Sealed storage technology on Australian farms

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Abstract

Australian farmers adopted commercially-available sealed storage technology from the early 1980s onwards. Widespread on-farm use was, however, restricted mainly to Western Australia (WA) until the early 1990s. Government policy, technology transfer methods, and grain quality standards demanded by buyers are key factors determining adoption rates of sealed storage in different regions.

WA silo manufacturers supply over 90% of their silos as sealed units, compared with less than 10% in the eastern states of Australia (January 1994 figures). Sealed storage use on farms is, however, increasing rapidly in the eastern grain belt of Australia. Most manufacturers construct sealed silos from sheet steel, in both on-ground (flat-bottomed) and elevated (cone-based) configurations. Fully-welded designs use light steel plate.

This paper summarises the evolution of sealing methods used on agricultural silos up to 400 m^3 in volume, and outlines compromises between cost, performance and ease of operation. The authors stress the importance of effective technology transfer for successful design and operation of sealed storage. Inadequate maintenance is identified as a major constraint to effective adoption of sealed storage technology on farms.

Background

Cereal grain production is a major export earning industry in Australia. Wheat dominates all grain types in both the domestic and export markets. The average gross value of wheat exports during the five year period spanning 1988–89 to 1992–93 was approximately $A2010m (Australian Bureau of Statistics 1994, pers. comm. 28 February). Australia generally exports around 70–80% of its annual wheat crop.

Australian farmers now hold an increasing amount of grain on-farm for extended periods before sale or consumption by livestock. Deregulation of the domestic grain market and increasing production of 'non-traditional' grain crops as alternatives to cereal grains such as wheat, barley and oats are key factors driving the move to greater on-farm storage. The authors estimate that over the next 5 years at least one-third of non-export stocks of grain will remain on-farm after each harvest for periods greater than 3 months. In Western Australia, on-farm storage levels are expected to increase at a slower rate.

Grain insects are a major threat to the Australian grain industry. The climate in most Australian grain-growing areas favours insect development throughout much of the year. This contrasts markedly with many other grain-producing areas of the world. Until the late 1980s contact insecticides dominated grain insect control strategies, both on-farm and in most bulk handling systems. Insect resistance development, tighter market standards on chemical residues, and environmental concerns have placed this reliance on chemical controls under increasing pressure.

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Market Standards

Australia depends heavily on its international markets for its grain sales. Although a low volume supplier by international standards, Australia has a reputation for high quality grains that are free of insect and chemical contamination. Chemical residue standards imposed by buyers are progressively tightening, with many customers specifying a nil tolerance for previously acceptable insecticides. Grain treated with phosphine fumigant is accepted by all non-specialist markets, though residue and contamination limits still apply.

Insect Control Options

Options available to control grain insects and meet the market's tightening standards on chemical residues include:

- restricting by legislation the range of chemicals and fumigants available commercially;
- developing 'new-generation' chemical insecticides and fumigants;
- adopting more effective systems for applying existing chemical insecticides;
- using efficient fumigation techniques more widely;
- developing physical or 'non-chemical' methods of controlling insects; and
- applying controlled atmosphere (CA) storage techniques e.g. CO_2 or N.

A combination of these options will emerge in the medium term, with an increasing emphasis on physical controls, CAs and fumigants. Widespread adoption of integrated pest management (IPM) strategies, while desirable, is unlikely at the farm level in the near future.

In the immediate future many farmers will make the transition to fumigation or CAs in fully-sealed silos as a key strategy in supplying their buyers with grain that is free of insects and unacceptable chemical residues.

Australia's major state-based bulk handling organisations now use fumigants such as phosphine gas (PH_3) in combination with other physical controls as their principal insect control tools. Many Australian grain growers use PH_3 to disinfest their grain, particularly just before delivery to buyers. But with the exception of Western Australia (WA), most growers do not use fumigants routinely on newly stored grain. Reasons include:

- contact insecticides are readily available to grain growers in all states except WA and control a wide range of insect pests for extended periods;
- phosphine provides no residual protection on grain stored in unsealed structures;

- uncontrolled fumigation (i.e. fumigation in unsealed structures) usually kills adult and larval stages of insects only, so insects reinfest the grain rapidly.

Fumigation on Farms

Australian farmers have traditionally fumigated grain in unsealed metal silos, bins or trucks. In most areas of Australia this is still a regular practice. Bullen et al. (1991) reported the findings from a survey of grain growers' fumigation practices in southeastern Queensland. Of 28 growers who fumigated with phosphine, none used sealed storages, and all application rates claimed by growers were below the recommended label rate of 5 g/m^3 for unsealed structures[1]. The fumigation periods reported by most growers were less than the 7–10 days (depending upon temperature) recommended on the fumigant label.

Unpublished data from a survey of grain growers in southeastern Queensland who fumigated grain in small (< 150 m^3) unsealed silos showed that the fumigation practices used by these growers would not have achieved the concentration–time (CT) relationships needed to kill all insect stages (G. White, pers. comm., August 1992).

Some growers hang bags of fumigant tablets over the inlet of aeration fans and blow gas generated by the tablets into storages via the aeration ducting. A monitored field trial of this method showed that concentrations varied widely throughout the 120 m^3 unsealed trial silo and that the highest concentration recorded was 4 ppm (P. Collins, pers. comm., January 1994). This result confirmed the non-effectiveness of the method for controlling insects regardless of the time period over which it is applied.

Newman (these proceedings) reported the fumigation practices of growers in the central wheat belt of Western Australia. Of the respondents who stored grain in unsealed structures, 85% used phosphine fumigants to control insects and applied an average of 5.8 g/t/year spread between one and three applications.

Each of the surveys and trials reported above revealed that poor practices dominated on-farm fumigation methods. But even poor fumigation practice often achieves significant adult mortality because of the lower phosphine tolerance of adult and larval stages in comparison with eggs and pupae. In fact, over 90% of growers surveyed by Bullen et al. (1991) classed their fumigations as 'successful', meaning that they killed sufficient adult insects to pass quality inspections during delivery to buyers or central storages. These fumigations are control failures from an entomological perspective because the concentrations and exposure times are insufficient to control all stages and species. Banks (1985) noted that such failures may contribute to insects developing resistance to the fumigant being used.

Annis (1992) described a computer model which simulated the performance of PH_3 fumigations in 'small' silos (<300 t wheat). The model has been further refined by Annis to more closely predict the field performance of storages. Figure 1 shows concentration versus time plots for sealed and unsealed silos of 100 m^3 volume. The output confirms the poor field performance of unsealed structures when used for fumigation.

Sealed silos on farms

Most silos on Australian farms are constructed from bolted or riveted steel sheeting (typically 1 to 2 mm thick). Some manufacturers use fully-welded steel sheet construction. One company uses a novel manufacturing technique to 'spiral-form' the silo barrel from a continuous coil of steel sheet.

Until recently, most silo manufacturers in eastern Australia made no allowance for sealing their storages either during construction or later. Traditional designs are usually difficult and costly to seal to the standard required for effective fumigation.

This paper concentrates on sealed silo technology for farm silos up to 400 m^3 in volume. Sealed storage allows operators to:

- rapidly and completely disinfest stored grain using fumigants (for example, phosphine gas) and controlled atmospheres (for example, high carbon dioxide);
- reduce fumigant dose rates, thus reducing costs;
- avoid unacceptable residues from contact insecticides; and
- minimise likelihood of insect reinfestation.

Silo operators who store 'non-traditional' crops are usually quick to recognise the benefits of integrating sealed silos into their stored-grain management systems. For example, commodities such as mung bean have strict market limits on quality and attract insects that are relatively tolerant of poor fumigation or CA practices.

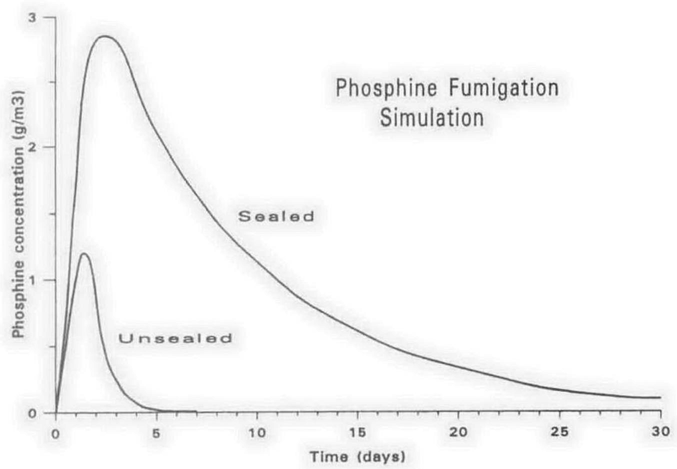

Fig. 1. Concentration versus time plots for PH_3 fumigations in 100 m^3 sealed and unsealed silos. Commodity type: wheat @ 860 kg/m^3; temperature: 25°C; moisture content - 12% wet basis; sorption loss - 7.4% per day; relative humidity - 56.7%; total silo volume - 100 m^3; capacity used - 100%; total gas volume within storage - 43.4 m^3; mixing time - 4 days; leakage loss (sealed) - 5.0% of total silo volume per day; leakage loss (unsealed) - 150%; dosage rate - 1.50 g PH_3/m^3 of total silo volume i.e. 150 g PH_3 total.

Historical Development

Assessments of the suitability of materials and techniques for sealing small (<400 m^3) silos have been reported from at least the mid-1970s. For example, Banks and Annis (1977), Banks and Annis (1980), and Williams and Murphy (1981) discussed materials and methods associated with sealing small structures.

Banks and Annis (1977) indicated that sealing of silos under 300 t capacity was unlikely to be viable using materials and methods available at that time. Since this early paper, however, advances in sealing technology, combined with tighter market demands and ongoing insect resistance development, have swung the economics in favour of sealed storage.

Western Australian silo manufacturers took the lead in developing sealed silos for use on farms from around 1980. The limited range of insecticidal grain protectants available to farmers in WA forced them to consider fumigation in sealed storages as a key tool in their insect control strategies.

[1] Amendments to the label recommendations since this survey remove the provision for fumigating in unsealed structures.

Two State government departments, the WA Department of Agriculture and the Agriculture Protection Board of WA (APB), stimulated this activity through their widespread promotion of sealed silo technology. The APB coordinates regulatory and advisory activities related to agricultural pests, including stored grain insects. Cooperative Bulk Handling of WA (CBH) undertook a major sealing program at their receival points during the same period, sending a clear message to growers that fumigants were the preferred option for future insect control.

Other grain-producing areas of Australia devoted few resources to on-farm stored-grain insect management through the use of sealed storage. This was due largely to the wide range of chemical-based control options available to growers in those States.

Sealed silos are now the standard line offered by most WA manufacturers. Newman (1989) reported that 95% of new silos sold in WA were sealed, and a telephone survey revealed that 65% of growers had at least one sealed silo on their property.

In other parts of Australia, expertise in sealed silo technology is concentrated amongst relatively few manufacturers.

Barriers to Adoption

Fumigation or CA in sealed storages has important advantages over other methods of controlling stored-grain insects. Despite this, a range of technical and non-technical barriers currently limit their wider adoption in most States of Australia, as summarised in Table 1.

Banks (1991) provided an overview of insect control options using fumigants or CAs on farms. He summarised that widespread successful use on farms was restricted by a lack of suitably sealed structures on farms, appropriate literature and training for operators, and market incentives.

Retro-Sealing Versus Sealing During Construction

Field experience by the authors over more than 10 years in WA and to a lesser extent in the eastern states of Australia shows that retro-sealed units are more likely to fail than factory-sealed units. Figure 2 shows areas which must receive specific attention (both on new and retro-sealed silos) to achieve reliable long-term performance. Common failure points on retro-sealed units are roof panel joints, roof/wall junctions, filling hatches and grain outlets.

Silo sealing contractors operate on farms in some areas of Australia. Experienced operators seal to a higher standard of reliability than could be achieved by most farmers. Many WA farmers undertook the task of sealing their own silos in the early 1980s but few achieved the standard of gastightness needed for efficient fumigation. The cost of contract services is usually offset by the greater long-term reliability of the finished storage.

During the early years of silo sealing activity in Western Australia, most contractors entered the industry with an unrealistic understanding of the expertise and financial outlay on equipment needed to seal silos effectively. As a result, contracts were often quoted too cheaply to effectively seal the units. Thin layers of sealant paints and the use of silicones or tapes to temporarily seal silo openings consistently resulted in failure within 12 months.

Some silos designs are relatively difficult to seal, putting high demands on labour and materials. This prices them out of the market or seriously reduces profitability of manufacturers who do not modify their designs appropriately. Experience over the last 15 years shows that custom-designed sealed silos are more cost-effective to manufacture than adaptations of existing designs. Purpose-built units also deliver better long-term performance in the field.

Manufacturers in WA progressively refined their designs through the 1980s to produce units they believe to be an acceptable compromise between function and cost. Small

Table 1. Summary of technical and non-technical barriers to adoption of sealed silos on farms.

Potential stimulus to demand for sealed silos	Potential barriers to stimulus
Widespread commercial availability of sealed silos for farm use	Resistance by manufacturers to changes in manufacturing methods and designs
	Variable demand by consumer
	Poor understanding of sealing technology by manufacturers
Restricted availability of grain protectants for on-farm use	Wide range of contact insecticides registered for on-farm use in most Australian states
Grain injection at point-of-sale if unacceptable chemical residues are present	Acceptance standards and sampling methods used by domestic buyers and handlers vary widely and are relatively imprecise
Premium prices paid for residue-free grain	Existing market for premium-priced residue-free commodities is limited in size
Details of reduced insect control costs achieved by using sealed storage transferred to operators	Growers unwilling to invest capital to seal existing storages or purchase new units
	Relative cheapness of fumigants allows growers to perform several inefficient, high dosage fumigations before delivery of grain
Extension programs to deliver accurate information on operation and maintenance aspects of sealed silos	Lack of widely available extension information targeted at growers, traders and manufacturers of grain storage and management equipment
	Limited funds to promote grain management practices (including sealed silo technology) within the rural sector
Industry-wide adoption of Integrated Pest Management (IPM) strategies for stored-grain insect control	Deregulated grain industry in Australia encourages on-farm holding of grain on farms under variable quality storage conditions

capacity silos for on-farm use do not vary greatly in their designs between manufacturers in WA, due in part to the highly competitive market.

Sealing Methods and Materials

Wall, roof and floor panels

Silicone-based sealants are used widely to seal sheet-metal panels during silo manufacture. Sealant is usually applied to sheets before riveting or bolting them together. One design spiral-forms the main barrel of the silo from a continuous coil of sheet metal — no sealant is needed to establish a gastight seal along the lapped seam thus created.

Flexible membrane paints were widely used by growers and contractors to seal both new and existing silos during the early years of on-farm sealed silo usage. Some manufacturers also used flexible membranes when constructing farm silos but few continued with them due to problems such as poor adhesion and practical difficulties in applying them internally. They continue to be used on retro-sealing jobs — usually applied on the outside of structures.

Sealants

Most sealants used for sealing work are either silicone-based 'mastics' or paintable 'flexible acrylic membrane' paints. Flexible membranes are used extensively to seal large central storage structures and existing on-farm steel silos. CBH in WA has sealed more than 70% of their sealable receival points using flexible acrylic membranes as a key material.

Acrylic sealants must be applied to manufacturers' specifications, with particular attention to thickness. The specified depth is often difficult to achieve with a brush, necessitating two or more applications. Airless spray guns apply acrylic membranes very successfully and most acrylic membranes will bridge gaps up to 5 mm wide.

On larger expansion joints or areas which are difficult to reach, a fabric backing is necessary. Early experience in WA showed that some of the fabrics and tapes used as substrates created relatively inflexible joints leading to subsequent failure.

Sealant adhesion is a problem on new steel or on the dusty internal surfaces of existing grain stores. Failure to adequately prepare surface according to the sealant manufacturers' recommendations often leads to poor performance. Field experience shows that external application of the product on weathered steel needs less preparation than on internal surfaces of silos.

Hatches and outlets

Loading hatches, access points and grain outlets must usually be either radically redesigned or retro-fitted with purpose-designed sealable units to ensure easy and reliable long-term operation on farms.

Early experiments which used silicone, tape or acrylic membranes to seal existing hatches and outlets caused problems for operators when loading or out-loading. Purpose-built hatches and outlets for on farm silos incorporate rubber strips for instant sealing when closed. These are far more con-

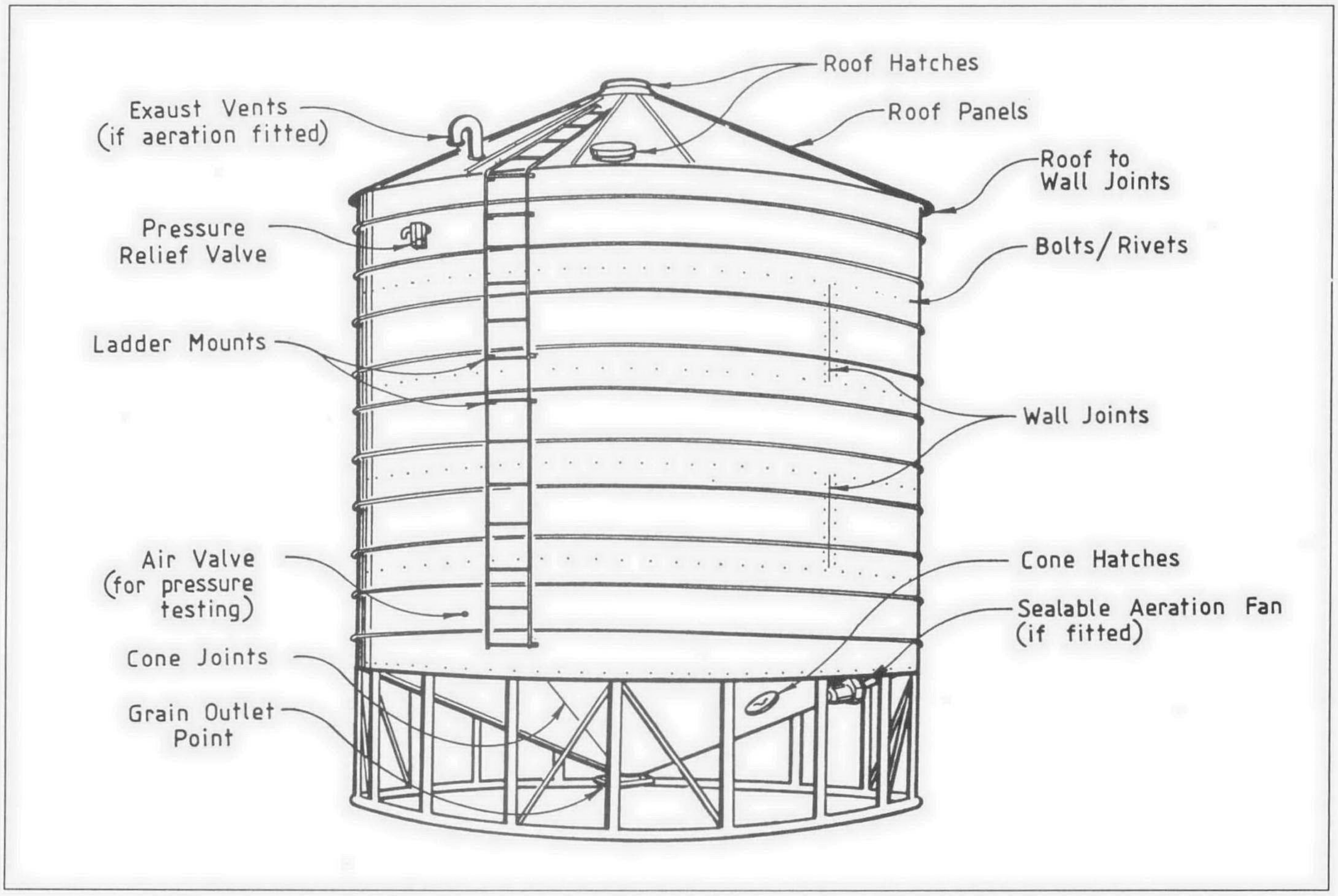

Fig. 2. Major areas needing attention during retro-sealing of existing farm silos or design of purpose-built units.

venient and reliable than sealing with tape or silicone each time the access point is closed.

Figure 3 gives examples of successful sealable grain outlets used on farm silos. Slide gates fitted with quick-release cams or screws are popular in eastern states. Their accessibility, clearance and high discharge rates are a major advantage over other designs when used with large conveyors.

Many sealable hatches have been developed and trialed during the evolution of sealed storage on farms. Most manufacturers now use variations of the cost-effective design shown in Figures 4 and 5.

Pressure Relief

Sealed storages experience wide swings in internal pressure due to variations in ambient conditions. Changes in incident solar radiation levels, temperature and barometric pressure can produce internal pressure deficits or excesses which may structurally damage a storage. Figure 6 is typical of relief valves fitted to all sealed farm storages to protect against pressure damage.

The most likely source of pressure-related damage in sealed storage is caused by implosion due to a pressure deficit within the storage. Additional protection against implosion is available by using a vacuum relief valve, as shown in Figure 7.

Hybrid Designs

Unpredictable weather at harvest in some areas of Australia, notably Queensland, often leads to grain being harvested at higher moisture contents than is safe for storage. High ambient temperatures and intense solar radiation encourage insect activity, moisture migration and quality loss in stored grain.

Aeration is a grain management technique which passes controlled amounts of ambient air through stored grain. It stabilises temperature and moisture levels in the grain, prevents localised temperature increases ('hot spots') and discourages moisture migration. Aeration also lowers the temperature of the grain bulk during long term storage, reducing insect activity.

Silo designs which allow both aeration and fumigation are an advantage in areas where climatic conditions predispose harvested grain to variations in moisture content and heating. Figure 8 shows typical features on an aeratable/sealable silo for farm use. Designs similar to this are now made by several Australian manufacturers.

Aeratable/sealable silo configurations need a higher level of management than a standard sealed silo. The 'decision tree' of Figure 9 assists grain growers and storage operators to determine sequences of fumigation and aeration practice which give best protection to their stored grain.

Pneumatic conveying has traditionally been considered incompatible with the structural requirements of sealed storage. Recent developments in this area have produced further hybrid designs incorporating the advantages of both technologies, as shown in Figure 10.

Until recently, the operating flexibility sought by experienced managers of farm-stored grain often conflicted with the perceived constraints imposed by sealed storages. Hybrid silo designs now allow multiple functions to be built in at the design stage. Figure 11 gives a commercial example of this approach.

Sealing Standards

Pressure testing

Silo manufacturers, users and advisers in Australia use half-life pressure decay tests to determine whether storages are sealed sufficiently for effective fumigation or CA use. The valve illustrated in Figure 6 is suitable for gastightness testing in addition to its primary role of pressure relief.

The standard adopted for small (<300 m^3) farm silos in WA from the early 1980s specified 3 minutes as the minimum half-life decay from an excess internal pressure of 25 mm water gauge (that is, from 25 mm to 12.5 mm). Most WA manufacturers still use this as a de facto industry standard.

Studies by the CSIRO Stored Grain Research Laboratory (SGRL) show that a 3 minute decay is acceptable in storages if they are tested when full of grain but not when they are empty (P.C. Annis, pers. comm. August 1993). A buffering effect created by the greater air volume in empty storages results in

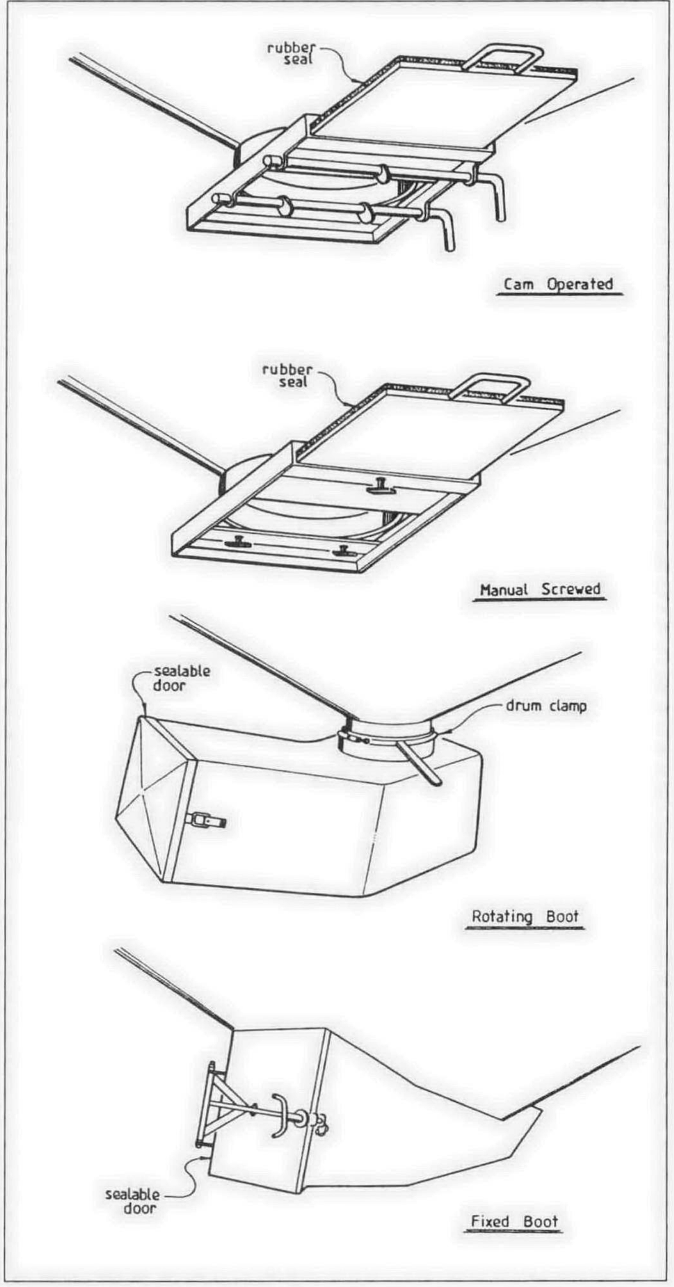

Fig. 3. Typical grain outlet configurations used on farm silos.

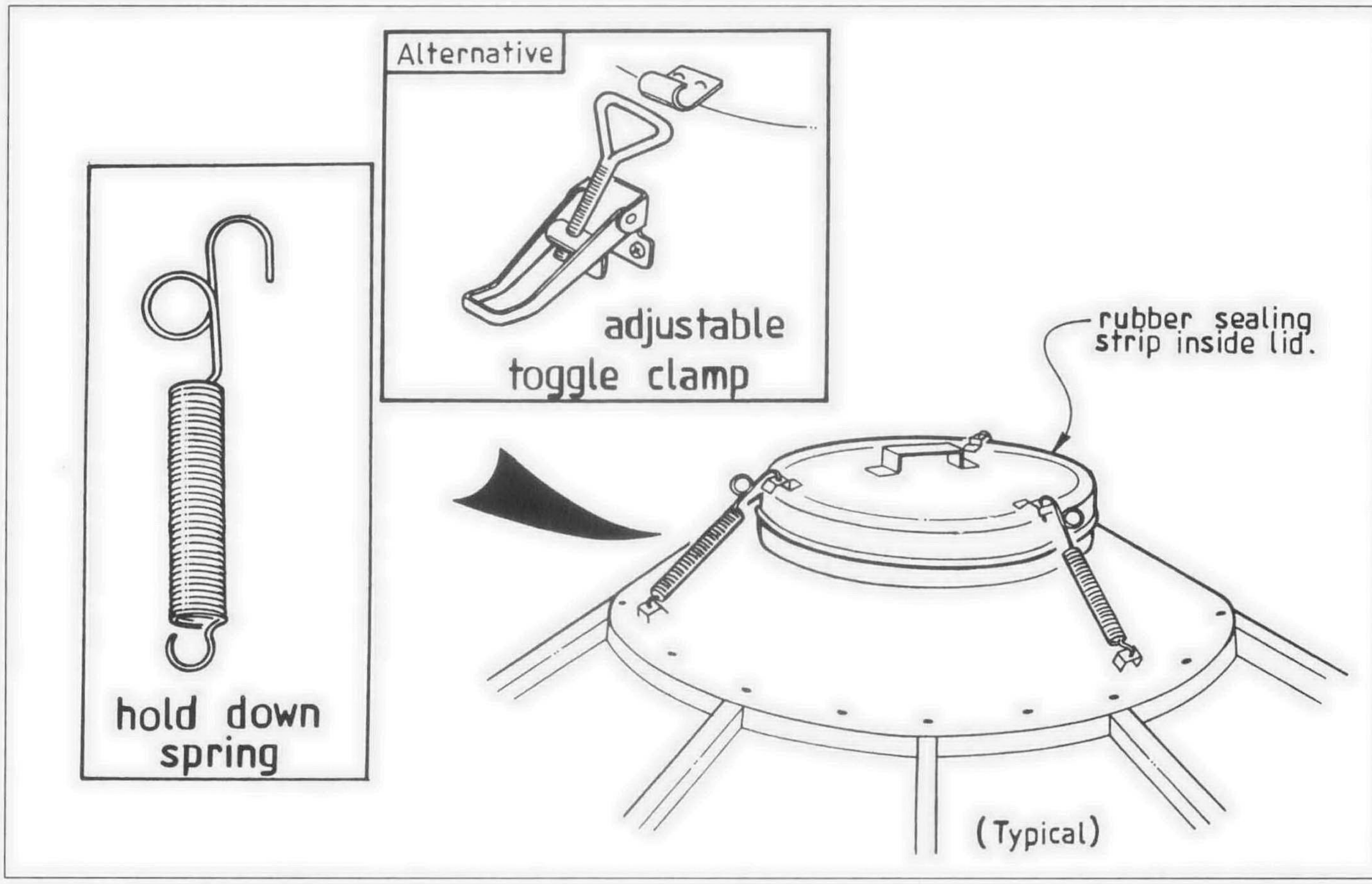

Fig. 4. Australian manufacturers of sealed farm silos use spun metal lids and metal bands widely as loading or inspection hatches (lid/band units manufactured by Andersons Metal Spinners, Kelmscott, WA).

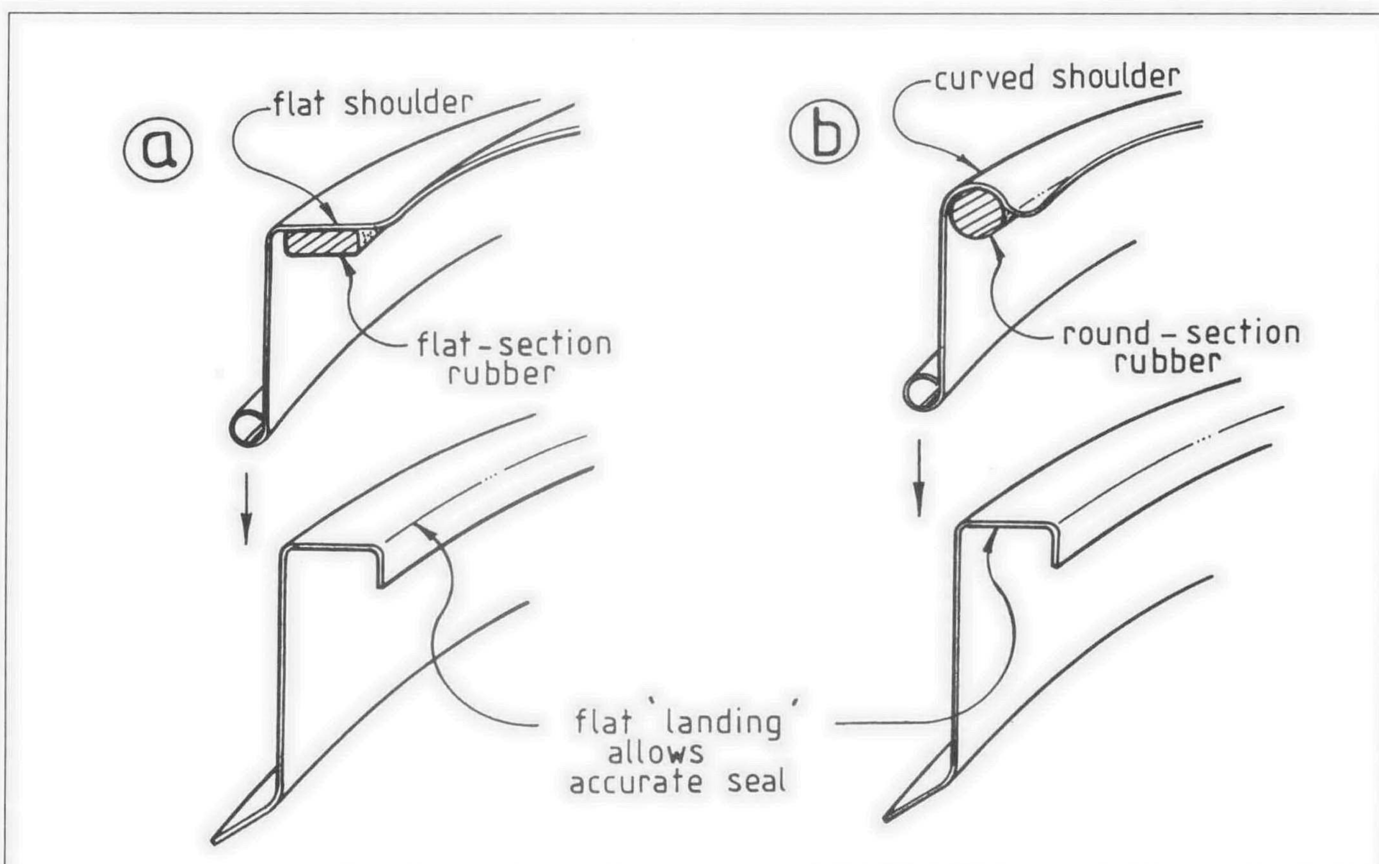

Fig. 5. Detail of alternative sealing strip arrangements in the spun lid shown in Figure 4. Option (b) gives a more reliable seal but requires extra care during installation of the round-section rubber.

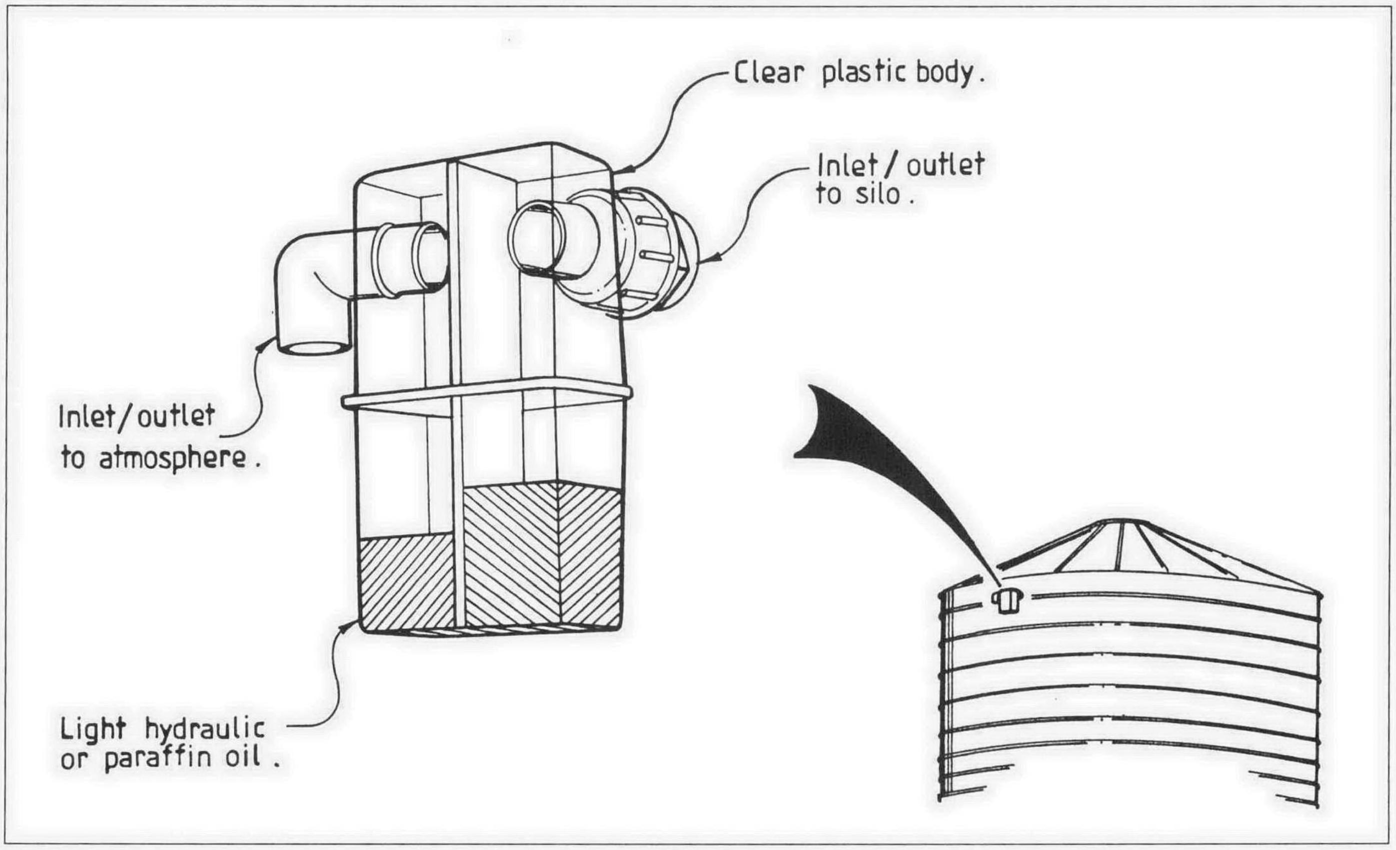

Fig. 6. Typical pressure/vacuum relief valve used on farm silos. The unit is also suited to gastightness testing using half-life pressure decays (Manufacturer: Acrifab, WA).

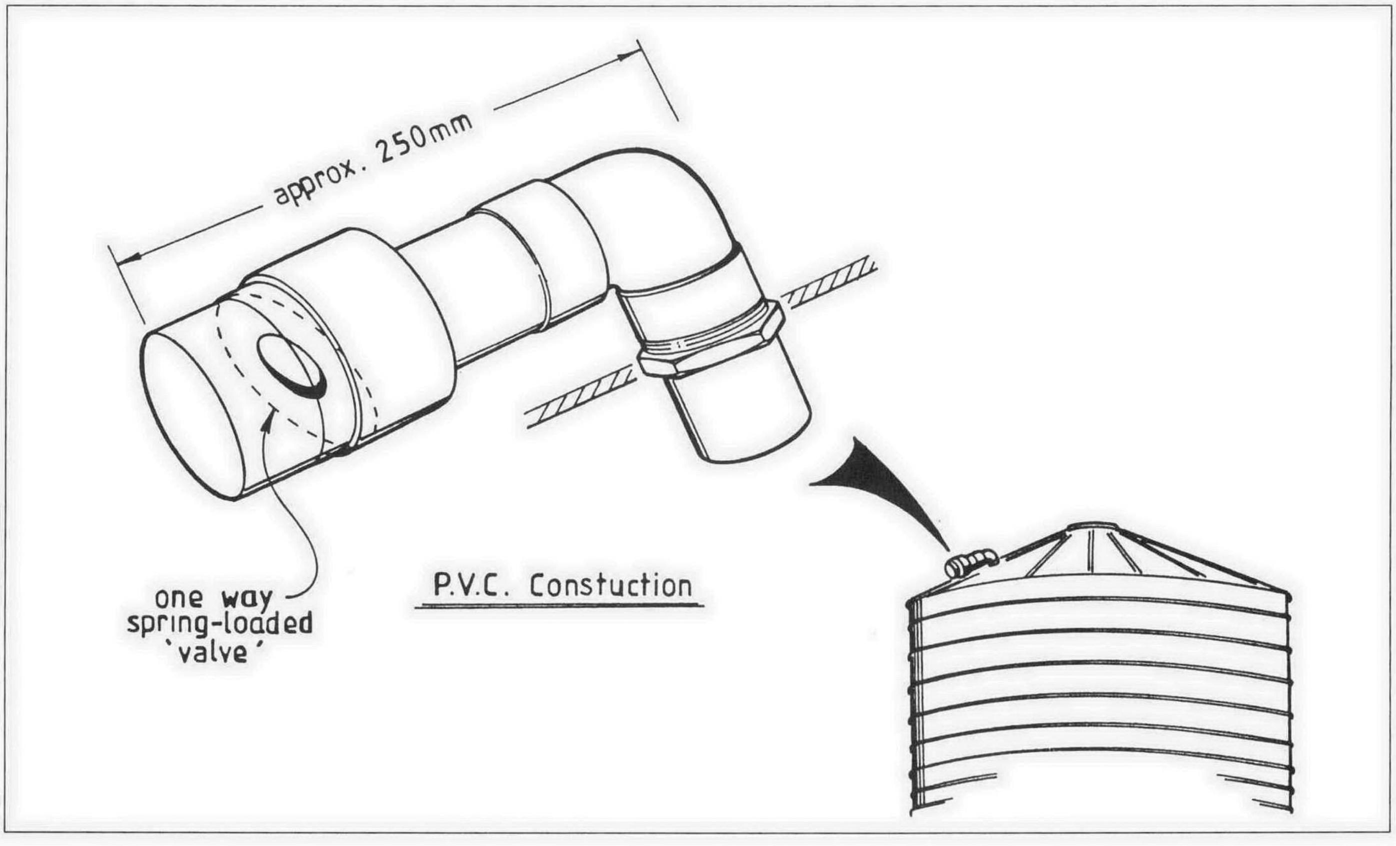

Fig. 7. Vacuum relief valve suited to implosion protection on small farm silos. The one-way valve does not provide protection against over-pressure events.

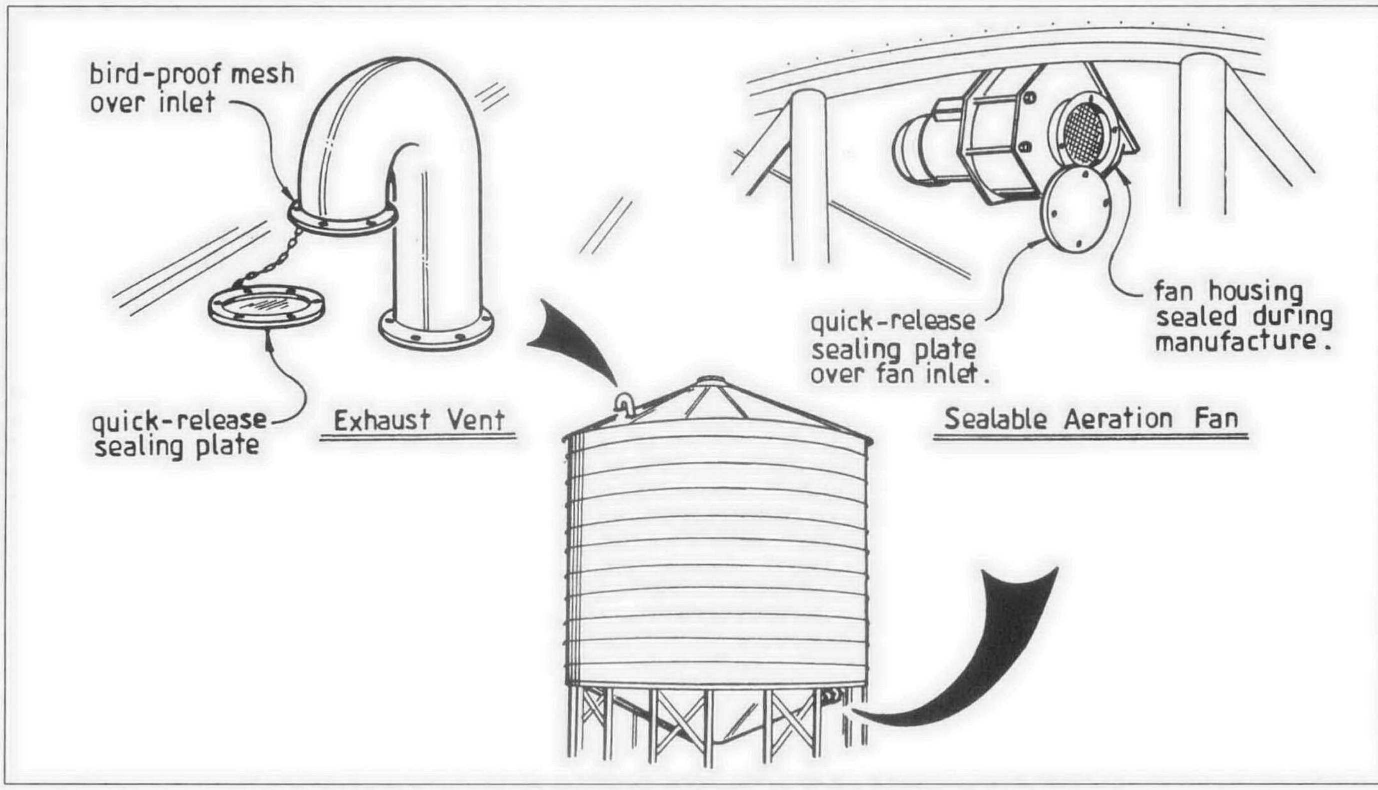

Fig. 8. Features of a typical hybrid sealable/aeratable silo. The storage is sealed to allow disinfestation with fumigants, then unsealed for long-term aeration.

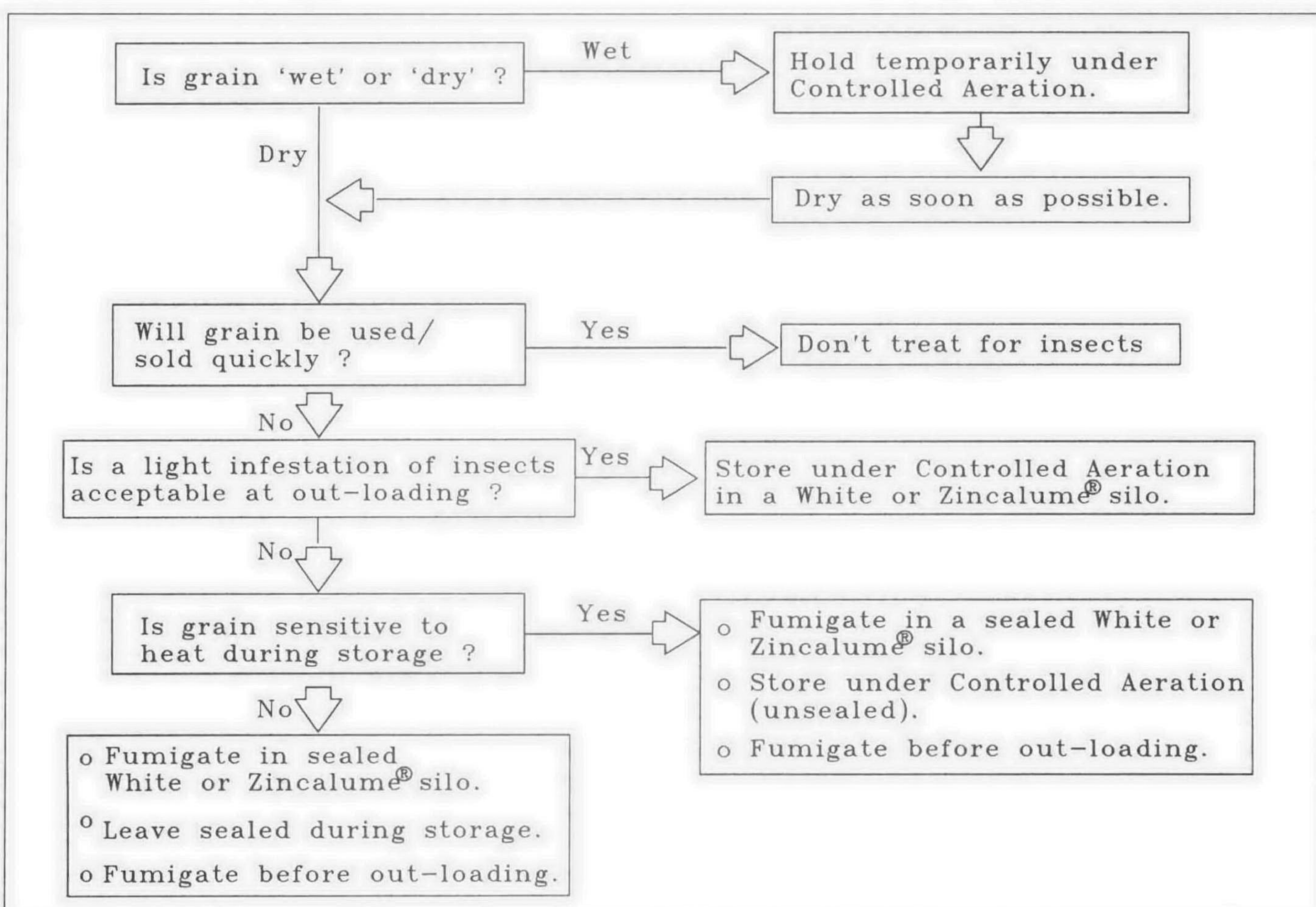

Fig. 9. Decision tree to assist in selecting effective fumigation/aeration sequences when using sealable/aeratable silos on farms (based on information from H.J. Banks, pers. comm., July 1993).

longer decay times than observed in the same silo when full of grain.

SGRL, in collaboration with a network of Grain Storage Associations representing Australian silo manufacturers, propose industry-wide adoption of a national testing standard for small farm silos. The draft proposal calls for half-life pressure testing to the following specification:

- maximum of 3 minutes for storages filled to capacity with grain;
- maximum of 5 minutes for empty or partially filled storages

Manufacturers groups are considering a proposal to adopt higher standards if testing is done in the more stable conditions associated with undercover silo assembly areas in factories.

Sealed silo quality standards

Advisory groups across Australia recommend buyers specify in their purchase agreement that the silo must meet the standard pressure test after installation or on completion of sealing. Most manufacturers of factory-assembled silos in WA are, however, unwilling to guarantee compliance with a standard pressure test at delivery on-site. They argue that a guarantee cannot be given because of the unstable weather conditions that exist in the field.

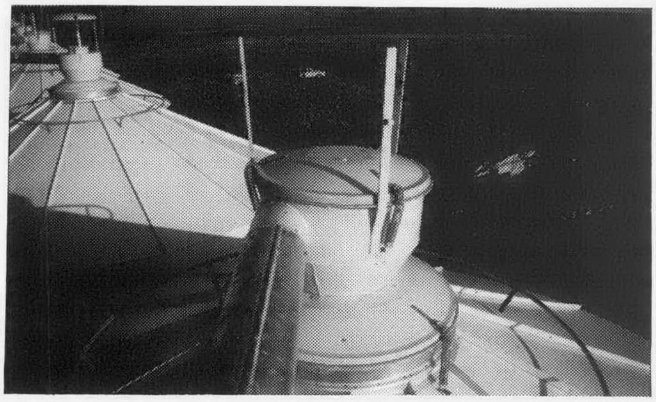

Fig. 10. Sealable grain cyclones fitted to a pneumatically-filled silos. Cyclones shown in both sealed (foreground) and unsealed (background) modes.

The rough road conditions over which some silos are delivered also predisposes them to loss of seal during transit. This reinforces the argument that on-site testing of silos is the only guarantee of performance.

The Grains Research and Development Corporation (GRDC) in Australia, an industry representative body funding RD+E activities, has suggested that a manual of instruction and a standard guarantee be written for use by all farm silo manufacturers.

Operation, Maintenance and Servicing

Soon after sealed silos were introduced in WA it became obvious from inspections that maintenance was being neglected. A postal survey in 1985 found 44% of silos were not achieving gastightness standards (Newman 1987). This survey involved a telephone call to the grower followed by a visual inspection.

A physical inspection and pressure test of silos on farm were carried out in 1989 (Newman 1989). This survey found 56% of silos were failing to meet gastightness standards. The main reasons for failure were leaking seals at the inlet and outlet ports or low oil in pressure relief valve. A further survey found 75% of silos tested were leaking excessively (Newman 1994).

Valve oil

Incorrect oils were used in some valves leading to premature failure e.g. vegetable oil was recommended during early 1980s, but solidified when phosphine bubbled through it. The current recommendations are paraffin oil in valves with silicone in joints, and light hydraulic oil in plastic valves (Newman 1987).

Fig. 11 . An on-farm bank of 140 m^3 hybrid silos incorporating several grain management and handling features: — sealable for fumigation or CA; white Colorbond® construction for temperature stability; pneumatic filling; provision for aeration equipment.

Technology Transfer

From the inception of sealed silos in WA, a concerted effort was made to transfer information on the use of sealed silos to the farming community (Chantler 1983), largely through the activities of the APB and the WA Department of Agriculture.

Information is delivered to silo operators through pamphlets, field days, static displays and direct advice from APB district officers based throughout the state. No full-time extension officers work specifically on sealed storage technology transfer in WA. Other States devoted minimal extension resources to on-farm sealed storage programs during the 1980s.

Recent initiatives funded by the GRDC, have improved the flow of information since the early 1990s. For example, the GRAINSAFE program run by the Department of Primary Industries (Queensland) and described by Bullen et. al. (these proceedings) transfers technology on stored-grain insect control to farmers and grain traders.

GRAINSAFE has impacted significantly on the adoption rate of sealed storage on farms in eastern Australia. Sealed silos now represent a major proportion of sales amongst those eastern Australian manufacturers with expertise in sealing techniques. Up to 90% of some manufacturer's sales are sealed units (GRDC 1994).

Despite this recent upsurge in sales of sealed silos, industry-wide understanding of the principles of sealed storage operation and maintenance is still at a low level, even in WA. An urgent need to translate fundamental and applied research findings into user-friendly literature for manufacturers and growers still exists.

Stored Grain Quality

Moisture

A common argument used against sealed storage is the potential for grain damage due to moisture trapped within the sealed structure. The authors agree that damage to moist grain placed in a fully-sealed storage is likely to occur faster than in a similar unsealed unit. But the argument points more to the need for a professional approach to grain management than a case against sealed storage. Placing over-moist grain in any storage structure, sealed or unsealed, predisposes it to a high risk of rapid quality loss.

Grain must be stored at a moisture level appropriate to its storage temperature. In WA, where the average bulk temperature of stored grain is likely to be relatively high, growers are advised to only store grain at moisture contents below 12%.

Even low levels of uncontrolled insect infestation can lead to moisture problems in silos. This is usually linked to failure to fumigate effectively at the time of loading.

Germination

Individual farmers throughout Australia occasionally suggest that phosphine fumigation in both sealed and unsealed silos affects grain germination. The authors are unaware of scientific studies to support this anecdotal theory.

Conclusion

Effective sealing and fumigation or CA treatment of grain in farm silos has the following advantages:

- less likelihood of control failures,
- lower dose rates of fumigants or CA gases,
- longer intervals between treatments,
- no unacceptable chemical residues on grain.

A major barrier to wider adoption of sealed silos on farms is lack of market incentive to change existing fumigation practices. Factors that would catalyse a more rapid transition to fumigation and CA use in sealed silos on farms include:

- restricted range of grain protectants available to growers;
- more precise sampling procedures at receival points;
- tighter market standards on chemical residues;
- greater consumer demand for 'chemical free' foods.

Each of these has already occurred within Australia, but not to the extent needed for growers to collectively change their insect control practices. With the exception of Western Australia, a wide range of chemical options is still available to grain handlers to solve their immediate insect control needs.

A broader, longer-term view is needed if insect resistance development and loss of export markets is not to occur. Change will occur more rapidly when clear economic benefits are demonstrated and understood by growers, particularly if these benefits accrue in a short time frame. Many Australian growers have adopted sealed silos in their insect management programs, but most continue to use contact insecticides and fumigate in unsealed structures. So long as the minimum acceptance criteria set by buyers are able to be met using these methods, there will be little incentive to change.

A significant gap exists between state-of-the-art practices in sealed silo technology and their adoption by end-users. Accurate information must be transferred not only to growers but to silo manufacturers, suppliers of sealing consumables, chemical resellers, advisers and grain buyers.

Initiatives by the industry funding body GRDC are helping to address these needs. The GRAINSAFE stored grain management extension project and establishment of Grain Storage Associations throughout Australia have already made significant advances.

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