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## Phosphine Recirculation Fumigation in Horizontal Storage in Low-temperature and Dry Region

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**Abstract:** The concentration change of phosphine was measured during recirculation fumigation in horizontal storage in low-temperature dry region. Aluminum phosphide was laid in the ventilation vents, the dosage of which was  $0.7 \text{ g/m}^3$ . After phosphine generated from aluminium phosphide formulation reacted with vapor in air, all the stored pests such as *Sitophilus zeamais* Motschulsky, *Rhizopertha dominica* (Fabricius) was killed completely. Compared with the expense of the conventional fumigation, the one of recirculation above was to reduce 68.7%, and a comparative analysis of it had been carried on.

**Key words:** horizontal storage, aluminum phosphide, recirculation

Compared with general warehouses built earlier, new horizontal storage warehouses are larger overall with greater height. Limited by the penetrating ability of phosphine by gravity, pests were hard to kill with first fumigation, and often had to be fumigated again. The resistant of pests against  $\text{PH}_3$  was increased, which causes the waste of manpower and resources. Phosphine recirculation fumigation technique is a management to control pests in this storages. In 1998, China began building new larger horizontal storage warehouses at state grain depots. These new 3 500 to 5 000 ton storages included recirculation fumigation systems incorporated with in-floor aeration ducts, which has played an important role in controlling stored pests and maintaining grain storage security. Recirculation fumigation systems were better designed to distribute phosphine gas evenly, providing higher grain security by killing insects much more effectively than the conventional fumigation.

Zhongning depot is situated at Ningxia in the northwest of China, which is in Low-temperature Dry Region all the year. During the winter, the average temperature is below  $0 \text{ }^\circ\text{C}$  for 5 months. The summer is short, a period lasting 3 months. According to climate characteristic, the depot staff took measures to improve grain security in order to reduce the number of fumigations and the dosage levels of phosphine, to save cost of storage and reduce the labor intensity.

Since 2002, Zhongning depot proposed new pest management practices to preserve grain, including such measures as laying aluminium phosphide in the ventilation duct channels using phosphine generated from aluminium

phosphide formulation which reacts with vapor in air, aeration for cooling in the fall and winter, phosphine fumigation under plastic sheeting in the spring, and ventilation in the summer. Using all these grain management practices all the pests were killed, which prevented insects from reproducing so much. After these measures, fumigation one time each year has provided obvious economic efficiency.

### 1 Materials

#### 1.1 Horizontal Storage

The capacity of the #5 depot warehouse was 3 600 t. The length was 36.8 m and width 24.0 m. The total volume was  $8\,390 \text{ m}^3$ , with the height of grain, 5.5 m. The volume of grain storage is  $4\,602 \text{ m}^3$  and the headspace volume above the grain is  $3\,788 \text{ m}^3$ . The horizontal storage has four U-shaped perforated aeration duct channels. The polyvinyl chloride sheets were used to seal all the doors, windows, vents and aeration fan ducts.

#### 1.2 Grain quality and environment

The kind of grain stored was wheat, with moisture of 12.5%, impurity of 0.8%. There were 3 721 t of wheat in the horizontal storage. The bulk temperature, highest grain temperature, and average grain temperature in the horizontal storage was  $25 \text{ }^\circ\text{C}$ ,  $25.8 \text{ }^\circ\text{C}$ , and  $16 \text{ }^\circ\text{C}$ . The average ambient air humidity outside and air humidity in storage was 60% and 69%.

#### 1.3 Pest Density

Pest density in the storage averaged 16 per kg; *Sitophilus zeamais* Motschulsky was 10 per kg, *Rhizopertha dominica* (Fabricius) was 3 per

kg, *Sitotroga cerealella* (Olivier) was 3 per kg.

### 1.4 Fumigants

The 56% aluminium phosphide pills were made in Shenyang. The dosage of  $0.7 \text{ g/m}^3$ , provided a target concentration of  $\text{PH}_3$  of 100 ppm required 6 kg of phosphine pills.

### 1.5 Equipment and Apparatus

Fixed recirculation fan and in-place suction piping from the warehouse headspace with pressure piping connected to the aeration in-floor ducts.

Phosphine monitor: XL-210G, Beijing Liangkemao CO., LTD, Range: 0.1 - 1000 ppm.

Alarm apparatus for phosphine personnel safety: XL-200, Beijing Liangkemao CO., LTD.

## 2 Methods

### 2.1 Confined Horizontal Storage

The windows and doors were sealed with polyvinyl chloride film sheets. In this way, the half-decay time for depot gastightness test was 1 minute and 20 seconds, which conformed to the state grain depot guideline request for horizontal storage.

### 2.2 Establishment of gas Sampling points

There are five sampling points within four corners and the central. The corner point is 1 meter away from the wall, and central point was intersected point of diagonal lines. All the gas tube sampling points were 1.5m below the grain surface. Each point had a return sample tubing line for monitoring  $\text{PH}_3$ .

### 2.3 Adjustment Wind Speed for Aeration

Operate aeration fans, then adjust the air volume distribution valves until air volume in each of the four aeration ducts achieved balance.

### 2.4 Determination of Grain Temperature

The grain temperature in the surface, the middle, the lower, and the base of the storage was monitored by using the microcomputer temperature measurement and data logging system.

### 2.5 Fumigation

Six kg of aluminium phosphide tablets were laid in four ventilation ducts, with 1.5 kg in each channel. Aluminium phosphide pills were in small plastic bags (0.50m, 0.10m), then phosphine was generated from aluminium phosphide formulation reacted with vapor in air.

### 2.6 Start and Stop of the Recirculation

### Blow

It takes a long time to produce  $\text{PH}_3$  since phosphine from the time it starts to be generated. After 12h, the recirculation blower was started. The blower should be stopped as soon as  $\text{PH}_3$  at all gas monitoring points reach an approximate balance, or uniform gas concentration.

### 2.7 Phosphine Concentration Test

Phosphine concentration was tested by a XL-210 phosphine monitor starting when the recirculation fan started, 12h from start of fumigation and every 12h after that until the fumigation was completed.

### 2.8 Aeration in the Winter

The depot was located in the northwest of China, which was in low-temperature, dry region all the year. The winter lasted a long time below  $0^\circ\text{C}$ , and the relative humidity is below 65% all the year. All these environment factors were adopted to aerate for grain storage. The moisture did not reduce significantly from the low-power aeration, which provide a low volume airflow through the grain. In this way, the fan-hours of ventilation and the consumption of energy was low.

### 2.9 Heat Insulation in the Spring

Before the temperature in the spring rose, windows, doors and ventilation vents of the horizontal storage were sealed at the end of February, in order to maintain the low grain temperature after aeration, specially the temperature of the surface grain influenced by the horizontal storage headspace temperature. The grain surface was sealed with PVC sheeting, then was covered with a layer of bags of rice husk to insulate surface grain from warm headspace temperatures.

### 2.10 Ventilation in Summer

In summer, the highest temperature reached above  $38^\circ\text{C}$ . Because of the roof absorption and radiation of sunlight energy, elevation of the horizontal storage temperature and humidity was main problem causing the grain surface temperature to rise which caused stored pest to grow again. Opening windows and doors, and operation of the axial-flow fan reduced the temperature and humidity of the horizontal storage between midnight and 6 am. This ventilation of the headspace lowered the roof radiation warming influence on the grain surface temperature and delayed the temperature rise.

### 3 Results and Discussion

#### 3.1 Fumigation

The results indicated that the grain management strategy was effective to kill all the stored pest by maintaining the phosphine concentration for 552h(23 days), then to continue airtight for 7 days, and dispersing PH<sub>3</sub> for 2 days. After one month, no live insect was found at sampling points where the pest density is big before fumigation.

#### 3.2 The Change of the Phosphine Concentration

The distribution of the phosphine concentration was shown as Table 1. From the result analysis, the ratio between the highest and the lowest concentration was 0.75 after recirculation for 24h, and the average phosphine concentration was 80ppm. After recirculation for 120h, the concentration distributed evenly, and the ratio was 0.97. The average phosphine concentration achieved the highest level 192 hours later(163 ppm at 312 h), then dropped slowly. The total time of fumigation was 30 days.

**Table 1. The change of the phosphine concentration**

Time (h)	phosphine concentration(ppm)						
	1	2	3	4	5	6	average
12	60	56	58	98	72	46	65
24	88	80	79	104	92	60	83
36	97	94	92	128	104	90	101
48	119	111	110	156	126	101	119
60	136	130	128	170	130	120	133
72	151	144	144	166	155	140	150
96	154	149	147	161	151	142	152
120	155	152	147	170	149	144	157
144	149	153	146	170	156	169	159
192	151	154	151	172	158	170	163
216	156	158	156	171	160	178	157
240	154	154	158	169	157	177	159
264	156	157	155	171	161	176	162
288	155	154	156	168	159	181	162
312	156	156	157	169	160	176	163
336	154	155	152	164	161	174	160
360	152	157	151	160	160	170	158
384	148	150	149	151	146	168	152
432	143	144	145	146	144	152	150
456	138	137	137	138	137	145	149
480	130	125	128	129	147	145	137

Time (h)	phosphine concentration(ppm)						
	1	2	3	4	5	6	average
504	109	109	110	114	119	139	117
527	103	105	106	103	106	1128	109
552	97	94	98	96	96	103	97
576	82	70	84	84	80	86	83

#### 3.3 Cost Analysis

The recirculation: The dose of Aluminum phosphide was 6 kg at the price of 37 yuan per kg, so the total expense was 222 yuan. The subsidy for Staff workers was 300 yuan, and the other cost( electric power, sealing materials and supplies) is 150 yuan. Finally, the sum total expense was 672 yuan.

The conventional fumigation: The dose of aluminum phosphide was 58 kg, so the total expense was 2 146 yuan, and the subsidy for Staffs was 300 yuan, the sum above is 2 446 yuan.

Compared with the expense of the conventional fumigation, The operating cost of Aluminum phosphide recirculation above was to reduce 1 774 yuan, and these was only 31.3% that of the conventional fumigation. Pest efficacy and grain quality was much better with recirculation.

#### 3.4 The Change of Temperature for A Year

**Table 2. The change of the temperature in 2002**

date	outside	bulk	surface	middle	lower	base	warehouse
2002.1.29.	-11.9	-9.2	-1.1	-3	-2.1	0	-1.5
2002.2.26.	-1.4	2.7	-1.3	-2.2	-1.2	4.0	-0.2
2002.3.26.	16.7	6.5	1.5	-1.1	0	5.6	1.5
2002.4.29.	15.5	11.4	6.3	1.1	2.0	7.4	4.2
2002.5.28.	21.0	16.6	9.8	2.9	3.5	8.6	6.2
2002.6.25.	28.7	22.7	13.7	5.3	5.4	10.0	8.6
2002.7.29.	24.8	23.7	17.4	7.8	7.0	11.2	10.8
2002.8.26.	31.0	23.7	17.5	9.0	7.4	11.4	11.3
2002.9.29.	16.5	16.3	16.2	9.6	7.4	11.2	11.1
2002.10.28.	9.0	9.6	13.9	9.3	6.9	10.4	10.1
2002.11.25.	7.1	0.9	9.3	8.2	6.4	9.6	8.4
2002.12.23.	-11.9	1.3	5.2	1.8	1.2	2.3	2.6

The change of temperature for a year was shown as table 2. The average temperature of grain was 11°C and it was benefit to use low temperature storage.

### 4 Conclusions

4.1 Aluminum phosphide was laid in the ventilation vents. The speed of the dynamic deliquescence was slow, but the phosphine distrib-

uted uniformly. Due to excellent sealing of the warehouse, the effective concentration was maintained for a long time, with good results of controlling pests.

4.2 The expense of the recirculation was only 31.3% that of the conventional fumigation.

4.3 Safe. Reduced the time contacting with the poison gas, and the labor intensity was small.

4.4 Low temperature storage combined

with phosphine gas recirculation gave good security.

4.5 The average temperature of storage was below 15°C all the year.

4.6 Recirculation fumigation in well sealed storage was effective to inhibit stored pests. Fumigation only one time in a year attached obvious economic efficiency and it reduced the times of fumigation and the pollution, saved the expense.