Emission Gas Analysis

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The importance of outgassing analysis, which is the investigation method of the chemical contamination source, has been increasing in the industrial field and the environmental field. The dynamic headspace method, which accelerates the emission rate from sample by heating, is used for the outgassing analysis. The emission rate and the decrease rate of outgassing from material depend on the experiment temperature. In this study, the relationship between the outgassing behavior and the experimental temperature was examined. The modeling formulas of outgassing behavior were proposed using these examined results.

Introduction

The analysis of the emission or outgassing of volatile chemical compounds from man-made products and construction materials is becoming increasingly important in many industrial fields, including electronics, construction and automobile manufacture. In the electronics industry, ever since the 1986 report by L.A. Fergason on organic compound contamination of a silicon wafer surface[1], the majority of research efforts have focused upon countermeasures for organic chemical contamination. Especially in the area of semiconductor device manufacturing, it is now almost impossible to manufacture advanced devices without incorporating strict measures to prevent chemical contamination. In the cleanrooms where semiconductor device manufacturing takes place, indoor air quality has been improved by the use of chemical filters, which eliminate chemical compounds, as well as by technologies that decrease the rate of outgassing from various man-made materials and construction materials. With the ongoing evolution of clean system technology, resin containers, such as the SMIF-Pod and the FOUP (used in mini-environments to create a small local clean space) are now being targeted for outgassing control in cleanrooms, as are other construction materials, such as flooring, wall paneling, ceiling materials, filters, paints, adhesive agents and sealants.

On the other hand, in response to the recent major environmental problem of indoor air chemical contamination, the construction and automobile industries are undertaking measures to decrease outgassing from component materials. The Indoor Air Contamination Assessment Group of the Ministry of Health, Labour and Welfare has stipulated the following areas as targets for indoor air quality guidelines: residential dwellings; office buildings; hospitals / medical institutions; schools / educational organizations; kindergartens / daycares; nursing homes; senior care facilities; accommodations / recuperation facilities; gymnasiums; libraries; restaurants; theaters / movie theaters; public baths; government offices; underground shopping centers; automobiles; and other indoor air spaces.[2] As a result of these guidelines, outgassing from a variety of products and materials (i.e.; construction materials, components, furniture, home electronics, AV equipment, OA equipment, car electronics) must now be thoroughly assessed. In this report, we describe the outgassing analysis technology required to improve air quality during the manufacture of electronic devices, as well as the outgassing analysis technology used to reduce environmental contamination within indoor air spaces. In addition, although both "outgassing" and "emissions" are synonyms, we have chosen to use the words most commonly utilized in these fields of technology, for each particular sec-

tion. We request and appreciate your understanding in the use of these synonyms.

Methods of Outgassing Analysis for Cleanroom Components

The "Standard for Evaluation of Airborne Moleculer Contaminants Emitted from Construction / Conposition Materials for Cleanroom" [3] (JACA No. 34) is the only method of analyzing the outgassing produced by cleanroom components, which has been accepted in Japan by the Japan Air Cleaning Association. This guideline encompasses almost every aspect of the outgassing analysis method. However, the chemical compounds that affect electronic device production yields are those that adhere to or condense on the surface of silicon wafers and other materials. A highly sensitive ability to detect the chemical compounds possessing such properties is required by any outgassing analysis method used for cleanroom components. **Table 1** depicts the methods of outgassing analysis and their characteristics. This section explains details about the dynamic headspace - screening test method (generally referred to as the "heating and accelerated outgassing test method"). The dynamic headspace - screening test is particularly effective in analyzing outgassing derived from cleanroom components.

Table 1   Comparison of emission analysis methods

Methods	Characteristic
Screening method	Excellent in fixed quantity, reproducibility, and analysis efficiency.
	It is necessary to make the shape of a sample according to the chamber shape.
Products test method	There is little restriction of sample size. (Large chamber method)
	Inferior in fixed quantity, reproducibility, and analysis efficiency as compared with the screening method.
Surface emission method	Suitable for evaluation of surface treatment material.
	It is necessary to make the shape of a sample according to the cell shape.
Surface adsorption method	It is possible to choose and evaluate the compounds which adsorb onto a substrate.
	It is necessary to take heed to the determination of exposure conditions.
Onsite method	Effective in emission source investigation of the site.
	In order to receive restriction of emission conditions at the site, there is a problem of sensitivity.
Static headspace method	Suitable for evaluation of low boiling point compounds.
	Inferior to the above emission test method about the sensitivity of high boiling point compounds.

1. Dynamic Headspace - Screening Test Method

In the dynamic headspace (DHS) method, a test piece is first placed in a chamber, then a carrier gas (inert gas or air) is continuously passed over it, with any outgassing then contained in the effluent carrier gas to be trapped within a solid adsorbent or liquid absorbent. As well, the screening test is a method that includes the simultaneous heating of the test piece, which accelerates the rate of outgassing, then collects the gases via the DHS method. The outgases collected via the DHS method are then analyzed using gas chromatography (mass spectrometry: GC-MS) or ion chromatography (IC). The chamber used for the screening test is selected in accordance with the size of the test piece, within sizes that range from a micro chamber ($\sim 0.001 m^3$) to a small chamber ($0.001 m^3 \sim 1 m^3$). **Fig. 1** depicts an example of the apparatus used for the DHS method.[4, 5] The screening test is basically a measurement of the outgassing given off by a bulk material. The chamber configuration is changed to accommodate the shape of the test piece, such that the gases can be collected from the surface of the test piece or from gases produced within a sealed container, etc.
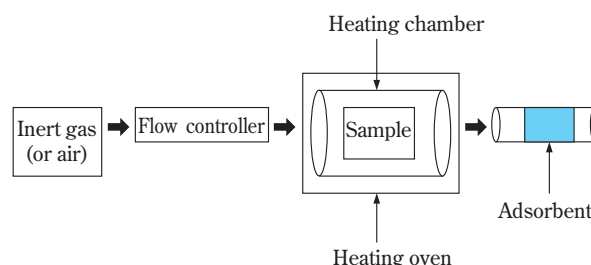
Fig. 1   Schematic diagram of dynamic headspace apparatus

Indoor Air Pollution and Gas Emission Analysis Methods

The methods used for gas emission analysis, which is employed for air quality improvement purposes in standard residential dwelling environments, follow the same basic principles as the methods used to analyze outgassing produced by cleanroom components, as described in the previous section. However, emission analysis methods do not require highly sensitive measurements of specific chemical compounds that adhere to and remain on substrate surfaces, affecting production yields, as with cleanroom component outgassing analysis. Instead, these methods involve conducting

analyses of all chemical compounds emitted from construction materials, raw materials comprising housing products and the finished products themselves, all of which contribute in the same manner to the environmental conditions within a residential dwelling. On this same point, the component screening method also differs from that in the outgassing analysis methods conducted under the heating conditions as described in the previous section. A component screening method for testing standard construction components and furniture was established on January 20, 2003; known as JIS A 1901, "Determination of the emission of volatile organic compounds and aldehydes for building products – Small Chamber Method" (commonly known as the "Small Chamber Method").[6], [7] Today, in conjunction with the revision of the Building Standards Act, the Small Chamber Method has become essential in the selection of residential construction materials. In addition, for methods of testing the emission produced from furniture and home appliances, although no method of emission analysis has yet been standardized for such products, JIS standardization efforts are now being undertaken.[8] In Europe, where emission analysis methods are more advanced, standardized methods have already been established for analyzing the emission produced from wooden furniture and OA equipment, such as PCs, photocopiers and printers. Thus, manufacturers who export products to Europe are finding new challenges in the need to decrease the levels of emission from their products. In the following section, we explain European emission testing methods for furniture, home appliances and electric / electronic devices, as well as providing details regarding the JIS A 1901 Small Chamber Method, which is now utilized most commonly in Japan

1. Emission Analysis Methods for Construction Materials –JIS A 1901 Small Chamber Method–

The Small Chamber Method is also a method that employs dynamic headspace analysis. In terms of the previously described outgassing test methods for cleanroom components, the Small Chamber Method is similar to an engineering test. The Small Chamber Method includes the establishment of test procedures for chamber volumes ranging from 20L to 1000L. In most cases, a small chamber with a volume of 20L is utilized. **Fig. 2** depicts the test facilities used for a 20L small chamber. In emission testing, the loading factor for the test piece (the ratio of the surface area of the

Fig. 2 JIS small chamber system (chamber volume : 20L)

test piece to the chamber volume) is the most important factor affecting the emission rate. The loading factor for each material has already been specified in the 20L small chamber test system. For example, if the test piece is comprised of wallpaper or flooring material, the loading factor is $2.2m^2/m^3$ (size of test piece is 147mm × 147mm, 1 sheet if both sides, 2 sheets if one side only). If the test piece is a painted sheet then the loading factor is $0.4m^2/m^3$ (size of test piece is 147mm × 147mm, single sheet, one side only). When conducting Small Chamber Method analysis, the measurements must be performed under the following standard environmental conditions for Japanese dwellings - temperature: 28°C; humidity: 50% RH and ventilation rate: 0.5 times / hr. The emissions under these conditions are then collected using a solid adsorbent agent. The aldehydes and VOCs that have been collected using the solid adesorbent agent are then analyzed using GC-MS or HPLC. The quantitative values obtained in the Small Chamber Method are expressed as an emission rate $(\mu g/m^2/h)$. There are certain variances in the actual degree of indoor air pollution by emission from construction material, as compared to the Guidelines for Indoor Air Quality established by the Ministry of Health, Labour and Welfare (**Table 2**). The indoor air quality must be calculated with consideration for a variety of factors, such as the area covered by the target construction material, the ventilation rate, the amount of chemical compounds contained within ventilated air and the absorption of chemical compounds by the room. Therefore, a variety of proposals have been made for the different formulae used to estimate the level of indoor air pollution.[9], [10] Formula (1) is a simple, yet rough calculation method that shows the

approximate effects of outgassing from construction materials and components upon the indoor air environment.[11]

Table 2 Guideline of the indoor air quality established by Ministry of Health, Labour and Welfare

unit : $\mu g/m^3$

Compounds	Established value	Compounds	Established value
Formaldehyde	100	Tetradecane	330
Toluene	260	Di-2-ethylhexyl phthalate	120
Xylene	870	Diazinon	0.29
p-Dichlorobenzene	240	Acetaldehyde	48
Ethylbenzene	3800	Fenobucarb	33
Styrene	220	Nonanal*	41
Chlorpyifos	1	TVOC*	400
	(Child : 0.1)		
Di-n-butyl phthalate	220	*Provisional target value	

$$C = \frac{EF \times A}{n \times V} \qquad (1)$$

In the above formula, C: Amount of indoor air pollution ($\mu g/m^3$); EF: emission rate ($\mu g/m^2/h$); A: surface area of indoor components (m^2); n: ventilation rate (times/h); and V: room volume (m^3).

2. Emission Analysis Methods for Finished Products – Large Chamber Method –

1) Methods of Testing Emission Produced from Furniture and Electric / Electronic Devices

The Large Chamber Method is most commonly utilized for measuring the emission produced by furniture, electric / electronic devices and other finished products. The volumes of the chambers used in the Large Chamber Method can vary greatly, as this method allows for testing with the largest chamber sizes under the JIS standard. Under the Japanese JIS testing standard for emission produced by furniture (draft proposal), which is currently under discussion, chamber volumes ranging from $1m^3$ to $80m^3$ are designated as large-sized chambers, in accordance with all of the American and European standards.[8] In general, large chambers having volumes ranging from a few m^3 to $20m^3$ are most often utilized. The advantage of a large chamber is that it can analyze finished products as is, without modification. In particular, this test method holds great significance for its ability to directly analyze the gasses emitted from a variety of products that are composed of many different components, such

as home appliances and OA equipment. However, on the contrary, as the chamber volume increases, problems arise in terms of the precision of the analysis (decreased yield due to adherence to chamber inner walls and increased difficulty of blank management), thus making the testing system more difficult to maintain, manage and verify. Our company prepared chambers of different volumes; 150L, $1m^3$, $2m^3$ and $20m^3$, in order to establish a system that could analyze the outgassing produced from a diverse range of finished products. For example, **Fig. 3** shows a Large Chamber system having a volume of $20m^3$. The analysis of outgassing from furniture and construction materials is performed by placing the target product inside the large chamber. However, for electric / electronics products, which during operation result in the generation of heat and thus increase the emission, testing must be conducted while the target product is actually operating.[12] With respect to these conditions, JIS standardization is currently being undertaken for the analysis of emissions from printers, as well as for emission test methods used to test all kinds of electric / electronic products. Within a few years, JIS standard methods for the analysis of emission from general electric / electronics products are expected to be formalized. Europe already employs these analysis methods and has standardized emission analysis methods for furniture, photocopiers and OA equipment. In Europe, the standard referred to as "ECMA-328"[13] has been established as the emission test method for electronic appliances and the German BAM testing method has been established for emission testing of photocopiers and printers.[14] In particular, the BAM testing method has

Fig. 3 Large chamber system (chamber volume: $20m^3$)

already become mandatory in order to obtain environmental certification in Germany (Blue Angel Mark). Thus, now emission analysis must almost always be performed prior to exporting printers to European countries.

2) Emission Analysis Methods for Automobile Interiors

The establishment of emission analysis methods for the emissions by automobile interior materials is also currently ongoing. The existing method includes the following test procedures: an entire automobile is placed within the environmental test lab; actual operating conditions are simulated inside the automobile (heating the interior using light from the outside, or by turning on the air conditioning system); then the chemical compounds released within the automobile are analyzed under these conditions.[15] In addition, each automobile manufacturer has established its own standards for interior components and conducts screening tests prior to the actual installation of such components.
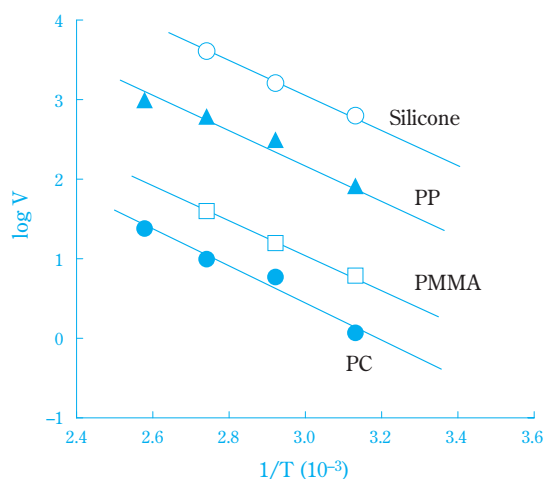
Relationship Between Temperature and Emission Rate

Previous sections have described the standards and guidelines used in the testing of emission. From this section forward, we report on the results of studies into the relationship between temperature and emission rates for chemical compounds. The emission rate is an important factor in the actual measurement of emission. In general, the indoor environment of a standard dwelling is assumed to have an emission rate obtained at a temperature of approximately 23°C. (However, the Energy Saving Standard stipulates a summer temperature of 28°C for the Small Chamber Method.) As well, automobile interior testing must take into account conditions in which the temperature may sometimes temporarily rise to 60°C-70°C. In addition, since electric / electronic products release heat during operation, the level of emissions also increases. Furthermore, when testing the outgassing of cleanroom components, the test piece must be heated (60°C-100°C) prior to performing a highly sensitive analysis, to allow for the detection of any semi-volatile organic compounds that may adhere to the substrate. Therefore, when discussing emission rates, the changes that may occur to emission under a variety of temperature settings must be carefully measured and calculated. We have evaluated many different measurement conditions, including

system manufacturing, and have established a method for determining the relationship between emission rate and temperature, as a heating and accelerated emission testing method for emission analysis.

1. Calculation of Emission Rates

It is known that as the temperature of a component rises, its emission rate increases significantly.[5] **Fig. 4** depicts the results of an experiment performed to obtain the total emission rates for organic compounds, within a temperature range of 60°C-120°C, by using the following chemical compounds as test specimens; polypropylene (PP); polycarbonate (PC); polymethylmethacrylate (PMMA); and silicon sealant. The horizontal axis represents l/T (T means absolute temperature in "K") and the vertical axis represents the logarithm of the emission rate ($\mu g/m^2/h$). As indicated by these results, the reciprocal of the component temperature (K) has a favorable linear relationship with the logarithm of the emission rate. Based on this result, an empirical formula can be established, as per formula (2) below:
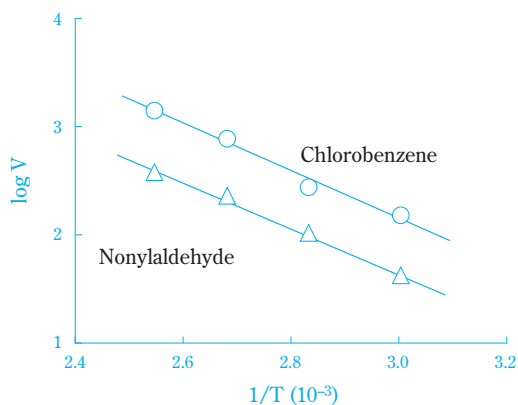

Fig. 4   Relationship between the emission temperature and the emission rate from several polymers

$$\log V = \frac{C_1}{T} + C_2 \qquad (2)$$

In the above formula, "V" represents the emission rate ($\mu g/m^2/h$), "T" represents the test temperature (K) and "C_1" and "C_2" represent constants. The use of this relational expression (2) enables the association of all emission rates derived from different components at different temperatures to each other, thus

making it an effective method for the generalization of emission rates.

As a more specific measurement example, **Fig. 5** is a plot of l/T (K) versus the logarithm of the emission rate for two chemical compounds derived from polycarbonate (chlorobenzene and nonylaldehyde). As indicated in the figure, the rate of emission from components can also be expressed using formula (2), for each organic compound.

Fig. 5 Relationship between the emission temperature and the emission rates of Chlorobenzene and Nonylaldehyde from polycarbonate
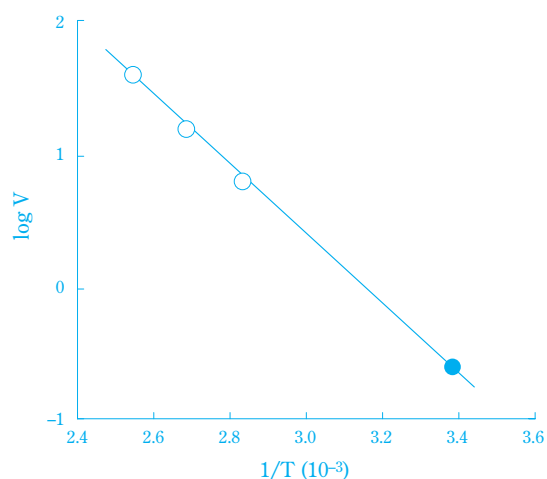
2. Calculation of Emission Rates at Room Temperature

The heating and accelerated emission testing method is a particular kind of accelerated test method, as its name describes. In this method, emission is encouraged in order that high sensitivity analysis can be conducted. However, the conditions used for the heating and accelerated emission testing method differ from those that actually occur in the environment in which the target materials are usually present. In many cases, the emission rate must be estimated at room temperature. **Fig. 6** depicts a comparison of the total emission rate for a PP test sample measured over 60°C-120°C, with extrapolation at room temperature, from the results of micro-scale room temperature emission test results. In this figure, the "●" represents the extrapolated value and the "□" represents the measured value (experimental data). The total emission rate (380μg/m^2/h) for PP obtained by formula (2) demonstrates a relatively good correlation with the experimental data (200μg/m^2/h). Phthalates and phosphates are often utilized as resin additives. The

emission from these compounds is a prime factor in the organic contamination of cleanrooms used for electronic device manufacture, as well as a significant contributor to contaminated indoor air within indoor environments. Thus, there is currently a pressing need to analyze this emission. However, high-boiling point organic compounds (so-called "semi-volatile" organic compounds) have very small volatilization volumes, thus making it extremely difficult to obtain accurate emission levels and emission rates at room temperatures. One solution to this problem is the use of extrapolation when applied to the heating and accelerated outgassing testing method. **Fig.7** depicts the results of an experiment in which the emisssion rate of di-2-ethylhexyl phthalate (DEHP) released from PP
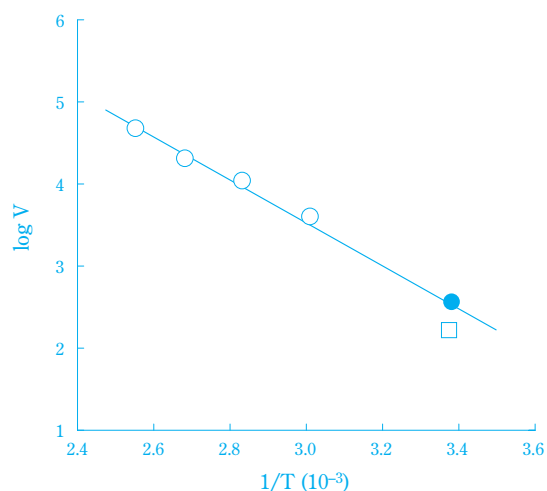
Fig. 6 Comparison of the total emission rate from polypropylene at room temperature by use of extrapolation and the experimental data

Fig. 7 Estimation of the emission rate of Di-2-ethylhexyl phthalate from polypropylene by use of extrapolation

was measured at temperatures ranging from 80°C-120°C, with emission at room temperature then being estimated from the measured values. The results of this extrapolation show an emission rate for DEHP estimated at 0.26μg/m^2/h, at normal temperatures. It is extremely difficult to perform a direct analysis of the minute amounts of emissions that would be released at room temperature, using the outgassing testing method. However, the use of the heating and accelerated outgassing testing method allows for an accurate extrapolation of the emission rate without requiring sampling over long periods of time.

Calculation of Emission Rates Using Physical Constants

In the previous section, we have explained the following emission rate calculation procedures: when using the heating and accelerated outgassing testing method the emission rate is measured at more than two different temperatures; when using formula (2) the relationship is determined and then the emission rate is extrapolated at an arbitrary temperature, including room temperature. We then described a method of estimating the emission rates at various temperatures from the measured value of the emission rate at a single point.[16] There is a large amount of data available about the equilibrium vapor pressures for organic compounds. Therefore, it is commonly known that the Clausius-Clapeyron formula (3) can be utilized to describe the relationship between equilibrium vapor pressure and temperature (K).

$$logP = \frac{C_3}{T} + C_4 \qquad (3)$$

In this formula, "P" represents the equilibrium vapor pressure at the absolute temperature "T." Formula (3) is closely related to the aforementioned formula (1). **Table 3** depicts an example showing a comparison between the constants C_1 obtained from the measured

Table 3 Comparison of the constants (C_1) estimated with the dynamic headspace method and the constant (C_3) estimated from vapor pressure

Compounds	C_1	C_3
Chlorobenzene	-2.1×10^3	-2.04×10^3
Nonylaldehyde	-2.3×10^3	-2.58×10^3

values for emission rates, with the constants C_3 estimated from the equilibrium vapor pressure. These values are strongly correlated. From this result, we have developed formula (4), which can be used to obtain emission rates at arbitrary temperatures, using constants C_3, which are obtained from the pressure data.

$$V_d = V_c \times 10^{\{C_3 (1/T_d - 1/T_c)\}} \qquad (4)$$

In this formula, Vd: the estimated emission rate at an arbitrary temperature (μg/m^2/h), Vc: the measured emission rate (μg/m^2/h), C$_3$: a constant calculated from the vapor pressure, Td: the absolute temperature (K) under the arbitrary conditions, Tc: the absolute temperature (K) at which the emission rate was measured. Using this formula, the emission rate can be estimated for a variety of temperatures, for certain types of organic compounds for which there exists equilibrium vapor pressure data. **Table 4** shows results derived from the use of formula (4) via a comparison of the experimental emission rate data for emission volatilized from polycarbonate, with calculated emission rate data. The experimental data and calculated data show a strong correlation.

Table 4 Comparison of the experimental data of emission rate and the calculated data of emission rate in various emission temperatures

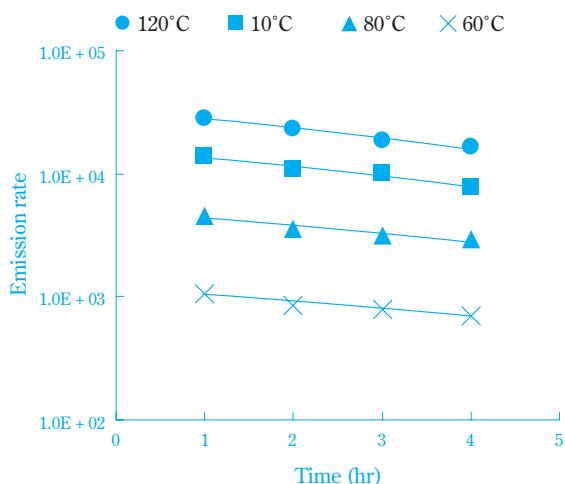| Compounds \ Temperature		120°C	100°C	80°C	60°C
Chlorobenzene	Calculated data	150	76	37	16
	Experimental data	143	76	27	15
Nonylaldehyde	Calculated data	53	24	10	3.7
	Experimental data	37	24	11	4.3

Evaluation of Emission Attenuation Behavior

Needless to say, it is always necessary to select finished products and construction materials with low emission in order to reduce chemical contamination. In addition, it is also important to select a material that has a high attenuation rate for the emission derived from the material. In the initial stages of emission from a material, the process is dominated by the desorption of chemical compounds from the material's surface. The later stages are marked by the predominance of diffusion from within the material's interior.[17] The

relationship between the attenuation of the emission level with time can be expressed as the product of a two-term exponential function model, as per formula (5).[18]

$$V = V_{01}e^{-k_1 \cdot t} \times V_{02}e^{-k_2 \cdot t} \qquad (5)$$

In this formula, V: emission rate ($\mu g/m^2/h$), V_{01}, V_{02}: initial emission rate ($\mu g/m^2/h$), K_1, K_2: attenuation constants (h^-), t: time (h). This two-term exponential function model is able to express the emission attenuation tendencies of a material with relatively good accuracy. However, in order to obtain an empirical formula, attenuation testing must usually be conducted over a period of approximately several weeks to a month. This kind of testing requires a tremendous amount of time, as it must be conducted for many different test specimens early in the materials screening & selection process. Therefore, we attempted to develop a method for assessing the emission attenuation tendency within a shorter time period, through the application of the heating and accelerated outgassin testing method. **Fig. 8** depicts a comparison of outgassing attenuation rates using a PVC sheet, at temperatures ranging from 60°C-120°C. Decreased emission at room temperatures can be expressed by using a two-term exponential function model. However, in the heating and accelerated outgassing testing method, in which high temperatures accelerate the emissions, the dispersion of such emissions is also accelerated within the test material. Thus, the emission attenuation under heating and accelerated emission conditions can be expressed in the form of an exponential function model.

$$V = V_0e^{-k \cdot t} \qquad (6)$$

In this formula, V: emission rate ($\mu g/m^2/h$), V_0: initial emission rate ($\mu g/m^2/h$), k: attenuation constants (h^-), t: time (h).

1. Relationship between Initial Emission Rate, Attenuation Constants and Temperature

In the previous section, we discovered that a linear relationship exists between the logarithm of the emission rate and the reciprocal of the absolute temperature. In addition, we learned that this relationship can be experimentally demonstrated by the total amount of emissions. **Fig. 9** shows that this same relationship was observed in the total initial emission rate obtained
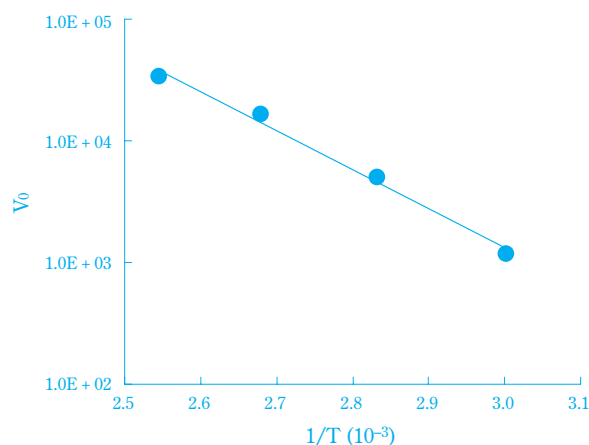
Fig. 9 Relationship between the emission temperature and the initial emission rate (V_0) from PVC sheet

Fig. 8 Comparison of the decrease rates of the emission from PVC sheet with the various emission temperatures
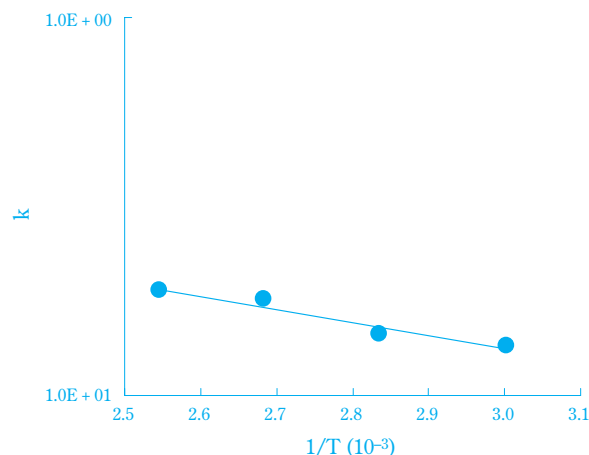
Fig. 10 Relationship between the emission temperature and the decrease rate of emission from PVC sheet

from the heating and accelerated outgassing testing method. In addition, as shown in **Fig. 10**, a linear relationship can be seen between the logarithm of the attenuation constant for the total amount of emission and the reciprocal of the absolute temperature. This relationship suggests that the initial emission rate and attenuation constants can also be calculated for arbitrary temperatures by using an experimental formula, which is similar to the formula that describes the relationship between the emission rate and the temperature, in the previous section. Furthermore, the attenuation constant needed is a numeric value that can act as an index for the degree of emission attenuation.

2. Calculation of Initial Emission Rate and Attenuation Constant

A test sample consisting of PVC floor sheeting commonly utilized in standard residential dwellings was used in a comparison between measured values and calculated values, for both initial emission rates and attenuation constants, at room temperature.[19] In this experiment, the following 2 values were compared using the Small Chamber Method: emission attenuation analysis results occurring during a 1-week period at room temperature; and emission attenuation analysis results occurring during a 4.5-hour period using the heating and accelerated emission testing method. **Table 5** depicts the results of a comparison between the experimental data and the calculated values for initial emission rates, for the 3 major contaminants: toluene, methylpentanone and tetradecane. The exper-

imental data and calculated values show a strong correlation. **Table 6** depicts a comparison of the 3 major contaminants in terms of experimental data and calculated values for the attenuation constants and thus the total emission rates. Although the calculated values for the attenuation constants at room temperature are slightly higher than the experimental data, the relative size relationship between time and attenuation is described with precision, thus we conclude that the calculated values are effective for use in screening tests.

Conclusion

The analysis of emission from construction materials, material components and various finished products is required throughout many different areas, from industrial fields to the environment. The objectives (targeted chemical compounds) of outgassing / emission analysis for industry differ somewhat from the environmental objectives, thus we have introduced in this paper several types of outgassing / emission testing methods suitable for each area. However, the basic concepts behind emission analysis are common to both industry and the environment, thus the following two methods may be combined and utilized in both areas: screening methods used for the selection of materials; and methods of emission analysis used to investigate actual outgassing conditions. In order to conduct screening, a method is required that can effectively and rapidly screen a large number of materials without underestimating the risk of emission. In this sense, the heating and accelerated outgassing testing method is an excellent method in terms of sensitivity and effectiveness (time), thus holds great importance in industrial applications. Environmental conditions, such as temperature and humidity, can affect the emissions from components and finished products. Of all these environmental conditions, temperature has the greatest impact on the occurrence of emission. Thus, we have conducted a variety of experiments to investigate the relationship between emission and temperature and have proposed the best possible use of the data collected, including the effectiveness of the heating and accelerated emission testing method and the analysis of outgassing behavior. We expect that the importance of emission analysis will continue to grow, in both industrial and environmental applications and we plan to work on the development of even more advanced emission analysis technology.

Table 5 Calculated results of the emission rates (V_{01}) of several emissions from PVC sheet

unit : $\mu g/m^2/h$

Conditions / Compounds	80°C Experimental data	25°C Experimental data	25°C Calculation data
Toluene	4400	340	450
Methylpentanone	8200	460	580
Tetradecane	960	34	25

Table 6 Calculated results of the decrease rate (k) of several emissions from PVC sheet

unit : h^{-1}

Conditions / Compounds	80°C Experimental data	25°C Experimental data	25°C Calculation data
Toluene	0.64	0.017	0.065
Methylpentanone	0.55	0.013	0.039
Tetradecane	0.68	0.003	0.018

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