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ON-SITE PRODUCTION OF NITROGEN FOR STORED-PRODUCT DISINFESTATION

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ABSTRACT

Treatments with controlled atmospheres for the disinfestation of stored products are often quite costly. This is one of the reasons for the slow acceptance of this technique in commercial practice. Although the costs for structural sealing and treatment supervision cannot be easily reduced, the costs for gas supply, especially in areas remote from industrial gas production sites, could be cut using flexible on-site production systems.

To determine the feasibility of on-site production, a pressure-swing absorption unit (PSA) and a membrane system were tested under semi-practical and practical conditions. It was demonstrated that at about 20°C, a nitrogen (N_2) atmosphere with a residual oxygen (O_2) content of 0.5% in a gastight welded-steel silo bin was sufficient to control all stages of *Sitophilus granarius* in slightly over 6 weeks, and of both *Ephestia elutella* and *Oryzaephilus surinamensis* within 3 weeks. When N_2 with 0.5% residual O_2 and was introduced at a flow rate of 5 m^3/h from below into a 188-m^3 concrete silo bin loaded with grain, ingress of O_2 into the silo produced an O_2 concentration of 3% at the top.

It was concluded that membrane and PSA systems are valuable techniques for the on-site production of hypoxic atmospheres, but that the use of N_2 should be limited to well-sealed silo bins, containers or chambers. Such gastight seals could be achieved using metal sheets, plastic foils or gas-impermeable coatings.

INTRODUCTION

Controlled atmosphere (CA) treatments for the disinfestation of stored products and materials are considered environmentally friendly, residue-free and safe for workers in the surrounding area at doses up to 5,000 ppm for carbon dioxide (CO_2) or higher for nitrogen (N_2). In some fields of stored-product protection, CA's may partially replace toxic fumigants and contact insecticides. The use of CA's, however, is limited to highly gastight enclosures; otherwise, leakage renders the treatment uneconomical.

In contrast to the situation in Australia, as described by Banks *et al.* (1991), in Germany CA treatments with N_2 are not yet in practiced use for stored-product protection. Although sheds and bag-stacks are commonly fumigated with phosphine (and in rare cases with CO_2), N_2 has not yet been registered for use in these treatments. Even though N_2 has been registered for use in grain bins, so far store keepers have been reluctant to use this time-consuming and often rather costly technique. Only in museums are N_2 treatments for pest control of artefacts (display pieces) widely accepted and carried out. This is because the inert nature of this gas means that it does not affect valuable artifacts (Reichmuth *et al.*, 1993; Wudtke *et al.*, 1984).

In this study, a pressure-swing absorption unit (PSA) and a membrane system for the production of a CA (N_2 with low oxygen (O_2) content) from pressurized ambient air were tested under practical conditions for the disinfestation of stored grain in silo bins.

MATERIALS AND METHODS

The welded-steel silo bin used in parts of this study was located within the Institute's Berlin premises. It had a 2-m diameter and a 9-m height, providing a volume of 26 m^3; its holding capacity was 20.5 t of wheat. The silo bin, the PSA unit and the membrane system were located in a building the constant temperature of which was 20 ± 2°C. Grain temperature at the top of this silo was 22°C and at the bottom of the silo 18°C.

Testing the PSA unit

The PSA system was a "Micro 15" from Carbo Tech Co.[1] This apparatus has a maximum output of 1.5 m^3/h and was adjusted to produce N_2 with a residual O_2 content of 0.4–0.5%. The gas was used to fill a 50-L container to a pressure of 5 bar. When the pressure in the container fell below 4.5 bar, the PSA was activated. A pressure tight tube was used to connect the container to the silo bin through a gas inlet at the bottom. A lid was left open at the top of the silo during the first hours of purging. The O_2 content within the grain close to the lid was determined using a Servomex 750 A O_2 analyser. After the initial purge at 720 L/h, the flow rate was reduced to 15 L/h. This guaranteed a slightly increased pressure within the silo, preventing the backflush of O_2-containing air through minor leaks. The complete treatment lasted 49 d.

The test insects were *Ephestia elutella*, *Oryzaephilus surinamensis* and *Sitophilus granarius.* Small wire-mesh cages containing a mixture of eggs, larvae, pupae and adults of these species were placed in the silo bin at three different points (1, 5 and 9 m above the bottom). After exposure times of 3, 4, 5, 6 and 7 weeks, the insects were removed and incubated in a climatised chamber at 25°C/75% r.h. for a further 8 weeks. The insect samples were examined weekly for both emergence and adult mortality.

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[1] Mention of a trade name does not imply its recommendation.

Testing the membrane system

The membrane system, a "Prism Alpha" from Messer Griesheim Co., was supplied with pressurized air at 10 bar by a 11-kW compressor, and the air was dehumidified prior to being introduced into the system. Because only a small output was needed, only one of the two membrane compartments was used. The N_2 gas was stored in a 500-L container at pressures of 6–10 bar. Gas was released at 1 bar. When the pressure in the container fell below 6 bar, due to gas consumption, the compressor was activated. The residual O_2 content depended on the gas flow rate; 1% O_2 was obtained when the compressor ran about 60% of the time. The silo was purged from below, and O_2 content was measured at the top. Cages containing eggs, larvae, pupae or adults of *S. granarius* were placed in the silo bin and exposed to the gas for 2, 3, 4, 5 and 6 weeks.

The same membrane unit was also tested in a field trial using a 188-m^3 concrete silo bin loaded with 131 t of barley. Fifty 1-L metal cans with wire mesh lids at top and bottom, containing insect cages with *E. kuehniella*, *O. surinamensis*, *S. granarius* and *Tribolium castaneum* had been placed in the grain when the bin was filled. Measurement prior to treatment determined that the pressure half-life was $Pt/2 \geq 30$ sec. The silo was purged from below with N_2 and 0.5% O_2 at a flow rate of 5 m^3/h for 6 weeks and then at a flow rate of 6.5 m^3/h for an additional 2 weeks.

RESULTS AND DISCUSSION

With the PSA unit, after purging the silo bin for approximately 10 h, a residual content of 0.4–0.5% O_2 was achieved at the silo top. All juvenile stages of *E. elutella* and *O. surinamensis* were controlled within the shortest exposure time (3 weeks). To achieve 100% mortality of all stages of the granary weevil 6 weeks exposure was required. This is comparable to the results of earlier CA treatments of these silo bins with N_2 from cylinders (Adler and Reichmuth, 1989).

The results achieved with the membrane system in the same steel silo bin were similar. The complete control of *S. granarius* egg stages within 2 weeks of exposure was striking, especially in comparison to treatments with N_2 from cylinders. It is difficult to explain this effect unless it was caused by desiccation caused by the high gas-flow rates. Six weeks were insufficient for complete control of pupal stages (Fig. 1). The five survivors from two samples, compared to 126 survivors in the untreated control samples, indicate that 7 weeks of exposure would have been sufficient to achieve 100% mortality in this stage. More survivors were found in the sample placed at the bottom of the silo bin than in that at the top. This may be explained by the protective effects of the lower grain temperature at the bottom.

In the concrete bin, at a flow rate of 5 m^3/h (membrane system), O_2 content of approximately 3% was measured close to the silo top. Increasing the flow rate to 6.5 m^3/h after 6 weeks reduced the residual O_2 content at the lid of the silo to 1.8% (Fig. 2). Control of most insect species in the samples was far from complete. This could be partly attributed to grain temperatures at the surface dropping from approximately 20°C to 12°C

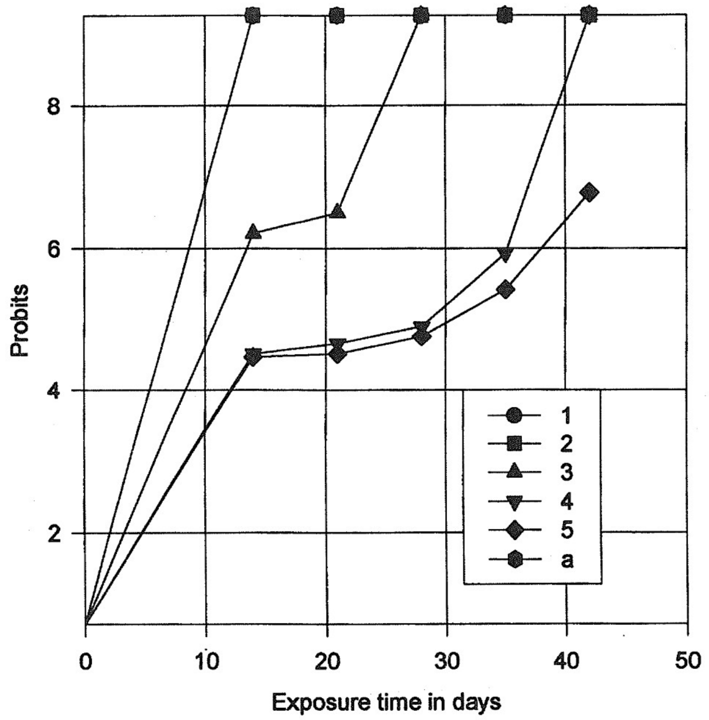

Fig. 1. Response of developing stages of the granary weevil *Sitophilus granarius* (a = adults, 1 = eggs, 2 = young larvae, 3 = larvae, 4 = older larvae, 5 = pupae) to treatment with N_2 from a membrane unit containing a residual O_2 content of 1% at 20°C in a welded steel grain silo bin.

during this time (Fig. 2), but even more to a significant ingress of atmospheric O_2 due either to diffusion or to a leak during the experiment. Since granary weevils survived in the probe close to the silo grain outlet spout, situated below the N_2 inlet, but were controlled in the samples above that point, there may have been a leaky spot in this region.

Running costs of these expensive devices are mainly linked to the cost and consumption of electricity, which is fairly cheap. This technique may therefore be considered for use even in leaky structures, as with fruit storage, overcoming the backflush of air by increased purge. If the structure must be treated several times, or if the sealing procedure is not too expensive, thorough sealing may make this technique more economically feasible. Seals to achieve a high degree of gastightness could consist of metal sheets, plastic foils or gas-impermeable coatings. For large grain storages or warehouses, these systems may be more convenient and more cost-efficient than supplying N_2 by cylinders or tanks (Table 1). The cost aspects are also discussed by Love (1984). Figure 3 illustrates cost-effectiveness in the form of a model. With no seal (0%) there are no sealing costs, but purge costs are prohibitive. With 100% gastightness, only one replacement of the air is

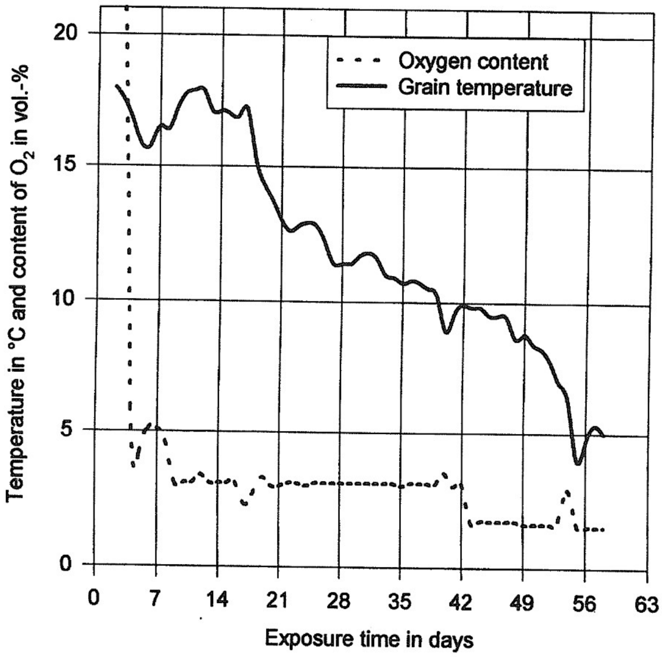

Fig. 2. O_2 content and grain temperature at the grain surface of a concrete silo during treatment with N_2 containing 0.5% O_2 from a membrane unit.

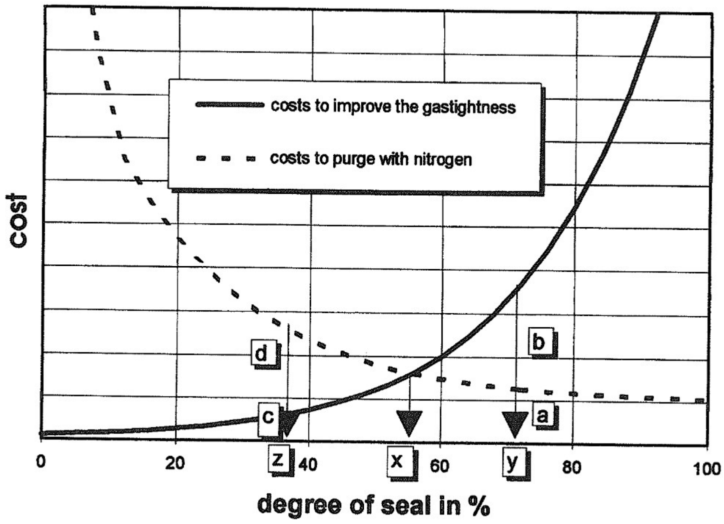

Fig. 3. Model showing the inter-dependency between the degree of seal and the costs of the purge necessary to achieve a low-O_2 atmosphere inside a treated enclosure, and also showing the costs of improving the gastightness of a structure in order to treat it effectively with N_2. The letters a, b, c and d represent costs in any currency unit.

TABLE 1
Approximate costs in Germany for supplying nitrogen for CA treatments

System used	Gas flow rate ($m^3 h^{-1}$)	Rent/year[1] (DM)	Operating costs (DM m^{-3})
Cylinders	0.001–10	180	3.00–3.50
Liquid tanks	1–100	6,000–34,000	0.20–2.50
Membrane or PSA	1–10	6,000–14,000	0.55–1.50
	10–20	20,000–25,000	0.35–0.45
	20–50	50,000–60,000	0.19–0.25
	50–100	60,000–70,000	0.14–0.18
	100–500	150,000–200,000	0.08–0.12

[1] Assuming a 10-year contract and electricity costs of 0.15 DM kWh^{-1}.

required; this is relatively inexpensive but only works effectively in an absolutely gastight structure. For better sealing beyond point x, e.g. at point y, it is more cost-effective to purge with N_2 instead of using the more expensive sealing procedures (a + b). The net saving is the cost of b. At point z it is more effective to seal than to compensate for leakage from the structure with increased N_2 purging. The saving resulting from sealing, quantified as d, can be compared with the costs of the purge, represented by c + d. Point x indicates the break-even point.

In conclusion, both the membrane and PSA units can be regarded as useful devices in providing N_2 for stored-product protection purposes.

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