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The effect of temperature on VOCs and carbonyl compounds emission from wooden flooring by thermal extractor test method

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The environmental chamber method is used to determine the area specific emission factor of VOCs emitted from building products, which is calculated from the small emission test chamber concentration by considering the passing air flow rate and surface area at 23–28 °C. Although indoor air temperatures are generally between 17 and 28 °C, floor heating can create exceptional conditions in flooring materials.

To determine the effect of temperature, the emission of VOCs and carbonyl compounds from engineered flooring and laminate flooring were measured using a thermal extractor (TE), which was applied at 25, 35 and 45 °C for 30 min.

At 35 °C, the level of TVOC emission was more than double that at 25 °C. At 35 °C and 45 °C, the level of formaldehyde emission was more than two and five times of that at 25 °C, respectively. Therefore, this TE method of VOCs and formaldehyde emission analysis will be a good alternative to the traditional chamber method for determining the VOC emission levels from flooring products. In conclusion, some wooden flooring may contribute to the contamination of indoor air with the use of floor heating.

1. Introduction

Building materials play an important role in determining the indoor air quality owing to their large surface areas and permanent exposure to indoor air. Building materials can release wide range of pollutants, particularly the volatile organic compounds (VOCs), which can cause indoor air related health problems. Since building materials are important sources of VOCs in indoor environments, their emission characteristics should be studied.

Wood-based panels, such as particleboard (PB), medium density fiberboard (MDF) and veneer, are used widely in the manufacture of furniture, flooring, housing and other industrial products. However, wood-based panels bonded with urea-formaldehyde (UF) resin emit formaldehyde, which is toxic and is associated with possible health hazards, such as irritation of the eyes and the upper respiratory tract [1].

Laminated flooring has been used widely in Europe for more than 20 years and has recently gained popularity in North America [2]. Engineered flooring and laminate flooring are commonly used in new apartment interiors and in remodeling flooring materials in Korea. However, there have been many concerns regarding human health and the environment. PVC flooring, laminated paper lacquered with bean oil, which was used in most Korean houses has been replaced by wood flooring materials, particularly in new apartments [3].

Some engineered flooring and laminate flooring may emit small quantities of formaldehyde and VOCs at 23–25 °C. Therefore, there is some apprehension that engineered flooring and laminate flooring may contaminate indoor air in the presence of floor heating. The maximum temperature of the floor is 29.4 °C, and the temperature at the interface between a concrete screed and carpet may reach 50–60 °C [4], accelerating the chemical reactions that produce the emissions.

Floor heating systems have been used in Korea since ~400 B.C [5]. Modern floor heating systems employ a gas boiler instead of wood or briquettes. Hot water from the boiler is piped to the floor coil, which is an X-L pipe underneath the floor surface. The thermal storage mass consists of cement mortar in place of a stone slab. Nevertheless, the principle of the floor heating system is essentially the same. At the floor surface, heat is radiated to warm the air, and hence the human body. This floor heating system is quite popular in Korea. Koreans spend considerable time sitting directly on a floor

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heating system and have traditionally slept on a thin cotton mattresses warmed directly from the floor surface [6].

Consequently, a number of Korean researchers have evaluated a range of floor finishing materials and determined the ideal floor surface temperature while a person is in the sitting position; 22.5–38.8 °C [7–11]. On the other hand, Western researchers conducted their experiments inside laboratories wherein the air temperature was controlled within a specified comfortable state to be 23–24 °C [6].

Indoor air temperatures are generally limited to a range between 17 and 28 °C, but floor heating can create exceptional conditions in flooring materials (temperatures of 50–60 °C). When the temperature is increased, all processes with the potential to contribute to the emission of VOCs, such as diffusion within a flooring material, desorption, evaporation and chemical reactions are increased [4].

Conventionally, a radiant floor heating system is used in Korean residential housing units. The heat is transferred from the floor surface to the other surfaces mainly via radiant heat transfer. This is different from air heating systems, which deliver heat from the air to the material by convective heat transfer. The heat transfer characteristics of the floor-heated space mean that the temperatures can differ according to material, installation position and thermal mass of the material [12].

This study examined the effects of the elevated temperatures on the emission of VOCs and carbonyl compounds from engineered flooring and laminate flooring using the Thermal Extractor (TE) method. The temperature of the TE was maintained at 25 °C, 35 °C and 45 °C according to the temperature in a residential housing unit with a radiant floor heating system.

In particular, it was used to examine the effect of various temperatures of flooring materials to TVOC (the sum of VOCs between C_6 and C_{16}), 5VOC (benzene, toluene, ethylbenzene, xylene, styrene), natural VOCs and the carbonyl compounds emission behavior of each temperature.

2. Experimental

2.1. Materials

Laminate flooring is composed of waterproof, high-density fiberboard (HDF) as the core material, overlay paper, deco paper and valance paper. Each paper is impregnated with melamine-papers pressed at approximately 200 °C.

In the case of engineered flooring, a 0.5 mm thick veneer of wood, such as birch, oak, beach, cherry, or maple, is glued to a 7.2 mm thick plywood sheet and pressed at approximately 160 °C. An ultra-violet (UV) curable coating is applied to this veneer. The moisture content of laminate flooring and engineered flooring is 7.6 ± 0.5% and 6.2 ± 0.5%, respectively.

2.2. Test method

2.2.1. Evaluation of the VOCs and formaldehyde emission using a TE test

A thermal extractor (TE, Gerstel) was used to measure the VOCs and formaldehyde emission from flooring materials at different temperatures. The TE is shown in Fig. 1.

Fig. 1. Thermal Extractor (TE).

Fig. 2 shows a schematic diagram of the mode of operation. The TE consists of an adjustable oven (temperature range: room temperature ~350 °C) heating a glass tube (length 178 mm, diameter 13.6 mm) with the sample inside. The sample size was limited both by the diameter of the tube and by the heatable length of the oven to a maximum 70 mm. Pure nitrogen was flowed through the glass tube. In normal use, the entire gas flow passes over the adsorbent material.

A sample of flooring material (10 mm × 50 mm × 7.6 mm, $W \times L \times T$) was placed in a glass extraction tube. The VOCs and formaldehyde were purged under a pure nitrogen gas stream at a constant flow on a Tenax TA tube and 2,4-DNPH cartridge. The emission rate considered the area specific emission factor and air exchange rate ratio of the volume of clean air brought into emission TE per hour and the free emission TE volume measured in identical units (mg/m^2 h). The thermal extraction process was applied at 25, 35 and 45 °C for 30 min (Table 1 lists the test conditions.).

The sampling volume was 1 L. Air sampling was performed at a flow rate of 39 ml/min for approximately 30 min. Due to the low volume of the glass tube and high nitrogen gas flow, the air exchange rate was 90 h^{-1} (Table 1 lists the test conditions). The tests were carried out at three temperatures, 25 ± 1, 35 ± 1 and 45 ± 1 °C, with the humidity uncontrolled but ~55 ± 10% R.H. The VOCs and carbonyl compounds concentrations were analyzed by TD-GC/MSD and HPLC, respectively.

3. Results and discussion

Figs. 3 and 4 show the TVOC and 5VOC emission behavior at 25 °C, 35 °C and 45 °C using the TE test method. A higher temperature resulted in a higher TVOC and 5VOC emission rate from the engineered and laminate flooring. The TVOC emission rate of the laminate flooring at 25 °C, 35 °C and 45 °C were 4.139, 8.715 and 14.980 mg/m^2 h, respectively. In contrast, the TVOC emission rate from the engineered flooring at 25 °C, 35 °C and 45 °C were 0.787, 2.081 and 4.103 mg/m^2 h, respectively. The rate of TVOC and 5VOC emission from the laminate flooring was higher than that from engineered flooring (Table 2) (Table 3).

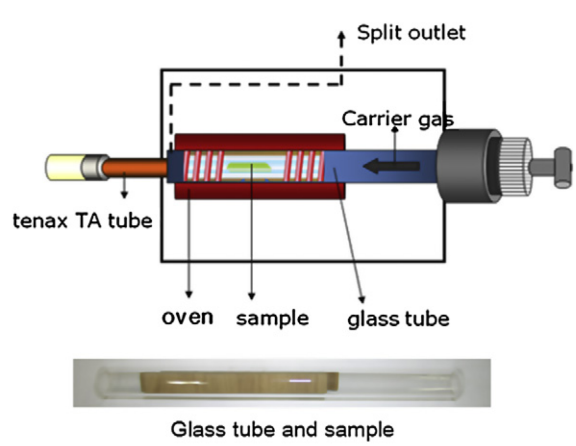

Fig. 2. Schematic diagram of the Thermal Extractor TE.

Table 1
Test conditions in the TE test method.

Test condition	TE method
Surface area of test specimen (m^2)	0.002076
Chamber volume (L)	0.26
Loading factor (sample area/chamber volume)	79.85
Air change rate (h^{-1})	90
Air supply (mL/min)	39
Sampling	after 30 min
Temperature (°C)	25, 35, 45 ± 1
Humidity (% R.H.)	Room condition (55 ± 10)
VOCs sampling flow rate (ml/min)	39
VOCs sampling volume (L)	1
Inlet air	High purity N_2
Cleaning process	Cleaning with pure water then placed in a TE for 30 min at 260 °C
VOCs analysis method	TDS-GC/MS
Formaldehyde analysis method	HPLC

As shown in Figs. 3 and 4, the TVOC and 5VOC emission was affected significantly by temperature. For engineered flooring and laminate flooring, increases in temperature cause a remarkable increase in the VOCs emission. At 35 °C, the level of TVOC emission was more than double that at 25 °C. The greatest increase was observed with engineered flooring, which varied from 0.787 mg/m^2 h to 2.081 mg/m^2 h at temperature changes from 25 °C to 35 °C.

The rate of TVOC and 5VOC emission from the engineered flooring was higher than that from laminated flooring but formaldehyde emission from the engineered flooring was lower than that from laminated flooring.

The high-density fiberboard (HDF) core of the laminate had the greatest effect on VOCs and formaldehyde emission in laminate flooring. This was made UF resin or melamine–urea–formaldehyde (MUF) condensed resin. This grade of laminate flooring can be used to determine the residences. Because plywood used as the core in engineered flooring was glued with phenol–formaldehyde resin (PF), its formaldehyde emission was lower than that of laminate flooring [13].

Temperature, air velocity and humidity are environmental parameters that affect VOCs emissions from building materials [14]. Previous studies reported the changes in emission with

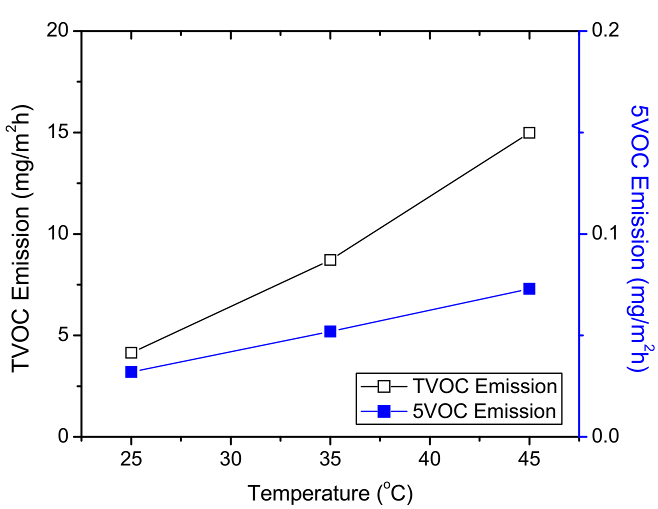

Fig. 3. TVOC emission behavior of the laminate flooring using the TE method at various temperature.

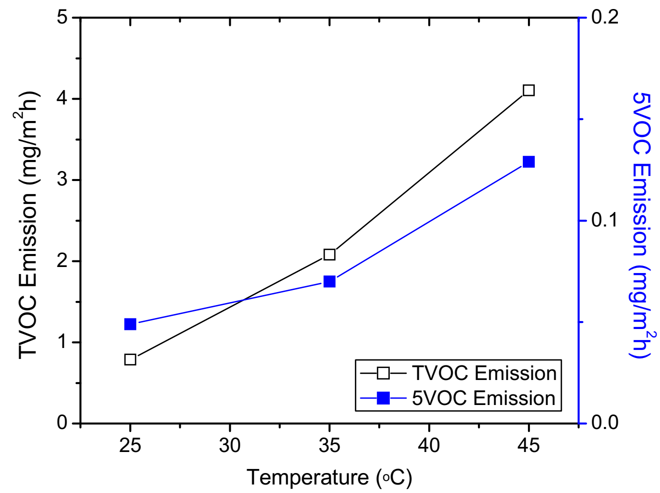

Fig. 4. TVOC emission behavior of the engineered flooring using the TE method at various temperature.

temperature, and concluded that the emitted substances were temperature dependent [15–17]. The temperature variations did not have a significant effect on the emissions of volatile compounds with a lower boiling point but had a stronger effect on volatile compounds with a higher boiling point [18].

However, some natural VOCs (NVOC) are emitted from engineered flooring and laminate flooring, such as benzaldehyde. The engineered flooring emitted a larger amount of NVOC than laminate flooring specimens, as shown in Fig. 5. This is similar to the observations of TVOC emission. The UV-cured coated surface of the engineered flooring is bare like the unfinished surface of a plywood veneer, and emitted NVOCs, such as benzaldehyde, cadinene, copaene and gurjunene.

In the fiberboard industry, chips are converted to fibers using a pulping process, where they are reduced by mechanical action aided by thermal softening of the lignin-rich middle lamella between wood cells. During the curing process, the temperature in the pressurized refiner is generally held between 160 °C and 185 °C. This high temperature process may drive the NVOCs from the furnish resulting in lower emissions by the product [19].

Fig. 6 shows the formaldehyde emission behavior at 25 °C, 35 °C and 45 °C using the TE test method. The formaldehyde emission rate for engineered and laminate flooring increased with increasing temperature. Formaldehyde emission from laminate flooring was affected significantly by temperature. At 35 °C and 45 °C, the level of formaldehyde emission was more than two and five times higher than that at 25 °C, respectively.

Laminate flooring is composite flooring with a HDF core with a density > 0.85 g/cm^3, and is one of the most commonly used wood composite panels for the core layer. A wear resistant decorative paper normally saturated with melamine base resin is located in the core layer. A clear cap sheet made from an aluminum oxide saturated film and a balancing backing were also placed on the top of decorative paper and on the back of the panel,

Table 2
VOCs and formaldehyde emission rate from the engineered flooring results.

Compound Emission (mg/m^2 h)		TE method (temperature)		
		25 °C	35 °C	45 °C
VOCs	TVOC	0.787	2.081	4.103
	5VOC	0.049	0.070	0.129
	NVOC	0.073	0.362	0.550
Formaldehyde		0.047	0.133	0.177

Table 3
VOCs and formaldehyde emission rate from the laminate flooring results.

Compound Emission (mg/m^2 h)		TE method (temperature)		
		25 °C	35 °C	45 °C
VOCs	TVOC	4.139	8.715	14.980
	5VOC	0.032	0.052	0.073
	NVOC	0.075	0.138	0.205
Formaldehyde		0.175	0.454	0.969

respectively. The main purpose of an aluminum oxide film is to protect the surface from stain [2].

Normally, HDF manufacturers employ formaldehyde-based resin, such as UF resin and UMF resin, for HDF and veneer bonding. The TE sample was unsealed. When the edges of wood-based composites were sealed with finishing materials, the level of formaldehyde emission was reduced dramatically compared to unsealed edges [20].

In engineered flooring, formaldehyde emission is lower than that of laminate flooring because the plywood that is glued with phenol–formaldehyde (PF) resin. The final step for engineered flooring is a UV-curable coating on a veneer. Basically, a UV-curable coating was used to increase the surface roughness of the soft veneer, which is the surface of engineered flooring [3]. This production process and adhesive reduces formaldehyde emission.

Figs. 7 and 8 show the total rates of carbonyl compounds emission determined using the TE test method. The carbonyl compounds emission behavior was similar to that of the formaldehyde emission behavior. The engineered flooring showed a higher emission rate, whereas the laminate flooring was lower, which is similar to the results of formaldehyde emission. The total carbonyl compounds and formaldehyde emission rates for each sample increased with increasing temperature.

In the TE test, acetone and hexaldehyde were the major carbonyls collected from the carbonyl compounds emitted from the engineered flooring and laminate flooring, respectively. The emission levels of the other carbonyls were remarkably low.

The most prevalent aldehydes in both engineered flooring and laminate flooring were acetone, acetaldehyde and formaldehyde. The presence of carbonyl in the emission from flooring materials indicates that the source of the carbonyls is some component of the wood or its secondary metabolites and adhesive used. Further information about the source of these materials, the manufacturing

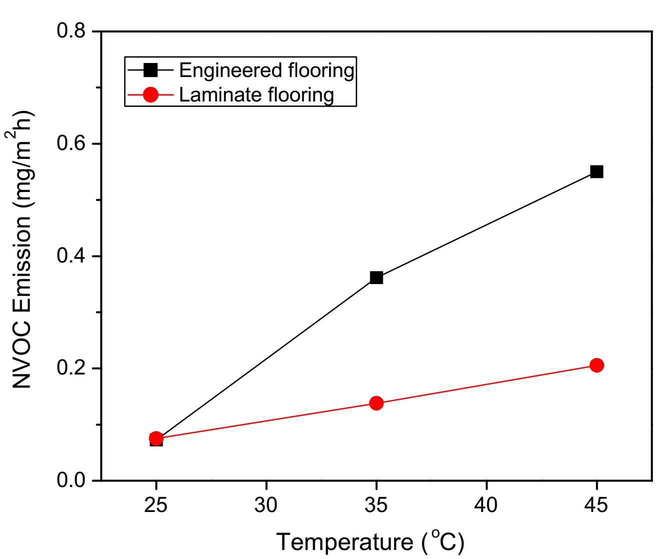

Fig. 5. NVOC emission behavior of the engineered flooring using the TE method at various temperatures.

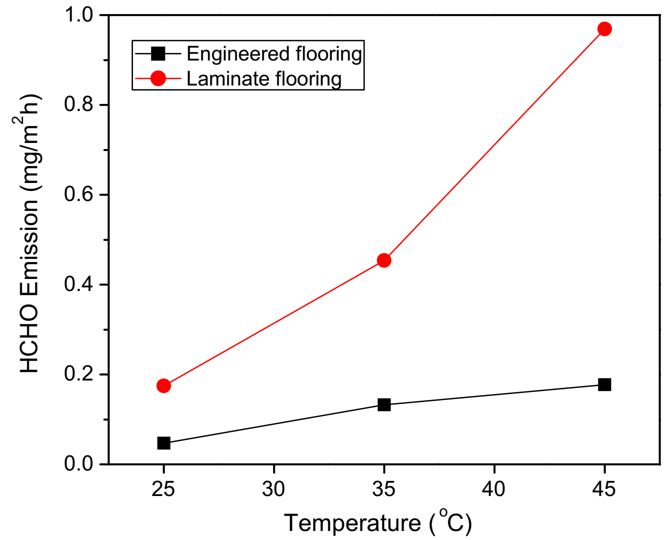

Fig. 6. Formaldehyde emission behavior of the engineered flooring using the TE method at various temperatures.

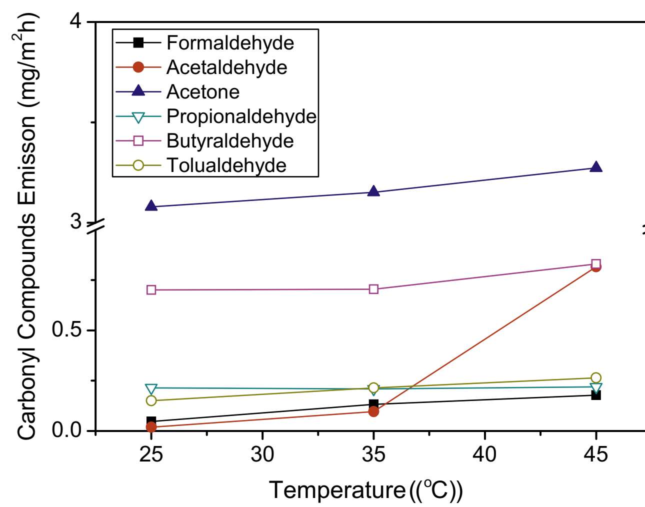

Fig. 7. Carbonyl compounds emission behavior of the engineered flooring using the TE method at various temperatures.

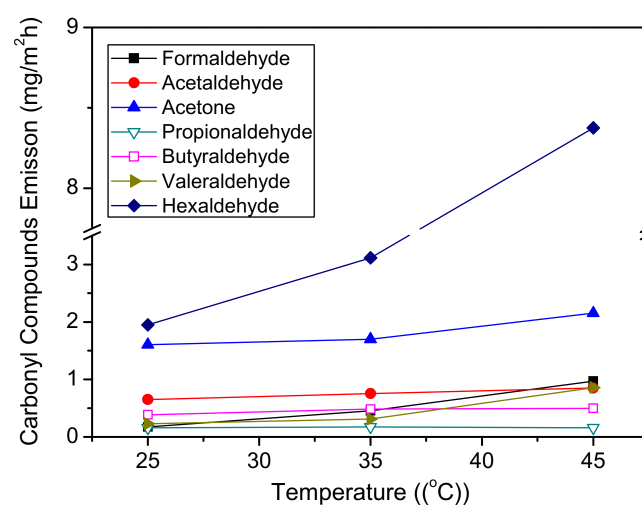

Fig. 8. Carbonyl compounds emission behavior of the laminate flooring using the TE method at various temperatures.

conditions and wood species will be needed to determine if these samples are representative of the mill from which they were sampled.

4. Conclusion

The results of this study show that temperature has significant effect on both the VOCs and carbonyl compounds emission from the wooden flooring materials tested.

The TVOC and 5VOC emission was affected significantly by temperature. For the engineered and laminate flooring, increases in temperature cause a remarkable increase in the VOCs emission. At 35 °C, the level of TVOC emission was more than double that at 25 °C. Formaldehyde emission from laminate flooring was affected significantly by temperature according to the TE method. At 35 °C and 45 °C, the level of formaldehyde emission was more than two and five times that at 25 °C, respectively. The carbonyl compounds emission of laminate flooring is most sensitive to temperature.

Indoor air temperatures are generally limited to a range between 17 and 28 °C but floor heating can create exceptional conditions in flooring materials (temperatures of 50–60 °C). When the temperature is increased, all the processes with a potential to contribute to the emission of VOCs and formaldehyde, such as diffusion within a flooring material, desorption, evaporation and chemical reactions are increased. In conclusion, some wooden flooring may contribute to the contamination of indoor air with the use of floor heating.

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