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Research of Phosphine Re-circulation under Plastic Sheet for Grain Fumigation in Horizontal Warehouse with Aluminium Phosphide in Air-duct

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Abstract: To effectively control the stored grain pests, the technology of phosphine re-circulation under plastic sheet for grain fumigation by placing aluminium phosphide (AlP) in air-ducts was researched. First, the aluminum phosphide tablet was placed in air – ducts, then reacted with moisture in the atmosphere and released phosphine. Meanwhile, phosphine was blown into grain bed by the circulation fan. In this way, the phosphine dispersed and distributed uniformly throughout the grain in the warehouse. All stages of stored grain pests were controlled by an effective concentration of phosphine held for enough time. In fact, this technology was the combination of "phosphine re-circulation fumigation under plastic sheeting" and "placing AlP at air – duct", which has many advantages, such as flexible and safe operations, functional, economical, reduced pollution to grain.

Key words: placing AlP in air – duct; re-circulation fumigation

Introduction

When we use phosphine re-circulation technology to control stored grain pests in horizontal warehouse, there are several ways of placing AlP, such as: (1) placing pellets or tablets on the grain surface, (2) using inserting tube or "probing", (3) packing and burying the phosphine under grain surface, (4) using on-site phosphine generator, and (5) high pressure steel cylinders of "2% phosphine + 98% carbon dioxide" gaseous mixture for grain fumigation. But, all these methods have drawbacks, such as heavy workload of methosds 1 – 3 methods; long duration of using (4) on-site phosphine generator, difficulty of purchasing carbon dioxide, complicated operation, or (5) the expensive steel cylinderized "phosphine + carbon dioxide"..

In this study, the phosphine gaseous generated by the AlP was placed in the air-duct of warehouse and was blown through the grain by the circulation fan, distributing the gas uniformly in the grain. All stages of stored grain pests were effectively controlled by the uniform concentration of phosphine for enough time for efficacy. This technology was combination of "phosphine re-circulation fumigation under plastic sheeting" and "placing AlP in air-ducts", which has advantages of flexible and safe operations, functional application, economical process, reduced pollution in grain, and easy recovery of phosphine residual dust from aeration ducts. This application method promotes the contintued development of phosphine re-circulation fumigation technology in horizontal warehouses throughout China and other countries.

1 Materials

1.1 Test Depot

Test depot: Rushan Depot of State Grain. No. 2, No. 3 (both warehouses placing AlP tablets in air – ducts).

Control depot: Rushan Depot of State Grain. No. 4 (using on – site phosphine generator).

Each of depots, equipping with above – ground ducting, five vent openings with 10 ventilation plants, fixed phosphine re-circulation fumigation system and microcomputer detecting system, was placed into service in 1999. See Table 1 for more details of depots.

Table 1. Detailed information of test depots in Rushan Depot of State Grain

No.	Grain	Quantity (t)	Height (m)	Volume (m^3)	Grain moisture content (%)	Depot air temperature (℃)	Grain temperature (℃)			Pests density (Insects/kg)
							Upper layer	Middle layer	Bottom layer	
2	Wheat	5763	6.02	6957	11.9	28	24	16	14	2^a, 1^b, 1^c

1. *China Grain Reserves Corporation, Shandong Branch (No. 29 East Wenhua Road, Jinan, Shandong, 250014, China)*

2. *Rushan Depot of State Grain (Station in Xiachu Town, Rushan, Weihai, Shandong, 2645014, China*

No.	Grain	Quantity (t)	Height (m)	Volume (m^3)	Grain moisture content (%)	Depot air temperature (℃)	Grain temperature (℃)			Pests density (Insects/kg)
							Upper layer	Middle layer	Bottom layer	
#3	Wheat	5661	6.0	6735	12.0	28	24	14	13	2^a, 1^b
#4	Wheat	5000	5.6	6284	12.2	26	23	10	11	1^a, 1^b

Note: The water content, depot air temperature, grain temperature and pests density was recorded on August 8 2007, before test, respectively. The a, b, c in "Pests density" row corresponding to *Sitophilus zeamais*, *Tribolium castaneum*, *Oryzaephilus surinamensis*, respectively.

1.2 Test Insects

Rhizopertha dominica Fabricius, *Tribolium castaneum* (Herbst), *Sitophilus zeamais* (Motschulsky), were reared in Chengdu Grain Storage Research Institute, State Administration of Grain, Sichuarn, P. R. China). Three insect specieis were all phosphine resistant strains.

The insects were placed in a small cloth bag, in which insects feed occupied one thirds volume. There were 30 insects of each strain in every bag.

1.3 Equipment and Insecticides

Fixed phosphine re-circulation fumigation system (Weilai Machines Engineering Co.; Ltd, Henan, P. R China); Phosphine monitoring device, HL-210 (New Hualao S&T Co., Ltd, Beijing); Home-made in-bin reverse flow gas distribution network under plastic sheet; 56% AlP tablets (Yongfeng Co., Ltd, Jining, Shandong, China)

2 Methods

2.1 Sealing and Gas Tightness Measuring

The home-made in-bin reverse flow gas distribution network was composed of Φ110mm main top suction (reverse flow) PVC pipe, Φ75mm branch suction (reverse flow) U-PVC pipes which contained no lead or cadmium, and the external blower and piping re-circulation fumigation system. Drilled holes on branch pipes A, B, C, D, E and F accounted for 10%, 12%, 14%, 16%, 18%, 20% of total areas of A, B, C, D, E and F, respectively. There were no holes on the main reverse flow pipe. The main and branch suction (reverse flow) pipes were connected and buried 30 centimeters deep below grain surface in advance. The main suction (reverse flow) pipe was connected with external re-circulation fumigation system. The level grain surface was firmly sealed with plastic sheeting connected to warehouse walls. The distance between the ends of branch pipe and the wall was 60cm. The interval between branch suction pipes was 4.9 m.

To detect the gas tightness of test warehouses, we measured the half-life time of negative pressure, -500 Pa to 250 Pa, in each warehouse. The negative pressure was made by centrifugal fan connected to in-floor ventilation ducts. The half-life times of No. 2, No. 3 and No. 4 warehouse were 124 s, 131 s and 114 s respectively. The values were in line with the standards of re-circulation fumigation set by the state. See Fig. 1 for more details of in-bin gas suction (reverse flow) piping network under plastic sheet.

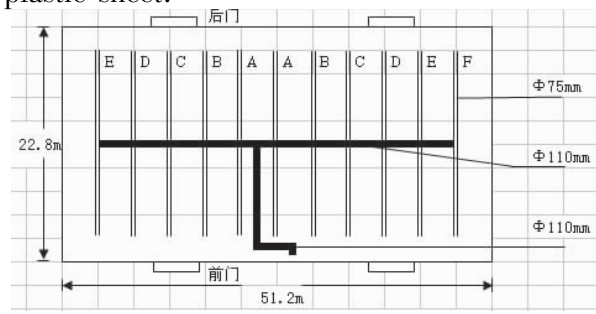

Fig. 1 The graph of in-bin suction (reverse flow) gas piping network under plastic sheet

2.2 Arrangement of Phosphine Monitoring Pipes and Test Insects

The arrangement of phosphine monitoring pipe and test insects grain depths and horizontal spacings are shown in Fig. 2. The points in the corner were at a distance of one meter from the wall. There were three kinds of test insects at each phosphine monitoring point. The phosphine monitoring pipe and test insects were placed to the specific depths by grain vacuum sampling probes.

2.3 Placing AlP at Air-duct

The quantity of AlP was calculated at 1.5g/t. The aluminum phosphide tablet was put into cotton bag (at most, 1 kg/bag). Each bag was tied with a long rope. The bags were placed in underfloor air-ducts. To prevent the tablets being too centralized to be safe, we spaced the bags along each air-duct using a long push-pole. The ends of the rope tied to the bags were tied together and put at the opening of the air-duct for convenient spent ash recovery after fu-

migation. Air-duct openings were sealed afters the AlP was placed.

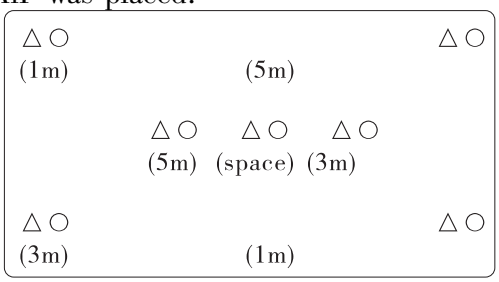

Fig. 2. The distribution of Phosphine monitoring points and test insects

Note: The symbols of "△" represent the sampling bag of Rhyzopertha dominica, Sitophilus zeamais, Tribolium castaneum, respectively. The symbols of "○" represent the phosphine monitoring point. The "*(m)" shows depth below grain surface of monitoring point and test insects bag.

In consideration of low moisture content of wheat, low relative humidity in warehouse and too dry air in air-duct, wet sand was placed in air-ducts to increase air humidity and promote faster reaction speed of phosphine generated from AlP.

2.4 Phosphine Re-circulation and monitoring

2.4.1 Intermittent re-circulation

Intermittent re-circulation fumigation was adopted after placing of AlP. It was supposed to turn off the electric power of the re-circulation device when phosphine concentration reached the level of basic balance (the ratio of highest concentration to lowest concentration should be at most 4:1). Twenty-four hours after starting the fumigation, we measured the concentration and made a decision of continuing re-circulation or not, according to the phosphine concentration we measured.

2.4.2 Phosphine monitoring

When re-circulation blower was going, the phosphine concentration was measured every 8–12 hours. After re-circulation blower was stopped, it was measured every 24 hours by HL-210 phosphine monitoring device. After the highest (peak) concentration was detected, gas levels were measured every 72 hours.

2.4.3 Inspection of insect mortality

To compare the insect density before and after this test, the grain was sampled at the same place in test warehouse before and after fumigation, and the insect in sampling grain was counted. At the same time, the insect sample bags, buried in advance, were taken out. Then, the adults were separated and reared on a diet of 10g wheat flour in an air-conditioned room at 28 ± 1℃, relative humidity (RH) 65%–75%. The adult insect mortality was detected and recorded after fourteen days, and was corrected according (compared) to the control mortality. To detect the growing of F_1, material left on the wheat floor was put into a new rearing bottle and reared under the conditions described above for 42 days.

2.4.4 Detection of Phosphine residue on wheat

The phosphine residue was determined using gas phase chromatography. Fifty kilograms of crushed fumigated wheat was put into a round bottom flask and then added to 150 mL water, and covered the flask by a grinding lid with rubber pad. Then, five ml concentrated hydrochloric acid was added into the flask at the location of silicon rubber. The flask was shook in a supersonic cleaner for five minutes. Then, the mixture in the flask was incubated for 30 min before measurement. The supernatant gas was used as residual Phosphine sources. The quantity of Phosphine residue on wheat was figured out according to the PH_3 standard curve regression equation.

3 Results

3.1 Insect Mortality

In our study, the mortality of all kinds of insect in test depot and control depot was 100% after fumigation. The mortality of resistant insects, buried in test samples in the depot warehouse grain during the tests, was checked after 30 days incubation, and was also 100%.

3.2 Development of PH_3 Concentration in Fumigation

In No. 2, No. 3 depot, average uniform concentration (over 80 mL/m^3) attained after 48 hours fumigation. Maximum concentration (281mL/m^3) attained in 144 hours in No. 2 depot, and maintained at 142 mL/m^3 26 days later. Maximum concentration (272 mL/m^3) attained in 152 hours in No. 3 depot, and maintained 138 mL/m^3 26 days later. In No. 4 depot (control depot), average concentration (over 80 mL/m^3) attained in 8 hours, maximum concentration (290 mL/m^3) attained in 30 hours, and maintained 124 mL/m^3 26 days later.

3.3 Phosphine Residue on Wheat

The PH_3 residues found on wheat of No. 2, No. 3 and No. 4 depot were 0.0054mg/kg, 0.0062mg/kg and 0.0048mg/kg, respectively. All residues were within the state's standards. However, compared to Phosphine re-circulation under plastic sheet fumigation using on-site phosphine generator, the residue of Phosphine re-circulation under plastic sheet by placing AlP in air-ducts was slightly higher.

4 Discussion

4.1 Safety of Phosphine re-circulation Fumigation under Plastic Sheet by Placing AlP in Air-ducts

For traditional phosphine fumigation (without Phosphine re-circulation system), the PH_3 generated from AlP tablets spread by the difference in gas pressure concentration. It was a static process. It was not safe because of high local concentration near dosage placements sites. So, the quantity of AlP tablets placed in each air-duct was limited. Compared to traditional phosphine fumigation, Phosphine re-circulation fumigation under plastic sheet by placing AlP in air-duct was safer for its flowing air, dynamic process and uniform PH_3 concentration. So, it's necessary to equip sites with alternate electric source using an emergency generator before fumigation to maintain operation of recirculation blower when needed if local electric power failure occurs during the fumigation.

4.2 Validity and environmental Protection of Phosphine re-circulation fumigation under Plastic Sheet by Placing AlP in air-ducts

According to our test, the PH_3 dispersed rapidly and uniformly and controlled the insects effectively. Three methods, re-circulation fumigation with on-site phoshpine generator, re-circulation fumigation with high pressure steel cylinder phosphine + CO_2, re-circulation fumigation under plastic sheet with placing AlP in air-ducts, were all effective for controlling insects with no fumigation trap. The method of re-circulation fumigation under plastic sheet with placing AlP in air-ducts was really a good technology to control insects for grain, because of reducing quantity of AlP, reducing fumigation cost, reducing discharge amount of CO_2 and poisonous gas, and no need of CO_2 for fire retardant, and easy recovery of AlP dust in cloth bags from air ducts by pulling all bags from ducts with ropes.

4.3 Comparison of Three Different Way of Generating PH_3 in fumigation

There were three different sources of phosphine in re-circulation fumigation, they were as follows: phosphine from on-site phosphine generator, high pressure steel cylinder phosphine + CO_2, phosphine from natural deliquescence of AlP tablets placing at air-duct. The first two methods were widely used nowadays. But, high pressure steel cylinderized phosphine + CO_2 was expensive and not convenient to purchase and transport to the site and return after fumigation. For the on-site phosphine generator, the CO_2 was essential to fire resistance of phosphine in fumigation. But, the efficient synergy concentration of CO_2 for controlling insects did not occur as the amount of CO_2 was not properly balanced with PH_3. The positive pressure, formed by large amounts of CO_2 under plastic sheet, promoted the leakage of poison gas during the fumigation, and shortened the PH_3 efficient concentration time. At the same time, the operation of on-site phosphine generator increased the labor intensity, exposure time to poison gas and costs of CO_2. However, phosphine re-circulation under plastic sheet fumigation with placing AlP in cotton bags in air-ducts was different from the first two methods. The negative pressure formed by re-circulation fan retarded the loss of PH_3 concentration and prolonged the hours of PH_3 at effective concentrations for high efficacy for all insect stages during the fumigation.

4.4 Economic Effect of Phosphine Re-circulation Fumigation under Plastic Sheet by Placing AlP in Air-ducts

Under the direction of the experts from Chengdu Grain Storage Research Institute, we compared the costs difference among fumigations of different phosphine resources (phosphine from on-site phosphine generator, high pressure steel cylinderized phosphine + CO_2, phosphine from natural air humidity generation of AlP tablets placing in air-duct) by fumigation tests in horizontal warehouses in August 2008. The result indicated there was no difference of controlling effect among fumigation with different phosphine resources. But, there was significant difference of costs among fumigation methods with different phosphine resources. See Table 2 for more details of costs of fumigation with different phosphine resources.

Table 2. Costs comparison of fumigation with different phosphine resources.

Fumigation method	Depot No.	Test time	Operation time	Labor force	Costs(yuan /ton grain)
A	2、3	2007.8	10min	2	0.070
B	5	2007.8	4h	2	0.210
C	2	2007.8	10min	8	0.256
D	3	2007.8	8h	4	0.337
E	1	2007.8	8h	4	1.080

Note:

a) The symbol "A" represents "placing AlP tablets in air-ducts + re-circulation fumigation under plastic sheet".

b) The symbol "B" represents "phosphine generated from on-site phosphine generator + re-circulation fumigation under plastic sheet".

c) The symbol "C" represents "placing AlP tablets on surface of grain stack + re-circulation fumigation".

d) The symbol "D" represents "phosphine generated from on-site phosphine generator + re-circulation fumigation".

e) The symbol "E" represents "steel cylinderized phosphine + re-circulation fumigation".

5 Conclusion

The greatest superiority of "Re – circulation fumigation under plastic sheet with placing AlP tablets in air-ducts" was that it promoted good phosphine dosage dispersion and distributed gas rapidly and uniformly through the grain bulk. Advantages of this method were as follows: flexible and safe operations, functional, economical, reduced pollution to grain, long efficient concentration, easy dust residue recovery.

In general, this technology was a combination of "phosphine re-circulation fumigation under plastic sheeting" and "placing AlP in air-ducts", which has many advantages, such as uniform distribution of PH_3, flexible and safe operations, functional, economical, reduced pollution to grain, decreased quantity of PH_3 used, good sealing property, and easy recovery of residual phosphine dust by pulling cloth bags from aeration ducts. The technology was particularly suitable for warehouse with broad space or plastic sheet.

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