CONVERSION OF EXISTING GRAIN STORAGE STRUCTURES FOR MODIFIED ATMOSPHERE USE

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ABSTRACT

It is uneconomic to provide a complete system of new sealed structures in an existing bulk handling system. Since storages must be sealed if modified atmospheres are to be used, methods must be developed for the sealing of existing structures. A pressure decay time in a storage of 300-10,000 tonnes capacity of five minutes for an excess pressure drop of 2500-1500 Pa or 1500-750 Pa or 500-250 Pa denotes that the structure is suitably sealed. In Australia, all types of bulk grain storage in use, bolted metal shed or bin, concrete cell and welded metal bin, have been sealed experimentally to an adequate standard for use for modified atmospheres. Generalised procedures are given for sealing of these types of storage and the mechanical modification required for application, distribution and removal of modified atmospheres are detailed. Further work is required to define the optimum commercial sealing process for concrete cells and bolted metal structures.

INTRODUCTION

If the various techniques of modified atmosphere storage either for insect, mould or quality control are to be applicable soon to a significant part of the grain storage industry methods must be developed for making the necessary modifications to existing storages. The existing system represents an enormous capital investment and it is not economically feasible to replace more than a very small proportion of it with structures specifically built to take some form of modified atmosphere treatment. In established bulk handling systems, the rate of replacement of existing structures and construction of new ones is low and thus cannot be expected to contribute a significant quantity of suitable storages quickly.

The provision of a sealed enclosure with correct fitments is crucial to the success of a modified atmosphere treatment. Gas usage is restricted and the possibility of insect survival reduced (see below). The aim of this paper is to show that despite the apparent difficulty of the task, sealing of large existing storages (> 300 tonne capacity) is not impossible, but can be carried out easily and with simple techniques. The variety of the storage structures in use and individual variations in design within a general type necessitate that an intelligent approach be made to the problem of sealing and does not allow a general prescription for success to be given. Nevertheless there are some generalisations, given below, which can be made as a guide to persons wishing to carry out modification of particular storage types. However, before giving a description of the sealing operations required it is necessary to set a target level of gastightness, which, when achieved, shows that the storage is suitable for use with modified atmosphere.

GASTIGHTNESS SPECIFICATION

It is not practically feasible to convert existing structures to completely leak-free enclosures. Some leakage is inevitable, but the magnitude of the leakage tolerable is of concern here. It can be shown (Banks and Desmarchelier, 1979; Banks et al., 1975) that there is a level of sealing at which the gas losses caused by wind and the 'stack' effect are small compared with those resulting from changes in temperature and barometric pressure. There is little benefit in achieving a higher level of sealing than this. If gas loss from temperature and barometric pressure variation were prevented by sealing only dangerous pressure differentials could be generated across the fabric of the structure. In current practice, excessive pressure differentials are relieved by allowing gas interchange through a safety valve and so gas loss still occurs. Methods other than sealing, such as the provision of a heat reflectant roof, must be used to minimise gas loss caused by temperature changes.

Mathematical analysis (Banks and Annis, unpublished data; see Banks et al., 1975 for a similar analysis for freight containers) of the factors causing gas loss from structures and the influence of leak size on the magnitude of the loss, leads to a specification of the 'gastightness' of structures suitable for controlled atmosphere use in terms of the time taken for an applied pressure to decay. In Australia, for structures of 300 to 10,000 tonnes capacity, a decay time of 5 minutes for an applied excess pressure drop of either 2500 to 1500 Pa, 1500 to 750 Pa or 500 to 250 Pa in a full storage is regarded as satisfactory and has been found to be so in practice (Banks et al., 1980). The test range is chosen so that it is the highest usable without unduly stressing the storage fabric of the store. Above 10,000 tonnes capacity, pressure testing is difficult to carry out satisfactorily and requires very stable atmospheric conditions. Below 300 tonnes capacity the standard is difficult to meet in practice and thus must be relaxed despite the consequent higher leakage rate and higher rate of maintenance gas requirement on a per tonne basis. Methods for pressure testing of storages are given in Banks and Annis (1977).

The gastightness specification given above is a design standard, which will give the optimum gas usage performance for modified atmospheres. If a structure fails to meet this standard, it does not mean that it is unsuitable for use with modified atmospheres, but only that leakage may be increased under certain meteorological conditions, notably during high winds, with the result that a higher rate of gas input may be required to maintain the correct atmosphere. The possibility that localised regions may develop where the gas concentrations are inadequate for insect or mould control is also increased. In contrast to use of nitrogen and other low oxygen atmospheres, if CO_2 is used for insect control, only a single application of the gas is necessary, if the storage meets the gastightness specification (Banks, 1979; Wilson et al., 1980). The absence of the need for a continuous input of gas to maintain the correct atmosphere is a significant advantage of CO_2-based modified atmospheres over low-oxygen ones. However if the specification is not met, additional gas may be required and this advantage is eliminated. A management decision must be made whether additional sealing effort is desirable or whether an increased gas cost and possibility of a control failure can be tolerated.

SEALING OF DIFFERENT TYPES OF STORAGES

There are three general types of storage. These are classified by their mode of construction and material used: welded metal bins, concrete cells and storages made of bolted sheet metal. Each general type has some common features which usually require attention (see Fig. 1) though individual structures may have other particular problems to be overcome before a satisfactory seal can be effected. Additionally most storages have various access points through the

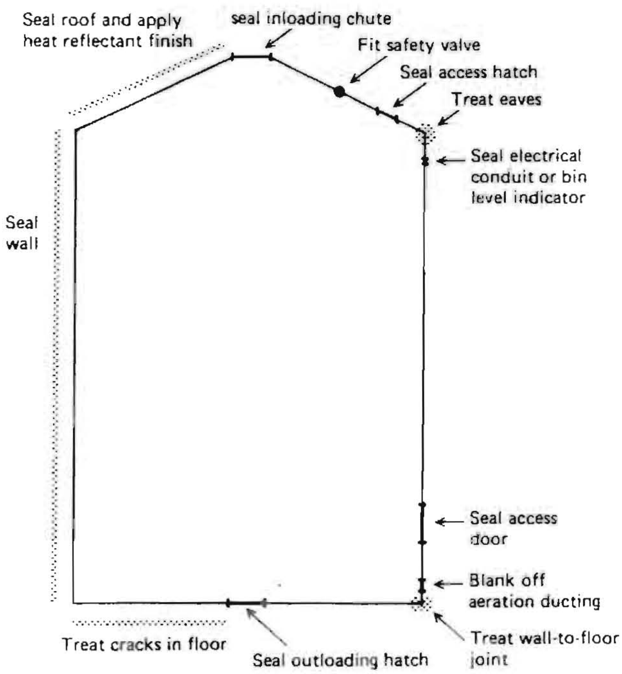

Fig. 1. Diagram of a generalised storage showing areas usually requiring treatment in an existing structure in order to provide a sealed enclosure suitable for modified atmospheres.

fabric of the building, here called 'penetrations', which may require sealing or modification before modified atmosphere systems can be used. A general description of the sealing techniques* used successfully in Australia for various structural types and penetrations is given below.

Welded Metal Bins

Detailed procedures for the treatment of welded metal bins have already been given in Banks and Annis (1977).

Welded metal bins are usually relatively easy to seal to the required standard. Many bins are set on a concrete ring beam with a concrete floor. In larger bins the floor itself does not usually require sealing, although the cracks should be filled with a flexible filler (e.g. bitumen emulsion, thiocol or silicone rubber). The junction of the steel wall and concrete ring beam often leaks and must be treated. The region is subject to substantial movement from both loading stresses and thermal expansion and should be treated with a resilient sealer such as a thiocol rubber. A bitumen emulsion sealer, overcoated with a PVC protective film, has also been found successful here (A.D. Wilson, personal communication). In smaller bins (e.g. 300 tonnes capacity) where sealing is more critical, the floor itself may need treatment with a sealer. Materials such as those used to surface industrial floors are suitable. The eave join will require sealing if it is not continuously welded and can be treated with sealant systems suitable for joins in bolted metal structures (see below).

Using these techniques, and after treating the various penetrations (see below), welded steel bins are routinely sealed under commercial conditions in Australia to the level of gastightness specified for modified atmosphere use. Pressure test results from some of these operations have been given in Banks (1979) and Wilson et al. (1980).

Concrete bins

It is possible to design and construct cylindrical concrete cells to achieve the require standard for modified atmosphere use (see Fig. 2). However most concrete cells are not constructed to be gastight and usually have cracks in the fabric formed during the curing of the concrete and from subsequent movement caused by outloading stresses on the walls. There may also be regions of the fabric which are porous to gases. Even in well-constructed bins this cracking

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* The classes of sealant compounds, not individual proprietry products, are given in the descriptions below as the availability will depend on where the storage to be sealed is located. Because of the importance of the skill of the applier rather than the exact properties of the compound used, many different brands of the same material may be successful in a given situation.

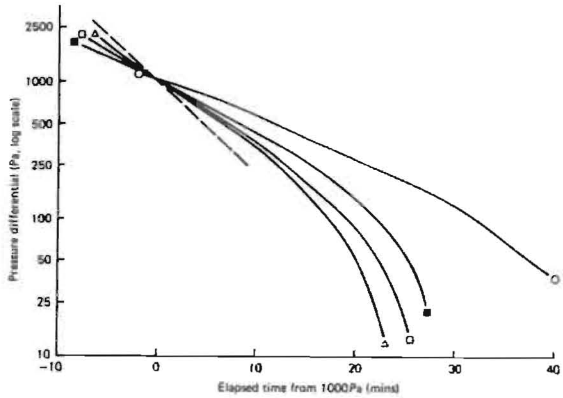

Fig. 2. Pressure decay curves for four 2000 tonne capacity concrete cells, constructed to be gastight and without any sealing treatment for the walls after construction (Gladstone Terminal, Queensland. After five years continuous use. Curves for bins full of wheat, filling ratio 0.95). Dashed line shows the acceptable pressure decay standard.

is often sufficient after operation of the storage for a few seasons to prevent the bin from meeting the pressure test specification.

In the absence of substantial porosity of the fabric, it, in theory, should be possible to treat the individual cracks and thus produce a sealed structure. However we have not found this to be a consistently effective method of giving an overall seal. The network of cracks can be very extensive and it is not possible to tell which cracks are the cause of the leakage and which are only superficial. Treatment of all visible cracks is usually impractical, but on one occasion treatment of the larger externally visible cracks on a concrete cell was found to give a substantial improvement in gastightness (Cooperative Bulk Handling Pty Ltd., unpublished results). This approach has been unsuccessful in other cases (see Fig. 3). In cases where cracks must be sealed it is important to use a resilient material such as a polysulphide rubber as the use of rigid materials may only aggravate cracking (Theimer, 1975).

As an alternative to treatment of individual imperfections, a sealant system can be applied over the whole bin surface. This approach has been used in the past for the sealing of grain storages in various parts of the world (e.g. Japan (Shimizu Construction, 1976); Switzerland (Burns Brown and Heseltine, 1951); USSR (Sergeev et al., 1969)). Currently candidate sealant systems for concrete cells are being evaluated by CSIRO Division of Entomology and the Australian Wheat Board's Coordinating Committee on Silo Sealants under full scale conditions (2000 tonne capacity cells). Full scale testing is being carried out as the

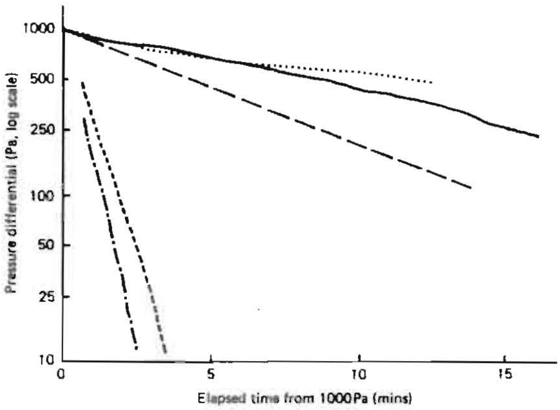

Fig. 3. Pressure decay curves for an 1300 tonne capacity bin, constructed 1935, before treatment (—·—), after coating the walls and roof with an acrylic emulsion (Siloseal) (········) and use for one season (———) and for a similar and adjacent bin after filling of wall and roof cracks > 1.5 mm across only (------). (Sydney Terminal, New South Wales) (Curves for bins full of wheat, filling ratio 0.95). Acceptable decay standard (— —) also shown.

range of problems which a suitable sealant system must overcome either have not been adequately defined or are not reproducible in the laboratory. In particular, the appropriate combination of flexibility, extensibility and abrasion resistance is not known. (Criteria used for the selection of promising materials is given in Appendix 1). Also less easily quantifiable factors such as ease of application and durability in use are important to the overall success of a system. At present, two internally-applied coating systems, a styrene-acrylic and a polychloroprene-based material show particular promise as cheap, effective sealants. Both are applied as water-based emulsions. Fig. 3 shows the improvement in pressure test results after applying the styrene-acrylic system. The other system gave similar results.

The wall-to-roof join in a capped concrete cell is often designed without any form of seal between the bin wall and the roof slab. This region can leak significantly and must be carefully sealed. It is subject to substantial thermal and mechanical movement and thus requires a flexible sealant system. A flexible cornice made from a woven fibreglass mat, fixed around the inside of the join and coated with a thick flexible sealer such as a styrene-acrylic emulsion, has been used successfully here.

In many concrete cells the roof does not rest directly on the cylindrical wall. These 'open-topped' cells require the construction of some form of capping to close off the cell. Various forms of closure based either on membrane systems or sheet polystyrene-metal sandwich materials supported on normal roof trusses are under test at present in Australia. Any such system is likely to appear expensive if viewed simply as a component of the costs of conversion of a storage to controlled atmosphere use, but the cost may be partly offset by the other advantages it provides, notably dust control.

Bolted Metal Structures (Bins and Sheds)

Many grain storage structures are made of sheet metal bolted or riveted together and fixed to a metal or wooden framework. They are often provided with open eaves and ventilators on the roof ridge. Tobacco stores, which are often constructed similarly, have been sealed routinely in the United States using a PVC coating system for the retention of fumigations (Roop, 1949; Anon., 1972). A similar technique presumably could be used for large grain storages and has been successfully demonstrated in Australia on a small farm storage bin (2 tonnes capacity) (Banks and Annis, unpublished data). It does not seem necessary to treat the complete structure with the sealant, as was done with the tobacco stores but only the lap joins, boltheads and other leak prone regions. A cheaper cosmetic and protective coating could then be applied over the whole storage.

Recently a shed-type storage of 16,400 tonnes capacity was sealed in Australia as a demonstration of the feasibility of sealing such large structures (Banks et al., 1979). The shed was constructed from corrugated galvanised iron sheeting, supported on a portal frame with A-frame wall supports and before treatment had ventilated eaves and roof ventilators. The eaves and ventilators were covered in with galvanised iron sheet riveted to the structure. All joins were then coated with a thick styrene-acrylic emulsion, reinforced where movement was expected with woven fibreglass tape embedded in the sealant. Silicone rubber sealant was used in some movement-prone joins. Larger holes and leaks, such as where the corrugated roof met the flat ridge capping, were filled with polyurethane foam, formed in situ.

After sealing, the roof and end gables were coated with a white acrylic paint as a heat-reflectant and protective treatment. Application of a heat-reflectant treatment to the roof is a necessary part of the modification of storages with large roof areas and headspaces for modified atmosphere use. Temperature changes are a major cause of gas loss in such structures and the treatment reduces the magnitude of the diurnal temperature variation in the headspace and thus the quantity of gas loss from this source. Pressure test results obtained over three seasons are given in Fig. 4. The sealed structure was successfully treated with CO_2 for insect control (Banks et al., 1980).

Other sealant systems (e.g. some polyurethanes) appear suitable for bolted metal structures and require testing. It is not yet certain which system will give the best results. However, as with the sealing of concrete cells, a major factor in the success of a sealing project is the skill of the applier and his

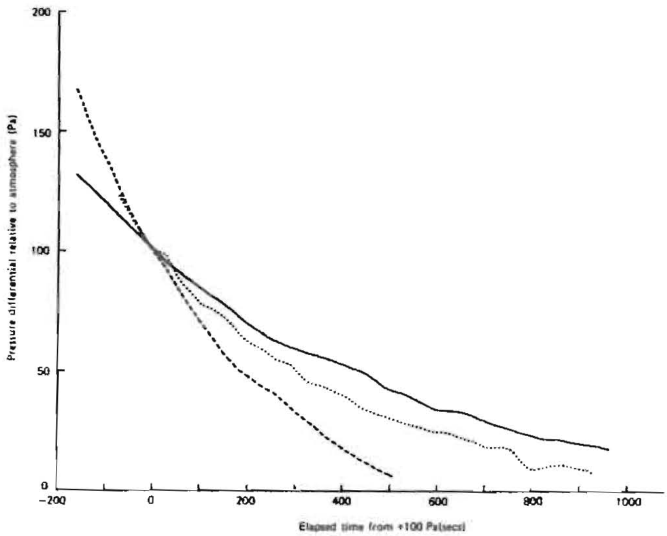

Fig. 4. Pressure decay curves for a 16,400 tonne capacity shed-type storage sealed as described (see text). Tests after sealing (————), after one seasons use (·······) and after two seasons use (------). Minor maintenance only carried out between seasons. (Curves for shed filled to capacity with wheat, filling ratio 0.58).

awareness of how the sealing system must be applied rather than the particular treatment used.

Sealing methods for farm-scale storages (< 300 tonnes capacity) are detailed in Williams et al. (1980).

SEALING OF PENETRATIONS

Grain storages usually have a number of fitments in the structure fabric which must be sealed in order to provide an enclosure of adequate gastightness. Correct treatment of these penetrations is very inportant as they are often major sources of leakage. These fitments include access doors, in- and outloading chutes, electrical conduit and aeration fans and ductwork. In many cases, they may be sealed suitably by ad hoc methods. Although expensive, silicone rubber building sealants and polyurethane foam can be very useful materials for this, providing a removable, but durable seal. In our experience, cheaper methods, such as taping or sealing with butyl mastics as recommended by Jay (1971), can be unsatisfactory in practice and jeopardise the overall success of a sealing operation. Taping with PVC tape can, however, be used to reinforce sealed joins treated with silicone rubber.

Some penetrations, particularly outloading valves, because of their design and accessibility, are often very difficult to seal satisfactorily and may require structural modification or even complete replacement in order to ensure that a good seal can be obtained reliably. Gastight valves of the type used in recirculatory fumigation facilities are suitable for modified atmosphere use.

Doorways into large storage sheds may also present problems for sealing. Spraying of the regions which may leak with a strippable PVC film has been recommended (Roop, 1949). Doors may also be sealed by judicious use of foam polyurethane or of silicone rubber sealants, reinforced with fibreglass or fabric open mesh tape where appropriate. In some cases, it may be better to replace the doors completely with a specifically designed gastight system rather than to attempt to seal the existing ones.

MECHANICAL REQUIREMENTS

If modified atmospheres are to be applied to a storage not specifically designed for their use, some mechanical modifications are required in addition to general sealing. These have been set out by Jay (1971) for CO_2 and Banks and Annis (1977) for modified atmospheres generally. The modifications are to allow the initial introduction of the gas to make the required atmosphere, to provide a means of maintaining the correct atmospheric composition, to prevent structural damage to the sealed structure from excessive pressure differentials across the enclosure walls and sometimes to provide a means of replacing the modified atmosphere with normal air.

Gas Handling and Distribution Systems

Either nitrogen or CO_2 can be introduced efficiently into cylindrical grain storages through inlet systems fitted into the base of the bin wall without additional ductwork. The dimensions of the introduction pipework are dependent on the back pressure which can be tolerated by the gas production system. In Australia, 8 cm diameter pipework is normally used, which can conveniently handle the purge rates currently applied (e.g. 6 m^3 min^{-1}). Precautions must be taken to ensure the end of the introduction pipe does not become blocked with grain. A simple shielded inlet system suitable for this has been described (Banks and Annis, 1977). Using a single inlet of this type, satisfactory purging efficiencies have been obtained even in large squat cylindrical storages (73% for nitrogen; 79% for CO_2, see Bordertown II and IV trials and definitions in Banks (1979)). Since high purging efficiencies can be achieved in cylindrical bins with simple introduction systems, there is little scope for improvement using more complex systems incorporating ductwork within the storage. However, existing ductwork such as fitted for aeration can be used conveniently for gas introduction and may provide a slight improvement in purging efficiency.

Even in horizontal storages, with large length to height ratios, relatively high gas usage efficiencies can be obtained with CO_2 introduced from a single point. An efficiency of 73% was obtained in a 16,400-tonne capacity shed with gas introduced at one end of the storage, improving to 92% using a longitudinal perforated introduction duct (Banks et al., 1980). The high efficiency achieved with CO_2 can be attributed to its density which causes the gas to layer horizontally even in large structures. No studies have been carried out on the introduction of nitrogen into large horizontal storages, but presumably, because nitrogen is similar in density to air and thus, unlike CO_2, has little tendency to layer when introduced, some introduction ductwork will be necessary in order to achieve adequate purging efficiencies with this gas.

With modified atmospheres which are to be maintained indefinitely, a system of external pipework is required to bring additional gas into the storage in order to compensate for leakage and keep the modified atmospheric composition correct. For gases lighter than air, i.e. nitrogen, the additional gas is introduced into the top of the storage; for those heavier, at the base (Banks and Annis, 1977). Two systems are available for maintenance of a modified atmosphere: a demand system, where gas is introduced when the pressure or gas concentration in the storage falls below a set level (Jay and Pearman, 1973; Shejbal, 1979) and a continuous system (Shejbal and Di Maggio, 1976; Banks and Annis, 1977), where gas is fed in at a constant rate. On this basis of available data these appears to be little difference in gas consumption using the two processes (Banks, 1979), but they have not been rigorously compared. In either case, if sealing has been adequate, the gas flows required are likely to be small and thus narrow bore pipework (e.g. 1 cm diam.) will be suitable. A steel 2000-tonne bin sealed to the standard given above requires about 25 l min^{-1} of nitrogen (Banks and Annis, 1977).

For 'one-shot' CO_2-based modified atmosphere systems, where no maintenance gas is used, it is necessary to keep the internal gases mixed in order to prevent formation of regions of inadequate CO_2 concentration for insect control (Wilson et al., 1980). This can be accomplished by recirculating the storage atmosphere from the base into the headspace via external pipework using a small sealed blower. A recirculation rate of about 0.1 volumes per day has been found to be adequate for bins and a shed (Banks and Annis, unpublished data). Recirculation can also be used to maintain a low-oxygen atmosphere with a propane-fired catalytic converter. Navarro et al. (1979) used a recirculation rate through the converter of about 300 l min^{-1} for this on a 1200-tonne bin. At such a rate only narrow pipework (e.g. 3 cm diam.) would be required.

Pressure relief valves

Pressure relief valves are required in sealed storages to prevent damaging pressures from developing in storages as a result of temperature and barometric pressure variation, wind effects or excessive rates of gas introduction in the absence of adequate venting. Simple systems suitable for sheds (Banks et al., 1979) and grain storage bins (Banks and Annis, 1977) have been described. However, both systems would benefit from further design work to provide cheap, rapidly acting systems. The pressures at which such relief valves should operate is dependent on the design of the storage and the pressure differential it can tolerate. In many cases and particularly for sheds, this differential can be small, e.g. 250 Pa.

Removal of the modified atmosphere

A means of venting the atmosphere must be provided to enable personnel to enter a storage treated with a controlled atmosphere for outloading or inspection. In small storages, natural ventilation may be sufficiently rapid for this when access hatches and other penetrations are opened. In large storages forced ventilation is required if it is necessary to enter the storage within a few days after unsealing. Sealable ventilation fans can be fitted to ventilate the workspace when required. A fan capable of an extraction rate of 500 m^3 min^{-1} was fitted in each gable end of a 16,400 tonne sealed storage treated with CO_2 was found adequate. This allowed access within 24 hours. Such large extraction fans are also useful for dust control within the sealed storage during grain movement. In the absence of some form of ventilation in large stores, the air may become dust-laden within the store making working conditions there unpleasant and creating a possible dust-explosion risk.

CONCLUSION

At present in Australia only welded steel bins, treated as set out above, are in commercial use with modified atmospheres. However the techniques for the conversion of both concrete cells and shed-type storages to take modified atmosphere treatments have been demonstrated experimentally. The cost of commercial sealing of large horizontal sheds (> 15,000-tonnes capacity) to an adequate standard of gastightness for controlled atmospheres will vary with method of construction but will probably lie between $A2-5 per tonne capacity, while the treatment of capped concrete cells is expected to be about $A10 per tonne capacity for a 2000-tonne cell. Where a choice is to be made, this cost difference is likely to favour conversion of horizontal storages. The sealing of several more large horizontal storages in Australia is currently under consideration.

With the conversion of a significant number of existing facilities to a sealed condition, it will be possible to assess the problems and potential of the various forms of modified atmosphere storage under the operational constraints of the industry and not at a restricted experimental level as hitherto. The experience gained in carrying out the modifications should be of great assistance in optimising sealing strategies and thus, as sealing is a major cost component of modified atmosphere storage, reducing the overall cost of the process and giving a viable system for use with existing structures.

ACKNOWLEDGMENTS

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APPENDIX I.

<u>Criteria uses for the selection of candidate sealants for internal application to concrete cells</u>

(1) The sealant system should be able to bridge cracks up to 1.5 mm across so to create a continuous film which will not fail when opened to 2 mm during outloading.
(2) It must be sufficiently plastic or elastic not to crack when imperfections in the structure open under pressures from the filling or emptying of the bin. A 100% extension on 0.3 mm crack should be withstood without failure.
(3) Because of high application costs, the system should be effective using 3 or less coats.
(4) Good adhesion to old concrete is required. A primer may be necessary. The coating must be able to withstand $\pm$ 2500 Pa on a 1 mm wide crack, 30 cm long without loss of adhesion.
(5) The sealing system must be easily repairable if damaged.
(6) The coating must be suitable for use with foodstuffs. Data should be available to show no adverse effects on direct contact with the sealant.
(7) The coating must not creep or perish.
(8) The coating should have a significant degree of abrasion resistance. A different material is acceptable in high wear areas.
(9) It is essential that the material is stable to gaseous methyl bromide or phosphine fumigants and is unaffected by high CO_2 levels (e.g. 60%).
(10) U.V. radiation resistance for the coating is not required.
(11) The coating must at least be stable between 0-42^{o}C.
(12) The total system should have at least a 10 year life but it is acceptable that easily accessible areas such as the outloading cone may be repaired prior to this.