Measurements of Chemical Emission Rates from Portable PC and Electronic Appliances

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Abstract
Indoor chemicals are emitted not only from building materials but also from various products such as furniture and electronic appliances, which were brought by occupants. Usually these electronic appliances are made of plastics and synthetic materials. Also adhesive and sorbent were used for them. In this paper, the emission rates of aldehydes and VOCs from electronic appliances including a portable PC, a remote controller of TV, a low frequency current massager, a cellular phone, and a photo journal were measured by using a small chamber. It was found that the emission rate of formaldehyde for the portable PC during turning on was 9 µg/unit-h, which was 9 times higher than that of switched off. In the second experiment, a portable PC was exposed under relatively high concentration of ozone. The outlet ozone concentration from the chamber with PC was decreased as low as 50% of the blank chamber.

Keywords: VOCs, emission, small chamber, ozone, electronic appliance

Introduction
Emission rates of aldehydes and VOCs for the building materials such as floorings, carpets and wall coverings have been determined by using a small chamber. However, indoor chemicals are emitted not only from building materials and furniture but also from various products such as electronic appliances. Many of them are made of plastics and synthetic materials. Also adhesive and sorbent are used for them.

Chemical emission rates from personal computers, electronic appliances widespread in offices and homes have been reported earlier by several studies (Braungart et al.1), Black and Worthan 2), Wensing et al.3-5), Bakó-Biró et al.6)). Braungart et al.1) reported emissions from 19 different products, which were commonly used in offices and households. Televisions/video recorders3,4) and computer monitors/laser printers5) were measured by using a 1m³ emission test chamber. It was found that electronic appliances including personal computers had significant effects on indoor air pollution. In 2001, ECMA (European Computer Manufacturers Association) published a standard measuring method for electronic equipment7). However, results of measurements were not widely published by the manufactures, so results for Japanese products shown in this paper may be useful to estimate their contribution to the indoor concentration.

In this paper, emission rates of aldehydes and VOCs from a portable PC, a remote controller of TV, a low frequency current massager, a cellular phone, and a photo journal were measured by using a small chamber ADP AC (Advanced Pollution and Air quality Chamber)8).

Moreover, electronic appliances like photocopy machine and lazar printers are one of the major sources for ozone indoors. On the other hand, ozone is widely used in the spaces for purifying the air and removing odor. However, U.S.EPA9) reported that ozone concentration under the public health standards applied to indoor air dose not effectively remove viruses, bacteria, mold, or other biological pollutants, additionally, at those concentrations, ozone has little potential to remove indoor air contaminants, and it is not effective at removing many odor-causing chemicals.

The reaction between ozone and indoor pollutants were reported in several papers10-14). For example, styrene reacts with ozone and produce formaldehyde and benzaldehyde10). Weschler et al.11) reported that the chemicals from carpets reacted with ozone. Knudsen et al.10) suggested that the secondary emission with ozone had a strong impact on the perceived air quality. In the second part of this paper, a preliminary experiment was conducted to investigate the effects of ozone for a portable PC, which was measured its emission rate in the first part. Oxidation reaction was observed for a portable PC exposed under the relatively high ozone concentration.
Measurements of Emission Rate

Test products

All test products except A shown in Table 1 were measured just after purchasing. Portable PC was measured under the conditions of switching on and off (B, C). Photo journal (G) was opened at the mid-page during the measurement period.

| No | Product          | Period of operation     |
|----|------------------|-------------------------|
| A  | Portable PC (A4 size) | 9 months after unpacking |
| B  | Portable PC (A4 size) | New / switched off      |
| C  | Portable PC (A4 size) | New / switched on       |
| D  | Remote Controller of TV | New                     |
| E  | Low Frequency Current Massager | New               |
| F  | Cellular Phone    | New                     |
| G  | Photo Journal (all color page) | New             |

Methods

Measurements were carried out by using a 20L chamber ADPAC. Its performance characteristics are met with the Japanese Industrial Standard (JISA1901). Throughout the measurements, air temperature and relative humidity inside the test chamber were kept constant at 25±1°C and 50±4%. Chamber was ventilated at 10L/h. However, internal temperature was increased during the measurement of product C due to the heat dissipation.

Ten litter of air was sampled for aldehydes with DNPH-Silica cartridge and 3.2L for VOCs with Tenax TA tube. Sampling rates for both aldehydes and VOCs were 0.167L/min respectively. This was the same as the ventilation rate of small chamber. After the sampling procedures, high-performance liquid chromatography (HPLC) was used for the analysis of aldehydes, and thermal desorption system (TDS), GC/MS was for the VOCs.

Results

The results were expressed by the unit specific emission rate in micrograms per unit and hour. Equation (1) shows the relationship between the unit specific emission rate ($EF_u$) and the chamber concentration ($C_t$).

$$EF_u = C_t \times \frac{nV}{u} = C_t \times \frac{Q}{u} \quad \text{...(1)}$$

where,

- $EF_u$ is the unit specific emission rate [µg/unit-h],
- $C_t$ is the chamber concentration [µg/m³]
- $n$ is air exchange rate [1/h]
- $V$ is chamber volume [m³]
- $u$ is a number test specimen [unit]
- $Q$ is ventilation rate [m³/h]

Since these measurements were carried out by using a 20L chamber, and ventilation rate with 10L/h, the figures of the emission rates per unit were 0.01 times smaller than those of the concentrations in the chamber.

Figure 1 shows the unit specific emission rate for aldehydes, and Figure 2 shows those for VOCs and TVOC. Fifty VOCs were identified and quantified. Table 2 shows the chamber concentrations and unit specific emission rates of the identified VOCs. In this paper, TVOC is defined as the sum of the concentrations of identified and unidentified VOCs between n-hexane and n-hexadecane. Toluene response factor was used for the calculation. Table 3 shows the unidentified substances with high peaks for the portable PC C and the photo journal G. These substances have been selected based on the literatures (the Ministry of Health, Labor and Welfare, WHO, EPA, ECA).

Portable PC

Emission rates of a portable PC during switched off were very low and little difference was observed between PCs A and B. On the other hand, the emission rate of formaldehyde for the portable PC (C) with switched on was 9.0µg/unit-h, that of acetone was 15.9µg/unit-h, and TVOC was 168.4µg/unit-h. Relatively high peaks observed for toluene, octane, 1-butanol, styrene, ethylbenzene, decane and phenol.
Table 2. Chamber Concentrations and Unit Specific Emission Rates of Identified VOCs

| Identified Substances | Chamber Concentration [µg/m³] | Emission Rate [µg/unit·h] | Identified Substances | Chamber Concentration [µg/m³] | Emission Rate [µg/unit·h] |
|-----------------------|-------------------------------|--------------------------|-----------------------|-------------------------------|--------------------------|
| A                     |                               |                          | D                     |                               |                          |
| TVOC *               |                               |                          | TVOC                 |                               |                          |
| octane               | 26                            | 0.26                     | dodecane             | 153                           | 1.53                     |
| toluene              | 23                            | 0.23                     | tetradecane          | 93                            | 0.93                     |
| butyl acetate        | 19                            | 0.19                     | decane               | 63                            | 0.63                     |
| 1-butanol            | 16                            | 0.16                     | undecane             | 37                            | 0.37                     |
| B                     |                               |                          | toluene              | 22                            | 0.22                     |
| TVOC                 | 2412                          | 24.12                    | hexadecane           | 18                            | 0.18                     |
| octane               | 115                           | 1.15                     | n-hexane             | 10                            | 0.10                     |
| toluene              | 85                            | 0.85                     | E                     |                               |                          |
| 1-butanol            | 75                            | 0.75                     | TVOC                 |                               |                          |
| butyl acetate        | 63                            | 0.63                     | dodecane             | 63                            | 0.63                     |
| decane               | 14                            | 0.14                     | 1-butanol            | 49                            | 0.49                     |
| 1,2,4-trimethylbenzene | 13                       | 0.13                     | tetradecane          | 34                            | 0.34                     |
| undecane             | 10                            | 0.10                     | toluene              | 17                            | 0.17                     |
| ethylbenzene         | 10                            | 0.10                     | E                     |                               |                          |
| styrene              | 10                            | 0.10                     | xylene               | 7                             | 0.07                     |
| C                     |                               |                          | G                     |                               |                          |
| TVOC                 | 16835                         | 168.35                   | TVOC                 | 30521                         | 305.21                   |
| butyl acetate        | 891                           | 8.91                     | decane               | 1469                          | 14.69                    |
| toluene              | 749                           | 7.49                     | nonane               | 522                           | 5.22                     |
| octane               | 672                           | 6.72                     | 1,2,4-trimethylbenzene | 488                       | 4.88                     |
| 1-butanol            | 466                           | 4.66                     | undecane             | 453                           | 4.53                     |
| styrene              | 117                           | 1.17                     | tetradecane          | 416                           | 4.16                     |
| ethylbenzene         | 105                           | 1.05                     | dodecane             | 250                           | 2.50                     |
| decane               | 103                           | 1.03                     | pentadecane          | 229                           | 2.29                     |
| xylene               | 81                            | 0.81                     | 1,2,3-trimethylbenzene | 194                       | 1.94                     |
| 1,2,4-trimethylbenzene | 79                       | 0.79                     | 1,3,5-trimethylbenzene | 186                       | 1.86                     |
| tetradecane          | 71                            | 0.71                     | ethylbenzene         | 171                           | 1.71                     |
| heptane              | 58                            | 0.58                     | m-ethyl toluene      | 153                           | 1.53                     |
| nonanal              | 53                            | 0.53                     | xylene               | 146                           | 1.46                     |
| ethyl acetate        | 44                            | 0.44                     | p-ethyl toluene      | 111                           | 1.11                     |
| dodecane             | 39                            | 0.39                     | 1-butanol            | 93                            | 0.93                     |
| ethanol              | 29                            | 0.29                     | o-ethyl toluene      | 82                            | 0.82                     |
| hexadecane           | 26                            | 0.26                     | toluene              | 78                            | 0.78                     |
| 1,2,3-trimethylbenzene | 25                       | 0.25                     | hexadecane           | 66                            | 0.66                     |
| α-pinene             | 23                            | 0.23                     | nonanal              | 63                            | 0.63                     |
| pentadecane          | 21                            | 0.21                     | D-limonene           | 50                            | 0.50                     |
| 1,3,5-trimethylbenzene | 19                       | 0.19                     | heptane              | 35                            | 0.35                     |
| o-ethyl toluene      | 16                            | 0.16                     | octane               | 30                            | 0.30                     |
| undecane             | 15                            | 0.15                     | ethanol              | 21                            | 0.21                     |
| n-hexane             | 14                            | 0.14                     | styrene              | 13                            | 0.13                     |
| m-ethyl toluene      | 12                            | 0.12                     | butyl acetate        | 10                            | 0.10                     |
| p-dichlorobenzene    | 10                            | 0.10                     | G                     |                               |                          |

Not only power supply but also PC itself emitted these chemical substances through exhaust opening of fan from parts. In these measurements temperature inside the chamber was reached over 40°C during switched on. This temperature may be unrealistic in the daily operation, so measurements under comfortable range are planed in the future. Under the well mixing conditions, indoor air concentration of these chemicals might be under the guideline values even with high density. Although the emission of formaldehyde for PC (C) was 9.0µg/unit·h, the concentration in the chamber was over 900µg/m³. If one inhales the exhaust air directly from PC, there is a possibility to be over the guideline value of formaldehyde.

**Photo journal**

Photo journal (G) emitted the highest TVOC of 305.2 µg/unit·h among them. That of decane was 14.7µg/unit·h and that of acetaldehyde was 8.0µg/unit·h. High peaks of nonane, 1,2,4-trimethylbenzene, undecane, tetradecane, dodecane, and ethylbenzene were observed. Alkanes and aromatic hydrocarbons were found relatively higher.
Other appliances

The emission rates of a remote controller of TV (D), a low frequency current massager (E), and a cellular phone (F) were very low.

Table 3. Unidentified Substances of Large Peaks for Portable PC (C) and Photo Journal (G)

| Portable PC (C)          | Photo Journal (G)  |
|-------------------------|---------------------|
| 2-butxyethanol          | hexanal             |
| 2-ethyl-1-hexanol       | naphthalene         |
| phenol                  | pentanal            |
| acetophenone            | 1-pentanol          |
| cyclohexanon            | n-butanol           |

Preliminary Measurement of Oxidation Reaction by Ozone with a Portable PC

In the second experiment, a portable PC which was measured its emission rates in the first part of this paper, was exposed under the relatively high concentration of ozone. Reaction between ozone and unsaturated VOCs is shown in Figure 3. This experiment is a preliminary result of reaction of ozone with a PC. If ozone reacts with VOCs, ozone concentration in the chamber might become lower.

PC was tested with either switched on or off. It was the same portable PC, namely B and C in Table 1. An ozone generator (MODEL 1410, Dylec Inc.) was used with the airflow rate of 1.0L/min. Inlet concentration of ozone into the chamber was approximately 200ppb. This is relatively high concentration in normal office spaces, but we observed this level from the exhaust air from a photocopy machine21). Concentration of ozone at outlet of the chamber was measured continuously for 20 hours by MODEL 1150 (Dylec Inc.).

Results and Discussion

Figure 4 shows the concentration of ozone for 20 hours. Concentration of ozone in the chamber with the PC was decreased over the half compared with the empty chamber even under the switched off. Under the condition of switched on its decrement was reached to the 86% from the initial value. The average concentration of ozone after 4 hours was 193ppb for the empty chamber, 82ppb for PC with switched off, and 27ppb for PC with switched on. Emission rates of chemical substances from the PC with switched on were the highest among three conditions. Oxidation reaction must be higher with the higher chemical concentration in the chamber. On the other hand, the deposition velocities of ozone are influenced by temperature and relative humidity (Weschler13), so increased temperature inside the chamber might also affect the reduction of ozone concentration. The measurements of secondary products are planed.

Conclusions

Emission rates of aldehydes and VOCs from electronic appliances including a personal computer were measured by using a small chamber. A portable PC was also exposed under the relatively high concentration of ozone. Following conclusions were obtained;

- The emission rates of aldehydes and VOCs from a remote controller of TV, a low frequency current massager, and a cellular phone were low.
- It was found that the emission rate of formaldehyde for the portable PC during turning on was 9.0µg/unit.h, which was 9 times higher than that of switched off. That of TVOC was 168.4µg/unit.h. Relatively high peaks observed for toluene, octane, 1-butanol, styrene, ethylbenzene, decane and phenol.
- Emission rate of a photo journal was the highest among them. That of TVOC was 305.2µg/unit.h, and its decane of 14.7µg/unit.h, acetone of 14.1µg/unit-h, and acetaldehyde of 8.0µg/unit-h. High peaks of nonane, 1,2,4-trimethylbenzene, undecane, tetradecane, dodecane, ethylbenzene were observed.
- The outlet concentration of ozone from the chamber with a portable PC was decreased as low as 50% of the blank chamber.

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Related paper

Funaki, R., Nakagawa, T., Tanaka, H., Tanabe, S., (2002) Measurement of Aldehydes and VOC Emission Rate by Using a Small-scale Chamber, ADPAC -Part 7 Measurements of electronic equipments, Proc. of AIJ,

Fig.3. Reaction between Ozone and VOCs22)
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