Concentration–Time Relationship for Fumigant Efficacy of Sulfuryl Fluoride Against the Formosan Subterranean Termite (Isoptera: Rhinotermitidae)

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ABSTRACT The Formosan subterranean termite, *Coptotermes formosanus*, was exposed to sulfuryl fluoride over a range of six accumulated concentrations (10–60 mg h/liter) and 12 exposure times (1–96 h), to determine the concentration–time relationship on termite mortality. Time threshold in sulfuryl fluoride fumigation was <1 h. The results demonstrated that $C^{0.93}t = k$ was a satisfactory model to describe the response relationship in fumigant efficacy of sulfuryl fluoride against this termite. Because the toxicity index (n = 0.93) approximates to 1, the assumption that the exposure time is equally important to concentration is functionally valid.

KEY WORDS Insecta, *Coptotermes formosanus*, concentration and time products, toxicity indexes

STRUCTURAL FUMIGATIONS with sulfuryl fluoride usually require exposure times of 20–24 h (Anonymous 1982). Our previous study (Osbrink et al. 1987) indicated that, under 22-h exposure, a concentration of approximately 2–2.5 mg/liter (or 44–55 mg h/liter accumulated dosage) killed 99% of the tested termites including the Formosan subterranean termite, *Coptotermes formosanus* Shiraki; the western drywood termite, *Incisitermes minor* (Hagen); and the southeastern drywood termite, *I. snyderi* (Light).

Busvine (1938) first proposed the model $C^n t = k$ (where C, concentration; t, time; n, the toxicity index; and k, the dosage for a specific mortality level) to describe the fumigant concentration, exposure time, and mortality relationship. The model states that the product of concentration and time (CT product) is constant for a specific mortality level. This model is accurate in describing fumigant efficacy of phosphine and methyl bromide against several stored-product insects (Bell & Glanville 1973, Bell 1979, Winks 1984, Winks & Waterford 1986).

The current prescribed label for sulfuryl fluoride assumes that exposure time is equally important to concentration, namely, n = 1, i.e., $Ct = k$ (Anonymous 1982). Stewart's (1957) results suggested that this assumption is valid with sulfuryl fluoride and methyl bromide against *I. minor*. Our previous study, however, indicated that a deviation from the simple model $Ct = k$ occurred when sulfuryl fluoride penetrated moistened wood barriers to reach *C. formosanus*, resulting in low concentrations (Su & Scheffrahn 1986).

Commercial application of sulfuryl fluoride requires the evacuation of occupants during fumigation. A reduction of fumigation time compensated for by a higher concentration of sulfuryl fluoride may be desirable in some instances. Therefore, the concentration–time relationship must be validated for sulfuryl fluoride against termites to ensure control from abbreviated, high-concentration exposure.

This study was done to establish if the product of two parameters, which constitute accumulated dosage of a fumigant, concentration and exposure time, yields a constant level of efficacy for sulfuryl fluoride against *C. formosanus*.

Materials and Methods

Foragers of *C. formosanus* were collected from three field colonies with the method of Su & Scheffrahn (1986). Thirty workers and three soldiers were placed in a Petri dish (5.0 cm diameter by 1.5 cm high) provisioned with a moistened filter paper disk. Three units were prepared for each of the three colonies and placed in a fumitorium similar to that described by Osbrink et al. (1987). Seven fumitoria, six receiving a prescribed dosage and one control, were used in the testing. Exposure times were 1, 2, 3, 4, 6, 8, 10, 12, 24, 48, 72, and 96 h. A total of 756 units was prepared for this study. Based on the volume of the fumitorium, a known quantity of commercial grade sulfuryl fluoride (99.5%, Vikane; Dow Chemical U.S.A., Midland, Mich.) was introduced by a gas-tight syringe to yield accumulated dosages (AD) of 10, 20, 30, 40, 50, and 60 mg h/liter for each exposure time trial. Immediately before exposure termination, concentrations of sulfuryl fluoride in fumitoria were determined by the method of Scheffrahn et al. (1987). Survival counts after exposure were made daily up to 7 d, and dead or moribund termites were removed from the units. Counts at day 7 were used for the analysis.

Table 1. ANOVA for *C. formosanus* workers' mortalities among 12 exposure times at accumulated dosages of 10–60 mg h/liter of sulfuryl fluoride

Accumulated dosage (mg h/liter)	10	20	30	40	50	60
df	11	11	11	11	11	11
MS	1.02	2.02	46.28	85.05	9.02	1.04
F	0.74	1.09	13.75*	160.60*	17.64*	8.56*

* Significant difference at $P = 0.05$.

Worker mortality was corrected by control mortality with Abbott's (1925) formula and square root transformed before analysis. For each accumulated dosage, mortalities corresponding to the exposure times were subjected to analysis of variance for the completely randomized block design (SAS Institute 1985). Colony origin was used as the block factor. Significant differences among exposure times were separated using the Student-Newman-Keuls test ($P = 0.05$; Steel & Torrie 1980). Lethal dosages for mortality levels at 50, 90, and 99% were estimated for each of the 12 exposure times using probit analysis (SAS Institute 1985). The LD_{50}, LD_{90}, or LD_{99} values were then independently regressed against the exposure time on a logarithmic scale to estimate the toxicity index (n), as described by Winks (1984).

Results and Discussion

The verified concentrations of sulfuryl fluoride at the end of each exposure time were within 98% of the initial concentrations. Control mortalities were <10% in all units. No differences in mortalities of *C. formosanus* workers were found among the 12 exposure times when accumulated dosage was ≤20 mg h/liter (Tables 1 and 2). At an accumulated dosage of 30 mg h/liter, significantly fewer termites died when exposure time was <3 h. Effects of exposure time became insignificant when accumulated dosage and corresponding mortality increased above before-mentioned levels. Time threshold (significant difference in CT mortality) was 2 h when accumulated dosage was 40 mg h/liter, while at accumulated dosages >50 mg h/liter only those termites confined to sulfuryl fluoride for 1 h responded with significantly lower mortality (Table 2). Because the recommended application rate of sulfuryl fluoride for termite control (120 mg h/liter at 27°C for drywood termites) exceeds the LAD_{100} (lethal accumulated dosage for 100% mortality) of most termite species (Osbrink et al. 1987), the practical exposure time threshold for dosage predictability is probably <1 h.

Linear regression lines of dosages (mg/liter) against exposure time for three mortality levels, 50, 90, and 99%, were: LD_{50}: $\log C = -1.0706 \log t + 1.6026$ ($R^2 = 0.9927$; $P < 0.0001$); LD_{90}: $\log C = -1.0727 \log t + 1.7280$ ($R^2 = 0.9943$; $P < 0.0001$); LD_{99}: $\log C = -1.0724 \log t + 1.8066$ ($R^2 = 0.9949$; $P < 0.0001$).

The slopes of these regressions demonstrated parallelism (Fig. 1). Despite the inclusion of data from the 1-h exposure that showed significantly lower mortality (Table 1), no systematic deviation from the general model $C^n t = k$ was found in the regressions. A model incorporating time threshold (t_0) such as $C^n(t - t_0) = k$ may improve the regression coefficient, but the general form of $C^n t = k$ is accurate enough for practical purposes.

From these regressions, concentration–time relationships from the model $C^n t = k$ were derived as follows: LD_{50}: $C^{0.934}t = 31.40$; LD_{90}: $C^{0.932}t = 40.82$; LD_{99}: $C^{0.932}t = 48.37$. For the model to be a useful description of the response relationship, values of the toxicity index, n, must remain reasonably constant over the tested range, i.e., the regressions should be parallel at various response levels (Winks 1984). Reflecting the parallelism of the regressions (Fig. 1), the toxicity index was approximately 0.93 regardless of the mortality levels. Our results demonstrated that, within the concentration and time range tested in this study, $C^{0.93}t = k$ is a satisfactory model to describe the response relationship for sul-

Table 2. Mortality (% ± SE) of *C. formosanus* exposed to sulfuryl fluoride

Exposure time (h)	Accumulated dosage (mg h/liter)					
	10	20	30	40	50	60
1	1.1 ± 0.8a	0.7 ± 0.5a	1.5 ± 0.8a	3.0 ± 2.6a	46.9 ± 8.4a	80.8 ± 7.2a
2	5.5 ± 2.1a	3.3 ± 1.4a	2.4 ± 1.7a	5.3 ± 0.7b	96.5 ± 1.5b	100b
3	2.8 ± 1.5a	4.4 ± 2.9a	19.6 ± 4.3b	78.3 ± 3.3c	92.3 ± 2.5b	95.9 ± 1.9b
4	1.5 ± 0.7a	1.8 ± 0.8a	58.8 ± 5.7c	92.0 ± 2.9c	99.2 ± 0.5b	99.6 ± 0.4b
6	2.7 ± 0.9a	6.8 ± 5.8a	31.6 ± 9.8bc	91.0 ± 2.3c	98.9 ± 0.8b	100b
8	2.2 ± 0.8a	4.6 ± 1.4a	41.3 ± 9.4bc	89.3 ± 3.3c	100b	100b
10	1.1 ± 0.6a	6.3 ± 2.7a	57.6 ± 4.6c	87.2 ± 2.8c	97.4 ± 1.1b	99.6 ± 0.4b
12	2.2 ± 1.0a	6.7 ± 3.9a	55.4 ± 12.4c	81.1 ± 5.5c	97.0 ± 1.2b	98.1 ± 0.8b
24	2.9 ± 1.2a	1.9 ± 1.0a	35.2 ± 4.2bc	90.7 ± 2.6c	97.4 ± 0.9b	99.6 ± 0.4b
48	0.8 ± 0.5a	5.1 ± 3.3a	34.9 ± 4.4bc	77.7 ± 6.1c	99.6 ± 0.4b	100b
72	1.9 ± 0.8a	3.7 ± 1.4a	33.4 ± 8.3bc	88.3 ± 3.4c	98.9 ± 0.6b	98.3 ± 0.9b
96	1.9 ± 0.9a	0.4 ± 0.4a	34.3 ± 6.9bc	95.3 ± 1.8c	100b	100b

Data are means of nine replicates. Within a column, means followed by the same letter are not significantly different ($P = 0.05$; Student-Newman-Keuls test [Steel & Torrie 1980]).

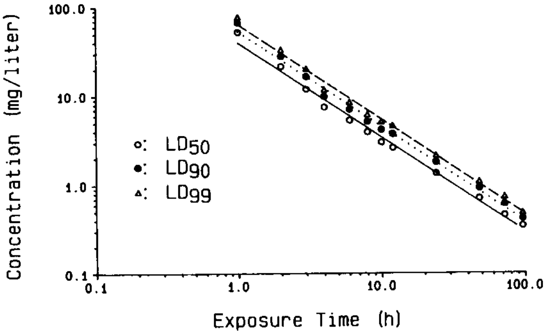

Fig. 1. The concentration–time relationship of sulfuryl fluoride toxicity against *C. formosanus* at mortality levels of 50, 90, and 99%.

furyl fluoride toxicity against *C. formosanus* workers.

The toxicity index is considered to be a specific characteristic of the response relationship between a given toxicant and a target organism (Winks 1984). An n value of 0.9 was reported from the phosphine toxicity studies against diapausing larvae of *Ephestia elutella* (Hübner) (Bell 1979) and *Tribolium castaneum* (Herbst) (Winks 1984). Our toxicity index for sulfuryl fluoride against *C. formosanus* was substantially higher than that derived by Winks & Waterford (1986) from a resistant strain of *T. castaneum* ($n = 0.65$) exposed to phosphine. Their low n value was attributed to tolerance of high phosphine concentration because of narcosis.

Because the toxicity index was <1, our model suggests that exposure time is a slightly more important variable than sulfuryl fluoride concentration against *C. formosanus*. In commercial applications of sulfuryl fluoride for termite control where high concentrations are generally used, the assumption that exposure time is equally important to concentration, or $n = 1$, is functionally valid.

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References Cited

Abbott, W. S. 1925. A method for computing the effectiveness of an insecticide. J. Econ. Entomol. 18: 265–267.

Anonymous. 1982. Vikane fumigation manual. Dow Chemical U.S.A., Ann Arbor, Mich.

Bell, C. H. 1979. The efficacy of phosphine against diapausing larvae of *Ephestia elutella* (Lepidoptera) over a wide range of concentrations and exposure times. J. Stored Prod. Res. 15: 53–58.

Bell, C. H. & V. Glanville. 1973. The effect of concentration and exposure in tests with methyl bromide and with phosphine on diapausing larvae of *Ephestia elutella* (Hübner) (Lepidoptera, Pyralidae). J. Stored Prod. Res. 9: 165–170.

Busvine, J. R. 1938. The toxicity of ethylene oxide to *Calandra oryzae, C. granaria, Tribolium castaneum* and *Cimex lectularius*. Ann. Appl. Biol. 25: 605–632.

Osbrink, W. L. A., R. H. Scheffrahn, N.-Y. Su & M. K. Rust. 1987. Laboratory comparisons of sulfuryl fluoride toxicity and mean time of mortality among ten termite species (Isoptera: Hodotermitidae, Kalotermitidae, Rhinotermitidae). J. Econ. Entomol. 80: 1044–1047.

SAS Institute. 1985. SAS user's guide: statistics, version 5 ed. SAS Institute, Cary, N.C.

Scheffrahn, R. H., N.-Y. Su & W. L. A. Osbrink. 1987. Precise dosage delivery method for sulfuryl fluoride in small-chamber fumigations. J. Econ. Entomol. 80: 705–707.

Steel, R. G. D. & J. H. Torrie. 1980. Principles and procedures of statistics. McGraw-Hill, New York.

Stewart, D. 1957. Sulfuryl fluoride—a new fumigant for control of the drywood termite *Kalotermes minor* Hagen. J. Econ. Entomol. 50: 7–11.

Su, N.-Y. & R. H. Scheffrahn. 1986. Field comparison of sulfuryl fluoride susceptibility among three termite species (Isoptera: Kalotermitidae, Rhinotermitidae). J. Econ. Entomol. 79: 903–908.

Winks, R. G. 1984. The toxicity of phosphine to adults of *Tribolium castaneum* (Herbst): time as a dosage factor. J. Stored Prod. Res. 20: 45–56.

Winks, R. G. & C. J. Waterford. 1986. The relationship between concentration and time in the toxicity of phosphine to adults of a resistant strain of *Tribolium castaneum* (Herbst). J. Stored Prod. Res. 22: 85–92.

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