ratio of 0.5 $m^3m^{-2}h^{-1}$ ± 0.05 $m^3m^{-2}h^{-1}$) based on the GB/T 18883 (2002) standard. The cell volume was 1.35 × 10^{-4} m^{-3}, and the loading rate was 41.85 m^2 m^{-3}. The VOCs released from the specimen surfaces were absorbed by the Tenax-TA tubes and were recorded at 1, 3, 7, 14, 21, and 28 days. Four samples were collected during a sampling cycle of 8 h to ensure accurate test results. After sampling, the Tenax TA tubes were wrapped in PTFE bags until needed, and the samples were removed and placed in the space with good ventilation and non-pollution.

Methods

Analysis of chemical compounds

Gas chromatography-mass spectroscopy/olfactometry (GC-MS/O) was used to analyze the chemical components. This technology was based on the unity thermal analysis desorption of unit I (Markes International Inc., Llantrisant, UK), a DSQ II series GC-MS (Thermo Fisher Scientific, Schwerte, Germany), and a Sniffer 9100 olfactory detector (Brechbühler AG, Echallens, Switzerland). The basic GC-MS/O parameters were as follows: 1) the parameters for thermal extractor: the carrier gas was nitrogen and a desorption temperature of 280 °C, a cold-trap adsorption temperature of -15 °C, thermal analysis time of 10 min, and an injection time of 1 min; 2) the parameters for GC-MS: chromatography was performed with a DB-5 quartz capillary column (a length of 3,000 mm × inner diameter of 0.26 mm × particle sizes of 0.25 μm). The carrier gas was helium of 99.996%, and the distribution flux rate was 1 mL/min. The chromatographic column was initially kept at 40 °C for 2 min; then, the temperature was increased to 150 °C (in 2 °C min^{-1} increments) and held at that temperature for 4 min. Finally, the temperature was increased to 250 °C (in 10 °C min^{-1} increments) and held at that temperature for 8 min. The injection port temperature was 250 °C. The following GC-MS parameters were used: ionization mode, electron ionization; ion energy at 70 eV; transmission line temperature at 270 °C; ion source temperature at 230 °C; and a mass scan range of 40 amu to 450 amu. The parameters for olfactory detector: the effluent of the GC capillary was divided into two parts, one part entered the mass spectrometer, and the other part was used for human sensory evaluation (ratio 1:1). The transmission line temperature was 150 °C, and nitrogen was used as the carrier gas through a purge valve. Humidified air was added to prevent dehydration of the nasal mucosa of the odor assessors.

The GC-MS and its built-in software were used to analyze the VOCs. The MS detection peaks were identified in the 2008 spectral library of the National Institute of Standards and Technology (NIST, Gaithersburg, MD) (matching degrees up to 800 or above). An internal-standard method was used in this experiment, with deuterium substituted for toluene at a concentration of 200 ng μL^{-1}, of which the added amount was 2 μL. The internal-standard quantitative-analysis method used the following equation,

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

where M_i is the mass (μg) of the internal standard added to the calibration standard, A_i and A_s are the peak areas (mvAmin) of the products tested and the internal standard, respectively, and M_s is the amount (μg) of the internal standard.

Identification of odor-active compounds

According to ISO 12219-7 (2017), four assessors (between 20 years old and 30 years old, with no history of smoking and no olfactory organ disease) were chosen after specific screening and training, which formed an odor-analysis evaluation group. The detailed process is shown in Fig. 2. The deionized water and n-butanol solution with the concentrations of 2 mL/L, 10 mL/L, 20 mL/L, 30 mL/L, and 99.5% n-butanol solution were prepared, and then were deposited in the following conditions: insulation of light, heat, and oxygen, 23 °C ± 2 °C, and a relative humidity of 40% ± 10%. The preparation times and concentrations were labeled. The solutions' storage lives were 3 days. One hour before the test, the prepared solutions were put into six wide-mouth 1-L bottles. The odor evaluation description of the solutions is shown in Table 2. The requirements of assessors were listed as following: for different grades of standard solution, the assessors could describe the odor characteristics correctly within 10 s, and they could remember the distinctive characteristics after the first smelling. After five min, when the labels were hidden, they could distinguish the odor grade correctly within 10 s (the correct rate should be higher than 80%); and the assessors could correctly point out the error when the solution was mislabeled deliberately (the correct rate should be higher than 80%).

Table 2. Odor Evaluation Description of n-Butanol Solution

Classification of Solutions	Grade	Odor Evaluation and Description
Deionized water	0	No smell, no sense
2 mL/L	1	Perceptible, slight intensity
10 mL/L	2	Perceptible, medium intensity, but no irritation
20 mL/L	3	Strong and irritant odor
30 mL/L	4	Very strong and intensively irritant odor
99.5% n-butanol solution	5	Unbearable odor

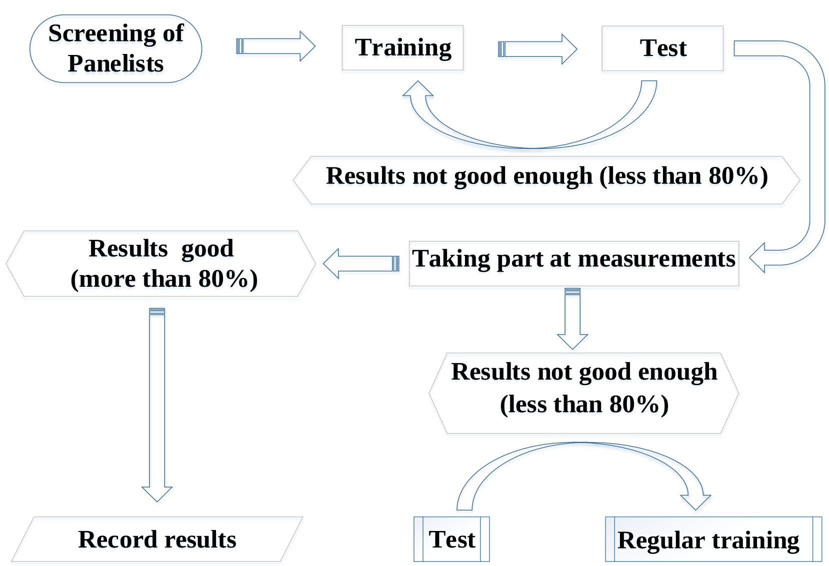

Fig. 2. Sniffer detection process of GC-O

After the training in Fig. 2, four sensory assessments (between 20 years old and 30 years old, with no history of smoking and no olfactory organ disease) were chosen to form an odor-analysis evaluation group. The experimental environment was set referring to standard BS EN 13725 (2003). The room was well ventilated, with no peculiar smell. The temperature was kept at 23 °C ± 2 °C throughout the entire experiment. Activities that might have an effect on indoor odors were forbidden for 5 h before the experiment. The Sniffer 9100 olfactory detector was used and combined with GC-MS. A time-intensity method was chosen in GC-O for analysis of the odorants. The intensity classification ranging from 0 to 5 refer to the Japanese evaluation standards (Ministry of the Environment Law No. 91 of 1971): 0 = none, 1 = very weak, 2 = weak, 3 = moderate, 4 = strong, and 5 = very strong. The fingerprints span was used simultaneously to verify the results. When the sample was injected, the human sensory-evaluation assessors simultaneously perceived and described the characteristics of the column outflow, which were detected by GC-MS from the odor port. Experimental results were recorded when the same odor characteristics were described by at least two assessors at the same time. The intensity value was based on the average value from the different assessors. The odorants were identified through comparing the MS spectra to the National Institute of Standards and Technology (NIST) library. The refractive index value was calculated by the retention time of n-alkane (C6-C30) under the same conditions (Dool and Kratz 1963).

Evaluation

The synthetic index evaluation method combined the index of different components (Eq. 2) and the synthetic index (Eq. 3), which comprehensively reflected the effect of hazardous substances on indoor air:

$$I_i = \sum \frac{C_i}{S_i} \tag{2}$$

$$I = \sqrt{\left(\frac{1}{n}\sum\frac{C_i}{S_i}\right)\max\left(\frac{C_1}{C_2},\frac{C_2}{S_2},\cdots,\frac{C_n}{S_n}\right)} \tag{3}$$

In Eq. 1 and Eq. 2, C_i is the concentration of one component (μg/m^3), and S_i is the standard limit. The index reaches the standard when $I_i < 1$. A larger I_i value results in a higher severity of pollution. The concentration limits of aromatic compounds, aldehydes, and ketones (excluding formaldehyde), alkanes, esters, alkenes, and total volatile organic compounds (TVOC) were 50 μg/m^3, 20 μg/m^3, 100 μg/m^3, 20 μg/m^3, 30 μg/m^3, and 300 μg/m^3, respectively (Liu 2012). The indoor air hazard level was divided into five levels according to the synthetic index (Zhang *et al*. 2012) (Table 3). Sensory evaluation was based on the subjective sensation of human beings, which reflected the overall odor evaluation of the boards. The assessment class is shown in Table 4.

Table 3. VOCs Quality Level Based on Synthetic Index

Synthetic Index	Level	Evaluation	Effects on Human Health
≤ 0.49	I	Clean	Best living environment
0.50 to 0.99	II	Unpolluted	Suitable living environment
1.00 to 1.49	III	Light pollution	Normal living environment (exclude sensitizers)
1.50 to 1.99	IV	Middle pollution	Damage on human health
≥ 2.00	V	Heavy pollution	Damage on human health greatly

Table 4. Odor Quality Assessment Class

Assessment Class	Comfort Evaluation	Odor Evaluation
A	Very comfortable	Odorless
B	Generally comfortable	Very weak
C	Generally comfortable (exclude sensitizers)	Weak
D	A slight influence on comfort	Moderate
E	A strong influence on comfort	Strong
F	A serious influence on comfort	Very strong

RESULTS AND DISCUSSION

Characterization of Odor-active Compounds

Figure 3 shows the odor-time intensity spectrums of the PB and PVC (8 mm). Compared to PB, the odors' intensities of PVC were generally reduced, indicating that the PVC veneer could prevent the emission of PB to a certain extent. Some odorants (ethylbenzene, styrene, 1-ethyl-2-methyl-benzene, 1,2,4-trimethyl-benzene, d-limonene, and nonanal) released from PB disappeared after they were overlaid, while the others (benzene, hexanal, acetic acid, butyl ester, 1,3-dimethyl-benzene, 1-methylene-1H-indene, and 1-methyl-naphthalene) remained. The odor intensities of the remaining compounds decreased, while the intensity of 1-methyl-naphthalene did not change. The odorants of PVC were concentrated from 5 min to 15 min, with a few odorant substances appearing from 15 min to 40 min, and the occurrence time of odorants from PB was from 5 min to 35 min. The PVC reached the maximum intensity at 4.11 min, with the intensity of 2, when the PB peaked at 3 min at 16.37 min.

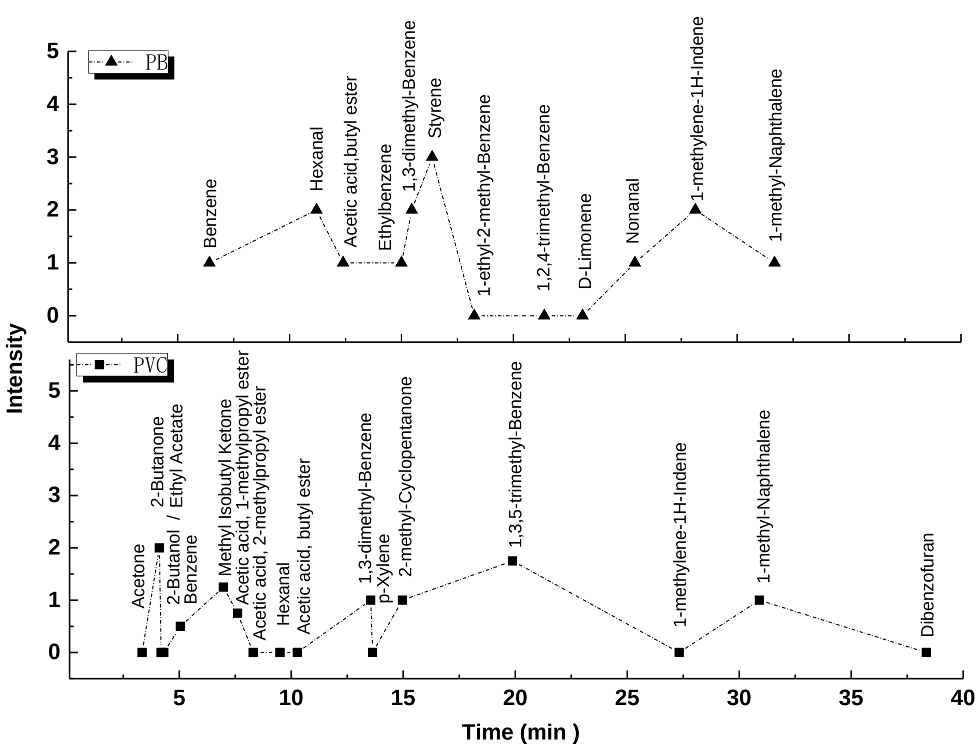

Fig. 3. The time-intensity spectrum of odorants

The odorant and source profiles of overlaid particleboard were drawn to show the odor characteristics and possible sources (Fig. 4). The results showed pleasant fragrance, sweet, and spicy were the key odor characteristics of PVC, with a rating of 2.25, 2.0, and 2.0, respectively, followed by mixed smell (1.75). The attributes honey (1), wheat (1), soil (1), fresh fruit (0.75), and burnt (0.5) rated with low intensities. For PB, the chief odor characteristics were creamy, fatty, and charcoal, with the rating of 3, followed by pleasant fragrance, sweet, and bitter with the rating of 2, and the other characteristics of burnt, wheat, flower, fruit, and fresh were rated with a low intensity of 1. The adhesive was the primary source of odor from PVC (total intensity of 4.5), and the odors were also released from the PVC and PB, with the same intensity of 2.5.

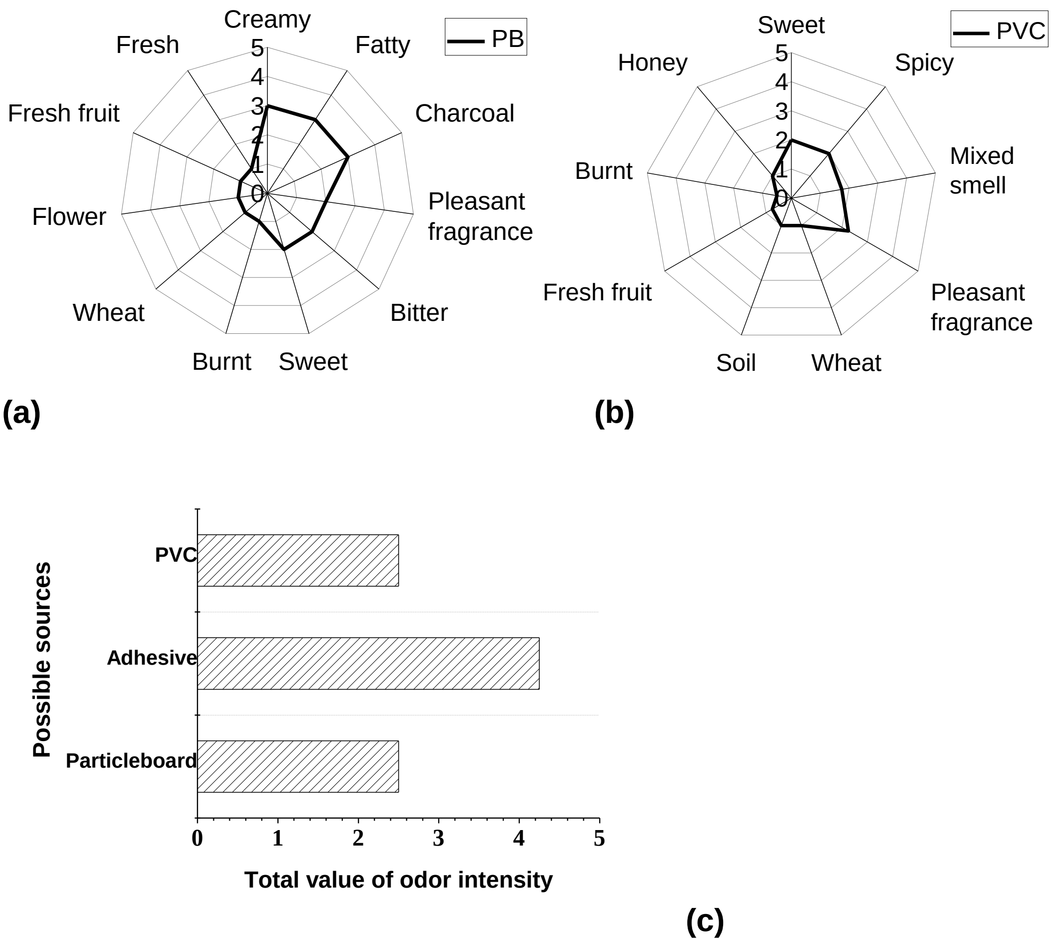

Fig. 4. Odor characteristics and sources profiles: (a) PB odorant profile; (b) PVC odorant profile; and (c) PVC sources profile

Referring to the acute toxicity classification of compounds given by the World Health Organization (WHO/IPCS 1996), the odor compound characteristics and relevant parameters of PVC were determined (Table 5). The key odor components of PVC were primarily from aromatics, ketones, and esters. Odorant components were also found in the alcohols and aldehydes. Among the compounds released from PVC, the benzene, p-xylene, butyl acetate, and 2- butanol were included in the list "VOCs from office furniture in greater than 10% of all products" from UL 2821-2013 (2013), which should be watched carefully.

Table 5. Composition of Odorant Compounds from PVC

Components	Compounds	RI	Mass concen-tration (μg·m^{-3})	Toxicity Classifi-cation	Odor Character	Odor Intensity	Possible Sources
Aromatic compounds (7)	Benzene	< 600	3.73	Low	Burnt	0.5	PB emission
	1,3-dimethyl-Benzene	822	43.00	Low	Fragrant, honey	1	PB emission
	p-Xylene	824	13.62	Slight	Pungent, fragrant	0	PVC film coating agent and adhesive
	1,3,5-trimethyl-Benzene	948	4.63	Low	Mixed smell	1.75	Stabilizer of polyester resin
	1-methylene-1H-Indene	1140	9.53	Low	Bitter, oil	0	PB emission
	1-methyl-Naphthalene	1284	4.55	Low	Wheat	1	PB emission
	Dibenzofuran	1493	2.41	Low	Almond, licorice	0	High temp. lubricant in preparation of PVC
Ketones (4)	Acetone	< 600	6.39	Slight	Special spicy	0	Adhesive mundificant
	2-Butanone	< 600	7.27	Low	Spicy, sweet	2	Adhesive mundificant
	Methyl Isobutyl Ketone	667	64.00	Low	Pleasant fragrance	1.25	Adhesive
	2-methyl-Cyclopentanone	848	92.44	Low	Soil	1	Solvent
Esters (4)	Acetic acid, 1-methylpropyl ester	696	330.67	Slight	Pleasant fruit scent,sweet	0.75	Preparation of PVC
	Acetic acid, 2-methylpropyl ester	713	1.20	Slight	Pleasant fruit scent, sweet	0	Preparation of PVC
	Acetic acid, butyl ester	755	18.38	Slight	Pleasant fruit scent, sweet	0	PB emission, organic solvent
	Ethyl Acetate	< 600	5.84	Slight	Pleasant fruit scent, sweet	0	Adhesive solvent
Alcohols	2-Butanol	< 600	1.38	Low	Sour, bitter	0	Adhesive mundificant, PVC plasticizer, & cosolvent
Aldehydes	Hexanal	738	5.10	Low	*Grass*	0	PB emission

* The information of mass concentration came from GC-MS tests.

VOCs and Odors Emission Properties and the Effect of Thickness

The trend of VOCs and odor emissions from PVC-overlaid particleboard with two kinds of thickness (8 mm/18 mm) were explored. Figure 5a shows that TVOC and total odor intensity released from the boards generally decreased over time. In the early stage, the TVOC and total odor intensity reached their maximum values, and then they decreased over time until a stable phase was achieved. The VOC concentrations sharply decreased on day 1 to day 7; after day 7 the rate of the decline slowed. That trend was due to the larger concentration difference between the VOCs and the external environment during the early release. According to the theory of mass transfer, the VOCs inside the particleboard continued to release until the concentration difference disappeared (Liu *et al*. 2017).

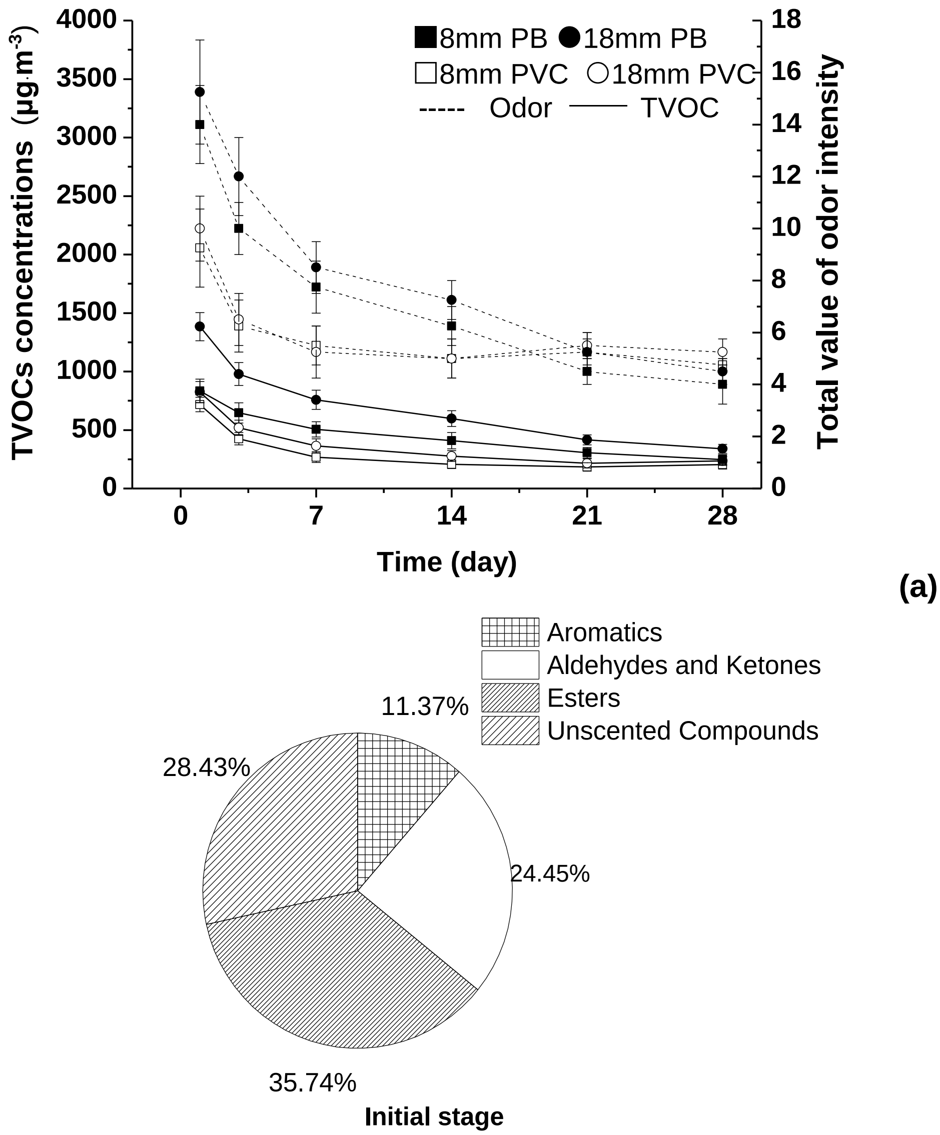

Fig. 5a. TVOC and total odor intensity release characteristics: (a) TVOC and total odor release trends from panels with different thicknesses

(b)

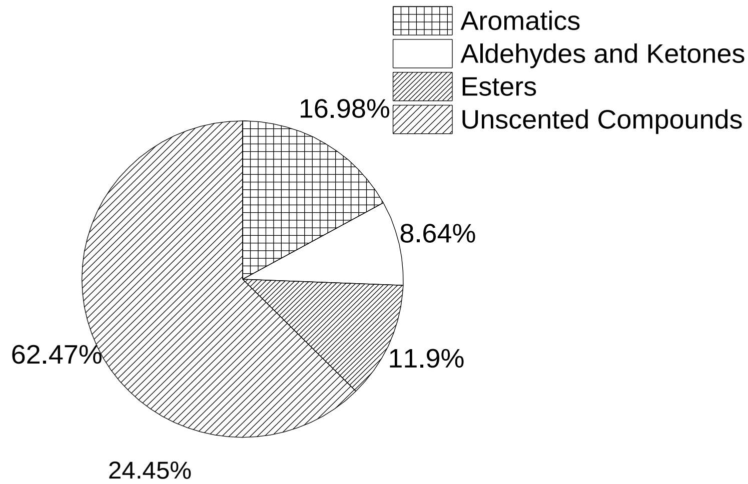

Fig. 5b. TVOC and total odor intensity release characteristics: the percentages of odorant substances in the initial and stable phases

For the boards with the same thickness, the TVOC and total odor intensity of PB were consistently higher than PVC during from day 1 to day 14. The gap between them gradually narrowed over time. It showed that surface decoration could effectively prevent the release of VOCs (Yali *et al*. 2018; Jiang *et al*. 2018b) and the odors inside the plate; however, the total odor intensity of PVC exceeded PB after day 21. Considering the deviation and subjective differences of assessors, there was little difference in the total odor intensity between the PVC and PB after day 21, and the total odor intensities were low during these periods. The TVOC slightly increased as the thickness of the particleboard increased when the changes of the total odor intensities were not obvious. In the early stages, the TVOC from 18-mm-thick PVC was greater than that of 8-mm-thick at 106.5 μg m^{-3}, while the total odor intensity was higher at approximately 0.75. When the emissions reached a plateau, the TVOC and total odor intensity of 18-mm-thick PVC was still more than the 8-mm-thick board at approximately 31μg m^{-3} and 0.5 μg m^{-3}, respectively. Related research also shows that a thicker board would emit more VOCs (Sun 2011), and the overlaying can prevent the VOCs emission from the PB, but because of the void structure it cannot completely prevent their release.

Figure 5b presents the main odor components from PVC with the thickness of 8 mm. Aromatics, aldehydes, ketones, and esters were the main odorant substances released from PVC during the initial and equilibrium state. Ester was the major odor source in the initial stages, while the proportion of ester dropped from 35.8% to 11.9% from the initial stages to the equilibrium state. In contrast, there was a noticeable increase in the percentage of odorant aromatics, which grew from 11.4% to 17.0% and became the major odor source in the equilibrium stage. Aldehydes and ketones accounted for 24.4% and 8.6% in the two stages, respectively. The percentage of unscented compounds from PVC more than doubled from 28.4% to 62.5%.

Synthetic Index-olfactory Evaluation

The synthetic index-olfactory evaluation method was used to evaluate the 8-mm-thick samples. Figure 6 shows the index of how each component and the odor evaluation changed with time. Generally, the index of most components reached its peak at the first day and gradually declined. Aromatics and esters were the major hazardous components of PB. Despite how the index of aromatics sharply dropped with time, it still exceeded 1 with the index of 2.48 and 1.45 at day 28, respectively. During the time of day 1 to day 28, the synthetic index I_i of PB was consistently higher than 1. At day 28, the synthetic index was 1.63, which indicated a middle level of pollution. Single component concentration was given full attention in the method of synthetic index, and the synthetic index was calculated based on the concentration of each component. Therefore, even though the concentration of TVOC had reached the standard at 28 days, with the index of 0.82, the synthetic index still exceeded 1 and had not reached the standard. The indoor use of PB at this stage was still not recommended because of the hazards of aromatics and esters. The odor evaluation of PB was class E in day 1, which strongly influenced the comfort, and it rose to class D during days 3 to 7, showing a slight effect on the comfort. At day 14, the odor evaluation reached the general comfort level condition of C (excluding sensitizers), and then reached class B at day 21.

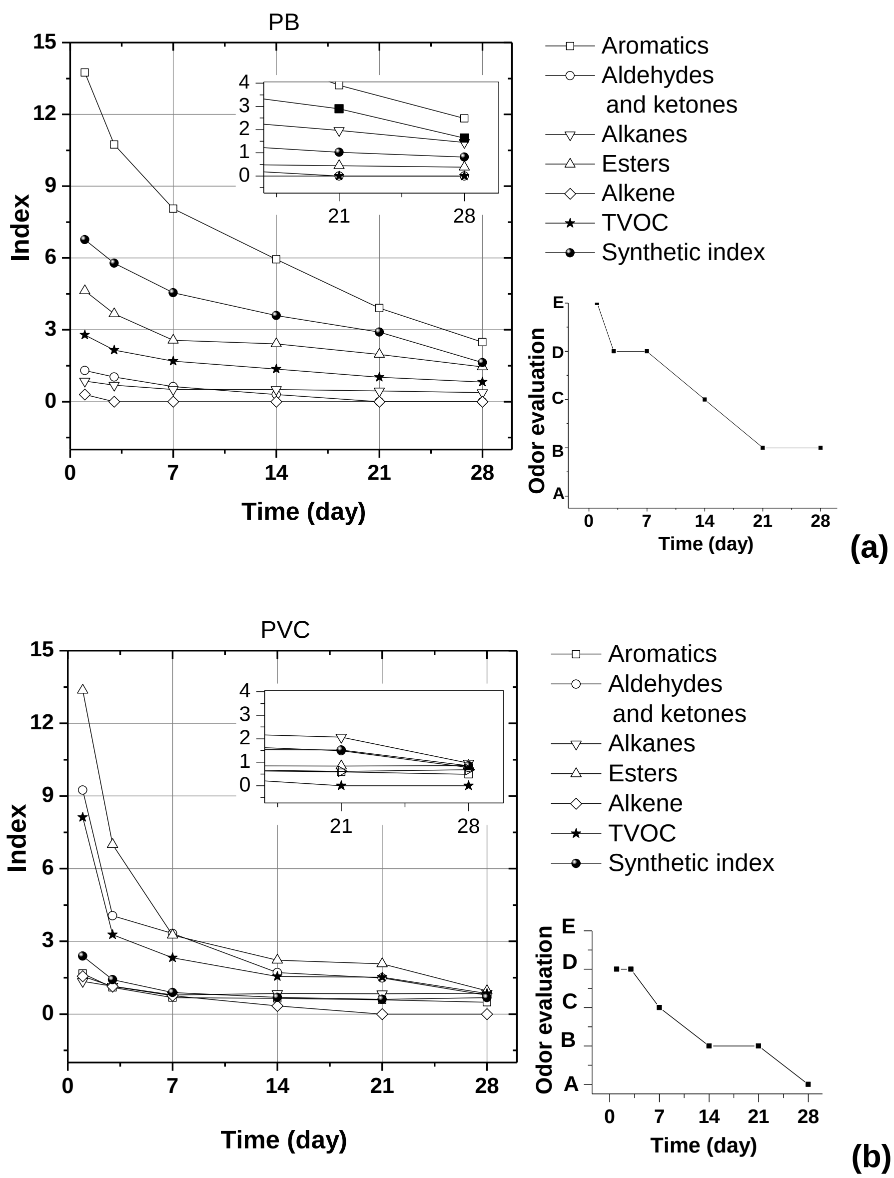

Fig. 6. Synthetic index-olfactory evaluation for (a) PB and (b) PVC

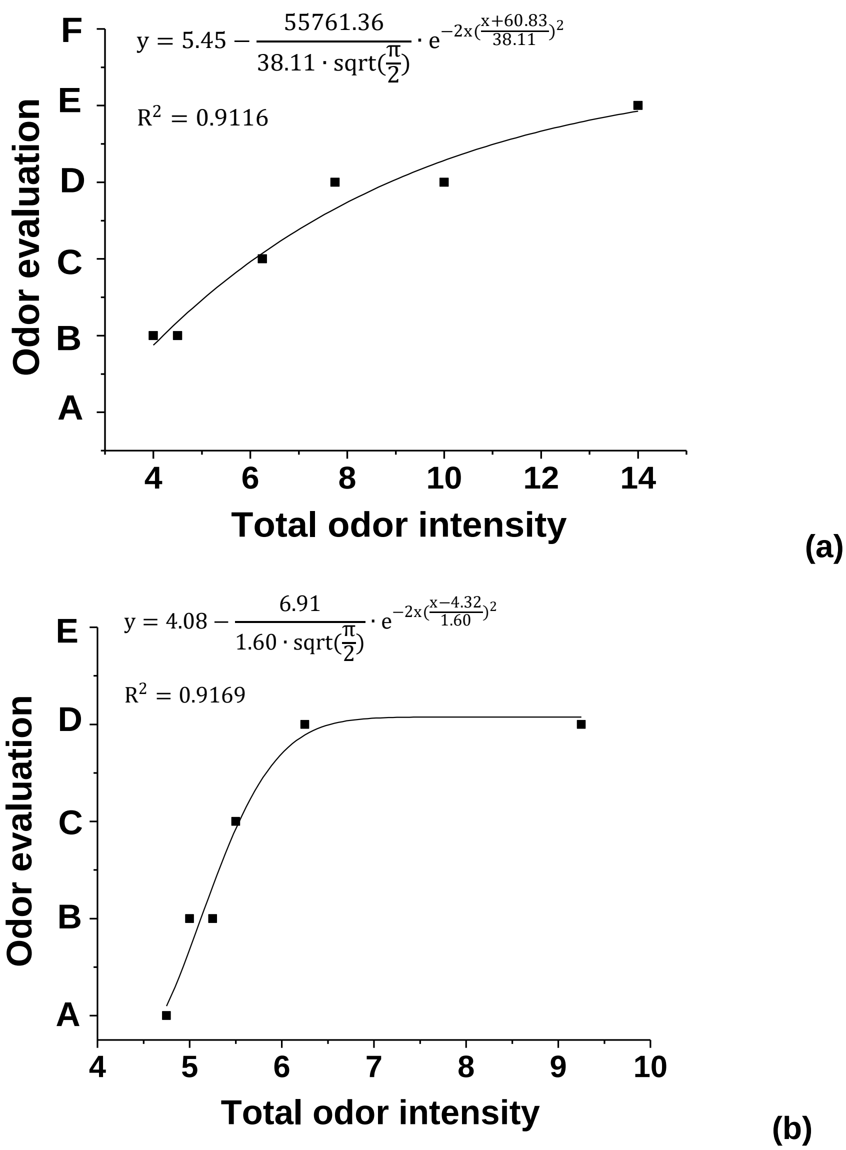

Fig. 7. Correlation of total odor intensity and odor evaluation of (a) PB and (b) PVC

Esters, aldehydes, and ketones were the most important damage sources of PVC through the release period, with the index of 13.37 and 9.24 in the first day and 13 and 8 times as high as the limit values. The index then consistently decreased and reached 0.98 and 0.78 at day 28. The decreasing trend was also seen in other constituents, such as aromatics, alkanes, and alkenes. At day 28, the synthetic index of 0.85 was lower than the limit value, which had reached the VOCs quality level of unpolluted (II). The odor evaluation of PVC was class D at day 1 and day 3, which would slightly influence the comfort, and it rose to class C at day 7, showing the general comfort condition (excluding sensitizers), and continued to climb to class B at day 14 and day 21. At day 28, the odor evaluation reached class A, which belonged to the very comfortable condition. It is suggested that PVC should be stored in a well-ventilated place for at least 28 days before used indoors.

The testing curve was generated, and the correlation total odor intensity-odor evaluation was analyzed using the Gaussian curve. The odor evaluation, influence, and the total odor intensity were defined as, "Z," "Y," and "X," respectively. When "Z" = 1, 2, 3, 4, 5, and 6, the corresponding odor ratings were A, B, C, D, E, and F. The relationship between "Y" and "Z" was defined in a rounding way, which meant when the value of "Y" was a non-integer, the value of "Z" belonged to the next level if its value was greater than or equal to 5, otherwise it belonged to the last level. On this basis, the correlation between total odor intensity and odor evaluation of PB and PVC were established. The variables "X" and "Y" could be well fitted by the Gauss function. Figure 7 shows the influence of PB and PVC on human living environments and showed a trend of non-linear increase with the increase of total odor intensity. When the total odor intensity increased to a certain value, the odor evaluation did not continue to increase, but tended to a certain value, which meant that human senses became insensitive in this condition. They felt bad but could not distinguish the rate. When the total odor intensity was at a relatively low value, its change would have a greater impact on human subjective comfort. The composition of odorous substances is complex, and different odors can interact with each other. When the two odorants were mixed, the effects of odorant compounds on the total odor intensity could be divided into: fusion (the total odor intensity was equal to the sum of odor intensity of the two compounds); synergism (the total odor intensity was greater than the sum of odor intensity of the two compounds); antagonism (the total odor intensity was less than the sum of odor intensity of the two compounds.); and unrelated effect (the total odor intensity was determined by a certain odorant). Considering the complex interaction among various odorant compounds, the effect of fusion on the total odor intensity was used in this experiment to preliminarily explore the internal relationship between the total odor intensity and odor evaluation. Although there was a good correlation between the total odor intensity and the odor evaluation of different boards, the value of the total odor intensity corresponding to the odor rating was different.

CONCLUSIONS

Polyvinyl chloride-overlaid particleboard was investigated and evaluated using the synthetic index-olfactory evaluation method based on GC-MS/O. The differences of the individuals should be considered due to the subjective differences of the assessors.

1. A total of 17 odor-active compounds, including aromatic hydrocarbons, ketones, esters, alcohols, and aldehydes, were identified from PVC, while aldehydes, ketones, and esters were the most important damage sources of PVC. Pleasant fragrance, sweet, and spicy were the key odor characteristics, and the adhesive was the primary source of odor.
2. The TVOC and total odor intensity released from PVC decreased over time. Based on the index-olfactory evaluation, at room temperature of 23 °C ± 1 °C, it was suggested that PVC should be stored in a well-ventilated place (more than 0.5 $m^3m^{-2}h^{-1}$) for at least 28 days before being used indoors.
3. Surface decoration effectively prevented the release of VOCs and odors. Some odorants released from PB disappeared after it was overlaid, while the others remained

with declining intensities. An increase in thickness raised the emission of VOCs when the change of the total odor intensities was minimal.

4. The correlation between the total odor intensity and odor evaluation was well curved by the Gauss function. The influence of PVC on the human living environment showed a non-linear increase trend with an increase in total odor intensity. There was a greater change in human subjective comfort when the total odor intensity was at a relatively low value. However, when the total odor intensity increased to a certain value, human senses became insensitive and the odor evaluation did not continue to increase.

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ETHICAL STATEMENT

The study was conducted in agreement with the Declaration of Helsinki. The study was approved by the College of Materials Science and Engineering, Northeast Forestry University. Informed consent was obtained from all subjects participating in the study.

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