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SEALING OUTDOOR STORAGE AND FUMIGATION FACILITIES USING PLASTIC SHEETING

T. deBRUIN
Haogenplast Ltd., Kibbutz Haogen 42880, Israel

ABSTRACT

Plastic sheeting used for modified atmosphere facilities for storing grain, dried fruits and bee-hives were discussed. Several aspects in the production of plastic membranes and in ensuring sufficiently sealed facilities were reviewed. There are prerequisites for sealed outdoor facilities. The plastic membrane of the structure should have adequate physical strength, a low gas-permeability rate and good UV resistance. The structure should be sufficiently gastight either to allow metabolic processes to create the desired atmospheric composition or to enable modification of the atmosphere by the addition of gas. Manufacturers should perform leak tests before the units leave the production plant.

On-the-spot sealing is employed only for very large units (such as bunkers for grain storage of over 10,000 t or sealed storage of dried fruits containing tens of tonnes) since sealing techniques demand high professional skills, including the use of hot air guns and adhesives. Where grain is stored in units of up to 1,000 t, sealing of liner sections with easily locked plastic tongue-and-groove zippers is convenient.

Prefabricated units have the advantages of a lower price, due to a standard manufacturing process, and ease in operation. On-the-spot-installations are less cost-effective, and testing is rather complicated. In addition, each time a fresh commodity is stored a new sealing process is required.

Tests used for determining airtightness include physically controlling seams and weldings, inflation and audio control, inflation and measurement of drop in pressure, inflation with colored smoke and ultrasound.

INTRODUCTION

In the seventies PVC sheeting was developed for the storage of military equipment in the open, a method frequently termed "dry storage". It was necessary that military emergency equipment be stored in a way that ensured minimal maintenance and maximum preservation of the stored equipment. Tanks, heavy artillery and planes are stored in plastic envelopes which prevent water vapor (and dust) from penetrating through the sheeting into the storage space. At the same time, because it is designed to be used outdoors, the sheeting has to be extremely robust, resistant to degradation by UV light and resistant to rodent penetration.

When the scientists of the Agricultural Research Organization (ARO) requested us to manufacture a plastic membrane for the hermetic storage of grain, it was clear that the properties of the sheeting described above also made it suitable for this civilian use. However the requirements for hermetic storage are different from those for military dry storage.

In the case of dry storage, the prevention of any movement of water vapor across the liner is the main issue. For hermetic storage and storage under modified atmospheres, the sheeting should prevent (or reduce to a minimum) the penetration of oxygen (O_2) from outside into the O_2-deficient atmosphere created within the liner, and it should at the same time prevent the carbon dioxide (CO_2) produced within the grain bulk from permeating outwards into the atmosphere. Our tests and experience have shown that the thickness of the PVC liner is crucial both in terms of gastightness and UV resistance. To put it differently, the thinner the PVC, the poorer will be both the gastightness and the UV resistance.

PVC sheeting is made flexible by the addition of plasticizers to the PVC resins. These oily substances tend to migrate from the resins under the influence of sunshine, thus causing the sheeting to become stiff and brittle with time. Only experienced producers of PVC lining can fabricate a membrane in which this migration process is sufficiently retarded to enable the material to have a reasonable life span. Under Israeli conditions, in certain areas there are 305 d of sunshine a year. We have, however, been able to develop a liner with a life span under constant exposure to solar radiation of over 10 years. Recent advances in the chemistry of plasticizers have resulted in the development of dry plasticizers which enable the life span of the sheeting to be doubled. However, these dry plasticizers are not very widely employed due to their high price.

MATERIALS AND METHODS

Sheeting requirements

Plastic sheeting used for sealed outdoor facilities should meet several conditions: the sheeting should be adequately gastight (impermeable to water and water vapor and with low permeability to CO_2 and O_2); the technique used for connecting the sheets together should provide a sufficiently gastight seal; the sheeting must be UV resistant; the sheeting should be rodent repellent or rodent proof; the price of the material should be reasonable; the sheeting should be flexible and easy to handle; and the sheeting should be easily welded by high frequency (HF) sealing methods.

Structures for storage

To provide a suitable and user-friendly storage solution that incorporates the PVC-based sheeting, a good design for the storage structure is required. Such a structure should meet several conditions. In the case of grain storage, it should be tailored to fit either bag-stacks or bulk. In the case of fumigation or artificial gasing, it should be manufactured to fit the size of the packed commodity. It should be simple to erect and to dismantle. Final sealing should be easy. The storage unit should be rodent proof. The price of the structure should make it cost-effective. The structure should be easy to repair.

Finally, the stack or the bulk load should be easy to move into the structure, given local usage, labor costs and transport facilities (O'Dowd *et al.*, 1987).

The best sealing results are obtained by hot-air welding or HF sealing. HF sealing is preferable since this technique does not affect the molecular substance of the PVC and is performed in workshops where final testing is easier than in the field. The structure should be sealed in such a way that the natural modification of the atmosphere, caused by the aerobic respiration of the grain, stored-product insects and microflora, will take place within a few days after sealing. The level of hermetic seal is best evaluated by a pressure test. This is done by creating a negative pressure within the liner using a vacuum cleaner and measuring the rate of pressure change (a negative pressure of 5 cm water gauge to fall to 2.5 cm in 15 min or more is usually taken as acceptable).

Three types of structure employing PVC liner technology are at present in use for grain storage (Navarro *et al.*, 1990). They are Volcani cubes for 5–150 t grain in bags, 250-t, 500-t and 1,000-t mobile silos and bunkers for large bulk storage (up to 10,000–15,000 t).

Although cereal grains are without any doubt the most abundant commodity suitable for hermetic storage, such additional applications (using artificially modified atmospheres) as storage tents for fumigation and storage of honey combs under CO_2 and storage of dried fruit under CO_2 have been developed. These latter two structures will be reported elsewhere.

RESULTS

Frameless flexible envelopes (Volcani cubes)

These consist essentially of the same PVC liner as that used for the larger structures. They are intended for bag storage of small quantities (approximately 10, 20 and 50 t) of cereal grains. Since no rigid frame is required, the liner is made of an upper and a lower section which can be zipped together to form a gastight seal. The envelopes, also termed "cubes", are easy to erect and dismantle. They are particularly suitable for on-farm storage and storage by farmer cooperatives. For trucking operations they can be transported with the grain load, and the sacks can be off-loaded directly into the cubes at the point of destination (Donahaye *et al.*, 1991).

The storage cubes consist of a lower floor-wall section of heat-welded flexible 0.83-mm-thick PVC formulated sheeting, laid on the ground, onto which the sacks are stacked. When fully loaded, the upper roof-wall section is drawn over the stack and the two sections are hermetically sealed using the gas-proof zipper. The zipper is covered by a protective over-flap. The "10-t" liner is 336 × 298 × 150 cm (l × w × h) (Fig. 1), giving a maximum storage volume of 15 m^3. It weighs 43 kg when empty. The "20-t" liner is 445 × 336 × 200 cm (l × w × h) with a maximum storage volume of 30 m^3. It weighs 76 kg when empty.

Weld-mesh walled silos (mobile silos)

These are suitable as medium-sized silos with a capacity of up to 1,000 t. A circular bag contained within a vertical wall of galvanized weld-mesh is used. After the ground is

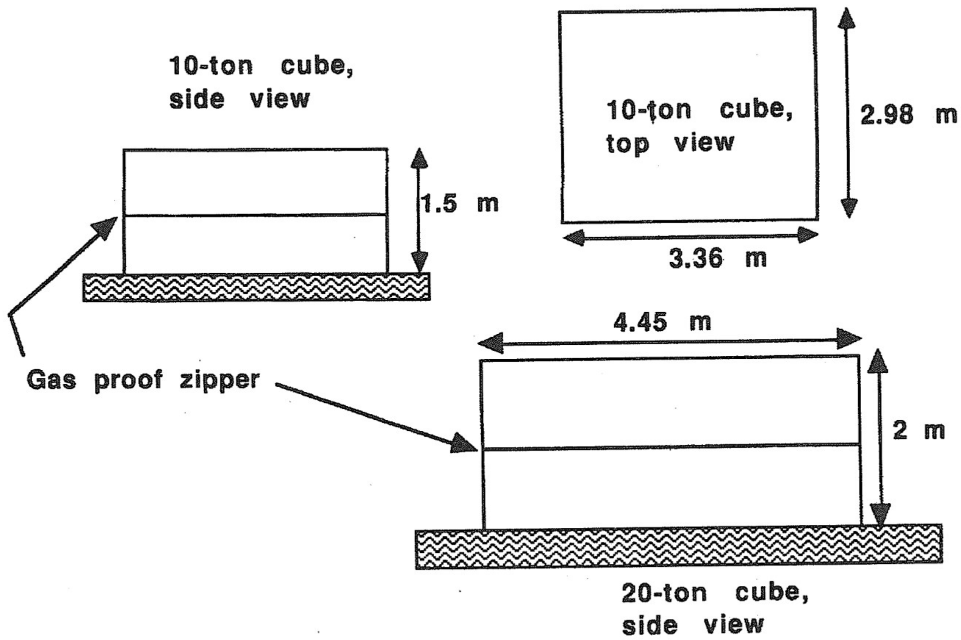

Fig. 1. Plan of 10- and 20-t capacity Volcani cubes for bag-storage of grain.

leveled and cleared of stones, weld-mesh sections are bolted into place to form a circle leaving the floor-wall package within the perimeter. The package is then opened and the walls of the liner are tied to the weld-mesh. These silos can be equipped with aeration systems, in which case the aeration ducts should be placed in position before loading the grain (Fig. 2). Care must be taken to load the silo exactly from the center point. The roof section is then placed over the grain, using a pre-attached rope to pull and unfold the PVC liner. After the roof section is evenly spread over the grain, it is zipped to the wall to obtain a gastight seal (Fig. 3). This method is highly suitable for mechanized grain handling and the integration of aeration systems for bag or bulk storage. The suitability of these silos for buffer storage of emergency stocks in arid regions has been evaluated (Calderon *et al.*, 1989).

Bunker-type storage

This is proposed for capacities larger than 1,000 t. It consists of a bunker bordered on three sides by ramps of earth, excavated from both inside and outside the site, which form the structural wall of the silo. The following is merely a description of the conditions under which the first storage trial in Israel was carried out. Detailed results of this trial have been published elsewhere (Navarro *et al.*, 1984). This bunker was 150 m long and 50 m wide. The earthen floor was bordered on three sides by earth ramps upturned from the floor during leveling and grading, and the fourth end was left open for grain loading. The ramps were 2 m

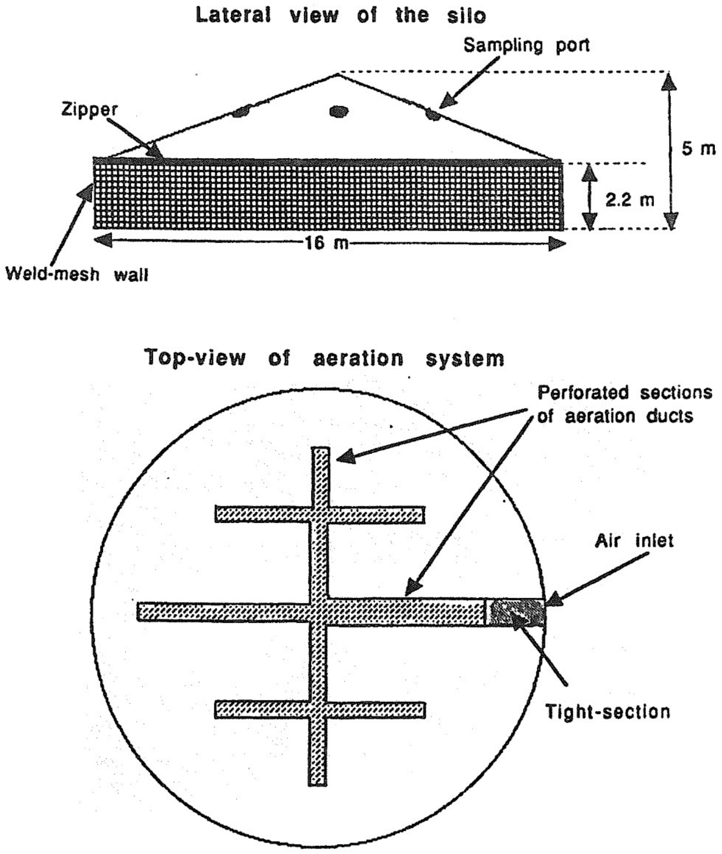

Fig. 2. Schematic view of a 500-t capacity weld-mesh silo including lay-out of aeration ducts.

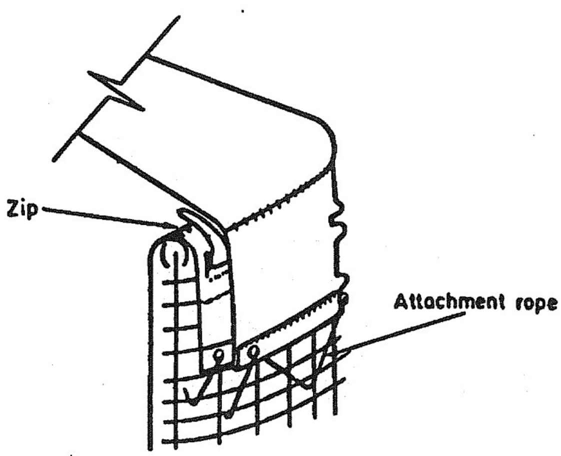

Fig. 3. Method of securing roof-cone to floor-wall unit and weld-mesh walls in silos.

high and 8 m wide at the base, and they were leveled to permit drainage of rain water away from the outer sides (Fig. 4). Before loading, the floor and ramps were lined with overlapping strips of 0.25-mm-thick polyethylene sheeting laid transversely to form a continuous underliner. The overliner was 0.83-mm-thick PVC formulated sheeting, factory-welded into strips 4 m wide, that were laid over the grain surface and then welded together *in situ.* The two liners were joined at the top of the ramps, where they were overlapped, folded and buried in a 60-cm-deep trench to form a hermetic seal (Fig. 5). The ramps were then further protected against erosion by rain-water run-off in winter by a 4-m-wide extension welded to the base of the overliner. Since completion of the first bunker trial, this method of storing grain reserves has become routine practice in Israel.

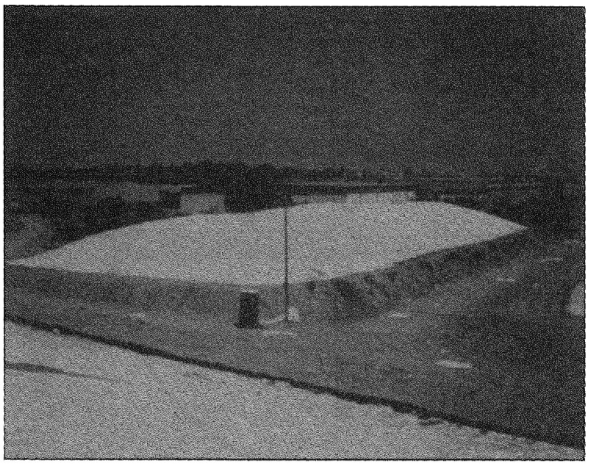

Fig. 4. General view of a bunker containing 15,000 t of wheat.

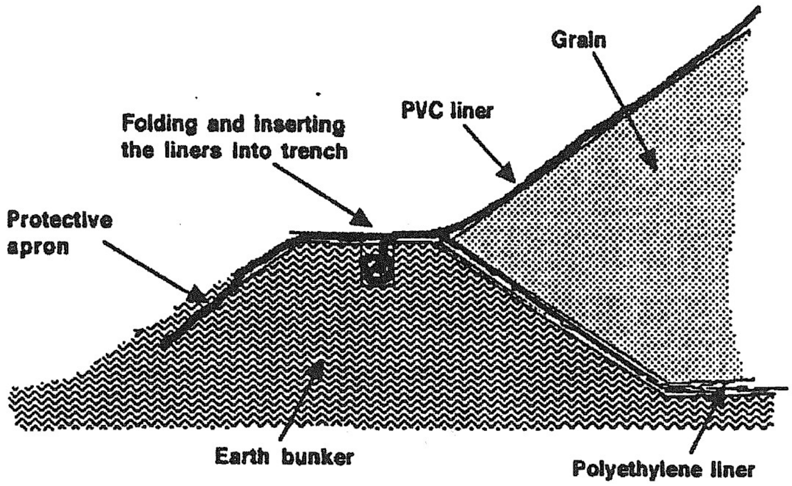

Fig. 5. Section of earth bank to show folded liners in trench and the protective apron.

DISCUSSION

The structures here described are recommended only for dry-grain storage (Navarro and Donahaye, 1976; Kenneford and O'Dowd, 1981). Although hermetic storage of moist feed-grain has been investigated in temperate climates (Hyde and Oxley, 1960), its use in the tropics has not so far led to encouraging results (Hyde, 1969). Loading and unloading cannot be carried out during rainfall unless the structures are under cover. Otherwise, loading and emptying can be carried out only during dry spells. All three types of structures described should be filled to their rated capacity and should not be left partly full (Navarro and Donahaye, 1985).

Rodents can gnaw through the plastic liners. However, the construction system and the layout of the material over the grain, which keeps the plastic under tension, provides a slippery surface which makes it extremely difficult for rodents to make an incision in the material with their teeth. This has been confirmed in trials carried out in our laboratory with liners kept under tension and exposed to both roof rats and house mice captured in the field. Field trials at heavily infested sites have revealed only isolated cases of rodent damage in full silos and bunkers. However, empty silos and envelopes are much more susceptible and should be folded up and stored above ground level to guard against rodent attack.

The durability of the plastic material and its resistance to adverse climatic conditions of solar UV irradiation and high temperatures both offer distinct advantages. The systems can be sealed to a degree of gastightness sufficient to control insects (Fig. 6), based on the principle of hermetic storage (Hyde *et al.*, 1973). Should the necessity arise for chemical control, the hermetic seal ensures effective retention of fumigant concentration. For larger bulks, mechanization of grain handling, temperature monitoring equipment and, for weld-mesh silos, aeration systems can all be easily incorporated.

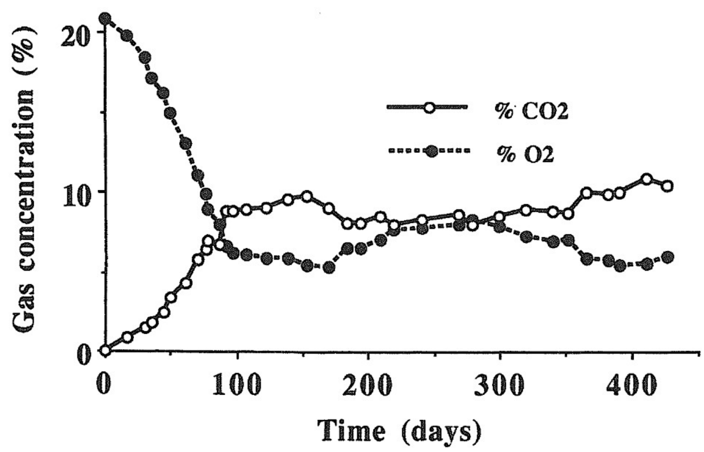

Fig. 6. Average CO_2 and O_2 concentrations (%) in the bunker-type silo containing 15,567 t of wheat bulk during the storage period (Navarro *et al.*, 1984).

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