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Application of sealing technology to permanent grain storage in Australia

C.R. Newman[1]

Abstract

Expanding grain production in Australia in the mid 20th century combined with a low population density provided millions of tonnes of surplus grain that could be sold on the world market but insect infestation was a problem. Investment in large-scale grain handling systems was needed and millions of tonnes capacity of grain storage was constructed, much of it as horizontal structures. The advent of chemical protectants in the 1960's provided a solution for controlling grain insect pests and enabled the export of insect-free grain. However, escalating insecticide resistance proved a challenge and a more effective control using fumigants in sealed structures was investigated.

Identification of appropriate acrylic sealant systems allowed existing structures (formerly considered un-sealable) to be retro sealed. Information provided by research organisations on sealing techniques and the commercialisation of the sealing process provided the impetus for the central grain handling authorities to commit to extensive retro sealing of existing storages. At the farm level, innovation by manufacturers of silos provided sealable structures to ensure an effective fumigation could be performed on farm grain stocks. This reduced the background level of insects on grain growing properties that had the potential to enter the central storage system.

This paper discusses the techniques employed on-farm, and in the central grain storage system over the last 20 years to create storage structures capable of containing fumigant gases at lethal levels to ensure effective control of insect populations.

Key words: sealing, quality grain, insect control, grain morket.

Introduction

Since the development of cereal based agriculture in Australia, the low population, and consequent low domestic consumption, has provided a large surplus of grain available to be traded on the world market. An efficient system of very large inland grain stores and the equipment to move it rapidly from the farm to export terminals has been developed to handle this surplus. Some grain may be stored on-farm to be traded into smaller export markets but the majority of the crop is protected in a central storage system then moved to overseas customers in bulk on ships. Early shipments of grain were most likely to contain grain storage insects. The arrival of the contact insecticide Malathion® in the early 1960's, provided the opportunity to export grain 'insect-free', enabling the Export (Grain) Regulations (1963) which required the product being exported is 'free of injurious pests and diseases'.

When chemical protectants were used it was not necessary to seal the grain store, in fact they

[1] Department of Agriculture and Food Western Australia, 100 Bougainvillea Avenue, Forrestfield, Western Australia, 6058. Ph 08 9366 2309. Fax 08 9453 1288. cnewman@agric.wa.gov.au

were constructed to allow good ventilation. The development of resistance in the major grain storage pests to Malathion® and other grain protectants, compelled the industry to turn to fumigant gases for insect control. Phosphine had already been imported into Australia in the early 1950's and used alongside chemical protectants. The ease of application of the product and the label recommendation for use in unsealed storages reduced its effectiveness. Subsequently tolerance to phosphine was detected in stored grain insects, which had been selected by exposure to sub-lethal doses of the gas in non gas tight structures.

To prevent escalating resistance, there was a need to contain the gas within a storage capable of holding it long enough to control all life stages of all target species.

This presented the grain industry in Australia with a problem of some magnitude. It was not practical to replace existing structures with purpose to built sealed storage without disrupting the supply chain and great expense. The alternative was to develop techniques to convert the existing ventilated storage to a suitable standard of gas-tightness.

In Western Australia the central handling system is a wholly owned farmer corporation, Co-operative Bulk Handling (CBH), which from its inception recognised the need for investment in permanent storage to create an efficient receival system. Management decisions made in the early 1980's created a climate of investment in quality sealed storage to enable the move from contact insecticides to fumigant based grain protection. The majority of the annual crop is now delivered directly from the farm as it is harvested then exported with a guarantee of nill chemical residues and grain insects.

Sealing systems develop

The experimental sealing of the 16,000 tonne horizontal grain storage at Harden, NSW in 1979 by the CSIRO Stored Grain Research Laboratory was a significant development for effective sealing of grain storages in Australia (Banks et al. 1979).

Also of significance was the formulation of a standard defining the required degree of gas-tightness for a fumigation enclosure by the Australian Standing Committee on Agriculture, stating, 'A candidate fumigation structure should maintain an excess internal pressure of 500 Pa decaying to 250 Pa in not less than 5 minutes' (Winks et al., 1980). This overcame the need to create hermetic storage for fumigation, allowing some leaks in the fabric but insufficient to compromise the fumigation protocol.

The sealing at Harden of a 33,100 m^3 'A' frame shed with a 56 % headspace proved a grain storage shed could be sealed to an acceptable gas tight standard and provided valuable experience that remains in use on contemporary sealing projects.

For example:

- strict attention to joints in the fabric of the construction to prevent excessive movement is essential to avoid constant repair.
- large holes that cannot be patched are filled with polyurethane foam and then over coated with the sealant membrane.
- some adhesive tapes that are used to cover gaps to carry the membrane are too rigid and fail under the seal.
- pressure testing must be conducted under stable atmospheric conditions to demonstrate the correct standard of the seal:
- re–engineering of access ports within the fabric of the construction to incorporate rubber gaskets, enabled instant re-sealing and greater economy over time, compared to temporary sealing and re-sealing after opening.
- pressure relief valves were installed.

The Harden structure was pressurised to > 150 Pa after a partial in-load of nearly 14,000 t of wheat and the pressure decay time recorded. Repeated testing demonstrated the frailty of some sealed joins that had to be repaired, eventually achieving a pressure halving time ($P_{½}$) of up to 483 seconds from 100 to 50 Pa under ideal stable temperature and wind conditions. Pressure tests conducted the following year under less than ideal ambient conditions produced a $P_{½}$ of up to 317 seconds.

The cost of the project was calculated at AU$ 3.40/tonne but it was uncertain at that time of the life of the seal or the annual maintenance cost. The shed remained in use as a fumigation enclosure for more than 20 years, eventually failing in 2000. The sealant membrane has now split along many of the joints and is in need of resealing. During this period minor annual maintenance was needed to reseal access doors that were opened for grain movement

Sealing in Western Australia

The demonstration, at Harden, of retro-sealing to an effective standard of gas tightness, provided the information needed by CBH in Western Australia to seriously consider sealing existing storage.

In 1979 CBH commenced research, known as the ‘Controlled Atmosphere Program’, with the experimental sealing of a 2200 tonne vertical concrete cell and the modification and sealing of some horizontal country stores. By 1980, it was realised this system would reduce treatment costs by using fumigants or controlled atmospheres instead of the increasingly expensive chemical protectants. More importantly, a marketing benefit would be gained by the ability to meet substantial demand for chemical residue-free grain (Burton, 1998).

In 1980 it was accepted that this was a practical technique that could be applied to a large proportion of horizontal bulk grain storages. CBH had at that time 15.3 million tonnes of storage of which 7.1 million was considered ‘sealable’ (Tutt 2002). The storages had been constructed over some 40 years in a wide variety of designs from concrete vertical cells to horizontal steel or wood frames covered with corrugated sheet steel. Some of the wood and steel-framed sheds are very large, for example the ‘E’ type sheds at Avon (Figure 1). Comprising structures of 21,000 t and 72,000 t and similar pitched roof horizontal sheds at Merredin of 80,000 and 140,000 t. These structures were sealed to the gas tight standard using the techniques described above and remain in use 10 years after the original sealing procedure.

By the end of 1999, CBH had sealed 6.55 million tonnes of storage (92 % of the ‘sealable’ total). By 2005, when newly constructed storage is included, CBH had 9 million tonnes of storage sealed to the gas tightness standard (Kostas. pers. comm. 2006).

Figure 1. Large shed type storage.

Evaluation of candidate sealant membranes

To assess sealants prior to application, CBH adopted a set of laboratory testing protocols for candidate membranes. A similar protocol remains in force with any sealant membrane required to undergo rigorous testing before it can be considered for use on CBH structures. The protocol has been modified slightly now that sealant membranes are required to have greater elasticity to accommodate the increased expansion that occurs in some of the new types of permanent storage. These test procedures are reproduced courtesy of Zedcon Scientific, the laboratory engaged in testing sealant systems.

Contemporary application of sealing systems

The task of sealing grain storage is a two stage process, first the preparation of the fabric including wash down, sheet metal work and gap covering and secondly the application of the sealant membrane. Preparation of the storage fabric of structures that have never been sealed takes up 20 – 30 % percent of the total time. Resealing a structure that has previously had a sealant membrane applied requires 40 to 60 % of the time allocated to the project, which accounts in part for the high cost of re-sealing some 10 to 15 years later. The success of the application of the sealing membrane depends on attention to detail in the preparation process. The project is undertaken by specialist sealing contractors who have developed their techniques through experience since the early days of sealing.

The first principle of sealing a grain store is to ensure cleanliness of the substrate. The single most common problem faced by contractors re-sealing a retro sealed structure is de-lamination of the original membrane, caused by poor preparation of the substrate. High pressure water blasting at approximately 344 bar on all surfaces both inside and out is the primary task. The key to the preparation of the fabric is to ensure gaps of no more than 2 mm to support the membrane, for example repair or replace damaged steel or concrete sections, fix down loose steel sheets, replace or seal skylights, cap ridge vents.

Where the gaps are very large various techniques such as sheet metal flashing are used to fill the gaps to carry sealant membrane or polyurethane foam. Joints may be bridged with a mastic type, single component, polyurethane product or acrylic sealant. Silicone sealants are rarely used because they cannot be over-coated with other substances.

Two component, polyurethane foam was found to be an ideal space filler and remains in common use. It expands rapidly into the most difficult cavities, dries hard and, remains stable, and accepts acrylic sealants. A foam density of 32 kg/m^3 is used which has a degree of flexibility to enable movement in harmony with the structure. Denser more rigid foam may separate under load, creating a leak difficult to detect. A great amount of this product was sprayed on the outside of structures in the early days of sealing, which has proved a magnet for parrots. The storage seal is frequently compromised by parrots tearing out large lumps of foam – for fun it appears! Parrot damage is significant at some storage, the birds also targeting rubber strips and the thicker sealant coatings. This can be very costly to repair and efforts must be taken to keep parrots away from the storage. New storage usually has the necessary polyurethane foam sprayed on the inside and precautions are taken to protect vulnerable rubber seals to reduce the cost of repairs. (Figure 2).

A number of adhesive tape products such as aluminium foil and paper types, were initially used but now the most common is fibreglass tape, fixed in place by the sealant product. This has been found to provide the greatest strength without fracturing, particularly in areas subjected to movement or vibration such as loading conveyors and is now used in preference to foam rubber.

Initially some temporary sealing techniques were employed such as using polythene sheeting or bags taped to outlets or using silicone rubber sealant in places that will be opened on outloading. These processes have given way to more permanent engineering solutions that do not require constant replacement for re-sealing and therefore are more economical over time.

When the fabric of the storage has been appropriately cleaned the surface is inspected for the need for a primer coat before sealing proceeds. Etch prime paints may be applied to new, unweathered steel, however, if the fabric has been exposed to the elements for some time, water blasting is usually considered sufficient.

The sealant membrane is applied with airless spray equipment, commencing with the joins and overlap sections laying down a coating thickness of 1500 mm (1.5 mm) using a narrow fan nozzle. (Figure 3).

Figure 2. *Parrot damage to polyurethane foam*

The selection of airless spraying equipment is depends on the viscosity of the sealant and the distance to the farthest point in the sealing project. The thicker the paint and the longer the delivery lines the larger the pump and the greater the pressure needed. Pressures up to 206 bar will be needed to move the most viscous paint 60 metres to the top of a horizontal store. The top coat of the sealant is a less viscous product and is sprayed on the outside of the structure at 150 mm (0.15 mm) with a wide fan nozzle as a protective covering for the lap joints and as a heat reflective coat. (Figure 4). This reduces the solar absorption by the steel surface, lowering the expansion and contraction of the surface material and diminishing membrane stress. Lower internal temperatures reduce the pressure on the seal from inside the storage.

Costs and economics of sealing grain storage

The costs of sealing any storage depend entirely on the complexity of the task, however the following figures can provide a perspective. The costs of sealing a horizontal 21,800 tonne storage in 1982 was nearly AU$ 3/tonne, therefore the full cost of AU$ 64,400 amortised over 10 years is AU$ 0.30c/tonne. In 1999 the

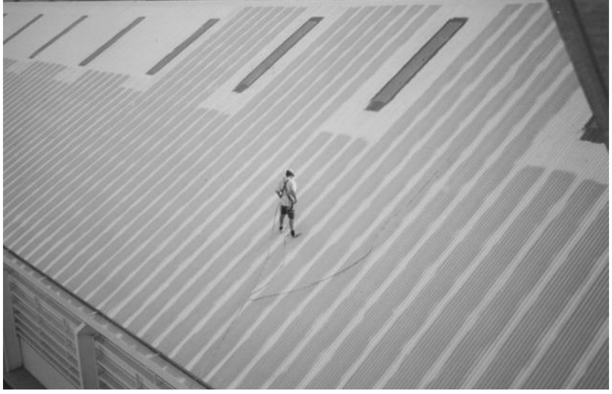

Figure 3. Overlap joints sprayed. Photo courtesy Sealing Technology Australia.

Figure 4. Top coat application. Photo courtesy Global Sealing Services.

costs of sealing a storage ranged from AU$ 3.50 - 4.50 per tonne depending on the structure. Now in 2006 the costs are closer to AU$ 5 per tonne equating to AU$ 0.50c / tonne over 10 years using the previous example.

Tutt (2002) reported that the capital expenditure on sealing permanent storage structures from 1980 to 1999 was AU$ 35.6 million and in the same period the savings from chemical application costs alone amounted to AU$ 186 million. The savings were calculated from the hypothetical use of Bioresmethrin (in that storage) at 2 ppm per treatment. Each application would have cost AU$ 2.25 while the cost of phosphine at the CBH rate of 0.75 g/tonne was AU$ 0.023 c/t at 1998 prices. This provided a saving per treatment of AU$ 2.23 (Burton 1998).

Additional benefits accrue in management of the operation, by reducing costs and making the overall enterprise more profitable but these are difficult to quantify.

Tutt (2002) outlined the benefits of moving to a mainly sealed system.

Pressure relief systems

Pressure and vacuum relief is a vital component of sealing a large structure, rapid changes in atmospheric temperature cause rapid contraction or expansion of the enclosed air, which is magnified in a large headspace. This can result in substantial pressure loading on the framework and possible damage such as roof buckling. The early pressure relief system on the Harden shed used counterweighted flaps to allow air interchange at > ± 300 Pa.

More recent pressure relief systems use liquid levels as the determinant for air bypass. The liquid used is pure mineral oil to prevent evaporation. Vegetable oil is unsatisfactory because it solidifies in the presence of hydrogen, atmospheric or fumigant. In Western Australia light hydraulic oil is recommended because it is manufactured without additives that may react with phosphine. Increasing the depth of oil in the valve, increases the internal pressure or vacuum achieved in the sealed storage structure.

It is more common to apply a positive pressure (Banks et al., 1979) with a fan or compressor to the structure but if the atmospheric conditions have created a negative pressure in the relief valve this is also a legitimate indication of the gas tightness of the candidate structure.

There are no clear guidelines for sizing pressure relief systems to the structure but Newman (1989) suggested a design guide of 1 mm^2 for each cubic metre of storage volume, which should be sufficient to relieve pressure differentials resulting from temperature changes of 1 °C per hour. From experience CBH install pressure relief valves according to the type of storage and for example allows 2 valves for an 'A' type horizontal store of 27,000 tonnes constructed with concrete walls and corrugated roof sheeting. The newer 'X' type structures of 20,000 t with concrete panel walls and a lighter constructed wide span corrugated steel roof also have two valves installed. A manufacturer of the pressure relief valves (Duraduct) recommends a rate of one valve for every 15,000 t of storage capacity, however this will depend on the strength of the storage. The Duraduct valve has an internal surface area in the oil chamber of 240,000 mm^2. (Figure 5).

Pressure testing

The $P_{½}$ test used by CBH is 140 Pa. for >10 minutes on existing sealed structures, conducted in the early hours of the morning when ambient temperatures are stable. To commission new sealed storages the type of construction determines the pressures:

- For newly sealed or re-sealed horizontal, corrugated steel shed type storage or concrete panel 'X' types the starting pressure is 200 Pa. and $P_{½}$ = >10 minutes.
- For vertical concrete cells the starting pressure is 1,500 Pa., $P_{½}$ = >10 minutes (Figure 6).

The $P_{½}$ standard for farm silos is more commonly stated as millimetres of water gauge (w.g.), which allows a simple test of pressure

Figure 5. Duraduct pressure relief valve.

Figure 6. Silo test using low pressure gauge.

holding capabilities in the absence of expensive pressure gauges. For small farm silos $P_{½}$ from 25 mm to12 mm w.g. (250 to 125 Pascals) in three minutes or longer in a full silo is recommended. For larger empty steel storages it is expected the same standard would be retained for five minutes or longer because of the greater volume of air contained. (Figure 7).

From an engineering perspective, this standard is assuming minimal atmospheric influence on the pressures within the silo. From a practical perspective $P_{½}$ test on farm is more likely to be undertaken in less than perfect conditions. A full silo under strong wind or declining temperatures is more likely to return $P_{½}$ = > 3 minutes due to the buffering effect of the grain bulk against a falling temperature. An empty or partially full silo could return $P_{½}$ test considerably lower than three minutes under the same conditions due to the internal air contracting more rapidly, however the seals may be adequate to retain the gas for an effective fumigation.

Tests on Western Australian farm silos conducted as part of a fumigation efficacy

Figure 7. Simple clear plastic ‘U’ tube manometer for pressure testing a farm silo.

experiment, showed good fumigations in silos returning $P_{½}$ = >30 seconds most likely demonstrating poor testing conditions (Newman, 2004).

The $P_{½}$ test is less than perfect but gives a reasonable indication of the quality of the seals in the candidate silo, a degree of operator judgement is needed and the ambient conditions should be regarded in the result

Monitoring fumigant concentrations is strongly recommended to confirm the efficacy of any fumigation treatment. In the absence of expensive electronic monitoring devices, a layer of green / black verdigris on a piece of copper placed in the furthest position from the point of introduction of the aluminium phosphide, will give an indication of the efficacy of the fumigation, after the appropriate period has elapsed (Emery and Kostas, 2000).

Maintenance

Sealant coatings are subject to a degradation process and soft gasket material will lose elasticity over time so a maintenance program must be put in place. The problem may be increased by ambient weather conditions at the site. In Western Australia for example, maintenance is more frequent on grain storages located in the higher rainfall areas of the south coast (Tutt pers. comm. 2006) (Figure 8).

Figure 8. Clean down at Beaumont. Photo courtesy Global Sealing Services.

CBH enact a maintenance program after the first year of operation in the sealed structure and as the sealing membrane ages the maintenance problems become greater. At some sites the cost of re-seal of a retro-sealed silo can equal the original cost, due to the higher charges for materials and labour as well as the time required for preparation of the fabric.

When initiating a retro sealing project, a budget for maintenance must be included. It is not unreasonable to cost this at 1 % of the original expenditure allocated annually for maintenance and eventual re-sealing of the structure.

Insect control regulations on farm

Before grain storages were sealed in Western Australia the Grain Weevil Liaison Committee, comprising representatives from government and industry, developed strategies to protect the export grain industry from insect contamination from farms. The ‘Agriculture and Related Resources Protection Act of Parliament’, initiated a regulatory program which required grain growers to control insects before the grain was delivered into central storage. CBH enforced this requirement by imposing a ‘non-receival’ rule if insects were found in a load of grain presented at a receival depot.

Staff of the Agriculture Protection Board, carried out inspections on farms, enforcing clean-up programs under the Act and collecting insects for resistance testing. Initially the tests were aimed at detecting Fenitrothion resistance but this changed to detection of phosphine resistance. This program of testing is on going and has reduced the numbers of farms found to be heavily infested with grain insects (Dean 1994).

On farm sealed storage

From the adoption of sealed storage by CBH, an extension campaign encouraged better fumigation on farms using sealed structures. In 1981 CBH invited all silo manufacturers in Western Australia to exhibit a prototype sealed silo at a demonstration site near Perth and submit them for pressure testing. This started the production of sealed transportable farm silos. Within a few years all silo manufacturers offered a sealed silo option, and since the early 1990's all grain storage silos delivered to farms are sealed to the recommended standard stated above (Newman, 1997). Transportable farm silos range in size from 15 to 100 tonnes, above this capacity the regulations and costs to move such structures on road become uneconomic.

Larger silos are constructed on farms using bolted preformed corrugated steel sheets. These range up to 5,000 tonnes but are more typically 300-600 tonne. Steel bolt pack silos generally have close joins that make them easier to seal during construction but at added cost. The additional cost at this stage is a small component of the cost of construction but provides a more durable and economic seal than a surface applied membrane. The sealant product is applied inside the joints of the silo as it being constructed and is unlikely to be broken except in extreme circumstances such as damage to the fabric.

Retro-sealing on-farm

The early APB campaigns to encourage on-farm use of sealed storage extended to retro-sealing of existing silos and many companies entered the market offering the service. Those that were most successful are those that invested in good equipment and employed skilled labour to prepare the silo for the seal coat. The minimum requirement is a hydraulic work platform and an airless spray gun, powered sheet metal working equipment will render the task more efficient. Companies that considered the task to be another form of painting quickly left the industry but not before they had completed some 'sealing' projects that left the silo in an unsealed condition unable to control insects any more efficiently than before. This caused considerable problems for farmers who suggested the 'sealed' system was a failure. (Figure 9).

Figure 9. Minimum equipment needs – hydraulic platform and airless spray gun.

Conclusion

The move to sealed storage has been beneficial to all central grain handling corporations across Australia, from reduced cost of grain protection, reduced product handling and the ability to guarantee a pest free product.

The Export (Grain) Regulations (1963) remain in place, requiring that a 'phytosanitary certificate' declaring the product free of injurious pests and diseases accompany all export grain, providing the reason to achieve the best possible insect control and the need to maintain sealed storages at a gas tight standard. This high standard has given Australia significant trading leverage to secure contracts in a difficult world market, supplying to the most discerning of customers. Appropriate contractual penalties for non-compliance are a strong motivator to create the storage environment that can meet the customer specifications.

The Australian experience and advantages accrued, are based on a quality driven export market sending some 63 % of the total crop overseas with a guarantee of no grain insects or chemical residues. This has required high investment in quality grain stores which may be difficult to justify in a domestic driven market or where there is a need to maintain a low price for the commodity.

It may be more appropriate under these criteria to consider the longer view, centred on food security and preventing deterioration of product by grain pests.

This decision making process must balance the cost of the initial sealing spread over the expected life of the seal plus annual maintenance, against the lower costs from reduced treatments, less product used and lower labour charges.

Sealed grain storage may also be regarded as an investment in future technology, providing the gas holding features needed for fumigant gases that are yet to be made available and will also contain modified atmospheres of inert gases that enable ‘organic’ control of pest species on registered organic produce.

The retro-seal industry has often stated that anything can be sealed, with the rider “if there is enough time and money”! However of greater concern is the long-term cost of maintaining the seal and the economics of creating a sealed storage under difficult conditions. Before proceeding consider the type of structure and its ability to hold a seal long-term. It may be beneficial to re-engineer the construction, prior to sealing, to reduce deflections created by grain pressures on the seal. Concrete load bearing walls instead of original wooden or sheet metal structures will provide greater resistance to pressure and movement in the grain pathway and subsequent reduction of stress on the sealing membrane or joint sealant.

When engaging a sealing contractor to retro seal a silo or grain storage, the contract must include a clause requiring the seal to be demonstrated by the pressure test already stated.

When investing in new steel silos, a longer lasting and lower cost seal is created by applying polyurethane sealing products between the joins of the silo before they are bolted together. The silo should also have instantly re-sealable inlets and outlets and the contract must include a clause to demonstrate the standard of the seal by a pressure test.

The single most important driver for gas tight grain storage is the threat of resistance to phosphine. Current levels of resistance to phosphine in stored grain insects remain controllable, provided the appropriate concentration of phosphine can be retained *inside* the structure, for the appropriate time.

Use of phosphine in unsealed structures where resistant insects have been detected can be expected, eventually, to lead to control failure. Inability to control insects except with contact chemical renders the commodity more difficult to trade on an increasingly discriminating world market.

The production of surplus grain in excess of domestic consumption provides the opportunity to trade on the international market. Given the potential to improve the wealth of a country it is not unreasonable to expect a level of investment by government in high quality gas tight grain storages to demonstrate the benefits that can be achieved.

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