0502

Effect of Airtightness Improvement in High Flat Warehouse on Recirculation Fumigation

Cui Dongyi and Wang Na

Abstract: Major gas leakage place in the tested warehouse after airtightness improvement were evaluated, and the pressure half-life ($t_{1/2}$) of the warehouse changed from 45s to 66s. Perform aluminum phosphide application experiment in the empty warehouse and perform timed test on changes of PH_3 concentration every day for 56 days continuously, the concentration half – life (reduces from 174mL/m^3 to 87 mL/m^3) is 31 days. After grain loading, perform PH_3 recirculation fumigation in it and the reference warehouse at the same time, under the same external conditions, perform timed tests on gas concentrations in the warehouse during fumigation process and collect, compare and analysis the obtained data to get the conclusion that the warehouse can keep the effective fumigation concentration for longer time through airtightness improvement.

Key words: flat warehouse, airtightness, recirculation fumigation, half-life

Fumigation is a process used for killing pest by chenicals in gas form. If the airtightness of fumigation environment is bad, it will cause leakage of fumigation gas and thus reduce the concentration of toxic gas and influence the efficacy of pest killing effect. For the past few years, recirculation fumigation technology has been used in various newly built warehouses generally. Since the recirculation fumigation technology use recirculation blower to force the fumigation gas to cycle and to be uniform in the fumigation environment during the fumigation process, if the airtightness of the fumigation environment can not meet the requirement, the leakage of toxic gas will happen at positive pressure section, and external gas will enter into negative pressure section[1].

Ct value shows that for most fumigation agents keeping lower concentration for longer time or higher concentration for shorter time results in same killing. However, based on practices and researches of many years, it has been proven that for PH_3 fumigation, the airtight time is more important than the concentration, and prolongation of the fumigation time of PH_3 is much better than the increasing of concentration[2]. It requires good airtightness of the fumigation warehouse to keep the effective concentration of the fumigation gas for adequate time. Therefore, when useing PH_3 fumigation, if the airtightness of the warehouse is not good, it will not be able to keep the time of effective concentration for pest killing, influence the fumigation effect seriously and result in failure of pest killing, or even result in vicious circle such as increasing of fumigation frequency, strengthening of resistance of pest, increasing of residual toxicity of grain, environment pollution, waste of human power and material resources and etc. Therefore, airtightness improvement of warehouse is the effective measure to keep the fumigation concentration and improve the fumigation effect.

The research of airtightness of fumigation warehouse is highly regarded by developed countries of the world. In Australia, this research has been started from the end of 1 970s and it performed airtightness improvement of warehouse and divided the warehouses into three classes by pressure decay method. It defined that if the time of reducing of original pressure from 2 500Pa to 1 500Pa is not less than 5 min, it will be defined as the first class warehouse; if the time of reducing of original pressure from 1 500Pa to 750Pa is not less than 5 min, it will be defined as the second class warehouse; if the time of reducing of original pressure from 500Pa to 250Pa is not less than 5 min, it will be defined as the third class warehouse [3]. In Holland, the fumigation warehouses also have been divided into three classes; the standard was the same as that of Australia basically. In Japan, it defined that after building of silo finished, increase the pressure of the empty warehouse to 4 900Pa, after 20 min., if the pressure is still more than 1 960 Pa, it will be defined as A class warehouse; if the pressure

Xinle Grain Depot, State Grain Reserves, Xinle, Hebei, 050700

is reduced to 980 Pa, it will be defined as B class warehouse. The airtightness standard of PH_3 fumigation of bagged grain of the Association of South East Asian Nations is that the time of reducing from 500Pa to 250 Pa should be more than 10 min[4].

Ever since a long time ago, grain storage technicians and related experts and scholars of our country also have done a large number of researches on airtightness of warehouse. In 1987, Tang Shungong suggested the standard of grain storage fumigation warehouse was that the time of reducing of pressure from 490 Pa to 250 Pa should be more than 30 seconds[5]; and after this Wu Zengqiang, Hu Dongsheng and Zhang Chengguang also performed determinations of airtightness of silos[6].

The test described in this article used advanced experiences at home and abroad for reference, and performed airtightness test in newly-built high flat warehouse by pressure decay method, then determined the changes of PH_3 concentrations in the empty warehouse and the reference warehouse separately after airtightness improvement is performed. The obtaining of these data provides some references for grain storage fumigation works in our company.

1 Airtightness Test and Concentration Decay Test of the Empty warehouse

1.1 Basic Content of the Test

Through test, we found that the major leakage places were door, window, mechanical ventilation outlet, axial-flow blower outlet, thermometric cable hole and wire hole, recirculation fumigation hole of the newly-built high flat warehouse and etc. Perform airtightness handling for above outlets and holes with suitable methods and thus improve the airtightness of the grain warehouse.

1.2 Materials of Test

1.2.1 Tested warehouse: No. 36 high flat warehouse, Xinle Grain Depot, State Grain Reserves, brick-concrete structure, top of arch bar; length: 53.74m, width: 23.15m, total volume: 13 434.06m^3, verified volume of the warehouse is 5 690 tones.

1.2.2 Silicone sealant Peeling strength of the material is 4N/mm, the maximum elongation is 35%, elastic recovery rate is 95%, movement capability is ±25%, produced by Beijing Gutebang Material Technology Co., Ltd.

1.2.3 Centrifugal blower Power: 7.5 kW, air volume: 5712 – 10562m^3/h, wind pressure: 2554 – 1673 Pa, produced by Shijiazhuang Blower Factory.

1.2.4 PH_3 concentration tester Test range: 0 – 500mL/m^3, produced by German Drager Company.

1.2.5 Polystyrene foam plate Density: 20kg/m^3, thickness: 100mm. produced by Hebei Xinji.

1.2.6 Others Pressure gauge, gate valve, connecting cylinder, stopwatch and etc.

1.3 Test Process

1.3.1 Pressure decay method

1.3.1.1 Before handling of airtightness, performed normal sealing of holes such as door and window of the warehouse with plastic film, and kept one ventilation opening for installation of gate valve, connecting cylinder, centrifugal blower, and installed pressure gauge at the front – end of airtight gate valve. See figure 1.

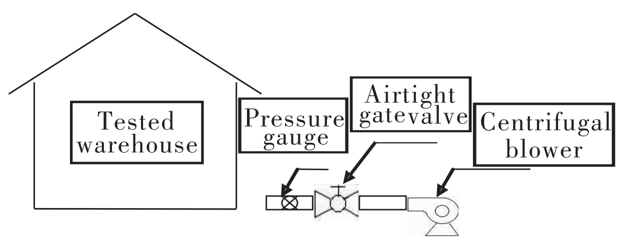

Fig. 1 Schematic diagram of airtightness test of warehouse

Performed pressurization through positive pressure ventilation by blower, when the pressure in the warehouse rose to 550Pa, closed the blower and airtight gate valve, and began to clock when the pressure reduced to 500Pa; the time of reducing to 250Pa i. e. the pressure half-life ($t_{1/2}$) was 45s. Performed observation and inspection for major places at which air leakage may happen at the same time, including door and window, thermometric cable hole, wire hole, recirculation fumigation hole and ventilation outlet, axial-flow blower outlet and etc. Determined if air leakage happened at the place which may had cracks by soap lye method. See table 1 for detailed status of air leakage.

Table 1. Record of air leakage inspection in the tested warehouse (pressure method)

Place	leakage(Y/N)	leakage degree
Door	Y	serious

Place	leakage(Y/N)	leakage degree
Thermometric cable hole	Y	general
Wire hole	Y	general
Recirculation fumigation hole	Y	general
Window	Y	general
Axial-flow blower outlet	Y	serious
Mechanical ventilation outlet	N	——

1.3.1.2 Handling measures of air tight

According to the test result of airtightness of the warehouse, performed airtightness improvements on related places, and the detailed measures are as follows:

Door: Installed one layer of polystyrene foam plate (hereinafter referred to as "polystyrene plate") near the inside of the external door. Joint seams between polystyrene plate and wall or polystyrene plate and polystyrene plate were sealed with silicone sealant. In order to enhance the strength of polystyrene plate, stick one layer of fiberboard on the polystyrene plate.

Window: Performed blocking with polystyrene plate, then smeared silicone sealant all around the joint seams between polystyrene plate and the window.

Axial-flow blower outlet: Performed sealing and blocking with polystyrene plate, and smeared silicone sealant all around the joint seams.

Recirculation fumigation hole: Smeared silicone sealant directly and filled up all around the pipelines and cracks of wall.

Mechanical ventilation outlet: In order to ensure the effect of test, performed blocking with polystyrene plate inside the outlet, then smeared silicone sealant all around the polystyrene plate.

1.3.1.3 After handling of air tight, performed pressure half-life test again; the method, steps and materials of pressurization was the same as

1.3.1.4 Through three times test, the pressure half-life was 66s. Performed observation and inspection on airtightness improvement places, and no air leakage was found.

1.3.2 Concentration decay method

After test with pressure method, charged 12kg of aluminum phosphide tablets into the tested warehouse and closed it immediately, tested for three times at east place and west place separately with PH_3 concentration tester on 8:30 every day (see table 2). After the airtight improvement, the half-life of PH_3 concentration (reduced from 174 mL/m^3 to 87mL/m^3) of the tested warehouse was 31 days.

Table 2. PH_3 concentration of the tested warehouse (mL/m^3)

Time (d)	1st time		2nd time		3rd time	
	East	West	East	West	East	West
1	23	19	18	18	21	18
2	67	63	67	60	69	67
3	108	106	109	110	110	110
4	143	140	146	143	147	147
5	150	148	154	150	154	158
6	161	162	161	163	162	160
7	168	169	170	168	171	169
8	174	173	172	178	175	174
9	170	168	164	166	165	167
10	159	160	157	159	160	167
11	150	156	151	156	160	160
12	157	152	157	152	157	154
13	149	149	149	147	151	147
14	147	144	147	146	147	146
15	143	139	143	139	144	140
16	142	138	142	138	142	138
17	135	132	135	132	135	132
18	132	129	131	129	131	129
19	127	129	127	126	127	126
20	124	125	124	125	124	125
21	124	116	124	116	124	116
22	116	113	115	113	114	113
23	112	109	111	109	110	109
24	109	106	109	106	109	106
25	107	106	107	106	107	106
26	105	102	104	102	103	103
27	104	103	103	102	102	101
28	100	99	101	99	100	99
29	99	98	98	97	99	98
30	96	95	96	95	96	95

Time (d)	1st time		2nd time		3rd time	
	East	West	East	West	East	West
31	94	92	94	93	94	92
32	92	92	92	92	92	92
33	93	92	92	92	92	92
34	92	91	91	92	91	90
35	91	90	90	89	89	87
36	89	89	88	94	87	86
37	86	86	88	92	93	88
38	87	85	88	89	86	87
39	80	82	88	81	83	82
40	78	79	78	79	77	80
41	76	76	76	76	76	76
42	74	73	74	73	74	73
43	73	72	72	72	73	72
44	71	70	70	70	70	70

1.4 Results and Analysis

1.4.1 Performed three times test of airtightness of the tested warehouse before and after airtightness improvement separately, and the pressure decay time of each time was the same basically and showed good reproducibility. Pressurization test of the empty warehouse showed that the pressure half-life $t_{1/2}$ after handling was prolonged from 45s to 66s, nearly prolonged for 1/3 time, and the improvement of airtightness was comparatively larger; see figure 2 for the airtightness curves before and after handling.

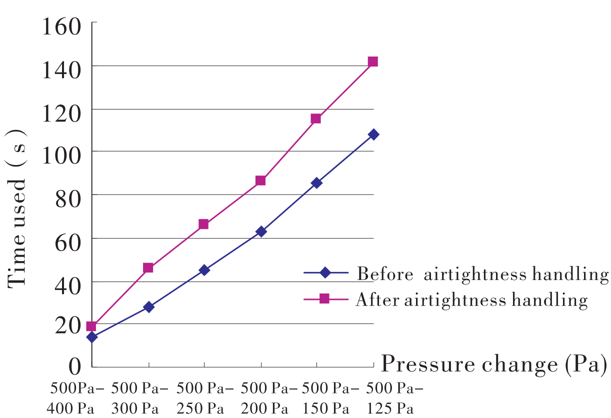

Fig. 2 curve graph of airtightness changes of the tested warehouse before and after handling

1.4.2 The major materials used for airtightness handling were polystyrene foam plate and silicone sealant. In which, polystyrene plate is the relatively ideal heat-proof, air-tight material, whose weight is light, and which is not easy to be distorted, no toxicity and heat proof. However, consider suitable density when select it and put it to use. Generally, choose the product whose density is around 20kg/m^3. Silicone sealant is a building material which is shapeless and can be pressed and used for filling of cracks, sealing and blocking of holes and make them airtight. It will not be softened excessively under the high temperature condition of North China, and brittle rupture of it will not happens under the low temperature in winter, the stickiness with joint seam is stable and it also has the function of water penetration resistance, its use is simple and it can be operated without professional personnel, and dismounting is convenience; polystyrene plate can be used repeatedly. These two materials are normal building materials and can be found everywhere in the market; they are cheap, practical and their performance-price ratio is higher.

1.4.3 When performing of airtightness improvement, one should not only pay attention to door, window, threading hole, ventilation opening, axial-flow blower outlet, but also showed pay attention to backfilling place of scaffolding during construction and cracks of wall.

1.4.4 The concentration half-life of this test was 31 days; theoretically, this air tight time is adequate to kill various pests in different stages. The set concentration of this test was 200 mL/m^3, and the actual measured maximum value was 178 mL/m^3; through analysis, the reason may be absorption and the leakage of some places which have not been inspected.

2 Field Test

2.1 Materials of Test

2.1.1 The tested warehouse was still No. 36 warehouse, in which, stored wheat was 5721t, impurity was 0.8%, water content was 11.2%, incomplete particles was 4.1%, grain loading time was August 2003; the reference warehouse was No. 48 warehouse of which structure was the same as that of No. 36 warehouse, its stored wheat was 5760t, impurity was 0.8%, water content was 12.1%, incomplete particles was 6.0%, grain loading time was July 2003, and the average grain temperature was 25.8 ℃. Both warehouses were bulk storage.

2.1.2 Aluminum phosphide tablet Purity 56%, Produced by Shandong Jining.

2.1.3 Centrifugal blower same as 1.2.3.

2.1.4 PH_3 concentration tester same as 1.2.4.

2.1.5 Others same as 1.2.6.

2.2 Test Process

Performed airtight handling for the tested warehouse according to the method of 1.3.1.2, and performed airtight of the door and window of the reference warehouse with PVC film only, then performed pressurization test separately; the results are shown in table 3 and table 4. The pressure half-life of the tested warehouse was 62s, and the pressure half-life of the reference warehouse was 38s.

Table 3. Record of field air tightness test of the tested warehouse (pressure method)

Changes of pressure (Pa)	Time used for determination of pressure decay (s)			
	1st time	2nd time	3rd time	Average value
500 – 400	16	17	17	16.7
500 – 300	42	42	43	42.3
500 – 250	60	63	64	62.3
500 – 200	79	80	81	80.0
500 – 150	108	110	110	109.3
500 – 125	132	133	132	132.3

Table 4. Record of field air tightness test of the reference warehouse (pressure method)

Changes of pressure (Pa)	Time used for determination of pressure decay (s)			
	1st time	2nd time	3rd time	Average value
500 – 400	12	12	13	12.3
500 – 300	26	27	27	26.7
500 – 250	38	39	38	38.3
500 – 200	59	58	57	58
500 – 150	79	80	79	79.3
500 – 125	100	100	100	100

From table 3 and 4, we can see that $t_{1/2}$ of the tested warehouse is higher than that of the reference warehouse, since $t_{1/2}$ represents the technical requirement of the warehouse airtightness for the PH_3 fumigation, and the higher $t_{1/2}$ represents the better airtightness of the warehouse.

Adult *Sitophilus zeamais* Motschulsky were found in both warehouses; performed recirculation fumigation with grain surface application. The concentration was set at 350 mL/m^3, dosage at 1.5g/m^3, and apply 20kg of 56% aluminum phosphide tablets separately, and set 120 application points. Set 10 test points of PH_3 concentration for each warehouse, and divided it into east area and west area, 5 points for each area. See figure 4 for details.

Fig. 3 Map of test points of PH_3 concentration

Test probes were buried at 50cm under the grain surface. Began to do fumigation from August 19, and performed circulation work 6 hours after application for 24 hours continuously. From the morning of the next day, tested the PH_3 concentration at 9:00 am every day. (table 5, table 6). Performed suitable recirculation according to the status of changing of the concentration; it should be not less than 12 hours for each time.

2.3 Result and Analysis

2.3.1 Pest killing effect: after the test finished, took 1kg of sample from both warehouses separately and cultured them in incubator of the laboratory under the conditions of 25℃ and 70% RH. Two weeks later, no live pest was found, and the pest killing ratios for both warehouses were 100%. Perform analysis from fumigation effect, and it is found that when the application dosages for the tested warehouse and the reference warehouse are higher than that specified in "Technical standards for PH_3 recirculation fumigation", the goal of complete pest killing can be achieved.

Table 5. Record of field PH_3 concentration of the tested warehouse unit: mL/m^3, d

Time	Test point 1		Test point 2		Test point 3		Test point 4		Test point 5	
	East	West	East	West	East	West	East	West	East	West
1	140	143	145	150	145	140	141	145	145	140
2	170	172	168	178	180	170	170	170	182	186
3	198	195	190	210	199	200	188	191	202	200
4	232	230	234	234	230	231	229	231	230	232
5	246	244	244	246	244	240	236	238	242	240
6	265	270	268	282	271	269	270	268	272	270
7	272	278	280	286	289	285	278	278	286	290
8	280	283	290	295	301	302	300	298	299	310
9	299	301	276	280	320	318	300	311	302	303
10	291	292	270	272	330	332	321	335	310	326
11	295	294	272	270	321	325	316	320	305	320

Time	Test point 1		Test point 2		Test point 3		Test point 4		Test point 5	
	East	West	East	West	East	West	East	West	East	West
12	300	290	275	270	315	321	305	306	300	311
13	291	288	270	272	295	300	289	295	290	298
14	283	283	268	270	292	293	270	275	280	279
15	282	276	254	248	280	262	248	276	253	288
16	289	282	267	260	290	270	240	265	250	275
17	274	270	230	256	289	278	240	266	240	280
18	268	260	220	248	270	270	220	257	230	263
19	246	245	208	230	263	260	200	250	210	261
20	252	241	208	232	260	253	192	244	203	261
21	243	230	218	224	270	246	188	230	212	248
22	237	222	210	210	268	232	179	211	216	233
23	222	208	204	191	253	222	172	200	204	231
24	210	198	200	178	230	200	169	191	200	223
25	202	184	194	168	219	185	168	177	198	206
26	199	170	189	150	200	168	170	159	175	192
27	196	169	188	143	200	162	158	157	189	189
28	184	150	171	132	189	151	150	138	173	159
29	162	139	154	120	173	138	140	129	163	140
30	154	119	140	101	161	102	123	103	139	120
31	141	96	130	88	151	87	113	80	127	92
32	132	90	118	84	146	83	102	78	120	90
33	114	90	108	80	132	80	94	79	113	88
34	102	89	100	82	128	79	90	78	101	86
35	105	88	95	78	112	82	87	70	93	71
36	90	75	84	72	105	68	81	70	82	76

Table 6. Record of field PH_3 concentration of the reference warehouse (unit: mL/m^3 d)

Time	Test point 1		Test point 2		Test point 3		Test point 4		Test point 5	
	East	West	East	West	East	West	East	West	East	West
1	132	125	130	128	135	140	138	158	120	125
2	160	155	160	150	161	165	165	172	150	154
3	192	188	172	177	175	172	178	189	167	160
4	212	200	190	198	190	189	202	216	200	200
5	240	232	213	215	230	226	220	231	218	223
6	266	260	235	236	256	257	255	250	248	256
7	273	270	275	270	298	289	275	279	262	273
8	290	288	278	278	315	320	288	290	278	295
9	265	263	282	280	290	289	291	282	280	284
10	248	250	260	271	275	270	273	274	262	250
11	230	249	235	264	260	259	262	254	255	245
12	228	248	230	242	238	252	229	238	242	236
13	218	218	218	218	221	218	220	217	217	216
14	220	212	224	220	222	224	220	222	224	224
15	204	210	210	212	212	206	210	204	210	208
16	198	199	200	201	200	199	201	190	203	196
17	189	190	180	180	190	180	188	178	192	189
18	188	190	165	190	192	170	192	170	170	175
19	172	178	146	171	179	161	170	159	152	161
20	153	162	131	152	156	149	162	148	141	149
21	140	150	125	125	140	140	150	130	130	140
22	117	116	124	117	122	120	126	124	119	120
23	98	100	112	102	110	105	106	100	106	106
24	88	99	103	103	81	104	90	104	96	101
25	75	77	93	90	70	85	75	85	75	88
26	72	73	76	83	68	67	64	63	65	66

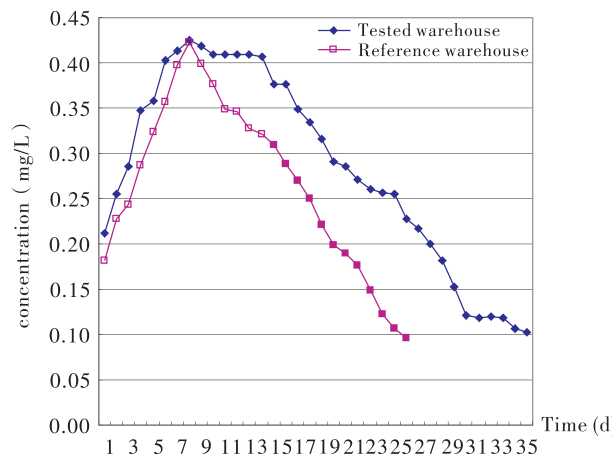

Fig. 4 Changes of PH_3 average concentration of the tested warehouse and the reference warehouse

2.3.2 Comparison of fumigation effects: Ct value of the tested warehouse was 224.5 mg h/L, the holding time of the effective concentration was 30 days; Ct value of the reference warehouse was 158.4mg h/L, the holding time of the effective concentration was 22 days. The Ct values and the holding times of the effective concentration for both warehouses were the same as the $t_{1/2}$ of both warehouses, i.e. $t_{1/2}$ of the tested warehouse was higher than that of the reference warehouse, and its Ct value and the holding time of the effective concentration were higher than those of the reference warehouse.

2.3.3 Changes of the concentration: after the concentration became to be uniform basically through recirculation, the minimum PH_3

concentration tested from each point was the fumigation concentration. From table 5, table 6 and figure 4, we can see that the trend of changing of the PH_3 fumigation concentration in the tested warehouse is relatively gentle; from the 8^{th} day to the 14^{th} day, the concentration kept in the higher range and concentration decay was slow. On the 15th day, the concentration reduced suddenly; through analysis, the reason may be the rate of ventilation was not enough since the recirculation time was shortened or because of slight leakage of individual place. In summary, the holding status of the PH_3 fumigation concentration of the tested warehouse was better than that of the reference warehouse. For the time of PH_3 fumigation concentration decaying to 100 mL/m^3, the tested warehouse was 30 days and the reference warehouse was 22 days. According to the effective concentration stated in "Technical standards for PH_3 recirculation fumigation", the tested warehouse can reduce the unit dosage and thus reduce total application dosage, it also can obtain good pest killing effect.

Test result showed that, the better airtightness of the warehouse, the longer holding time of the effective concentration, the higher Ct value, the better fumigation effect.

3 Conclusion

The test showed that, through the airtightness improvement of the warehouse, it can improve airtightness of the warehouse, prolong the pressure half-life, not only can improve the pest killing effect of fumigation and reduce fumigation cost, but also can reduce exchange of wet heat gas in and out of warehouse, reduce generation of entomomycete and thus reduce fumigation frequency, improve grain storage environment, delay aging of the stored grain and keep quality of the stored grain, realize energy saving and discharging reducing and create good social benefits and economic benefits.

References

[1] Bai Xuguang et al. Stored product pests and their prevention and treatment. Science Press

[2] Wang Dianxuan, Cao Yang et al. PH_3 pest killing technology. Chengdu Science and Technology Press

[3] Zhang Lailin, Li Chaobin, Zhao Yingjie. Test and improvement of airtightness of grain warehouse. Grain Storage 2003(4)

[4] Compiled by East Asian Nations Food Bureau and ACIAR; recommended to be used as fumigation guideline for East Asian Nations Food, 1990

[5] Tang Shungong, Discussion on airtightness standard of silo, Grain Storage 1987(6)

[6] Liu zhenyong, Fan Lei, Zhou Xiaojun et al, Research on relationship between airtightness and PH_3 concentration. Grain Storage 2002(1)