—Original Paper—

大 気 環 境 学 会 誌
J. Jpn. Soc. Atmos. Environ.
36 (6) 319～325 (2001)

Purification Ability of Interior Plant for Removing of Indoor-Air Polluting Chemicals Using a Tin Oxide Gas Sensor

Takashi OYABU*, Takeshi ONODERA**,
Haruhiko KIMURA*** and Yoshihiko SADAOKA****

Due to economic growth, human beings have been coming in greater contact with various chemicals. Thus, the people who have become the chemical sensitive are also increasing, which results in anaphylaxis for various chemicals. Recently, a sick house syndrome is occurring frequently in an indoor environment. Especially, since the aged and infants who are physically weak, pass their time mainly in a room, there is a high risk for them to fall into the syndrome, of which the results are asthma or allergy. In this study, the ability of houseplant (Golden pothos) to remove the chemicals was examined. An indication of the ability, purification rate P_a of the plants, was examined in an experimental sealed chamber. P_a was derived from the measurements by tin oxide gas-sensor characteristics for a chemical. To calculate P_a, the peak of the sensor output was divided by the full-width at half maximum. The following chemicals were examined; formaldehyde, toluene, xylene, benzene and trichloroethylene. The rate became high when the plant was illuminated. The smaller the molecular weight of a pollutant was, the larger the purification rate became. Namely, it took a long time to remedy an indoor environment when chemicals with large molecular-weight were adopted in the architecture-materials. Gaseous chemicals diffuse directly into soil. Features of the sensor characteristics in the soil were similar to the characteristics in the chamber atmosphere. Low purification ability of potted soil without plants was found. In this study, it was demonstrated that the plant tested had a higher ability to absorb ammonia than formaldehyde.

1. Introduction

There are various chemicals present on the earth as a result of economic growth. Many chemicals are discharged in the world due to industrialization. In Japan, there are about 50,000 kinds of chemicals at present. People come in contact with about 8,000 kinds of these chemicals in daily life. Therefore, chemical sensitivity of people is increasing[1]. Sick house syndrome is occurring in tightly constructed houses, although the concentrations of various indoor chemicals have been regulated by nations[2]. Formaldehyde, toluene and xylene, which are used in building materials, are typical indoor air pollutants. It is almost impossible to make a living without coming in contact with these materials. Since the aged and infants spend most of their time in a house and they are physically weak, it would be better to reduce their exposure time to the chemicals at high concentrations.

Formaldehyde, toluene and xylene are adopted considerably as an adhesive in indoor con-

* Faculty of Economics, Kanazawa University of Economics, Kanazawa, 920-8620 JAPAN
** Faculty of Engineering, Kyusyu University, Fukuoka, 812-8581 JAPAN
*** Faculty of Engineering, Kanazawa University, Kanazawa, 920-8667 JAPAN
**** Faculty of Engineering, Ehime University, Matsuyama, 790-8577 JAPAN

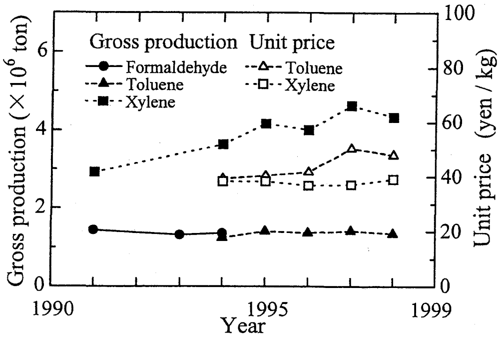

Fig. 1. Gross productions and unit prices of three indoor air pollutants in Japan.

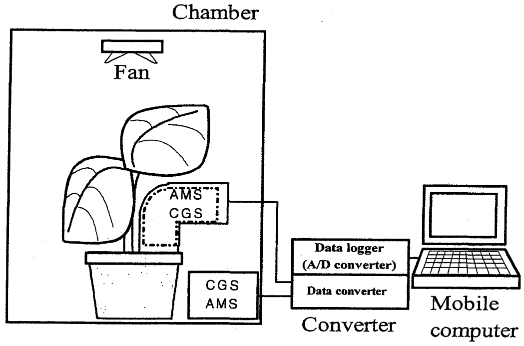

Fig. 2. Measurement system of removal rate of indoor air pollutants by plants.

struction materials. Gross production and unit prices of these chemicals in Japan are summarized in Fig. 1. The outputs of formaldehyde and toluene remain on the same level for the last several years and are about 1.3 million tons per year. The output of xylene is, however, increasing gradually and amounted to 4 million tons in 1995. It is necessary to decompose these chemicals so that they may not accumulate on the earth. An effective means is to use plants and microorganisms, for example bacterium. They are very effective for environmental remediation.

In this study, the ability of an interior plant in potted soil to remove indoor air pollutants was examined[3,4]. The ability was estimated on the values derived from a response characteristic of a tin oxide gas sensor to the pollutants. The sensor is reliable in detecting a reducing gas and is stable over long-time use. The resistivity of the sensor element decreases when there is a reducing gas in the atmosphere[5]. The ability of a houseplant to remove the chemicals was examined not only in the light but also in darkness. The ability of the potted soil without plants was also examined.

2. Experimental

Plants are able to remedy geophysical environmental pollution, especially air and soil pollution, and to contribute to natural environmental preservation. The remedial function of plants has scarcely been examined. In this study, the ability of the interior plant to remove volatile organic chemicals (VOCs) was tested[6]

Golden pothos was used in this study as an interior plant. It was approximately 53 cm in height and growing in a pot with a diameter of 30 cm. It was placed inside a sealed plexiglass chamber of about 300 liters (575 * 510 * 1000 mm). Various indoor air polluting chemicals were injected into the chamber using a micro-syringe[7,8]. Illumination was provided during the test period by three grow-lights (HITACHI: FPL27EX-N) outside the chamber. Two types of tin oxide gas sensors (CGS: TGS#800, AMS: TGS#826 manufactured by Figaro Engineering Inc.) were used in this study to continuously monitor the polluting level in the experimental chamber. The CGS and AMS were placed in the atmosphere in the chamber, and another pair of CGS and AMS were placed in the potted soil to monitor the polluting level in the soil. These sensors in the soil were encircled with a wire netting pipe and sealed from the atmosphere of the chamber. The outputs of four sensors were monitored during the experiments. These sensors are also influenced largely below 65% RH. The output of AMS in the atmosphere of the chamber was mainly analyzed in this investigation. The measurement system is shown in Fig. 2. Sunlight was cut off in the experimental room. The light intensity was kept at about 970 *lx* at plant level. The following chemicals were tested; formaldehyde, toluene, xylene, acetone, benzene and trichloroethylene. The AMS output voltage (v) to formaldehyde concentration (C) was indicated using following equation: $v = (-32.44/(C + 18.68)) + 1.75$.

3. Results

The output characteristic of the sensor in the case of the plant exposed to formaldehyde of 50

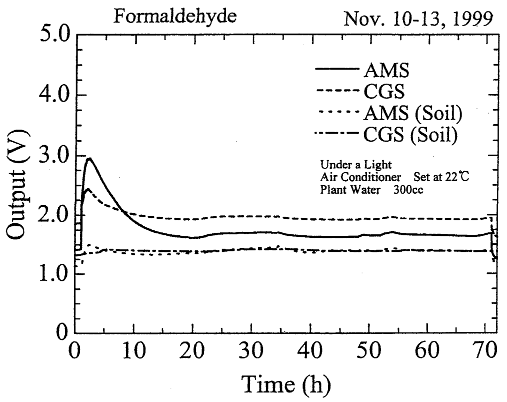

Fig. 3. Sensor characteristics in the case of removal of formaldehyde by plants in the light.

ppm (v/v) is indicated in Fig. 3. The experimental room was controlled by an air conditioner so that the room temperature was kept at 22℃. Temperature in the chamber was 22 to 23.5℃. Formaldehyde was injected into the chamber using a microsyringe after 1 hour from the beginning of the experiment. An experimental plant was already installed in the chamber and illuminated. The experiments were carried out under same daily cycle-condition, for example, the injection time of chemicals was usually 12:30. The AMS sensor, which was placed in the atmosphere of the chamber, responded to the gas at high sensitivity. Another AMS sensor in the potted soil also responded to the gas at low sensitivity, because the concentration of the polluting chemicals was lower in the soil compared with the concentration in the atmosphere. The sensor characteristics came down according to the absorption of the pollutant by the plant and it reached a clean level after ten hours. The purification effects were achieved by the plant-leaves, roots, the soil and microorganisms, which worked together[4]. In general, the absorption and/or decomposition function of the plant and the microorganism depend on the surrounding temperature[7]. Therefore, the purification ability changes as the temperature changes. Temperature changes in the room, atmosphere of the chamber and the potted soil as a function of time are indicated in Fig. 4. These three characteristics are quite similar to each other and the range was among 22.0 to 23.5℃. It seems likely that the characteristics in Fig. 3 are not

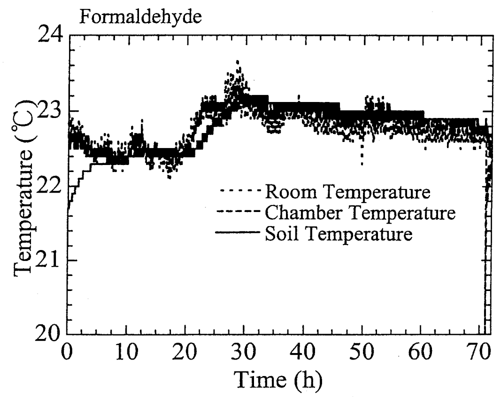

Fig. 4. Temperature changes in the room, atmosphere of chamber and potted soil.

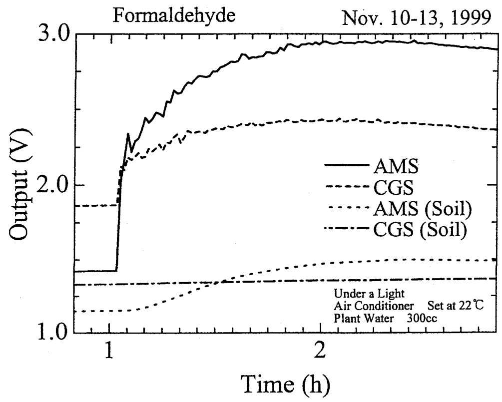

Fig. 5. Sensor characteristics when the time axis of Fig. 3 is expanded.

influenced by this range of temperature change. The time taken for formaldehyde to diffuse from the atmosphere to the potted soil was examined. In Fig. 5, the unit of time axis in Fig. 3 was expanded. The time lag was about 6 minutes. The soil is very porous and thus the chemical easily sinks into it. Therefore, the diffusion velocity seems to be comparatively high.

The similar experiment was performed in darkness. The results are shown in Fig. 6. The time needed to reach the clean level was longer in this figure than in Fig. 3. It took about twenty hours. The plants absorb various kinds of polluting chemicals through the stomata by gas diffusion. The stomatal opening becomes larger, as light intensity is higher. The potted soil without a plant was also tested and the results are shown in Fig. 7. The tested soil was

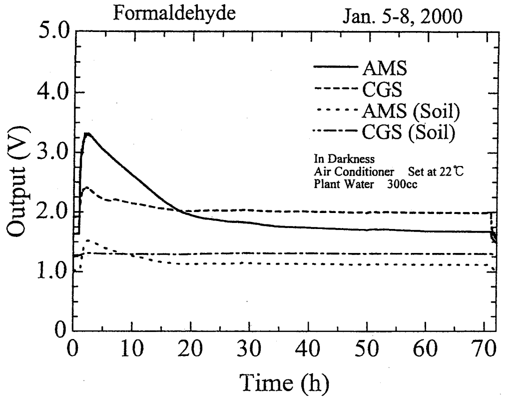

Fig. 6. Sensor characteristics in the case of removal of formaldehyde by plants in darkness.

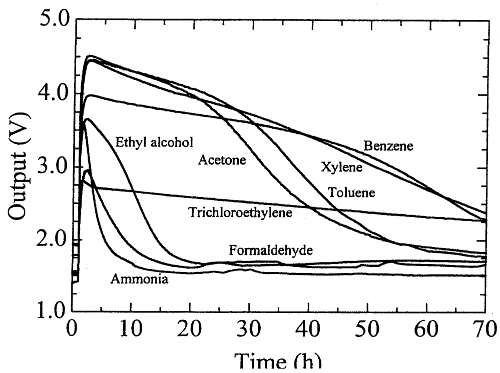

Fig. 8. Sensor characteristics in the case of removal of various chemicals by plants in the light.

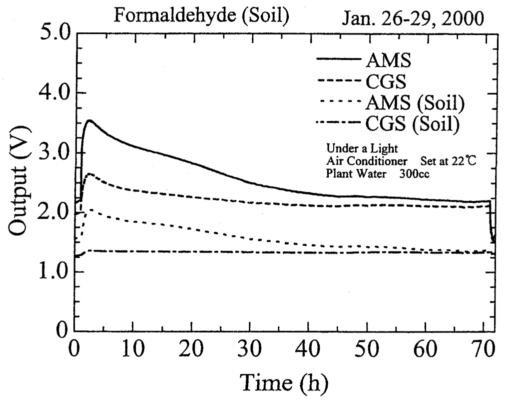

Fig. 7. Sensor characteristics in the case of removal of formaldehyde by potted soil in the light.

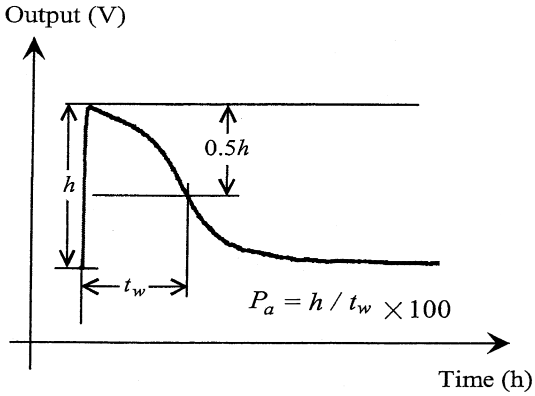

Fig. 9. Meaning of the parameters, h, t_w.

of the same kind and same volume as in Fig. 3 and 6. The time required to completely remove the chemical was over forty hours. In the experiments of soil without plants, there was not a large difference in the sensor characteristics between in the light and in darkness, but the time needed to remove the chemical becomes a little longer in darkness. It is thought that microorganisms in the potted soil have a little higher activity in the light than in darkness. These results show that the rate of removing the chemical takes a maximum value when the plant is planted in the potted soil and illuminated. The ability of the potted plant to absorb various chemicals in the light is compared in Fig. 8. The concentrations of these chemicals are within 28 to 68ppm. The abilities to absorb ammonia, formaldehyde and ethyl alcohol were high.

As for the results, the purifying rate P_a was defined using the AMS sensor output located in the atmosphere of the chamber and indicated in equation (1), where h means the peak value of sensor characteristics from the base level before the chemical being introduced into the chamber. The t_w means full-width at half maximum. The meanings of each parameter are shown in Fig. 9.

$$P_a = h/t_w \times 100 \quad (1)$$

P_a of the plant in the light as a function of molecular weight of polluting chemicals is indicated in Fig. 10. The vertical axis was marked with a logarithmic degree. The characteristic was roughly linear. Each chemical of 0.05 cc was injected into the chamber and the plant was exposed to each chemical. The concentration of each chemical was not clear but

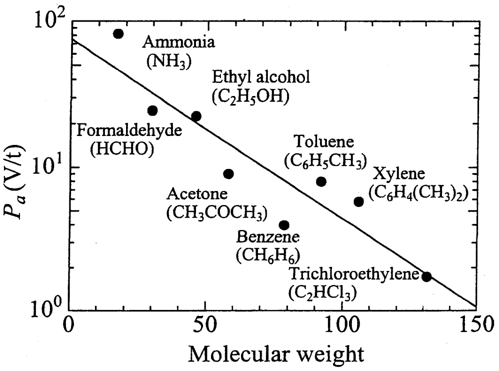

Fig. 10. Purifying rate P_a as a function of molecular weight of pollutant.

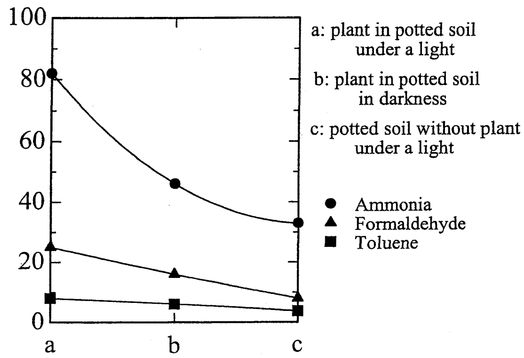

Fig. 11. Purifying rate of P_a of potted plants in the light and in darkness and of potted soil without plants.

the injected volume was fixed. When the injection volume was known, the range of the molecular weight of the polluting chemical could be estimated using the value of P_a. The plot for ammonia is located at a higher level than the characteristic curve. A plant generally favors it because it can be used as a nitrogen nutrient in the light. A potted plant has a lower purifying rate in the case of larger molecular-weight chemicals such as benzene, toluene and xylene. These three chemicals do not dissolve in water. The mechanism of the phenomena is not clear in this study. It is thought that the gaseous chemicals are absorbed mainly through stomata by plants and decomposed. It is also thought that these chemicals sometimes react on bio-substances or become nutrients. Absorption rate becomes smaller when molecular weight of the polluting chemical is large, because the diffusion coefficient of the chemical is small and thus the chemical can be absorbed by leaves only slowly. An approximate function of the characteristic in Fig. 10 is indicated in Eq. (2). The equation expresses the relation between P_a and molecular weight m_w. We can estimate P_a when m_w of a pollutant is known, and refer to the equation to reduce the polluting level in a domicile. The purifying rate of the plant and potted soil for ammonia, formaldehyde and toluene under various conditions are summarized in Fig. 11. The a-condition in the figure means the plant in potted soil in the light, b means the plant in potted soil in darkness and c means the potted soil without plant in the light. The plots for a-condition had the highest rate of P_a. Light illumination makes a great contribution to the absorption through stomata and metabolism of ammonia in plants.

$$P_a = \exp(-0.028m_w + 4.3) \quad (2)$$

In this study, P_a is calculated using the gas sensor output characteristics. P_a was almost constant for the concentration changes. This characteristic for removing formaldehyde is shown in Fig. 12. The system can derive the full-width value at half maximum from the maximum value of sensor output and estimate the purifying time of the room. It is considered that purifying rate P_a by a plant is useful to design an indoor environment for removing various types of air-pollution.

4. Conclusions

Purifying rate P_a of the interior plant for indoor air pollutants was examined using a tin oxide gas sensor. The sensor is effective in

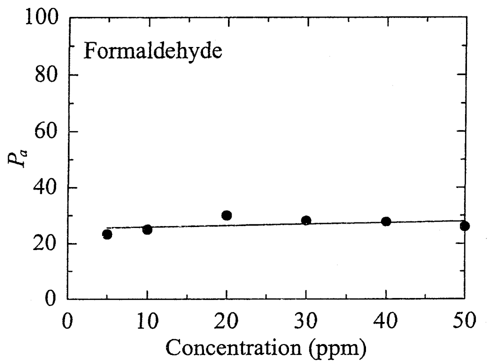

Fig. 12. Purifying rate P_a as a function of formaldehyde concentration. The experiments were carried out in the light.

monitoring the change in the concentration of gaseous chemicals and has been presently put on the market to detect combustible gases. P_a was tested under various conditions, namely in the light, in darkness and potted soil without plants. P_a was introduced using sensor output. It is the value obtained from the peak height of the output divided by the full-width at half maximum. Plants sometimes favored nitrogenous chemicals, for example, ammonia as nitrogen nutrients, and P_a was higher in the light than in darkness. P_a changed according to the molecular weight of chemicals. The smaller the weight was, the larger it became. This tendency has also been observed in an experiment of a snake plant[9]. It has not become completely obvious what mechanisms of plants remove chemicals and makes them harmless. It is also thought that bacteria near the plant-roots decompose chemicals. It does not take a high cost to remove various types of chemicals in the atmosphere by using plants and the soil.

References

1) Tunga Saithammer; Organic Indoor Air Pollutants, WILEY-VCH (1999).
2) Thad Godish; Air Quality, Lewis Publishers (1997).
3) B. C Wolverton and J. D. Wolverton., Continued Research By Dr. Wolverton and FCAC, INTERIORSCAPE, March/April, pp. 6-10 and 62-63 (1991).
4) B. C. Wolverton and J. D. Wolverton; Plants And Soil Microorganisms: Removal of Formaldehyde, Xylene, and Ammonia from the Indoor Environment, *Journal of the Mississippi Academy of Sciences,* **38**(2), pp. 11-15 (1993).
5) T. Oyabu, T. Onodera, S. Hirobayashi, and H. Kimura; Outputs of Plural Tin Oxide Gas Sensors for Compound Gaseous Indoor-air Pollutants, IEE of Japan, **118-E** (12), pp. 572-577 (1998).
6) T. Oyabu, T. Onodera, T. Nishikawa and H. Kimura Detection of Polluting Grade of Soil in a Foliage-Pot Using Tin Oxide Gas Sensor, The Tenth Annual West Coast Conference on Contaminated Soils and Water (March 20-23, 2000, San Diego, California).
7) T. Kondo, K. Hasegawa, R. Uchida, M. Onishi, A. Mizukami and K. Omasa; Absorption of Formaldehyde by Oleander (Nerium indicum), ENVIRONMENTAL SCIENCE & TECHNOLOGY, **29**(11), pp. 2901-2903 (1995).
8) T. Kondo, K. Hasegawa, R. Uchida, M. Onishi, A. Mizukami and K. Omasa; Absorption of Atmospheric Formaldehyde by Deciduous Broad-Leaved, Evergreen Broad-Leaved, and Coniferous Tree Species, *Bull. Chem. Soc. Jpn.*, **69**, pp. 3673-3679 (1996).
9) A. Kato, T. Oyabu, Y. Nakamoto, T. Onodera, T. Kamimiya, H. Kimura, H. Nanto: Composition of purification ability of potted plants for atmospheric formaldehyde, IEE of Japan, CHS-00-75, pp. 75-80 (2000).

酸化スズガスセンサを用いた観葉植物の室内空気汚染浄化指数の測定

大藪多可志*・小野寺　武**・木村春彦***・定岡芳彦****

* 金沢経済大学　〒920-8620 金沢市御所町丑10
** 九州大学工学部　〒812-8581 福岡市東区箱崎6-10-1
*** 金沢大学工学部　〒920-8667 金沢市小立野2-40-20
**** 愛媛大学工学部　〒790-8577 松山市文京町3

経済成長とともに人間は多くの化学物質に触れている。このため，化学物質過敏症になる人が増えつつある。特に，室内においてはシックハウス症候群が多発する傾向にある。老人や子供など身体的弱者は室内で時間を過ごすことが多いため，これらの病気になり喘息やアレルギィを引き起こす確率が高い。ここでは，観葉植物（ポトス）の室内空気汚染浄化効果を調べた。浄化能力 P_a を示すために，酸化スズ系ガスセンサ出力のピーク値をその半値幅で除した値を採用した。P_a は汚染物の分子量が小さいほど大きく，分子量が大きくなるにつれ小さくなる。汚染物としては代表的なホルムアルデヒド，トルエン，キシレン，ベンゼン等を選んだ。ポトスのホル

ムアルデヒドに対する P_a は25，アンモニアに対しては80程度であった。

Key words: Indoor Environment, Environmental Remediation, Air Pollution, Gas Sensor, VOC

（受稿 2000.7.25）