Fumigation of a 7000 t bulk of wheat with phosphine using the Phyto-Explo[1] system to assist gas circulation

B. Chakrabarti*, C. R. Watson†, C. H. Bell*, T. J. Wontner-Smith*and J. Rogerson†

Abstract

A 7000 t bulk of wheat in an improvised store was treated with phosphine at the rate of 1.9 g/t following the sinking of three pairs of temporary shafts into the grain using the Phyto-Explo pneumatic hammer device. Each pair of shafts was linked via plastic (land drainage) piping to a fan which was operated for the first four days after dosing to push air through the shafts and assist gas distribution.

After 12 days a further 0.5 g phosphine/t was added adjacent to the foremost fan and to the ventilation ducts opening at the rear of the store, bringing the total dosage to 2.4 g/t, still substantially less than the normal recommended dosage of 3–5 g/t for floor-stored grain.

Apart from one corner in the direct path of the wind, where concentrations were held down, and one sample point giving high readings near a dosing position, concentration–time products after 15 days did not vary by more than a factor of 3, ranging from 88 to 249 g.hours/L. Such dosages would achieve a very high level of control of storage insects over this timescale, even at low temperature.

Introduction

Cereal grain grown in U.K. is stored on farms, in bins from 100–300 t capacity and floor-stores of 200–800 t. Deep silo bins of 250–2000 t and floor-stores from 500–60000 t capacity are used by grain merchants and for the storage of grain by the Intervention Board. Purpose-built floor-stores are a comparatively recent development. None of these structures is designed for gas retention. Often a building constructed for a quite different purpose is used for grain storage. Aircraft hangars or old munitions factories are examples of buildings used for bulk grain storage. They have many disadvantages. Internal stanchions are often present at regular intervals throughout the building and create problems in covering the grain surface for fumigation.

The treatment of grain in ships' holds in transit between one country and another is also widely practised and offers further problems in achieving adequate distribution of gas throughout grain depths of up to 30 m (Redlinger et al. 1979, 1982). For bulk commodities such as grain, oilseeds etc. phosphine is now the most commonly used fumigant worldwide. If the structure is reasonably gastight, a successful fumigation, though dependent on various factors, i.e. temperature, sorption, gas distribution, weather conditions etc., should destroy all the target pests including pre-adult stages.

Due to the diverse nature of storage structures, each storage facility demands a different approach to dosing and there may be further problems in achieving and maintaining an adequate concentration of phosphine over the period necessary for the control of insects. Using standard sealing methods it is difficult to maintain phosphine concentrations above the minimum level for effective action for the 16 days required at temperatures below 15°C to control all stages of *Sitophilus granarius* (L.), the most phosphine-tolerant species of the common grain pests (Anon 1984; Hole et al. 1976). Also, in a large bulk of floor-stored grain, phosphine concentrations tend to build up slowly at deeper levels. It is very common for a small upward draught in a bulk of grain to be apparent during treatments. Although it has been claimed by the manufacturers of aluminium phosphide preparations that phosphine travels 3 m/day up to 20 m deep in a grain silo, in practice this hardly ever seems to be achieved. To enable a successful treatment to be carried out, infested grain would have to be turned from one bin to another while phosphide preparations are being added, and to retain phosphine for the requisite period, every effort is necessary to seal the bin top, bottom and all the cracks and crevices in the sides. This practice for bin fumigation is, however, no longer encouraged due mainly to the high concentrations of phosphine that can rapidly develop in parts of the workplace during application, and the powdery residues that remain in the grain.

A novel method of dosing has been developed by 'Desinsectisation Moderne' for use in deeper grain bulks (tall silos, ship's holds etc.). The process is called the Phyto-Explo System and is a patented method for the introduction, distribution and maintenance of phosphine or any other fumigant in bulk cereals (Vacquer and Vacquer 1991). This technique has been investigated in recent trials in the U.K.

Experimental

In the Phyto-Explo process an expandable, corrugated shaft of about 63 mm diameter, wholly or partially perforated, is slid over a metal pipe and fitted to a metal probe which is introduced into the grain using a pneumatic hammer. When it reaches the desired depth, the probe is withdrawn leaving the shaft expanded in position (Fig. 1). Aluminium phosphide tablets or pellets are put in dust-retaining nylon socks and introduced into the shaft. Phosphine generated in the shaft spreads in the grain mass through the perforations in the shaft and, if the seal is adequate, will spread evenly throughout the bulk. For a large bulk of grain in a floor-store, a number of shafts in a matrix may assist distribution (Igrox 1993). A further refinement has been the use of fans to draw phosphine

[1] Phyto-Explo® is the registered trade name and patented system of Desinsectisation Moderne (D.M.) France, 34 Rue du Contrat Social, Rouen 76000, France.

* Central Science Laboratory, Ministry of Agriculture, Fisheries and Food, London Road, Slough, Berks SL3 7HJ, U.K.

† Igrox Ltd, White Hall, Worlingworth, Woodbridge, Suffolk IP13 7HW, U.K.

generated on the surface into the grain mass, with the objective of achieving a more rapid and even distribution of gas.

In a recent trial, a 7000 t bulk of wheat in a floor-store was treated with phosphine using the Phyto-Explo system. The grain bulk was contained by corrugated iron walls on three sides, sloping down to the floor at the front. There did not appear to be any sealant at the joints, and the walls were far from gastight. The outer wall of the store was constructed of corrugated aluminium sheeting and there was a gap of 0.5 m from the grain retaining walls. The surface of the bulk was very uneven with several peaks and troughs and the depths of grain ranged from 3–8 m.

Altogether 6 shafts were introduced into the grain from the surface, each with only the bottom half metre perforated, 4 in the front half and the other 2 in the back half of the grain. Each shaft was positioned halfway between the wall and the centre of the store (Fig. 2). The shafts were linked in pairs to a fan with the air-inlet attached to a perforated suction pipe laid along the ridge of the grain under the sheeting.

The grain mass was dosed along the centre of the ridge with 'Detia' bag-chains at the rate of about 1.9 g of phosphine/t of grain, and was covered with 150 micron polythene sheeting with the fans underneath. The edges of the sheeting were buried under the grain all the way round and joints were rolled and then stapled together.

After dosing, the use of the fans to inject phosphine was continued for 4 days and the gas concentrations were monitored on-line from 23 positions using a Hewlett Packard 5880 gas chromatograph fitted with a flame-photometric detector and housed in a purpose-built mobile laboratory. The sheeting near the ridge of the bulk was slit open after 12 days and an additional dose of about 0.5 g/t was introduced to the area adjacent to the four shafts near the slope, and to the ventilation ducts at the rear of the store to extend the treatment period. Then the bulk was resealed, the fans connected to the four shafts were switched on and the test was continued up to 15 days.

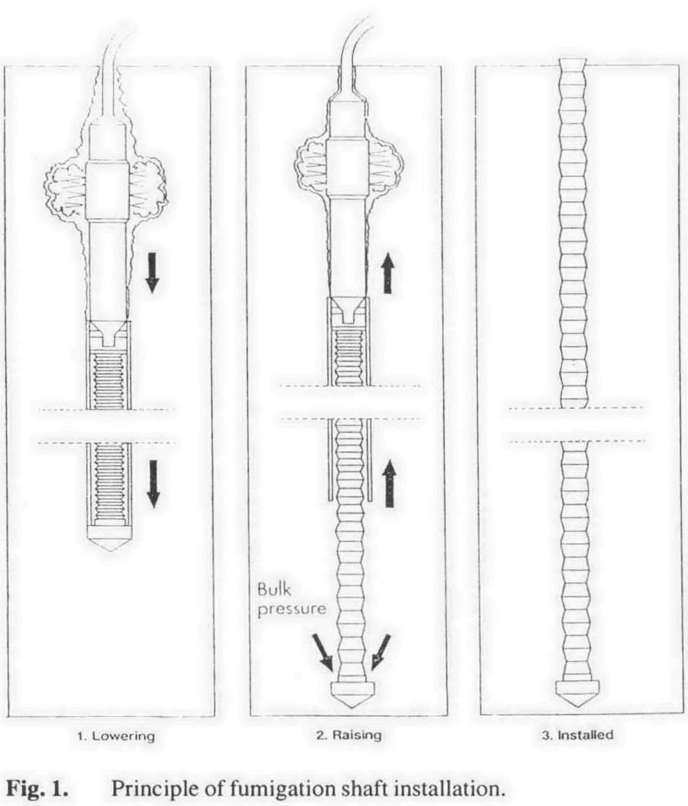

Fig. 1. Principle of fumigation shaft installation.

The results obtained were compared with those obtained in an earlier program investigating application methods for fumigating grain with phosphine (Bell et al. 1991).

Results

A typical data set for concentration–time (*CT*) products of phosphine obtained from fumigating a small bulk of grain are presented in Table 1. In spite of dosing both at the grain surface and below the bulk in the ventilation ducts, the gas concentrations and *CT*s obtained varied widely.

A very different result was obtained in the treatment of the larger bulk using the Phyto-Explo system where some gas circulation was provided by fans and the pattern of sunken shafts. In spite of the surface dosing method, concentrations of phosphine were generally lower near the surface. However, the distribution of phosphine throughout the bulk occurred rapidly, concentrations ranging from 6×10^{-4} g/m^3 to 3.8 g/m^3 within 10 hours and reaching at all points a threshold level of 0.05 mg/L within 15 hours. By 55 hours the phosphine level ranged between 0.5 g/m^3 and 2.5 g/m^3. After 8 days, phosphine levels at positions near the windward edge of the store started dropping below the threshold level. In normal circumstances, redosing would occur after 7 days. In this case, to create a worst case scenario and to see how long phosphine would remain within the bulk without further dosing, fumigation was continued and redosing was carried out only on the 12th day when the levels of gas at most positions had dropped below or near the threshold (Table 2).

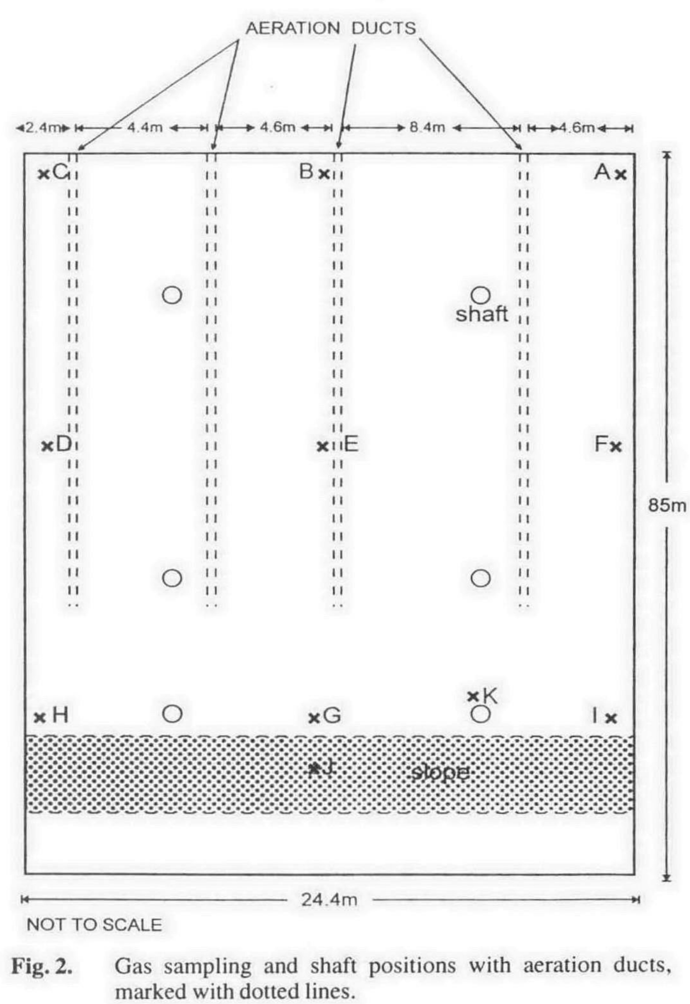

Fig. 2. Gas sampling and shaft positions with aeration ducts, marked with dotted lines.

Table 1. A typical trial on 900 t of barley with both surface and in-duct dosing at the rate of 5g/t using retrievable bag formulation (after Bell et al. 1991).

Gas sampling positions in a rectangular bulk	Depth in grain (m)	Grain temperature (°C)	Corrected % mortality of *S. granarius*	*CT* product (gh/m^3)
Top of slope, at front of bulk	0.0 (surface)	6.1	99	154
	1.0	—	100	200
	2.0 (bottom)	7.0	100	88
Centre of bulk	0.0 (surface)	7.7	100	367
	2.0	12.7	100	416
	4.0 (bottom)	13.0	100	477
Back of bulk in corner	0.0 (surface)	5.6	11	Trace only
	1.0	—	18	Trace only
	2.5 (bottom)	8.1	0	Trace only
On diagonal between centre and front corner	0.0 (surface)	5.4	100	317
	2.0	8.2	100	318
	4.0 (bottom)	—	100	314
Back of bulk near rear door	0.0 (surface)	—	76	82
	3.5 (bottom)	—	0	Trace only
Centre at side of bulk	0.0 (surface)	—	98	21
	3.0 (bottom)	—	98	21
Centre part way down front slope	0.0 (surface)	—	—	312
	1.0	7.9	100	—
	1.5 (bottom)	—	—	71

Table 2. Phosphine concentrations at different positions on the 12th day before redosing and on the 15th day before the termination of the test using the Phyto-Explo system.

Position	Depth from surface (m)	Phosphine concentration (g/m^3)	
		12th day	15th day
A	3.25	0.148	1.080
	1.0	0.197	0.309
B	4.5	0.032	0.890
	1.0	0.003	0.328
C	3.5	0.002	0.176
	1.0	0.002	0.335
D	4.0	0.001	0.064
	1.0	0.002	0.070
E	6.0	0.038	0.025
	3.0	0.036	0.006
F	3.5	0.200	0.045
	1.0	0.182	0.035
G	6.0	0.019	0.116
	3.0	0.022	0.028
H	4.0	0	0.033
	1.0	0	0.177
I	4.0	0.083	0.011
	1.0	0.063	0.213
J	4.0	0.015	0.209
	0.5	0.017	0.004
K (highest peak)	0.5	0.245	0.007
In duct.	—	0.236	1.149

Table 3. Concentration-time products of phosphine obtained after 7, 12 and 15 days in the test using the Phyto-Explo system, dosing at the rate of 2.4 g/t of grain.

Position	Depth from surface, m	*CT* product (gh/m^3)			Remarks
		7 days	12 days	15 days	
A	3.25	133	186	249	
	1.0	66	104	123	
B	4.5	152	186	211	
	1.0	136	157	166	
C	3.5	103	104	230	
	1.0	88	90	108	
D	4.0	105	107	116	
	1.0	83	86	88	
E	6.0	134	166	167	
	3.0	117	138	139	
F	3.5	116	157	161	
	1.0	109	149	152	
G	6.0	79	101	106	Line blocked
	3.0	159	193	205	
H	4.0	59	59	68	
	1.0	43	47	53	
I	4.0	135	171	184	
	1.0	126	141	153	
J	4.0	102	156	168	
	0.5	11	25	26	Line damaged, later restored
K (highest peak)	0.5	350	420	423	
In duct		160	198	232	

The highest *CT* product was recorded near the highest peak of the bulk at position K (Table 3), probably because of its proximity to a dosing point. Positions C, D and H were all on the windward side of the store and recorded lower concentrations and *CT* products. The lowest *CT* product was recorded near the surface at position J but it was suspected that the sampling line to this point was damaged.

Discussion

From the data it can be seen that good gas distribution can be achieved by the Phyto-Explo System. To retain phosphine at the desired level for the required period to kill tolerant strains without redosing, a more gastight store than the one investigated here would be necessary. However, the system does allow low doses of phosphine to be used effectively in less than gastight situations. The six shafts passing gas drawn from the grain surface to the bottom of the bulk enabled gas to distribute rapidly throughout the bulk. Fewer shafts, say three or four, may well have been sufficient, as the gas distribution in the rear of the store where only two shafts were present was just as good as at the front.

The *CT* products achieved after 15 days were sufficient to achieve control of tolerant grain pests at all positions except position H. This was the corner position most affected by the wind prevailing throughout much of the trial. However, as the grain temperature ranged up to 20°C at several points, the expected level of survival would have been minimal.

The Phyto-Explo System could also prove useful for localised hot-spot treatments but no work has been done in this area. For whole bulks, if the required dosage is applied in two halves at an interval of 7 days, the phosphine concentration may be maintained for the necessary period. Uneven distribution of phosphine and insufficient exposure period are the most common causes for ineffective treatments which may lead to the development of resistance. Both factors can be tackled using the Phyto-Explo System.

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