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CTP Model for Optimum Efficacy of Closed Loop Fumigation (CLF) Systems in Partially Sealed Storages

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Abstract: Phosphine fumigations often use larger dosages than necessary, yet fail to accomplish satisfactory insect control because gas concentrations are not maintained in storages at sufficient levels long enough for complete kill of all life stages of stored grain insects. This CTP CLF model (concentration-time product) uses "half-life loss time" of storage structures. It recommends use of aluminum phosphide tablets rather than pellets for slower gas release, lower peaks, which extends time of higher gas concentrations which improves efficacy.

An alternative dosage method recommends using partial pellet dosage (15% –25%) for fast early gas release with the balance of the dosage (75% – 85%) in tablets for slower release with lower peak concentrations. This split dosage method, "flattens" peak gas levels, slows losses and sustains higher overall gas concentrations for longer fumigation times with lower dosage.

Lower peak concentrations reduce gas leakage rates from storages. This CLF process allows a fumigator to calculate total dosage required for future fumigations for each storage structure based on the half-life loss time from peak gas levels to maintain concentrations above 200 ppm for 100 hours or more for maximum efficacy, minimizing insect resistance to phosphine.

Key words: closed loop fumigation (CLF), partially sealed storage, CTP, half-life, gas concentration, efficacy, phosphine resistance

Background

Dry aluminum phosphide pellets and tablets have been used as an inexpensive source of grain fumigant in Oklahoma grain elevators for more than 60 years. Pellets have been the primary fumigant of choice due to its fast response. Many concrete elevators in the U. S. A. use automatic dispensing machines to apply pellets at preset application rates when "turning" grain from one silo to another.

Phosphine dosages often exceed maximum recommended levels, yet fail to achieve maximum efficacy due to poor sealing, non-uniform distribution and insufficient concentration for long enough times. Due to fumigation failures, insect resistance to phosphine has increased dramatically in the past two decades.

Entomologists have found from research that if phosphine is maintained at levels of 200 ppm or higher uniformly throughout a structure for 100 hours or longer, all life stages of all stored product insects are killed. Engineers and entomologists have found that phosphide tablets generates peak gas levels about 2.5 times slower than pellets, and although tablets sustain a lower peak level of gas for the same AI dosage, the gas duration is much longer with tablets.

Tablets vs pellets gas release time

Under identical air temperature and humidity conditions, phosphine gas release from pellets is approximately twice as fast as gas release from tablets. Under warm conditions, 24 – 30C (75 – 85F) in wheat with 11 – 12 percent moisture, peak gas release from thin layers of pellets will typically occur in 12 – 24 hours with maximum gas release in 36 – 48 hours. Under similar temperature and moisture application conditions, gas production from tablets will peak in about 40 – 60 hours with maximum gas release in 70 – 90 hours. Thus, gas generation time ratio for tablets vs pellets is about 2.5:1.

Structure 'half-life time' gas loss

The time when the gas concentration drops to half the peak gas level is the "***half-life time***" (HLT) of the structure. During calm stable weather, leakage is slow and relatively steady-the HLT is longest. Gas losses increase with higher wind velocities due to lower barometric pressure outside the structure, causing faster gas outflow from the differential pressure. The fumigation HLT in poorly sealed storages is often less than 24 hours.

Gas concentrations are more uniform and

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HLT is easier to determine using closed loop fumigation (CLF) in partially sealed structures. With forced recirculation by CLF fans, relatively uniform gas concentrations after the first day of CLF fumigation can be checked at headspace or base location to determine structure HLT for current and similar future weather conditions. Structural sealing tightness and resulting gas leakage rates will determine the HLT for each structure under existing grain and weather conditions during fumigations. Be aware that structural HLT during summer fumigations may vary significantly from HLT during fall or winter fumigation due to weather differences.

Example 1: The headspace gas level in a 'partially' sealed steel silo using CLF dosed with pellets peaked at 1200 ppm, 18 hours after dosage. With periodic recirculation the headspace gas reading dropped to 600 ppm, 54 hours from the start. The first HLT of that silo under that fumigation weather condition was 54 − 18 = 36 hours. With stable weather conditions, the second HLT of that silo, when the recirculated gas level dropped from 600 to 300 ppm, for a total of 18 + 36 + 36 = 90 hours from the start of the fumigation. The third HLT gas reading of 150 ppm would likely occur about 90 + 36 = 126 hours (5 1/4 days) from fumigation start

Note: CLF fans should not run continuously throughout a fumigation-leakage rates are higher when gas is continually recycled because the headspace is continually pressurized-run CLF fans just enough to keep headspace gas levels within 50%-75% of gas readings in the grain bulk or to maintain at least 200 ppm in the headspace-about 1 − 2 hours per 24 hours.

Example 2: In September, 2000, Mid − Oklahoma Coop Elevator sealed a flat grain storage warehouse and installed a CLF system in it. During their first fumigation in October, 2000, they recorded a recirculated peak gas concentration of 2 050 ppm after 24 hours. Seven days later (8^{th} day of fumigation), the gas concentration during recirculation was 850 ppm. Assuming uniform gas loss, the HLT of that flat storage of 1025 ppm can be computed. HLT = (2050 − 1025)/(2050 − 850) × 7 = 5.98 or 6 days (144 hours). During the fall 2001 fumigation, Mid − OK Coop reduced the dosage by 50% in the flat storage. The 24 hour headspace gas reading was 1 050 ppm. Seven days later, the recirculation headspace reading was 450 ppm. The 2001 HLT = (1050 − 525)/(1050 − 450) × 7 = 6.125; still about 6 days.

Gas Loss Rates Vary with Concentr Ation Levels

An important factor to consider when deciding whether to use pellets or tablets is that in any structure, higher gas vapor pressures at high gas peak concentrations will result in faster gas leakage from pellets than tablets in a given period of time.

Example 3: If a pellet dosage results in a peak concentration of 1000 ppm in 18 hours, the same AI tablet dosage may peak at 850 ppm in 48 hours. If the partially sealed structure sustains a HLT of 30 hours, the gas concentration for pellets would drop to for about 500 ppm, 48 hours from the start of the fumigation. From a peak of 850 ppm in 48 hours, tablet fumigations would drop to about 425 ppm 78 hours after dosage. The pellet gas level would drop to about 250 ppm after 78 hours during its second HLT while the tablet second HLT would be 108 hours at about 212 ppm.

Gas concentration vs Time @ 200 ppm for 100% Efficacy

The ***half − life time*** (HLT) from peak gas concentration is a useful guide for characterizing a structure for fumigation. Stored grain entomologists generally feel that if phosphine concentrations remain above 200 ppm for a minimum of 100 hours in all points in the grain mass, **all life stages of all grain insects will die**. Thus, an important grain management tool for steel, concrete or flat storage fumigators is to determine the length of time that all parts of the grain storage stays above 200 ppm.

Thus, combining the HLT concept and the principle of maintaining gas concentrations above 200 ppm for a minimum of 100 hours provides a very useful tool for predicting the appropriate dosage for partially sealed CLF systems. Once a storage structure HLT has been characterized during the first CLF using a conservative initial dosage, the grain manager can calculate the level of dosage expected to maintain gas levels above 200 ppm for 100 hours. This allows fine tuning of target dosages for one − dose fumigations. Keep in mind that this HLT is based on weather conditions during that fumigation. If the weather forecast during a fumigation predicts adverse weather, based on long range (10 − 14 day) forecasts, it may be prudent to increase dosage, unless a convenient re − dose method is available.

Example 4: The steel silo in Example 1 was fumigated the next year under similar weather conditions and the manager wants to determine how long the gas level might be expected to remain above 200 ppm (for more than 100 hours).

If gas generation from pellets was straight line from initial dosage to peak gas concentration, then the point where CLF gas recirculation reached 200 ppm would have been about 200/1200 × 18 hours = 3 hours from the start of the fumigation. Thus, the structure would be above 200 ppm for 15 hours before peak concentration.

From Example 1, the gas level at the third HLT (at 126 hours) was 150 ppm. To determine the time when the gas concentration dropped from the peak of 1200 ppm to 200 ppm, one can calculate the second HLT of 90 hours at 300 ppm.

Solving for the lapsed time for the gas drop from 300 ppm to 200 ppm, or a 100 ppm loss would be: 36 hrs/(300 − 150) = HLT/(300 − 200); inverting, HLT = 36 × (300 − 200)/(300 − 150) = 36 × 100/150 = 36 × 0.67 = 24 hours after the second half − life time. So, 90 + 24 = 114 hours from start of fumigation. Since 3 hours was calculated to elapse before CLF gas concentration reached 200 ppm after fumigation started, total time above 200 ppm would be 114 − 3 = 111 hours. This should provide about 10% more time beyond the minimum 100 hours at 200 ppm for 100% efficacy of all life stages. Unless fumigation is during adverse weather, the dosage that provided the 1200 ppm peak concentration in Example 1 should provide 100% efficacy.

Length of time above 200 ppm concentration time should be a guiding factor for maximum efficacy-killing of all life stages of all grain insects in fumigations. Because of the longer release time of tablets, a factor of at least 2.5:1 slower than pellets, this guideline definitely favors use of tablets for initial dosages.

If the storage unit HLT is characterized during stable weather conditions, gas losses during fumigations in stormy weather will be faster. If inclement weather is predicted, dosage can be increased by 10% − 25% to compensate for expected increased gas losses.

Optimum Efficacy CTP-CLF Model

A one-dosage CTP CLF model for optimum efficacy of fumigation can be developed for each grain storage structure by combining the following five fumigation management strategies: (1) use phosphide tablets (or other forms of slow release phosphine packaging) for slower, longer duration gas release; (2) replace tablets with 15% − 20% of dosage as pellets for fast early gas release to shorten time when initial gas concentration reaches 200 ppm; (3) install closed loop fumigation (CLF) for uniform gas distribution in well sealed or partially sealed structures; (4) maintain 200 ppm or more for 100 hours for 100% efficacy of all life stages of stored product insects; (5) apply the principle of HLT from peak gas concentration to calculate minimum future dosages for each structure for weather extremes (examples: windy vs calm, hot/dry vs cool/rainy).

To estimate the optimum CTP dosage for a partially sealed storage with CLF, fumigate using a conservative dosage which is estimated to end up with a gas concentration at 100 hours that is well above 200 ppm. Document the point at which 200 ppm is first reached after dosage, document the time and gas level at peak concentration, monitor the time when the first HLT occurs (peak gas ppm/2). Then monitor gas levels at the predicted second HLT, and see how close it is to the first HLT when the gas level isof peak level. Document the additional HLT increments until gas concentrations are below 200 ppm. Example 4 can be used as a model to compute the time when 200 ppm is reached.

Large CTP – CLF field Demonstr ation Comparing Pellets Vs Tablets

In the Fall of 2000, Peavey Company, Tulsa Port of Catoosa installed a CLF system (designed by R. Noyes) in their 3.3 million bushel, 500 ft × 150 ft by 30 ft sidewall, flat storage barn, Figure 1. The CLF system design on the pre-cast concrete sidewall structure included a 4-inch ID PVC pressure pipe manifold on each side. The aeration system had 18 vane − axial fans (26.3 ft spacing) per side, each connected directly to a straight 65 − ft perforated duct that extended toward the center. Figure 2 illustrates the CLF blower design.

CLF plumbing was divided into three equal 1.1 million bushel sections with 6 − inch ID PVC suction pipes extending from the roof at the center of each section to 3 − HP (2.25 Kw) CLF fans, which deliver 1300 cfm/fan. Full-flow PVC ball valves were placed in the 4 − inch PVC pressure pipe between the three CLF fans per side. During normal fumigations, all ball valves were open. When the warehouse is full, the 6 CLF fans supply 7 800 cfm to 3 300 000 bushels of wheat. The gas flow rate is

7 800 cfm/3 300 000 bu = 0. 00236 cfm/bu = 1/425 cfm/bu. This provides one gas exchange in about 3. 5 hours, or 6. 8 gas changes per day.

Data taken at the 3. 3 million bushel flat storage at Peavey Grain Company, Tulsa Port of Catoosa in the Fall, 2000 and Fall, 2002 provides contrasts pellets and tablets. The 2000 fumigation used a one-dose application of phosphine pellets. The 2002 fumigation used a one-dose application of phosphine tablets. Some resealing of the structure took place before the 2002 fumigation to reduce gas losses experienced in 2000 and 2001. Dosage each year was 42 cases of aluminum phosphide at 7 000 grams AI per case for a computed warehouse volume of 6 000 000 cubic feet. This would provide a theoretical concentration (in a perfectly sealed structure): Total ppm = 42 cases × 7 000 gm/case × 25 ppm/gram/1 000 cu ft × 1/6 000 (1 000 cu ft units) = 1, 225 ppm. The average peak reading from pellets in 2000 was about 740 ppm; in 2002, with tablets, peak gas level was about 650 ppm (Figure 4).

How Did the CLF System Perform

Figure 3 shows gas concentration data taken at the six CLF fan locations for both fumigations. Figure 4 compares the average of gas concentrations at the six fans for 2000 and 2002. The elevator superintendent was not pleased with the gas leakage during 2000 and 2001 fumigations, so the warehouse was partially re-sealed before the 2002 fumigation.

From Figure 4, in 2000 the average pellet gas concentrations peaked at about 740 ppm in 18 hours compared to the tablet dosage peak of 650 ppm about 53 hours from the start in 2002. The time from dosage until average concentration reached 200 ppm in 2000 was about 8 hours; for tablets in 2002 the time at 200 ppm was about 10 hours. The warehouse HLT for both pellets and tablets were about 32 hours.

These fumigations were under similar grain moisture and temperature conditions. Peak gas concentration time ratios were about 2. 9: 1. 0 for tablets versus pellets. Using tablets in 2002, this facility reached the first HLT from 650 – 325 ppm about 86 hours after start of the fumigation. At that point, the entire warehouse had a gas concentration above 200 ppm for 76 hours. If the fumigation had continued at the same percentage loss of gas, the second HLT at 162 ppm would have been about 86 + 32 = 118 hours. Subtracting 10 hours, when the entire facility was at 200 ppm, assuming a steady decline in gas loss, the time when gas concentrations reached 200 ppm near the end of the fumigation would be: 86 + (325 – 162)/(325 – 200) × 32 = 86 + 162/200 × 32 = 86 + 26 = 112 hours. Subtracting 10 hours for the 200 ppm initial time, gives 112 – 10 = 102 hours above 200 ppm. This tablet fumigation should have killed all life stages of all insects.

Combined Tablet and Pellet Dosage Strategy

Use of 15 – 25% of the dosage AI as pellets for quick early release and 75 – 85% of the dosage as tablets would be a way to capitalize on the different release rates and loss rates of tablets vs pellets. This facility needs additional sealing to assure reaching the condition of 100 hours above 200 ppm at the present dosage levels for each future fumigation. With improved sealing, this structure HLT could be increase to 45 – 60 hours, and dosage AI could be further reduced. Savings in dosage could pay for tighter sealing, improving efficacy.

Fig. 1 Peavey Company's 3. 3 million bushel warehouse at Tulsa Port of Catoosa, showing concrete silos an steel bins. Company installed CLF system in warehouse in 2000

Fig. 2 Left photo shows closed loop fumigation (CLF) system PVC pressure piping system above aeration fans along one side. Right – Suction pipe from roof headspace and pressure pipe connected to CLF fan on movable base. Note vertical pressure pipe to aeration transition duct, with seal plate where aeration fan was removed.

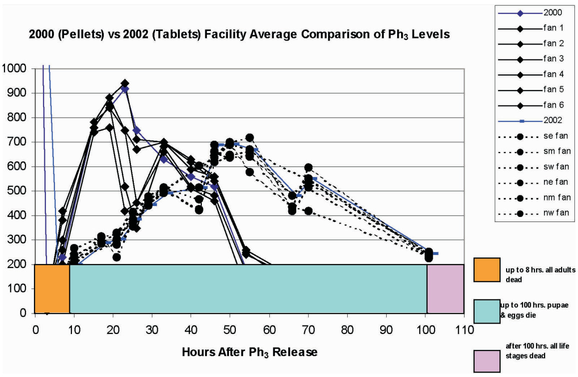

Fig. 3　Plot of gas levels at six CLF fan locations comparing pellets in 2000 and tablets in 2002

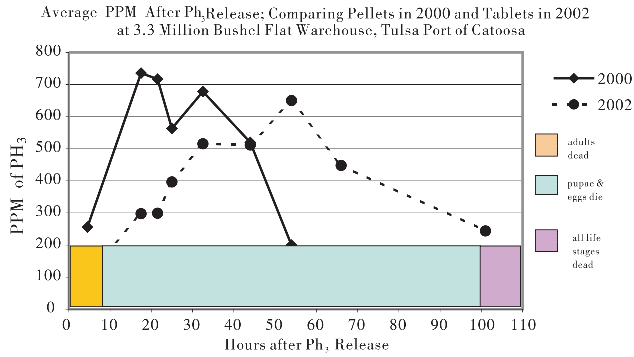

Fig. 4　Plot of average phosphine gas concentrations at six CLF fan locations comparing pellets in 2000 with tablets in 2002