Storing Apples in Controlled Atmosphere
Advantages of Controlled Atmosphere Storage

. The storage life of certain varieties of apples is markedly increased by this type of storage as compared to ordinary refrigerated storage. Apples of high quality can usually be sold to advantage late in the spring or summer.

. Apples out of CA storage have a longer shelf life. This is probably the most striking effect of this type of storage. Even McIntosh should remain marketable for a week or more in a retail store in May. Delicious remain marketable somewhat longer.

. Scald is reduced in intensity. Apples can scald in CA storage but, in general, the scald is about one-third of that on comparable apples in regular storage.

. Varieties such as McIntosh that are subject to low temperature disorders such as brown core can be stored at a higher temperature to avoid the disorder and still be firm upon removal from storage. Disorders such as Jonathan spot are prevented.

. Mice and rats cannot live in this type of storage.

Disadvantages of Controlled Atmosphere Storage

. The room is kept closed up until it is time to remove the apples for sale. The operator must wear an air mask or an oxygen mask when he goes into the room to make repairs or for any purpose.

. Not all varieties can be stored in the same room. To be in the same room, the varieties must have the same time of picking and have the same temperature and atmospheric requirements.

. It is more expensive than conventional cold storage.

. Storage until late in the season involves a certain speculative risk.
STORING APPLES IN CONTROLLED ATMOSPHERE

By Archie Van Doren*

Introduction

Washington grown apples can be held in regular cold storage for several months before the aging process severely impairs their eating quality. Cold storage alone is not enough to extend "harvest freshness" and prime eating quality of the fruit into the following summer. Delicious apples develop mealiness and lose crispness late in the regular storage season. It is in late April through August that good tasting, crisp Delicious apples demand a premium price if they have real "harvest freshness" and crisp, juicy eating quality.

Apples in controlled atmosphere storage (hereafter referred to as CA) in Washington State totaled 23,000 bushels in 1958-59, 174,000 bushels in 1959-60, and over 700,000 bushels in 21 separate CA rooms in 1960-61. The total CA storage capacity of the United States in the fall of 1960 was 4,700,000 bushels.

CA storage of apples to extend the period of prime eating qualities of this fruit is a logical supplement to cold storage practices in Washington State where larger crops of high quality apples are expected in the years to come.

Principles of CA storage were discovered by research workers in England. This publication is based on research done by the author at Cornell University and by additional studies on construction and management in Washington State.

What is Controlled Atmosphere Storage?

Fruits are living things even after being separated from the tree they continue to respire as they oxidize sugars. They use oxygen from the air and in turn produce carbon dioxide, heat and some water vapor.

Rapid respiration means quick fruit deterioration. To extend the period of good quality, it is necessary to reduce the respiration rate. The first means of reducing it is to lower the temperature of the fruit but not to the point where it freezes or suffers from low temperature disorders.

The second means is to reduce the amount of oxygen available to the fruit. Although accumulations of carbon dioxide also tend to slow down respiration they tend to induce mealiness in Delicious if present in quantities more than $2\frac{1}{2}$ to 3 per cent.

A combination of these principles and the use of such aids as activated carbon filters for filtering out foul or contaminating odors from the storage air are involved in CA

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storage. The relative humidity is kept above 95 percent by addition of water in vapor form to the storage air and by suitable adjustment of refrigerant gauge pressure to avoid shriveling of the fruits during prolonged storage periods.

The atmosphere in ordinary air is composed of 78 per cent nitrogen, 20.8 per cent oxygen, 0.03 per cent carbon dioxide, and small percentages of other inert gases. After sealing a gas-tight storage room of fruit the constituents of the atmosphere changes. As the fruit respires, the oxygen is consumed and would be completely exhausted if the storage operator were to make no provision for supplying fresh air. Since the fruits give off volumes of carbon dioxide about equal to those of oxygen consumed, carbon dioxide in the room could eventually build up to about 21 per cent. Such a high content of carbon dioxide and oxygen starvation is very harmful to the fruit. But if you hold the carbon dioxide at the desired concentration by scrubbing out the excess from the air in the storage room, the concentration of oxygen then continues downward until it reaches a point where you wish to hold it. You simply introduce into the room as much outside air as needed then to keep the oxygen up to the desired percentage.

Varieties differ in their oxygen, carbon dioxide and temperature requirements for best storing. For instance, McIntosh store well at 2.5 per cent oxygen, 2-3 per cent carbon dioxide and 38° F. temperature. Washington Delicious keep best at 2.5 per cent oxygen, 1 to 1.5 per cent carbon dioxide and 30° F. core temperature.

In the actual operation of a CA room filled with apples, the oxygen level is slowly reduced by the process of respiration in the gas-tight room. After the oxygen has been reduced to the desired point, it is necessary to supply some fresh air from the outside in order to avoid suffocation of the fruit. Therefore, daily or more frequent, air analyses must be made. As the oxygen drops slightly below the desired percentage, fresh outside air is blown into the room and excess pressure in the room is released through another opening at the same time. With a little experience you can quickly determine the time required to blow in the volume of air necessary to raise the percentage of oxygen to the desired fraction of a per cent.

As the carbon dioxide is washed out of the atmosphere in the CA room, the loss of volume can be replaced with compressed nitrogen released at a rate sufficient to keep a plastic bag attached to the room partially inflated. This may be necessary only during the first few days of operation while you are trying to get the oxygen level down to the desired percentage quickly.
Table 1. Atmospheric and temperature requirements for CA storage in Washington State.

<table>
<thead>
<tr>
<th>Response</th>
<th>Apple Variety</th>
<th>Temperature</th>
<th>% Carbon Dioxide</th>
<th>% Oxygen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>Standard Delicious</td>
<td>30°-31°</td>
<td>1.5</td>
<td>2 1/2-3</td>
</tr>
<tr>
<td>Excellent</td>
<td>Red Delicious</td>
<td>30°-31°</td>
<td>1.5</td>
<td>2 1/2-3</td>
</tr>
<tr>
<td>Good</td>
<td>Golden Delicious</td>
<td>30°-31°</td>
<td>1.5</td>
<td>2 1/2-3</td>
</tr>
<tr>
<td>Good</td>
<td>Rome Beauty</td>
<td>30°-31°</td>
<td>1-5</td>
<td>2-3</td>
</tr>
<tr>
<td>Good</td>
<td>Stayman Winesap</td>
<td>30°-31°</td>
<td>1-5</td>
<td>2-3</td>
</tr>
<tr>
<td>Good</td>
<td>Jonathan</td>
<td>30°-31°</td>
<td>1-3</td>
<td>2-3</td>
</tr>
<tr>
<td>Good</td>
<td>McIntosh</td>
<td>38°</td>
<td>2-3</td>
<td>2-3</td>
</tr>
<tr>
<td>Good</td>
<td>Yellow Newtown</td>
<td>38°</td>
<td>5</td>
<td>3</td>
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</tbody>
</table>

Handling Fruit Prior to Storage in CA

Maturity

For best storage life and good quality after storage, apples must be mature enough to avoid storage scald but firm enough to insure good eating quality after a long storage period. For Delicious, trees of medium vigor and with a full crop, this stage of maturity can occur at about 140 to 145 days from full bloom. This period quickly passes after 150 days from full bloom and a stage of over maturity and watercore develops making the fruit unsuitable for CA storage. Therefore, prompt picking and movement into the cold storage rooms are essential.

Prompt Storage

Pick and move the fruit into the CA room on the same day. Avoid any delay or setting in the hot sun. Refrigeration capacity should be such that the rate at which you load the room will permit you to achieve a core temperature in the apples of 32°F. within 72 hours or less. Your rate of loading should not exceed your ability to show 32°F. air temperature in your storage room at some point during each 24 hours during the time you are filling the storage. Several very fine CA rooms have installed close to one ton of refrigeration capacity for each 1,000 bushels of storage capacity. This enables the equipment to provide proper temperature and higher humidities by means of higher back pressures of the refrigerant gas in the diffusers. Fresh water defrost is desirable in as much as it minimizes corrosion and helps maintain high humidity.
Any delay in moving the fruit into the cold rooms or delay in getting the core temperature down to 32°F simply increases the hazard of storage scald and dissipates the potential storage life of that fruit. Prompt movement to storage and speedy cooling justifies your most careful planning and judicious use of refrigeration facilities. For each 10 hours of delay between time of picking and movement of the fruit into the cold storage room, the percentage of storage scald that may develop on your apples, can amount to from 3 to 10 per cent. One way to determine the amount of storage scald that will develop on a given lot of fruit is to remove test samples of fruit from storage at mid season and hold it for one week at 70°F. Any scald that is going to develop will show up with this test.

**Careful Handling**

Only crops of good quality and high percentage of best grade fruit should be picked for CA storage. Light crops; crops from a long drawn out bloom period; high nitrogen level crops or hail damaged crops are all unsuitable for this expensive premium type storage. Careful picking, hauling and stocking in the CA rooms are the best way to safeguard the fruit. Avoid keeping sunscalded or water-cored fruit by picking it off the trees for immediate sale. Don't contaminate a CA room with a small proportion of overripe fruit. This simply increases the scald hazard of the better fruit and like a "rotten apple in a barrel" it may adversely influence the rest.

**Filling the Room**

The size of your room is gauged by the quantity of fruit you can get off the trees and promptly move into storage. The room should be full and ready to seal up within 8 to 10 days after the first fruit is harvested and brought in. Rapid filling and closing of the room is important, but it is more important to cool down the fruit properly.

Prompt closing of the room aids in a rapid oxygen drop. It is during these first few days that compressed nitrogen gas can be used most effectively to replace the volume of carbon dioxide scrubbed out of the storage atmosphere. A slight positive pressure of nitrogen flowing into the breather bag attached to the CA room prevents oxygen from the outside being drawn into the room either as the result of air pressure variation caused by the refrigeration equipment or the loss of carbon dioxide removed by the scrubber.

In loading the room, fill it until only 4 or 5 inches of space is left around all walls and a 6 to 10-inch aisle space for the returning air to be drawn to the suction side of the diffuser. A careful arrangement of the pallets, bulk bins, or boxes is necessary to insure proper air movement through the stacks and past each container.

A rate of air flow past each package during the removal of field heat of not less than 75 linear feet per minute is desired. Diffuser blowers that move one cubic foot of air per minute for each bushel of fruit capacity of the room do a good job of cooling the fruit and moving the air. One-half this rate of air movement past each
package is sufficient during the long storage period. A two speed motor or a change of pulleys on the blower can accomplish this. The slower speed of air movement must be great enough to prevent temperature stratification or air stagnation. Head room above the fruit stacks need only be enough to permit the mixing and flow of air across the top and down the walls. Any extra space is wasteful and simply means more oxygen to be removed by the fruit.

To prevent freezing of fruits in the top boxes, place heavy wrapping paper over the bins or boxes and tack it down with slats so it won't blow off. This can be nailed on the top of the container before it is lifted into place with a fork lift. Usually paper on top of the fruits, one-third of the way across the storage room, is all that is necessary. Be sure to cover those areas directly in front of the blower or duct openings. Avoid stacking high enough so that the fruit is in the direct blast of the cold air. Keep the level of fruit a few inches below the rapidly moving cold air blast.

A room that is not well filled is slow to come down in oxygen. It will not qualify as a CA storage if the oxygen is not reduced to 5 per cent within 20 days after closing the room. Fruit stored at 32°F uses less oxygen than fruit stored at 38°F. Therefore in Washington State where we need to use core temperatures of 30°F to 31°F for best keeping, in contrast to Eastern McIntosh and the Yellow Newtows of California stored at 38°F, it is imperative to have full and gastight rooms.

Mixing Varieties

As shown on Table 1, certain varieties have the same temperature and atmosphere requirements and can be stored together.

When harvest dates and fruit maturity coincide, more than one variety can be stored together. Such varieties as Standard Delicious, Red Delicious, Golden Delicious, Rome Beauty, and Winesap can go into one room, but it is unusual for Winesap to be mature enough to be included unless hauled in from an earlier district. If varieties are included in a CA room that are themselves tolerant of high concentrations of carbon dioxide along with other varieties such as Delicious or Golden Delicious that are not tolerant, then the lower concentration of carbon dioxide required by the Delicious should not be exceeded. For instance, it would be unwise to exceed 2 1/2 per cent carbon dioxide on Delicious. Delicious respond best to carbon dioxide ranges of less than 2 per cent.

Packing Before or After Storage

Many growers will prefer carefully to select certain blocks of trees for harvest and storage in CA of field run fruit. It takes time to grade and sort fruit before storage and this prevents prompt storing and cooling. To avoid storage scald, it is best to have the fruit in the cold storage rooms and bring the core temperature down below 32°F. within 72 hours after picking. Every hour delay from the moment the fruit is picked from the tree until it is chilled down to proper temperature
increases the hazard of serious storage scald. This rule applies to all apples on the proper, early side of maturity. With overmature varieties such as Golden Delicious soft scald becomes a hazard, and such overmature fruit is not suitable for CA storage.

Containers

The chief consideration in a container is that ample ventilation be provided and that the high relative humidity will not cause damage to the container. Standard wood boxes or lugs, as well as bulk bins, are satisfactory.

Golden Delicious have showed compression bruising on the bottom layer after long storage periods when stored in bulk bins with a fruit depth of 26 inches. No such bruising was noted when the fruit depth was 12 inches or less.

Polyethylene box liners should not be used in CA storage because of the high percentage of decay which results on the fruit in such a tight film.

Operating Temperatures and Relative Humidity During Loading

With all varieties going into CA, the field heat should be removed as rapidly as possible. Since the fruit freezes at about 28.5°F, the flesh temperature should be kept above this point. A flesh temperature of 30°F. is most desirable and should be achieved as quickly as is practical. The engineering design and refrigeration installation should provide rapid cooling of fruit at the desired rate of loading and, at the same time, it should not freeze some of the fruit or dry it out.

Air velocities should not be less than 75 linear feet per minute past each fruit container. One cubic foot of air per bushel per minute is usually ample blower capacity. After initial "cool down" this rate can be reduced by one half.

Relative humidity should be at least 85 per cent during loading. After loading and after all fruit is below 32°F. core temperature, the humidity should be around 95 per cent. Field run fruit can be wet down with a hose each day while loading. This helps saturate the wood in the containers which takes up about one pound of water per bushel box stored. Water atomizers may be used to advantage during the loading period, but as temperatures fall below 32°F. it is best not to keep adding more water because it simply freezes a lake of ice on the floor and the boxes may freeze in a solid block, causing encasement of the fruit and suffocation due to lack of air circulation around the fruit. At 30°F. fruit temperature the apples do not freeze, but free water around them does.

A properly engineered refrigeration system that provides high enough back pressure on the refrigerant will enable the maintenance of the desired high relative humidity during the storage season after the initial cool down period. See Table 2.
Table 2

<table>
<thead>
<tr>
<th>Freon 12 (psig)*</th>
<th>Coil Temp. °F.</th>
<th>Ammonia (psig)*</th>
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</tr>
<tr>
<td>37.0</td>
<td>40</td>
<td>58.6</td>
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*Pounds per square inch gauge pressure.

Construction of the Controlled Atmosphere Room Size

The size of the CA room is controlled by such considerations as the ability of the operator to fill with suitable fruit in a period of time usually not to exceed 10 days. Expeditious harvesting, loading, cooling down of fruit and sealing the room are prime considerations. A small operator may want only a few thousand bushels of space. However, many Washington operators have rooms from 25,000 to 50,000 bushels each. Several operators have more than one room to facilitate loading and closing as well as to provide a more orderly, extended marketing period, each room being opened as the marketing demand warrants.

Practically no ripening activity takes place with good fruit in a well operated CA room. Fruit from rooms opened in the tenth month after closing is in just as good condition as fruit from rooms opened on the sixth month after closing.

The marked residual effect on the fruit of having been stored in CA insures adequate time to unload the room, grade and sell the fruit over a month's time and still have it in the consumer's hand in excellent eating condition. The shelf life of CA fruit following storage is one of the most valuable benefits coming from this unique type storage.
The insulation requirements of CA storage rooms are the same as for standard refrigerated storage construction. The most important difference is that CA storages require **perfect vapor seals** placed on the outside of the insulation. Any water vapor penetration will be stopped at the inner gas seal inside the CA room. In a number of poorly constructed CA rooms, wet insulation and rotten timbers have resulted because a **perfect vapor seal** was not installed outside the insulation.

### Making the CA Room Gastight

A gastight room is a basic requirement. Many different ways are being found to make storage rooms gastight and the prospective operator will need to evaluate which way suits his requirements best.

A good gastight floor is required and the method of sealing is now fairly standard. Two layers of 55 pound or heavier asphalt impregnated roofing paper are hot mopped in hot asphalt on the sub-floor under the insulation. The wall seal must tie in with this floor seal. This means that the wall material must be flashed into the floor seal and fastened into it with plenty of hot asphalt. To prevent corrosion from the wet concrete floor, the wall gas seal metal that runs through the surface floor slab should be protected with a coating of hot asphalt.

Many successful CA rooms have been made with walls and ceilings of 28-gauge galvanized iron sheets. A high grade gun caulking compound that will not dry out is used to seal the joints. The sheets may be overlapped or butted. If they are overlapped 1 1/2 to 2 inches, caulking is laid down under the first sheet before it is fastened on the wooden grounds. Then another bead of caulking is laid down on the top of the first sheet at the edge where an overlap is made. The second sheet is fastened down with large headed, galvanized nails 1 1/2 to 3 inches apart. The caulking that oozes out is smoothed down over the overlap and all nail heads. If the sheets are butted, a space of 1/8 inch is left between the sheets. Caulk under the sheets before they are fastened down and use a galvanized sheet strip molding which is slightly overfilled with caulking compound and is screwed down with galvanized screws every 6-8 inches. The caulking that oozes out is smoothed down over the joint between the molding and the metal sheet to give a good seal.

The steel sheets are fastened to wood. Either the studding, furring strips or grounds are imbedded in the insulation with hot asphalt. When wooden grounds (1" x 3") are placed in "routed" out grooves in the insulation with hot asphalt it is wise to anchor these wooden members to the outside wall occasionally.

In the corners of the ceiling or around beams or irregularities in the walls, carefully bent and soldered sections should be fitted in so that the sheets joining can be caulked and securely nailed or screwed in place.
Attempts have been made to make gastight rooms with other materials such as aluminum sheet, but it is subject to corrosion. Foil has been used with adhesive and calking, but it is easily ruptured and is subject to corrosion. Other films and plastic materials have been tried. Some have been successful but most have not. There is trouble in sealing the joints. Tearing and lack of strength to withstand stress and abrasion is a major shortcoming. Building distortion is a problem as temperatures, wind, and loading may move portions of the storage structure.

Plywood can be used successfully as a gastight seal when high density plywood is used or when outdoor plywood, painted with two coats of outside oil paint over one coat of undercoat, is used. Soft gun grade caulking and metal molding overfilled with calking and screwed down is one way of making the joints gastight. Leave 1/8 inch between the plywood sheets and use galvanized nails around the edge of the plywood. Use nails with neoprine gaskets elsewhere on the plywood. Metal flashing at the floor level extending down and into the floor gas seal as with the steel lined rooms is satisfactory.

Another way to seal the walls to the gastight floor is to extend the wall seal down to the asphalt floor seal and leave a trench in the final floor cement about 3 inches wide all around the room. Fill this trench with a soft, non-drying, non-odorous mastic that will bond the wall seal to the floor seal. A 4 x 4 inch guard rail on the floor around the room will then serve to cover the mastic and as a bump rail for equipment and fruit containers, thus insuring space between the fruit and the walls for air movement.

After determining what holes are needed through the walls for refrigeration pipes, etc., metal sleeves can be caulked in each opening. After the pipes are in place, board insulation is cut to fit roughly around the pipes and then the pipes are thoroughly encased in caulking compound on both faces of the hole. All electrical conduits must be sealed with caulking around the wires in the conduits as they go through the wall.

A small 1/4 inch (outside diameter) copper tube should be run from the gas analyses test station outside through one of the holes made for the refrigeration pipe and extended into the room to a point where air distribution is good.

A gastight door must be fitted inside the usual insulated refrigeration door. It is more convenient to have it seal on door jams so that it can be removed from the outside and be put on and taken off from outside the room. Plywood covered with 28 gauge steel with the steel edge resting on the door jams and temporary threshold or set into a crack recess in the floor is satisfactory. Non-odorous cannery grease or vaseline-type grease is used to seal the gastight door as it is drawn down with large screws or bolts and wing nuts. A large, removable window at least 25 x 30 inches is cut in the door about 30 inches from the floor. This glass or plastic window is to see a fruit display, thermometers, hygrometers and telltale ribbons that show air movement at the duct or blowers inside. A light controlled with an outside switch should be installed above the door inside so one can better observe the display of fruit and instruments inside. A small reach-through porthole with
detachable airtight cover should be located so you can reach in and get apple samples. It also can be used to let out excess air as outside oxygen is pumped into the room.

**Scrubbing Carbon Dioxide from the Storage Air**

Carbon dioxide is given off by the fruit at about the same rate that oxygen is utilized. The carbon dioxide is harmful to the fruit in concentrations much higher than those recommended. The excess amounts of this toxic gas must be removed from the storage atmosphere as it gradually accumulates daily. Although the rate of carbon dioxide evolution from the fruit varies with such factors as maturity, temperature, oxygen level, and age, we find that for Delicious apples of proper maturity held at a temperature of 31°F. core temperature in a storage atmosphere of 2½ per cent oxygen that the rate of carbon dioxide production is about 2 pounds carbon dioxide gas per 1,000,000 pounds fruit per hour. This rate falls off with age so that about 20 per cent less is being produced after five months in storage.

To remove the excess carbon dioxide from the air, sodium hydroxide (NaOH) can be used to combine with the carbon dioxide (CO₂) thus forming the compound sodium acid carbonate (NaHCO₃).

Experimentation has shown that a water solution of 5 per cent caustic sodium hydroxide rapidly absorbs carbon dioxide and at this strength of solution the NaHCO₃ remains in solution and suspension so that excess precipitation and plugging of the machinery does not occur. The exhausted solution can be drained away and the scrubber flushed out and recharged.

A carbon dioxide scrubber, then, consists of a unit in which the storage air can be exposed to the liquid caustic. Where the scrubber is outside the storage room, the flow of air through the scrubber need not exceed 4 changes of air in the room per hour. The concentration of the solution should not exceed 5 per cent caustic sodium hydroxide and operators who use the flake caustic soda should not exceed much over ½ pound of the caustic per gallon of water in the scrubbing solution. Lower concentrations are to be desired, with only enough caustic soda being put in the water to keep the increase of CO₂ removed from the storage air.

About 100 gallons of capacity for water should be available in the scrubber for each 10,000 bushels of storage space. This solution needs to be circulated with a small pump so that absorption surfaces in the scrubber are kept well drenched and flushed. This will require about 6 to 20 gallons pumped per minute for each 10,000 bushels of storage capacity.

If the storage atmosphere contains more than 1 per cent carbon dioxide the caustic in the scrubber solution is quickly used up so that within 4 to 6 hours most of the capacity is gone. The unit can run until time to recharge or it can be drained and flushed with clean water. The solution should be drained before turning off the solution pump so as to flush out the small crystals of NaHCO₂ that are entrained as suspended
crystals in the solution. If these particles settle down by leaving the unit turned off several hours, the machine gradually clogs up.

Large lumps of coke make a good bed to pump the solution over and to draw the storage air through. A tower 4 feet in diameter with 2 feet of coke lumps as big as your fist gives good exposure. A droplet eliminator or space for the air velocity to slow down above the solution distribution manifold helps prevent carryover of the caustic in the air to the storage room. The blower can be placed inside the storage room on either the intake side of the scrubber or on the discharge side. By having the blower in the storage room, air leaks around the fan shaft or blower housing are avoided. However, good airtight blowers with refrigeration type seals on the shaft are in wide satisfactory use.

Black iron can be used to build the scrubber. All pumps, valves, and parts should be of steel or cast iron rather than brass because the caustic will corrode brass parts rapidly.

Some CA operators find that they can purchase liquid concentrate of sodium hydroxide which they then dilute to 5 per cent strength for use in their scrubbers. Other operators find that the dry flake caustic suits their methods of handling better. It is wise to plan on having about one pound of caustic per bushel of apples stored, although most operators will use only about \( \frac{1}{2} \) pound per bushel per season.

One method of handling the flake caustic is to perforate the steel drum with a pick, making holes about 3/4 inch in size and about 50 in number scattered over the drum. Then lower the drum by block and tackle into a steel tank where water can be put in to bring the concentration up to not more than \( \frac{1}{2} \) pound caustic per gallon of water.

The caustic dissolves rapidly as the water is added. A supply of caustic solution is available for several changes of the scrubber. By having the supply tank at the proper elevation, the caustic solution can be drained by gravity into the scrubber unit with a minimum of handling effort.

Water scrubbing of \( \text{CO}_2 \) from CA is another approach to this problem. It is cheaper because it saves on the use of caustic soda, and it materially aids in the air purification problem. It does not remove the odor of burnt insulation in motors.

At the lower temperature which our CA storages are operated, the water freezes solid unless continuously warmed. Some oxygen is added to the room with water scrubbing, but much less oxygen is taken in than \( \text{CO}_2 \) is taken out. For these reasons we suggest using caustic soda for carbon dioxide removal during the pull down period. After an operator has had a year or two experience he can engage in water scrubbing as an added effort toward economy, but with full knowledge of how to operate a CA storage.

The practice of water scrubbing is simple: Water is sprayed inside the CA room, then circulated outside and sprayed in the air. \( \text{CO}_2 \) is absorbed inside and released outside. The greater the volume and the finer the spray, the more efficient the
system is. Usually about 100 gallons of water per minute per 10,000 bushels of stored fruit is sufficient. Various aeration schemes and packing such as Intalox or rolls of screening and air blowers can be used but the chief difficulty in our low temperature CA storages is freezing of the water and introduction of unwanted outside oxygen.

**Testing for Gastightness**

When the CA room is finished, it should be carefully tested for gastightness. One convenient way of doing this is to have a man or two remain inside the room with caulking materials and equipment to get to any part of the wall or ceiling surfaces. Then seal the room up and apply air pressure up to $\frac{1}{2}$ inch water pressure as measured with a tilted manometer draft gauge. When the pressure is established and the blower is turned off and all is quiet, listen carefully at various points in the room for leaks. A leak makes enough noise to be heard, and a repair can be made in the seal. Run the air pressure up as often as necessary to plug all leaks. Then keep track of the time for the pressure on a simple manometer to fall off from the $\frac{1}{2}$ inch water column to zero.

Damage to the structure can occur with large rooms of 20,000 bushels or more when too much pressure is applied. One inch of water pressure can be too much in some rooms. Experience has shown that a CA room should not lose all the pressure (down to zero) in less than 30 minutes. Most of our 21 rooms completed by 1960 held some pressure for considerably longer periods of time and were excellent, gastight chambers.

It is best to undertake a test on a CA room during a period of time when radical temperature changes or atmospheric pressure changes are not taking place outside. A cloudy day, or early morning before sunup, is best suited for the testing period. The room should not be refrigerated, but kept at as near equilibrium with regard to outside temperature as possible.

Rooms of less than 15,000 bushel capacity that lose pressure from $\frac{1}{2}$ pound to zero in less than 30 minutes will be failures as CA storage rooms. Extreme difficulty would be experienced in getting the oxygen down to the 5 per cent level in the first 20 days after closing in such a leaky room. The advantages and economy of having a good tight room are so great that every effort should be made to have the room and all operating equipment such as CO$_2$ scrubber gastight before starting into operation.

**Equipment**

The cooling capacity of the system must be able to remove the field heat from the fruit at the specified loading rate to a core temperature of $32^\circ$F. in 72 hours or less. Coil surface, coil temperature and air movement must be such that a 95 per cent relative humidity can be maintained during the holding period. Air movement should be about one cubic foot of air moved per minute per bushel of capacity of
Fruit loses much less moisture in storage air that contains high relative humidity. Most engineers find that a back pressure control valve on the refrigeration line helps maintain a higher coil temperature and thus a high relative humidity.

Either Freon or ammonia can be used as refrigerants, but a leak of ammonia into the storage room of fruit can cause great damage whereas Freon does not.

The cold diffuser is more handy to get to for adjustments and repair if located near the doorway or if an opening is provided nearby. Less space is lost in a passageway to the cold diffuser if it is near the door. A ship's bulkhead door that was salvaged and installed near the diffuser to permit easy access for servicing has been satisfactory. With an oxygen mask, a person can enter the CA room and perform necessary tasks and inspections.

Through a porthole or view window one should be able to detect any blower stoppage or failure. Cloth streamers in the air stream will indicate whether or not the blower is working. Motor belts have been known to break and motors burn out, so daily inspection through a view window is a good safeguard. Each season new belts should be installed and all bearings and critical parts carefully inspected and serviced or replaced.

All refrigeration controls such as thermostatic controls and back pressure regulators should be on the outside of the room so they can be adjusted as needed.

Operating the CO₂ Scrubber

Caustic soda (sodium hydroxide) is used as a solution in air washing devices to prevent accumulations of carbon dioxide above the desired amount in the CA storage rooms.

The design of the scrubber is simple in that the atmosphere from the chamber is drawn up through a dripping solution of caustic soda. To aid in contact with the atmosphere and the liquid, the tower can be packed with fist-size coke pieces, baffles or porcelain saddles. With an exterior scrubber, the blower and washer unit can be serviced more readily and space in the storage room is not taken up. A solution of about 5 per cent caustic soda is used. Usually ¼ pound of caustic soda per gallon of water is a good strength of solution to use. Not more than ½ pound of caustic per gallon of water should be used because as the carbon dioxide is taken up chemically and the resulting compound of sodium acid carbonate is created, it will not remain in suspension at the higher concentration of the scrubbing solution and the excess settling out of the sediment will cause trouble, but with the more dilute solution of caustic soda it is easy to flush out the scrubber and keep it from plugging up. About 75 to 100 gallons of water capacity per 10,000 bushels of storage space is adequate and a pump that circulates at a rate to keep the surfaces in the tower well wetted without excess spray carry-over is desired. About one gallon of pump capacity per 1,000 bushels of storage space in the CA room is adequate.
The blower capacity should avoid velocities that carry-over caustic spray foam or droplets, but the volume of air movement should equal 3 to 5 times the net air volume of the storage room per hour when loaded with fruit. It is safe to assume that about half the volume of the storage room will be utilized by fruit and wood containers.

Daily or more frequent changing of the scrubber solution is to be desired, with enough caustic soda added to just remove the excess carbon dioxide in the room. In this way, no wastage of the caustic occurs and the relative humidity is augmented in the storage air by the continuous operation of the scrubber.

During the first few days of operation the volume of carbon dioxide that is scrubbed out of the storage air and removed from the room can be replaced by using bottled nitrogen to replace the deficit pressure created by its removal. In this way less outside oxygen is taken into the room by the deficit pressure caused by removal of the carbon dioxide. As the rate of oxygen fall-off is established in the CA room, a line can be plotted on a graph that will indicate what the percentage of oxygen will be at the end of the 20th day. No more nitrogen should be used in flushing the CA room than may be needed to be sure that the 5 per cent level of oxygen is reached in 20 days. Most well-filled, good, gastight rooms will not need the use of nitrogen flushing gas to insure adequate oxygen disappearance down to the 5 per cent level by the end of the first 20 days after closing the CA storage room.

One pound of caustic soda will absorb about one pound of carbon dioxide. An average season's usage of caustic soda will be about \( \frac{1}{3} \) pound per bushel of stored apples, but it is well to have on hand about one pound of caustic per bushel as you start the season.

Water scrubbers may have a place in carbon dioxide removal after the first 20 days are ended but, since the exposure of a water spray inside the storage room absorbs CO\(_2\) and this CO\(_2\) is released as the water is pumped through a spray outside the room, there is also a carry-in of oxygen which is absorbed outside and released inside. This slows down the removal of oxygen from the storage room.

After the proper low oxygen level has been established in the CA room, water scrubbing with some antifreeze could be employed. Most CA operators have not wished to employ water scrubbing as well as caustic soda scrubbing in CA chambers. However, water scrubbing may have a minor advantage after low oxygen levels have been achieved in a room.

**Adding Outside Air to CA Rooms**

The usual method of replenishing the oxygen level in CA rooms is to remove a 2 inch cap on the suction side of the blower in the caustic scrubber and at the same time open a porthole in the room at another point to let the pressure out of the room.
Some operators prefer a small special blower to add air to the room with a valve in the line to shut it off. A small vacuum cleaner type blower will suffice. Trial and error will determine how many seconds operation is needed to bring the oxygen in the storage room up to the desired level. Some operators find that they can use a "regulated leak" into the room by blocking off an opening into the room so that the proper size hole lets just enough breathing take place to replace the oxygen used up daily.

**Air Purification Equipment**

To keep the air sweet and fresh in the closely confined CA storage room, ten pounds of freshly activated coconut shell carbon is used for each 1,000 bushels of storage space. This volume of carbon will absorb all musty odors, building material odors, odors from the fruit, boxes, filth on the floor and will keep down foul odors that tend to accumulate and thus affect fruit flavor.

Another function of air purification is to keep down the scald disease. In a severe scald year, it does not insure perfect scald control, but it reduces the extent of the disorder. Prompt cooling after harvest to a core temperature below 32°F. is the greatest deterrent to scald, and avoiding placing overmature fruits in the same room with fruits of proper storage maturity are important points to observe in scald control.

**Gas Analysis Equipment**

An Orsat apparatus is standard equipment for measurement of oxygen and carbon dioxide twice daily. An all-glass Orsat analyzer is likely to have fewer leaks than other types. Automatic indicators for these two gases are too expensive for the average operator and would require frequent checking with a standard Orsat apparatus.

Gas samples are taken from the gastight chamber through ¼ inch (outside diameter) copper tube running into the room.

An accurate log of all analyses and calculations is important for each room. Below may be seen a typical log in which entries are made.

**Date of sealing this room September 23, 1960.**

<table>
<thead>
<tr>
<th>Date</th>
<th>Hour</th>
<th>Room</th>
<th>CO₂</th>
<th>CO₂ + O₂</th>
<th>O₂</th>
<th>Caustic added</th>
<th>Temp.</th>
<th>Air added</th>
<th>By</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/23</td>
<td>4 pm</td>
<td>1</td>
<td>1.7%</td>
<td>21.2</td>
<td>19.5</td>
<td>50 lbs</td>
<td>32°F</td>
<td>0</td>
<td>AVD</td>
</tr>
</tbody>
</table>
Temperature and Humidity Equipment

An accurate thermometer and humidity indicator should be placed in the room so it can be seen through the glass view window in the door.

Costs

The larger CA rooms of 25,000 bushels to 50,000 bushels capacity, when installed in old cold storage buildings, may cost as high as $1.00 per bushel to convert to CA storage. Smaller rooms may cost more per bushel of space.

New CA storages in Washington State are being built for slightly less than $2.50 per bushel depending on the size and the materials used. Operating costs of a CA storage are higher than regular cold storage because of the daily labor involved in checking the atmosphere and changing the solutions in the scrubbers. The extra cost of caustic soda may add 2 to 3 cents per bushel of stored fruit. The storage season is longer and there is the added cost for additional power and air purification costs.

Precautions

1. The room must be quite gastight or the venture will be a failure.
2. The room must be well filled with apples.
3. The fruit must be of high quality and of the proper degree of maturity to justify the added expense of this type of storage.
4. The room must be filled and closed within a few days after starting to fill it in the fall. It is desirable to fill and close in less than a ten-day period.
5. The proper atmospheric and temperature requirements for each variety must be followed.
6. The atmosphere must be checked daily.
7. The oxygen should not be allowed to go lower than 2.5 per cent and the carbon dioxide level should not be allowed to rise higher than that recommended for the variety.
8. Open the porthole in the door when adding air to the room to let excess air pressure out of the room.
9. A relative humidity of 90-95 per cent should be maintained during the holding and unloading period. During the loading period it should be as high as possible, at least 85 per cent.
10. There must be good circulation of the atmosphere in the room. The apples must be properly stacked.

11. Never go into the room without an air mask or an oxygen mask to supply you the required oxygen.

12. The caustic soda solution is harmful to the skin. It will also burn clothing. If it gets on the skin or eyes, wash it off immediately. Do not breathe the fumes of the caustic soda when making up the solution.


14. Do not let the spent caustic soda or salt solutions come in contact with the roots of trees or other plants.

15. Air out the room well before entering the room to work. Gas analyses should show 18-20 per cent oxygen before men work in the room to remove the fruit.