The Adoption of Thermosiphon Powered, Ground Level Phosphine Application Systems in Australia.

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Abstract

Safe storage of grain on Australian farms requires a sealable silo to exclude grain insects and enable effective fumigation to avoid the development of insect resistance to phosphine.

A sealable silo must also be fitted with a pressure relief system that allows air to enter the silo rapidly, to avoid damage to the silo fabric, in the event of a sudden temperature drop and subsequent contraction of the internal atmosphere.

The most effective pressure relief system allows air into the headspace by a pipe attached to the silo wall, which is connected to an oil bath valve at ground level to facilitate servicing. The oil bath valve prevents grain insects entering and will allow air to bypass when the internal pressure exceeds or falls below 30 – 40 Pascals.

The addition of a pipe connecting the headspace pipe to the base of the silo creates a gas recirculation loop. Ambient temperature influences the air within the external pipe and Thermosiphon currents are created, circulating the internal atmosphere.

In 2004, a silo manufacturer in Western Australia proposed such a recirculation loop adding an aluminium phosphide (AlP) reaction chamber into the circuit at ground level. A ground-level application system removes the need to climb the silo, making fumigation simpler and safer.

Initial experiments in 2005 revealed that the phosphine gas would be extracted from the reaction chamber by Thermosiphon air movement, without building to dangerous concentrations.

Seven silo manufacturers across Australia have adopted the Thermosiphon recirculation system linked to a ground level AlP reaction chamber, producing nearly 12,000 transportable silos of 80 – 100t capacity in that period.

The development of the recirculation system and effectiveness of Thermosiphon gas distribution is discussed in this paper.

Keywords: sealed silo, Thermosiphon, recirculation, Aluminium Phosphide, Phosphine.

1. Introduction

Storing grain in Australia is characterised by the challenges of grain insect attack, similar to all warm climate countries in the world. The grain is harvested warm in early summer and remains warm in the silos unless aeration is used but this has limitations in the ability to cool the grain until winter occurs some 3 – 4 months later. Stored grain insects are endemic in the environment, and present a constant threat to stored food products.

To prevent insect attack and enable effective fumigations, sealed gas-tight grain stores have been a feature of the Western Australian grain industry since the 1980's when the central storage operators, Cooperative Bulk Handling of Western Australia, decided to seal all permanent grain storage (Newman, 2006). A 'nil-tolerance' of stored grain insects in grain delivered to the central system was established.

To meet this standard, higher quality of grain storage on farms was needed and assistance was co-opted from local silo manufacturers to produce sealable grain silos (Newman, 1997). The most common types of grain silos in Western Australia are <100t capacity, assembled in a factory and delivered on hydraulic trailers in one piece to the farm, ready to be set up for storage and fumigation. The factory construction process enables a high quality product to be manufactured and sealed to a gas-tight pressure test standard (AS 2628 - 2010).

A sealable silo must be fitted with a pressure relief system to avoid damage to the silo fabric. It allows air to enter the silo rapidly in the event of a sudden temperature or atmospheric pressure drop and subsequent contraction of the internal atmosphere.

The most effective pressure relief system allows air into the headspace via a pipe attached to the silo wall, which is connected to an oil bath valve at ground level to facilitate servicing. The oil bath valve prevents grain insects entering and will allow air to bypass when the internal pressure exceeds or falls below 30 – 40 Pascals. One silo manufacturer in Western Australia (WA) Moylan Silos, based at Kellerberrin, created an efficient pressure relief system using a 90 mm PVC pipe to the headspace coupled to a PVC oil bath valve at ground level (Fig. 1). Many thousands of these silos were produced and remain in use on farms.

Fig 1.

Fig 2

To initiate fumigation in these silos, fumigators attach a safety harness, carry the required amount of AlP to the top of the silo, fit on a personal air-purifying respirator, spread the solid formulation onto a wide tray in the headspace of the silo and close and seal the top hatch (Fig. 2).

2. Ground level phosphine application system proposed

In 2004, Mr Don Bird, owner of Bird's Silos, Popanyinning, WA proposed a recirculation loop, connecting a 90 mm headspace pipe to the base of the silo as a conduit for gasses and adding an AlP reaction chamber into the circuit at ground level (Boland, 1984). Ambient temperature influences the air within the external pipe and Thermosiphon currents are created, moving the gas up or down the pipe depending on the temperature gradient with the commodity. The ground level phosphine application system make the fumigation safer for the fumigator, removing the need to climb the silo. Simultaneously in 2004 a company in WA created a translucent, diesel resistant, Linear Low Density Poly Ethylene oil bath pressure relief valve (PRV) to fit to a 90 mm headspace pipe (Fig. 3). This enabled instant inspection of the oil levels in the valve to ensure the air entering will by-pass at a safe pressure and can also be used as a manometer for pressure testing.

Fig 3.

Fig. 4

3. Methods

In January 2005, a 90.9 m^3 elevated silo was prepared for a pilot trial of the Thermosiphon ground level phosphine application system on a farm at Yornaning, WA. A phosphine reaction chamber was constructed consisting of a metal box with a shelf to hold the AlP tablets and 32 mm internal diameter flexible tubing entering each side of the box to allow air to flow through. This phosphine reaction chamber was placed underneath the silo and the flexible tubing was connected into the base of the silo and to the headspace pipe (Newman et al., 2006). The gas concentrations were measured with a Spectros Non-dispersible Infrared Phosphine Monitor (Supplied by Fosfoquim of Chile), which could record phosphine concentrations up to 10000 ppm. The Thermosiphon pipe attached to the silo wall connecting the headspace to the phosphine reaction chamber was constructed of white PVC and included a translucent PRV.

Phosphine tablets at a rate of 1.5 g/m^3 (#130) were spread on solid trays in the phosphine reaction chamber. Peaks ranging up to 7000 ppm in the phosphine chamber were observed when the air ceased to move in the headspace pipe. This happened twice daily as the airflow direction reversed due to the change from diurnal or nocturnal ambient conditions and air moved up or down the pipe. There was a concern that the flexible tubing connecting the phosphine reaction chamber to the Thermosiphon pipe was restricting the airflow allowing higher concentrations of phosphine to occur.

The next experiment on the same farm in a similar silo incorporated a black painted PVC Thermosiphon pipe and an application rate of 1.1 g/m^3 (#100) using the same phosphine reaction chamber. The silo experienced lower peaks of up to 2300 ppm, which was due to a lower rate of application and faster air movement in the black Thermosiphon pipe.

In February 2005, airflow monitoring was conducted on a black coloured 90 mm PVC Thermosiphon pipe attached to a 90.9 m^3 capacity silo. The pipe to the headspace was connected to a 40 mm steel pipe into the base of the silo. Measurements were taken over 24 hours of the air flowing through the Thermosiphon system using a Kurz hot wire anemometer. The results showed the air moving under favourable warm ambient conditions and stopping completely when the ambient and commodity temperatures were similar (Tab. 1).

Table 1.
Thermosiphon air speed test, February 26th 2005, E Popanyinning WA
Silo pressure test >180s, Barley @ 9.6% m.c. and 29°C

Weather	Time	Ambient °C	Ambient wind speed kph	Airspeed tube m/s (32 mm orifice)	Metres/s 90 mm pipe	Litres / min 90 mm pipe	m/3/hr
Fine	12:30	31	7.2	0.55	0.068	25.95	1.55
Fine	13:30	34	8	0.6	0.074	28.24	1.69
Fine	14:30	36	11	0.45	0.056	21.37	1.28
Fine	15:30	35.5	22	0.48	0.059	22.521	1.35
Fine	16:30	36	13	0.45	0.056	21.37	1.28
Cloud	17:30	35	16	0.29	0.035	13.6	0.8
Cloud	18:00	34	18	0.29	0.035	13.6	0.8
Cloud	18:30	33.5	15	0.21	0.026	9.9	0.59
Cloud	19:00	33	7	0.19	0.023	8.7	0.53
Cloud	19:30	32	6	0.11	0.014	5.3	0.32
Cloud	20:00	31	5.5	0.09	0.011	4.2	0.25
Cloud	21:21	30	0	0		0	
Cloud	22:00	29	0	0		0	
Cloud	23:00	28	0	0		0	
Part cloud	0:00	26	3	0		0	
Part cloud	2:00	24	6	0.04	0.005	1.9	0.11
Part cloud	4:00	24	5	0.06	0.007	2.67	0.16
Part cloud	6:00	23	0	0.1	0.012	4.6	0.27
Cloud	7:00	26	2	0.05	0.006	2.3	0.14
Cloud	8:00	28	8	0.08	0.01	3.8	0.23
Cloud	9:00	30	15	0.19	0.023	8.7	0.53
Cloud	10:00	31	20	0.15	0.018	6.8	0.41
Rain	11:00	27	9	0.04	0.005	1.9	0.11
Rain	11:30	27	7	0		0	

A fumigation was commenced in the same silo the following month when AlP tablets at a rate of 1.5 g/m^3 were placed on the sealing plate (Fig. 4) at the base of the silo. The space between the seal plate and the grain control 'butterfly valve', provided adequate space as a phosphine reaction chamber. In this experiment gas concentration reached a maximum of 3500 ppm in the phosphine reaction chamber and up to 1750 ppm in the headspace (Fig. 5). A test in a similar silo the following summer produced similar results with the characteristic high and low peaks in the phosphine chamber and even concentrations in other parts of the grain mass.

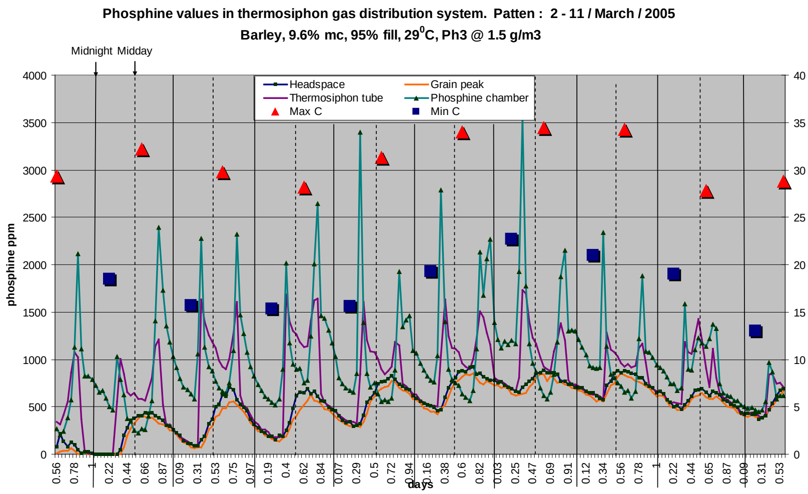

Fig. 5

The low concentrations in the phosphine reaction chamber shown in Tab. 2 are caused by the air flowing rapidly up the Thermosiphon pipe in the morning as the sun heats the pipe. The high concentrations in the evening are a result of the air moving down the pipe as the ambient temperature falls below that of the stored commodity. The even concentrations of gas in the grain mass demonstrate the mixing effect of the Thermosiphon induced air currents. This is in contrast to a 'top loaded' AlP fumigation where there is an initial high concentration in the headspace, which reduces over time as convection currents and diffusion carry the gas to the lower parts of the silo.

The results of these experiments demonstrated to Bird's Silos that the system was safe, efficient at moving released phosphine gas into the grain profile and removed the need to climb the silo to apply AlP into the headspace. The company modified the production line to produce all silos from their factory with the Thermosiphon powered ground level phosphine application system.

An important modification to the new silos was a deep bowl phosphine reaction chamber to hold a 'Bag Chain' formulation of AlP or a removable perforated steel plate in the base to hold the tablet formulation of AlP and allow the powder to drop through as phosphine gas is generated (Figs. 6a & 6b). In addition, the top lid on the silo was fitted with a cable and winch device, which is operated at ground level to open, close and seal the top lid also without having to climb the silo.

Fig. 6a &6b

4. Ground level phosphine application system adopted by other silo manufacturers

A silo manufacturer in South Australia showed interest in the system and a cooperative arrangement with Bird's Silos was established to share the technique. A silo company in Victoria also became interested in the system and came to an agreement with Bird's Silos to share the information. This company was part of a larger corporation controlling three independent manufacturing plants in three other Australian states who also adopted the ground level application system.

Modifications to the phosphine reaction chamber and connections have been made by silo factories across the country but retain the principle of the system with a 90 mm headspace pipe connected to the base of the silo. Fig. 7 shows one of the variations of the phosphine reaction chamber at ground level.

Six silo manufacturing plants around Australia have now adopted the translucent PRV and statistics provided by the manufacturing company indicate that up to December 2017 approximately 6500 silos have been fitted with the Thermosiphon powered ground level phosphine application system. In addition, Moylan Silos in WA, who first fitted the 90 mm headspace pipe, have also created a ground level phosphine application system but retained the PVC, PRV (Fig. 8) and retrofitted it to all silos produced since 2009. In that period, they have produced approximately 5400 silos. Across Australia there are now approximately 12,000 silos fitted with the ground level phosphine application system with Thermosiphon distribution.

Fig. 7

Fig. 8

5. Inert atmosphere application

The simple addition of three ball valves into the lower Thermosiphon pipe allows purging of the silo atmosphere at ground level through one of the valves while loading gas such as nitrogen (N_2) or carbon dioxide though one of the other valves (Fig. 9). The purging valve provides a convenient point at which to measure the composition of the internal atmosphere. When using inert gasses in a sealable silo, the halving pressure test must be elevated to a minimum of 5 minutes to avoid oxygen (O_2) ingress over the longer fumigation periods required.

Application of N_2 using a 30 m^3 per hour Pressure Swing Absorption N_2 generator (Fig. 10) into a 90.0 m^3 silo takes approximately 2.5 hours with an additional 0.5 hour the following day to remove the oxygen desorbed from the grain and retain the O_2 concentration at 1% (Newman, J – personal communication). Measurements over the succeeding 28 days showed even concentrations at all points as the gas was recirculated by the Thermosiphon pipe with a slight decay to ~3% O_2.

6. Testing of the Thermosiphon system at Kansas State University (KSU), USA

In 2015, a 63 m^3 Bird's Silo was transported from Popanyinning, WA to KSU, to conduct detailed analyses of the Thermosiphon ground level phosphine application system. The silo was shipped in pieces and assembled on site by a group of people including Mr. Don Bird and the author. Sealing on site was more complicated and the standard achieved in the factory could not be emulated in the field. In addition, a locally manufactured 71.9 m^3 SCAFCO silo was assembled on the site and sealed as it was being constructed; however, it was not designed to be sealed and required considerable innovation on site to achieve a seal (Fig. 11). The result was that both silos were sealed to a lower standard than required in Australia under AS 2628 (5 minutes halving pressure for a newly constructed silo).

Mr. S. Cook commenced experiments in August 2015 as part of a Master of Science degree (Cook, 2016). The experiments were conducted with solid formulation AlP, gaseous phosphine and sulfuryl fluoride. AlP tablets were applied in the ground level phosphine reaction chamber, gaseous phosphine was applied via the Thermosiphon pipe and sulfuryl fluoride was applied through one of the monitoring lines directly into the grain. The silos were set up to include a ball valve in the lower pipe so that the gas recirculation could be studied with and without Thermosiphon.

Fig. 9

Fig. 10

Fig. 11

Experiments showed the Thermosiphon effect moving phosphine gas upward into the headspace during the period when the sun was warming the external pipe and concentrations rising in the lower parts of the silo in the cool evening as the air flow reversed and moved released gas out of the phosphine reaction chamber. When the Thermosiphon was turned off, the phosphine was forced to move upwards through the grain mass taking some time to reach lethal concentrations in all parts of the silo, relying only on thermal convection currents. Air speed velocities in the Thermosiphon pipe were between 0.02 – 0.08 m/s under sunny conditions and 0.01 – 0.02 m/s in partly cloudy conditions (Cook, 2016).

7. Discussion

The development of the Thermosiphon ground level phosphine application system has made Australian grain silos safer for the fumigator and grain manager. Experiments in Australia on silos up to 1200 t have demonstrated that a Thermosiphon system provides effective recirculation without the use of electrically powered fans (Newman, 2012).

The addition of a Thermosiphon pipe to any silo ensures continuous mixing of the internal atmosphere and has been shown to be effective when used as the delivery conduit for a gaseous phosphine application. The gas is injected into the silo and the aeration fans operated with all seal plates in place to circulate the gas for 60 – 90 minutes, after which the aeration fans are turned off. The gas continues to circulate as powered by Thermosiphon alone, producing even concentrations throughout the silo for the remainder of the fumigation period (Ball, S personal communication).

Research at KSU demonstrated the effectiveness of the Thermosiphon powered ground level application system in distributing phosphine rapidly throughout the grain bulk. In that experiment, turning off the Thermosiphon air currents demonstrated the slower incorporation of phosphine by thermal air currents and diffusion alone. In comparison, with the Thermosiphon operating there was rapid mixing of the phosphine gas throughout the silo.

Future developments that could be explored to reduce the need to climb the silo include using the headspace pipe as conduit for extracting grain odours or carbon dioxide to determine grain quality and presence of mould or insects. Custom-made pheromone traps inserted into the headspace pipe at ground level would attract grain insects, providing a decision tool to initiate a fumigation procedure.

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