

# EFFECT OF PANEL AREA–VOLUME RATIO ON TVOC RELEASED FROM DECORATIVE PARTICLEBOARDS

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**Abstract.** Home renovation can improve our living environment, but it can cause pollution and endanger human health. Wood-based panels are a main source of polluting volatile organic compounds (VOCs). This article studied the VOC concentration of different types of decorative particleboards (PBs) and different panel area–volume ratio, and the effect of panel area–volume ratio on release of various substances. In this study, the main experimental conditions are as follows: the temperature was controlled at  $23 \pm 0.5^\circ\text{C}$ ; the humidity was controlled at  $50\% \pm 3\%$ ; and the rate of ventilation was controlled at once 1 h. And a 15-L small–environmental chamber was used to test the VOC emission. The experimental material was PB with different decorative materials (water-based paint, melamine-impregnated paper, polyvinyl chloride, and PB with no decorative material), and VOC emission was collected under different panel area–volume ratios (1, 1.5, 2, and  $2.5 \text{ m}^2/\text{m}^3$ ). The result showed that the VOCs were present, with the trend of decreasing with time. The decline velocity of water-based paint (WP) was the fastest, whereas that of the PB with no decorative material was the slowest. Increase of panel area–volume ratio could cause the VOC concentration to increase, but the panel area–volume ratio does not have a linear relationship with VOC concentration. Surface decoration can reduce the release of various kinds of material inside the plate to a certain extent. Melamine impregnated paper (MI) and polyvinyl chloride (PVC) can reduce the release of aromatic hydrocarbons in panels, and PVC can inhibit the release of esters in panels.

**Keywords:** VOCs, panel area–volume ratio, particleboard, small–environmental test chamber.

## INTRODUCTION

The contradiction between increasing demand and decreasing forest area became more and more obvious, as wood-based panels such as

particleboards (PBs) are widely used in furniture and in interior decoration (Chen and Shen 2010; Liu and Shen 2016). Indoor decoration can effectively improve our living environment. PBs present a beautiful appearance after surface decoration, but too much decoration will cause

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indoor air pollution (Kelly et al 1999). Study results showed that VOC concentrations in indoor air were typically 10 times greater than that outdoors (Wolkoff et al 1991; Yu and Crump 1998; Tuomainen et al 2001). Lots of adhesive are added to wood shavings during PB production, so the pollution caused by total volatile organic compounds (TVOCs) cannot be ignored (Park et al 2013). At present, the adhesive used for PBs is mainly urea–formaldehyde resin. The VOC components released by urea formaldehyde resin (UF) at 23°C mainly include alcohols, aldehydes, ketones, alkanes, aromatic hydrocarbons, esters, and a small amount of alkenes. (Baumann et al 2000) In the newly renovated room, the main VOCs are benzenes, ethylene glycol, acetaldehyde, acetic acid, etc., and the experiment also determined that these compounds are mostly released from the plywood, PB, and a variety of coatings (Wolkoff 1998). Various studies have shown that the components of VOCs are extremely complex in which the aldehydes, benzene, toluene, xylene, etc. mainly come from all kinds of coatings, adhesives, and various kinds of synthetic materials and so on (Kim et al 2001; GB 2002; WHO, 2003; Kim et al 2006). The skin and mucous membranes will be affected by the toxicity, causing irritation, carcinogenicity, and special odor of VOCs, and acute damage to the human body (Wolkoff et al 2010; Zhang and Smith 2003).

Because VOCs are harmful to the human body and the environment, lots of experimental research on how to reduce VOC emissions has been performed. Shen's study showed that the resin content of veneered PBs and hot-pressing temperature had an obvious impact on TVOC release (Zhang et al 2010). A study by Liu showed that TVOC concentrations increased with the temperature and humidity in the ranges from 23–40°C to 10–70% RH, respectively, whereas the increasing air change rate causes the TVOC concentration to decrease (Liu et al 2010). After surface decoration, the TVOC emission of PB has reduced. The study by Sumin Kim shows that all types of laminations dramatically reduced the formaldehyde and TVOC emission compared

with the PB without lamination, but TVOC and toluene emission were greatly increased by surface coatings (Park et al 2013). Scholars have confirmed that the decorative layer has a barrier effect on the release of VOCs from the PB substrate, in which the polypropylene veneer is superior to the melamine-impregnated paper veneer and the veneer overlay. In the attenuation test of VOCs, the environmental performance of water-based varnish finishing is better than alkyd varnish and nitrocellulose paint (Zhang and Shen 2011).

Scholars have studied the effects of wood-based panel processing and sheet finishes on the release of VOCs. But no study has researched the impact of panel area–volume ratio (the ratio of the surface area of the panel to the cabin volume) on VOC release (Wang et al 2014). To reduce the harm caused by VOCs to the environment and human health, VOC concentration of different types of decorative PBs and different panel area–volume ratios were studied in this article. Furthermore, the concentration trend of various substances has been obtained; this data has meaning for improving indoor living environments.

## MATERIALS AND METHODS

The wood-based composite panels used in this study were E1 grade PBs with 18 mm thickness from a furniture manufacturer in China. Table 1 lists the detailed parameters of the PB used in this study. The experimental panels were as follows: PB with no surface lamination; panels were decorated with Manchurian ash veneer and then coated directly with WP (the main ingredients include aromatic water-based acrylic polyurethane dispersions, defoaming agent, wetting agent, leveling agent, water, etc.); and panels were overlaid with two different surface laminating materials, PVC (the main components include PVC resins, plasticizers, stabilizers, fillers, etc., the following are expressed in PVC) and melamine-impregnated paper (The main components include melamine formaldehyde resin, urea formaldehyde resin, plasticizer, stabilizer,

Table 1. Detail parameters of the particleboard.

Option	Parameters	Option	Parameters
Length × width × thickness (mm × mm × mm)	1200.0 × 1200.0 × 18.0	Adhesive	Melamine-modified UF resin
The proportion of melamine resin to the total amount	35%	pH	7.2-74
Viscosity (-4 cup, 30°C)	50-60 s	Competent period	6-12 h
Hot-pressing temperature	190-200°C	Surface water content after sizing	8.5-9.5%
Surface pressure	295 kg	Water content of core layer after sizing	8.5-10%
Unit pressure	35 MPa	Water content of slab after hot pressing	6%
Hot pressing time	210 s	Solid content of colloid	60-65%
Density of panel	0.7 g/cm <sup>3</sup>	Surface sizing accounts to the total	10%
Curing agent content	1.8%	Core layer sizing accounts to the total	90%
Water content of shavings before sizing	1-3%	Resin content	180-220 g/m <sup>2</sup>

and filler. The following are expressed in MI) by this manufacturer.

### Surface Lamination

The panels were coated with water-based paint in accordance with standards. First, the panels were cut into a size of 400 mm × 400 mm. Then, the Manchurian ash veneer was overlaid on the surface of the panels using urea formaldehyde resin (the main components are urea, aqueous solution of formaldehyde, melamine resin, curing agent, filler, lubricants, stabilizers, plasticizers, and a small amount of oxalic acid and phthalic acid, that is UF) and polyvinyl acetate (PVAc, the main components are vinyl acetate made from acetic acid and ethylene, titanium dioxide, and other powder) with the scale of 60:40, and the consumption was 100 g/m<sup>2</sup>. After that, the Manchurian ash was laminated on the panels at 100°C and 5 MPa for 3 min. Finally, these panels were brought down to room temperature, and the surface was sprayed with 100 g/m<sup>2</sup> of water-based

paint according to the standards. Table 2 shows the detailed parameters of this study on water-based paint finishing. Then, the panels were cut into the required size (the main parameters of size are given in Table 3) as according to panel area–volume ratio. Next the panels were edged by aluminum tape and sealed by plastic bag, finally put the panels in the refrigerator for use.

According to the panel area–volume ratio of the experiment (panel area–volume ratio was set to 1, 1.5, 2, and 2.5 m<sup>2</sup>/m<sup>3</sup>), particleboards (including PVC, MI, WP, and PB) were cut into 4 pieces of 150 mm × 50 mm (numbered as 1, 2, 3, and 4) and two pieces of 150 mm × 75 mm (numbered as 5 and 6). The specific parameters of panel area–volume ratio are as Table 3.

### Experiment Conditions

The emission of VOCs from PBs with different surface laminates and panel area–volume ratio was tested using single factor method. The sampling device for the rapid test method was

Table 2. Detail parameters of water-based paint finishing.

Type of PB	Facing material	Adhesive	Resin content (g/m <sup>2</sup> )	Pressing area (mm × mm)	Pressing pressure	Pressing time	Pressing temperature
Water-based PB	Manchurian ash and water-based paint	UF with PVAc of 60:40	100	400 × 400	5 MPa	3.0 min/mm	100°C

PB, particleboard.

Table 3. Specific parameters of panel area-volume ratio.

Panel area–volume ratio (m <sup>2</sup> /m <sup>3</sup> )	Number of PB
1	PVC-1, MI-1, WP-1, and PB-1
1.5	PVC-5, MI-5, WP-5, and PB-5
2	PVC-23, MI-23, WP-23, and PB-23
2.5	PVC-46, MI-46, WP-46, and PB-46

PB, particleboard.

a 15-L small environment chamber. According to the requirements of the experiment, the main experimental parameters were as follows: nitrogen was used as a carrier gas (the purity was 99%); the temperature was controlled at  $23 \pm 0.5^\circ\text{C}$ ; the humidity was controlled at  $50\% \pm 3\%$ ; and the rate of ventilation was controlled at once per h. The inner surface of the cabin was cleaned using absolute ethanol and distilled water; then clean nitrogen; next, the fan was turned on (which is installed in the cabin as a circulation device); and finally the temperature and moderate controller were switched on. The cycle time was 3.5-5 h/d, and Tenax-TA tubes (200 mg, 60-80 mesh; SKC, Shanghai, China) were used to collect gas in this study. Before gas collection, the Tenax-TA tubes should be desorbed using an analytic tube processor TP-2040 (Beifen Instrument Technical, Beijing, China). The main experimental parameters were as follows: the temperature of heating was  $325^\circ\text{C}$ , the heating time was 30 min, and nitrogen was the carrier gas. When collecting the gas, the Tenax-TA tubes were connected between the 15-L small–environmental test chamber and the vacuum pump ANB3025 (Weicheng Electronic Machinery Co., Ltd., Sichuan, China). The airflow speed was controlled at 250 mL/min, the sampling time was 12 min, and the total amount of gas collected was 3 L. In this way, samples of the VOCs under different experimental conditions at specified times (1, 3, 7, 14, 21, and 28 d) were collected as the original data of this experiment.

The VOC analysis process was as follows: first, a standard curve according to the peak area of different solution concentrations was drawn (C7D8 was used as solute, methylene chloride was used to make up the solution to concentrations of 50, 100, 200, 500, and 1000 ng/ $\mu\text{L}$ ), the

solutions were characterized and quantified with a DSQII gas chromatography–mass spectrometer (GC-MS; Thermo Fisher Scientific, Waltham, MA), and then the exact value of internal standard was obtained. The basic GC–MS parameters were as follows: 1) the parameters for gas chromatography: A capillary column TRACE TR-5MS (30 m  $\times$  0.25 mm  $\times$  0.25  $\mu\text{m}$ ); 2) the carrier gas was helium of 99.996% and the distribution flux rate was 1 mL/min, the injection amount was 1  $\mu\text{L}$ , the injection port temperature was  $250^\circ\text{C}$  and the distribution ratio was 40; 3) the temperature program: kept at  $40^\circ\text{C}$  for 2 min, increase temperature to  $150^\circ\text{C}$  (at  $4^\circ\text{C}/\text{min}$ ) and held for 4 min, and then increased to  $250^\circ\text{C}$  (at  $10^\circ\text{C}/\text{min}$ ) and held for 8 min; 4) mass spectrometry: the energy of ionization was 70 eV, the ionization temperature was  $230^\circ\text{C}$ , and with the condition of mass spectrum of electron ionization (EI), the mass scan range was 40–450 amu and the transmission line temperature was  $270^\circ\text{C}$ . 2  $\mu\text{L}$  of C7D8 was injected into a Tenax-TA tube, 5 min before prepurge, and then the Tenax-TA tubes were installed in an automatic injector, UNITY2 (Markes International, Inc., Llantrisant, UK). Gas collected in the Tenax-TA tubes were analyzed using the NIST spectrum and the match degrees greater than 90% were chosen, and the volatile components were confirmed by retention time; the VOCs were determined as all areas of the peaks at the range of C6 and C16 (according to GB/T 18883-2002 Interior Air Quality Specification standards). Finally, the VOCs were quantified by the amount of C7D8 and peak area response of each substance, and the concentration of VOCs was obtained.

## RESULTS AND DISCUSSION

### The Effect of Panel Area–Volume Ratio on VOCs Emission

Figure 1(a) displays the change of VOC concentration over time under PB with water-based paint and different panel area–volume ratio. Generally speaking, the concentration of VOCs increased with the increase of panel area–volume ratio. But there is no obvious linear relationship between

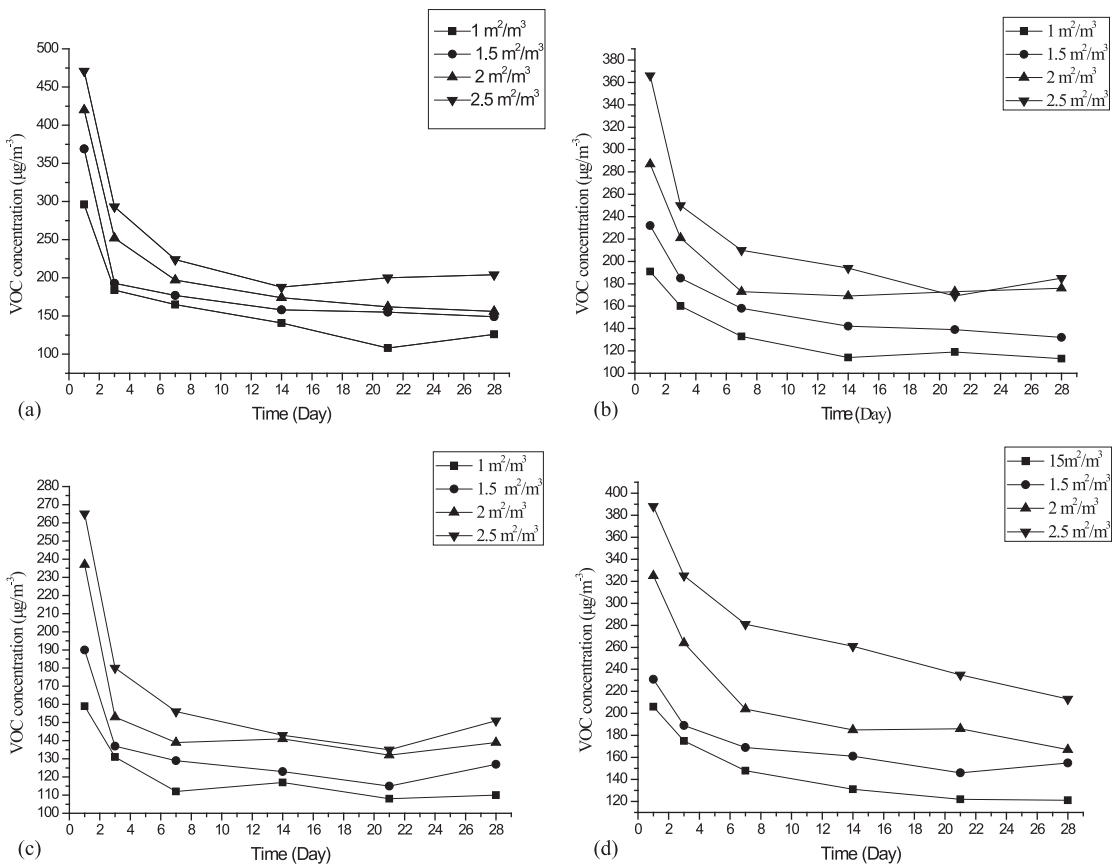


Figure 1. The relationship between concentration of total volatile organic compounds and different panel area–volume ratio: WP (a), MI (b), PVC (c), and PB (d).

VOC concentration and panel area–volume ratio; they have no variation of direct proportion. The VOC concentration sharply decreased from Day 1 to Day 3, the decrement was approximately  $200 \mu\text{g}/\text{m}^3$ . In fact, previous research suggested that the VOC concentration has a sharp decrease in the initial period (Zhang and Shen 2011), which may be related to the fact that water-based paint has a large amount of VOCs and the VOCs evaporate at a faster rate. From Day 3 to Day 7, the concentration decrease of VOCs became slower; the concentration has a noticeably slow speed of reduction from Day 7 to Day 21; and after Day 21, the concentration reached equilibrium.

Figure 1(b) displays the influence of panel area–volume ratio on the VOC concentration of PB decorated by melamine-impregnated paper,

and, in PB with water-based paint. From Day 1 to Day 28, the concentration of VOCs increased with the increase of panel area–volume ratio, but there was no variation in direct proportion. From Day 1 to Day 7, the concentration of VOCs had a rapid release but the decrement was less than that of PB with water-based paint; the decrement was approximately  $150 \mu\text{g}/\text{m}^3$ . The rate of decrease slowed noticeably from Day 7 to Day 21, and from Day 21 to Day 28 it was at an equilibrium state.

Figure 1(c) shows VOC concentration of PB decorated by PVC under different panel area–volume ratios. The VOC concentration of PB decorated by PVC decreased with time. The concentration decreased faster from Day 1 to Day 3, and the largest decrement was approximately

200  $\mu\text{g}/\text{m}^3$ . From Day 3 to Day 14, the rate of decrease became slow. The rate of decrease became smooth from Day 7 to Day 14, but it still declined slowly; after Day 21, the concentration reached equilibrium. The concentration of VOCs increased with the increase of panel area–volume ratio, but there is no obvious linear relationship between VOC concentration and panel area–volume ratio.

Figure 1(d) shows VOC concentration from Day 1 to Day 28 of PB with no surface decoration under different panel area–volume ratios. The VOC concentration of PB with no surface decoration was less than that of PB with surface decoration, they still have no obvious linear relationship between VOC concentration and panel area–volume ratio. From Day 1 to day 7, the VOCs concentration showed an obvious rate of decrease; the rate became slow from Day 7 to day 21; the concentration showed equilibrium after Day 21.

Figure 1 shows the change of VOCs concentration over time under PB with different finishes and different panel area–volume ratio. Generally speaking, the emission of VOCs decreased over time and reached a balance gradually. During the initial step, the release of WP was the biggest then followed by PB, and the MI was slightly higher than PVC. But, the concentration of WP reduced at the most rapid rate, the PVC was slightly higher than MI, and the PB was the slowest. During the final stages, the total VOC concentration of PB was higher than that of others. The reason is that water-based paint has a large amount of VOCs, and the VOCs can evaporate at a faster rate, the film of water-based paint has an effect of obstructing the VOC concentration of PB, the PVC film and the melamine-impregnated paper can also obstruct the concentration of VOCs. The VOC concentration has no obvious linear relationship with panel area–volume ratio; the reason is that under the same gas exchange rate condition, the air movement of PB and the cabin's boundary layer concentration gradient decreased with increasing VOC concentration. According to mass transfer theory, the reduction of concentration gradient can slow the rate of VOC

concentration by the PB through the boundary layer and inhibit the release of VOCs; the attenuation of VOC concentration was becoming rapid as well.

### The Effect of Decorative Materials Factors on the Components of VOCs Emission

The main components of VOCs (Table 4) emitted from the PB with different surface decoration were confirmed as esters and aromatic hydrocarbons; alkanes, alkenes, aldehydes, and ketones; and there were still some small amounts of alcohols, acids, and ethers. The concentration of alkanes, aromatic hydrocarbons, esters, aldehydes, and ketones under initial and equilibrium conditions with different experimental conditions are given in the following figure.

Figure 2 shows the concentration of alkanes under initial and equilibrium conditions; there is a significant trend. The release amount of alkanes decreased with time under different surface decorations and panel area–volume ratios, and the concentration of alkanes reduced to 10  $\mu\text{g}/\text{m}^3$  at equilibrium condition. In the initial condition, the release amount of alkanes under panels with water-based paint was far greater than that of other panels. The reasons are as follows: there are a large number of alkanes contained in water-based paints; alkanes were mainly released from the defoamer in water-based paints; adhesives also contain a certain amount of alkanes (Baumann et al 2000); and the decorative materials have little effect on blocking the release of alkanes. This showed that the concentration of alkanes increased in the initial condition because of the panel surface decoration, but it has a fast release rate and the influence of surface decoration was negligible in equilibrium condition and became environmentally friendly.

Figure 3 displays the change trend of aromatic hydrocarbon concentration. All kinds of panels' aromatic hydrocarbon concentration decreased with time. The concentration of aromatic hydrocarbons in water-based paint was

Table 4. The main components of volatile organic compound emitted from the particleboard with different surface decoration.

Category	Main components
Aromatic hydrocarbons	Benzene; Toluene; ethylbenzene; Fluorene; p-Xylene; 1H-Phenylene, Phenanthrene; and Benzene, 1,3-dimethyl-
Alkanes	Hexane; Undecane; Tetradecane; Pentadecane; and Hexadecane
Alkenes	Bicyclo[3.1.1]hept-2-ene, 3,6,6-trimethyl-; Cyclohexene, and 1-methyl-4-(1-methylethenyl)-, (ñ)-; 3-Carene
Aldehydes and ketones	Hexanal; Octanal; Nonanal; Undecanal; Decanal; Undecanal; Cyclopentanone, and 2-methyl-; Naphtho[2,1- <i>b</i> ]furan
Others	1,5-Heptadiene-3,4-diol, 2-methyl-

significantly higher than that in other decorative materials and PB under the initial conditions. The reason is that the water-based paint contains a large number of aromatic hydrocarbons. The water-based paint used in this

experiment belongs to the aromatic waterborne acrylic polyurethane dispersion, which leads to the release of aromatic substances. Under equilibrium condition, the release amount of aromatic hydrocarbons was lower than PB, this

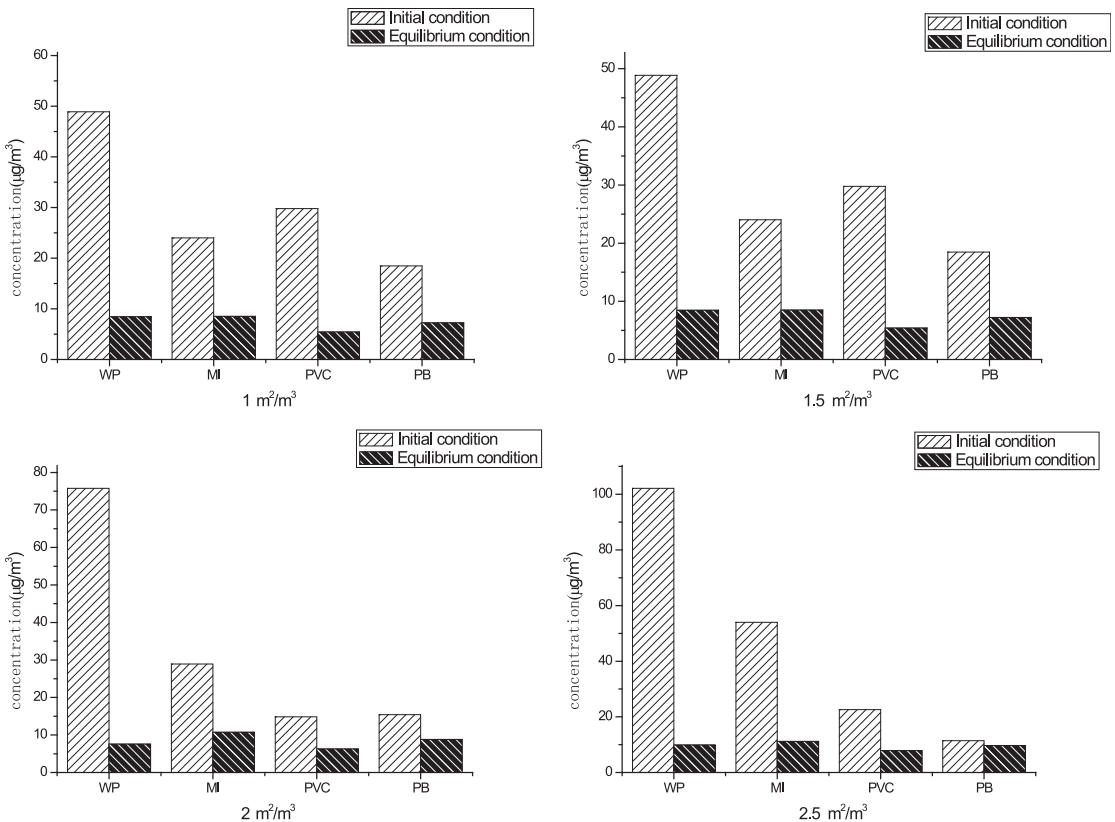


Figure 2. The concentration of alkanes under initial and equilibrium conditions with different experimental conditions.

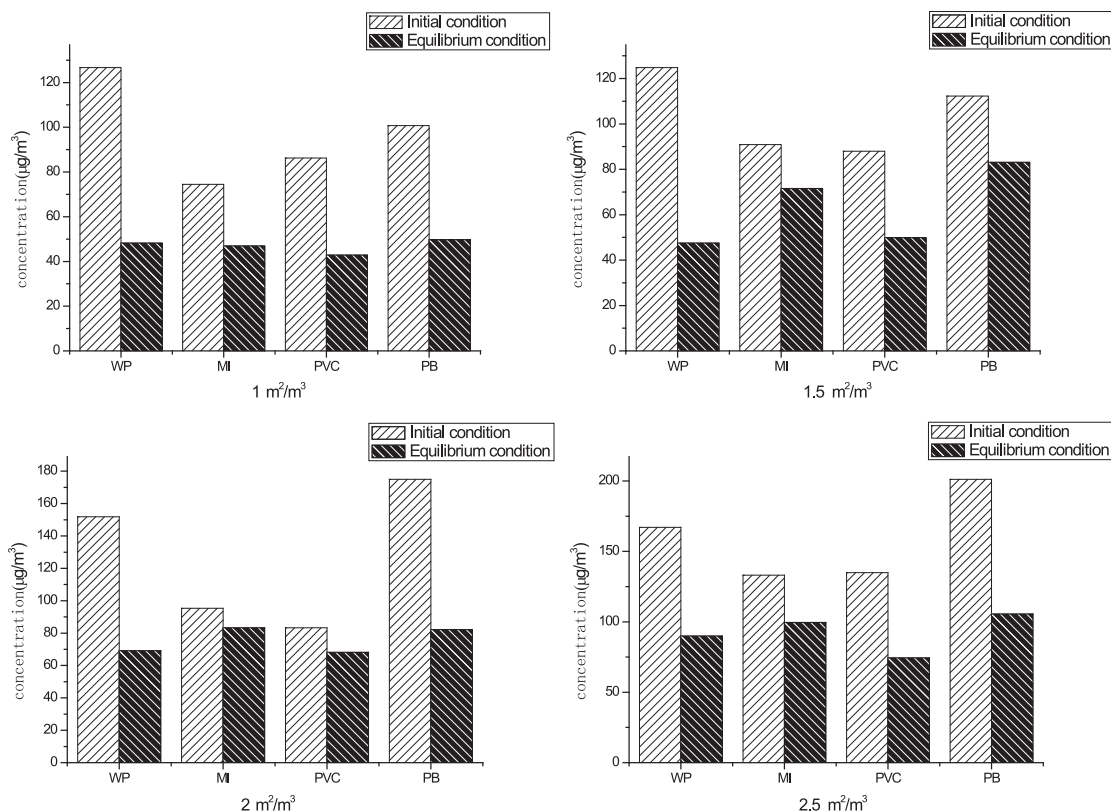


Figure 3. The concentration of aromatic hydrocarbon under initial and equilibrium conditions with different experimental conditions.

shows that the release was fast, and with the extension of storage time, the pollution to the environment became lower. Under the initial and equilibrium condition the aromatic hydrocarbon concentration of MI and PVC were lower than that of PB; this shows that the decorative materials of MI and PVC have an influence on blocking the release of aromatic hydrocarbons.

Figure 4 shows the release trend of esters with time. Under the initial condition, the esters concentration of the panel with water-based paint was higher than that of PB. This is related to the wetting agent in water-based coatings. The wetting agent contains esters (vinyl acetate and polyacrylate). The concentration of MI has no significantly deferent with PB; the PVC concentration was lower than PB. In the equilibrium condition, the concentrations of

WP, MI, and PVC were a little lower than those of PB. This shows in the initial conditions, the concentration of WP was higher and the environmental pollution was serious; as time goes on, the release amount reduced and the environmental pollution became smaller. MI has little effect on blocking the release of esters, but PVC has great effect on blocking the release of alkanes.

Figure 5 displays the concentration of aldehydes and ketones with time. The aldehyde and ketone concentrations of WP, MI, and PB were higher at equilibrium than in the initial condition; the concentration of PVC decreased with time. The reason may be that the substances contained by WP, MI, and PB could block or adsorb aldehydes and ketones. With the extension of time, these substances released, and the blocking and absorbing effect



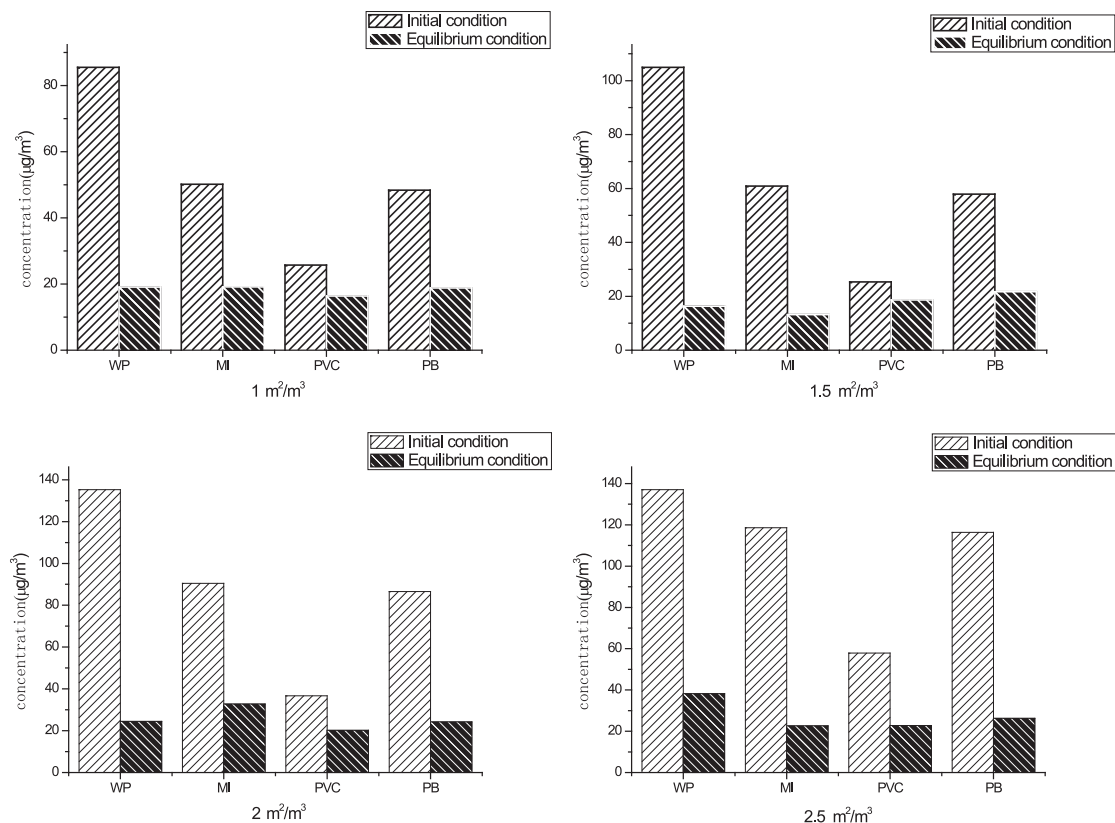


Figure 4. The concentration of esters under initial and equilibrium conditions with different experimental conditions.

was reduced and the concentration of aldehydes and ketones increased. This shows that the PVC has little effect on blocking the release of aldehydes and ketones.

Because water-based paint contains alkanes, aromatic hydrocarbons, and esters, the concentration of WP was higher in initial condition; as time went on, the release amount was lower than that of PB and the environmental pollution became lower. The MI and PVC could effectively reduce the release of aromatic hydrocarbons in panels and the PVC could reduce the release of esters in panels. The aldehyde and ketone concentration of WP, MI, and PB increased with time, but the PVC decreased. On the whole, various substance concentrations of panels with surface decoration (WP, MI, and PVC) were lower than panels with no surface decoration (PB) in equilibrium condition.

## CONCLUSIONS

In this paper, VOC concentration of different types of decorative PBs and different panel area–volume ratio with small–environmental test chamber method (15-L chamber method) were studied. The conclusions were as follows: the concentration of VOCs showed the trend of decreasing with time, the decline velocity of water-based paint was the fastest, and the PB with no decoration was the slowest. The increase of panel area–volume ratio could cause the VOC concentration to increase, and the panel area–volume ratio does not have a linear relationship with VOC concentration. The main components of VOCs were confirmed as esters and aromatic hydrocarbons; and alkanes, aldehydes, and ketones. Surface decoration can reduce the release of various kinds of material inside the plate to a certain extent. MI and PVC

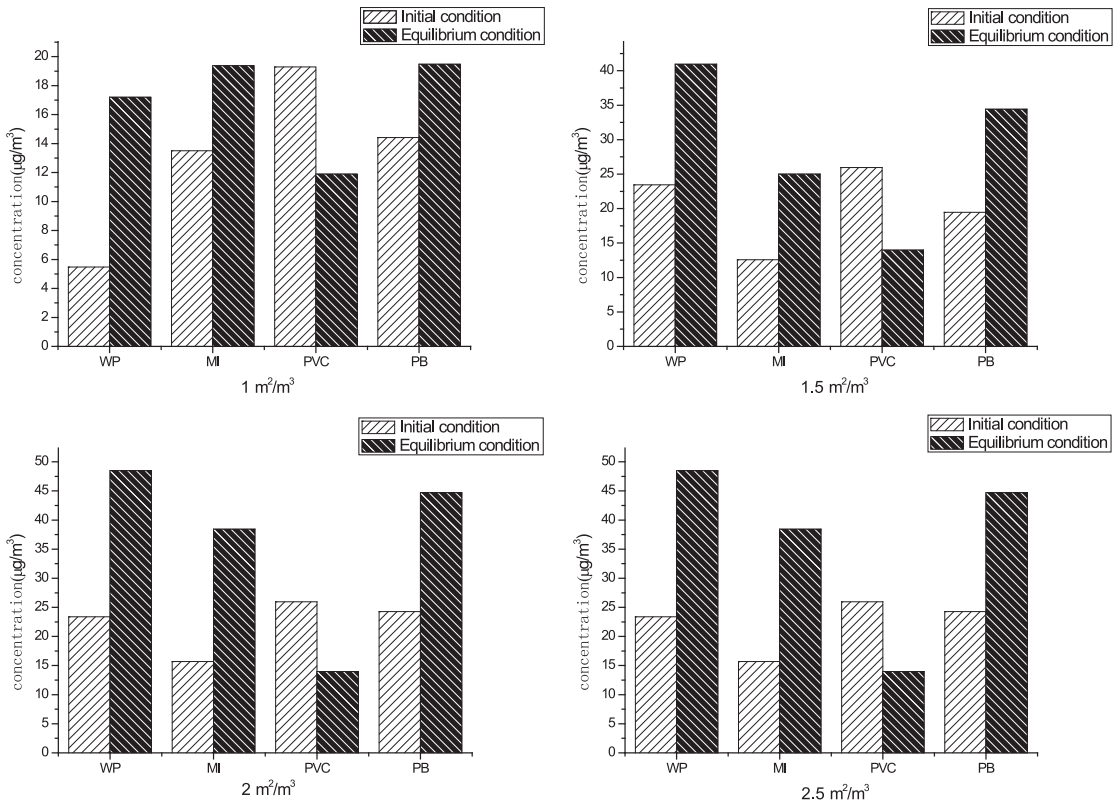


Figure 5. The concentration of aldehydes and ketones under initial and equilibrium conditions with different experimental conditions.

can reduce the release of aromatic hydrocarbons in panels, and PVC can inhibit the release of esters in panels.

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