Use of Controlled Atmosphere and Fumigation as a Management Tool for Grain Stocks: the Problems and Prospects

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Abstract

Co-operative Bulk Handling Limited, the grain Bulk Handling Authority for Western Australia, has a total grain storage capacity of 10.4 million tonnes. Since 1980 the company has initiated a policy of progressively sealing grain storages to maintain stocks free of insect infestation at substantially reduced levels of pesticide residues, by the use of controlled atmospheres and fumigants. Fumigation is also extensively used in PVC covered storages. It is acknowledged that the quality and condition of grain currently received in Western Australia is compatible with CA storage and that any future changes in receival standards, such as higher grain moisture tolerance, may influence pest control strategy. The paper discusses the operational advantages, problems and strategy associated with the reliance on the use of controlled atmospheres and fumigants on a large scale and the prospects of such a system for the future.

Approximately 90% of Western Australia's grain production is received into the central storage system as it is harvested over the months of November and December. Grain temperature is within the range 28°–32°C when the commodity is put into storage. With a typical Mediterranean-type climate, the storage of large volumes of bulk grain over substantial periods of time offers a favourable environment for development of populations of a range of stored product insects.

Before 1980 Co-operative Bulk Handling Limited relied almost entirely on the wide-scale use of organophosphorous grain protectants, with a limited use of fumigants at export terminals, to maintain grain stocks free of infestation. It was from 1980 that the company initiated a policy of progressively sealing existing storages to allow the use of controlled atmospheres or fumigants and started to augment capacity with PVC covered storages suitable for fumigation. This fundamental change in stored product pest control was prompted by the following circumstances:

- An increase in the level of insect resistance to broad-spectrum and relatively inexpensive protectants.
- The high cost of alternative, second generation protectants, such as the pyrethroids.
- An increased reluctance by domestic and international markets to accept grain containing pesticide residues.

To date, of a total storage capacity of 10.4 million tonnes, Co-operative Bulk Handling has approximately 6.8 million tonnes (Table 1), or 65%, that exclusively uses either controlled atmosphere or fumigation as the control measure.

Changes to control strategy introduced since 1980 have significantly altered the management of grain stocks.

Storage Hygiene

Before intake of new season's grain, unsealed storages are thoroughly washed to remove accumulated grain residues and dust. A residual insecticide is then applied to the storage fabric. While necessary, this procedure is expensive in terms of labour and resources, and may not always be possible where there is insufficient time between emptying the storage and receival of new season's grain.

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An advantage with CA storages is that all background insect populations are eradicated during treatment. Pre-harvest hygiene in these storages is now confined to ancillary handling equipment and the removal of grain dust only where there is sufficient quantity to produce a potential fire or explosion hazard.

The physical barrier these storages provide (once sealed) against external reinfestation offers the added advantage of not having to implement comprehensive and expensive herbicide treatments around them to eliminate potential harbours for insects.

The physical barrier is also effective against rodents. Consequently, control programs and the quantity of rodenticides used have both declined in recent years.

CA storage, by total exclusion of birds, has completely eliminated contamination of bulk stacks from this source, although flocks of one of the native parrot species have occasionally caused considerable and expensive damage to external sealing membranes. As a consequence, changes have been made to sealing techniques to reduce shielding urethane foams where they have been utilised externally.

A recent survey indicated that the use of CA storages had, since 1980, realised some $2 million savings in the company's expenditure towards storage hygiene

Grain Protectants

Previously, all grain received into the central storage system was treated with a grain protectant. Detailed storage planning and staff training were required to ensure uniform treatment, with different maximum residue limits (application rates) and protectants to meet market requirements.

With CA storages there is no need for protectant application equipment (pumps, vats, solenoids, nozzles, etc), or for additional trained staff to ensure correct application. The costs associated with purchase, storing, stock-taking, and distribution of protectants, and the provision and maintenance of application equipment, have dramatically decreased as the proportion of CA storages has increased.

An indication of the decrease in the usage of grain protectants can be demonstrated (Fig. 1),

Table 1. Storages exclusively using controlled atmosphere or fumigation: 1979–1988 (capacities shown in tonnes).

		Vertical	Horizontal	Sub-totals	Totals
1979	Seaboard	2 200		2 200	2 200
1980	Country		69 000	69 000	69 000
1982	Country	95 000	453 900	548 900	548 900
1983	Seaboard		285 800	285 800	
	Country		394 600	394 600	680 400
1984	Seaboard	106 600	182 400	289 000	
	Country		530 900	530 900	819 900
1985	Seaboard	238 350	100 000	338 350	
	Country		360 500	360 500	698 850
1986	Seaboard	50 600	365 800	416 400	
	Country		415 400	415 400	831 800
1987	Seaboard	28 600		28 600	
	Country		191 200	191 200	219 800
1988	Seaboard	22 000		22 000	22 000
	Total	543 350	3 350 400		3 893 750

To the end of 1988 figures show:-

1. Country ('Inland') storage capacity sealed	= 2 511 400
2. Seaboard installations total capacity sealed	= 1 382 350
Total sealed storage capacity	= 3 893 750
Total PVC covered storage capacity	= 2 963 300
Grand total	= 6 857 050

with usage for 1988–89 expected to be only 20% of that in 1985–86.

The advent of CA storages has also enabled the continued use, in non-CA storages, of less expensive protectants such as fenitrothion. There is no doubt that, with a system relying solely on grain protectants, Co-operative Bulk Handling Limited would, through increased levels of insect resistance, have had to utilise more expensive alternative protectants.

Resistance

While each grower's load continues to be sampled for grain insect infestation when delivered to storage, the consequences of undiscovered infestations are greatly diminished if the grain is allocated to CA storages.

Furthermore, the level of 'on-farm' insect resistance to grain protectants has less impact on grain protection strategy as the number of CA storages increases.

An increase in the level of on-farm resistance to phosphine is of some concern in Western Australia. The State Department of Agriculture is conducting an on-going survey of on-farm phosphine resistance. Preliminary results show an increase from 4.5% (71 of 1581 farms surveyed) in 1982, to 20.5% (92 of 448 farms surveyed) in 1986. The extent and significance of this increase is difficult to determine in the absence of comprehensive survey data. There is, however, evidence to suggest that recent sampling has been biased toward farms with a poor hygiene record, or where it is known inadequate on-farm fumigations have been conducted.

At this stage phosphine resistance levels are low and infrequent and can be readily controlled with the existing phosphine dosage and exposure regime.

Versatility and economics lead to the extensive use of phosphine as the preferred material. Nevertheless, at additional cost, existing CA storages can utilise other gases. Extensive field trials have been conducted using methyl bromide, carbon dioxide, and nitrogen. Comparative costs per tonne of each treatment are: phosphine $A0.02; methyl bromide $A0.22; carbon dioxide $A0.10; nitrogen $A0.60.

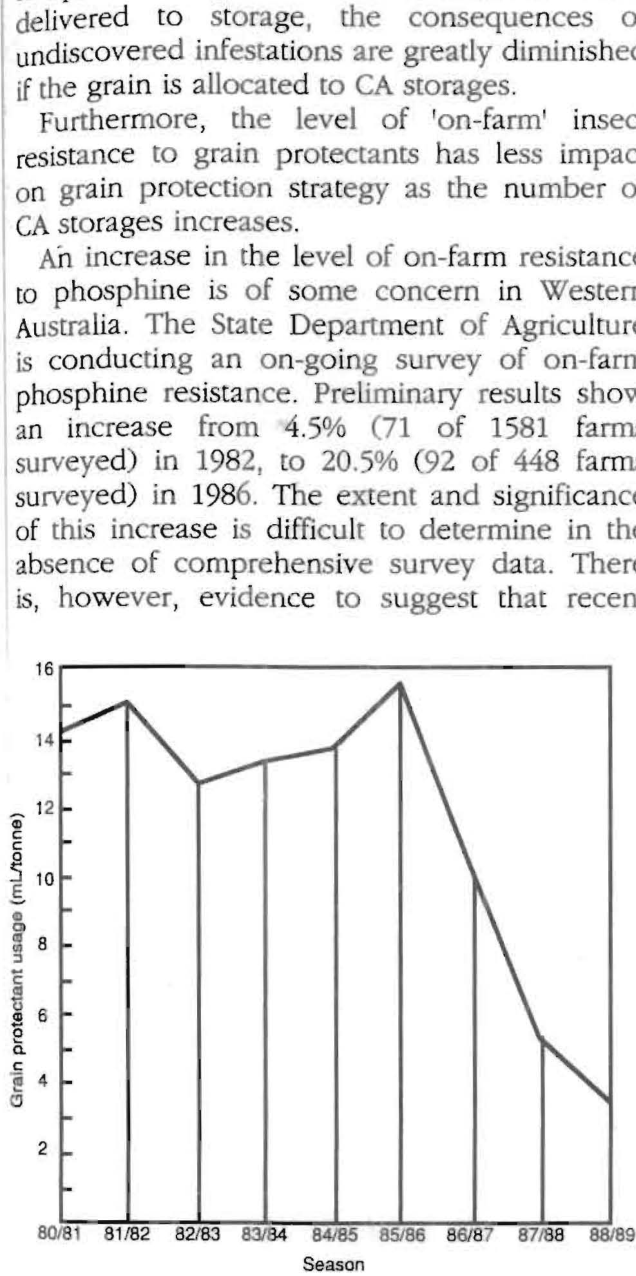

Fig. 1. Grain protectant usage in Western Australia over the period 1980–81 to 1988–89.

Storage

Grain stored in bulk or bags is prone to moisture migration and subsequent spoilage. Primary factors influencing the rate of moisture migration are the grain moisture content at harvest and the temperature gradients experienced during storage. Storages in Western Australia are predominantly horizontal and up to 300,000 tonnes in capacity. With 'surface-only' techniques being used, and thermal convection relied upon for uniform distribution of gas, minimum exposure periods prevail for four weeks and frequently much longer if the grain is not required for out-loading.

Fortunately, Western Australian grain is relatively dry when harvested (less than 12% moisture content) and storage losses resulting from moisture migration are rare. Therefore, grain can be stored for prolonged periods while under fumigation with the confidence that quality will be maintained.

Typically, a Western Australian country CA storage will be fumigated in January and the grain inspected or sampled in April or May. Should the grain not be required for outturn in the immediate future, the storage will then be refumigated and held, in a sealed condition, pending movement. It is unusual for such storages to be fumigated more than once in 4–5 months, or more than twice over 8–10 months.

Similar strategies are adopted in horizontal storages at export terminals where this need for prolonged exposure periods requires careful planning and placement of grain stocks. However, vertical cells at terminals are equipped for recirculation allowing for shorter minimum exposure periods of 7–10 days with phosphine, and 14–20 days with carbon dioxide.

Difficulties in the use of CA and fumigation occasionally arise in large horizontal storages, particularly those at export terminals. Until these storages are full—and this can take from several weeks to several months—the grain is subject to insect infestation. Coupled with the prolonged exposure periods required, grain may not be available immediately after harvest from country installations; or to meet unexpected shipping commitments from export terminals.

Similarly, the length of time it takes to outload, particularly if outloading is intermittent, can require a refumigation due to infestation from external sources.

Front-end loaders are normally used for outloading horizontal storages. The resultant atmosphere of grain dust and exhaust gases make mechanical ventilation of storages and respiratory protection for drivers essential.

Productivity and efficiency are markedly affected by 'down-time' resulting from mechanical or electrical failures. Co-operative Bulk Handling runs a comprehensive routine preventative maintenance program. The long exposure periods of CA storage mean that for much of the year equipment is unavailable for maintenance. Accordingly, maintenance programs must now be scheduled and coordinated to coincide with times when it is safe to enter these storages.

It should be emphasised that the advent of CA storage has necessitated a fundamental change to storage strategy. Grain in these storages is now fumigated as a matter of routine and as an integrated quality control measure. Previously, fumigation was used as a last resort where infestation could not be controlled by other methods. Frequently, it was the end result of constant turning of grain prior to export, a strategy that is now largely obsolete with consequent savings in resources and an increase in productivity.

Sampling

In the past, grain in Western Australian country storages was physically inspected on a weekly basis. Additionally, representative samples were drawn bi-monthly for residue analysis and, in the event of insect infestation, further samples were required for insect resistance testing. Following the introduction of CA storage, the need for intensive sampling has been much reduced, with consequent better utilisation of labour and laboratory resources, and a reduction in costs.

Nevertheless, problems can occasionally occur

Table 2. Number of pesticide residue tests undertaken in Western Australia, 1978–88.

Season	Organo-phosphates	Bioresmethrin	Organo-chlorines	Carbaryl	Pyrethrins	Misc.	Year total
78–79	9490	628	99	262	–	–	10 479
79–80	12 538	2007	62	231	12	17	14 867
80–81	6104	587	69	115	28	65	6968
81–82	8222	405	10	10	110	52	809
82–83	5935	131	27	–	25	8	6126
83–84	8147	269	112	–	73	154	8755
84–85	8114	350	70	2	5	75	8616
85–86	8844	785	20	–	–	40	9689
86–87	7847	162	71	–	45	130	8255
87–88	7792	65	212	2	7	32	8110
Grand total	83 033	5389	752	622	305	573	90 674

Organophosphates include fenitrothion, malathion, chlorpyrifos-methyl (Reldan), dichlorvos (DDVP), pirimiphos-methyl (Actellic), and etrimfos.
Miscellaneous includes deltamethrin, s-methoprene, piperonyl butoxide, carboxin, fenvalerate, and 2 ,4 ,5-T.

where samples of grain are required and cannot be readily obtained because the storage is being fumigated. Fortunately, such samples are seldom required as accurate data are kept on quality characteristics of the grain in each storage.

Pesticide Residues

The CA and fumigation regime has permitted flexibility in preparing cargoes to meet stringent and diverse overseas and domestic market requirements as regards levels of pesticide residues.

Depending on destination, these requirements can range from total acceptance of CODEX Maximum Residue Limits (MRLs) to a virtual 'nil tolerance' for any level of pesticide residue.

The volume of nil residue grain now resulting from CA storages provides sufficient stocks to supply markets requiring nil residues. Additional flexibility is provided through blending of treated and untreated grain to meet any outturn standards. The Co-operative Bulk Handling has no problem in complying with CODEX MRLs.

The number of pesticide residue tests conducted by the company (Table 2) has remained fairly constant, with a slight trend downward, over recent years. This is despite increasing consumer concern over pesticide residues in food commodities (reflected in market specifications) and a significant increase in crop production over the last decade. The downward trend is expected to continue as more storages are modified for CA and fumigation.

Handling and Transport

Rail transport is used to take some 70% of grain from inland receival points to seaboard export terminals. The remaining 30% is conveyed by road.

There are 321 CA storages and 186 PVC covered storages in the system and, consequently, more than 50% of all grain is not treated with a residual grain protectant. To prevent this grain from becoming infested during transport, particular emphasis is placed on the design and hygiene of all rail rolling stock and road transport vehicles.

In order to make best use of existing resources and improve efficiency, all of one type of grain is now loaded to each train (Block or Unit train) where possible. CA storages complement this system, as grain can confidently be outloaded knowing it is free of infestation. The concept of total outloading means more effective use of CA and fumigation, rather than frequent treatment of progressively smaller stacks in a storage. The Block train concept, due to higher daily loading rates, also reduces the possibility of grain becoming infested during outloading.

In non-CA (unsealed) storages, outloading programs may be frequently interrupted due to previously undiscovered infestation and the need to implement remedial retreatment or fumigation. The sensitivity of some markets to specific pesticide residues also affects out-loading programs from non-CA storages.

All major Western Australian export terminals have a combination of integrated vertical and horizontal storages, with a significant proportion adapted for CA or fumigation. The success of this strategy is reflected in the decline, in recent years, in the number of shipping rejections due to insects (Table 3).

The years 1976–77 to 1978–79 indicate the high rejection levels associated with the use of malathion only. The slight reduction in 1978–79 arose from the introduction of fenitrothion to treat approximately 50% of that year's crop.

The dramatic decline in rejection levels between 1978–80 and 1982–83 was the result of the total move to fenitrothion and the influence of inland CA storages.

The equally dramatic increases over 1983–84 and 1984–85 primarily arose from a lack of fumigation capacity at export terminals due to the unavailability of hydrogen cyanide and the unsuitability of storages at that time for controlled atmospheres or phosphine fumigation.

Table 3. Shipping rejections (insects) at export terminals.

Year	Tonnes exported	Insect rejections
Nov 76 – Oct 77	3 444 317	68
Nov 77 – Oct 78	3 884 222	64
Nov 78 – Oct 79	3 557 750	51
Nov 79 – Oct 80	4 350 094	22
Nov 80 – Oct 81	3 271 549	13
Nov 81 – Oct 82	4 798 618	8
Nov 82 – Oct 83	5 372 932	7
Nov 83 – Oct 84	5 012 538	27
Nov 84 – Oct 85	6 205 570	27
Oct 85 – Oct 86	5 829 644	7
Nov 86 – Oct 87	6 290 477	5
Nov 87 – Oct 88	4 043 760	6

The impact of the introduction of CA and fumigation capacity at export terminals is evident from 1985–86 onwards.

Safety

The broadscale use of grain protectants requires hundreds of employees, both permanent and casual, to become involved in some aspect of the storage, distribution, mixing, and application of pesticides. At each and every stage, despite intensive training and close supervision, there is a risk of exposure to toxic chemicals.

CA storages have significantly reduced the number of sites where grain protectants are now applied, and the occupational hazards involved in their use have correspondingly declined.

Fumigations are conducted at country installations after the receival staff have left the site. At export terminals, CA storages are totally enclosed ensuring a safe working environment.

More than five million tonnes of grain are now fumigated annually in Western Australia by fewer than 50 fully qualified, experienced, and licensed specialists.

Future

From the results of a study of the period 1980–81 to 1986–87, it was estimated that CA storage had saved Western Australian grain growers some $30 million in additional expenditure. This was principally because there was no need to introduce more expensive, alternative protectants.

In the absence of further dramatic 'breakthroughs' in stored product pest control, it is Co-operative Bulk Handling's intention to continue, as finances allow, to modify all remaining 'sealable' storages to suit CA and fumigation.

While initial establishment costs are higher than current alternatives, they are quickly offset by considerably lower operating costs.

The confident ability to provide national and international trade with insect and pesticide-free grain is an added advantage in markets placing an emphasis on quality.

As previously stated, the company relies primarily on the use of phosphine and, to a lesser extent, carbon dioxide. Nevertheless, the industry is well aware that pesticides are under constant toxicological review, and many that were previously considered suitable are now no longer available.

Similarly, as environmental concerns develop into major social issues, even the long-term future use of carbon dioxide cannot be assured.

Fortunately, Western Australian CA storages have been designed for other atmospheres (such as low-oxygen), although at this stage phosphine will continue to be used as the preferred material.

Summary

This section of the paper provides a brief outline of the strategies applied at country in-stallations, in transport, and at export terminals.

Country CA Storage

September– October

• Storage plans and allocation finalised according to estimated quantity of grain to be delivered; anticipated quality; anticipated term of storage (liaison with marketers).

• Storages prepared for forthcoming receivals. Maintenance completed; ancillary equipment cleaned (no use of pesticides).

November– December

• Grain received from growers—no grain protectants applied.

• Grain exceeding storage capacity is transported (rail or road) to export terminal.

January

• Grain receivals completed

• Ancillary equipment cleaned and accessible grain dust and residues 'blown-down' with compressed air.

• Storage entry points sealed and pressure test conducted.

• Storage fumigated

February– May

• Storage remains under fumigation with gas concentrations monitored weekly.

• In the event of grain being required for outloading, one weeks ventilation is necessary.

May

• At this stage gas concentrations have declined to very low levels or are 'nil'.

• Storage is ventilated followed by a thorough check of grain quality.

• Should grain have been partly outloaded previously, and program is complete, storage will be refumigated.

• Should grain be required for outloading within four weeks, storage will be resealed and checked weekly, but not refumigated.

June – September

• Gas concentrations continue to be monitored on a weekly basis until grain is required for outloading.

Transport

On outload from country receival points, each rail wagon or road truck is clearly marked to indicate the grain type and quality, and whether it is untreated or treated (including the treatment rate).

When inloaded at an export terminal, the grain — through computer inventory control — maintains its identity until it is loaded to ship.

Export Terminal

With the exception of Kwinana, all Western Australian export terminals receive untreated grain direct from growers. The proportion of this grain that is treated with a protectant depends primarily on:

• the CA storage capacity at each terminal and;

• market requirements for specific residue limits.

Grain received direct from growers and allocated to CA storage is fumigated as a routine procedure. Grain that is received following fumigation in a country CA storage, is not re-fumigated if it is scheduled for export within a period of 4–6 weeks.

After fumigation at a terminal, the grain is seldom ever refumigated and may remain in a sealed environment for up to six months, or until consigned to ship.

Conclusion

No attempt has been made in this paper to describe all the circumstances that have varied following the introduction of CA storage on a large scale. Rather, the objective has been, by way of comparison, to give a broad outline of some of the major changes that have influenced operational management practices.

Under existing storage and handling strategies, the advantages of CA storage far outweigh the disadvantages. Nevertheless, should circumstances change (such as, for example, the need to store grain with high moisture content), then the current CA storage program could radically alter.

CA storages have provided an economic and versatile method of meeting increasingly stringent market requirements. However, the nature of the gases utilised, and the circumstances under which they are used, necessitate thorough co-ordination of all facets associated with the storage, transport, and outturn of bulk grain.