

Influence of Environmental Factors on Volatile Organic Compound (VOC) Emission from Plywood

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Abstract

In this study, the impact of temperature (T=18°C, 23°C and 28°C), relative humidity (RH=35%, 50%, 60%, and 75%), and air exchange rate (ACH=0.5/hr, 1/hr, and 2/hr) on the Volatile Organic Compound (VOC) emission rate and concentration from plywood were investigated by small chamber testing for 5 days. Gas chromatography-mass spectrometer (GC/MS) was used to measure components of Total Volatile Organic Compound (TVOC). The aim of this study was to explore the properties of VOC emission from plywood in different environmental conditions. The experiment result showed that increasing temperature, relative humidity and air exchange rate accelerated VOC emission from plywood. The influence of environmental factors on VOC emission was only significant for initial emission. Few days later, the effect was not obvious. Arene compound were the main compounds of TVOC emission from plywood, and the content of alkane compounds were the second. Small amounts of alkene, esters and aldehydes compounds were emitted from plywood. The emission rate of arene compounds was higher than that of alkane compounds. Environmental factors affected arene compounds emission rate more obviously than alkane compounds. Toluene emission rate was the highest, m,p-xylene was the second, and the ethylbenzene was third. The influence of environmental factors on these three compounds had no big differences.

Keywords: plywood ; Volatile Organic Compound (VOC) ; temperature ; relative humidity ; air exchange rate

Introduction

Many factors, such as hot-pressing process, secondary processing, and environmental conditions, affect Volatile Organic Compounds (VOC) emissions. Local and foreign researchers (Liu 2010, Zhang 2011, Kim et al 2010) had studied the influence of hot-pressing and secondary processing on VOC emissions from wood-based panels. Environmental factors, namely, temperature, relative humidity (RH), and air exchange rate (ACH), have a major influence on VOC emissions. Studies (Fang 1999, Wolkoff 1998) proved that the influence of environmental factors on VOC emissions depend on the type of materials and VOC.

This study used plywood that is widely used in indoor decorations. The influence of temperature (18 °C, 23 °C, and 28 °C), RH (35%, 50%, 60%, and 75%), and ACH (0.5/hr, 1/hr, and 2/hr) on VOC emission rate and concentration from plywood were investigated using small chamber testing for five days. The study used a gas chromatography-mass spectrometer (GC/MS) to measure the components and quantities of TVOC.

Materials and Methods

Materials. The plywood came from a wood-based panel factory in Harbin. The plywood (1220 mm×2440 mm×9 mm) was cut into small pieces immediately after manufacture. The volume of the small chamber was 15 L. The loading rate was 1 m² m⁻³, and the exposed area of the plywood was 0.015 m² (123 mm×123 mm). To prevent VOC emissions, the edges and other side of the plywood were wrapped with aluminum foil. After the edges and one side were wrapped, the plywood was wrapped with tin foil and polytetrafluoroethylene plastic. In the end, the plywoods were kept in the refrigerator at -30 °C.

Equipments and methods. The volume of the environment chamber was 15 L. The background TVOC concentration of the chamber was less than 20 ug/m³, and any individual compound concentration was less than 2 ug/m³. These amounts corresponded with the *Technical requirement for environmental labeling products–Wood based panels and finishing products* (HJ 571-2010). The parameters of 15L small chamber is showed in Table. 1.

Table.1. The parameters of 15L small chamber

Experiment parameters	15L small chamber		
	A	B	C
Volume(m ³)	0.015	0.015	0.015
Loading factor(m ² m ⁻³)	1	1	1
Air exchange rate(hr ⁻¹)	1	1	0.5/1/2
Relative humidity (%)	35/50/60/75	50	50
Temperature (°C)	23	18/23/28	23
Chamber air flow(m ³ h ⁻¹)	0.015	0.015	0.0075/0.015/0.03
Specific air flow rate (m ³ h ⁻¹ m ⁻²)	1	1	0.5/1/2

The thermal desorption (TP-5000, China)-GC/MS (Thermo, DSQII) experiment parameters are as follows:

Thermal desorption: Carrier gas, helium; desorption temperature, 300 °C; desorption time, 5 min; sample air entrance time, 1 min.

GC/MS: Chromatographic column (25m×0.25mm×0.25µm DB-5 silica capillary columns) was used. The temperature program started at 40 °C, which was kept for 2 min. At 2 °C/min, temperature rose to 50 °C, which was maintained for 4 min. At 5 °C/min, temperature rose to 150 °C, which was maintained for 4 min. Finally, at 10 °C/min, the temperature rose to 250 °C and maintained for 8 min. The carrier inlet temperature was 250 °C; the split flow rate was 30 l/min; the split flow ratio was 1:30. The electron impact ionization source (EI) was used. The ionization source temperature was 230 °C, and auxiliary temperature was 270 °C.

Results and discussions

The influence of environmental factors on TVOC emission. In this research, the TVOC is the sum of compounds within the retention time between the n-hexane and hexadecane. VOC emissions from plywood were tested in different environmental conditions. Air samples were collected in the Tenax tube using an air sample pump with electronic flow controller. A flow rate of 150 ml/min was used for sampling an air sample volume of 6 L. Then, the air sample was desorbed for 5 min and qualitatively analyzed with the GC-MS using the internal standard method (internal standard substance is toluene-d8). The emission rate or concentration/time profiles of TVOC emissions from plywood in different environmental conditions are shown in Figs. 1, 2 and 3.

Temperature

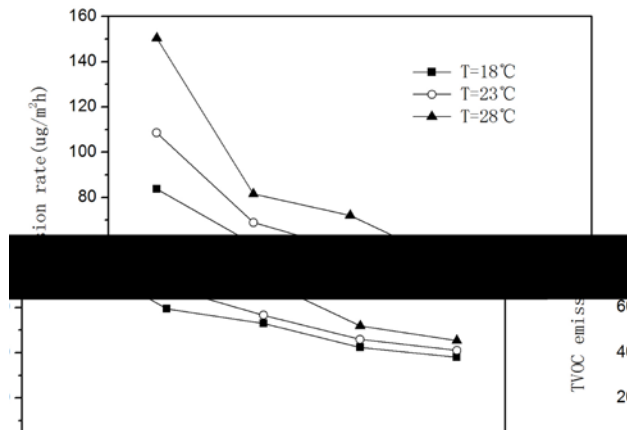


Fig. 1. TVOC rate/time profiles at different temperature

Fig. 1 shows that the increasing temperature accelerated the TVOC emission rate from the plywood. At higher temperatures, the TVOC emission rate decreased faster than that at lower temperatures. At the temperature of 28 °C, the TVOC emission rate decreased 51.6% from the first day to the second day. On the first day, the TVOC emission rates at three different temperatures had the biggest differences. When temperature increased from 18 °C to 28 °C, the TVOC emission rate increased two times. With the emission of TVOC, no obvious difference was observed among emission rates, and the TVOC

emission rate gradually stabilized. This phenomenon showed that the effect was obvious only during short-term emissions; long-term emission levels were similar. The reason is that temperature can affect the vapor pressures and the diffusivities of VOC within the material. The temperature dependence of diffusivities D_a of VOC within materials can be expressed as the following equation (1):

$$D_a = D_{ref} \exp \left[-E \left(\frac{1}{T} - \frac{1}{296} \right) \right] \quad (1)$$

where D_a is the VOC diffusion coefficient within the material at the temperature of the environment (m^2/h), D_{ref} is the VOC diffusion coefficient within the material at 23 °C (m^2/h), E is determined by experiment (with the general value at 9,000 K), and T is the absolute temperature (K). With the enhancement of temperature, the diffusion coefficient increases. According to the mass transfer theory, increasing the diffusion coefficient within the material can promote VOC emissions.

The temperature dependence of the vapor pressure of VOC can be expressed as follows equation (2):

$$\log p = a - \frac{b}{c + T} \quad (2)$$

where P is the vapor pressure of the compound within the material (atm), T is the absolute temperature (K), and a , b , and c are parameters greater than zero. According to this equation, enhancing the temperature can increase the compound vapor pressure within the material. Therefore, the vapor pressure gradient in the boundary layer between the surface of the material and the bulk phase of the air stream will become greater. A greater vapor pressure gradient will promote VOC emissions. Both diffusion control and vapor pressure control influence the VOC emission together for the initial emission (Fang 1999). However, the effect of vapor pressure on VOC emissions was not significant for long-term emission in his study. When the materials were ventilated for a long period, VOC emissions decreased to a low level, and the emissions became diffusion-controlled. In addition, the increasing diffusion coefficients of the emitted VOC within materials would be less than 10% for a temperature increased from 23 °C to 35 °C (Reid 1987). Therefore, the effect of temperature on VOC emissions is only obvious for initial emission.

Relative humidity

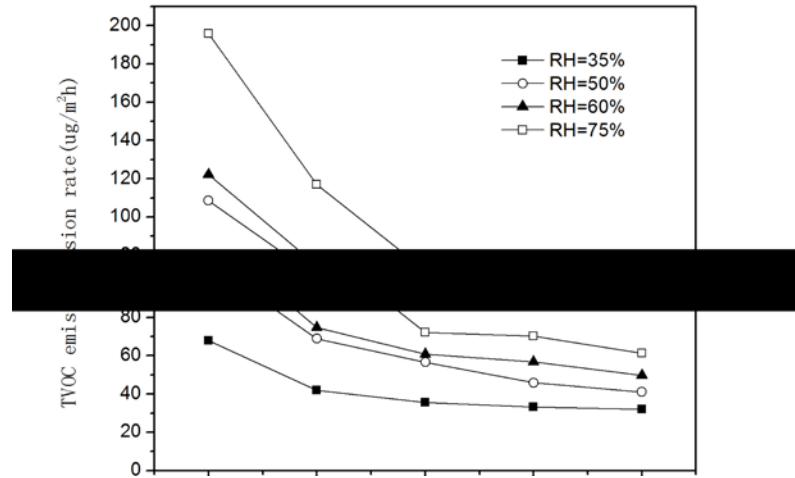


Fig. 2. TVOC rate/time profiles at different RH

As shown in Fig. 2, a higher RH resulted in a higher TVOC emission rate. At a higher RH, the TVOC emission rate decreased faster than that at a lower RH. On the first day, the TVOC emission rate had the biggest decrease. When the RH increased from 35% to 50%, from 35% to 60%, and from 35% to 75%, the TVOC emission rate increased 1.6, 1.8, and 2.9 times on the first day, respectively. For the emission of TVOC, no significant difference was observed among emission rates, and the TVOC emission gradually stabilized. This phenomenon showed that the influence of RH on VOC emissions for the initial emission was more significant than that on the long-term emission. The TVOC emission rate had the smallest change at the RH of 50% to 60%, and the biggest change at the RH was from 60% to 75%. The impact of RH on VOC is different in various RH ranges, which depend on the ranges of the RH. The enhancement effect of humidity on VOC emissions may result from the positive effect of humidity on the water vapor pressures of the external environment. Increasing the RH could improve the environment water vapor pressure, such that the evaporation rate of water vapor within the material becomes smaller. This process (evaporation of water) could absorb the heat of vaporization and retard VOC emissions. Under a lower RH, the retardation of VOC emissions was more significant than that under a higher RH (Lin 2009).

Air exchange rate

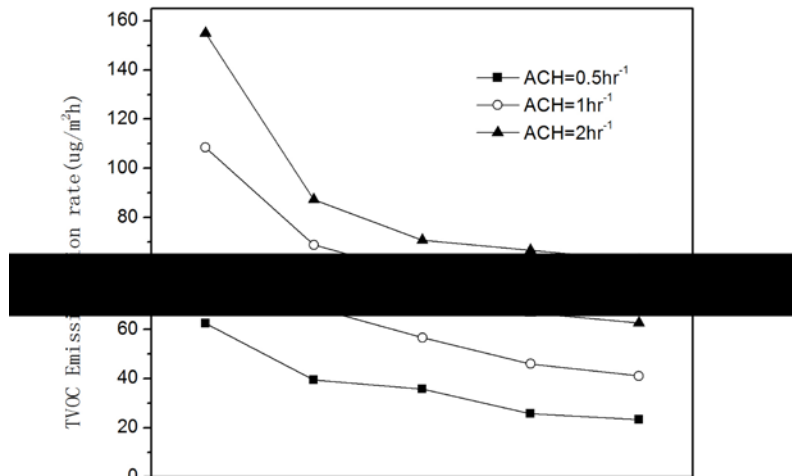


Fig. 3. TVOC rate/time profiles at different ACH

As shown in Fig.3, TVOC emission rates accelerated with the increase in the ACH, whereas TVOC concentration in the chamber decreased. Under a higher ACH, the TVOC emission rate decreased faster than that under a lower ACH. Under the ACH of 2 hr⁻¹, the TVOC emission rate decreased 43.7% from the first day to the second day. With increasing time, the TVOC emission gradually stabilized. Under the ACH of 0.5, 1, and 2 hr⁻¹, TVOC concentrations in the chamber were 46.68, 41.06, and 31.29 ug·m⁻³ on the fifth day, respectively. The reason in the increased VOC emission rate under a higher ACH is that the VOC concentration in the chamber decreased under the higher ACH. The decrease of VOC concentrations in the gaseous phase would result in the increasing concentration gradient in the boundary layer between the surface of the material and the bulk phase of the air stream. Therefore, VOC molecules were emitted into the air by the boundary layer faster.

The influence of environmental factors on individual components

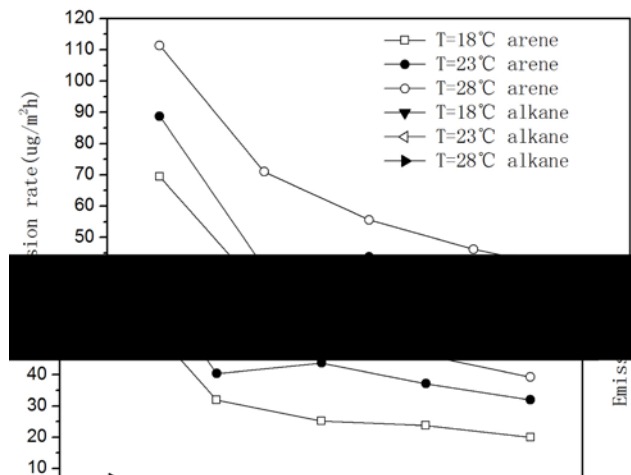


Fig. 4. Arenes and alkanes rate/time profiles at different temperature

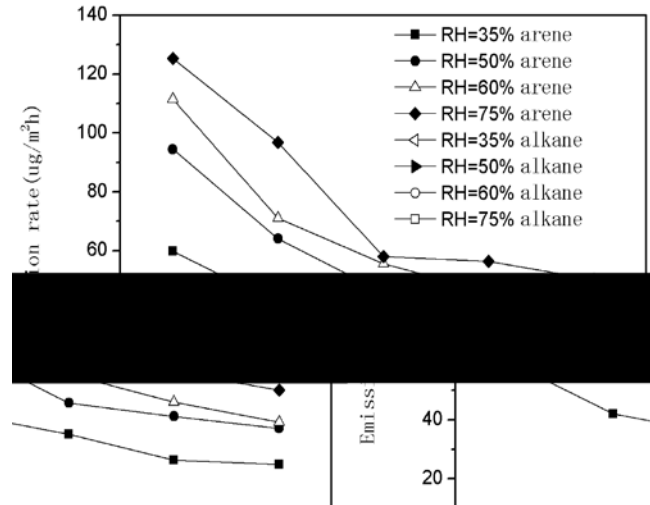


Fig. 5. Arenes and alkanes rate/time profiles at different RH

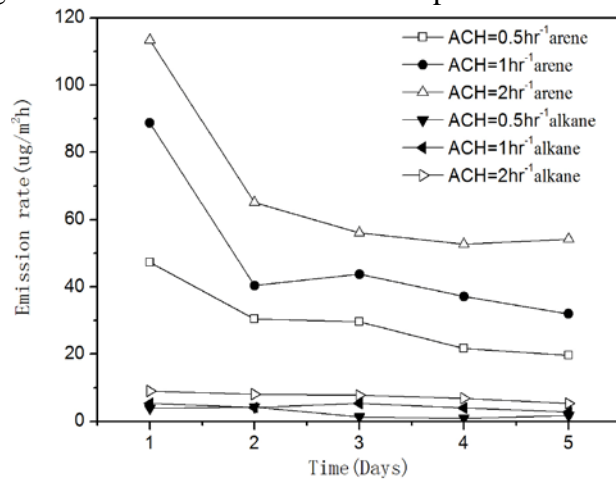


Fig. 6. Arenes and alkanes rate/time profiles at different ACH

As shown in Figs. 4, 5 and 6, the emission rate of arene compounds was higher than that of alkane compounds. In the early emission, arene compound emission rates declined rapidly; the rate declined about a third on the second day, and declined about one half on the third day. Finally, the emission rate gradually stabilized. However, there was no obvious characteristic that emission rates decreased rapidly during the emission process of the alkane compounds. The alkane compound emission rate was stable during the emission process.

The influences of temperature, RH, and ACH on arene compounds were more obvious than those on alkane compounds. The effect of temperature mainly depended on the VOC vapor pressure within the material affecting the VOC emission rate. The effect of temperature on the vapor pressure of alkane compounds within the material may be less obvious than that on arene compounds. The water vapor pressure was the dominant factor of RH affecting the VOC emission rate. For the low emission rate of alkane compounds, the retardation of alkane compound emission may be less significant than that of arene compounds. The effect of ACH mainly depended on VOC concentration in the chamber, which affected the VOC emission rate. The concentration of alkane compound in the

chamber was lower than that of arene compounds. The influence of ACH on the alkane concentration gradient in the boundary layer between the surface of the material and the bulk phase of the air stream may be less significant than that on arene compounds. Consequently, arene compounds emission rate was affected obviously by temperature, RH and ACH.

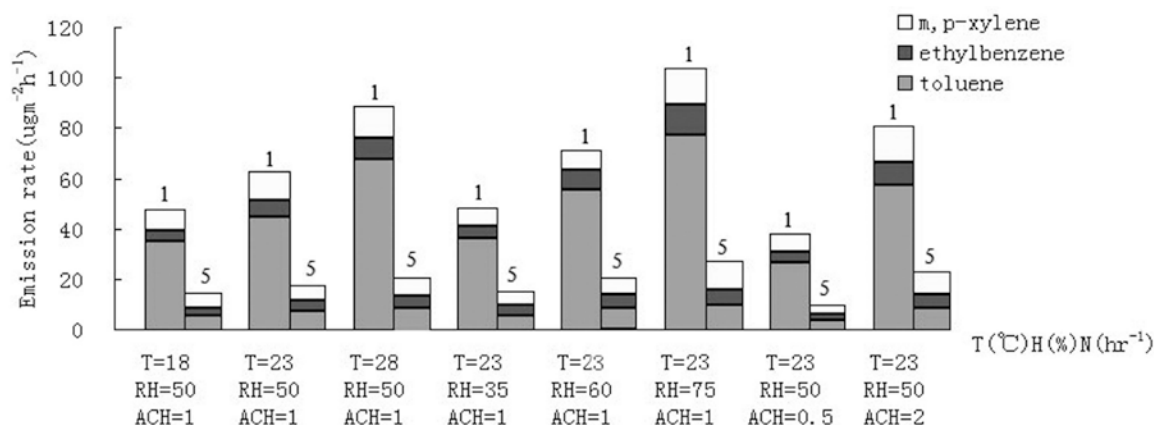


Fig. 7 Toluene, ethylbenzene and m,p-xylene emission rate on the first day and the fifth day

Toluene, ethylbenzene, and m,p-xylene were the main individual compounds of VOC emissions from the tested plywood. As shown in Fig. 7, the toluene emission rate was the highest, ethylbenzene was the second, and m,p-xylene was the lowest. The emission rates of ethylbenzene and m,p-xylene did not have a significant difference as both were lower than the emission rate of toluene. On the first day, the emission rates of the three compounds had the biggest difference in eight environmental conditions. With the emission of VOC, the emission rates of these three compounds had no significant difference. The emission properties of the three compounds were different. The toluene emission rate was higher for the initial emission than that for the later emission. The ethylbenzene and m,p-xylene emission rates were stable during the emission process. The effect of environmental factors on toluene, ethylbenzene, and m,p-xylene was more significant during the initial than the later emissions. The effects of the environmental factors did not differ significantly among these three compounds.

Conclusion

This study investigated the impact of RH, temperature, and ACH on VOC emission rates and concentrations from plywood using small chamber testing for five days. The VOC emission properties in different environmental conditions were analyzed.

With increasing temperature, RH, and ACH, the VOC emissions from plywood accelerated. The influence of environmental factors on VOC emissions was only significant during the initial emission. Arene compounds were the main compounds of TVOC emissions from plywood, and alkane compounds were the second. The influence of temperature, RH, and ACH on arene compounds was more significant than that on alkane compounds. The main VOCs emitted from plywood were toluene, ethylbenzene, and m,p-xylene. Toluene emission rate was the highest, m,p-xylene was the second, and

the ethylbenzene was the third. The effect of environmental factors on three individual VOCs had no major difference.

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