Characteristics of Volatile Organic Compounds Released from Various Types of Decorative Particleboards

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Abstract

Surface finishes change the characteristics of volatile organic compounds (VOCs) released from wood-based panels. This research studied the effects of different finishes on the VOCs released from particleboard (18 mm thick). Various materials, such as polyvinyl chloride (PVC), melamine paper, and water-based paint, were compared with unfinished particleboard. A 1-m^3 climate chamber and gas chromatography–mass spectroscopy were used to examine the types and rates of release and the percentages of various VOCs released by decorative particleboard over 28 days. By comparing the characteristics of VOCs released from unfinished particleboard, the effects of different surface finishes were determined. The VOC substances of concern released from particleboards were analyzed by their type and concentration until they reached a state of equilibrium on day 28. Results showed that none of the surface finishes changed the variety of total VOC (TVOC) released from particleboard, but they had a prominent influence on the rate of TVOC released, especially in the early stages. Acrylic water-based paint increased the TVOC release rate from the particleboard, whereas the PVC and melamine finishes decreased the rate. Surface finishing greatly influences the concentration of various VOCs. Although the same types of VOCs were released by the various finished particleboards, they each had different release rates and different variations in their release-rate tendencies. Surface finishing can change the percentages of various VOC components, so that the amounts were different depending on the finish, and different types of VOCs were controlled better by certain types of finishes.

With modern industrialization, the use of decorative wood-based panels in interior decorating has become more widespread. Wood-based panels, such as particleboard and plywood, are often used as substrates in the production of furniture, flooring, and other household products (Sun et al. 2014, Liu et al. 2015). People spend more than 80 percent of their time indoors in smaller spaces without well-circulated ventilation. Indoor air quality can directly influence people's health. Research suggests that there are almost no inorganic substances in most buildings; the main sources of indoor air pollution are the volatile organic compounds (VOCs) released by wood-based panels (Sidheswaran et al. 2012). VOCs can cause symptoms such as dry cough, fatigue, headaches, dizziness, and inattention (Kim et al. 2006). Therefore, effectively controlling and reducing the release of VOCs from wood-based panels would greatly improve indoor air quality.

Surface finishing can have a significant effect on the release of VOCs, which is being researched worldwide. Chen (2010) studied the influence of veneers on releases from particleboard and found that veneering reduced the release of both total VOCs (TVOCs) and formaldehyde. Shen et al. (2006) and Liu et al. (2015) evaluated the release of formaldehyde and VOCs from different decorative wood-based panels and found that the various materials prevented formaldehyde and TVOC release at different rates. In addition to TVOC and formaldehyde, there are probably other differences between decorative particleboard and unfinished, control particleboard. In fact, surface finishing has a significant effect on the release characteristics of VOCs. Furthermore, different surface finishes have different closure rates for each monomer, but there is little research on this aspect of off-gassing.

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Surface finishing has been proven to affect the closure rate of TVOC released from wood-based panels. Therefore, it would be helpful to understand the effect of surface finishing on VOC release characteristics and closure effects from various surface finishes. In this study, the differences in TVOC release rates, individual VOC release rates, and the percentages of VOCs from decorative particleboard and unfinished control particleboard were analyzed to calculate their closure rates and to interpret and analyze the reasons for those effects. A few VOC constituents were analyzed according to their type and the concentration they achieved at a state of equilibrium on the 28th day.

Materials and Methods

Materials

Particleboard, produced at Foshan Shunde Sophia Furniture factory (Guangdong, China), had the following specifications (length by width by thickness): 1,200 by 1,200 by 18 mm, and formaldehyde emission level was at E_1 (the formaldehyde emission rate was $\leq$0.124 mg/m^3, according to the GB18580-2017 Chinese standard [General Administration of Quality Supervision, Inspection and Quarantine [GAQSIQ] 2017]). The particleboard samples had single-sided areas of 1,000 by 500 mm with both sides able to release gases. The edges of the particleboard samples were sealed with foil to prevent VOCs from being released, except from the board faces. The production process parameters for the particleboard are given in Table 1.

Methods

Chamber for collection of VOCs.—A 1-m^3 climate chamber, equipped with temperature control, humidity control, a high-temperature cleaning system, and a circulatory system, was used to collect gases released from the particleboard. Before the start of the experiment, the inner chamber was washed with distilled water, and the high-temperature cleaning system was turned on until the temperature in the chamber reached 240°C, and it was then cleaned for 4 hours to ensure that the background TVOC concentrations within the climate chamber were <20 μg/m^3, and the concentration of each monomer was <2 μg/m^3. The parameters for the 1-m^3 climatic chamber are listed in Table 2. The VOCs were absorbed by Tenax-TA tubes (Markes International, Cardiff, UK). The adsorption tube was 89 mm long and had an outer diameter of 6.4 mm.

Analysis of VOCs by GC-MS.—The thermal desorption instrument was a Unity gas chromatography–mass spectroscopy (GC-MS) system (Markes International) with a thermal desorption autosampler (Ultra 100; Markes International). Helium was the carrier gas, and the equipment could reach an analytical temperature of 300°C and a pipeline temperature of 180°C. The thermal analysis time was 10 minutes, and the injection time was 1 minute. Table 3 presents the basic program parameters for the GC-MS equipment. The chromatographic column was initially run at 40°C for 2 minutes, then increased to 50°C (in 2°C/min increments) and maintained there for 5 minutes, which was followed by 150°C (increased in 5°C/min steps) maintained for 4 minutes. Finally, the temperature was increased to 250°C (in 10°C/min increments) and maintained at that temperature for 8 minutes.

Table 2.—Parameter settings for the 1-m^3 climate chamber.

Variable	Condition
Climate chamber volume (m^3)	1
Sampler suction speed (liters/min)	0.16
Sampling temperature (°C)	23 ± 1
Sampling humidity (%)	45
Air exchange rate (h^{-1})	1 ± 0.05
Load rate (m^2/m^3)	1.0 ± 0.05

Experimental design

Sampling in the 1-m^3 climate chamber was based on the International Organization for Standardization (ISO) 16000-9 (2006) and ISO 16000-6 (2011) standards. The climate chamber parameters were set according to the ASTM standard D5116 (ASTM International 2010). Three particleboard samples were kept at 23°C and at a relative humidity of 45 percent for 1 week. After 1 week, the samples were placed horizontally in the center of the climate chamber, and the door was closed after ensuring ample air flow around the two sides of each sample. The VOCs released from the specimen surfaces were absorbed by Tenax-TA tubes and the rates were recorded on days 1, 3, 7, 14, 21, and 28. Purified, humidified air was supplied throughout the experiment. Chinese standard GB/T29899-2013 (GAQSIQ 2013) was used for the GC-MS analysis of VOC release rates, TVOC concentrations, and monomer concentrations in one cycle, comparing the results from the unfinished control particleboard with those from particleboard with finished surfaces.

Results

Influence of surface finishing on release of VOCs from particleboard

According to the Chinese standard GB/T18883-2002 (GAQSIQ 2003) on interior air quality specifications, VOCs are determined as all peak areas in the range of hexane (C_6) and hexadecane (C_{16}). Per that standard, in this experiment, toluene-d_8 was used as the internal standard. Individual VOC constituents were identified by their retention time from a standard mass-spectra library with a match quality of

Table 1.—Production process parameters for particleboard used in this study.

Type of particleboard	Plate thickness (mm)	Tree species	Hot press temperature (°C)	Hot press time (s)	Adhesive type
Control, unfinished	18	Hardwood			Modified urea–formaldehyde glue
PVC finish[a]	18	Hardwood	150	35–38	Modified urea–formaldehyde glue
Melamine finish	18	Hardwood	186–190	35–38	Melamine adhesive
Acrylic water-based paint finish	18	Hardwood			Modified urea–formaldehyde glue

[a] PVC = polyvinyl chloride.

Table 3.—Basic parameters for the gas chromatography–mass spectroscopy instrument.

Variable	Condition
Column (m × mm × μm)	DB-5 (3 × 0.26 × 0.25)
Carrier gas (%)	Helium (99.99)
Temperature program, °C (min)	40 (2) → 50 (4) → 150 (4) → 250 (8)
Source of ion	Electron ion
Ion source temperature (°C)	230
Scanning mode	Full scan

not less than 90 percent. VOCs were quantified on the basis of the response factors derived from the standard curves. The relationship between VOC concentration in the chamber and the amount released per unit area of the particleboard was determined as follows:

$$\mathrm{SER} = C \times q \quad (1)$$

where SER is the quality of the VOCs released per unit area of particleboard at the unit time (μg/m2/h), C is the concentration in the chamber ($\mu g/m^{-3}$), and q is the ventilation volume per unit area ($m^3/h^1/m^2$).

Influence of surface finishing on TVOC released from particleboard.—From the first to the 28th day, the rate of TVOC released from the particleboard declined. The greatest decline was from particleboard finished with acrylic water-based paint, followed by the unfinished control board and the melamine-finished particleboard. The least decline in TVOC came from the particleboard with the polyvinyl chloride (PVC) finish. During the first 7 days, the average TVOC release rates from the four particleboard samples were 196 (paint), 154 (unfinished), 116 (melamine), and 106 $\mu g/m^2/h$ (PVC), which reflected a decrease of 59, 57, 62, and 57 percent, respectively. Between the seventh day and the 28th day, the average TVOC release rates from the four particleboards were 59 (paint), 54 (unfinished), 48 (melamine), and 46 $\mu g/m^2/h$, which reflected a decrease of 27, 25, 25, and 24 percent, respectively (Fig. 1). Therefore, the trend in the TVOC release rates for the various decorative finishes was the same, decreased off-gassing over time. During the initial stage, the TVOC release rates were high, but they decreased rapidly. At the later stage, the release rates were slower and more stable. In the first 7 days, the average TVOC release rates for acrylic water-based paint, melamine, and PVC finishes were 37, –24, and –31 percent faster than the TVOC release rate from the unfinished control particleboard. At the later stage, the average TVOC release rates for the three kinds of decorative particleboards were 9, –11, and –15 percent faster than the average TVOC release rate of control board (Fig. 1). This showed that in the preliminary stage, the TVOC release rates were prominently influenced by the various surface finishes, and the influence was weaker in the latter stage.

Therefore, surface finishes do not change the trends in TVOC release rates—declining sharply in the preliminary stage and becoming steady in the later stage—from that of unfinished particleboard. However, surface finishes had a prominent influence on the TVOC release rates. The TVOC release rates from the PVC- and melamine-coated particleboard were slower when compared with unfinished particleboard, whereas the release rate from acrylic water-based paint was faster than it was from the control particleboard. Therefore, PVC and melamine finishes help prevent particleboard from releasing TVOC as rapidly, which could have a tremendous environmental effect. In contrast, the water-based paint accelerates the release of TVOC from particleboard because water-based acrylic paint is intensely volatile.

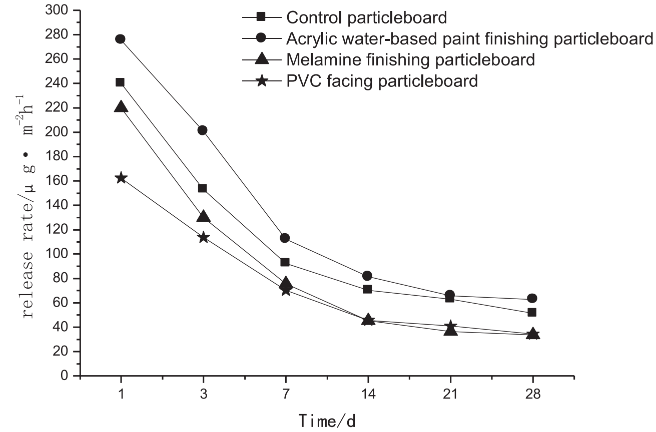

Figure 1.—Total volatile organic compound (TVOC) release rates for particleboards in the same environment.

Influence of surface finishes on the release rate of individual VOCs from particleboards.—The most important VOCs released from the particleboard samples were classified as alcohol ketones, terpenes, and aldehyde. By comparing the release characteristics from these three types of substances as they were released by the various decorative particleboards, we found some consistent trends.

The emission rate for aldehyde released from the unfinished control particleboard was about 20 $\mu g/m^2/h$. For the three finishes, from fastest to slowest, aldehyde emissions were 24 (PVC), 17 (melamine), and 15 (paint) $\mu g/m^2/h$ (Fig. 2). Acrylic water-based paint increased the release rate of alcohol ketones nearly eightfold, reaching 160 $\mu g/m^2/h$, whereas the PVC and melamine finishes increased the rate of alcohol ketones release by two and three times, respectively, reaching 40 and 60 $\mu g/m^2/h$ (Fig. 3). The different decorative particleboard finishes released the same VOCs at different rates, showing that the surface finishing method has a disparate effect on the same types of

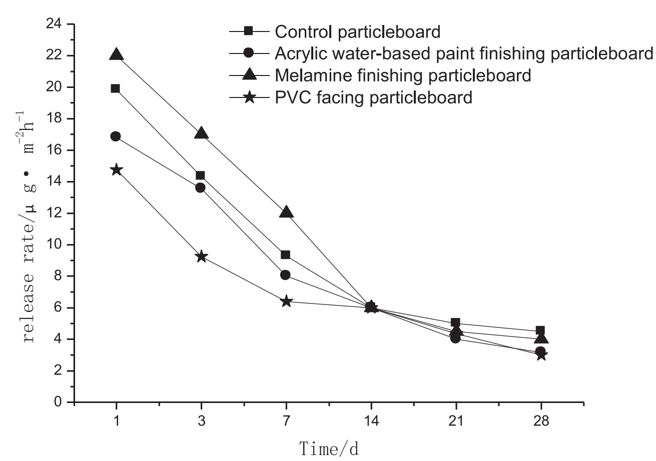

Figure 2.—Characteristics of aldehydes released from particleboard.

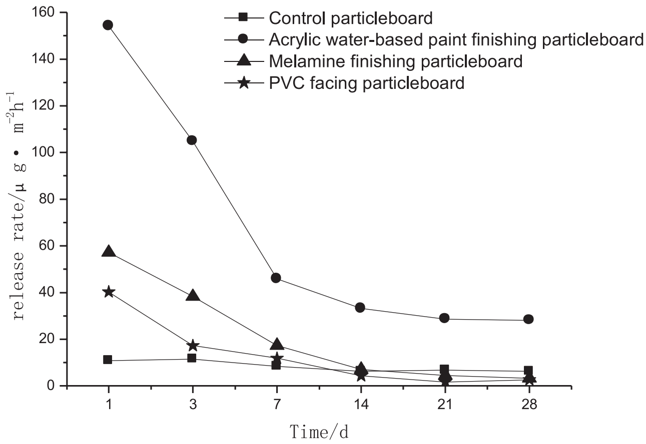

Figure 3.—Characteristics of alcohol ketones released from particleboards.

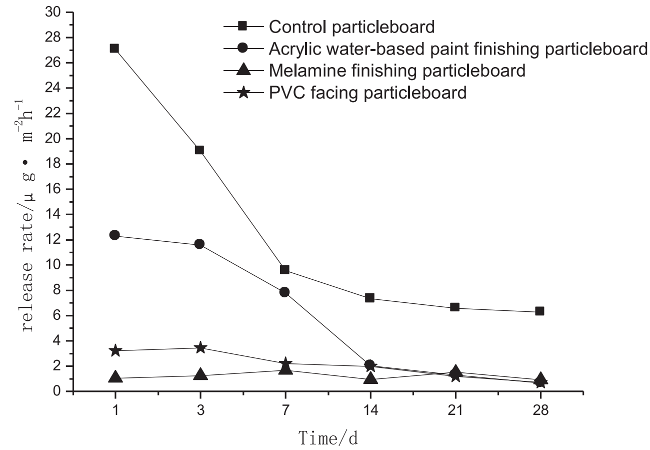

Figure 4.—Characteristics of terpenes released from particleboards.

substances, i.e., for the same substance, the various surface finishes can either decrease or increase the release rate. In addition, some finishes have a large effect on release rate, whereas others have little effect on emission rates. The emission rate of terpenes from acrylic water-based finish and from the control particleboard decreased dramatically, especially in the preliminary stage, whereas the emission rate of terpenes from the melamine- and PVC-coated particleboard was stable over time (Fig. 4). Figure 4 demonstrates that the particleboard release rate for the same substance with the various decorative finishes was disparate.

Therefore, the following conclusions can be reached about the influence of surface finishing on the release of VOCs:

1. The release rates for the same substance from different decorative finishes on particleboard are different. Some surface treatments help prevent particleboard from releasing VOCs. For instance, PVC, melamine, and water-based paint coatings all reduce the release of terpenes from the particleboard. Some surface treatments can increase VOC release rate, such as the water-based paint finishing increasing the release rate of alcohol ketones.
2. Individual VOC emission rates are distinctly different because of the different decorative materials and their different closure effects.
3. The trend in release rate for the same type of substance released by the different decorative particleboards is also disparate. The release rates for one substance may be steady from start to finish, whereas the release rate of the same substance produced by another type of finish could change dramatically.

Influence of surface finishing on the composition of VOCs released by particleboard

VOCs released by the different decorative particleboards were divided into six categories: alkanes, aromatic hydrocarbons, aldehydes, esters, alcohol ketones, and terpenes. Other substances were released in very small amounts. Table 4 shows the concentration data of the VOCs released from the four types of particleboards during the initial stage and shows that the main components produced by the different surface finishes were extremely different.

The main VOC components released by the unfinished control particleboard were aromatic hydrocarbons, esters, and terpenes at 28, 27, and 16 percent, respectively. The main VOC components by the particleboard with the PVC facing were esters, alcohol ketones, alkanes, and aromatic hydrocarbons at 25, 24, 21, and 15 percent, respectively, with concentrations that were little different from each other. The main VOC components released by melamine-coated particleboard were aldehydes, aromatic hydrocarbons, esters, and alcohol ketones at 26, 24, 19, and 17 percent, respectively. Terpenes had the lowest concentration and were found at only 1 percent. Alcohol ketones were the most predominant VOCs released from the particleboard coated with acrylic water-based paint, whereas other substances made up only a small proportion of the off-gassing.

Comparing the unfinished control particleboard with the various surface finishes showed that they have a disparate impact on the percentages of VOC constituents. The PVC finishing method greatly increased the percentage of alkanes and alcohol ketones but had little effect on the percentage of aldehydes and esters. The melamine surface finishing increased the percentages of aldehydes and alcohol ketones, whereas the acrylic water-based paint had a remarkable effect on the percentage of alcohol ketones, increasing the rate up to 59 percent. All three finishes decreased the percentage of terpenes released, especially the melamine and PVC finishes. In summary, the main VOC constituents released from decorative particleboard are fairly different and have disparate impact on the percentages of various VOCs released.

Analysis of results

Surface finishing has a marked effect on VOC release characteristics from the particleboard. There were some prominent differences in the TVOC and VOC release rules and in the main constituents of the VOCs between the decorative particleboard and the unfinished control particleboard because the different decorative materials have disparate VOC closure rates. Surface finishing reduces the amount of VOCs released from the particleboard itself because decorative material has a closure effect on VOCs to

Table 4.—Volatile organic compounds released from particleboard.

Type of particle board	% released					
	Alkanes	Arenes	Aldehydes	Esters	Alcohol ketones	Terpenes
PVC finish	21	15	10	25	24	3
Melamine finish	8	24	26	19	17	1
Acrylic water-based paint finish	6	9	8	10	59	4
Control, unfinished	7	28	9	27	8	16

[a] PVC = polyvinyl chloride.

some extent. At the same time, both the decorative materials and the adhesive used can release VOCs. When the reduction in VOCs released from the particleboard itself is greater than the additional VOCs released from the decorative materials and adhesives, the closure rate is greater than zero. Finishing methods with closure rates above zero have efficacy in reducing the emissions of VOCs from particleboard. Conversely, if the closure rate is less than zero, then the method increases the VOCs released from the particleboard because the increased VOCs come from decorative materials and adhesives used. Per the research methods of Chen (2010), we studied the VOCs released by the various surface finishes by calculating the closure rates using the following formula:

$$A = \frac{C_0 - C_i}{C_0} \times 100\% \tag{2}$$

where A is the closure rate as a percentage, C_0 is the average mass concentration of the TVOC or the single substance released by control particleboard (without any surface finishing) in the initial stage (in $\mu g/m^3$), and C_i is the average mass concentration of the TVOC or single substance released by decorative particleboards during the initial stage (in $\mu g/m^3$). The results of those calculations are shown in Table 5.

Table 5 shows that the different surface finishes have different TVOC closure rates. The PVC finishing had the highest closure rate and decreased the TVOC released by 25.02 percent relative to unfinished particleboard. Therefore, the TVOC release rate from particleboard with a PVC facing was much slower than it was from the control particleboard. The acrylic water-based paint finishing increased the amount of TVOC released by 27 percent relative to the unfinished control particleboard, indicating that acrylic water-based paint increases the rate of release over the control particleboard.

The various surface finishes also had different closure rates for any particular type of substance, which explains why the release rates for the same substance were different and why the VOCs released by the various decorative particleboards had different compositions. For instance, PVC and melamine finishes decreased the amount of terpenes released by about 90 percent relative to the control particleboard, which means that the release rate of terpenes from those finishes was much slower than it was from the unfinished particleboard and that the terpenes, therefore, represented a smaller proportion of the VOCs released.

The differences in closure rates from the different surface treatments lead to VOCs with different release characteristics. Generally speaking, the release rates of VOCs are inversely proportional to the closure rate: the greater the closure rate, the more the release of that VOC will be hindered, and the lower the VOC release rate will be, providing better environmental protection from that surface treatment method. Of course, the quantitative value of closure rate is related to decorative material, the type of adhesive, and method of surface treatment used, which are issues for further research.

VOC substances of concern released from decorative particleboard

On the 28th day, the release of VOCs had reached a state of equilibrium, in which the concentration, the type of VOCs, and the release rate were all steady and invariable, suitable for analyzing the few substances produced.

VOCs released by PVC-coated particleboard.—By the 28th day, the VOCs released from particleboard coated with PVC were mainly aromatic hydrocarbons, esters, and alcohol ketones (Fig. 5). Among those, the concentration percentages of ethylbenzene, toluene, xylene, 1,2-benzene dicarboxylic acid, and mono(2-ethylhexyl) ester were the greatest, at 11.16, 9.07, 7.93, and 7.39 percent, respectively (Table 6). For the PVC coating, the concentration percentage of ethylbenzene was the greatest when a state of equilibrium was reached. The chemical properties of ethylbenzene are such that after it is inhaled, most of the metabolites are excreted within 2 hours, a small portion of the metabolites are excreted in about 48 hours, and only a negligible amount remains after that and is accumulated in the body. Therefore, concentrations of ethylbenzene found

Table 5.—Closure rates for various volatile organic compounds from different surface finishes.[a]

Type of decorative particleboard	Concentration of TVOC ($\mu g/m^3$)	Closure rate (%)						
		TVOC	Alkane	Arene	Aldehyde	Ester	Alcohol ketones	Terpenes
Acrylic water-based paint finish	196.1	−27.42	−19.02	48.55	15.28	52.17	−884.33	45.13
Melamine finish	126.4	17.87	6.34	57.26	−31.78	44.04	−265.17	93.06
PVC finish	115.4	25.02	−181.23	61.33	30.35	56.08	−191.44	84.15
Control, unfinished	153.9	—	—	—	—	—	—	—

[a] TVOC = total volatile organic compound; PVC = polyvinyl chloride; — = not applicable.

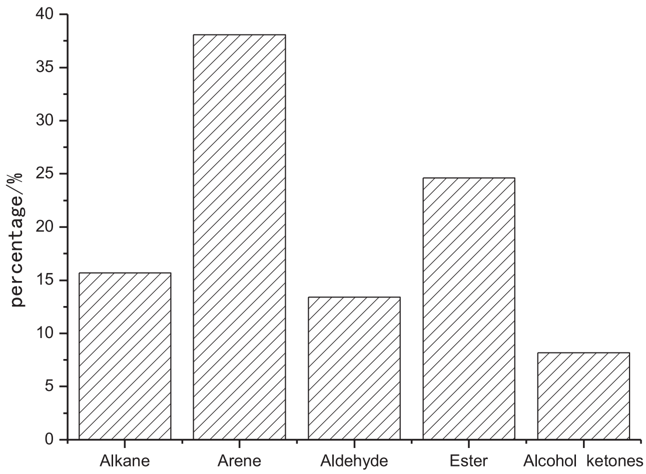

Figure 5.—Proportion of volatile organic compounds (VOCs) released on the 28th day from particleboard coated with polyvinyl chloride (PVC).

in this study would not jeopardize people's health. Many regulations worldwide only control ethylbenzene at high concentration. The standard in China is that the concentration of ethylbenzene indoors must be less than 400 μg/m^3, whereas the latest European standard limits the indoor ethylbenzene concentration to 750 μg/m^3. In our experiment, the concentration of ethylbenzene released by particleboard with a PVC finish at equilibrium was much less than 400 μg/m^3 and can be expected not to harm human health. Toluene is more toxic than ethylbenzene, and some concentrations of toluene can irritate human skin and mucous membranes and can even paralyze a person's central nervous system. Toluene is, therefore, the primary substance whose release must be reduced from wood-based panels. In China, limits for the concentration of toluene released from wood-based panel must be lower than 260 μg/m^3, whereas US Business and Institutional Furniture Manufacturers Association limits toluene concentration released by office furniture to 250 μg/m^3, and the Japanese Industry Standard for an indoor concentration of toluene must be less than 200 μg/m^3 when the VOCs reach a state of equilibrium. In our experiment, the concentration of toluene released by PVC-coated particleboard reached a state of equilibrium at less than 200 μg/m^3, and we strongly recommend that the concentration of toluene be controlled.

Although individual aromatic hydrocarbons are not harmful to humans unless they are at high concentrations, total aromatic hydrocarbons can be toxic at lower concentrations and are important indoor air pollutants. Nature Plus regulates the concentration of aromatic hydrocarbons released by building materials at 50 μg/m^3. Dibutyl phthalate, an aromatic hydrocarbon, is highly toxic, and can enter the body through the gastrointestinal tract and the respiratory system and can be absorbed by skin. The threshold concentration of dibutyl phthalate by smell for the most sensitive person is 0.00026 mg/liter, and the threshold concentration for an effect on the eyes is 0.00016 mg/liter. On the basis of our analyses, the primary substances that are released by PVC particleboard and that need to be controlled are toluene, aromatic hydrocarbons, and dibutyl phthalate.

VOCs released by particleboard coated with acrylic water-based paint.—By the 28th day, the VOCs released by particleboard finished with acrylic water-based paint were mainly aromatic hydrocarbons, alkanes, and alcohol ketones (Fig. 6). Among those, the concentration percentages of hexane, 2,4,6-trimethyl-decane, ethylbenzene, and ethylene glycol were the greatest at 10.53, 9.15, 9.11, and 9.00 percent, respectively (Table 7). The VOCs released were mainly derived from the water-based paint and the adhesives. The VOCs released by the water-based paint were primarily ethylene glycol and 1,2-propanediol. Ethylene glycol is mainly used in paint as a solvent to dissolve or disperse the film-forming substances into a uniform, liquid state to facilitate the construction of the film. Ethylene glycol is toxic and can kill people at as little as 30 mL/kg.

Table 6.—Volatile organic compounds (VOCs) released by the 28th day from particleboard with a polyvinyl chloride finish.

Sample no.	VOCs	Chemical formula	Percentage
1	Ethylbenzene	C_8H_{10}	11.16
2	Toluene	C_7H_8	9.07
3	Xylene	C_8H_{10}	7.93
4	1,2-Benzene dicarboxylic acid, mono(2-ethylhexyl) ester	$C_{16}H_{22}O_4$	7.39
5	Anthracene	$C_{14}H_{10}$	6.97
6	Acenaphthene	$C_{12}H_{10}$	5.47
7	1,3-Dimethyl-benzene	C_8H_{10}	5.38
8	Dimethyl phthalate	$C_{10}H_{10}O_4$	5.27
9	1-Methylene-1H-indene	$C_{10}H_8$	5.18
10	Acetic acid, 1-methylpropyl ester	$C_6H_{12}O_2$	5.07
11	Decanal	$C_{10}H_{20}O$	4.28
12	Methyl cyclohexane	C_7H_{14}	4.11
13	Pentadecane	$C_{15}H_{30}O$	3.71
14	2-Methyl-4-methylene-hexane	C_8H_{16}	3.37
15	Nonanal	$C_9H_{18}O$	3.12
16	Dibutyl phthalate	$C_{16}H_{22}O_4$	3.09
17	3-Methylheptane	C_8H_{18}	2.83
18	Hexane	C_6H_{14}	2.38
19	Oxalic acid, isohexyl pentyl ester	$C_{13}H_{24}O_4$	1.73
20	2-Methylcyclopentanone	$C_6H_{10}O$	1.3
21	2-Ethyl-1-hexanol	$C_8H_{18}O$	1.19

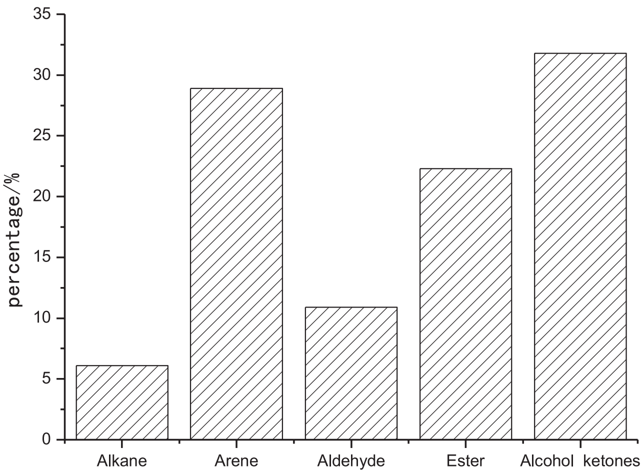

Figure 6.—Proportion of volatile organic compounds (VOCs) released on the 28th day from particleboard coated with acrylic water-based paint.

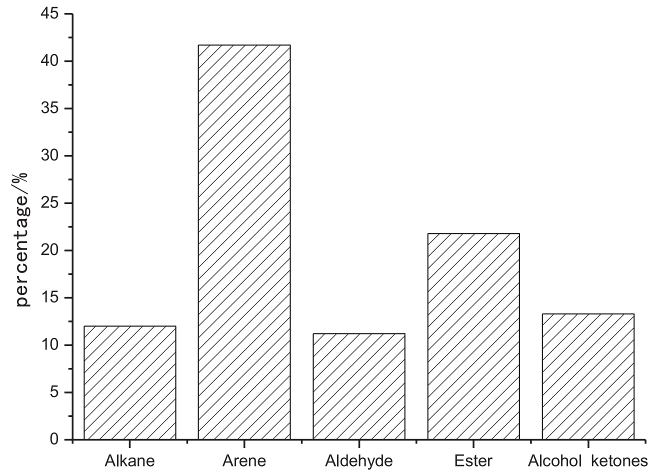

Figure 7.—Proportion of volatile organic compounds (VOCs) released on the 28th day from particleboard coated with melamine.

Propylene glycol acts as cryoprotectant in water-based coatings to keep the coating from freezing at 0°C. 1,2-Propanediol is slightly toxic, and propylene glycol concentrations of 10.7 mL/kg can kill mice. Adhesives and paints release a large amount of toluene and xylene, which can injure people's eyes, respiratory system, and nervous system. Cyclohexanone is highly toxic, and even low concentrations of cyclohexanone can cause harm to humans by irritating the skin and respiratory system. Therefore, when acrylic water-based paint is used as the finish for particleboard, the ethanediol, 1,2-propylene glycol, aromatic hydrocarbons, methylbenzene, xylene, and cyclohexanone should be controlled.

VOCs released by particleboard coated with melamine.—By the 28th day, the VOCs released from particleboard with a melamine finish were mainly aromatic hydrocarbons, alkanes, and aldehydes (Fig. 7). Among those, the concentration percentages of toluene, methyl phthalate, phenanthrene, ethylbenzene, and ethane were the greatest at 9.85, 9.11, 8.53, 7.6, and 7.01 percent, respectively (Table 8). The VOCs released by the melamine-coated particleboard come primarily from melamine-impregnated paper and the adhesives. When producing melamine-impregnated paper, the usual formula is 70% melamine glue and 30% urea-formaldehyde glue. Urea-formaldehyde glue has urea and formaldehyde as raw materials, which release large amounts of aldehydes and other VOCs. The VOCs released by the adhesives are mainly aromatic hydrocarbons, esters, and alkanes. On the basis of our analysis, the substances of concern released from particleboard with a melamine finish are aldehydes, toluene, and xylene.

Conclusions

Different surface finishing methods can change the release rates of TVOC, but they cannot change the different tendencies from TVOC release rates. The TVOC emission rates from different decorative particleboards differ from each other under the same conditions, especially in the initial stage. However, the tendency for TVOC release rates from the different decorative particleboards are the same,

Table 7.—Volatile organic compounds (VOCs) released by the 28th day from particleboard with an acrylic water-based paint finish.

Sample no.	VOCs	Chemical formula	Percentage
1	Phenanthrene	C_6H_{14}	10.53
2	Cyclohexanone	$C_{13}H_{28}$	9.15
3	Toluene	C_8H_{10}	9.11
4	1,2-Propanediol	$C_2H_6O_2$	9
5	Dibutyl phthalate	$C_{14}H_{10}$	8.49
6	1,2-Benzoic 2-formic acid, butyl 2-methyl propyl ester	$C_6H_{10}O$	8.24
7	Ren	C_7H_8	7.41
8	Capraldehyde	$C_3H_8O_2$	7.11
9	(*Z*)-2-Decenal	$C_{16}H_{22}O_4$	4.43
10	(*Z*)-2-Nonene aldehyde	$C_{16}H_{22}O_4$	4.14
11	2-Propanediol monomethyl ether	$C_9H_{18}O$	3.88
12	4-Phenylcyclohexene	$C_{10}H_{20}O$	3.81
13	Eucalyptus	$C_{10}H_{18}O$	3.05
14	2-Methylnaphthalene	$C_9H_{16}O$	2.54
15	2-Propanediol monomethyl ether	$C_7H_{16}O_3$	2.54
16	4-Phenylcyclohexene	$C_{12}H_{14}$	2.36
17	Styrene	C_8H_8	2.25
18	2-Methylnaphthalene	$C_{11}H_{10}$	1.96

Table 8.—Volatile organic compounds (VOCs) released by the 28th day from particleboard with a melamine finish.

Sample no.	VOCs	Chemical formula	Percentage
1	Toluene	C_7H_8	9.85
2	2-Methyl phthalate 2 formate	$C_{10}H_{10}O_4$	9.11
3	Phenanthrene	$C_{14}H_{10}$	8.53
4	Ethylbenzene	C_8H_{10}	7.6
5	Hexane	C_6H_{14}	7.01
6	Benzene	C_6H_6	6.91
7	1-Methylnaphthalene,	$C_{11}H_{10}$	5.49
8	2-Acryl, butylene	C_7H_8	5.44
9	1,2-Benzoic 2 formic acid, butyl 2-methyl propyl ester	$C_{16}H_{22}O_4$	5.19
10	Dibutyl phthalate	$C_{16}H_{22}O_4$	5.05
11	Capraldehyde	$C_{10}H_{20}O$	4.75
12	Ren	$C_9H_{18}O$	3.67
13	Eucalyptus	$C_{10}H_{18}O$	2.94
14	Pentadecanal	$C_{15}H_{30}O$	2.89
15	Eleven alkane	$C_{11}H_{24}$	2.84
16	2,6,11-3-Methyl-12-alkane	$C_{15}H_{32}$	2.35
17	2-Ethyl cyclic butanol,	$C_6H_{12}O$	2.15
18	2,4-Bis(1,1-2-methyl ethyl)-phenol	$C_{14}H_{22}O$	2.15
19	4-Ethyl octane	$C_{10}H_{22}$	2.11
20	Benzaldehyde	C_7H_6O	2.11
21	2-Hexyl-1-decyl alcohol	$C_{16}H_{34}O$	1.86

that is, in general, the rates decline and they decline sharply in the preliminary stage, becoming steady in the later stage.

Different surface finishes change not only the individual VOC emission rate but also vary the individual VOC emission rate tendency. The release rates of the same substance produced by the different decorative particleboards were different, especially in the initial stage. Some surface treatments prevent particleboard from releasing certain types of VOCs, whereas other treatment methods can increase that same type of VOC emission.

Different surface finishes can alter the primary constituents of the VOCs. The main components of the VOCs released from the different types of decorative particleboards are fairly different. Different surface finishes have a disparate impact on the percentage of VOC components.

The differences in the closure rate from the different surface treatments lead to disparate VOC release characteristics. The release rates of VOCs are inversely proportional to the closure rate, that is, the greater the closure rate is, the stronger will be the hindering effect on the VOCs, lessening the release rates, and better protecting the environment in which the treatment is used.

Different sorts of VOCs are controlled by different decorative materials. For PVC-coated particleboard, methylbenzene, aromatic hydrocarbons, and dibutyl phthalate should be kept at low levels. For particleboard finished with acrylic water-based paint, the ethanediol, 1,2-propylene glycol, aromatic hydrocarbons, methylbenzene, xylene, and cyclohexanone should be controlled. For melamine-finished particleboard, aldehydes, methylbenzene, and xylene should be limited.

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