THE USE OF A SELF-COOLED EXOTHERMIC CONTROLLED ATMOSPHERE GENERATOR TO PROVIDE A MEANS OF CONTROLLING INSECT PESTS IN GRAIN

C.H. BELL, B.E. LLEWELLIN, B. SAMI*, B. CHAKRABARTI AND K.A. MILLS

ADAS Central Science Laboratory, Ministry of Agriculture, Fisheries and Food, London Road, Slough, SL3 7HJ
* The Aerogen Company Ltd, Newman Lane, Alton, Hants, UK

Abstract

Atmospheres produced by the combustion of hydrocarbon fuels and containing 10-14% carbon dioxide, less than 1% oxygen with a balance of deoxygenated air, have been shown to be effective in controlling insect pests of stored products. Adult beetles are killed by exposures of 3-4 weeks at 10°C shortening to a few days at 25°C. Immature stages require much longer periods for control but tend not to be able to complete development when commodities are cooled below 15°C.

A gas generator fuelled by propane and featuring a cooling system powered off the combustion chamber, a preadjusted fuel to air ratio and an automatic safety system has recently been developed in the UK and has been tested under various conditions to purge and maintain a lethal atmosphere in loaded grain bins. Trials with a first prototype demonstrated the advantage in increasing the rate of gas flow in improving the purging efficiency.

Using a second prototype, a typical bolted metal bin loaded with 180 tonnes of milling wheat sealed only by sheeting the grain surface and blanking off the auger system was brought to below 1% oxygen at most points with just over 5 atmosphere changes, purging at the rate of 10.5 cu m per h.

The low oxygen atmosphere was maintained by 1.2-2.0 atmosphere changes per day, depending on wind conditions. Results of the effect of the cycling but generally low oxygen concentrations on survival of test insects in the trial proved comparable with data obtained in earlier laboratory investigations. Costs for a 4-week exposure to the atmosphere, based on fuel costs, were less than £1.50 per tonne of grain.

Introduction

The last decade has seen a steady increase in interest in the use of controlled atmospheres as a means of controlling infestations of insects in grain. More recently this interest has been enhanced by the increasing awareness of toxic side effects arising from the use of chemicals, particularly those that have enjoyed long term usage, and by the demands from consumers and society in general for significant reductions in the use of pesticides. There is currently public suspicion of any chemical of a persistent nature whether or not evidence is available of any adverse side effects, and the prophylactic use of pesticides to protect crops may soon carry financial implications for trading, because of the desire for residue-free foods.

Limitations that have prevented the more widespread adoption of controlled atmosphere techniques are the long exposure times required for control of pests, the belief that treatment costs will prove to be high, the apparent lack of specialist equipment for providing suitable gas, and a lack of technical expertise in setting up the precise arrangements for physically applying the gas to the store. There is a need firstly to achieve the complete replacement of air during the initial purge, and secondly to successfully maintain the new atmosphere for the period necessary for pests to be killed. Because few existing structures are gas tight, it has long been realized that continuous flow systems offer the only practicable method for treatment.

For a number of years research at Slough has been addressed to the problems of gas application methods and to the development of a suitable gas generating device. Early trials in the USA by Storey (1973; 1975a; b; 1980) demonstrated the effectiveness of an exothermic exhaust gas generator in controlling a range of stored product pests. The device was fuelled by natural gas and was capable of an output of about 2.8 cu m per hour. The exhaust contained about 9.5% carbon dioxide,less than 1% oxygen with the balance mostly as nitrogen. More recently trials in the US centred on a propane-fuelled generator which has now been developed commercially. Trials in France with a permanently installed propane burner at a harbour silo have also demonstrated that potential exists in the use of such atmospheres for insect control (Fleurat Lessard and Fuzeau, 1984; Fleurat Lessard and Le Torc'h, 1987).

For the UK grain industry, with the withdrawal of the old liquid fumigants long relied on for control, the need for a reliable non-chemical method was apparent, but in spite of the pioneering work done in the USA and France no suitable instrument was available for purchase by farmers, grain store managers or pest control companies. Hence the current programme was started as a joint venture between the Central Science Laboratory at Slough and The Aerogen Company Limited to develop a transportable propane-fuelled burner device that could be used to treat grain held in a wide variety of situations, and to establish the parameters necessary for its successful use.

Materials and methods

THE GENERATION OF GAS

Two prototype generators have been tested during the experimental programme. Both incorporated an open flame burner unit in a closed vessel with fan assistance to reduce back pressure and with a self-regulating fuel and air supply. The first prototype was primarily air-cooled but required an improvised mains water cooling system to keep temperature levels below 30°C and to reduce the amount of moisture carried to the silo inlet. With an output of about 3 cu m per h of exhaust gas, temperatures at the silo inlet remained within 1°C of ambient. Doubling the output increased gas temperatures to about 15°C above ambient, and led to the deposition of moisture at the bottom of the silo.

The second prototype was cooled by an ammonia solution refrigeration circuit linked to a water and glycol heat exchanger. The efficiency of the cooling was so high that exhaust gas was produced at several degrees below ambient. The maximum output of the machine was 17 cu m per h. Both machines featured an ignition and cut out safety cycle to guard against overheating of the combustion chamber assembly and the risk of explosion.

ON-SITE EXPERIMENTAL TREATMENTS

Pilot scale trials at the Laboratory were conducted in welded steel bins of 19 cu m capacity held on metal supports under cover in a barn, and featuring a hopper base for unloading. Gas sampling lines at 1 m intervals and a central thermocouple were attached to a steel cable run from inside the hopper to the bin apex. Each bin was then loaded with 12 tonnes feed wheat.

These bins were relatively gas tight and the gas tightness was adjustable for experimental purposes by alteration of the degree of seal at the 3 cm apical port through which the gas sampling lines and thermocouple were fed out of the bin. For the current tests a pressure test half life of 2.5 min was obtained, as in previous tests with a simulated burner gas atmosphere (Bell, 1987). Gas was introduced at flow rates ranging from 3-6 cu m per h via a 15cm aeration port in the side of the hopper and using a modified plate to receive the 5 cm dia flexible outlet hose of the generator. The progress of gas through the silo was monitored using a paramagnetic oxygen analyser and an infrared carbon dioxide analyser, both manufactured by Servomex Ltd. Most trials in these bins were conducted with the first prototype burner.

TRIAL IN A TYPICAL BOLTED METAL FARM BIN

For this experiment, conducted in May, a farm bin containing 180 tonnes of wheat cv Avalon dried to about 14% moisture content was selected. The bin was free-standing but featured a permanently installed auger leading to an adjacent barn. A 2.5 inch (6.5cm) port was present at the base for aeration purposes and this was modified to receive the flexible hose outlet of the second prototype burner. For the treatment, the auger was uncoupled near the barn and sealed with polythene. Working on the grain surface, nylon gas sampling lines of 2mm bore, thermocouples and caged laboratory samples of 100 adults of two beetle species, *Sitophilus granarius* (L.) and *Cryptolestes ferrugineus* (Stephens), were inserted in pairs at 1 m intervals down to 4 m depth in the grain at the bin centre and at the side near the access hatch. Control samples were inserted in an adjacent bin. The grain surface was then sheeted over with polythene which was tucked into the grain at the sides.

The gas generator was started and the product gas was monitored to ensure that oxygen levels were well below 1% and that carbon dioxide levels exceeded 12%. The connection to the silo was then opened and purging commenced at the rate of 8 cu m gas per h. This was later increased to 10.5 cu m per h and thereafter, on achieving the replacement of the atmosphere, the flow rate was repeatedly adjusted to ascertain the level of input required for maintenance of less than 1% oxygen throughout the grain.

After 14 days operation, the burner was switched off and the disappearance of the applied atmosphere was monitored over 24 hours before unsheeting and removing lines and insect samples. At the laboratory, insect samples were examined for survival after 14 days.

Results

PILOT SCALE TRIALS IN 19 cu m WELDED STEEL BINS

Cooling of the exhaust gas proved a problem at higher flow rates but purging of the bin atmosphere to less than 1% oxygen was accomplished with only 1.9 atmosphere changes in just over 3 hours at 5.9 cu m gas per h (99 litres per min), compared with 4.4 atmosphere changes at half this flow rate (Table 1). Oxygen levels were brought below 2% with only 1.2 atmosphere changes at the higher flow rate, compared with 1.3 changes at 49 litres per min (3 cu m per h) and 1.5 changes at 5 litres per min with gas fed from cylinders via a gas blender.

TRIAL TREATMENT OF 180 TONNES OF WHEAT IN A FARM BIN

The grain surface within the bin formed a shallow cone so that the grain depth reduced from nearly 6 m at the central apex to just over 4m at the sides. During the initial stages of introducing gas, billowing of the sheet over the grain surface was observed and a slit was cut in the sheet near the apex to allow the atmosphere to vent freely. The gas flow rate was then increased to 10.5 cu m per h and with the exception of the region near the apical slit, oxygen levels fell to 1% or below throughout the bin within the next two days (Table II). The temperature of the exhaust gas released from the burner was 6-12°C below the ambient temperatures of around 20°C. Assuming an interstitial volume of just over 100 cu m, based on 45% of the stowage volume for 180 tonnes of wheat (225 cu m), oxygen levels were brought to 1% by 5.2 atmosphere changes. Wind speeds ranged from 0.5 to 1.5 m per sec during the purge.

Following some stoppages of flow caused by interruptions in the power supply, the bin was repurged at flow rates of up to 16 cu m per h and was then held under lower gas flow rates to find the input necessary for maintenance. Under calm conditions a flow rate of 5-6 cu m per h was sufficient to keep down oxygen levels but in windspeeds of only 1-2 m per sec the input needed to be increased to 8 cu m per h. Thus the applied atmosphere could be maintained in low winds by about 2 atmosphere changes a day. For 180 tonnes of grain, this represents a daily consumption of 17 kg propane. At many points, oxygen levels fell to rather less than the burner output, indicating some microbiological activity. In contrast, carbon dioxide levels persistently remained below the burner output level until after the first week when further interruptions in the power supply temporarily disrupted both the performance of the burner and the distribution of gas in the bin (Table III).

Because the trial did not extend beyond a 15-day period, test insects were not all killed. Their survival pattern reflected the conditions which prevailed during the trial. Laboratory studies have demonstrated that at stable concentrations adults of both *C. ferrugineus* and *S. granarius* require 6-7 days exposure at 20°C (Krishnamurthy et al, 1986) but at no position in the bin did oxygen levels remain below 2% for more than 10 days (Table IV). Complete kill of both species was obtained at the 2m depth side position where oxygen levels were below 2% for a total of 9 days at 17°C. As can be inferred from Table III, at this position and at the 4m depth positions at side and centre, oxygen levels in fact remained below 1% for much of the time, thus accounting for the high levels of kill obtained.

Table 1

Times and atmosphere replacement rates to reduce oxygen levels below 2 or 1% during the purging of small welded grain bins with burner gas

Flow rate (L/min)	Temperature at silo inlet (°C above ambient)	2% O_2 Time (h)	2% O_2 Atmosphere change rate	1% O_2 Time (h)	1% O_2 Atmosphere change rate
5*	0	51	1.5	-	-
49	1	4.5	1.3	15	4.4
99	15	2.0	1.2	3.2	1.9

* Gas supplied from cylinders by a blender

TABLE II

Relationship between gas flow rate and oxygen concentration at different points during the purging of a 180 tonne bin of wheat with burner gas

Hours after start of purge	Gas input rate (l/min)	Oxygen (%) at sampling line positions: Side at bottom	Centre, 2m from bottom	Side, 2m from bottom	Centre 4m from bottom	Side, at surface (4m from bottom)
0	Set to 132	-	20.4	-	-	20.8
6	132	2.7	9.5	16.5	19.5	18.5
9	132→176	0.5	4.8	5.2	19.2	11.8
28	176	-	3.7	-	15.5	-
52	176	0.2	0.4	0.3	1.0	0.2

Table III

Oxygen and carbon dioxide levels at a range of positions during the second purge and subsequent maintenance phase of a burner exhaust gas treatment of 180 tonnes of milling wheat in a farm grain bin.

Hours after the start of the treatment	Burner output: Flow rate (m^3/h)	Burner output: %O_2	Burner output: %CO_2	Sampling line position: Centre 4m depth (2m from bottom) O_2/CO_2	Centre 2m depth O_2/CO_2	Centre 0.5m depth O_2/CO_2	Side 4m depth (bottom) O_2/CO_2	Side 2m depth O_2/CO_2	Side 0.5m depth O_2/CO_2
52	10.5	0.4	12.4	0.4/11.8	1.0/10.3	2.8/ 7.9	0.2/12.2	0.3/11.8	0.3/11.6
91	0	-	-	- /12.1	- / 9.7	- / 9.0	- /12.2	- /12.0	- /11.8
97	0	-	-	- / 3.9	- / 5.8	- /10.0	- / 4.8	- / 4.7	- / 4.4
150 (after 24h at high flow rates)	8	0.7	12.6	0.6/12.2	1.0/11.4	2.1/ 9.8	0.7/12.4	0.7/12.2	0.7/12.2
173 (in low winds)	8	0.5	12.8	0.3/12.4	0.5/11.6	1.0/10.2	0.2/12.5	0.2/12.4	0.2/12.2
270 (following power cut and repurging at 8 -11 m^3/h)	5.3	1.0	11.3	0.8/11.8	0.8/11.5	1.0/11.0	1.0/11.8	0.6/12.0	0.6/12.0
292 (in low winds, 1-2m/sec)	5.3	0.8	11.5	1.2/11.5	1.1/10.7	2.5/ 6.7	0.9/ 9.2	0.9/11.0	1.0/11.2

Table IV

Mortality of adult *Sitophilus granarius* and *Cryptolestes ferrugineus* exposed to burner gas in a bin containing 180 tonnes of wheat.

Sample position and depth (m)	Days below 2% O_2	Mean temp. (°C)	*Sitophilus granarius* (% kill)	*Cryptolestes ferrugineus* (% kill)
Centre 4m	10	11	99	100
Centre 2m	7	13	91	100
Centre surface	3	15	13	56
Side 4m	10	16	99	100
Side 2m	9	17	100	100
Side surface	8	20	91	89
Controls	0	12	9	30

Discussion

Results from the pilot scale trials with burner gas illustrated that as with pure carbon dioxide, the efficiency of the purge increases with the rate of application of gas. Both prototype gas generators were able to deliver gas of appropriate composition for insect control in foodstuffs over a wide operational range of flow rates, although the first prototype was limited by temperature as flows were increased.

The experiment with the 180 tonne capacity farm bin illustrated that no special preparations beyond those performed for fumigation were necessary for the successful use of a controlled atmosphere treatment to kill insects in grain. The self-cooled gas generator was capable of producing a sufficient supply of gas for extended periods at a temperature several degrees below ambient, and the strategy of continuously introducing gas was able to prevent any localised areas of intermittently high oxygen levels occurring in the bulk.

The grain, at an average moisture content of 14% and with mean temperatures ranging from 11 to 20°C, contributed to the modified atmosphere obtained by removing both oxygen and carbon dioxide from the generator exhaust gas, the former probably by microbial activity and the latter by physical sorption. A similar result was obtained with grain above 14.5% moisture content at 13-18°C in earlier trials in the welded steel bins with simulated burner gas (Bell, 1987).

A critical factor in determining the gas flow required to hold an applied atmosphere was wind speed. The smaller the structure the more critical this factor becomes because of the ratio betwen volume and surface area. For every doubling of volume in structures of similar shape, surface area increases by a factor of less than 1.6, and hence the potential rate of leakage, assuming a similar distribution of small multiple leak sources, is reduced by over 20%. Thus the cost of treatment per tonne of grain is likely to reduce as the size of the grain bulk is increased. For the 150 tonne bin tested here, the cost of the propane required for a treatment to control all stages of most common pests would be between £1.30 and £1.50 per tonne of grain, based on a minimum of 4 weeks exposure to less than 1% oxygen and over 10% carbon dioxide. These costs are comparable with the current costs payable for fumigation.

References

Bell, C.H. (1987) Treatment of grain with low oxygen atmospheres containing carbon dioxide. In Stored Products Pest Control, ed. T. J. Lawson, BPCA Monograph No.37, pp. 237-246.

Fleurat Lessard, F. and Fuzeau, B. (1984) Disinfestation of wheat in a harbour silo bin with an exothermic inert gas generator. Proc. 3rd Internat. Wkg Conf. Stored-Prod. Ent., Manhattan, Kansas, 1983, KSU 1984, pp. 481-485.

Fleurat Lessard, F. and Le Torc'h, J. M. (1987) Practical approach to purging grain with low oxygen atmosphere for disinfestation of large wheat bins against the granary weevil *Sitophilus granarius*. Proc. 4th Internat. Wkg Conf. Stored Prod. Prot., Tel Aviv, 1986, ed. E. Donahaye and S. Navarro, Maor-Wallach Press, Jerusalem, pp. 208-217.

Krishnamurthy, T. S., Spratt, E. C. and Bell, C. H. (1986) The toxicity of carbon dioxide to adult beetles in low oxygen atmospheres. J. stored Prod. Res. **22**, 145-151.

Storey, C. L. (1973) Exothermic inert-atmosphere generators for control of insects in stored wheat. J. econ. Ent. **66**, 511-514.

Storey, C.L. (1975a) Mortality of adult stored-product insects in atmosphere produced by an exothermic inert atmosphere generator. J. econ. Ent. **68**, 316-318.

Storey, C. L. (1975b) Mortality of three stored-product moths in atmospheres produced by an exothermic inert atmosphere generator. J. econ. Ent. **68**, 736-738.

Storey, C. L. (1980a) Mortality of various stored product insects in low oxygen atmospheres produced by an exothermnic inert atmosphere generator. In Controlled Atmospheres Storage of Grains, ed. J. Shejbal, Developments in Agricultural Engineering 1, Elsevier, Amsterdam, Oxford and New York, pp. 85-92.

UTILISATION D'UN GENERATEUR D'ATMOSPHERES EXOTHERMIQUES A AUTO-REFROIDISSEMENT COMME MOYEN DE LUTTE CONTRE LES INSECTES RAVAGEURS

C.H. BELL, B. CHAKRABARTI, B.E. LLEWELLIN et B. SAMI (1)

(1) The Aerogem Company Limited
Newman Lane, Alton, Hampshire, U.K.
ADAS Central Science Laboratory
London Road, Slough, Berks SL3 7HJ, U.K.

RESUME

On a montré l'efficacité dans la lutte contre les insectes ravageurs des produits stockés, des atmosphères produites à partir de la combustion d'hydrocarbures et contenant 10 à 14 % de dioxyde de carbone, environ 1 % d'oxygène avec un équilibre en air désoxygéné. Les coléoptères adultes sont tués s'ils sont exposés à de telles atmosphères pendant trois à quatre semaines à 10° C, durée pouvant être réduite à quelques jours à 25° C, bien que les stades immatures de l'insecte exigent des durées plus longues, particulièrement à température plus basse, pour être éliminés. Au Royaume-Uni, un générateur de gaz conçu pour avoir un taux d'émission variable et couplé à un système de refroidissement actionné à l'extérieur de la chambre de combustion, a récemment été développé et testé à différents régimes de fonctionnement. Il comprend des dispositifs automatiques de mise en marche intermittente et continue, à un taux de courant réglé pour entretenir l'atmosphère d'une cellule pleine. On compare les résultats des études en milieu agricole aux études de laboratoire sur l'effet des concentrations en oxygène cycliques mais basses pour la survie de l'insecte.