Construction for Controlled-Atmosphere Apple Storage

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Refinements in regular storage techniques as well as special construction features and equipment constitute the principal requirements for adequate controlled-atmosphere storage of apples in Michigan.

MOST Michigan apples are stored at the orchard in structures built and operated by fruit growers. Whereas many farm structures are becoming simplified and less costly in construction, the trend is the opposite for fruit storages. More expensive and complex storages are necessitated by advanced techniques such as the controlled atmosphere method of storing apples. Controlled atmosphere storage is becoming widely accepted for apples since it provides better preservation of quality; also it controls certain storage disorders, such as brown core of McIntosh and spot and soft scald of Jonathan apples which are often severe in regular refrigerated storage.

Controlled atmosphere (CA) storage requires low temperatures (32 to 38 F, depending on varieties) and modification of the oxygen and carbon-dioxide levels of the atmospheric gases surrounding the fruit. The physical requirements for attaining these conditions are discussed in this paper under the heading of structure, gasproof lining and seal, refrigeration system, and auxiliary equipment.

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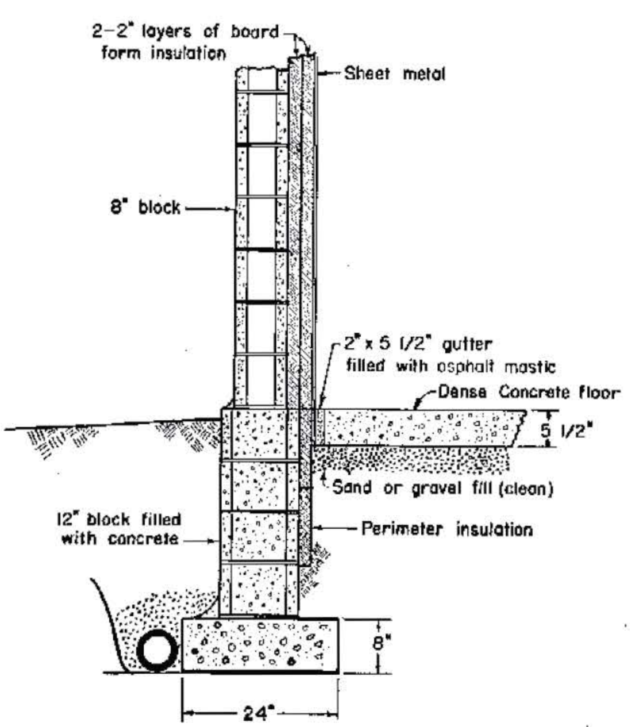
The Storage Structure

The insulated structure is the basic component of the CA storage. Since apple storages are an integral part of the fruit farm operation, the size of the structure will depend upon the nature of the orchard operation and the grower's interest in utilizing it as a marketing tool. Rooms of 10,000 to 12,000 bu capacity are ideal in size for most operations since they can be readily loaded, economically operated and quickly unloaded once the room is opened. Growers of large quantities of apples utilize buildings with several rooms as a means of providing the required capacity, for storing several varieties, and for lengthening their market period for the apples.

Michigan storages are designed for fork-lift truck operation with floors at ground level, doors 5 to 6 ft wide and 8 to 9 ft high, and minimum ceiling heights of 18.5 ft. Standard practice is to stack the bushel crates of fruit on pallets, five crates high, and then stack three pallets high (total of fifteen crates) in the storage, or if the fruit is in 30-in. bulk boxes, they are stacked six boxes high. At least one foot of clear space above the boxes of fruit is required for adequate air movement.



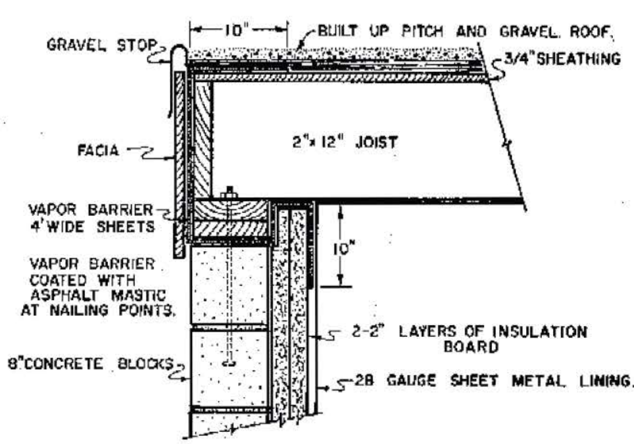


Fig. 2 *(Above)* Roof-wall juncture showing vapor-barrier location for flat roof

Fig. 1 *(Left)* Floor-wall juncture detail showing method of forming gas seal

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Michigan storage-construction recommendations do not include insulation in the floor. A concrete floor of 4-in. minimum thickness is poured on a sand or gravel fill that is well-drained and firmly compacted. Two inches of perimeter insulation extending 1 to 2 ft below the top of the floor, as illustrated in Fig. 1, is recommended. Where single-wall construction is used, the wall insulation is a continuation of the perimeter insulation. Perimeter insulation for the storage having double-wall construction can be provided by extending the double wall 12 in. below the bottom of the floor.

Walls of the building may be constructed with a single wall of concrete blocks insulated with a board-form insulation, or with a double or cavity wall insulated with fill-type insulation. They may also be constructed by the tilt-up method(4)* where the concrete is poured and compacted into a dense monolithic mass in a horizontal position and then erected by suitable power equipment to form the vertical walls. Board-form insulation is utilized in this method of construction. The thickness of the insulation will vary with the material used but should be equivalent to 4 in. of corkboard.

For the single-room structure the shape of the roof (arch, gable or flat) is not important; however, the addition of a second room or packing house to a gable or arch-roof structure presents problems of attachment and maintenance. Where the storage plant is likely to undergo further expansion, a flat roof is usually desirable.

Steel or concrete roof construction is more expensive than wood, but has the advantages of being fire-resistant and rotproof. For rooms up to 24 ft wide, wood joists that extend from wall to wall are used. Wood joists supported on I beams can be used for rooms of greater width. Flat, arched or gable-type steel trusses can be used with either wood or metal joists for large rooms. Ceilings require 4 to 5 in. of insulation, which may be applied in granular, blanket or board form.

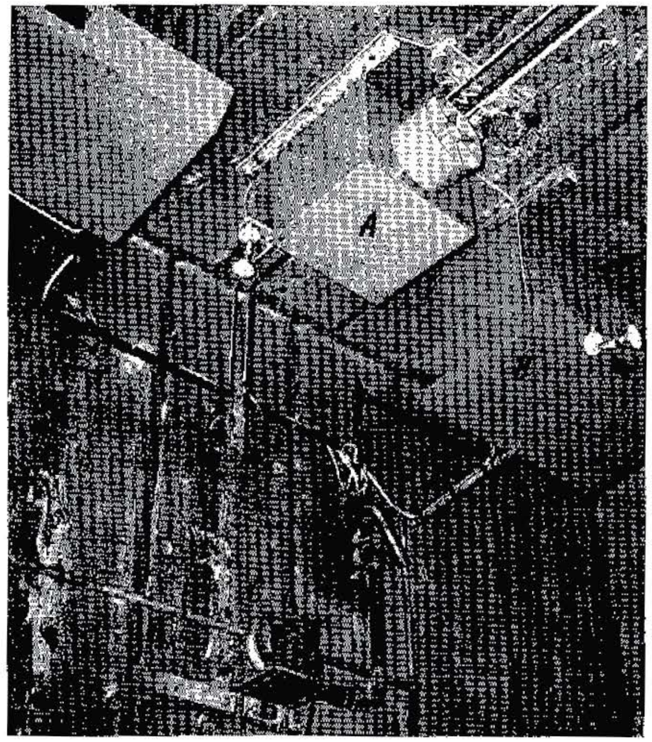
The external vapor barrier is essential in the controlled-atmosphere storage since the internal gas lining is resistant to the flow of water vapor as well as carbon dioxide and oxygen. A poorly applied or permeable external vapor barrier will allow moisture to accumulate in the space between the outside and internal vapor barrier. This problem is minimized if a board-form insulation impervious to vapor penetration is used. Moisture accumulation is most serious in fibrous or granular insulation materials whether applied as fill or in bats.

A commercial grade pitch and gravel built-up roof is gastight and serves as the outside vapor barrier for the ceiling, but the ends of the supporting joists are difficult to seal. A method of providing an adequate moisture barrier to the ends of wood joists is illustrated in Fig. 2.

The cost of the storage structure generally ranges from one to two dollars per bushel of storage space and is about one-half the total cost of the completed storage. The most economical type of construction will utilize wood in a great many places, while the most expensive construction is a fireproof structure of masonry and steel. Since the storage structure is a functional building, the builder should be cautious of false economies as well as expensive frills. The op-

*Numbers in parentheses refer to the appended references.

Fig. 3 Interior of sheet-metal-lined CA storage. A, carbon air purifier; B, refrigeration evaporator, and C, air blower for carbon dioxide absorber



timum building design will provide the desired longevity at minimum per-bushel storage cost.

The high humidity conditions required for satisfactory fruit storage are favorable for the development of rot and accompanying deterioration of the building; therefore, a wood structure may be of considerably shorter useful life than a steel and masonry structure. Wood, when used, should be of a decay-resistant variety like redwood and properly treated with a preservative prior to installation.

Sealing Controlled-Atmosphere Storage

The gas seal is critical for the successful operation of the CA storage. Since complete air tightness is not feasible, Pflug and Dewey(3) calculated the rate of leakage of the CA storage that can be tolerated and still permit development of a desired atmosphere as a function of the fullness of the room and the rate of respiration of the fruit. The maximum leakage allowable for a CA room may be as low as 0.028 air changes per day, or one air change each 35.7 days. The gas seal must maintain this low leakage rate against continuous pressure differentials that may be as high as 0.1 in. of water gage(8). A breather bag is a practical necessity in small rooms to keep these pressure differentials to a minimum(1, 2).

Although many materials can be used for the gas seal, galvanized sheet steel is generally recommended(7). The interior of a sheet-metal-lined room is illustrated in Fig. 3. Flexible materials, such as paper and plastic films, must be glued in place with the joints taped together. Their lack of rigid strength makes it difficult to attain an adequate seal. In 1958, however, two 12,000-bu CA rooms were successfully lined with a mylar-aluminum foil laminated film adhered to board-form polystyrene insulation with a cold asphalt adhesive.

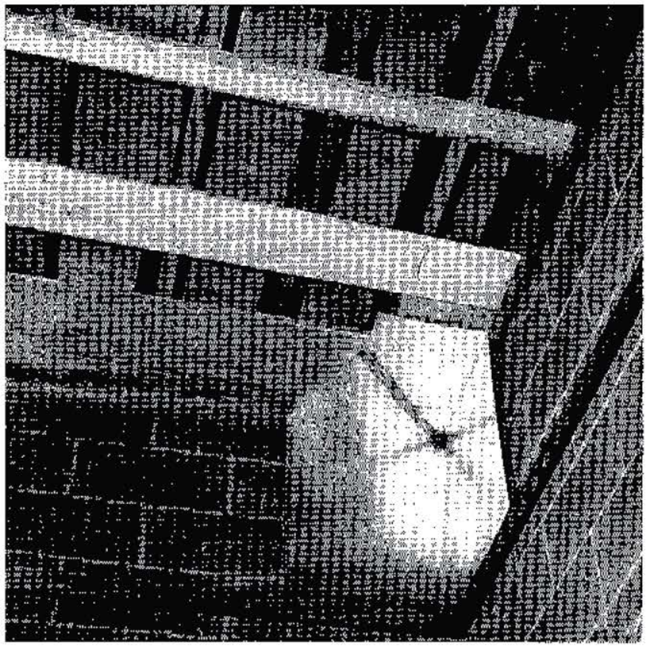


Fig. 4 Prefabricated sheet metal corner

Galvanized sheet steel (28-gage) is used to provide the gas seal in most Michigan CA storages. The sheets of steel are lapped at least 1½ in. and the joint is sealed with nonhardening, odorless caulking compound (such as Pecora) within the lap joint plus an external covering of the nail heads and the exposed edges of the joint.

The sheet metal is nailed to ¾-in. furring strips. Where concrete block walls with board-form insulation are used, the furring strips may have to be anchored through the insulation to the blocks. Another method of attaching the furring to board-form insulation is to route out an area of insulation equal to the area of the furring strip and then glue the furring strips to the insulation, after which the sheet metal can be applied against the insulation. All wood furring should be treated for decay resistance.

Construction of the gastight lining at the ceiling is simple where wood joists are used without posts or beams in the room since the sheet metal is applied directly to the bottom of the joists as shown in Fig. 2. A two-by-four is toenailed between the joists at the juncture of the steel sheets to insure a tight joint. The joints in the ceiling are caulked in the same manner as in the walls.

A prefabricated corner, as shown in Fig. 4, will simplify construction and assure a good seal in these areas.

Steel rafters or ceiling joists supporting a sandwich-type board-form insulation roof deck or a steel roof deck present special sealing problems. A false ceiling can be constructed at the lower edge of the joists to support the sheet-metal ceiling, or the gastight built-up roof at the top of joists can be joined tightly to the wall seal.

Experience gained through experimentation during the past few years indicates that a dense concrete floor is sufficiently resistant to air movement to serve as a seal. The floor, however, must be free of open cracks or other breaks. Care must be taken to join the dense concrete floor to the wall steel with an airtight juncture. One method of sealing this juncture is illustrated in Fig. 1, whereby a 1¾-in.-wide gutter is formed between the perimeter insulation and the edge of the floor into which the wall steel is extended at least 3.5 in. To complete the seal, the gutter is filled with an asphalt mastic that will remain flexible at 32 F.

Once the room is filled the seal is completed by bolting a metal door against the wall steel. The door normally contains a window for observing a thermometer and the fruit inside the room. A hinged porthole is also desirable for removal of fruit samples and as a vent when air is added to the room.

Refrigeration

Retention of fruit quality in a controlled-atmosphere storage is dependent upon low temperatures and high humidities as well as the modified atmospheres. The CA storage must be adequately refrigerated to rapidly remove the field heat during the loading period and designed to maintain a high relative humidity (90 to 95 percent) at 31 F. Adequate air distribution for rapid cooling and uniform temperature of the entire mass of fruit is essential. The refrigeration system should be provided with instrumentation that will control the temperature in the storage within narrow limits (±0.5 F).

The refrigeration system should be equipped with positive defrosting evaporators. They are essential for rapid cooling of storages operated at temperatures above freezing as well as for storages in which the fruit is held at 31 to 32 F. Water defrost evaporators of the ceiling-mounted and floor-mounted types are being used successfully; however, an elaborate trapping system is necessary to allow the water to drain from the evaporator without air leakage. The temperature of the defrost water must be 50 F or below to prevent excessive pressures developing in the room from vapor evaporation during defrosting. Electric defrost ceiling-mounted evaporators also have been proven satisfactory. These units do not require additional plumbing, but have the disadvantage of requiring a heavy electrical service. A few brine-spray evaporators are used and while these operate satisfactorily, they are unpopular in Michigan because of the rather high maintenance costs due to the corrosive action of the salt.

Regardless of the defrost system, the evaporator must have adequate cooling surface so that a high humidity is maintained even during the cooling-down period. Once the fruit is cooled, a properly adjusted suction-pressure regulating valve will aid in maintaining the humidity (up to 95 percent) that is needed to avoid fruit shrivel.

Regular inspection of the evaporator surfaces to ascertain adequate defrosting is made possible by means of strategically located mirrors or special windows. An evaporator is relatively easy to defrost when there is only four to six hours accumulation of frost, but once an evaporator is allowed to become plugged or frozen solid, many hours may be required to melt the ice. A frost-clogged evaporator may severely reduce the humidity in the storage room. This is especially true where multiple evaporators are used since one evaporator may become clogged and cause the other evaporators to operate on too wide a temperature difference.

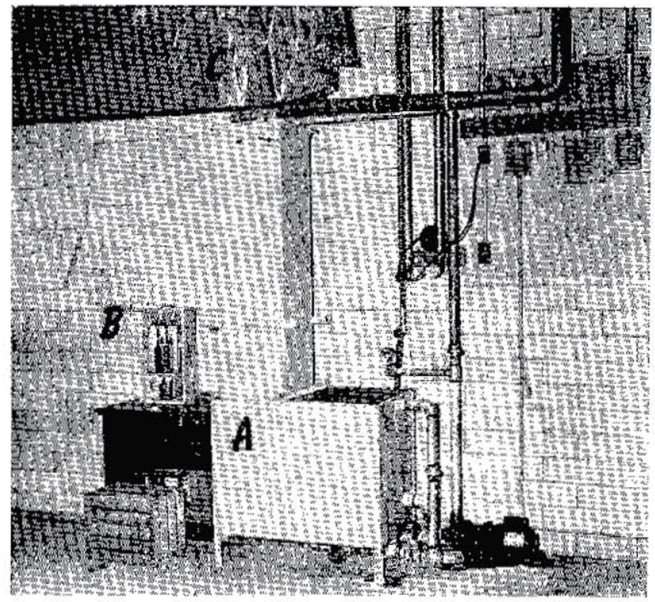
Auxiliary Equipment

Additional equipment required for the CA storage are: the gas analyzer for measuring the concentrations of carbon dioxide and oxygen of the room atmosphere, an absorber to remove carbon dioxide from the room, and a small air blower for adding air (oxygen) to the room. A typical arrangement of these items outside the CA room is shown in Fig. 5.

It is imperative that all devices operate satisfactorily. The gas analyzer should be checked frequently for leaks and adequate strength of the measuring solutions. Spare parts should be accessible in case of breakage so the unit can be repaired without losing control of the storage room. Daily removal of carbon dioxide from the storage room is essential since this gas is constantly produced by the apples. At present carbon dioxide is being removed by chemical reaction with a solution of caustic soda (NaOH) circulated through an absorption tower. For a detailed description of the operation of air absorber and the characteristics of carbon dioxide absorption, references 5 and 6 should be consulted. Several new types of absorption systems are in the developmental stage and it is anticipated that caustic-soda absorbers may be replaced by a more simple carbon-dioxide absorption system.

The addition of outside air to the room is a routine duty during the storage season to prevent the oxygen from being depleted below the critical 3 percent level needed for the fruit. Operators frequently overlook the need to vent the room in order to add air even though the porthole in the metal door is provided to serve this purpose.

Fig. 5 Auxiliary equipment: A, absorber; B, gas analyzer; C, breather bag



Operating the CA Storage

The operation of a CA fruit storage is considerably more exacting than a regular storage. With the regular refrigerated storage short-time mechanical troubles may cause only minor changes in the fruit. For example, a refrigeration breakdown where a non-toxic refrigerant is used will have little effect other than a more rapid ripening of the fruit than would occur under normal refrigeration conditions. The grower can be away from his storage for several days at a time with little cause to worry. The controlled atmosphere storage operates under conditions infinitely more critical than the regular refrigerated storage. The oxygen level of 3 percent and the carbon dioxide level of 5 percent employed for the Jonathan and McIntosh varieties of apples are the minimum and maximum levels, respectively, that can be tolerated without damage. Constantly oxygen is consumed and carbon dioxide is produced by the natural respiration processes of the apples. Consequently there is a tendency to decrease the oxygen and increase the carbon dioxide in a CA storage to levels which will severely damage the apples beyond salvage within a few days.

The controlled-atmosphere storage requires daily care. The operator must analyze the gas in the storage at least once every 24 hours to determine the amounts of carbon dioxide to be removed and oxygen to be added. The quantities will vary from day to day depending upon the respirational activity of the fruit and the fluctuations in gas leakage due to changes in weather conditions, especially barometric pressure and wind.

Temperatures should be closely observed and regulated, particularly to avoid the development of low temperatures in isolated non-observable areas of the CA storage room. Some apples, such as the McIntosh variety, are susceptible to carbon dioxide injury when subjected to temperatures below the recommended 38 F. Other varieties are stored at 32 F and can be readily injured by freezing should the temperature drop several degrees.

It is common practice to place a thermometer in front of the window of the metal door to enable the operator to determine the temperature at this point. One or more distant-reading thermometers, to ascertain the temperature within the stacks of fruit, are advisable. Growers with two or three controlled-atmosphere storage rooms sometimes use a temperature-indicating-potentiometer thermocouple system to determine the temperature at various locations in their rooms.

Summary

Controlled atmosphere storages for apples require refinements of regular storage techniques as well as special construction features and equipment. The storage building must be structurally sound, well insulated, and properly refrigerated. A gas seal is required to make the room sufficiently tight that the desired storage atmosphere can be developed and maintained. A carbon dioxide absorber, gas analyzer, and a small air blower are needed for determination and maintenance of the proper levels of carbon dioxide and oxygen.

Once properly constructed and equipped, the success of the CA storage is dependent upon exacting daily operational procedures.

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