Donahaye, E.J., Navarro, S. and Leesch J.G. [Eds.] (2001) Proc. Int. Conf. Controlled Atmosphere and Fumigation in Stored Products, Fresno, CA. 29 Oct. - 3 Nov. 2000, Executive Printing Services, Clovis, CA, U.S.A. pp. 483-495

PHOSPHINE FUMIGATION FAILURES IN CONCRETE SILOS IN THE SOUTHWESTERN U.S.A.

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ABSTRACT

For over half a century uniform pellet distribution in grain was thought to be the "ideal" concrete silo fumigation method in U.S. grain elevators. In the mid-1990s, a U.S. phosphine (PH_3) manufacturer used three dosage methods in four unsealed silos, sampling gas at four levels to study PH_3 gas movement (1995). Two uniformly dosed silos lost most of their gas in 48 h. Silos with pellets in the bottom half of the silo maintained gas levels beyond 72 h. Headspace readings were low in all tests. Strong upward convection currents from wind blowing through under-roof exterior wall vents apparently sucked gas out.

In 2000, OSU researchers fumigated six silos twice, first "unsealed", then "sealed" with gas samples taken at 6 depths. Silos vents were "sealed" using expanding foam during the second test series.

The test dosages were the mean of PH_3 dosages for concrete silos, 210 pellets per 27.2 tonne, or 7.8 pellets per tonne. Three dosage methods were "uniform", "layered" and "bottom" dosage in two silos per dosage. Weather conditions were documented by OSU MESONET. In general, gas readings decreased more rapidly in unsealed than sealed silos. Daily readings in sealed silos showed that gas plumes moved upward slower in sealed than unsealed silos. Although gas dissipated steadily, gas levels remained generally higher in the same silo after the exterior under-roof vents were sealed, regardless of dosage method. Leakage occurred faster than expected in some "sealed" silos. These "head-house" silos had unsealed 35.6 cm fill spouts that apparently created strong convection currents from wind. The data reveals that in general, sealing under-roof exterior vents makes a significant difference in PH_3 gas retention compared with the same silo unsealed. Sealing down-spouts by setting the distributor to a blank position should increase gas retention in head-house silos.

INTRODUCTION

For decades, failures have been experienced in fumigations at U.S. concrete silo grain elevators using automatic pellet dispensers while "turning" grain from full to empty silos. The placing of pellets uniformly throughout the grain was thought to be the "ideal" concrete silo fumigation method.

"Random" concrete silo fumigation failures did not arouse USDA or university researchers' concern until the mid-1990's, when a U.S. phosphine manufacturer conducted field tests on four silos with gas sampling tubes at 0 (headspace), 6.1, 18.3 and 35.7 m (0, 20, 60 and 117 ft) depths in an attempt to identify causes of failure. Their results were startling. Unsealed silos that were uniformly dosed lost most of their gas during the first 48 h. Silos with pellets hand applied in the bottom half of the silo maintained gas levels beyond 72 h. However, headspace readings were very low throughout all tests. The apparent cause for failure was strong upward convection air currents caused by wind blowing through silo under-roof exterior wall vents that continuously sucked the gas out.

In September/October, 2000, OSU researchers studied six "unsealed" versus the same six "sealed" concrete silos, sampling gas at 1.5 (headspace), 3.0 (just below the surface), 7.6, 15.2, 22.9 and 27.4 or 30.5 m depths of the silo during field tests targeted at 7 d. "Sealed" silos involved foam sealing of exterior under-roof vents and manholes in roofs.

THE STUDY: MATERIALS AND METHODS

The concrete silos used in the research study were at the Douglas Farmers Exchange Elevator, Douglas, Oklahoma. Prior to starting the tests an elevator site visit was made by the researchers to survey the facility and equipment in order to design the apparatus needed for sampling the gases during the test, and to discuss the research protocol plan with the elevator manager and the elevator superintendent. The country grain elevator concrete head-house containing 10 silos was selected to study three fumigant pellet dosage treatments in six silos chosen at random.

The three treatments were: (i) uniform pellet placement in the grain using an automatic pellet dispenser; (ii) bottom application with all the pellets being hand dispersed during a 2 min period in the initial 3-5 min of grain transfer; (iii) layered application with the dosage split in thirds and applied during the first 3-5 min of grain transfer, then at one h intervals, so that the second layer was approximately at the mid-point of the silos. Pellets were applied automatically in two silos, placed in the bottom of two silos, and placed in three equally spaced layers (in the bottom half of each silo) in another two silos.

Facilities, equipment and apparatus

Six PH_3 gas sampling depths were selected for each silo. Gas was sampled at 1.5 (headspace), 3.0 (just below the surface), 7.6, 15.2, 22.9 and 27.4 or 30.5 m depths. Silo 9 was 27.4 m deep, while silos 1, 5,6, 7 and 8 were 30.5 m deep.

Gas was monitored at PH_3 concentration levels from 1 to 10,000 ppm using digital electronic gas monitoring equipment, glass gas sample tubes and a hand pump. Electronic samplers used were an ATI Porta Sens II with a 200-2,000 ppm and a 20-200 ppm PH_3 sensor, a Dräger Mini Warn with 0-500 ppm PH_3 sensor. A Dräger hand pump with 0-1,000 ppm, 25-900 ppm and 50-10,000 ppm PH_3 glass sample tubes was also used for verification of electronic monitor calibration and to measure gas readings that exceeded 2,000 ppm.

Wind speed, direction, and temperature data were observed on site when gas readings were taken using a hand held digital velometer and a Fluke digital thermocouple thermometer. Area weather conditions were documented by two OSU MESONET weather stations located about 15 miles south and north of Douglas, OK (there are 110 MESONET stations in Oklahoma, with at least one

MESONET weather recording site in each of Oklahoma's 77 counties). Hourly wind speed, temperature and humidity data were obtained.

Figure 1 shows the plan view of the concrete head-house and silos. Silos 1, 5 and 7 form the north side of the concrete elevator. Silos 3, 6 and 8 were along the south side, silo 2 was at the west end and silo 9 was on the east end. Silos 4 and 10 were internal silos. Silos selected for "**uniform**" treatment were 6 and 9. Silos 1 and 8 received the "**bottom**" dosage, while silos 5 and 7 received the "**layered**" dosage.

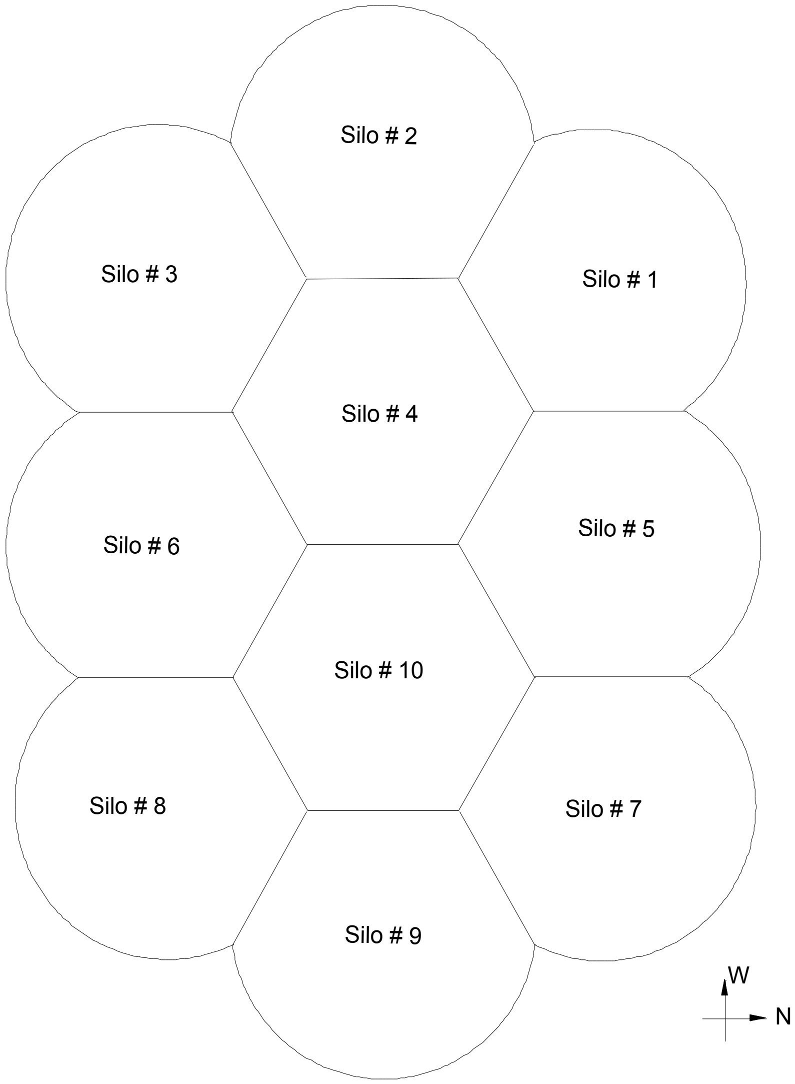

Fig. 1. Elevator silo layout pattern used for unsealed and sealed silo tests.

The "**unsealed**" tests were conducted first, (phase I) followed by foam sealing of the exterior under-roof wall vents. Then the "**sealed**" tests were conducted (phase II).

Phosphine gas sample tubes were 4.75 mm (3/16 in) o.d. and 2.375 mm (3/32 in) i.d. polyethylene tubing cut to lengths for sampling at 1.5 m (5 ft), 3 m (10 ft), 7.6 m (25 ft), 15.2 (50 ft), 22.9 (75 ft) and 27.4/30.5 m (90/100 ft). These six tubes were taped to a 30.5 m (100 ft) long by 1.11 cm diameter woven nylon rope with a rated breaking strength of 1360 kg (3,000 lbs). Poly sample tubes were taped to the rope at 0.5-0.6 m intervals using 4.5 cm wide medium quality duct tape.

During grain unloading after the "**unsealed**" tests were run and immediately before initiation of the "**sealed**" tests, most of the ropes and tubing assemblies had to be rebuilt due to severe shearing forces caused by the grain sliding down between the tubing and rope. This caused the tubing to pull down, and slide along the rope. After the first silos were unloaded, most of the tubing had to be replaced and the ropes re-taped. A spray adhesive, Camy 363, was used between the duct tape and the rope and poly tubes to increase the bonding and increase the physical resistance to sliding of the duct tape and poly tubes along the rope. A high quality nylon mesh reinforced heating system duct tape with high adhesion was used for rebuilding of the tubing/rope assemblies. Both 4.5 cm and 7.5 cm widths of the high quality duct tape were used for securing the tubing to the ropes by making an initial wrap of duct tape around the rope, then continuing wrapping at least two to three revolutions around the tubes and rope. The 7.5 cm wide tape was ideal for sealing manholes as it spanned the gap between the concrete roof deck and the cast iron manhole cover.

Two pieces of 3.75 cm x 3.75 cm by 0.3 cm thick steel angle iron bracket with adjustable chain link assembly were connected to a loop at the top of the rope to support the rope and gas sampling tubes. The angles were formed to fit across the rim of the 47.5 cm (19 in) i.d., 5 cm high steel manhole lip so the cast iron manhole cover fitted over the brackets. One side of the cover was held up by the brackets, and allowed the 6 poly sampling tubes to pass between the manhole rim and cast iron cover without crimping the tubes.

As soon as a silo was empty, the steel support bracket assembly was placed over the manhole rim and the gas sample tube and rope unit was lowered into the silo.

Phosphine dosage levels and gas sampling

As soon as grain turning started, pellet placement was initiated for the planned dosage treatment. Test dosages were the mean level of the PH_3 dosage ranges used for concrete silos, namely 120-300 pellets per 27.2 tonnes (1000 bu), 210 pellets per 27.2 tonne, or 7.7 pellets per tonne. For "**Uniform**" treatment, an automatic pellet dispenser was set to dispense about 4,200 pellets (1.5 canisters) into 545 metric tonnes of grain in 4 h at 1,050 pellets per h, or 17.5 pellets per min.

The PH_3 dosage of 210 pellets per 27.2 metric tonnes (1000 bu), or 7.8 pellets per metric tonne, were adjusted for variations in silo volume, as listed on the official elevator facility specification sheets, supplied by the elevator manager. For example, some silos contained only 490 metric tonnes (18,000 bushels) while others contained 545 tonnes (20,000 bushels). The 490 tonne silo received 90% as many pellets as the 545 tonne silo.

For the **"bottom"** dosage tests, approximately 1.5 canisters of pellets (2,490 pellets per canister) were dispersed by pouring the pellets into the man-hole during a 60-90 sec period starting within 5 min of the beginning of grain transfer into the silo.

During the **"layered"** dosage tests, about 1.5 canisters of pellets were divided into three equal portions with 0.5 canister dispersed at about 1 h intervals. The first layer was added by slowly pouring the pellets into the silo man-hole during a 60-90 sec period starting within 5 min of the beginning of grain transfer into the silo. The next two layers followed the same procedure at one hour intervals, so the third layer was approximately at the middle level of the silo.

Gas sampling was done at about 24 h intervals as long as there was measurable gas in the silo starting the day following the fumigant dosage application. Sampling continued until the low gas readings were below a level considered to provide efficacy during fumigations, about 25-30 ppm.

Sealing exterior under-roof vents

When all silos were clear of gas following phase I that comprised the "unsealed vent" tests, the exterior under-roof vents were then sealed using a closed cell expanding foam dispensed from pressurized canisters. The foam applicator wore a safety belt with the safety rope tied securely to the safety rail around the top of the silos to prevent him from falling off the silos in the event of sudden high wind gusts. Compressed air was used to blow dust out of the 15 cm x 25 cm vent openings just before the foam was applied in layers to each vent opening.

A cardboard template about 12 cm x 20 cm in size, with a piece of stiff aluminum wire connected to the middle of the cardboard, was inserted between the steel 1.5 cm diameter vertical reinforcing bars so the cardboard was positioned about 1-2 cm behind the steel bars. Layers of foam were injected around the cardboard template and behind the steel bars. Foam was placed in layers from the bars to the outer edge of the concrete wall. This should be done slowly so the foam has adequate time to expand to about 3 times its original volume. However, since 8 vents needed to be sealed before the second phase of research could begin, larger layers were placed than was recommended. Wind was also a factor as wind pressures tended to buffet the foam while it was soft prior to "setting-up" or curing on the outer surface. Thus, some of the foam tended to flow forward and down past the edge of the concrete wall. Also air currents blowing through the silo headspace caused openings at the top and sides of the foam before it hardened. These were filled in during a follow-up pass to check all vents.

A retainer cord was taped to the foam can and was secured to prevent the can from being blown off the elevator. A side mirror from a truck, also secured by a retainer cord, was held over the edge so the applicator could check the vent foaming without leaning over the roof edge. After initial layering of the vent openings was completed, several more vents were foamed, allowing the foam to complete expanding, and the surface to harden. Then the mirror was used to see how much more foam layering was needed, and another layer of foam was added to the original layer. By the third application, gaps in the foam at the top of each vent were filled and the vents were sealed.

Note: Experience showed that it is very important to recheck and seal even small leaks in the foam, and foamed vents should be checked during silo filling. Leaks were found on two of the eight silo vents. Leaks were indicated when grain dust was blown out of small openings. To seal the leaks, the dust was cleaned off and blown out of the openings using a high-pressure air hose. Then the foam-can spout or applicator tube was pushed against or into the opening to fill the inside voids. Then additional foam was added to the outside over the leak point.

RESULTS: UNSEALED *VS.* SEALED EXTERIOR UNDER-ROOF VENTS

As soon as the vents were sealed, transfer of grain, and dosage applications were undertaken at the same rates into the same silos to begin the phase II of "**sealed**" silo testing. Although the sequence of tests did not follow the exact daily pattern in phase II as in phase I, the same silos were used with the same gas dosage levels applied.

Gas readings were started on each fumigated silo about 1 day after the fumigant dosage was applied. Tables 1-6 list PH_3 concentrations at daily intervals. Test results of each "unsealed" and "sealed" silo are listed together to provide a direct visual indication of the change in gas levels throughout each test.

Table 1 lists **uniform** dosage in Silo 6. Since most of the gas in ***unsealed*** Silo 6 was gone by the end of Day 1, about 24 h from the time the dosage started, it is obvious that this fumigation was a failure. Gas levels suitable for efficacy were only retained from the 15.2 m level and higher at the end of Day 1, and only in grain near the surface and headspace by the end of Day 2.

The ***sealed*** test results in Silo 6 showed a definite improvement obtained by sealing with much higher gas concentrations in the upper 75% of the silo, and usable gas levels to almost the full depth at the end of Day 1. However, the movement of the gas plume is quite obvious, and even with the exterior vents sealed, gas in the lower 75% of the silo was below usable levels by the end of Day 3. Most of the gas had dissipated by the end of Day 4. So, uniform application of phosphine pellets in this silo with the exterior under-roof vent sealed did not result in successful fumigation conditions. Average wind conditions during the ***sealed*** tests were lower than the first two days of the ***unsealed*** tests for Silo 6, then increased sharply during the remaining three days of the recorded test. Maximum wind speeds were near the same levels for the first two days of each test.

MESONET wind data is sensed at 10 m above ground level. This level is only about 33% of the height of the under-roof vents on this and most concrete silos in the U.S. Wind speeds tend to increase by 50 to 75% between 10 and 30 m above ground elevation. As shown in Fig. 1, Silo 6 was located in the middle of the south side of the elevator head-house. The roof deck extends out past the silo wall by about 0.20 m, which acts as a wind dam, increasing the wind pressure against the vent. The elevator leg head-house extends another 10-12 m above the silo roof deck, where winds create strong pressure differentials between up-wind and down-wind sides.

The second **uniform** dosage treatment was in silo 9, on the east end of the elevator. Gas leaked during both the unsealed and sealed tests, though in the latter case it was slower. The ***unsealed*** test showed suitable gas concentration levels at the full silo depth during Day 1 only. Substantial gas levels were only retained in the top 50% of the silo through Day 3. By Day 4 gas concentrations were below 100 ppm throughout the silo.

TABLE 1
Phosphine concentrations in ppm in silo 6, and daily wind speed in km/h

Fumigation conditions: **uniform** dosage, ***unsealed*** roof vents.
Started September 23, 2000

Depth (m)	Day 1	Day 2	Day 3	Day 4
1.5	800	110	9	2
3.0	64	57	5	2
7.6	230	7	1	1
15.2	43	1	0	0
22.9	9	0	0	0
30.5	0	0	0	0
Wind speed (km/h)				
Av.	11.9	13.5	5.1	6.1
Max.	21.7	22.7	18.7	14.8

Fumigation conditions: **uniform** dosage -- ***sealed*** roof vents
Started October 3, 2000

Depth (m)	Day 1	Day 2	Day 3	Day 4	Day 5
1,5	2,500	1,030	460	16	5
3.0	1,830	1,150	270	8	3
7.6	740	1,120	33	2	2
15.2	485	177	4	0	0
22.9	230	15	0	0	0
30.5	16	0	0	0	0
Wind speed (km/h)					
Av.	9.6	7.1	14.6	11.3	6.9
Max.	24.4	23.2	25.1	24.9	24.0

Uniform dosage ***sealed*** tests indicated a slow upward movement of the gas plume. A loss of gas in the headspace and grain surface occurred by the end of Day 2, but upward movement of the plume kept gas levels of 27-30 ppm at the top until Day 5. This would be considered a successful fumigation.

Table 3 lists **layered** dosage data for Silo 7, located on the north-east corner of the elevator. This silo is also only about 1-1.5 m from the silo annex, so it is sheltered from north and south winds. The **layered** dosage method with all gas in the bottom half of the silo caused a diagonal pattern of gas development and movement. The plume in this **unsealed** test shows a narrow profile. Most of the high concentration at the bottom of the silo on Day 1 had dissipated, with only 2,400 ppm recorded at the midpoint of the silo at the end of Day 2. Because of the 7.2 m distance between sampling points in the bottom 75% of the silo, high levels of gas concentration seem to have been moving between sampling points at the 24 h sampling time, but the major part of the plume seems to have been about 10-15 m thick as it rose. Between Day 4 and 5, most of the gas had dispersed from the silo.

Sealed tests in Silo 7 showed stronger gas retention during the early part of the tests with a thicker layer of gas than in the ***unsealed*** test, but it moved upward in a similar pattern. Although the top half of the silo had sufficient gas concentrations for four days or more and would be considered satisfactory, the fumigation condition at the 30.5 and 22.9 m levels lasted slightly more than three days. Although ***sealed*** silo gas concentration levels were 30-50% higher than in the ***unsealed*** gas levels, even with these higher levels, the gas plume seemed to dissipate faster during the ***sealed*** tests than during the ***unsealed*** tests, even though average wind velocities were lower during the ***sealed*** tests. The difference was likely to have been due to the orientation of the wind, with the wind blowing from a more easterly direction during the ***sealed*** tests.

TABLE 2
Phosphine concentrations in ppm in silo 9, and daily wind speed in km/h

Fumigation conditions: **uniform** dosage -- ***unsealed*** roof vents
Started September 19, 2000

Depth (m)	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
1.5	50	340	1	0	4	1
3.0	370	410	48	42	13	16
7.6	590	420	213	65	35	4
15.2	640	180	51	16	7	0
22.9	190	10	8	6	4	2
27.4	100	3	5	1	1	0
Wind speed (km/h)						
Av.	15.0	8.0	12.1	13.5	11.9	13.5
Max.	31.0	26.5	25.7	26.9	21.7	22.7

Fumigation conditions: **uniform** dosage -- ***sealed*** roof vents
Started October 4, 2000

Depth m)	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
1.5	13	0	27	28	27	4	2
3.0	12	0	27	30	28	5	2
7.6	1750	15	760	670	150	73	36
15.2	2,000	2,110	1,310	370	118	43	24
22.9	1,040	710	70	48	32	17	8
27.4	1,400	530	140	55	17	8	1
Wind speed (km/h)							
Av.	7.1	15.0	10.9	6.7	4.0	6.1	10.3
Max.	23.2	25.1	24.9	24.0	16.9	15.6	22.2

The second set of **layered** dosage tests was carried out in Silo 5, (Table 4). Both ***unsealed*** and ***sealed*** tests show a narrow gas plume with rapid dissipation. Most of the gas was gone in the ***unsealed*** test by the end of Day 2. Even though the ***sealed*** silo test definitely provided higher levels of retention, and slower movement of the gas plume, neither test appears to provide a satisfactory duration of fumigation conditions. Weather conditions do not appear to have been very different during the two test periods. However, the discharge spout may have allowed more air leakage through the distributor during the ***sealed*** than the ***unsealed*** tests. Another factor may be that Silo 5 is positioned close to the silos in the annex, where the wind can accelerate due to the "funnel" effect of the narrow space between the head house elevator and the annex silos.

TABLE 3
Phosphine concentrations in ppm in silo 7, and daily wind speed in km/h

Fumigation conditions: **layered** dosage -- ***unsealed*** roof vents
Started September 20, 2000

Depth (m)	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
1.5	4	0	30	6	18	83	30
3.0	3	0	116	19	13	162	27
7.6	2	35	1,710	1,000	7	98	14
15.2	PT	2,400	370	PT	0	20	5
22.9	6,800	490	49	40	0	13	1
30.5	6,000	35	12	17	0	14	1
Wind speed (km/h)							
Av.	6.9	13.5	12.9	11.9	12.7	4.5	6.0
Max.	26.9	26.2	22.4	22.7	17.0	14.8	13.2

Fumigation conditions: **layered** dosage -- ***sealed*** roof vents
Started October 6, 2000

Depth (m)	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
1.5	0	420	1,360	142	33	12
3.0	4	72	780	161	34	13
7.6	8	2,100	2,200	134	33	14
15.2	940	3,100	2,700	30	14	6
22.9	1,320	2,200	180	5	1	0
30.5	7,900	2,100	44	5	1	1
Wind speed (km/h)						
Av.	11.7	7.1	4.0	5.5	9.8	11.4
Max.	24.9	24.0	16.9	15.6	22.2	27.0

Positioning the open discharge opening of the distributor to a "blank" position is very important during head-house fumigations to minimize suction of gas from all silos through the unsealed interior under-roof vents between silos. Even if the spout is open to a silo that is not included in the test, if that silo is adjacent a test silo, significant air movement can be induced through adjacent internal under-roof vents.

Table 5 shows the **bottom**-dosed tests from Silo 1. Extremely fast dissipation occurred during the ***unsealed*** tests. Strong gas concentrations were retained only through Day 2. Even though this is a bottom-dosed test, with all of the gas pellets dispersed within the first 3-5 min of filling, no high levels of gas are observed in the bottom. This would indicate that a rather strong convection air current was continually moving upward through the grain mass. This silo, is on the north west corner of the elevator, adjacent to Silo 5.

Sealed tests also showed a very fast gas plume movement, with no strong gas levels at the silo bottom. During the morning of Day 3, the research team remembered that this was the final silo filled on October 6 and that the distributor was still set with the distributor open to the fill-spout into Silo 1. The elevator manager was contacted at 10:00 AM and instructed to turn the distributor so that the opening was on a "blank" position, blocking air suction up open spouts. This appeared to slow the gas loss, but a major part of the gas loss appeared to have occurred with the fill-spout open during Days 1, 2 and most of Day 3.. By closing of the valve the rapid gas plume movement was slowed, but most of the gas was lost early in the test.

TABLE 4
Phosphine concentrations in ppm in silo 5, and daily wind speed in km/h

Fumigation conditions: **layered** dosage -- ***unsealed*** roof vents
Started September 22, 2000

Depth (m)	Day 1	Day 2	Day 3	Day 4
1.5	2	1,400	1	5
3.0	8	1,000	38	5
7.6	520	210	470	2
15.2	1,210	9	42	0
22.9	200	1	24	0
30.5	0	0	15	0
Wind speed (km/h)				
Av.	12.9	12.1	12.6	4.7
Max.	22.4	22.7	17.0	14.8

Fumigation conditions: **layered** dosage -- ***sealed*** roof vents
Started October 5, 2000

Depth (m)	Day 1	Day 2	Day 3	Day 4	Day 5
1.5	0	4	1,770	480	46
1=3.0	1	8	1,710	320	28
7.6	1	2,130	1,350	36	10
15.2	19	3,400	40	4	3
22.9	6,200	90	0	0	1
30.5	0	0	0	0	1
Wind speed (km/h)					
Av.	14.0	11.6	7.1	4.0	5.6
Max.	25.1	24.9	24.0	16.9	15.6

By far the most successful tests were the **bottom** dosed tests in Silo 8, (Table 6.) This silo, located on the south east corner did not seem to have been affected by convection air movement during the ***unsealed*** tests, as both ***unsealed*** and ***sealed*** tests had significant gas concentration retention that extended to a week on the ***unsealed***, and about 9 days for the ***sealed*** tests. Gas retention at the bottom and top of the silo for ***unsealed*** tests was 4-5 days, compared with 5-6 days for the ***sealed*** tests.

Another variable that may have caused wide variations in convection air movement through the 10 different silos in this elevator may be the level of air seal of the rack and pinion slide-gate on the silo discharge.

TABLE 5
Phosphine concentrations in ppm in silo 1, and daily wind speed in km/h

Fumigation conditions: **bottom** dosage -- ***unsealed*** roof vents
Started September 21, 2000

Depth (m)	Day 1	Day 2	Day 3
1.5	2	30	1
3.0	6	1,610	52
7.6	32	440	34
15.2	1,050	28	3
22.9	PT	PT	4
30.5	44	0	0
Wind speed (km/h)			
Av.	12.4	13.5	11.9
Max.	25.7	26.9	21.7

Fumigation conditions: **bottom** dosage -- ***sealed*** roof vents
Started October 6, 2000

Depth (m)	Day 1	Day 2	Day 3	Day 4	Day 5
1.5	0	1,380	1,010	71	5
3.0	0	2,400	450	28	14
7.6	7	950	24	2	0
15.2	123	55	3	0	0
22.9	240	0	1	0	0
30.5	36	0	2	0	0
Wind Speed					
Av.	10.6	6.6	3.9	7.1	10.8
Max.	24.95	24.0	16.9	21.9	24.3

CONCLUSIONS

Gas concentration levels appeared to be in the order of two to three times higher in ***sealed*** silos compared to ***unsealed*** silos.

It is obvious that strong convection air currents were present in the silos used in the test, and this must be the reason for the rapid loss of gas in ***sealed*** silos.

Distributors should always be set to a blank position (no down-spout) during fumigations. The rapid gas loss of the **bottom** dosage ***sealed*** test compared to the ***unsealed*** test, and the extreme difference in **bottom** dosage tests in silo 1 compared to silo 8 indicates major variations in convection air movement, even within a sealed silo, and even after sealing off the down spout on Day 3 on silo 1.

Uniform dosage using metal phosphide **tablets** instead of pellets would probably have extended the fumigation efficacy in all silos that were ***sealed*** compared with ***unsealed*** silos. The useful gas concentrations in ***sealed*** silo 6 could have been extended at least one extra day or more due to the slower release rates of tablets *vs*. pellets.

The use of automatic pellet dispensers is not recommended in head-house fumigations, or silo-annex fumigations where silos are filled by down-spouts However, use of automatic pellet dispensers in silo annexes, where all grain is delivered by horizontal conveyors, and no down-spouts are connected, should deliver satisfactory results with **sealed** under-roof exterior vents.

TABLE 6
Phosphine concentrations in ppm in silo 8, and daily wind speed in km/h

Fumigation conditions: **bottom** dosage -- ***unsealed*** roof vents
Started September 19, 2000

Depth (m)	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9
1.5	4	1	0	1	8	47	72	59	37
3.0	5	1	0	0	6	107	108	89	53
7.6	3	2	1	2	70	27	44	46	21
15.2	6	30	46	620	PT	PT	PT	PT	PT
22.9	40	940	44	280	154	101	55	12	10
30.5	4,500	19	210	103	200	25	9	1	0
Wind speed									
Av.	14.1	6.9	13.5	13.5	11.9	12.7	4.5	6.0	4.2
Max.	20.9	26.9	26.2	22.4	22.7	17.0	14.8	13.2	24.4

Fumigation conditions: **bottom** dosage -- ***sealed*** roof vents
Started October 3, 2000

Depth (m)	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9
1.5	14	3	3	25	24	33	18	8	2
3.0	10	0	5	17	151	230	191	94	50
7.6	9	0	5	38	470	232	152	75	43
15.2	13	32	51	480	153	132	63	32	18
22.9	20	1,920	2,010	780	380	121	50	39	30
30.5	4,750	1,910	810	490	161	41	39	24	22
Wind speed									
Av.	9.6	7.1	14.6	11.2	6.9	4.0	5.8	10.1	11.4
Max.	24.4	23.2	25.1	24.9	23.9	16.9	15.6	22.2	27.0

ACKNOWLEDGEMENTS

With appreciation, we wish to acknowledge Mr. Chris Fuksa, General Manager, and Mr. Steven Johnson, Elevator Superintendent, Farmers Cooperative Elevator Company, Douglas, Oklahoma for the excellent support and cooperation received from them and for the use of their concrete elevator head-house facility during the entire conduct of this study. Mr. Fuksa provided the fumigant at considerable expense to his company. He also supplied the expandable foam sealing materials used to seal the exterior under-roof vents. The OSU Stored Products Group sincerely appreciates the fine level of support that made this study possible.

The authors also greatly appreciate the assistance of Ms. Ronda Danley, M.S. Graduate Student, AGECON Department, Oklahoma State University for her tirelessness in assembling the sample tube/rope units, and assisting in the conduct of the research, including the taking of fumigant gas readings.

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