ARTICLE 40-22
AUGUST 1957

A TENT FOR THE CONTROLLED-ATMOSPHERE STORAGE OF APPLES

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A VINYL PLASTIC FILM tent was tested as a controlled-atmosphere chamber for the storage of apples, to determine if a regular storage room could be satisfactorily converted to controlled-atmosphere uses without modification of the room structure and refrigeration system.

The tent was designed to provide the gastight enclosure necessary for carbon dioxide and oxygen control of the atmosphere surrounding the fruit. It was installed for refrigeration by the jacketed system whereby the storage contents are cooled by air circulation between the chamber walls and the insulated primary walls of the storage building. This system of refrigeration has been used for the cold storage of produce in the Netherlands (Van Hiele, 1951) and in Canada (Lentz and Rooke, 1957).

TENT

The tent,[1] with dimensions of 30 by 15 by 10 feet, was installed in a small insulated apple storage at the Vernon Bull Orchards near Casnovia, Michigan. The storage room, with dimensions of 34.4 by 19.5 by 11.8 feet and a capacity of 3,000 bushels, is refrigerated with water-defrost evaporators mounted near the ceiling at one side of the room.

The unitized ceiling and walls of the tent were prefabricated of 8 mil. (.008 inch) vinyl plastic film. One end was fitted with inner metal and outer plastic slide fasteners so it could be opened to facilitate loading and unloading. The bottom or floor of the tent was made of 12 mil. vinyl plastic film. No provision was made for air circulation beneath the tent floor. The tent ceiling, however, was extended

[1]Fabricated and furnished by Wells-Donavan Manufacturing Co., 4205 Dahlman Ave., South Omaha, Nebraska, through Genn & Logan Associates, 7607 W. Addison St., Chicago, Illinois.

Reprinted from the QUARTERLY BULLETIN of the Michigan Agricultural Experiment Station, Michigan State University, East Lansing. Vol. 40, No. 1, pages 181 to 192. August 1957.

beyond the ends and joined to the walls of the storage building to assure air movement across the ceiling and down and around the sides.

The tent was suspended from a wooden frame attached to the ceiling of the storage room by 15 grommeted holes in each of five tabs extending across the top side of the tent ceiling. These failed to give adequate support, and tabs were attached to the top edge of the walls to provide additional support.

The sides were rolled up and held in place by wire hooks during loading (Fig. 1) to facilitate rapid removal of field heat from the fruit. Field crates of apples were loaded into the tent and supported on ¾-inch wooden stringers on the vinyl floor covering.

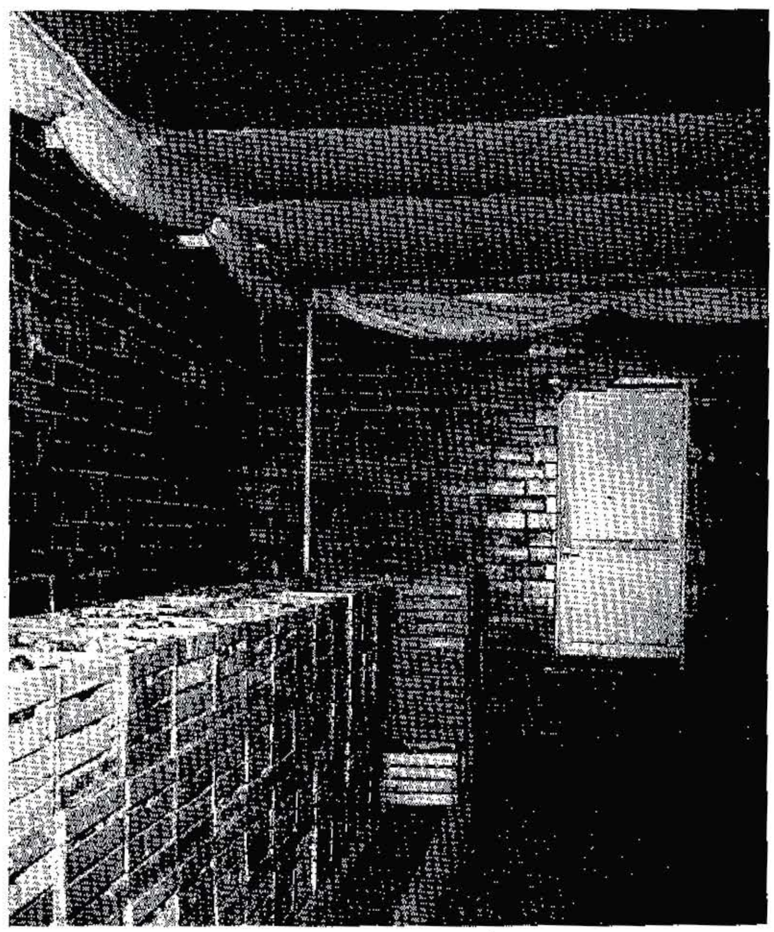

Fig. 1. Tent installed in storage room with sides rolled up to facilitate loading and initial cooling.

A carbon air purifier unit of 6,000 bushels rated capacity was placed in the tent at the top of the stacked fruit to provide air circulation and to reduce the accumulation of undesirable odors within the tent.

When the apples had cooled to about 40° F., the sides were lowered into place. Plastic slide fasteners proved unsuitable for sealing the sides to the floor because the plastic lost elasticity at the storage room temperature of 35 to 40° F.

A seal was made by installing a water trough formed with 2-by 6-inch wooden planks placed on edge about 4 inches from the stacked crates. The trough was lined with 1.5 mil. polyethylene film and sealed to the concrete floor at the edge of the plastic floor covering by a bead of caulking compound. The lower edge of the sides was placed into the trough which was then filled with water.

An atmosphere sampling tube and the outlet of the airblower were attached to a 4-inch diameter sleeve which was incorporated into the loading end of the tent. The absorber inlet and return tubes and the thermocouple leads entered the tent through the water trough beneath the sides.

FRUIT

The tent was filled with 2,460 bushel crates of McIntosh apples from the Bull Orchards on September 25 to 27, 1956. Experimental bushel samples of comparable fruit were made up from 16 crates of the grower's apples. Fourteen were placed at predetermined positions selected to give a range of conditions within the tent during storage (Fig. 2). The other 2 bushels were placed in regular storage at 32° for comparison at the end of the storage season.

The apples were removed from the tent on April 10, 1957, and sorted for decay, carbon dioxide injury, storage scald, shrivel and other surface disorders. Samples of 20 fruits from each of the 14 bushel samples were evaluated for ground color with a color chart (Southwick and Hurd, 1948), and for flesh firmness by pressure test. Fifty fruits were examined for internal condition and eating quality.

These examinations were repeated with equal quantities of apples which had been held after removal from storage for a simulated marketing period of 10 days at 75° F.

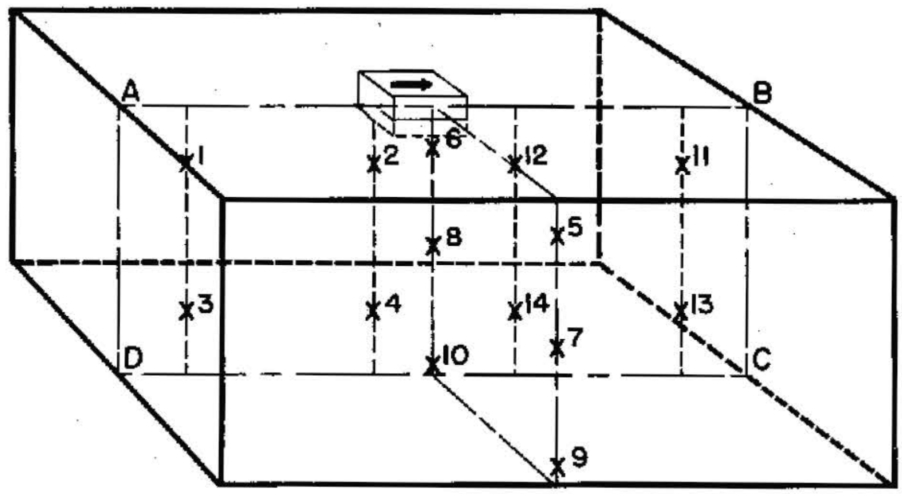

Fig. 2. Diagram showing location of the experimental fruit samples and thermocouples within the tent. Positions 5, 7 and 9 were beneath the refrigeration evaporators. The others and the air purifier were located in the center plane, A B C D.

OPERATION

Recommended controlled-atmosphere (CA) storage conditions for McIntosh apples (Smock and Van Doren, 1941) of 38° F., 5 percent carbon dioxide, and 3 percent oxygen were used.

Thermocouples were installed to measure temperatures of the experimental samples of fruit in the storage and air temperatures outside the tent.

The oxygen and carbon dioxide of the tent atmosphere were determined daily with an Orsat analyzer. Excess carbon dioxide was removed by a remote caustic soda absorber; oxygen was supplied by adding outside air with a blower.

Gas leakage tests of the tent were conducted at the end of the storage season using the method described by Pflug and Southwick, 1954, with the exception that air was metered out of the tent rather than into the storage.

RESULTS

Temperature Control

Fruit temperatures, as determined by the thermocouples in the 14 selected positions within the tent, varied widely from the desired

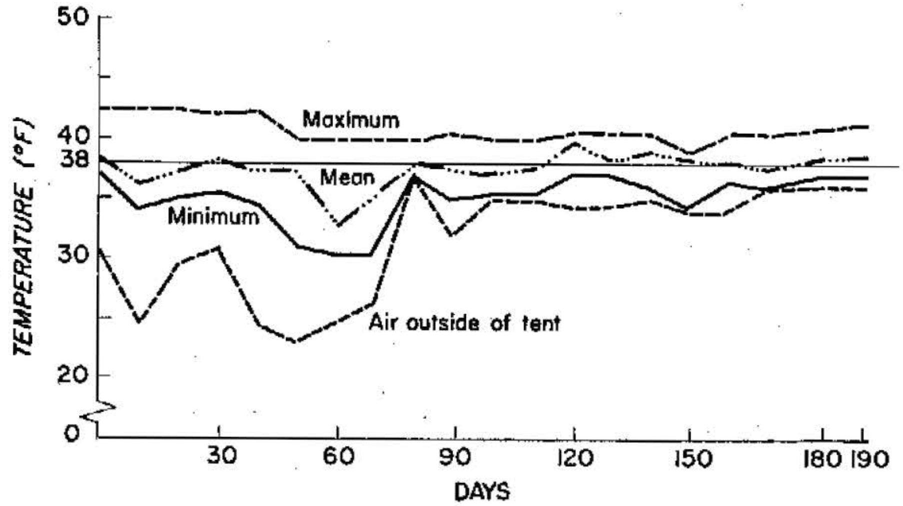

Fig. 3. Fruit temperatures within the tent and air temperature outside the tent during the storage period.

level of 38° F. The maximum and minimum temperatures for the 6½-month storage period (Fig. 3) show that a spread of 8 to 10 degrees occurred during the first 2 months. During this time, a malfunction in the thermostatic control caused unusually low temperatures of the supply air, and manual control was necessary.

Under these conditions, the maximum temperature ranged 4 to 5 degrees above the desired 38° F. This occurred in the bottom layer of fruit at the center of the room (Position 10, Fig. 2). Minimum temperatures during the early portion of the storage period occurred in fruit stacked near the tent walls, especially near the evaporators.

When the temperature control system was repaired, the desired mean temperature for all positions was attained, and maximum and minimum temperatures were held within approximately 3 degrees of the desired level.

Apples at positions 11, 12, 13 and 14 in the tent (Fig. 2) had temperatures representative of the average temperature for all positions. Fruit at positions 1, 2, 3 and 4, although similarly located in the opposite one-half of the tent to positions 11 to 14, had temperatures about 2 degrees above the mean for all positions.

An expression of the temperature conditions for the entire storage period was obtained by multiplying the daily mean temperature in degrees above or below 38° F. by the number of days in storage. (These values are represented in Fig. 5 for comparable conditions at the 14 positions in the tent.) Generally, there were more positions showing a greater number of degree-days below 38° F. than above. This is in agreement with the average temperature plotted in Fig. 3.

Atmosphere Control

Fig. 4 gives the carbon dioxide and oxygen concentrations of the tent atmosphere. The desired levels were readily attained and easily held for the storage period. Gas analysis after sealing the tent showed an initial oxygen content of 18.6 percent and a reduction to the desired 3 percent within 10 days.

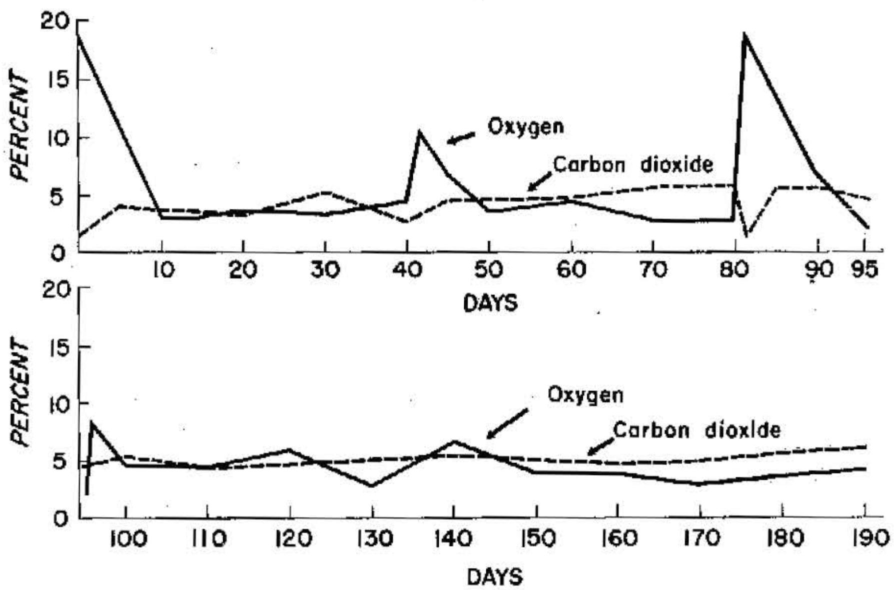

Fig. 4. Oxygen and carbon dioxide concentrations of the tent atmosphere.

Although carbon dioxide absorption was started immediately, the carbon dioxide level was 3 to 5 percent, instead of the 2.5 percent usually desired for the first 30 days of storage. The sudden and large increases in oxygen and simultaneous smaller decreases in carbon dioxide in the second and third months of operation resulted from inadvertently adding excessive quantities of outside air. The subsequent reductions of oxygen were slightly slower than at first, requiring 6 days in the first instance to yield a reduction of 9 percent, and 13 days in the second for a reduction of 15 percent.

TABLE 1—Air leakage of tent and a CA-room sealed by sheet metal lining at several differential pressures

Pressure (inches of water)	Tent leakage (cu. ft. per hr.)	Room leakage(a) (cu. ft. per hr.)
.05	24	26
.10	36	49
.20	54	78
.30	78	111
.40	93	149
.50	108	..
.60	126	..

(a) Pflug, I. J., and F. W. Southwick (1954). Air Leakage in controlled-atmosphere storage. Agr. Eng. 35 (4): 635-637.

Adequate gastightness is also evidenced by the leakage data of Table 1. The tent was more gastight than a metal-lined room tested in Massachusetts and reported (Pflug and Southwick, 1954) to be satisfactorily tight for the CA-storage of McIntosh apples.

Fruit Quality

Upon removal from the controlled-atmosphere in April, the apples were generally sound and of fair market quality. There was excessive moisture accumulation on the fruit at the top of the stacks near the ceiling and in the crates near the sides of the tent. Although no apparent adverse effects on quality were apparent, these apples had to be dried before handling over the grader in preparation for market. The crates near the floor were dry and the fruit showed considerable shrivel.

The occurrence of shrivel and brown core of the fruit upon removal from storage and the development of storage scald during the subsequent holding period at 75°, together with a summation of storage temperatures for the various positions within the tent, are illustrated in Fig. 5.

Shrivel was severe in areas having high temperatures and directly beneath the air purifier (position 6, Fig. 2) where the temperature was generally below 38° F. After 10 days at 75° F., all fruit samples showed shrivel.

Brown core was the most severe for CA-fruit having the largest numbers of degree-days below 38° F. The simulated marketing period

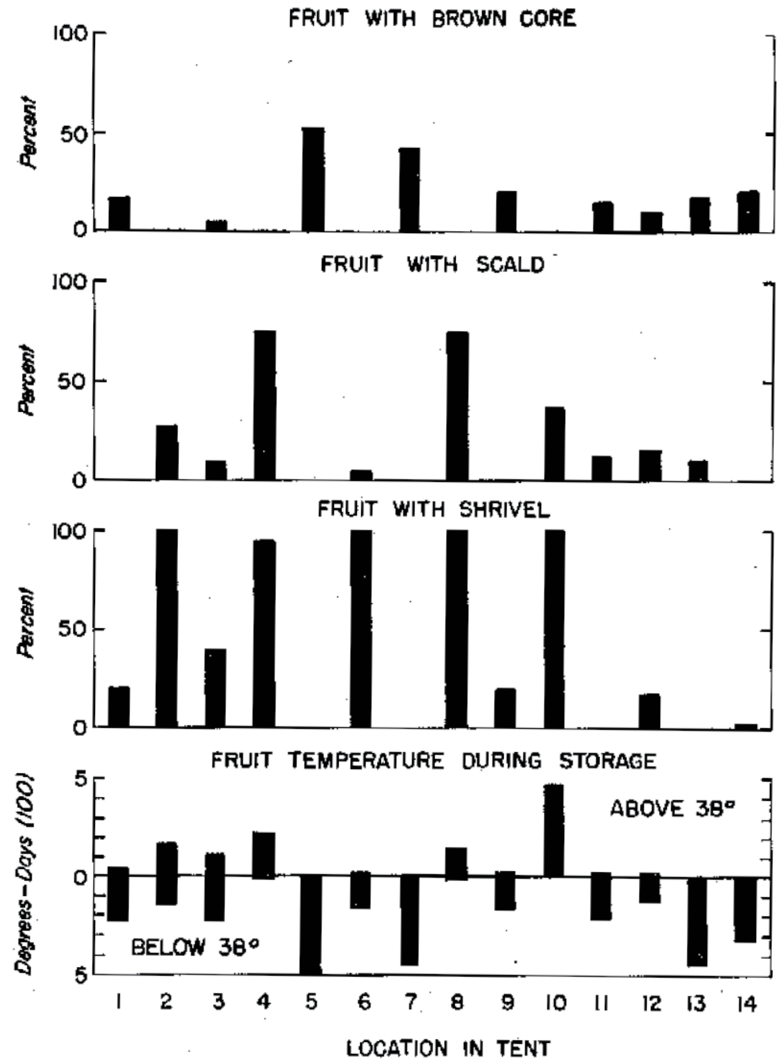

Fig. 5. Quality characteristics and temperatures of McIntosh apples stored at various positions (see Fig. 2) in the tent. Brown core and shrivel were present at the conclusion of storage; scald after 10 days at 75 F°.

following storage did not affect the incidence of this defect. About 80 percent of the apples stored in regular storage at 32° F. had brown core at the end of the storage period.

Storage scald appeared extensively only upon exposure of the fruit to warm temperatures for 10 days after removal from storage.

At this time, 28 to 78 percent of the apples stored in areas of high temperature (150 degree-days or more above 38° F.) were scalded. Scald averaged 20 percent for apples from CA-storage and 100 percent for those from regular storage at 32° F.

Carbon dioxide injury was observed on 1.7 percent of the fruit examined. Most injury occurred as depressed wrinkled areas, sometimes light brown in color, on the nonblushed surface of the apples. Several instances of internal injury (cavities or voids in the flesh) were noted. Damage from carbon dioxide could not be related to temperature conditions.

Decay averaged 1.9 percent in the tent and 5.2 percent in regular storage at 32° F. at the end of the storage period.

Ground color changes from green to yellow during and after storage were variable and showed no particular relationship to storage conditions.

Flesh firmness at harvest averaged 16.9 pounds. The average loss of pressure during storage in the tent amounted to 6.2 pounds, with an additional loss of 1.5 pounds during the 10-day holding period of 75° F. Although there was a greater tendency for fruit stored in the warmest areas to soften, there was no clear-cut relationship of firmness to storage temperature.

Flavor was mild and slightly "carbonated" when the apples were taken from CA-storage, but it became more typical of the variety upon holding in normal air. The fruits were pleasingly edible in that they were crisp and juicy. Slight mealiness developed in all lots by the end of the 10-day marketing period.

DISCUSSION

The vinyl plastic tent, although serving satisfactorily as a CA-chamber for McIntosh apples under conditions of this experiment, offered several problems of installation and operation. Improved tent design to give adequate support for overhead suspension is desirable.

The water trough provided an adequate seal of the tent walls to the floor, but it was probably more costly than the original slide fasteners supplied for this purpose. Possibly, the cost of the trough would be balanced by elimination of the plastic floor covering; however, a storage building floor free of cracks or other openings for gas leakage would be essential.

Several factors contributed to the wide range in temperatures after the thermostat trouble was corrected. Air circulation within the tent was obviously inadequate, since fruit stored near the ceiling and walls were 4 to 10 degrees lower in temperature than fruit stacked at the interior and near the floor. Smock and Neubert (1950) recommend that two sides of each crate of stored apples should be exposed to a 1-inch space for air circulation. Two to four inches of airspace at the floor is also desirable.

The low space factor of 1.8 cubic feet per crate suggests a minimum of airspace, since at least 2.5 cubic feet for each bushel are usually considered essential in regular storage (Marshall, 1951).

It is also likely that relocation of the blower within the tent to assure positive air circulation near the floor would help provide more uniform temperatures.

The noninsulated concrete floor of the storage served as a constant source of heat. Without an airspace between the building floor and tent floor, there was no opportunity to prevent heat conduction into the room. Normally, jacketed rooms have space for the circulation of refrigerated air at all surfaces, including the floor (Lentz and Rooke, 1957). Installation and loading problems made it desirable to eliminate a false floor in the design of the tent.

According to present findings, it is plausible that a tent held at 38° F. could be operated as part of a large room in which commodities are also stored in a regular atmosphere at 32° F. Regardless of whether the tent is used in a separate room or in a room with other fruit, temperature measuring devices should be installed in fruit stacked near the walls and at the center of the load where the lowest and highest temperatures are likely to occur.

The fruit should be cooled to the storage temperature by direct air circulation before closing the tent. If used for storage temperatures near 32° F., positive air movement must be maintained within the tent and close attention must be given to avoid freezing damage to the fruit.

The rapid rate of oxygen reduction within the sealed tent is attributed to the relative gastightness of the tent and to the low space factor of 1.8 cubic feet per bushel for the stored fruit. Using the data of Pflug and Dewey (1956), an allowable leakage rate of approximately .04 air changes per 24 hours would have been permissible for the tent.

Since the tent is flexible, differential pressures greater than 0.001 or 0.002 inch are unlikely unless it is severely inflated or deflated. Considering a differential of 0.002 and extrapolation of the data from Table 1, the leakage rate would be about 0.017 air changes per day. This would have permitted satisfactory atmospheric control with a space factor up to 3.5 cubic feet per bushel.

Many of the wide differences in quality of the stored fruit are attributable to variations in temperature and air circulation within the tent. Excessive fruit shrivel near the floor and at the interior of the tent was associated with high fruit temperatures and caused by high vapor pressure differences between the apples and the tent atmosphere (Smock and Neubert, 1950).

Brown core is known as a low-temperature disorder, and storage temperatures of 36 to 40° F. are recommended for its prevention in McIntosh apples, even in controlled atmospheres (Smock and Van-Doren, 1941).

The development of storage scald is retarded but not prevented by CA-storage and high storage temperatures generally cause an earlier manifestation of scald than do lower temperatures (Rose, McColloch and Fisher, 1951). Fruit temperatures as low as 32° F. in the tent (Fig. 3), however, did not cause excessive carbon dioxide injury, even though they occurred when the carbon dioxide was maintained at 5 percent (Smock and Neubert, 1950).

It is estimated that the apples were stored in controlled atmosphere in this tent at a cost of about 24 cents per crate (bushel) over the cost of regular refrigerated storage. This includes the tent cost depreciated over 5 years, the additional equipment and power costs for CA-storage, and the loss in storage space due to the excessive airspace between the tent and the storage room walls.

By using a larger tent, an additional 500 bushels of fruit could have been stored; however, wider spacing of the crates to facilitate better air circulation would balance the space gained by better designing of the tent to fit the storage room. Dalrymple (1956) estimates that the cost of storing apples in permanent-type rooms in New York State is 18 to 40 cents more per bushel than in regular storage.

SUMMARY AND CONCLUSIONS

A vinyl plastic film tent installed in a commercial refrigerated storage room served satisfactorily as a controlled-atmosphere storage chamber for 2,460 bushels of McIntosh apples for 6½ months. The jacketed system of refrigeration circulated cooled air over the ceiling and around the outside of the tent. A carbon air purifier provided air circulation within the tent.

Although average fruit temperatures of approximately 38° F. were attained, variations of plus or minus 5 degrees were responsible for quality depreciation due to shriveling, susceptibility to storage scald, and the development of brown core. Effective development and regulation of 5 percent carbon dioxide and 3 percent oxygen were realized in the tent atmosphere. Good atmospheric control was attributed to the low leakage rate of the tent and the small space factor provided for the fruit.

The estimated cost of CA-storage, in addition to that of regular refrigerated storage, was 24 cents per bushel for the fruit stored in this test.

The results indicate that a tent can be satisfactorily used for the CA-storage of apples. It appears that its use should be limited to temporary storages, to conditions where a sheet metal lining is impractical for providing the necessary gas seal, and to installations where large rooms are partitioned into several CA-chambers.

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