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A MODEL FOR SELECTING TABLET VS PELLET DOSAGES IN STORAGES WITH CLOSED LOOP FUMIGATION (CLF) SYSTEMS

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BACKGROUND

Dry aluminum phosphide pellets and tablets have been used as an inexpensive source of grain fumigant in Oklahoma grain elevators for the past 50-60 years. Pellets have been the primary fumigant of choice due to their fast response. During that time, almost all concrete elevators in Oklahoma used automatic dispensing machines to apply pellets at selected preset application rates as grain was turned from one silo to another.

One phosphine tablet releases the equivalent active ingredient (AI) of 1.0 gram of phosphine gas. Each phosphine pellet release 0.2 grams of phosphine gas, so one tablet is equal to 5 phosphine pellets. A dosage level of 300 pellets/1,000 bu is the equivalent dosage as 60 tablets/1,000 bu.

Grain at a specific moisture content will generate a specific air relative humidity in the inter-kernel air void spaces in the grain. Air temperature and relative humidity both contribute to activating phosphine gas chemical release action of pellets and tablets. Relatively speaking, the higher the air temperature and air humidity, the faster phosphine gas is generated in grain in a grain storage structure or a fumigation chamber.

TABLETS VS PELLETS GAS RELEASE TIME

From experience, 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 such as 24-29C (75-85F) in wheat with 11-12 percent moisture, the peak of gas release from pellets will typically occur in 12 to 24 hours with full release in about 36-48 hours. Tablets, with a mass five times larger than pellets, will release gas under similar temperature and moisture conditions in about 40-60 hours with complete gas release in about 70-90 hours, a ratio of about 2.5:1 to 3:1.

Like all gases, phosphine gas generates its own "partial vapor pressure" when mixed with air or other gases. When phosphine reaches high concentrations in an un-pressurized grain storage bin or silo, if air in the grain mass is stable (no upward moving convection air currents), phosphine will try to equalize its pressure and concentration throughout the structure. Experienced commercial fumigators have reported that in a tightly sealed structure, the gas plume or cloud from phosphine dosages placed in the surface grain moves downward about 10 ft per day.

Based on this information gas in a 40 ft deep grain bin dosed only at the top should reach the bottom in about 4-5 days. This is why some fumigators place about 75% of the dosage in the top grain and 25% in the base in aeration ducts (check for standing water in the aeration ducts before placing the bottom dosage -- to avoid a fire or explosion). Splitting the dosage reduces the time required for the concentration to equalize by 1-2 days, as well as placing a high concentration in the base where residual insect populations might develop.

GAS LOSS RATES VARY WITH CONCENTRATION LEVELS

An important factor to consider when deciding whether to use pellets or tablets is that in structures with some leakage, gas concentrations with pellets will reach higher peak values and peak faster than with tablets. Because of the higher gas vapor pressure, higher gas concentrations will result in relatively higher gas loss per unit of time. Since tablets release gas slower, and peak out at somewhat lower maximum gas concentrations (some leakage starts to occur from the start of the fumigation while gas concentrations are building to peak values), relative gas losses per unit of time will be lower with tablets than pellets.

GAS HALF-LOSS THEORY

Commercial fumigators and researchers call the time at which half the maximum gas concentration has leaked out of a structure the "***half-loss***" time (HLT) of the gas. The HLT is often affected adversely by convection currents generated by high wind conditions and storms. When weather is relatively stable with low wind conditions, leakage is slower, and the HLT is longer. As barometric pressures drop and wind speeds increase, leakage occurs faster. The HLT of a fumigation in poorly sealed storages may be 24 hours or less.

HLT is easier to monitor with closed loop fumigation (CLF) because forced gas recirculation causes the gas concentration to become relatively uniform throughout the structure and headspace gas readings can be easily measured for ***half-loss*** tests. Steel bin and silo structural sealing tightness, and the resulting gas leakage rate, will determine the HLT for the structure under existing grain and weather conditions during each fumigation. HLT during summer fumigations may vary significantly from HLT during a fall or winter fumigation due to weather differences.

Example 1: If the headspace gas level in a steel bin using CLF dosed with pellets peaked at 2000 ppm, 18 hours after dosage, and the time when the recirculated headspace gas reading dropped to 1000 ppm was 54 hours, the HLT of that bin under those fumigation conditions would be 36 hours. If weather conditions remained stable, it could be expected that the second HLT of that bin, when headspace gas during recirculation dropped from 1000 to 500 ppm, might also be about 36 hours, or a total of 18 + 36 +36 = 90 hours from the start of the fumigation. With no weather changes, the third HLT of 250 ppm would be expected to occur about 36 hours after the second level, at 90 + 36 = 126 hours, or 5 1/4 days from the start of the fumigation.

Example 2: Mid-Oklahoma Coop Elevator sealed their flat storage and installed a CLF system at Kingfisher, OK in September 2000. During their first fumigation that fall they had a peak gas concentration in the headspace of 2050 ppm 24 hours after dosage. Seven days later, the headspace gas concentration during CLF recirculation was 850 ppm. Assuming straight line gas loss, the HLT of that flat storage at 1025 ppm can be computed. HLT = (2050-1050)/(2050-850) x 7 = 5.98 or 6 days (143.5 hours). During the fall 2001 fumigation, Mid-OK Coop reduced the dosage by 50%. The 2001 fumigation 24-hour headspace gas reading was 1050 ppm. Seven days later, the headspace reading during recirculation was 450 ppm. The HLT was still approximately 6 days during their 2001 fumigation.

TIME VS GAS CONCENTRATION VS TIME (T @ 200 PPM) FOR 100% EFFICACY

The ***half-loss*** time from maximum dosage is a useful guide for characterizing a fumigation for the fumigation management plan (FMP) for the elevator. Another important fumigation factor is that grain storage entomologists generally feel that phosphine concentrations must remain at 200 ppm for a minimum of 100 hours in all points in the grain mass to **kill all life stages of grain insects** (Personal Conversation with Tom Phillips, 2003). Thus, an important factor for steel, concrete or flat storage fumigators is to determine the length of time that all sections of the stored grain stay above 200 ppm. This is an especially important factor given the convection movement of gas concentration plumes in concrete silos, regardless of dosage method. This is also a major reason for all storages to be well sealed and be equipped with CLF systems.

So, if the *half-loss time* principal and the concept of maintaining gas concentrations above 200 ppm for a minimum of 100 hours are combined, the fumigator or grain manager will have a very useful tool for improving fumigation efficacy, especially in well-sealed CLF systems. Once a storage system is characterized during the first CLF fumigation at conservative initial dosage levels, a grain manager should be able to calculate the level of dosage that will provide gas levels above 200 ppm for 100 hours, thus fine tuning his target dosage for a one-dose fumigation.

> **Example 3:** If the bin in Example 1 was fumigated the next year under similar weather conditions with a reduced pellet dosage that gave a peak of 1200 ppm, assuming straight line leakage rates and based on an 18-hour peak gas concentration, the gas concentration would pass the 200 ppm level about 4 hours from the start of the fumigation. Then, **total time at or above 200 ppm** could be calculated based on the FMP HLT from the previous year of 36 hours. The first *half-loss* of 600 ppm would be at 36 + 18 = 54 hours, the second *half-loss* at 300 ppm would be at 54 + 36 = 90 hours. The third *half-loss* at 150 ppm would occur at about 126 hours from the start of the fumigation.
>
> To determine the predicted time above 200 ppm, assuming straight-line or linear leakage loss, the "total time above 200 ppm" for this example using CLF can be computed by analyzing the ratio of the third *half-loss* time when the gas level would drop from 300 to 150 ppm in 36 hours to the ratio of time for the gas to drop from 300 to 200ppm. Then, combine that result with the *half-loss* times from the peak level of 1200 ppm to 300 ppm, plus the initial

time from 200 ppm to the peak level, or 18-4 = 14 hours above 200 ppm to the peak of 1000 ppm.

To solve for the lapsed time for the gas drop from 300 ppm to 200 ppm, or a 100 ppm drop would be about 36 hrs/(300-150) = X/300-200; so, X =36 x (300-200)/(300-150) = 36 x 100/150 = 36 x 0.67 = 24 hours.

Thus, the time above 200 ppm is computed to be about (18-4) + 36+36 + 24 = 14 + 72 + 24 = 110 hours. Since the estimated time at or above 200 ppm for this fumigation is computed to be more than 100 hours, it would be likely to kill all life stages.

LARGE SCALE FIELD DEMONSTRATION COMPARING PELLETS VS TABLETS

In the fall of 2000, Peavey Company, Tulsa Port of Catoosa installed a closed loop fumigation (CLF) system in their 3.3 million bushel flat storage warehouse. The CLF system design on the 500 ft. long x 150 ft wide by 30 ft pre-cast concrete sidewall structure involved a 4-inch Sch. 40 PVC pressure pipe manifold on each side. Their aeration system included 18 evenly spaced vane-axial fans (at 26.3 ft centers) per side connected directly to straight perforated on-floor round ducts. Roof venting was supplied by 24 goose-neck evenly spaced vents per side. Figure 1 shows the 3.3 million bushel warehouse. The two photographs in Figure 2 illustrate the CLF fan connections.

The warehouse was divided into three equal 1.1 million bushel sections with 6-inch Sch. 40 PVC suction pipes extending from holes part way up the roof to the CLF fan inlet. Suction pipes and each 3-HP CLF fan were located at the center of each third of the building. Full-flow PVC ball valves were placed in the 4-inch PVC pressure pipe between the three CLF fans. During normal operation, the ball valves remain open. Using 6 CLF fans x 1300 cfm/fan = 7,800 cfm supplied to 3,300,000 bushels of wheat, the gas flow rate was 7,800/3,300,000 = 0.00236 cfm/bu = 1/425 cfm/bu. This design provides one gas exchange in about 3.5 hours, or 6.8 gas changes per day.

In 2002, one middle CLF fan malfunctioned, so the opposite center CLF fan was shut off to maintain balanced flow. Thus, the 2002 fumigation was conducted with four CLF fans, or two-thirds of the gas flow (about 1300 x 4 = 5,200 cfm). This provided about 5,200/3,300,000 = 0.0016 cfm/bu = 1/635 cfm/bu, one gas change per 5.3 hours or 4.5 gas changes per day.

Two sets of data taken at the 3.3 million bushel flat storage at Peavey Grain Company, Tulsa Port of Catoosa in 2000 and 2002 provide an interesting set of contrasts. The 2000 fumigation was with a one-time application of phosphine pellets. The 2002 fumigation used a one-time application of phosphine tablets. Some resealing of the structure took place before the 2002 fumigation to reduce gas losses experienced in 2000 and 2001. The dosage was 42 cases of aluminum phosphide at 7,000 grams AI per case in each of the fumigations for a computed warehouse volume of 6 million cubic feet. This would provide a theoretical concentration (in a perfectly sealed structure, TPPM = 42 cases x 7,000 gm/case x 25 ppm/gram/1000 cu ft x 1/6,000 (1,000 cu ft units) = 1,225 ppm. The theoretical concentration, TPPM = 1,225 ppm, compared to the highest readings of 940 ppm in 2000 and around 700 ppm in 2002.

How did the system perform?

Figure 3 shows the gas concentration data plot curves for the six CLF fan locations for both fumigations. Figure 4 shows the average of the six fans for each of the two years. Due to excessive gas leakage during 2000 and 2001 fumigations, the warehouse was partially re-sealed before the 2002 fumigation.

In Figure 3 the gas levels in aeration ducts near all six CLF fan locations were monitored during both years. Pellet dosages in 2000 peaked in 16-18 hours compared to tablet dosages in 2002 which peaked in about 55 hours. Figure 4 provides average values for all six blowers for 2000 and 2002. Note the time from dosage until the concentration initially reached 200 ppm for both pellets in 2000 and tablets in 2002. The average peak gas levels for pellets was about 740 ppm. Average peak gas levels for tablets reached about 650 ppm. The HLT for both pellets and tablets was about 30 hours. This data is somewhat conservative as the roof vents were uncovered with CLF fans running 4 hours before the final gas reading of about 250 ppm average were taken at 103 hours during the 2002 fumigation. These average readings would likely have been 300-325 ppm if taken before the roof vents were unsealed.

Data shown in Figures 3 and 4 are developed from fumigation reports for Peavey Company, Tulsa Port of Catoosa, developed by the commercial fumigator, with their descriptive report of the sealing and dosage method used in the fumigation process during a pellet fumigation in 2000 and a tablet fumigation 2002 (Biggler , 2003). The data sheets listed in the report for 2002 show that the time for tablets to reach peak concentration was 55 hours. The 2000 data sheet indicated that peak concentrations with pellets occurred at about 16 to 20 hours from start of dosage. Both fumigations were under similar grain moisture and temperature conditions.

These data support the concept of peak gas concentration ratios of 2.5:1.0 to 3:0-1.0 for tablets versus pellets.

Figure 1. Peavey Company's 3.3 million bushel warehouse at Tulsa Port of Catoosa, showing concrete silos and steel bins. Company installed CLF system in warehouse in 2000.

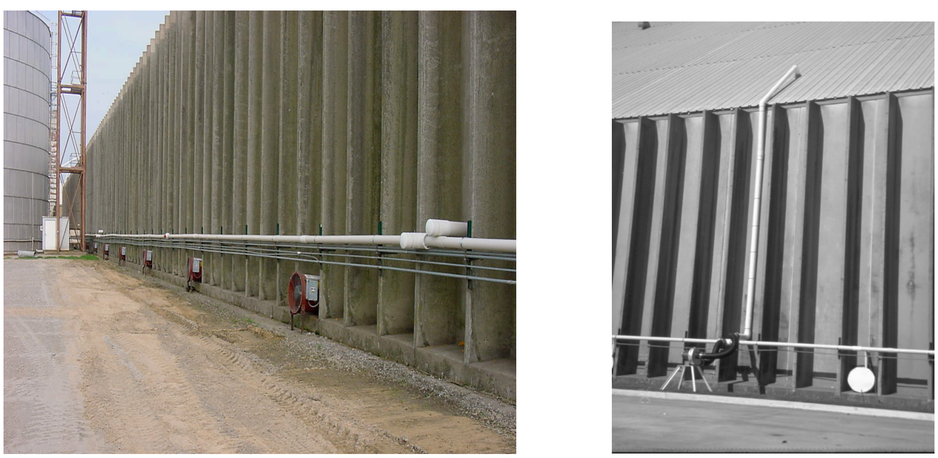

Figure 2. Left photo shows closed loop fumigation (CLF) system PVC pressure piping system above aeration fans along one side. Right --CLF fan, suction pipe from roof and pressure pipe.

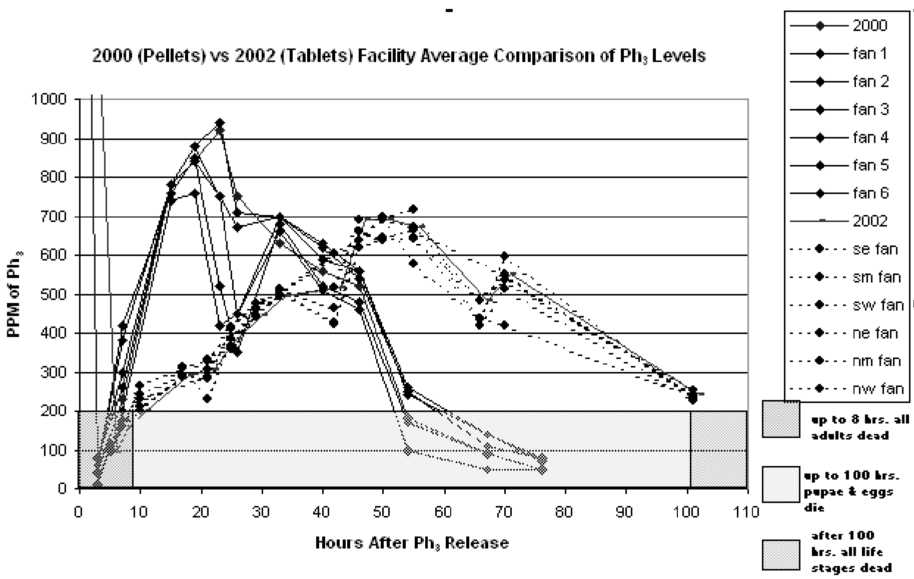

Figure 3. Plot of gas levels at six fan locations comparing pellets in 2000 with tablets in 2002 (Biggler, 2003)

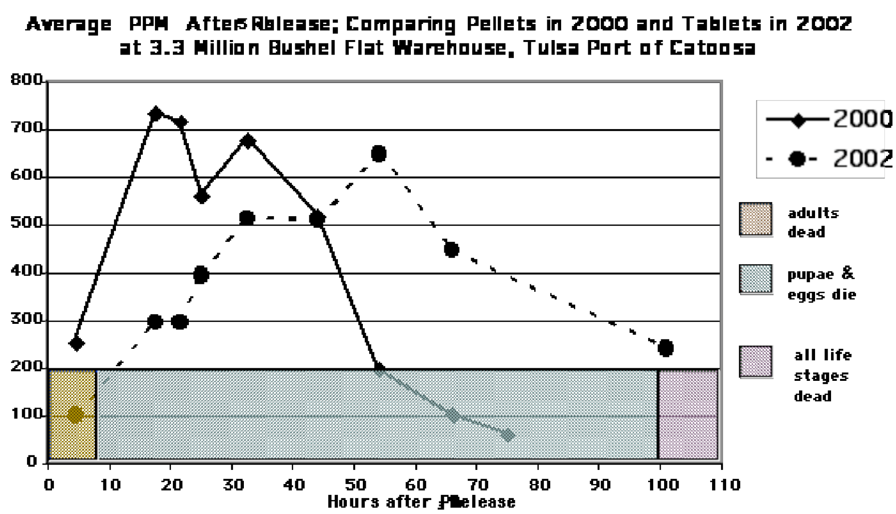

Figure 4. Plot of <u>average phosphine gas concentrations</u> at all six fan locations comparing pellets in 2000 with tablets in 2002 (Biggler, 2003).

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