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Effects of Outside Air Temperature on Movement of Phosphine Gas in Concrete Elevator Bins

Paul Flinn[1] and Carl Reed[2]

Abstract: Studies that measured the movement and concentration of phosphine gas in upright concrete bins over time indicated that fumigant movement was dictated by air currents, which in turn, were a function of the difference between the average grain temperature and the average outside air temperature during the two weeks following application of the aluminum phosphide pellets. When the grain was warmer than the average outside air temperature during these two weeks, the phosphine gas would move upward through the grain mass. When the grain was cooler than the average outside air during these two weeks, the fumigant moved downward. Because insect problems normally occur in the top of the grain mass early in the storage season (June-August), a uniform application of fumigant pellets was more effective when the grain and outside air temperatures were similar during the two weeks following application of the fumigant. When grain was much warmer than the average outside air temperature during these two weeks, applying more fumigant pellets into the bottom half of the grain mass was the most effective strategy. If the grain temperature is expected to be cooler than the average outside air temperature during the two weeks following application of the fumigant, applying more pellets to the upper half of the grain mass would be the best strategy.

Introduction

Phosphine fumigation failures in concrete bins are common when a lethal concentration (200 – 300 ppm) of phosphine is not maintained for a sufficient duration (normally 3 – 5 days). Factors that affect the phosphine concentration and duration are grain temperature and air-tightness of the bin. Other factors such as convective air movement in the grain mass can also impact phosphine dispersion in the grain mass. Tall concrete bins (26 – 37 meters tall) are particularly susceptible to "chimney" effects. These effects should be strongest when there is a large difference between the outside air temperature and the grain temperature. In temperate climates, this often would occur in the fall, winter and spring. Winks and Russell demonstrated this chimney effect in bins monitored for temperature and pressure differential at the base of concrete bins[1]. Insect density is often highest in the top third of the grain mass[2]. Because of the vents in concrete grain bins, it is often difficult to maintain fumigant concentrations at high levels for sufficient time to kill all stages of the insects that are present. This problem can be exacerbated by cooler temperatures during the fall and winter.

Elevator grain managers have used various phosphine application strategies when fumigating grain. These can be characterized as uniform and non-uniform applications. The fumigant tablets or pellets are typically added to the grain stream as the grain is transferred from a full bin to an empty bin. For a uniform application, the operator adds the pellets at regular intervals throughout the grain transport period. For non-uniform applications, the operator adds all of the pellets to a certain portion of the grain; for example, to the bottom half of the grain mass. The reason why a grain manager may use one application strategy over another varies greatly. Some answers given by grain managers are that they often have insect hotspots in the bin bottoms; other managers prefer an even distribution because they often find more insect problems in the top of the grain.

The objective of the fumigation study was to characterize the movement of phosphine gas in grain stored in concrete elevator bins during the two weeks following application of the fumigant pellets. We wanted to investigate how cold and warm season fumigations affected gas movement, and whether uniform or non-uniform applications would be best for cold or warm season fumigations.

1. *USDA – ARS Grain Marketing & Production Research Center, Manhattan, Kansas* 66502 (*USA*)
2. *Kansas State University, Manhattan, Kansas* 66502 (*USA*)

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Methods

This study was conducted at three different commercial elevators over a 3yr period in Kansas, USA. Gas sampling equipment consisted of 3.2 mm nylon tubes attached with plastic heat-shrink tubing to a 6 mm diameter steel cable. The nylon tubes were cut to different lengths so that the end of a single nylon tube protruded from the heat shrink at 3 – meter intervals. The bins were either 26 or 37 meter – tall, so a gas-sampling cable typically had 8 to 12 gas sampling tubes. In addition, three thermocouple wires were attached to the steel cable so that grain temperatures in the top, middle and bottom of the grain could be measured. Three gas – sampling cables were suspended from the roof of each bin, one at the center, and the other two at opposite directions about 60 cm from the bin wall. We used a PortaSens II gas meter with a 10 – 2000 ppm phosphine sensor to measure gas concentrations. A small electric vacuum pump (Cole-Parmer L79200) was used to pump gas from the gas sampling tubes to the PortaSens II gas detector at a flow rate of 0.4 – 0.5 liters/minute. Because of the amount of time needed to measure phosphine for each bin, and the expense and time needed to manufacture cables, only two bins per trial were sampled.

The cables were installed in two bins, then grain was turned into the bins and fumigant was applied either as a bottom application (all of the fumigant applied to the bottom half of the grain mass) or uniformly applied throughout the grain mass. The same dose of phosphine (300 pellets/27.2 tonnes) was used for all experiments. We sampled gas concentrations every 1 – 2 days, usually at noon. Data was analyzed by using contour plots (Surfer, Golden Software 1999) to provide a visual image of the change in the phosphine concentrations over time in each bin.

Results and Discussion

Phosphine gas has a specific gravity that is almost the same as air (air = 1.0, PH_3 = 1.17). Thus, if the air in the bin is not moving, the phosphine gas will diffuse very slowly in the grain mass and remain near the highest concentrations of pellets. If there is convective air movement in the grain mass, the phosphine gas will move with the air. For the first case that we investigated, during the two weeks following application of the fumigant pellets, the grain and outside air temperatures were similar, averaging 9℃ and 5℃, respectively. The fumigant pellets were applied uniformly to all layers of the grain in this 26 meter-tall bin.

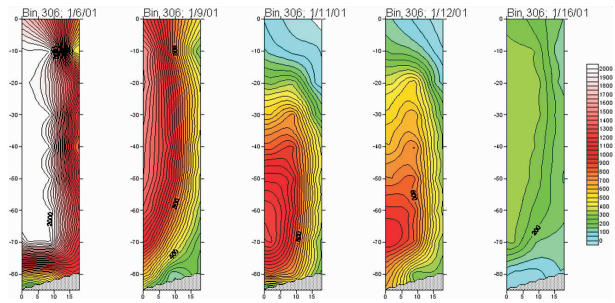

Fig. 1

Fig. 1. Phosphine concentration (ppm) in an upright concrete bin. Cold grain fumigated during January in Kansas. Fumigant pellets were added uniformly to the grain. The average grain and outside air temperatures were similar during the two weeks following application of the fumigant pellets, were 9℃ and 5℃, respectively.

Figure 1 shows that gas concentrations were fairly even in the grain mass, and did not move much either up or down during the 14-day fumigation. Because the grain and outside air temperatures were similar during this two week period, strong convective air movement inside the grain mass (chimney effect) would not be expected.

For the second case, we measured phosphine concentrations in wheat fumigated in November; in this case the grain was much warmer than the outside air temperature during the two weeks following addition of the fumigant (Fig. 2). Pellets were added to the bottom half of the grain in the 37 meter-tall bin. The grain and outside air temperatures during the two weeks following application of the fumigant pellets averaged 27℃ and 5℃, respectively. Because the grain was warmer than the outside air temperature during these two weeks, convective air movement within the bin caused the fumigant to move upwards.

Figure 2. Warm grain fumigated in November in Kansas. Fumigant pellets were added to the bottom half of the grain mass. The average grain and outside air temperatures during the two weeks following application of the fumigant pellets were 27℃ and 5℃, respectively.

For the third case, fumigant pellets were added uniformly to the wheat as it was moved to a 26-meter-tall bin in June, (Fig. 3). The average grain temperature was 18℃ and the average outside air temperature was 26℃ during the two week period following application of the fumigant pellets.

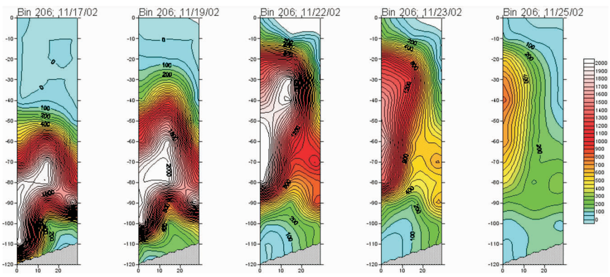

Fig. 2

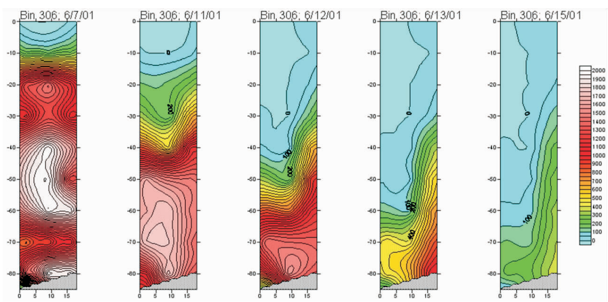

Fig. 3

Figure 3. Cool grain fumigated in June in Kansas. Aluminum phosphide tablets were added uniformly to the grain. The average grain and outside air temperatures during the two weeks following application of the fumigant pellets were 18℃ and 26℃, respectively.

On the first day after the fumigant pellets were added to the grain (7 June), an even distribution of phosphine gas was evident throughout the grain except near the grain surface. By the fifth day, the phosphine gas had moved to the lower half of the bin. On the ninth day, only a small amount of fumigant was present in the bottom of the bin. Because the grain temperature was cooler than the outside air, the air in the grain would tend to move down in the bin because it was denser than the outside air. This last case shows how difficult it is to treat the top layer of grain when the grain is cooler than the outside air. It's similar to trying to hold water in a glass that has a small hole in the bottom. Because air was moving down in the grain mass, it is obvious that if there were insects in upper layers of the grain mass, the worst application method would be to apply pellets to only the bottom half of the grain mass.

Because most concrete elevators have vents (both inter-bin and outside bin vents) in the walls just beneath the roof, it is difficult to hold lethal concentrations of phosphine gas for 3 – 5 days in the upper layers of the grain mass in most upright concrete grain bins. Lower gas concentrations, combined with the fact that insect populations in newly-stored grain often start in the upper layers of the grain mass, increase the probability of fumigation failures in the top of the bin.

When the average outside air temperature during the two weeks following application of the fumigant pellets is expected to be similar to the grain temperature, in most situations, applying pellets evenly to all of the grain would result in the best fumigation. When the average outside air temperature during the two weeks following application of the fumigant pellets is expected to be cooler than the grain temperature, it may be best to apply most of the fumigant to the bottom half of the grain mass. This would ensure adequate phosphine concentration and duration in cases where insect populations existed throughout the grain mass. Finally, when the average outside air temperature during the two weeks following application of the fumigant pellets is expected to be warmer than the grain temperature, it is probably best to apply most of the fumigant to the top half of the grain mass; however, it may still be difficult to get an effective fumigation under these conditions.

References

[1] Winks, R. G., Russell, G. F. Effectiveness of SIROFLO® in vertical silos. In: Highley, E.; Wright, E. J.; Banks, H. J.; Champ, B. R. (eds.), Stored Product Protection, Proceedings of the 6th International Working Conference on Stored-Product Protection, Canberra, Australia. CAB International, Wallingford, United Kingdom, 1994: 1245 – 1249

[2] Reed, R. R., Hagstrum, D. W., Flinn, P. W., Allen, R. F. Wheat in bins and discharge spouts, and grain residues on floors of empty bins in concrete grain elevators as habitats for stored-grain beetles and their natural enemies. Journal of Economic Entomology, 2003, 96: 996 – 1004