Study of circumfluent fumigation with phosphine for killing stored-grain insects in silos

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Abstract

A study of circumfluent fumigation with phosphine for killing insects was conducted in silos 14.63 m tall by 6.63 m inside diameter. Before fumigation, aluminium phosphine tablets were put on the surface of bulk red wheat in the sealed silo. A multifunctional duct system was fitted to circulate phosphine gas. The fumigation resulted in 100% mortality of *Sitophilus zeamais*, *Oryzaephilus surinamensis*, and *Tribolium castaneum*. The method was easy to operate, and the small axial fan used was sufficiently slow, gave a recirculation rate low enough to be safe and had low power consumption.

Introduction

Recirculation fumigation with phosphine has not previously been tested in large silo bins in China. In 1990 a multifunctional duct system for aeration and fumigation was tested for killing stored-grain insects using methyl bromide with recirculation. Based on this successful experience, a trial on recirculation fumigation with phosphine using the duct system was carried in 1991 and 1992. This study is complete and has passed assessment by a scientific panel.

Materials and Methods

Silo bins and grain used for the trial

The trial silo was part of Tanggu Storage. The bins were constructed of brick, rendered inside and out with cement. Bins 5, 6 and 7 were used for the trial. Between the render and the brick was a layer made of sand, hydrated lime and cement. The bins had steel concrete bases and flat concrete tops. Each bin was 14.27 m high, 7.45 m outside diameter and 6.63 m inside diameter. Each bin contained 240 t red wheat with 11m height of the grain mass and a bin volume of 380 m^3.

Grain temperatures and moisture contents, and ambient temperatures are given in Table 1.

Gastightness tests

Pressures were observed at three points in the empty bin during pressure testing. The half-life for 2000–1000 Pa was 45 seconds for each point.

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Test and recirculation equipment

The duct work attached to the bins is shown in Figure 1. The trial used the following equipment: phosphine detector tubes; temperature/humidity sensor; electronic air-velocity meter; in-bin automatic temperature recording system; small axial fan. The grain parameters are given in Table 1.

Test insects

Adults of *Sitophilus zeamais*, *Oryzaephilus surinamensis* and *Tribolium castaneum* (20 of each) were sealed into phosphine-permeable envelopes. Twelve of these envelopes were distributed evenly in the upper, middle and lower parts of the wheat in the test bins.

Gas testing and phosphine dosages

Phosphine dosages (as aluminium phosphide) used in three trial bins are given in Table 1.

Phosphine concentrations were determined at 12 points in each bin, with sample points distributed in the upper, middle and lower parts of the bin. Gas samples were taken through polyethylene tubing.

Conduct of the fumigation

The wheat was loaded into the bins after placement of the insect-containing envelopes and the gas sample lines. Aluminium phosphide (AlP) tablets were then placed on the surface of the grain bulk in dishes. The phosphine concentrations were checked during the recirculation of the internal gases using a small axial fan and before and after recirculation. The fan gave one air change per hour and was run for 2 hours at specified

Table 1. Experimental parameters

Bin No.	5	6	7
Quantity of wheat (t)	240	240	240
Moisture content (%)	12	12	12
Average grain temperature (°C)	22	17	21
Date of AIP application	2/8	25/6	20/7
Temperature in headspace (°C)	30	24	27
Relative humidity in headspace (%)	80	72	73
Ambient temperature (°C)	34	27	30
AIP tablets applied (g)	940	1500	2250
Time of exposure (hours)	240	168	120
Time of first recirculation (hours)	22	8	10
Time of second recirculation (hours)	–	22	22
Time of third recirculation (hours)	–	46	46
Recirculation period (L)	2	2	2

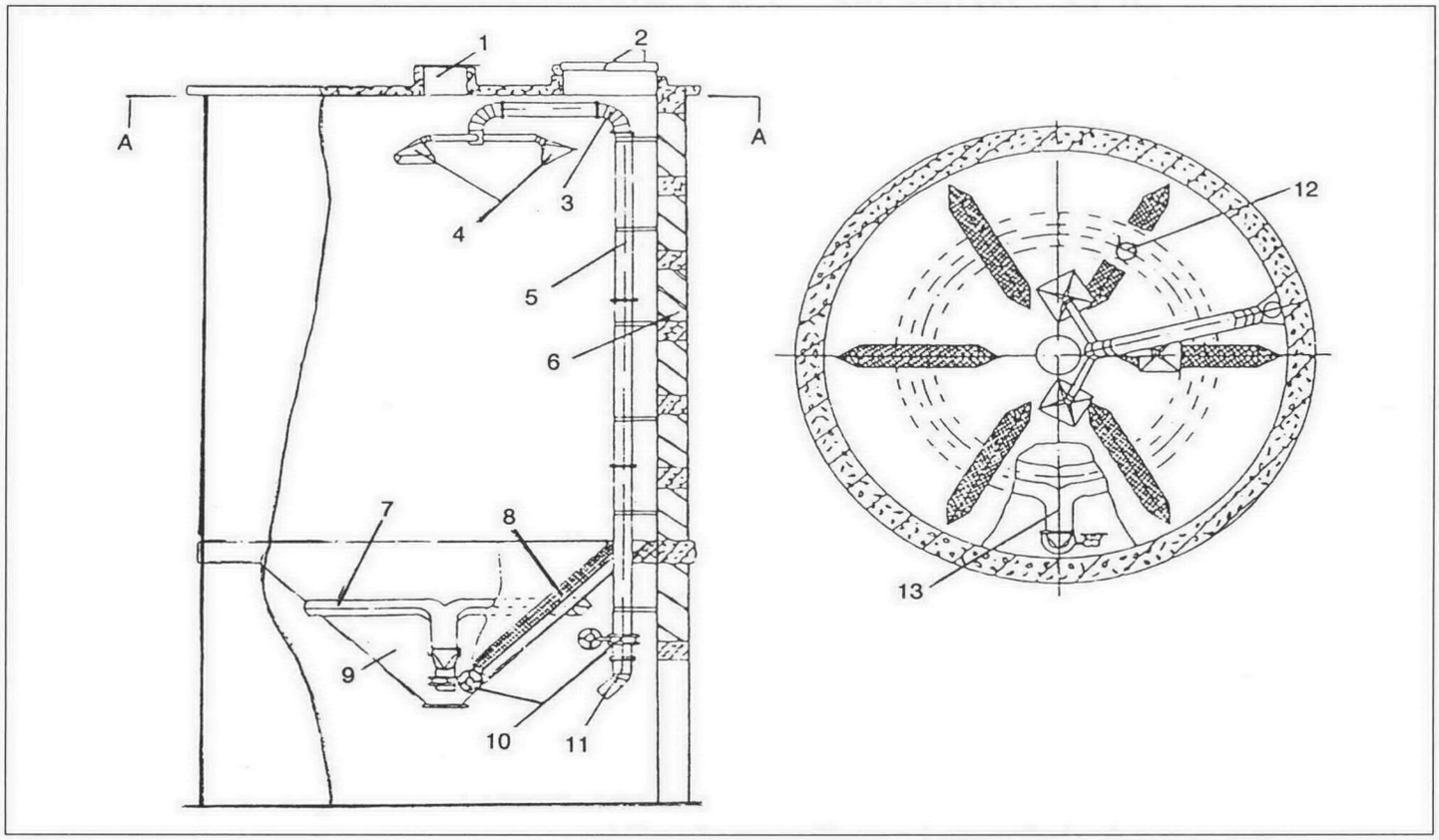

Fig. 1. Trial silo equipped with multifunctional duct system. 1. Grain inlet; 2. Sealable manhole; 3. Tube at 90° angle; 4. Nozzles; 5. Vertical pipe; 6. Silo; 7. Circular pipe surrounding the outer cone; 8. Radiating pipes inside the cone; 9. Steel base of the cone; 10. Wing nut; 11. Movable tube at 135° angle; 12. Air inlet (6 in total); and 13. Standing and returning pipe.

times after putting the aluminium phosphide tablets in the bin (Table 1). Recirculation was stopped as soon as the gas had been distributed evenly.

After the fumigation, the bins were aerated and then unloaded. The envelopes were recovered and the mortality of test insects assessed. Mortality was reassessed after 21 days incubation.

Results and Discussion

The three trial bins were all treated with different aluminium phosphide dosages and were slightly different in temperature and humidity (Table 1). Phosphine levels recorded in the trial are given in Tables 2–6.

Bin 5 was dosed at 2.5 g AlP/m^3. After 22 hours the phosphine levels varied from 0.6–2.5 g/m^3. After 2 hours of recirculation the gas concentration was even throughout the bin at 1.2 g/m^3. The concentrations at 48 hours were even and similar to those at 24 hours, so no further mixing by recirculation was needed.

Bins 6 and 7 were dosed at 4 and 6 g AlP/m^3, respectively. Both required three periods of recirculation (2 hours each) in order to keep gas concentrations even. The first recirculation was carried out when the highest concentration reached 1.8–2 g/m^3. This occurred 8–12 hours after addition of the tablets. Further recirculation was carried out at 22 and 46 hours.

Bins 5, 6 and 7 were exposed to phosphine for 240, 168 and 120 hours, respectively. There was 100% mortality of test insects both immediately after fumigation and recovery of the envelopes, and after 21 days of incubation.

Table 2. Phosphine concentrations (g/m^3) before and after first recirculation periods

	Bin No.	Time after application of tablets (L)	Headspace	Depth of sampling point										
				Central sampling line						Lateral sampling line				
				1	3	5	7	9	10.5	1	3	5	7	9
Before recirculation	5	22	2.5	2.0	0.6	0	0	0	0	2.0	0.5	0	0	0
	6	10	1.8	0.7	0.2	0	0	0	0	0.8	0.2	0	0	0
	7	8	2.0	0.6	0.14	0	0	0	0	0.5	0.1	0	0	0
After recirculation	5	24	1.2	1.0	1.0	1.0	1.0	1.0	1.1	1.2	0.9	1.0	1.0	0.8
	6	16	0.7	0.6	0.7	0.5	0.6	0.6	0.3	0.6	0.4	0.5	0.5	0.4
	7	12	1.0	0.8	0.8	0.8	0.9	0.9	1.0	1.1	0.9	0.9	0.9	0.9

Table 3. Phosphine concentrations (g/m^3) after recirculation and 24 hours later

	Bin No.	Headspace	Depth of sampling point										
			Central sampling line						Lateral sampling line				
			1	3	5	7	9	10.5	1	3	5	7	9
After recirculation	5	1.2	1.0	1.0	1.0	1.0	1.0	1.1	1.1	0.9	1.0	1.1	1.0
	6	1.6	1.5	1.5	1.5	1.6	1.6	1.7	1.6	1.4	1.4	1.5	1.5
	7	2.6	2.5	2.6	2.4	2.1	2.1	2.3	2.5	2.2	1.8	2.0	2.0
24 hours later	5	1.2	1.1	1.0	0.9	1.0	0.9	0.9	1.2	1.0	1.0	1.0	0.9
	6	1.5	1.4	1.5	1.5	1.5	1.6	1.6	1.5	1.5	1.3	1.4	1.5
	7	2.5	2.2	2.0	2.0	2.0	2.0	1.8	2.5	2.0	2.0	2.0	2.0

Table 4. Change in gas concentrations (g/m^3) in Bin 5, dosed at 2.5g AlP/m^3

		Time (hours)									
		24	48	72	96	120	144	168	192	216	240
Headspace		1.2	1.2	1.2	1.1	0.9	0.8	0.6	0.5	0.5	0.4
Central sampling line	1	1.0	1.1	1.0	0.9	0.9	0.7	0.5	0.4	0.3	0.3
	3	1.0	1.0	1.0	0.9	0.9	0.7	0.6	0.4	0.4	0.3
	5	1.0	0.9	1.0	0.9	0.8	0.7	0.5	0.4	0.3	0.3
	7	1.0	1.0	1.0	1.0	0.9	0.7	0.7	0.6	0.3	0.2
	9	1.2	0.9	1.0	0.9	0.8	0.6	0.5	0.5	0.4	0.3
	10.5	1.1	0.9	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3
Lateral sampling line depth below surface (m)	1	1.2	1.2	1.2	1.0	0.9	0.7	0.6	0.5	0.4	0.4
	3	0.9	1.0	1.0	0.9	0.9	0.7	0.6	0.4	0.4	0.3
	5	1.0	1.0	1.0	1.0	0.9	0.6	0.5	0.5	0.3	0.3
	7	1.1	1.0	0.9	0.8	0.8	0.6	0.5	0.4	0.4	0.3
	9	1.0	0.9	0.9	0.8	0.8	0.7	0.5	0.4	0.3	0.3
Average		1.1	1.0	1.0	0.9	0.9	0.7	0.6	0.4	0.4	0.3

Table 5. Change in gas concentrations (g/m^3) in Bin 6, dosed at 4 g AlP/m^3

		Time (hours)								
		12	24	36	48	72	96	120	144	168
Headspace		0.6	0.8	1.1	1.6	1.5	1.4	1.2	0.9	0.5
Central sampling line	1	0.5	0.8	1.1	1.5	1.4	1.2	1.1	0.9	0.5
	3	0.5	0.9	1.2	1.5	1.5	1.4	1.3	1.0	0.4
	5	0.4	0.8	1.2	1.5	1.5	1.3	1.2	0.8	0.4
	7	0.4	0.8	1.1	1.6	1.5	1.3	1.1	0.8	0.5
	9	0.4	0.8	1.1	1.6	1.6	1.4	1.2	0.9	0.5
	10.5	0.5	0.9	1.3	1.7	1.6	1.4	1.3	1.0	0.6
Lateral sampling line depth below surface (m)	1	0.5	0.9	1.1	1.6	1.5	1.2	1.2	0.8	0.4
	3	0.4	0.8	1.2	1.4	1.5	1.4	1.3	0.8	0.5
	5	0.4	0.8	1.3	1.4	1.3	1.3	1.2	0.7	0.5
	7	0.5	0.9	1.3	1.5	1.4	1.4	1.2	0.8	0.4
	9	0.4	0.8	1.1	1.5	1.5	1.3	1.2	0.9	0.5
Average		0.46	0.83	1.18	1.53	1.48	1.33	1.21	0.86	0.54

Table 6. Change in gas concentrations (g/m^3) in Bin 7, dosed at 6 g AlP/m^3

		Time (hours)						
		12	24	36	48	72	96	120
Headspace		1.0	2.0	2.5	2.6	2.5	2.2	2.0
Central sampling line	1	0.8	2.0	3.0	2.5	2.2	2.0	1.8
	3	0.8	2.0	3.0	2.6	2.0	2.0	1.9
	5	0.8	2.0	2.1	2.4	2.0	2.0	1.8
	7	0.9	2.0	2.0	2.1	2.0	1.9	1.7
	9	0.9	2.5	2.0	2.1	2.0	1.7	1.7
	10.5	1.0	2.5	1.8	2.3	1.8	2.0	1.8
Lateral sampling line depth below surface (m)	1	1.1	2.0	3.0	2.5	2.5	2.0	1.8
	3	0.9	2.0	2.0	2.2	2.0	1.9	1.6
	5	0.9	2.0	2.0	1.8	2.0	2.0	1.8
	7	0.9	2.0	1.8	2.0	2.0	1.8	1.8
	9	0.9	2.0	1.8	2.0	2.0	1.8	1.7
Average		0.91	2.08	2.25	2.26	2.08	1.94	1.78

Conclusion

This study has demonstrated highly efficient, economic and safe treatment with phosphine in large silo bins. It is concluded that:

- with correct design and multifunctional duct system it is possible to distribute gas evenly so as to achieve 100% mortality;
- the small, sparkless axial fan was sufficiently slow and gave sufficiently low circulation rate for the fumigation to be safe;
- the buildup of phosphine from the aluminium phosphide tablets, applied to the grain surface, could be controlled by the recirculation so as not to exceed a predetermined safe limit. With dosages of 4–6 g AlP/m^3 two to three recirculation periods of 2 hours duration were sufficient to prevent excessive concentrations;
- the time of exposure can be regulated according to dosage, with 5 days sufficient at normal rates of application and longer for the low dosage treatments; and
- the fumigation is safe, easy to carry out and will save power.