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NITROGEN-FLOW FUMIGATION FOR THE PRESERVATION OF WOOD, TEXTILES, AND OTHER ORGANIC MATERIAL FROM INSECT DAMAGE

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ABSTRACT

Valuable old sculptures of wood, paintings on wood or with wooden frames, as well as furs and skins in museums are all very susceptible to damage by insects capable of digesting cellulose through the intermediary of microorganisms in their gut. The usual method of disinfestation is by treatment with residual insecticides. Due to the potential undesirable chemical reaction of insecticides with the dyes of paint or with furs and skins as well as the ban on ethylene oxide, an urgent demand has arisen for alternative methods. The development of inert atmosphere treatments (using mixtures of nitrogen and/or carbon dioxide with rather low content of oxygen) in stored agricultural products to control insect pests, has led to the same approach for other materials of organic origin also susceptible to insect damage. Nitrogen-Flow-Fumigation (NFF) is a simple method designed to control pests in museum artifacts by application of nitrogen to gasproof plastic bags or gastight chambers at constant low oxygen concentrations under a constant low pressure of 5 to 10 Pa.

INTRODUCTION

In addition to stored-product pests, several other species of arthropods specialize in attacking organic materials of human interest such as wood, fabrics, and hides. These include termites, among them the subterranean termite *Reticulitermes santonensis* De Feytaud, and beetles, among them the common powder post beetle *Lyctus brunneus* Stephens, the common furniture beetle *Anobium punctatum* De Geer, the house longhorn beetle *Hylotrupes bajulus* L., species of the family Dermestidae including the bacon beetle *Dermestes lardarius* L., the common hide beetle *Dermestes maculatus* De Geer, the cigarette beetle *Lasioderma serricorne* F., the carpet beetles *Anthrenus verbasci* L., *Attagenus* spp., and *Trogoderma* spp., and moths, particularly the common clothes moth *Tineola bisselliella* Hummel. These species are major pests of wood, or fabrics, animal skins, furs and hides, as well as other materials of organic origin of economic importance.

Damage to wood may occur in structural wood, where houses suffer structural damage by insect attack, but also in precious wooden artefacts, such as frames of old paintings, wood paintings, wooden sculptures and carvings, and old altars in churches. Other species attack old skins and furs, and many other artefacts of historical interest in museums. Nearly all historical museums throughout the world are vulnerable to the ravages of the above groups of insects.

The classic way to approach this problem has been, and still is, the use of residual insecticides. In addition, fumigants such as methyl bromide (CH_3Br), hydrogen cyanide (HCN), and phosphine (PH_3) are employed in certain situations. Recent work in a few countries has focused on the possibility of replacing these toxic substances with non-toxic gases, such as nitrogen (N_2) and carbon dioxide (CO_2), by what is commonly termed "modified atmosphere (MA) fumigations" (Gilberg, 1989, 1990; Valentin, 1990; Valentin and Preusser, 1990; Frank, 1991; Reichmuth *et al.*, 1991).

To undertake an effective and cost-effective treatment, the inert gases must be applied to the objects to be treated during containment within a sufficiently gastight enclosure. The exposure period must allow for the displacement of O_2 even from within wood, or bales of textiles or furs, and for a period sufficient to kill all stages of pest insects by anoxia (using either 100% N_2 or CO_2) or hypercarbia (high-CO_2 concentrations). From the viewpoint of controlling insect infestations without affecting the quality of ancient artefacts, N_2 appears to be the superior choice, being completely inactive chemically. Application of CO_2 seems preferable in those cases where the risk of CO_2 becoming dissolved in water within the treated material and forming carbonic acid or carbonates is negligible. Apart from this minor disadvantage, the use of CO_2 often leads to complete control within a shorter time than the application of N_2 (Reichmuth, 1987).

In many museums and art galleries, where wood-damaging insects pose a permanent threat to the works of art, fumigation chambers or special rooms are available for control treatments. These facilities, employed at present for fumigation with toxic gases, can be easily adapted for the application of MAs thereby reducing the considerable amount of procedures required to ensure worker safety and prevent pollution. The economic factors of this alternative insect control method are determined mainly by the degree of gas tightness that can be achieved.

This study reports laboratory data obtained by Frank (1991) and field results of the response to N_2 treatment by different species and stages of wood and fabric insect pests. Using a new N_2 flushing technique, termed **N**itrogen-**F**low **F**umigation (**NFF**), treatments were carried out in fumigation chambers and in gastight plastic bags in a museum and a church. Test insects used in the treatments were: *Anobium punctatum*, *Anthrenus smirnovi*, *Anthrenus verbasci*, *Dermestes maculatus*, *Hylotrupes bajulus*, *Reticulitermes santonensis*, *Lasioderma serricorne*, *Lyctus brunneus*, *Tineola bisselliella*, and *Trogoderma angustum*.

MATERIALS AND METHODS

Laboratory Experiments

The sensitivity of different stages of *L. brunneus* to exposure to a 100% N_2 atmosphere (a) outside and (b) inside wood, was investigated in the laboratory of the Federal Biological Research Centre at 20°C (a), 25°C (a,b) and 28°C (a) (Frank, 1991).

a: Forty insects of each of the developmental stages larva, pupa and adult, that had been reared on artificial diets, were exposed to the MA of low-O_2 content for 1, 2, 5, 8, 13, 16, and 21 days, respectively.

b: Two weeks prior to exposure of the adult beetles, 3 kg pieces of oak wood (50 mm x 30 mm x 15 mm) were soaked for 2 hr in a solution of 400 g glucose and 80 g peptone in 4 l distilled water. After rinsing with water, the wood pieces were dried for 3 days at 37°C and then stored at 25°C and 75% relative humidity (r.h.). Sets of 5 males and females selected for equal size were exposed to pieces of wood to equate the number of progeny with pieces of wood. This wood was stored in glass bottles with insect-proof but non air-tight caps for 1, 4, 7, 10, and 13 weeks, respectively to incubate all developing stages for the N_2 treatments.

During the experiments, insects were placed either (a) on filter paper or (b) in the pieces of wood, in gas washing bottles. Other experiments were carried out similarly with individual larvae of *A. punctatum*, *T. angustum*, and *A. verbasci*.

The bottles were flushed with humidified N_2. The O_2 concentration was observed at the outlet of the bottles until it reached 0%. The sealed vessels were held in constant temperature rooms for the different exposure periods until they were re-opened. Survival of insects was recorded 6 months after the end of gas treatment and transfer of the samples to culture conditions. The number of emerging or surviving insects in untreated samples was taken as

100% survival and the mortality results after fumigation were calculated in relation to these figures as percent reduction of emergence (**PRE**).

Museum trials

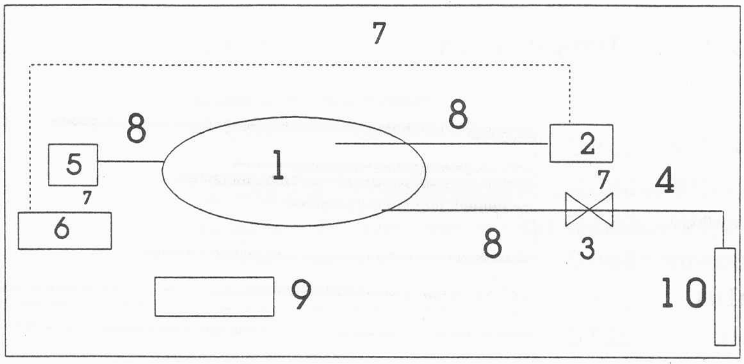
For treatments in the plastic bag or in the fumigation chamber in the museum, the developmental stages of *A. punctatum*, *H. bajulus*, and *R. santonensis* were placed in small pieces of pine-wood (50 mm x 25 mm x 15 mm) between two halves of wooden test blocks (250 mm x 100 mm x 70 mm) sealed together with silicon glue and placed next to infested altars and wooden carvings (Reichmuth, 1991). Adult beetles and developmental stages of *A. smirnovi*, *D. maculatus*, *L. serricorne*, *T. angustum*, developmental stages of *A. verbasci*, and eggs of *T. bisselliella* were placed in insect-tight cages and were inserted into the fumigation chamber prior to treatment with N_2.

The O_2 in the treated airspace was displaced by purging. The lethal gas composition (N_2 with less than 2% residual O_2) was maintained by holding a constant slight positive pressure of 10 Pa by purging with N_2. Due to this pressure difference, the surrounding air was not able to diffuse back into the treated space and any leakage of N_2 through apertures in the container was automatically compensated for. The r.h. in the treated space could be adjusted using saturated solutions of salt in water or by the regular addition of distilled water.

The system design of this NFF method is derived from stored-product pest control technology (Reichmuth, 1992), and is shown in Fig. 1. A recent further development combines the O_2 measuring device (#5) and the gas flow regulator (#2) in one unit that can also be designed to monitor and possibly control temperature and r.h., the last being a very important factor in the conservation of artefacts (Reichmuth *et al.*, 1991).

RESULTS AND DISCUSSION

Figure 2 shows mortality data for various insects and their stages at different temperatures after treatment with nitrogen, based on transformed data from Frank (1991), Reichmuth (1991), and field data. The laboratory data can be distinguished from field data by the asterisk preceding the name of the species. The mortality data from field treatments indicate where exposure periods were sufficient for complete insect control. Under some circumstances even a shorter N_2 treatment might be successful. As the wood-damaging insects were placed inside thick wooden blocks in the chamber, the data represent a rigorous test condition. As wooden sculptures and carvings rarely contain wood thicker than 10 cm, these results are quite representative. Whether this technique, developed by W. Unger, can be developed and used as a standard procedure for testing the efficacy of wood fumigation against insects is open to discussion.



1 : gastight plastic bag or fumigation chamber
2 : regulating unit (opens 3 at $p < 5$ Pa)
3 : regulated magnetic valve
4 : nitrogen supply (1 bar)
5 : oxygen measuring device
6 : registrating unit
7 : electric connection
8 : measuring connections (tubing and leads)
9 : room or chamber heating (regulated)
10 : nitrogen cylinder and regulator

Fig. 1: Nitrogen-Flow Fumigation system design.

A comparison of the exposure periods required to achieve 99% mortality (LT_{99} values) between larvae and pupae of *L. brunneus* within wood and those exposed outside the wood at 25°C (20 and 17 days, and 22 and 13 days, respectively) indicates the time necessary for the N_2 to displace O_2 in the wood. Pupae in wood were most difficult to control at 25°C with $LT_{99} = 22$ days.

The pronounced influence of temperature on the lethal exposure time can be derived clearly from the data for *L. brunneus, H. bajulus,* and *A. punctatum*. Reducing the temperature by 8°C (from 28-20°C) extends the lethal exposure time of surface-exposed larvae, pupae, and adults of *L. brunneus* by about 13, 5, and 6 days respectively. Temperature reduction by 19°C from 35-16°C leads to the prolongation of the lethal exposure period of *A. punctatum* and *H. bajulus* by about two weeks.

In laboratory experiments, the fabric pests *T. angustum* and *A. verbasci* were more susceptible to exposure to nitrogen or depletion of O_2 than were the tested wood-damaging insects. The tested insects did not survive the nitrogen treatment in the chamber at 22°C (Figs. 2 and 3), with the exception of *L. serricorne* that survived in all samples and one pupa of *H. bajulus*.

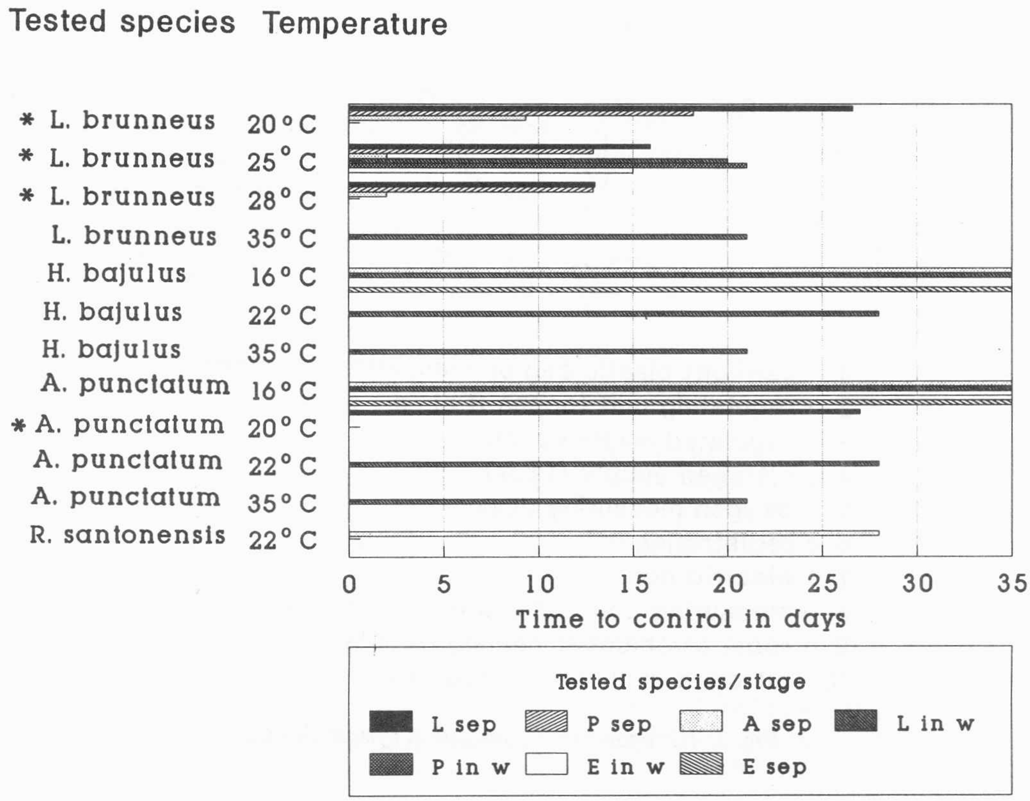


Fig. 2: Control of different stages of four insect pests of wood with N_2 enriched atmospheres and very low O_2 content at various temperatures (Laboratory data are marked with " * ". Genus : L = *Lyctus*; H = *Hylotrupes*; A = *Anobium*; R=*Reticulitermes*. Stage: E = Eggs; L = Larvae; P = Pupae; A = Adults; sep = separate; in w = in wood).

Adults and eggs of *L. serricorne* proved to be most tolerant to the NFF treatment. This coincides with experiences of high pressure treatment with CO_2 where *L. serricorne* was also very tolerant as compared with other stored-product insects (Gerard *et al.,* 1988). In several experiments it was established that not more than 3 times the volume of the treated space of N_2 is necessary to displace the air completely. The factor depended strongly on the shape of the treated materials and the possibility of even distribution within the enclosed volume. A small ventilator enhanced the distribution and reduced the required amount of N_2 to achieve residual O_2 contents of less than 1% by volume.

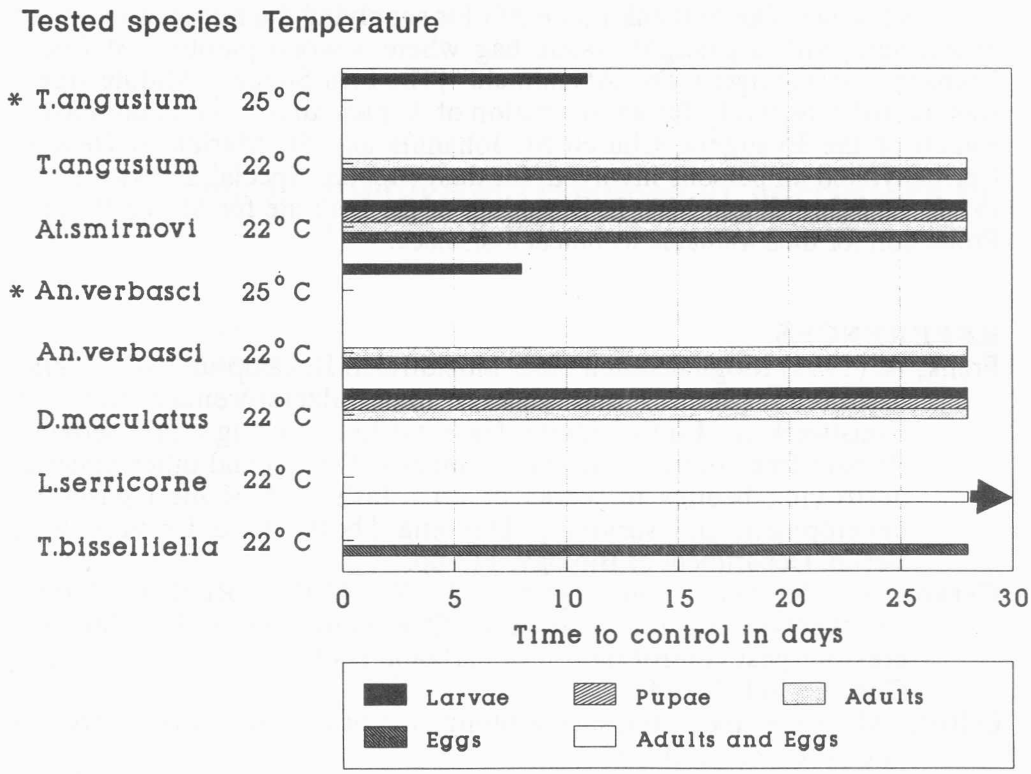


Fig. 3: Control of various fabric pests with N_2 enriched atmospheres and very low O_2 content (Laboratory data are marked with "*". Genus : T = *Trogoderma*; At =*Attagenus*; An = *Anthrenus*; D = *Dermestes*; L = *Lasioderma*; T = *Tineola* . The arrow indicates surviving eggs and adults of *L. serricorne* in all samples.)

CONCLUSION

The proposed method of displacing air in a sealed chamber or sealed bag by flushing continuously with nitrogen (possibly after slight evacuation prior to the treatment) offers a cost-effective and safe alternative to chemical control of insect pests of fabric and wood, especially in precious works of art. The flushing and maintenance technique ensures the effectiveness of the method even if the hermetic seal of the container is not complete. Provided a gastight enclosure is available, the method is very cheap and requires only a thorough initial flush (1-3 times the volume of the treated space). An apparatus to regulate low O_2 content, slight positive pressure difference, temperature, and r.h. within the treated space has been developed and can be purchased.

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