

Evaluation of VOC Emissions from Electrical Components

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Because increasing attention has been paid to indoor air pollution from chemical substances, the Japan Electronics and Information Technology Industries Association (JEITA) formulated volatile organic compound (VOC) guidelines for personal computers (PCs). They give emission criteria and describe a measurement procedure using a chamber method. All the models of PCs and display monitors produced by Fujitsu are checked against these criteria before they are released. In addition, it is preferable to check the electrical components in advance to confirm compliance with the guidelines. We have developed a technique for evaluating the VOC emission rate of an electrical component by using a bag method, which is much simpler and easier than the chamber method. We studied the VOC emission behavior of an electrical component by using the bag method and evaluated the influences of ventilation and operation on the emission rate. We also investigated the correlation between the results obtained by the chamber and bag methods. We found that the emission rate of a product, an operating liquid crystal display (LCD) monitor, measured by the chamber method could be estimated from the emission rate of a component, a transformer, measured by the bag method. Therefore, the bag method is a useful technique for screening inspections of components.

1. Introduction

Increasing attention has been paid to indoor air pollution from chemical substances in the environment. In Japan, the “Standards of School Environment and Health” were partly revised by the Ministry of Education, Culture, Sports, Science and Technology in 2004, and five volatile organic compounds (VOCs) (toluene, xylene, p-dichlorobenzene, ethyl benzene, and styrene) and formaldehyde are currently regulated.

In accordance with this standard, the Japan Electronics and Information Technology Industries Association (JEITA) formulated “VOC Guidelines for Personal Computers”¹⁾ version 1 in 2005 and revised them (version 2) in 2008. The scope of these guidelines covers personal computers (PCs) and display monitors, which are items produced by Fujitsu. Emission

rate criteria and a measurement procedure based on a chamber method²⁾ are standardized taking into consideration normal usage environments. In other words, a product should be evaluated while operating with proper ventilation. Fujitsu, of course, evaluates all the models of its PCs and display monitors and confirms that they are within the criteria before the models are released.

The chamber method, however, needs a large-scale measurement system, takes a lot of time, and leads to extra cost and labor for rectification if failures are discovered only after production. Therefore, it is preferable to check the electrical components in advance and to use ones that have a low risk of failure. The chamber method is a dynamic evaluation, and the emission rate is obtained from the measurement. On the other hand, the bag method is a static evaluation and is

generally used for qualitative analysis. We have developed a technique for evaluating the emission rate by using a bag method³⁾ by measuring the concentration repeatedly. We studied the emission behavior of a transformer by using the bag method and found that the emission rate of an operating product measured by the chamber method could be estimated from the emission rate of a component measured by the bag method.

2. VOC guidelines for PCs

2.1 Emission criteria

The JEITA guidelines cover seven substances: acetaldehyde and the six substances specified in the Standards of School Environment and Health. JEITA emission criteria are listed in **Table 1**. The criteria for VOC emission rates are

defined as the mass (μg) of each substance emitted from a single product per unit time (h). The emission criteria are determined assuming that 40 PCs in a classroom contribute approximately 10% of the Standards of School Environment and Health criteria for indoor air concentration.

2.2 Measurement by chamber method

The conditions specified for the measurement are listed in **Table 2**. The measurement must be carried under a certain level of ventilation while the PC is operating, assuming normal usage conditions. A schematic diagram of the measurement system is shown in **Figure 1**, and a photograph of an example chamber setup is shown in **Figure 2**. This large chamber, 170 L in volume and 60 cm in diameter, is placed in a temperature-controlled

Table 1
JEITA emission criteria.

Substances	[$\mu\text{g}/(\text{h}\cdot\text{unit})$]			
	Laptop PC	PC with built-in display monitor	Desktop PC	Display monitor
Toluene	260	260	130	130
Xylene	870	870	435	435
p-dichlorobenzene	240	240	120	120
Ethyl benzene	3800	3800	1900	1900
Styrene	220	220	110	110
Formaldehyde	100	100	50	50
Acetaldehyde	48	48	24	24

Table 2
Measurement conditions specified in JEITA guidelines.

Chamber size	$0.01 < V_p/V_k < 0.25$
Chamber material	Glass or stainless steel
Operating temperature	$23 \pm 2^\circ\text{C}$
Operating relative humidity	$50 \pm 5\%$
Air supply rate	0.5 or 1 ACH
Equipment under test	Equipment in the unopened, packaged condition as shipped
Collection time	After 3 full exchanges of air with operating PC unit

ACH: Air changes per hour
 V_p : Volume of the equipment under test
 V_k : Chamber volume

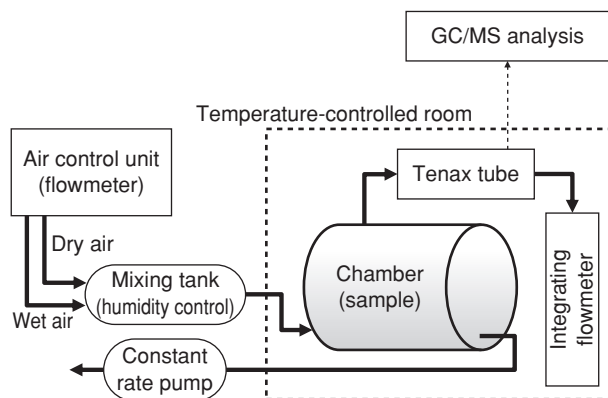


Figure 1
Schematic diagram of measurement system.

room. A single gas sample from the chamber is collected and condensed in a Tenax tube after a certain length of time has elapsed and then analyzed with a gas chromatograph mass spectrometer (GC/MS). The emission rate is calculated by the following formula.

$$ER_c = (C_B - C_{B0}) \times n_B \times V_K \quad (1)$$

C_B : Concentration of each constituent ($\mu\text{g}/\text{m}^3$)

C_{B0} : Background concentration of each constituent ($\mu\text{g}/\text{m}^3$)

ER_c : Emission rate of each constituent ($\mu\text{g}/\text{h}$)

n_B : Chamber air exchange rate (1/h)

V_K : Chamber volume (m^3)

3. Experiment

3.1 Evaluated samples

Transformers for liquid crystal display (LCD) monitors were chosen as components to test. Each transformer is covered with a varnish film for insulation and fixing. In the fabrication

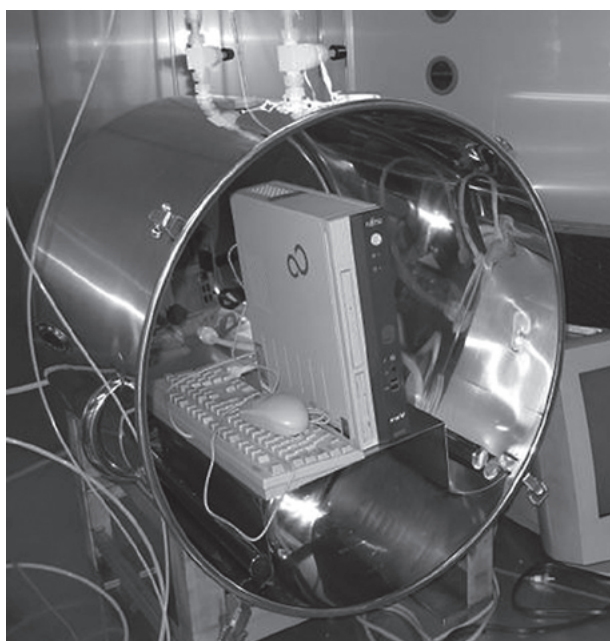


Figure 2
Photograph of example chamber setup.

process, the transformer is dipped into varnish solution that contains VOCs and then dried by heating, so there could be residual solvent in the varnish film. Therefore, this type of transformer tends to be one of the main sources of VOCs in LCD monitors. The substances emitted from the transformer are ethyl-benzene, xylene, and a little toluene. We investigated the emission rate focusing on xylene, since this accounts for the largest share with respect to the criterion.

3.2 Bag method

For the bag method, we used a Tedlar bag with a cock. The transformer to be tested was put into the bag, which was heat-sealed. In the first step, all of the air inside was evacuated once and a certain amount of purified nitrogen (N_2) was introduced into the bag through the cock. We used a 10-, 20-, 30-, or 50-L bag according to the emission mass and allowed 10 minutes for N_2 introduction. The VOC concentration in the bag was determined every hour starting just after the bag was filled with N_2 . The VOC emission mass was calculated by the following formula.

$$Q = C_B \times V_N \quad (2)$$

Q : Mass of each constituent (μg)

C_B : Concentration of each constituent ($\mu\text{g}/\text{m}^3$)

V_N : Encapsulated volume of purified gas in the bag (m^3)

From the change in VOC emission mass, the emission rate was estimated as follows.

$$ER_b = (Q_n - Q_{n-1}) / (t_n - t_{n-1}) \quad (3)$$

ER_b : Emission rate determined by bag method ($\mu\text{g}/\text{h}$)

t_n : Elapsed time after encapsulation (h)

3.3 Chamber method

The chamber method normally uses a glass or stainless steel chamber, as described in Table 2. In our experiment, however, we used a Tedlar bag

with two cocks instead of a chamber. The transformer to be tested was put into the bag and heat-sealed. All of the air inside was exchanged for purified N_2 in the first step in the same manner as in the bag method above. A certain chamber air exchange rate was achieved by introducing N_2 into the bag through one cock and pumping air out through the other cock. A small sampling bag was connected to the outlet cock to collect the gas from inside for analysis once an hour for periodic experimental sampling instead of the single time specified in the JEITA guidelines.

3.4 Quantification of VOC concentration

We used a portable VOC monitor (model: JHV-1000) manufactured by JMS Inc. instead of a GC/MS to measure the VOC concentration. This VOC monitor has a Tenax tube for gas collection, chromatography column for separation, and semiconductor sensor for detection. It draws in 100 mL of sampling gas per analysis. This small sample makes it possible to measure the VOC concentration in the bag repeatedly.

4. Results and discussion

4.1 VOC emission behavior measured by bag method

4.1.1 Two types of emission phenomena

The transition of the mass of xylene emitted into the bag is shown in **Figure 3**. Samples-A and -B were the same type of transformer from different production lots. Sample-A was a typical example of relatively high emission. Its emission curve was convex; that is, it emitted a lot of xylene at the beginning and the amount gradually decreased. Sample-B, on the other hand, was an example of relatively low emission. Its emission curve was a straight line; that is, xylene was emitted slowly and constantly.

We assume that these different behaviors are the result of two phenomena:⁴⁾ evaporation of VOC from the surface and diffusion (or supply) of VOC toward the surface. When the VOC content

at the surface was high enough, as in sample-A, evaporation from the surface was dominant at the beginning and the emission gradually became limited by diffusion. In the case of sample-B, the emission was limited by diffusion from the beginning because the VOC content at the surface was low.

The differential of the emitted xylene mass turns out to be the emission rate described in equation (3). The emission rate of sample-A was high at the beginning and then gradually decreased. The emission rate of sample-B was low at the beginning and stayed low. Therefore, we conclude that the emission rate in the early phase represents the emission behavior. The emission rate in the early phase, especially within the first hour after the bag is filled, can be used as an evaluation measure.

4.1.2 Effect of temperature on emission rate

A bag containing a sample and N_2 was kept in a heat-controlled oven to investigate the effect of temperature. In this experimental system, the temperatures of both the sample and the atmosphere were raised. The xylene concentration

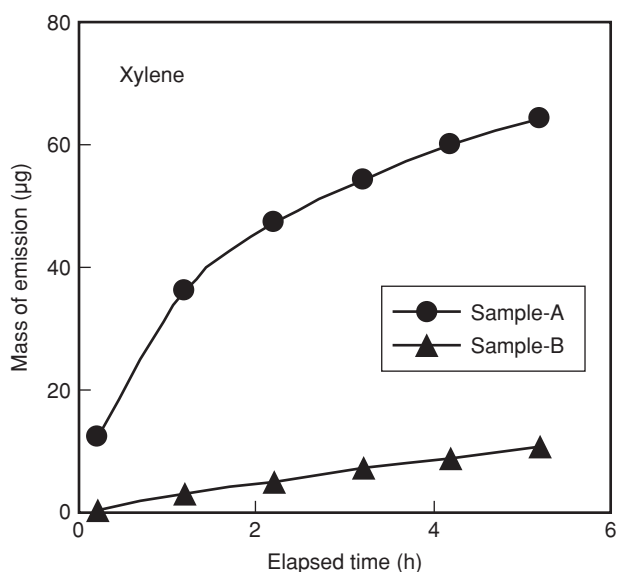


Figure 3 Transition of mass of xylene emitted into bag.

in the bag was measured once an hour and the emitted mass was calculated from this value. The results are shown in **Figure 4**. The change in the mass of xylene emitted depended on the temperature. This sample showed similar behavior to sample-B at room temperature. The emission mass increased as the temperature increased. Furthermore, evaporation became dominant at higher temperatures, while diffusion was dominant at room temperature.

4.1.3 Effect of product operation on component's emission rate

When an LCD monitor is operating, its transformer heats up, so we assumed that the VOC emissions increase when the product is turned on. We modified a display monitor so that different transformers could be easily installed in it, so that we could measure the emission rate of each transformer alone and of the monitor with each transformer installed. The monitor was put into a bag and heat-sealed except for a through-hole for cables. All the air inside was evacuated once, and N₂ was then introduced into the bag and the

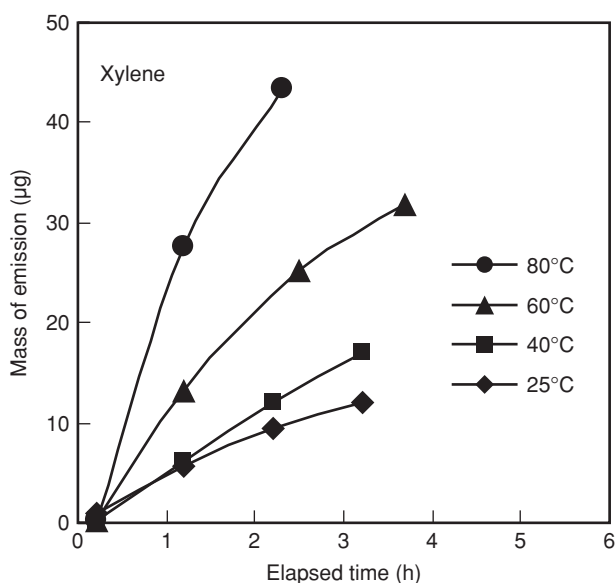


Figure 4
Change in xylene emission mass depending on temperature.

monitor was simultaneously turned on. The VOC concentration was measured in the same manner as for the transformer alone.

The correlation between the emission rates of the operating monitor and of the transformer alone is shown in **Figure 5**. These emission rates were taken in the early phase, up to 1 hour after N₂ introduction. The emission rates of the operating monitor had an almost linear relationship with those of the transformer alone. In the case shown in Figure 5, the emission rate of the operating monitor was around 2.5 times that of the transformer alone.

4.2 Comparison of chamber and bag methods

4.2.1 Chamber-method concentration calculated from bag-method concentration

If we suppose that the emission behavior does not change with and without ventilation, the VOC concentration at a certain time in chamber method can be calculated from the bag-method results by the following formula.

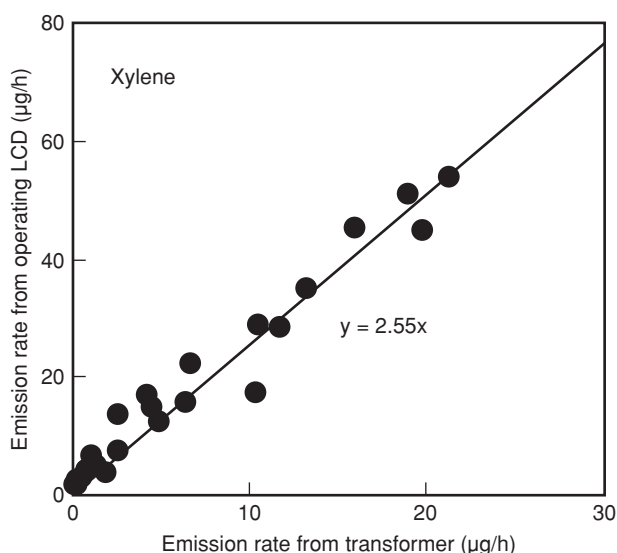


Figure 5
Correlation between emission rates from operating LCD monitor and from transformer alone.

$$Y_n = \frac{Y_{n-1} \times V_K + (Z_n - Z_{n-1}) \times V_N}{V_K + \Delta V} \quad (4)$$

Y_n : Concentration of constituent at time t_n in the chamber method ($\mu\text{g}/\text{m}^3$)

Z_n : Concentration of constituent at time t_n in the bag method ($\mu\text{g}/\text{m}^3$)

V_N : Encapsulated volume of purified gas in the bag (m^3)

V_K : Chamber volume (m^3)

ΔV : Chamber air exchange volume (m^3),
 $\Delta V = V_K \times n \times \Delta t$

n : Chamber air exchange rate (1/h)

Sample-C was evaluated by both the bag and chamber methods. A 10-L bag was used for the chamber method. The chamber air exchange rate was set to 1 bag-full per hour, which was achieved by an N_2 flow of 167 mL/min. The xylene concentration is shown in **Figure 6**. Closed symbols indicate chamber-method measurement data and open ones indicate values calculated from bag-method measurements. The calculated values coincide well with the measurement data. This means that ventilation has negligible influence on emission behavior.

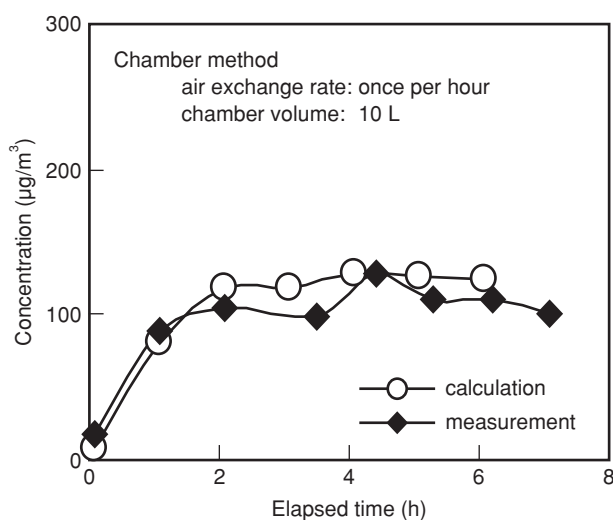


Figure 6 Comparison of xylene emissions measured by chamber method and estimated from bag-method measurements.

4.2.2 Difference in chamber-method emission rate depending on emission amount

As described above, the chamber-method emission rate can be calculated from bag-method measurements. That is, we can use the results of simple bag-method measurements to estimate the values that would be obtained by chamber-method measurements instead of having to perform the latter, more cumbersome measurements. Here, we discuss the calculated chamber-method emission rate. **Figure 7** shows the calculated chamber-method emission rates for samples-A and -B, whose bag-method results are shown in Figure 3. Sample-A had a peak at around 1 hour. On the other hand, sample-B showed a very gradual change and had a maximum at around 3 hours. Samples with larger amounts of emission, which is dominated by evaporation, have a sharper peak in the chamber-method emission rate. Samples with smaller emission amounts, which are limited by diffusion, show a slower change and stay almost constant.

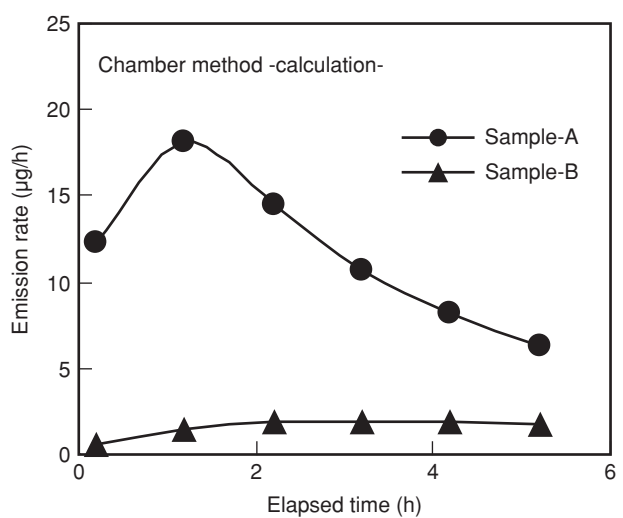


Figure 7 Xylene emissions calculated from bag-method measurement results.

4.2.3 Effect of chamber air exchange rate on chamber-method emission rate

The calculated chamber-method emission rates for sample-A for two different chamber air exchange rates are shown in **Figure 8**. When the exchange rate was once per hour, the emission rate had a higher peak, but later converged to the same emission rate as for 0.5 exchanges per hour. Note that even though the chamber-method emission rates appeared to be different for different exchange rates, the actual emission rates were the same. The chamber-method emission rate does not precisely reflect the actual emission for the first transient hours. However, there was a clear correlation between the emission rate in the early phase of the bag method and the peak of the apparent emission rate obtained by the chamber method. The emission rate in the early phase of bag-method measurements of sample-A was about 25 $\mu\text{g}/\text{h}$, as can be determined from Figure 3. The peak for one exchange per hour was 18 $\mu\text{g}/\text{h}$, which is about 2/3 of the bag-method emission rate. The peak for 0.5 exchanges per hour was 12 $\mu\text{g}/\text{h}$, which is about half the bag-method emission rate.

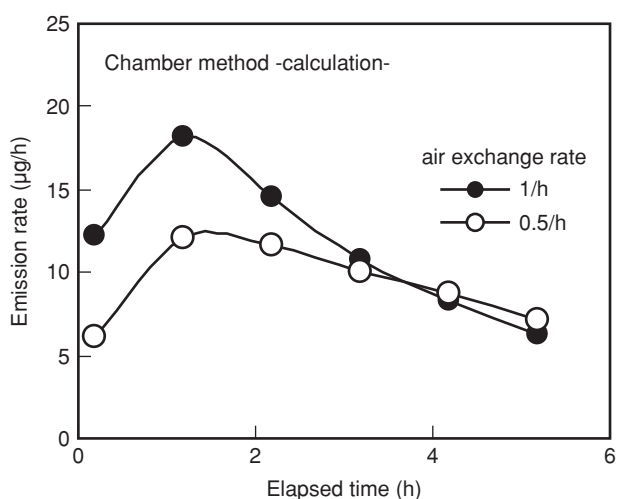


Figure 8
Effects of chamber air exchange rate on apparent chamber-method emission rate.

4.3 Application for screening inspection

Based on all the results discussed so far, the emission rate of a product measured by the chamber method can be predicted from the emission rate of a component measured by the bag method. In the case of an LCD monitor and a transformer, the peak emission rate of the monitor operating in a chamber with a chamber air exchange rate of 0.5 times per hour, for example, can be estimated by calculating 2.5 times (for operation) plus 0.5 times (for ventilation) the bag-method emission rate of a transformer in the early phase of measurement. Since a simple quick evaluation is preferable for screening inspections, the bag method is good enough for component evaluation.

5. Conclusion

We evaluated the rate of VOC emission from an electrical component, a transformer. In this study, we focused on the emission behavior and the correlation between chamber and bag methods. Our results are summarized below:

- 1) Samples with high contents at the surface emitted a lot of VOCs at the beginning and then the emissions gradually decreased. Samples with low contents emitted slowly and constantly.
- 2) The emission rates for an operating LCD monitor had an almost linear relationship with those for a transformer alone. For this experimental setup, the emission rate of the operating monitor was 2.5 times that for its component.
- 3) Ventilation had a negligible influence on emission behavior, so the emission rate obtained by the chamber method can be calculated from bag-method measurements.
- 4) The chamber-method emission rate does not precisely reflect actual emissions for the first transient hours.
- 5) Samples with greater emissions, which are dominated by evaporation, had a sharper peak in the chamber-method emission rate.

- 6) The emission rate for an air exchange rate of once per hour had a higher peak than that for 0.5 times per hour.

VOC emissions from products must be strictly controlled for a safe and comfortable environment. To control products, it is important to understand their emission behaviors and to evaluate emissions at the component stage. The best way would be to use VOC-free components, of course, and we are making efforts toward that. However, some components still contain VOCs. In this case, using the bag method to measure emission rates of components is a good alternative for screening inspections aimed at controlling the emissions from products.



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