Detection of Metabolic Gas Emitted by Termites Using Semiconductor Gas Sensors

Yoshiyuki Yanase
Yoshihisa Fujii
Shogo Okumura
Tsuyoshi Yoshimura

Abstract

The feasibility of using three types of semiconductor gas sensors to detect the metabolic gas generated by termites was investigated. Odor, methane, and hydrogen sensors made of a tin oxide semiconductor were tested. A polypropylene container was prepared with three sensors in the lid to investigate the relationship between the number of termites and food material on gas concentration over time. Worker and soldier termites (*Coptotermes formosanus*), collected from a laboratory colony, were put into the container with and without food material (wood specimen). The variation in the electrical resistance of the sensors during the detection of gas components was monitored, and the detected voltage was converted into gas concentration.

The hydrogen concentration increased with an increase in the number of termites and was not influenced by gases released from the wood specimen. Similar findings were obtained for the odor sensor, even though it detected odor components from both termites and the wood specimen. The methane sensor did not detect any significant increase in gas concentration. The results showed that the hydrogen emission depended on the feeding activity of worker termites, whereas soldier termites that were supplied with food material by worker termites made a small contribution to hydrogen emission.

These findings suggest that because of the high selectivity and sensitivity of the hydrogen sensor, its performance is better than that of the odor and methane sensors for the detection of termite attacks.

Presently, the detection of termite attacks in wood is mostly performed by visual inspection. However, it is difficult to detect early termite attacks in this way. Few nondestructive methods for the detection of termite attacks are currently in use in Japan. In the future, there will be a greater need for efficacious nondestructive detection methods to assist in developing a termite control process that requires less termiticide or to realize a chemical-free process.

Several methods have been developed and investigated for nondestructive detection of termite attacks. They are classified into two categories: detection of termite activity in wooden structures and evaluation of the loss of mass of wooden structures attacked by termites. Traditionally used methods, such as acoustic emission (AE) monitoring, were developed and investigated for nondestructive detection of early termite attacks. This method involves the detection of elastic waves, or AEs, generated by the feeding activity of worker termites in wood (Fujii et al. 1990, 1998; Noguchi et al. 1991; Yanase et al. 1999). A technique to detect the reflection of micrometer (Evans 2002) or millimeter (Fujii et al. 2007) electromagnetic waves from termite movement in wood has been developed and applied. As for the latter methods, evaluation of inner cavities by measuring the velocity or loss of sound, elastic, or radio waves propagating in wood is one of the popular methods. A scanning radar apparatus at 1.4 GHz, which detects the reflection of waves radiated onto the wood, has been applied for nondestructive

---

The authors are, respectively, Assistant Professor, Associate Professor, and Professor, Div. of Forest and Biomaterials Sci., Graduate School of Agric., Kyoto Univ., Kyoto, Japan (yanase@h3news1.kais.kyoto-u.ac.jp [corresponding author], fujii@h3news1.kais.kyoto-u.ac.jp, oumura@h3news1.kais.kyoto-u.ac.jp); and Professor, Research Inst. for Sustainable Humanosphere, Kyoto Univ., Kyoto, Japan (tsuyoshi@rish.kyoto-u.ac.jp). This paper was received for publication in August 2012. Article no. 12-00091.

Forest Prod. J. 62(7/8):579–583.

detection of inner defects in wood, such as cavities (Fujii and Yanase 2001).

Trained dogs can also be employed to detect odors emitted from termite colonies. The ability of dogs to detect varying numbers of subterranean termites has been investigated to (1) differentiate five species of termites, (2) discriminate termites from termite-damaged wood, and (3) distinguish cockroaches and carpenter ants from subterranean termites (Brooks et al. 2003). The trained dogs identified more than 40 termite workers with 96 percent accuracy. However, they incorrectly indicated the presence of termites in 2.7 percent of the containers in which termites were not present. The ability of trained beagles and the use of electronic odor-sensing devices to detect gases emitted by termites have also been investigated by Lewis et al. (1997), who reported that in experiments using wooden blocks with different densities of subterranean termites, beagles identified blocks with termites with an accuracy of 81 percent, whereas electronic odor-sensing devices that primarily detect methane gas had an accuracy of only 48 percent. However, it must be considered that even though trained dogs possess the ability to detect odors from termites with reasonable accuracy, the cost and time required to train these dogs is exorbitant.

The most common and abundant gases emitted from termite colonies are CO_2 and CH_4; other gases, such as $CHCl_3$, N_2O, CO, and H_2, may also be emitted (Khalil et al. 1990, Sugimoto et al. 1998). Therefore, the early and accurate detection of these gases might enable nondestructive detection of early termite attacks. On the other hand, semiconductor gas sensors that detect odors, methane, and hydrogen have recently been developed (Suzuki and Takada 1995, Katsuki and Fukui 1999), and these sensors might also be applied to accurately detect termite attacks.

In the present study, we investigated the nondestructive detection of termite attacks in wooden structures using three types of semiconductor sensors (odor, methane, and hydrogen) to determine the presence of metabolic gases emitted by termites. The odor sensor applied in this study detected chemical compounds with molecular weights under 300 (e.g., carboxylic acid, amine, and sulfur compounds).

Materials and Methods

Semiconductor gas sensors

Three types of semiconductor gas sensors provided by New Cosmos Electric Co., Ltd., were used for the detection of combustible gases—namely, hydrogen, methane, and hydrocarbon-rich odor components. The gas detection unit of the sensors is made of a tin oxide (SnO_2) semiconductor and is connected to a heater. In clean air, oxygen is adsorbed onto the surface of the unit in the negatively charged state (i.e., O^-). When a combustible gas component accesses the unit that is heated at a fixed operating temperature between 300°C and 450°C, it is combined with the adsorbed oxygen (oxidized), and the oxygen simultaneously releases an electron. This results in an increase in the electrical conductivity of the metal oxide, which is monitored as the electrical resistance of the unit decreases. Using a small amount of another type of metal oxide as a catalyzer or changing the formation of SnO_2 and heaters, the gas detection unit is made functional; the unit selectively detects odors, methane, and other hydrocarbons (Suzuki and Takada 1995).

The SnO_2 unit covered with a dense but fine porous silica (SiO_2) layer is used to detect hydrogen (Katsuki and Fukui 1998). Using a filtering function, only gases with the smallest molecular weight, such as hydrogen, can reach the gas detection unit.

A transparent container (inside diameter, 110 mm; height, 80 mm; capacity, 725 mL) made of polypropylene was prepared, and three types of gas sensors were connected to the container lid (Fig. 1). A specific number of worker and soldier termites with and without food material were placed in the container. The variations in the electrical resistance of the sensors during the detection of the gas components were monitored by a bridge circuit and a buffer amplifier, recorded to a voltage logger, and eventually postprocessed by a computer. The detected voltage was converted into a gas concentration by a calibration curve obtained previously using the target gas (ethanol for odor sensor).

Experiment 1

Subterranean termites (*Coptotermes formosanus*) were collected from a laboratory colony (Research Institute for Sustainable Humanosphere). Four termite groups, each comprising a worker–soldier pair, were formed: (1) 100 workers with 10 soldiers, (2) 200 workers with 20 soldiers, (3) 500 workers with 50 soldiers, and (4) 1,000 workers with 100 soldiers (10% of the each worker group). Each termite group was placed in a polypropylene container prepared under one of the four conditions shown in Figure 2:

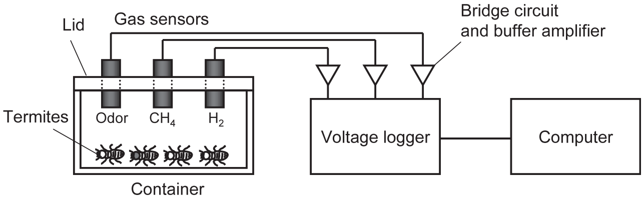

Figure 1.—Setup of the three types of semiconductor gas sensors and data acquisition.

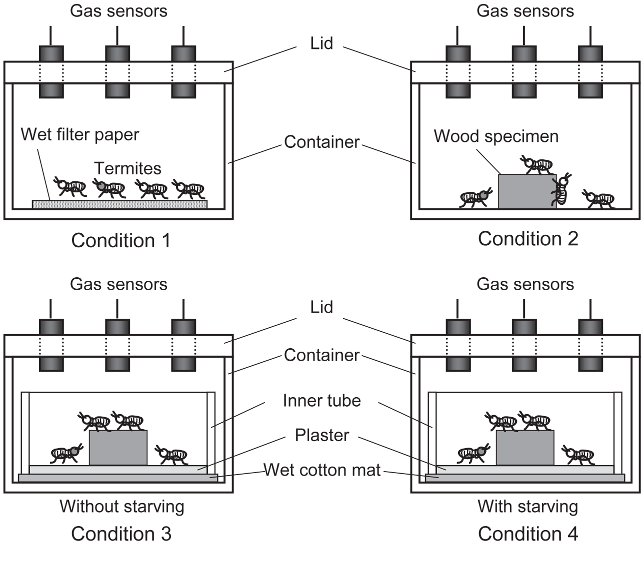

Figure 2.—Test conditions for detecting metabolic gas.

Condition 1: A sheet of wet filter paper was placed in the container.

Condition 2: A small wood specimen (30 by 30 by 50 mm) of Japanese red pine (*Pinus densiflora*), with water supplied, was placed in the container as food material.

Condition 3: A wet cotton sheet was placed under an acrylic tube (inside diameter, 80 mm; height, 50 mm) sealed by water-permeable plaster at the bottom, and a small specimen of Japanese red pine was placed in the tube as food material.

Condition 4: Same as Condition 3, except that the termites had not eaten for 2 days (starving) before gas measurement.

Gas measurements without termites in each of the four conditions were also conducted as a control. All gas measurements continued for 10 hours after placing the termite group in the container, and the measured gas concentrations were compared for different termite groups and container conditions. All gas measurements were repeated five times.

Experiment 2

The relationship between the gas concentration and ratio of the number of workers to that of soldiers in a group of 200 termites was also investigated. Termite groups in Experiment 2 were as follows: (1) 200 workers, (2) 150 workers with 50 soldiers, (3) 100 workers with 100 soldiers, (4) 50 workers with 150 soldiers, and (5) 200 soldiers. These groups were placed in the polypropylene container under Condition 4 as shown in Figure 2, and after 10 hours, the gas concentrations were measured using the three types of gas sensors. All gas measurements were repeated five times.

Results and Discussions

Figure 3 shows the gas concentrations over time for a termite group of 500 workers and 50 soldiers in Condition 3. The gas concentrations increased for the first 3 hours but then changed only slightly thereafter. For the methane sensor, the gas concentration was greater than 300 ppm from the beginning of the measurement, even though no methane-emitting objects other than the termite group were present in the container. Similar trends were observed in the other conditions containing termites. The initial methane concentration can be attributed to an offset voltage in the gas-detecting device, and we will subsequently discuss the differences relative to the initial value.

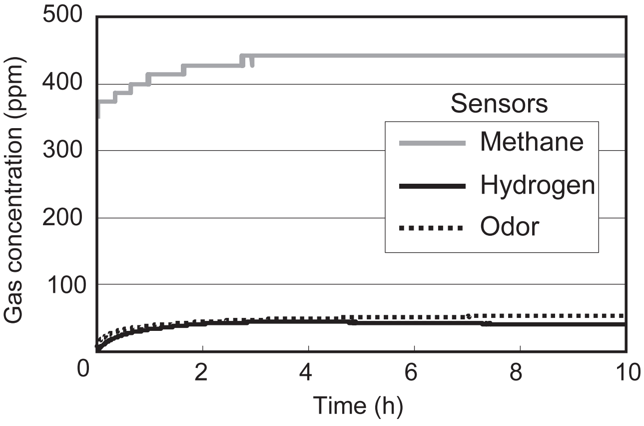

Figure 3.—Gas concentrations detected over time by the three gas sensors for a group of 500 worker and 50 soldier termites in Condition 3.

The gas concentrations measured by each gas sensor after 10 hours from the beginning of the measurement are shown in Figures 4, 5, and 6. For the odor sensor (Fig. 4), gas concentrations measured in each termite group were greater than 20 ppm, except for the group in Condition 1 without food material. However, the correlation between gas concentrations and the number of termites was not significant, and the difference in the gas concentration between Conditions 3 and 4 (with and without starving) was not clear. In addition, more than 20 ppm of the odor component was detected for Japanese red pine without termites. These findings suggest that the gas concentrations measured by the odor-selective sensor can be attributed to the odor components generated from the wood specimen. Thus, the odor sensor is not considered to be suitable for the selective detection of odors generated from termites.

For the methane sensor (Fig. 5), the gas concentration in the conditions without termites was approximately 300 ppm, and this can be attributed to the previously mentioned offset voltage in the device. However, the gas concentration increased with the number of termites. The feeding activity of worker termites was expected to increase by the addition of moisture, as in Condition 3 as opposed to Condition 2, or by using the termites in a starving state, as in Condition 4 as opposed to Condition 3. However, corresponding changes were not observed in the methane concentration. Thus, it was difficult to detect methane gas generated from termite activity using the methane sensor, even though methane is one of the most dominant metabolic gases emitted by termites (Khalil et al. 1990). The measurement time of 10 hours may not have been sufficient to detect methane gas, because the extent of wood consumption by termites was small in these measurements.

For the hydrogen sensor, gas concentrations ranging from 10 to 60 ppm were measured only for the conditions with termites (Fig. 6). The gas concentrations increased with the number of termites in the container, with the exception of Condition 3. The gas concentrations for Condition 4 (with starving) were higher than those for Condition 3 (without starving), except for the case with 200 workers and 20 soldiers. The gas components emitted from the wet filter paper or wood specimen were found to have no influence. Therefore, the change in hydrogen concentration can be attributed to the termite activity, and literature reporting that hydrogen is produced in the guts of termites by a termite–symbiont system (Sugimoto et al. 1998) supports these results. The hydrogen sensor detected small numbers of termites and may be useful in early detection of structural infestations.

Figure 7 shows the gas concentrations for five termite groups with different worker:soldier ratios; concentrations were measured using the three gas sensors for 10 hours. No significant relationship was found between the ratio of workers to soldiers and the concentrations of odor or methane, whereas higher concentrations of hydrogen were measured as the ratio of workers to soldiers increased. In particular, the hydrogen concentration was remarkably higher for groups of 200 or 150 workers than for the group with no workers. This suggests that hydrogen is generated by the feeding activity of workers, whereas soldiers that

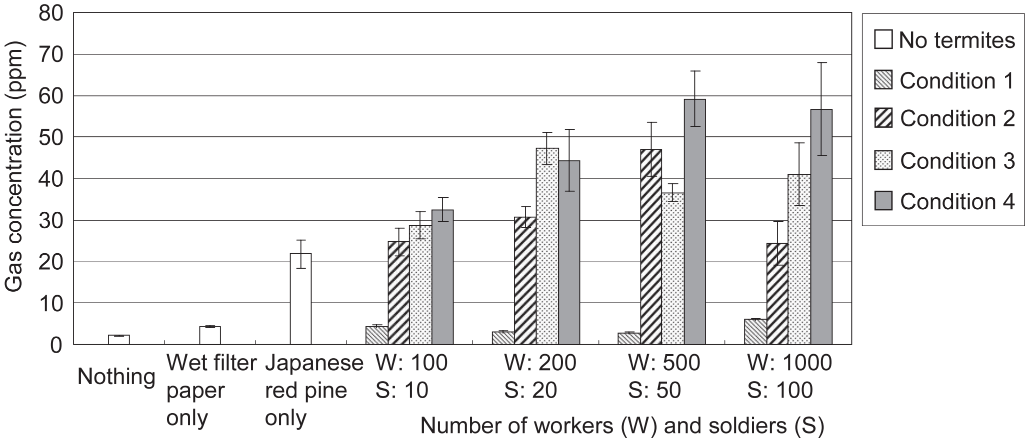

Figure 4.—Gas concentrations detected by the odor sensor after 10 hours. Error bars indicate the standard deviations of five replications.

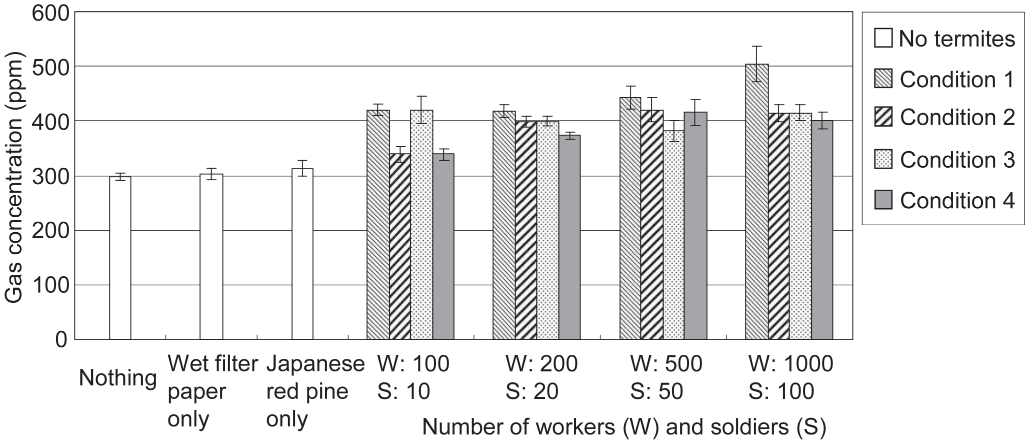

Figure 5.—Gas concentrations detected by the methane sensor after 10 hours. Error bars indicate the standard deviations of five replications.

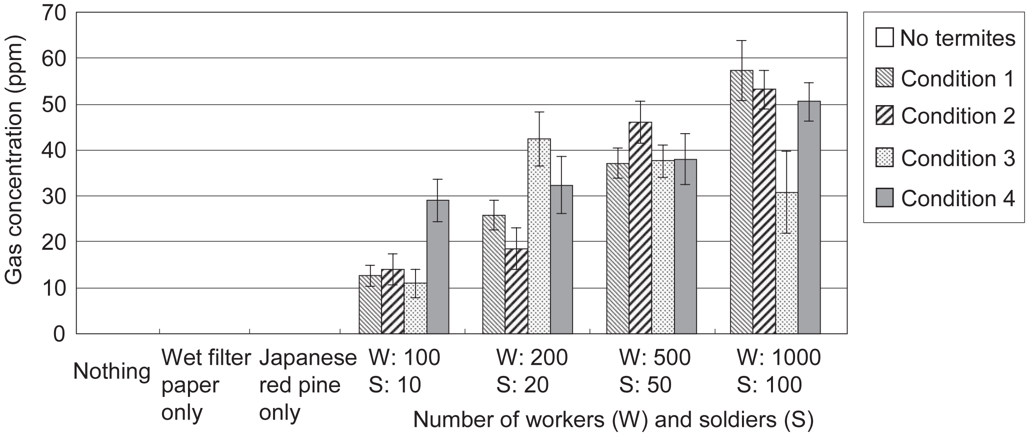

Figure 6.—Gas concentrations detected by the hydrogen sensor after 10 hours. Error bars indicate the standard deviations of five replications.

were provided with food material from workers generated only a small amount of hydrogen.

Conclusions

Regarding the detection of metabolic gases generated by a small number of termites using three types of semiconductor gas sensors, the performance of the hydrogen sensor was better than that of the odor and methane sensors. Hydrogen was generated by the feeding activity of workers, whereas soldiers that were fed by workers generated only a small amount of hydrogen.

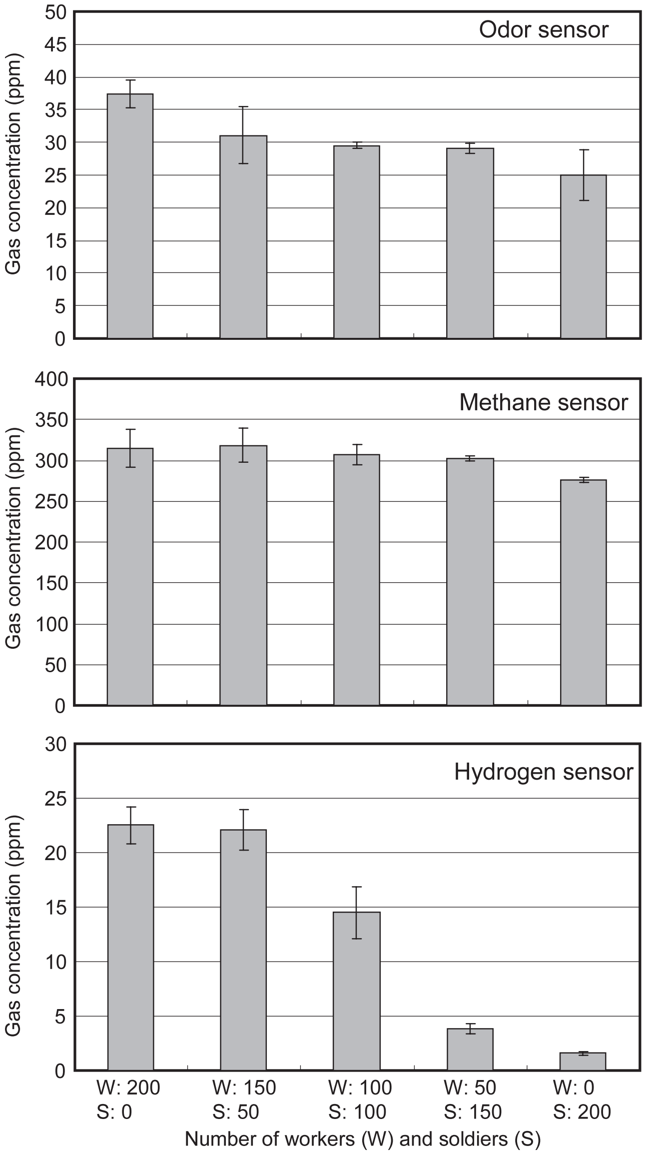

Figure 7.—Gas concentrations for five termite groups of different worker:soldier ratios after 10 hours in Condition 4. Error bars indicate the standard deviations of five replications.

It appears that the gas concentration is below the lower detectable limit when gas sampling is conducted in the condition of exposure to air. Thus, to establish the use of gas sensors, especially the hydrogen sensor, for nondestructive detection of termite attacks, it is necessary to develop sampling and evaluation methods for smaller gas concentrations. It is also important to obtain useful information about the mechanisms of metabolic gas emission by investigating the effects of other termite species and environmental factors (e.g., humidity and temperature) on gas emission and the relationship between termite feeding activity and gas emission.

Acknowledgments

We thank Dr. Toru Maekawa and Mr. Kengo Suzuki of New Cosmos Electric Co., Ltd., for providing semiconductor gas sensors.

Literature Cited

Brooks, S. E., F. M. Oi, and P. G. Koehler. 2003. Ability of canine termite detectors to locate live termites and discriminate them from nontermite material. *J. Econ. Entomol*. 96(4):1259–1265.

Evans, T. A. 2002. Assessing efficacy of Termatrac™; a new microwave based technology for non-destructive detection of termites (Isoptera). *Sociobiology* 40(3):575–583.

Fujii, Y., Y. Fujiwara, Y. Yanase, S. Okumura, K. Narahara, T. Nagatsuma, T. Yoshimura, and Y. Imamura. 2007. Nondestructive detection of termites using a millimeter-wave imaging technique. *Forest Prod. J*. 57(10):75–79.

Fujii, Y., M. Noguchi, Y. Imamura, and M. Tokoro. 1990. Using acoustic emission monitoring to detect termite activity in wood. *Forest Prod. J*. 40(1):34–36.

Fujii, Y. and Y. Yanase. 2001. Nondestructive evaluation of decay and insect attack in wood using acoustic emission (AE) monitoring and a radar technique. Tools for maintaining wood in outdoor applications. *In:* High-Performance Utilization of Wood for Outdoor Uses. Wood Research Institute, Kyoto University, Kyoto, Japan. pp. 145–160.

Fujii, Y., Y. Yanase, Y. Imamura, S. Okumura, and S. Oka. 1998. Detection of termite attack in wooden buildings with AE monitoring: Case study at a traditional Japanese warehouse. *Jpn. J. Environ. Entomol. Zool*. 9(3):101–105.

Katsuki, A. and K. Fukui. 1998. H_2 selective gas sensor based on SnO_2. *Sens. Actuators B Chem*. 52(1):30–37.

Katsuki, A. and K. Fukui. 1999. Applications of gas sensors for security and control systems in use of hydrogen. *In*: Proceedings of the 5th Korea–Japan Joint Symposium '99 on Hydrogen Energy, Yusong, November 26, 1999; Korean Hydrogen Energy Society, Taejon, Korea. pp. 183–191.

Khalil, M. A. K., R. A. Rasmussen, J. R. J. French, and J. A. Holt. 1990. The influence of termites on atmospheric trace gases: CH_4, CO_2, $CHCL_3$, N_2O, CO, H_2, and light hydrocarbons. *J. Geophys. Res*. 95(D4):3619–3634.

Lewis, V. R., C. F. Fouche, and R. L. Lemaster. 1997. Evaluation of dog-assisted searches and electronic odor devices for detecting the western subterranean termite. *Forest Prod. J*. 47(10):79–84.

Noguchi, M., Y. Fujii, M. Owada, Y. Imamura, and M. Tokoro. 1991. AE monitoring to detect termite attack on wood of commercial dimension and posts. *Forest Prod. J*. 41(9):32–36.

Sugimoto, A., T. Inoue, I. Tayasu, L. Miller, S. Takeichi, and T. Abe. 1998. Methane and hydrogen production in a termite-symbiont system. *Ecol. Res*. 13(2):241–257.

Suzuki, K. and T. Takada. 1995. Highly sensitive odor sensors using SnO_2 thick films. *Sens. Actuators B Chem*. 24–25:773–776

Yanase Y., Y. Fujii, S. Okumura, Y. Imamura, and M. Kozaki. 1999. Detection of termite attack in wooden buildings using AE monitoring: A case study at a house of wooden panel construction. *Jpn. J. Environ. Entomol. Zool*. 10(4):160–168.