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PERFORMANCE AND COST EFFECTIVENESS OF THE HORN DILUPHOS SYSTEM FOR GRAIN FUMIGATION AT AUSBULK WALLAROO GRAIN TERMINAL

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ABSTRACT

The Horn Diluphos System (HDS), the latest technology in phosphine and air mixing, was used to fumigate two sealed grain silos with a recirculation system at AusBulk Wallaroo Grain Terminal. The first silo, a 2000-tonne concrete vertical silo, containing about 500 tonnes of wheat was treated with 950 grams of VAPORPH$_3$OS (99% cylinderized phosphine) to achieve a target concentration of 300 ppm for a 15-day fumigation. The second silo, a 10,000-tonne welded steel silo, containing about 6000 tonnes of barley was treated with 11.46 kg of VAPORPH$_3$OS to achieve a target concentration of 700 ppm for 5-7 day fumigation. A 10,000-tonne welded steel silo full of chick peas was also fumigated with 4.6 kg of VAPORPH$_3$OS for a 200-ppm 10 day treatment. The least amount of phosphine is required at full capacity to achieve the target concentration due to minimum free air space inside the silo.

The HDS provided the benefits of quick attainment of target concentration in a few hours, safety and ease of operation, less weather dependence, less labour requirement, capability for topping up concentration for leakage replacement, no residue and disposal issue, and cost competitiveness as compared to using the phosphine tablets or blankets. At full capacity, the fumigation cost (fumigant and labour costs) of using the HDS with VAPORPH$_3$OS is A\$0.11/tonne for the 2000-tonne silo and A\$0.07/tonne for the 10000-tonne silo for a 15-day fumigation.

A C^nT product equation for *Rhyzopertha dominica* (lesser grain borer) was used to estimate the exact day of insect population extinction in the fumigation of 10,000 tonnes of chick peas. Due to higher initial phosphine concentration of about 350 ppm the population extinction was achieved in 8 days instead of 10 days protocol.

INTRODUCTION

After the successful field trial tour of the Horn Diluphos System (HDS) for sealed storage fumigations throughout Australia in the early 2003, AusBulk was one of the bulk handling companies in Australia that commercialised its use for grain fumigation at its grain terminals. AusBulk has seven grain terminals in South Australia with sealed silos fitted with recirculation systems in the range of 2,000 – 10,000 tonnes capacity. The HDS has completed successful trials and is now being used at one of AusBulk grain terminals at Wallaroo, South Australia.

Description and Features of the Horn Diluphos System (HDS)

The Horn Diluphos generator is a compact and mobile automated system, which allows the direct dilution of pure phosphine (VAPORPH$_3$OS) with air below the combustion limit, allowing the injection of an air and phosphine mixture into the enclosure to fumigate with concentrations from 0 to 10,000 ppm PH_3 without risk of ignition. The HDS includes a series of safety mechanisms, which will avoid damage in any risky situation, such as a power failure. In order to operate the system it is only required to connect the equipment to an electrical supply, to a nitrogen cylinder and to a phosphine cylinder.

There are currently 2 models, the HDS-80 with a phosphine flow rate of 19 g/min (1.14 kg/hr) and the HDS-200 with a phosphine flow rate of 47 g/min (2.82 kg/hr). The unit is user-friendly with all the operations controlled by an on-board PLC, with the instructions for operation shown on an LCD screen. Nitrogen is used to purge pipes and hoses before and after dispensing phosphine as well as to actuate the valves and do pressure tests of all the lines for leak testing before dispensing phosphine. The system injects an air and phosphine mixture at a pressure of 30 cm water column (3000 Pa), enough pressure to penetrate and distribute the air gas mixture in any stored commodity, with the great advantage that the mixture has density close to pure air, which assures a very fast and good distribution and diffusion.

Description of VAPORPH3OS Phosphine Fumigant

VAPORPH$_3$OS is a cylinderised source of 99% phosphine with an 18 kg net content of liquefied gas under pressure. It is manufactured and supplied by CYTEC Industries and currently registered in the USA, Australia and China. It is generally used for fumigation applications on food and non-food commodities using on-site mixing equipment either with carbon dioxide (e.g. CO_2 blender) or air (e.g. Horn Diluphos System). Unlike metallic phosphide fumigants, phosphine is not generated through a chemical reaction in the HDS and its release is instantaneous.

Figure 1. The 2000-tonne sealed concrete vertical silos at AusBulk Wallaroo grain terminal.

Figure 2. The 10000-tonne welded steel squat silos at AusBulk Wallaroo grain terminal.

Description of Sealed Silos

The grain terminal at Wallaroo, South Australia has blocks of 2,000-tonne sealed concrete vertical silos and 10,000-tonne sealed steel squat silos (Figures 1 and 2). In terms of sealing, the 2,000-tonne silos has a pressure decay of at least 3-minute half life while the 10,000-tonne silos has better sealing of at least 5 minutes half life. The recirculation system for the 2,000-tonne silos is composed of PVC ducts and a small centrifugal blower with an air change in 12 hours. The 10,000-tonne silos are fitted with steel ducting, a 25 kW aeration fan, a 7 kW methyl bromide fan and a 1.5 kW phosphine fan. At full silo loading and using the methyl bromide fan, the 10,000-tonne silos can achieve an air change in less than one hour.

Setup of the HDS Connections

Figures 3 and 4 shows the setup of the HDS-80 connected to the recirculation duct system of a 2000-tonne concrete silo. There are 2 connections used, one of the phosphine/air inlet and one for the recyling air outlet. The phosphine/air inlet is located 40 cm after the recyling air outlet downstream of the recirculation fan. The purpose of recyling the air from the silo is to prevent too much build up of pressure inside the silo due to addition of air from the HDS. The use of a small recirculation fan is to add more dilution air and hasten the movement of the gas from bottom to top of the silo. With the recirculation fan the airflow can do one air change in 12 hours.

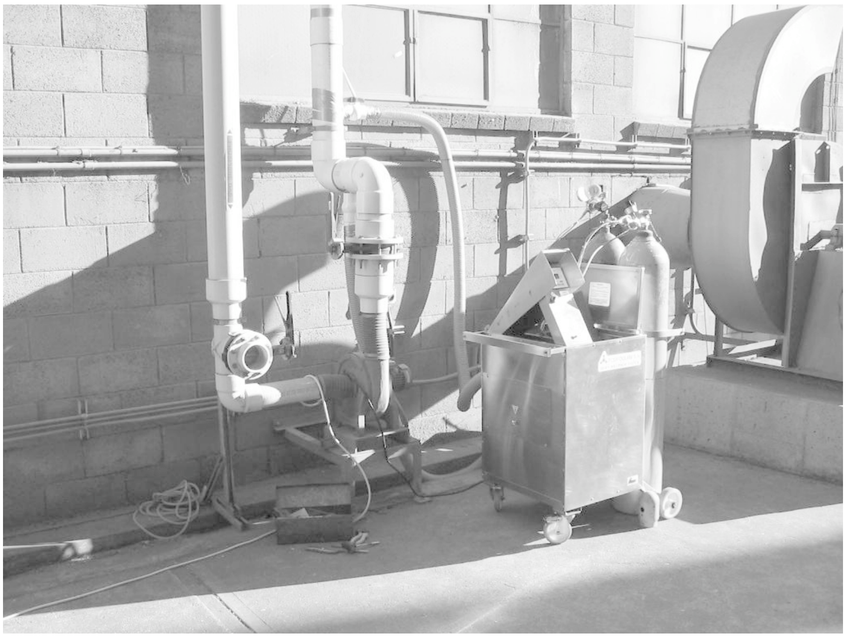

Figure 3. The HDS-80 and flexible hose connections to the phosphine/air inlet and recyling air outlet downstream of the recirculation fan.

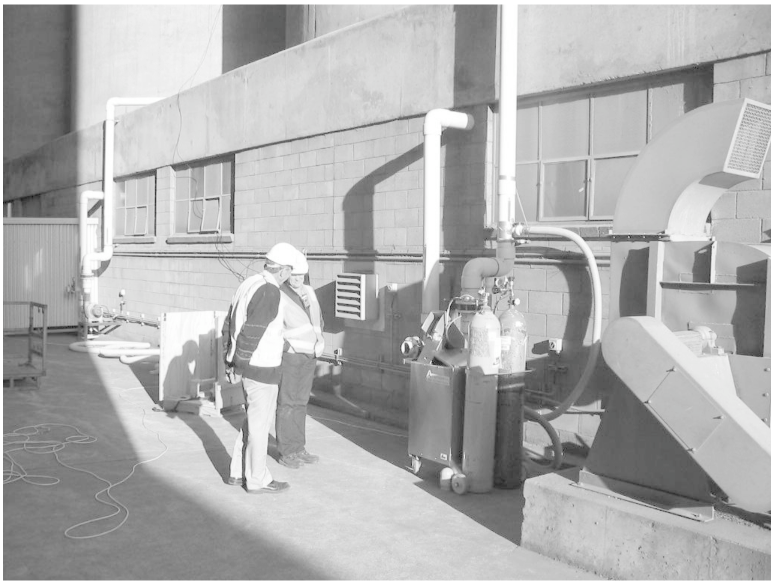

Figure 4. The HDS-80 connection with the cylinders of nitrogen and $VAPORPH_3OS$.

Figure 5. The 10,000-tonne welded steel sealed silo with the HDS-80.

The setup of the HDS-80 connection to a 10,000-tonne steel silo is shown in Figures 5-8. During gas dispensing, the 7-kW methyl bromide fan was used to move the phosphine/air mixture from bottom to the top of grain in less than an hour. As in the case of the 2000-tonne silo, the phosphine/air inlet is located after the recycling air outlet downstream of the fan. This is to prevent the recyling air outlet to suck some phosphine back into the HDS.

Figure 6. Close view of the HDS-80 setup.

Figure 7. Flexible hose connections to the recirculation duct of the 10,000-tonne silo.

Figure 8. The HDS setup and the two fans, the bigger 7-kW methyl bromide fan and the smaller 1.5-kW phosphine fan.

RESULTS AND DISCUSSION

Fumigation of 2000-tonne Silo - October 21, 2003

The first fumigation was set up on cell 307 (2,000-tonne cell) with a target concentration of 300 ppm or 912 g of VAPORPH$_3$OS and the objective to maintain a minimum of 100 ppm for 15 days including the gas distribution time of 1 day. The 300 ppm initial concentration was expected to cover gas leakage (5% /day) and some sorption by the grain. The cell had 500 tonnes of wheat in it with the rest of the cell air space. If the silo is full at 2000 tonnes the amount of VAPORPH$_3$OS to be used would be 467 g to achieve the 300 ppm target concentration. Fumigation uses less phosphine when the cell is full as there is less air volume to dose with phosphine to obtain the required concentration.

In the calculation for dosage of VAPORPH$_3$OS, an Excel spreadsheet calculator specific to grain type is used by inputting the silo dimensions, amount of grain stored and target concentration. The output values were the different volumes of silo grain air space, head space and effective air space; the amount of phosphine dosage, time of delivery and fumigant cost. The spreadsheet is a straight-forward and user-friendly tool for dosage calculation without tedious manual calculations.

From the time the fumigation was commenced to the time the calculated grams of phosphine had been dispensed into the cell by the Horn system, total time taken was around 1 hour. The recirculation system was left to run over-night to even out the phosphine levels in the cell. By morning the gas levels in the cell had stabilised to around 220 ppm. To explain for some of the gas loss there was quite a strong wind in the afternoon and up to around 10:00 PM that night, which caused gas egress from the silo due to reduced pressure on the down-wind side of the silo, followed by air ingress into the cell as the weather event passed, diluting the head space gas concentration. The figures used are from calculations of cell size so there is some room for error in the calculation. As the air space in the cell increases the gas concentration falls.

Fumigation of 10,000-tonne Silo - October 22, 2003

In the morning, the HDS was packed up and moved with a fork- lift to block 8 where the 10,000-tonne silos are located. The target concentration for cell 803 (10,000-tonne cell) was set for 700 ppm to test the ability of the Horn system to deliver the required phosphine and also to observe the sealing ability of the steel bin to maintain the gas level over a 5-day fumigation period. This could permit short fumigation periods for QPS operations. When calculated, the total requirement in phosphine terms was 11.5 kg to achieve a concentration of 700 ppm in this bin at a grain fill point of 8,000 tonnes of barley.

The time taken to dispense the gas took around 11 hours, which included some training time during which the unit was stopped and started.

The recirculation system was left running to help even out the gas levels within the cell. The steel silo was well sealed and this contributed to greater retention of the gas, which decreased slightly during the fumigation period.

Fumigation of 10,000-tonne Silo - April 27, 2004

A good example of full silo fumigation was conducted in April 27, 2004 with the silo filled with about 10,000 tonne of chick peas. A total of 4.6 kg of VAPORPH$_3$OS was dispensed to achieve an initial target concentration of 350 ppm to maintain at least 200 ppm during the 10-day fumigation protocol. Table 1 shows the phosphine concentration readings and the fan operation for 11 days. It took about 4 hours to achieve a good distribution of gas from bottom to the top of the grain. As the fumigation period progressed, the phosphine reading at the bin was lower than at the recirculation duct, indicating that there was a relatively large gas leak and air ingress in this area. Dispensing of phosphine was done with the methyl bromide fan operating to quickly move the gas to the top and allow recirculation of the gas until target concentration uniformity was reached. The 1.5 kW phosphine fan was operated for recirculation to equalise the gas distribution from bottom to top. The use of the methyl bromide fan is not recommended due to greater pressure that can develop inside the silo and consequently greater gas loss during recirculation.

TABLE 1
Phosphine concentrations and fan operation during fumigation of 10,000 tonnes of chick peas

Date	Time of day	Day of fumig-ation	Phosphine Concentration (ppm)			Fan Operation
			Recirculation Duct	Bin	Average	
27 Apr	10:00		190	98		methyl bromide fan on
	11:00		216	138		phosphine fan on
	12:00		289	242		methyl bromide fan on
	13:00	1	350	320	335	methyl bromide fan on
29 Apr	09:00	3	302	302	302	methyl bromide fan off phosphine fan on
30 Apr	09:00	4	280	170	225	phosphine fan off
3 May	09:00	7	236	148	192	phosphine fan off
4 May	09:00	8	228	136	182	phosphine fan off
5 May	09:00	9	314	172	243	phosphine fan on
6 May	09:00	10	196	112	154	phosphine fan off
7 May	09:00	11	187	170	178	phosphine fan on
10 May	08:00		commenced venting bin as the peas where required for a ship			

After fumigation, the chick peas were loaded on a ship for export and passed the quality inspection of the Australian Quarantine Inspection Service (AQIS) without live insects.

Use of C^nT Product to Estimate Success of Fumigation

A C^nT product calculation was done to estimate the actual time for insect population extinction. A C^nT equation is a more accurate indicator of population extinction than the conventional CT product (Daglish *et al* 2002). A C^nT equation for strong resistant *R. dominica* (lesser grain borer) as updated from Pat Collins (2004) was used as below:

$$C^n t = k \qquad (1)$$

where: C = concentration (mg/L), t = time (days) and n = the 'toxicity index', a measure of the relative importance of concentration and time to the dosage.

For strong resistant *R. dominica* the equation is

$$C^{0.6105} t = 4.0404 \qquad (2)$$

For resistant *Sitophilus oryzae* (rice weevil) the equation is

$$C^{0.4812} t = 4.1371 \qquad (3)$$

To apply these equations, a fumigation curve is drawn with time versus concentration, and the C^nT value is calculated for each day of exposure. The daily values of C^nT are added and the day when the cumulative value reached or exceeded the k value of 4.0404 will be the day of predicted population extinction or 100% mortality for all insect stages of *R. dominica.*

The C^nT equations are specific to insect species with different values of the constants n and k. The use of C^nT equation for strong resistant *R. dominica* is a conservative approach to assess fumigation success. For multiple test points, the test point with the lowest k value should be the reference for selecting the day of predicted population extinction.

As shown in Table 2, the k value of 4.0404 was exceeded in day 8 with the k value of 4.0724. The cumulative C^nT values were conservative since C^nT on the missing days (day 2, 5 and 6) were calculated based on the phosphine concentration of the next day with available reading. If interpolation will be done to fill up the days without phosphine readings, a shorter time of population extinction can be expected. This means that day 8 was the actual day 100% insect mortality or population extinction was achieved instead of the 10 days of protocol. This is because of the higher initial concentration of over 300 ppm in the early stage of fumigation which account for higher C^nT values. If there is a constant 200 ppm throughout the fumigation period then the k value of 4.0404 will be reached in 10 days. The average of two sampling points (top and bottom silo) is enough to get a representative C^nT value considering that the silo is well sealed and recirculation is done to equalise gas distribution throughout the silo.

TABLE 2.

Average phosphine concentration, daily and cumulative C^nT product during the fumigation of 10,000 tonne of chick peas in a sealed steel silo.

Date	Day of fumigation	Average Phosphine Conc. (ppm)	Average Phosphine Conc. (mg/L)	Daily C^nT	Cumulative C^nT
27 Apr	1	335	0.4666	0.6279	0.6279
29 Apr	3	302	0.4206	0.5894	1.8067
30 Apr	4	225	0.3134	0.4924	2.2991
3 May	7	192	0.2674	0.4469	3.6398
4 May	8	182	0.2535	0.4326	**4.0724**
5 May	9	243	0.3384	0.5161	4.5885
6 May	10	154	0.2144	0.3907	4.9792
7 May	11	178	0.2479	0.4268	5.4060

The use of C^nT is a good tool to estimate or predict the success of fumigation provided that the phosphine readings are taken from representative sampling points, the gas is uniformly distributed by recirculation fans and the gas is monitored regularly.

Cost of Fumigation

For a 14-day or 15-day fumigation using VAPORPH$_3$OS for a full silo, the total fumigation cost (labour and fumigant) using the 2,000-tonne silo is A$0.11/tonne. This is distributed to A$0.07/tonne for labour and A$0.04/tonne for VAPORPH$_3$OS. The equivalent fumigation cost for tablets is A$0.14/tonne divided into A$0.11/tonne for labour and A$0.03 for tablets. The use of the HDS requires less labour of 6 man-hours as compared to the use of tablets of 9 man-hours. There is extra time required for the removal, deactivation and disposal of tablets.

For a 14-day or 15-day fumigation of the 10,000-tonne silo full of grains, the total fumigation cost is A$0.07/tonne divided into A$0.035/tonne for labour and A$0.035/tonne for VAPORPH$_3$OS. The equivalent cost for tablets is A$0.10/tonne divided into A$0.05/tonne for labour and A$0.05/tonne for tablets. The use of the HDS requires 14 man-hours and compared to the use of tablets which requires 20 man-hours.

For shorter fumigation period of 10 days or 5-7 days in a well sealed steel silo, the fumigant cost will increase due to higher amount of VAPORPH$_3$OS to use for higher dosage. The equivalent total fumigation cost would be A$0.125/tonne for a 10-day fumigation and A$0.215 for a 5-7 day fumigation.

BENEFITS OF THE HORN DILUPHOS SYSTEM

The Horn Diluphos System had some benefits compared to our current use of phosphine tablets and blankets to fumigate either the 10,000-tonne steel bins at block 8 or the 2,000-tonne concrete silos at block 3.

Some of the major advantages are as follows:

1. Ability to introduce phosphine gas into cells and have all of the grain-bulk up to required fumigation concentration within a day or a few hours with fast recirculation system. Level of phosphine is not dependent on moisture or temperature of grain to achieve gas generation. Therefore the HDS fumigation actually starts earlier as the gas concentration is achieved within 24 hours while the tablets may take up to 3 days to reach these concentration levels.
2. Apart from sealing of cells (silos) all phosphine operations are at ground level.
3. The HDS is less weather dependent when compared to solid formulations of phosphine generation.
4. If required the HDS can perform ''top-up'' operations if concentrations fall below requirements.
5. There is no need to lift fumigation products up to the top of the cells, then dispense the product and remove the residues at the completion of the fumigation thereby saving exposing staff to a range of occupational health and safety (OH&S) risks.
6. Once the HDS is in place and operating it would only require one person to monitor the unit until the concentration is achieved.
7. No residues to remove, lower and dispose-of at the completion of the fumigation.
8. Greater control of fumigation in terms of achieving a specific phosphine concentration for different fumigation periods of 5, 7, 10 or 15 days.

ACKNOWLEDGMENTS

The authors wish to thank the following persons for their contributions in the conduct of fumigations at Wallaroo Grain Terminal:

Robert Jamieson - Wallaroo Operations Coordinator for organising the storages for fumigation, and arranging support staff.

Brenton Murphy - Fumigator-in-Charge for monitoring of phosphine levels.

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