Controlled Atmosphere Tents for Storing Fresh Commodities in Conventional Refrigerated Rooms

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SUMMARY. A plastic tent was designed and constructed for the controlled atmosphere (CA) storage of small quantities of fresh produce. The CA tent is suspended from pallet racking in a standard cold room and can hold two standard pallets stacked 6 feet high with produce. Tents are sealed with two air tight zippers and a small water trough, resulting in an airtight chamber that successfully maintains CA storage environments. The CA tents are easily set up and removed to allow flexibility in use of storage space. To provide efficient use of storage space tents can be stacked two or three high on pallet racking. Tents are easily loaded and unloaded by a single person using a forklift. CA tents provide an economical alternative to traditional CA rooms for the storage of small quantities of fresh produce under CA environments.

The storage life of many fresh horticultural commodities can be extended using controlled atmosphere (CA) storage. The use of CA involves the reduction of oxygen and/or the elevation of carbon

dioxide concentrations in the storage atmosphere. Modification of the storage atmosphere requires an airtight room or chamber and equipment to monitor and control the gas composition. Commercially, CA storage has been used primarily for the long term storage of apples (*Malus × domestica* Borkh.) and pears (*Pyrus communis* L.) where large rooms are sealed and CA conditions are maintained for 3 to 9 months.

Many other fruits and vegetables, in addition to apples and pears, benefit from storage in CA (Kader, 1997; Saltveit, 1997). However, because of the shorter storage life of many of these commodities, the large CA storage rooms used for apples and pears are not economically practical. Alternatives to the traditional CA storage room include modified atmosphere packaging (MAP), smaller CA chambers, and plastic tents. Atmosphere modification obtained by MAP requires special packaging and may not always produce the desired atmosphere. Small CA chambers have the advantage of allowing precise atmosphere control but can be expensive and may occupy valuable space when the crop is no longer being stored. CA tents are a less expensive alternative to a dedicated CA storage room, and unlike MAP, they still allow precise control of the storage atmosphere composition.

Plastic CA tents can be used in traditional cold storage rooms to provide CA conditions but are easily removed to allow non-CA use of the same space. CA tents have been used since the early days of CA storage as a less expensive alternative to dedicated CA rooms. Eaves (1957) described a tent used for CA apple storage over 40 years ago. Similar large tents have been used in New Zealand for the CA storage of apples and kiwifruit [*Actinidia deliciosa* (A. Chev) C.F. Liang et al. R. Ferguson var. *deliciosa*] (McDonald, 1982). More recently, smaller CA tents have been developed that hold single pallets of product (Gariépy et al., 1988; Zong, 1989). These tents provide an alternative to traditional CA rooms for holding small quantities of fresh produce under CA and provide marketing flexibility. Existing CA tent designs do not always seal properly, are awkward to use, or do not allow efficient use of cold-room space. In this paper we describe our efforts to design a CA tent that provides efficient, economical, and convenient CA storage of two pallets of fresh produce.

Materials and methods

The CA tent described here was designed to meet two objectives: to house pallets of produce in a controlled atmosphere environment, and to maximize the efficient utilization of the cold-room space. The tents were designed to hold two pallets of product and were constructed from 20-mil [0.02-inch (0.508-mm)] polyvinyl chloride (PVC) (Figs. 1 and 2). The PVC sheets were durable while remaining very flexible when subjected to temperatures of 30 to 33 °F (−1.0 to 0.5 °C). The number of pieces of PVC used to construct the tent was minimized to reduce the number of seals required. The top, sides, and bottom were one sheet with the ends comprised of two additional sheets. All joints and seams of the tents were heat welded. One side of the tent functioned as a door and could be opened and rolled up to fill the tent with produce (Fig. 3). To maintain an airtight seal when closed, the tent opening incorporated plastic tracking down each side of the opening panel, which could be slipped together or apart using a zipper mechanism to create an airtight seal (Fig. 4). The only unsealed portion of a closed tent was the seam between the floor of the tent and the bottom of the

Fig. 1. Diagram of two controlled atmosphere tents suspended from standard pallet racking. The top tent is sealed by closing zippers on both sides of the door and immersing the bottom of the door and the adjacent floor panel in the water trough. The bottom tent is shown with the door rolled up and one pallet of fruit loaded in the tent.

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door panel. To maintain the airtight seal, this seam was submersed in water held in a trough. The trough was constructed using 6-inch (15-cm) diameter PVC pipe with end caps and one-third of the pipe wall removed to create an opening. Brackets mounted on the cross members of the pallet racking held the troughs in place during their use. When not used, the troughs could be drained and removed from the brackets if required. The trough also allowed supply and sample gas lines and temperature probe wires to enter the tent environment without affecting the airtight seal (Fig. 4). Gas concentrations within the tent were monitored and controlled using an Oxystat 200 Controlled Atmosphere System (David Bishop Instruments, Heathfield, E. Sussex, U.K.).

One end of the CA tent included a pressure relief valve to control the pressure within the CA tent (Fig. 5). The relief valve fit into a 6-inch (15-cm) diameter, 20 mil PVC sleeve. The pressure relief valve was constructed from a 6-inch (15-cm) diameter PVC Tee fitted with neoprene gaskets. The gaskets were adjusted so that an atmospheric pressure differential between the inside and the outside of the tent of 0.5 or -1.0 inches (1.3 or -2.5 cm) water column would allow the tent to equilibrate with atmospheric pressure. This valve prevented the tent material or gas lines from experiencing excessive positive or negative pressure.

A sampling port was also present on the side of the tent with the pressure relief valve. This port was an 8-inch (20-cm) diameter hole with a 12-inch (51-cm) long, 20-mil PVC sleeve. The sample port was sealed by rolling up the sleeve tightly and securing it with a large plastic clamp. To open the sample port, the clamp was removed and the sleeve unrolled. This allowed sampling of product without opening the tent, resulting in a minimal disruption of the CA environment within the tent.

Traditional pallet racking was used to maximize the storage capability of the refrigerated room. The racking allowed pallets of product to be stacked two or three layers high, thus doubling or tripling the storage capacity of the room in the same amount of floor space. The racking used was 160 inches high $\times$ 108 inches long $\times$ 40 inches deep (4.06 $\times$ 2.74 $\times$ 1.02 m). Cross members were located at the 7 ft (2.13

Fig. 2. Controlled atmosphere tent loaded with two pallets of product before sealing. The water trough has been removed to facilitate loading.

m) and 14 ft (4.26 m) heights allowing 6 ft (1.83 m) high pallets to be stored on each level. The racking was also used as the framework to support the CA storage tents. The tents were suspended from the racking with rope threaded through 1-inch (2.5-cm) diameter PVC piping placed in sleeves located on the top of the tent. This allowed the tents to be removed easily and rolled up to be stored, if desired. Sheets of plywood were placed on each side of the tent floor to displace the weight of the pallets, and protect the tent floor from being pierced by splinters or nails in the wooden pallets.

Discussion

The tent, as described, provides CA capabilities without large capital investment and creates tremendous flexibility in terms of storage location. Any cold storage room with space for pallet racking is capable of becoming a CA storage room, or can be used as a room with CA and non-CA stored products that require the same holding temperature. Installation of the CA tents requires $\approx$ 1 h each and is best done by two people to reduce the risk of damaging the tent. The tents can be disassembled and prepared for storage in $\approx$ 30 min.

Fig. 3. Controlled atmosphere tent being loaded with pallets of product.

Fig. 4. Airtight zipper used to seal tent doors. The bottom of the door and an extended flap from the floor are sealed by immersion in a water trough made from 6-inch (15-cm) diameter polyvinylchloride pipe. Tubing for gas sampling and flushing, and wire for temperature probes enter the tent through the water trough.

Fig. 5. End of tent showing pressure release valve used to equilibrate pressure in the tent with atmospheric pressure.

Monitoring of these CA tents during two seasons of commercial use has shown that the atmosphere within the tents remains quite stable. Minor leaks are easy to detect due to the drift of the gas levels during the monitoring process. Areas where leaks could occur include the sampling port, if the port is not tightly rolled; the pressure relief valve, when the neoprene gasket is not sitting properly on the valve openings; the zipper ends, if the water trough is not filled sufficiently to cover them; and separation of the zipper, if the zipper is bent or closed without ensuring proper zipper alignment. Punctures in the tent are also a concern and care should be taken during installation and removal since a puncture within a tent can be more difficult to locate. If a puncture is

found, patching of the tent is very easy and effectively maintains the required gas seal for CA storage. Tents that have an adequate seal are identifiable by the increased CO₂ and decreased O₂ concentrations during storage.

Condensation on the inside walls and ceiling of CA tents has been a

concern with previous designs that used water troughs to seal all four sides of the tent bottom. However, with this improved tent design there have been no incidents of condensation. The lack of condensation can be attributed to the minimal surface area of water in the narrow water trough and the minimal difference in temperature between the inside and the outside of the tent walls. Temperature data collected during commercial monitoring has shown that the temperature within the tents is 1 to 2 °F (0.6 to 1.1 °C) higher than the room temperature. Because of this temperature differential, the room temperature was lowered 2 °F (1.1 °C) below the desired holding temperature. This resulted in the temperature in the tent being closer to the ideal setting and products in the tents never experienced damage due to excessively cold temperatures. To maintain temperature control, good air movement is needed around the tent. A minimum air space of ≈6 inches (15 cm) was maintained between tents, and between the back of the tent and the storage room wall. Removal of heat of respiration from the product in the tent is slow because of the minimal air movement within the tent. It is, therefore, crucial to insure that all products being placed in a CA tent are thoroughly cooled before sealing the tent, since once in the tent, cooling can be very difficult.

The CA tents can be filled with a forklift since the side panel of the tent can be lifted for filling or emptying (Fig. 3). With this arrangement, two people can easily open a tent, load the tent with two pallets of product using a forklift, fit the required gas lines, fill the water trough, and seal the tent for CA storage in less than 30 min. By using the pallet racking, the capacity of the room can be doubled or tripled. The two-pallet tent size is manageable for one or two people to install or take down. The two-pallet tent is also very suitable for small volumes of produce, or products that have multiple harvest dates. The tents can be individually filled when needed without interrupting the CA environments of other tents. Products stored in this manner can be marketed in small volumes as well. Rather than paying the cost of a large CA storage, producers can customize their CA requirements to suit their particular volumes and marketing strategies, and easily increase their CA storage capacity by adding additional tents as required.

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