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# ON THE EFFICACY OF SULFURYL FLUORIDE AGAINST STORED-PRODUCT PEST MOTHS AND BEETLES

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## ABSTRACT

Sulfuryl fluoride ($SO_2F_2$) is a fumigant currently applied for the control of termites and wood-infesting beetles. In this study its efficacy against eight species of stored-product insect pests was studied. Each insect sample was exposed for 24, 48 or 72 h to concentrations ranging from 11.7 g/m$^3$ to 35 g/m$^3$. Concentrations of $SO_2F_2$ were measured using an infrared absorption spectrometer.

Complete control of adults of all tested species and of all larval stages and pupae of *Sitophilus granarius*, *Tribolium confusum* and *Tenebrio molitor* was achieved within a 24-h exposure period at 13 g/m$^3$. Some individuals of *Stegobium paniceum* and *Trogoderma versicolor* continued to develop to the adult stage, but no reproduction occurred. *Oryzaephilus surinamensis* survived and reproduced for all tested fumigation times at 18.6 g/m$^3$. *Plodia interpunctella* survived and reproduced within the 24-h and 48-h exposure times at 18.2 g/m$^3$. *S. granarius* and *Ephestia kuehniella* produced progeny within 6 weeks after fumigation for 24 h with 26.5 g/m$^3$ and 23.5 g/m$^3$, respectively. Complete control of eggs of *S. granarius* was achieved within the 24-h exposure time at 35 g/m$^3$. These results suggest that, as known from the treatment of wood-destroying insects, the eggs are the most tolerant stage of these species towards $SO_2F_2$.

## INTRODUCTION

Sulfuryl fluoride ($SO_2F_2$) is a biologically active inorganic chemical that is odourless, colourless, non-corrosive and inflammable. It has low water solubility (750 ppm at 25°C), a high vapour pressure (15.98 bar at 21.1°C) and a boiling point of –55.4°C. Its density at 20°C is 1.36 kg/L, and its molecular weight is 102.06. The critical exposure route is via inhalation and the Threshold Limit Value is 5 ppm. On skin, the liquid can cause the tissue to freeze (Schneider, 1993).

$SO_2F_2$'s potential for replacing methyl bromide (MB) in certain areas of stored-product protection is currently under investigation. In 1992, MB was listed under the Montreal Protocol as a significant ozone-depleting substance (UNEP, 1994), and in 1995 controls on the global use of MB were added to the treaty. Bromine from MB is estimated to be 50 times more effective at destroying ozone, on a per molecule basis, than chlorine from CFC's (WMO, 1995). Production and distribution of MB for fumigation will be phased out; therefore, alternatives are urgently needed. Non-chemical alternatives include controlled atmospheres (Prozell *et al.*, 1997), as well as physical and biological control methods. Chemical alternatives include phosphine (Benzing, 1997) and carbonyl sulfide (Plarre, 1997).

$SO_2F_2$ is fully oxidised and has no direct ozone-depletion potential. Furthermore, the degradation product of $SO_2F_2$, fluorine, has not been demonstrated to take part in ozone-destruction reactions (Fisher *et al.*, 1990; Bailey, 1992). The primary use of $SO_2F_2$ has been as a structural fumigant for the control of drywood termites. However, it is increasingly being adopted for the control of wood-infesting beetles and household insect pests. It is registered for use in Germany, Sweden and the USA. Research is currently being undertaken to evaluate the efficacy of $SO_2F_2$ on beetles infesting imported timber and on stored-product insect pests. This paper reports on a preliminary laboratory study undertaken to determine the fumigant's activity on eight stored-product insect pests.

## MATERIALS AND METHODS

Six beetle species and the two moth species listed in Table 1 were included in the study. All insects originated from laboratory cultures maintained at the Institute for Stored-Product Protection.

TABLE 1
Insect species investigated in the study on the efficacy of sulfuryl fluoride

| Species | Common name | Order | Investigated stages |
|---|---|---|---|
| *Sitophilus granarius* L. | Grain weevil | Coleoptera | Egg, larva, pupa, adult |
| *Oryzaephilus surinamensis* L. | Saw-toothed grain beetle | Coleoptera | Egg, larva, pupa, adult |
| *Tribolium confusum* J. Du Val | Confused flour beetle | Coleoptera | Egg, larva, pupa, adult |
| *Stegobium paniceum* L. | Drugstore beetle | Coleoptera | Egg, larva, pupa, adult |
| *Trogoderma versicolor* (Creutzer) | European larger cabinet beetle | Coleoptera | Egg, larva, pupa, adult |
| *Tenebrio molitor* L. | Meal-worm beetle | Coleoptera | Egg, larva, pupa, adult |
| *Ephestia kuehniella* Zeller | Mediterranean flour moth | Lepidoptera | Egg, larva, pupa |
| *Plodia interpunctella* (Hübner) | Indian meal moth | Lepidoptera | Egg, larva, pupa |

Different stages of *S. granarius* and *T. molitor* were treated separately. A mixture of stages was exposed concurrently, together with the rearing substrate, for all other insects. Insects were exposed at 20°C to concentrations of $SO_2F_2$ ranging from 11.7 ± 0.4 g/m$^3$ to 35 ± 0.2 g/m$^3$ for 24, 48 and 72 h, respectively, in a 0.5-m$^3$ steel chamber, as described by Reichmuth (1981). The concentration of $SO_2F_2$ was determined using an infrared absorption spectrophotometer (Miran 1A). The lowest detectable concentration was 0.09 ppm. The extinction of infrared was measured and $SO_2F_2$ was absorbed at 11.5 µm. The fixed optical length was 20.25 m. Calibration was carried out by means of a calibration gas ($SO_2F_2$, 12560 ppm = 52.3 g/m$^3$) by injecting 5 ml of calibration gas three times to obtain three test points. Extinction was documented graphically using a recorder. The spectrum obtained with the spectrophotometer for 100 ppm $SO_2F_2$ is shown in Fig. 1. The calibration curve, a non-linear regression of the calibration data using the computer program TABLECURVE, enabled determination of the concentrations from the measurements.

In the trials, 5 ml of the atmosphere inside the fumigation chamber was measured three times. The average values of the three measurements were calculated, and the corresponding absolute values were determined using the calibration curve.

Following exposure, the insects were subjected to aeration for 3 h and then transferred, with additional standard substrate, and maintained at 20°C and 65% r.h. The efficacy of

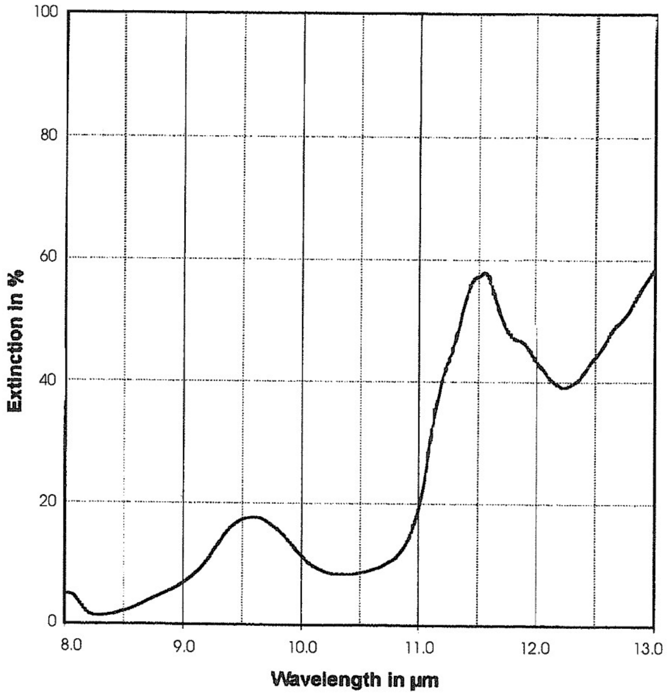


Fig. 1. Spectrum obtained with the spectrophotometer type Miran 1A for 100 ppm $SO_2F_2$, where $SO_2F_2$ is absorbing at 11.5 µm.

the $SO_2F_2$ on eggs, larvae, pupae and adults, as well as the ability of adults to produce progeny, was determined by counting dead, surviving and emerging adults 10–12 weeks after fumigation. Except for the fumigation, the untreated samples were handled in the same manner.

## RESULTS

At the lower concentrations of $SO_2F_2$ (11.7–13.3 $g/m^3$) and the shortest exposure period (24 h), 100% mortality of larval, pupal and adult stages was achieved for *S. granarius*, *T. confusum* and *T. molitor* (Table 2). Some individuals of *S. paniceum* and *T. versicolor* continued to develop to the adult stage, but no reproduction occurred. Higher concentrations (23.5 $g/m^3$) at this exposure period were required to obtain 100% mortality of eggs,

TABLE 2

Efficacy of sulfuryl fluoride for 24, 48 and 72-h exposure at 20°C (one trial per experimental design)

| Exposure | Concentration ($g/m^3$) | Species/stage | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1/As | 2/As | 3/As | 4/As | 5/L | 5/P | 5/A | 6/E+L+P | 7/E+L+P |
| 24 h | 11.7 ± 0.4 | – | – | ○ | ○ | ■ | ■ | ■ | Δ | ■ |
| | 13.3 ± 0.2 | ■ | ■ | – | – | – | – | – | – | – |
| | 18.2 ± 0.4 | – | – | ■ | ■ | ■ | ■ | ■ | Δ | Δ |
| | 18.6 ± 0.5 | Δ | ■ | – | – | – | – | – | – | – |
| | 23.5 ± 0.3 | – | – | ■ | ■ | ■ | ■ | ■ | Δ | ■ |
| | 26.5 ± 0.3 | ■ | ■ | – | – | – | – | – | – | – |
| 48 h | 11.7 ± 0.4 | – | – | ○ | ■ | ■ | ■ | ■ | Δ | ■ |
| | 13.3 ± 0.2 | ■ | ■ | – | – | – | – | – | – | – |
| | 18.2 ± 0.4 | – | – | ■ | ■ | ■ | ■ | ■ | Δ | ■ |
| | 18.6 ± 0.5 | Δ | ■ | – | – | – | – | – | – | – |
| | 23.5 ± 0.3 | – | – | ■ | ■ | ■ | ■ | ■ | Δ | ■ |
| | 26.5 ± 0.3 | ■ | ■ | – | – | – | – | – | – | – |
| | 35.0 ± 0.2 | – | – | – | – | – | – | – | ■ | ■ |
| 72 h | 11.7 ± 0.4 | – | – | ○ | ○ | ■ | ■ | ■ | ■ | ■ |
| | 13.3 ± 0.2 | ■ | ■ | – | – | – | – | – | – | – |
| | 18.2 ± 0.4 | – | – | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| | 18.6 ± 0.5 | ■ | Δ | – | – | – | – | – | – | – |
| | 23.5 ± 0.3 | – | – | ■ | ■ | ■ | ■ | ■ | Δ | ■ |
| | 26.5 ± 0.3 | ■ | ■ | – | – | – | – | – | – | – |
| | 35.0 ± 0.2 | – | – | – | – | – | – | – | ■ | ■ |

E = egg; L = larva; P = pupa; A = adult; As = all stages.
1 = *Oryzaephilus surinamensis*; 2 = *Tribolium confusum*; 3 = *Stegobium paniceum*; 4 = *Trogoderma versicolor*; 5 = *Tenebrio molitor*; 6 = *Ephestia kuehniella*; 7 = *Plodia interpunctella*.
○ = surviving insects, no progeny produced; – = no experiment; ■ = 100% mortality; Δ = surviving insects, progeny produced.

larvae and pupae of *P. interpunctella*; 26.5 g/m$^3$ were required to obtain 100% mortality of all stages of *O. surinamensis*; and 35.0 g/m$^3$ were required to obtain 100% mortality of eggs of *S. granarius* (Fig. 2). Eggs of *E. kuehniella* survived the 24-h exposure to 23.5 g/m$^3$, which was the highest concentration tested.

Exposure for 48 h achieved 100% mortality for all stages of *T. versicolor* at 11.7 g/m$^3$, the lowest concentration evaluated. When exposed to 35.0 g/m$^3$, the highest concentration, for 72 h, eggs of both *S. granarius* and *E. kuehniella* were all killed (Table 2).

In both series of experiments with *E. kuehniella* and *S. granarius* (Figs. 3 and 4), the Ct-products for $LD_{50}$ and $LD_{95}$ increased slightly when the exposure period was prolonged.

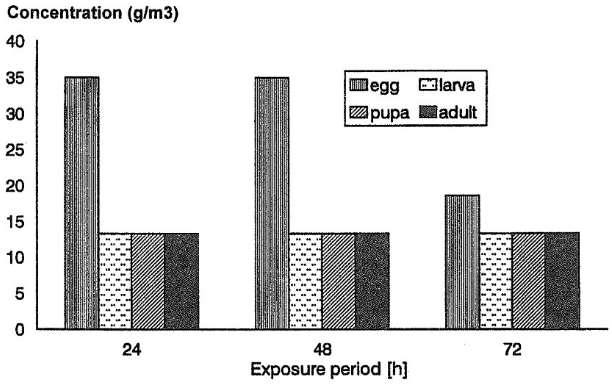


Fig. 2. Efficacy of $SO_2F_2$ against four developmental stages of *Sitophilus granarius* for exposures of 24, 48 and 72 h at 20°C (one trial per experimental design).

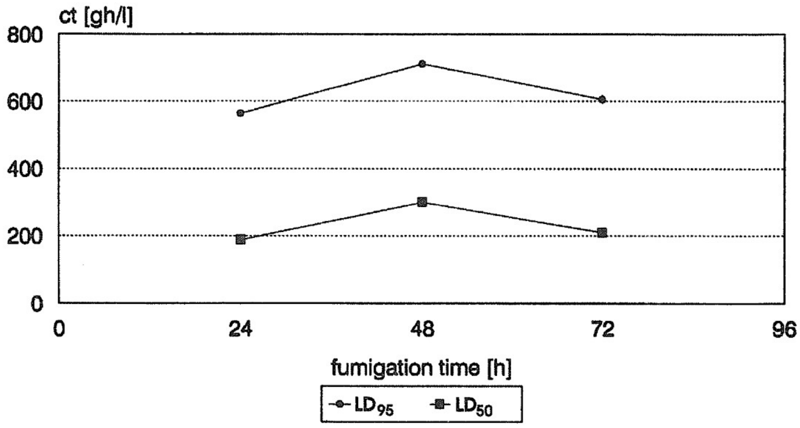


Fig. 3. $LD_{50}$ and $LD_{95}$ Ct-values for exposure of eggs of *Ephestia kuehniella* to $SO_2F_2$, in relation to fumigation time.

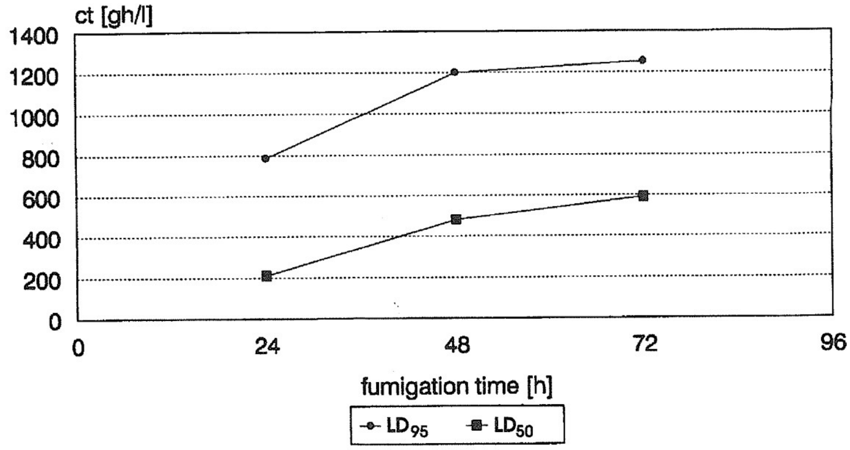


Fig. 4. $LD_{50}$ and $LD_{95}$ Ct-values for exposure of eggs of *Sitophilus granarius* to $SO_2F_2$, in relation to fumigation time.

## DISCUSSION

This study demonstrated that larvae, pupae and adults were the most susceptible stages to $SO_2F_2$. The lowest concentrations (11.7–13.3 g/m$^3$) tested for 24 h produced 100% mortality of *S. granarius*, *T. confusum* and *T. molitor*. The eggs appeared to be the stage most tolerant to the fumigant. A dose of 35.0 g/m$^3$ for 24 h was required to achieve complete kill of *S. granarius* and *E. kuehniella* eggs. The results of this preliminary laboratory evaluation of the fumigant suggest that total control of all stages of the tested insects can be achieved by use of 350.2 g/m$^3$ for 24-h exposure at 20°C.

Insect pests are controlled by $SO_2F_2$ through disruption of the glycolysis cycle, leading to deprivation of metabolic energy (Meikle *et al.*, 1963). Its effect depends upon both the concentration which reached the target insect and the duration of exposure. The egg stage has been reported as being the most tolerant to $SO_2F_2$ for the stored-product beetles, *S. granarius* (Kenaga, 1957) and *T. molitor* (Outram, 1967), and also for various fabric and household pests (Kenaga, 1957; Lafage *et al.*, 1983; Thoms and Scheffrahn, 1994). Complete data for all developmental stages are not available for other stored-product insect pests, but data on certain developmental stages are available for *T. confusum* (Kenaga, 1957; Thoms and Scheffrahn, 1994), *Rhyzopertha dominica*, *O. surinamensis* (Kenaga, 1957), *Tenebroides mauritanicus* (Bond and Monro, 1961), *Dermestes maculatus* (Su and Scheffrahn, 1990), *Lasioderma serricorne* (Kenaga, 1957; Su and Scheffrahn, 1990), *Trogoderma granarium*, *E. elutella* (Thoms and Scheffrahn, 1994), *Sitotroga cerealella* and *E. kuehniella* (Kenaga, 1957). The results for *E. kuehniella* and *S. granarius* obtained in this study appear to indicate that the Ct-product increased when the exposure period was prolonged. Further laboratory studies on $SO_2F_2$ are required to validate the results of this preliminary observation.

$SO_2F_2$ has never been used for stored-grain fumigations due to both the cost competitiveness of other fumigants and the potential for residues (Schneider, 1993). However, the use of this fumigant for certain areas of stored-product protection, such as the fumigation of empty food processing and storage structures, is being investigated. Should the results of this study be confirmed, the performance of the fumigant under practical field conditions will be investigated.

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