Guidelines for Constructing and Operating Controlled Atmosphere Storages for Apples

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Guidelines for Constructing and Operating Controlled Atmosphere Storages for Apples

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Controlled atmosphere storage, commonly known as CA storage, extends the storage and market life of apples by regulating the oxygen and carbon dioxide gasses of the storage room atmosphere. Since it is used in conjunction with application of low temperature, CA is a supplement, rather than a substitute, for cold storage. With proper consideration for varietal differences and requirements, it is useful only for fruit of suitable maturity that has a high potential for long-term storage.

Benefits

Respiratory activity of the fruit is reduced markedly in CA over cold storage so as to slow the rate of loss of stored carbohydrates within the fruit. Also, for a variety like McIntosh, which is susceptible to low-temperature breakdown during extended storage, a higher storage temperature can be used with CA to lengthen the marketing season for the fruit to 6 months or longer following harvest. Other varieties, such as Jonathan, Idared and Rome Beauty, can be stored longer in CA than in cold storage because the low oxygen and enriched carbon dioxide of the CA atmosphere inhibits the development of Jonathan spot. Soft scald, another physiological disorder of these varieties, is completely controlled by CA storage. Other disorders (examples are internal breakdown and storage scald) are somewhat, but not completely, inhibited by CA. Still another benefit is that a higher relative humidity often can be maintained in a CA room than in a cold storage room, thereby decreasing water loss and wilting and providing a more crisp texture and higher juice content.

Disadvantages

CA storage does not improve the quality of apples but retards the occurrence of normal postharvest changes that bring about a reduction in fruit quality. It can be detrimental to fruit whenever extremely low levels of oxygen or high levels of carbon dioxide inadvertently occur. Since a CA storage room cannot be entered without disturbing the atmosphere, all interior conditions, including temperature, must be monitored and regulated from outside the room; consequently there are numerous opportunities for error.

CA storage is more costly than cold storage because of the need for constructing and maintaining an airtight structure and for special operating equipment, plus the generally longer operating season.

There are other disadvantages. A CA room needs to be filled and closed within a few weeks at harvest time. The mixture of varieties may be limited due to their season of maturity and storage requirements. Daily regulation of the atmosphere throughout the storage period is essential. At the conclusion of the storage period, the fruit should be removed and marketed within a few weeks.

Fruit Selection

Apples selected for CA storage must be of suitable maturity and quality for long-term storage and of adequate market value to eventually justify the extra storage costs. A common error in CA is to store fruit that is over-mature, usually as a result of delaying harvest to offset the slow development of enough red color to assure good marketability. Partially ripened apples have a relatively short storage life in either cold or CA storage and should be marketed within several months following harvest. Apples unsuitable for fresh market due to poor color, the presence of defects or improper size do not usually bring high enough return to justify CA storage costs. A pack-out of 90% of U.S. No. 1 fruit is generally needed to justify the added costs associated with long-term storage and final fruit sorting.

Recommended Storage Conditions

The proper temperature and CA atmosphere conditions for apples are given in Table 1. Cool McIntosh and hold at 32°F in storage until starting to develop the controlled atmosphere, then slowly raise in temperature to 36-37°F. Hold Jonathan at 36°F prior to sealing the room so as to avoid development of soft scald, then continue at this temperature for the initial month of CA storage so as to reduce the hazard of brown heart formation. All other varieties can be cooled immediately and maintained at 31 to 32°F in either air or CA.

Table 1. RECOMMENDED CA STORAGE CONDITIONS FOR MICHIGAN APPLES

Variety	Temperature (°F)	Carbon dioxide (%)	Oxygen (%)
Jonathan	36 1st mo., then 31-32	2.5 to 5[1]	2.5-3
McIntosh	36	2.5 1st mo., then 5%[2]	2.5-3
Rome Beauty	31-32	2.5	2.5-3
Delicious, Red and Yellow; N. Spy, Idared, Stayman, Spartan	31-32	2.5 to 5[1]	2.5-3

[1]Variable depending upon whether or not stored with Rome Beauty. Less than 1% CO_2 is acceptable.

[2]Maintain at least 2% CO_2 throughout if stored for 4 mo. or longer.

Carbon dioxide levels near zero can be utilized for all varieties except McIntosh, Jonathan and Idared. Zero levels can be reached when dry lime is placed directly in the storage room for removal of the carbon dioxide produced by the fruit. McIntosh requires 3 to 5% carbon dioxide and 2.5% oxygen to minimize ripening. A somewhat lower level of carbon dioxide (below 3%) is suitable where 2% oxygen is employed. Jonathan and Idared may develop Jonathan spot if the carbon dioxide is held below 0.2%. All strains of Rome Beauty may be damaged by more than 2.5% carbon dioxide.

It is important to develop and maintain at least 3% or lower oxygen in order to achieve the benefits of CA storage. There is no harm in reducing the oxygen during the initial day or so of operation upon sealing the room, provided the fruit is already cooled to the recommended storage temperature. Levels below 2.5% are tolerable for a day or so at a time during the storage season, but reductions below 2% oxygen should be considered hazardous, particularly for fruit having a high rate of respiration.

Following CA storage retain the apples at 31-32°F and practice good refrigeration throughout the marketing period. Although 30 days is a normal marketing period following CA storage, it can be longer, depending on the condition of the fruit. Several days of aeration may be needed for the fruit to acquire a more normal flavor when removed from CA storage.

Building Design and Construction

CA requires a building properly designed and equipped for cold storage with modifications to provide air tightness and regulation of temperature and atmosphere from the exterior of each room. The number or size of rooms is based on the size of the crop and the varieties to be stored together in consideration with the marketing plans. Adequate space at the right times is crucial because a room should be loaded and closed within a week or 10 days after the start of loading, and then the fruit should be marketed within 4-6 weeks after opening of the room. Small rooms with a capacity of 5,000 bushels or less are uncommon in that they are more expensive and difficult to operate than larger rooms. The degree of airtightness needed to maintain low oxygen and a means for testing the tightness of CA rooms are described in MSU Extension Bulletin E-1428.

Although there are many ways to construct an adequately airtight structure, the most common procedure is to utilize foam-in-place polyurethane for both the insulation and gas seal. This material presents a fire hazard and must be protected with a suitable fire barrier. Construction is easily accomplished by the so called "inside-outside" method whereby a pole frame wooden structure is first lined internally with plywood sheathing. The foam-in-place polyurethane is then applied to the external side of the interior lining of plywood prior to attaching the external sheathing to the building. The system is illustrated in Fig. 1 with details for providing an airtight seal at the wall-floor juncture. The ceiling is normally constructed with a plywood interior lining with the polyurethane applied to the exterior side and left exposed to a ventilated attic. An equally suitable alternative utilizes masonary walls with polyurethane applied to the internal surface. A fire barrier material is applied to cover the layer of insulation-gas seal material on the inside of the walls.

The floor may or may not include an airtight lining. Dense concrete flooring will serve as a suitable airtight barrier if it is relatively free of cracks and properly joined to the side wall gas lining as shown in Fig. 1. If floor insulation is needed — generally only if the building is located on a site where the water table is within 10 feet of the floor — the insulation can be covered with roofing material and hot mopped much the same way as a built-up roof is applied to provide an airtight lining connected to the side walls. Finally, the surface layer of concrete is applied.

All service lines can be brought into a room via a prefabricate manifold with minimum opportunity for air leakage. Airtight doors constructed of plywood or metal complete the air seal once the room is filled (Fig. 2). They are generally bolted in place and sealed by a gasket **or** odor-free caulking compound or grease. Combination airtight and insulated service doors with hinges and special latches and gaskets (Fig. 3) are sometimes used. The airtight door is generally placed and removed only once a season,

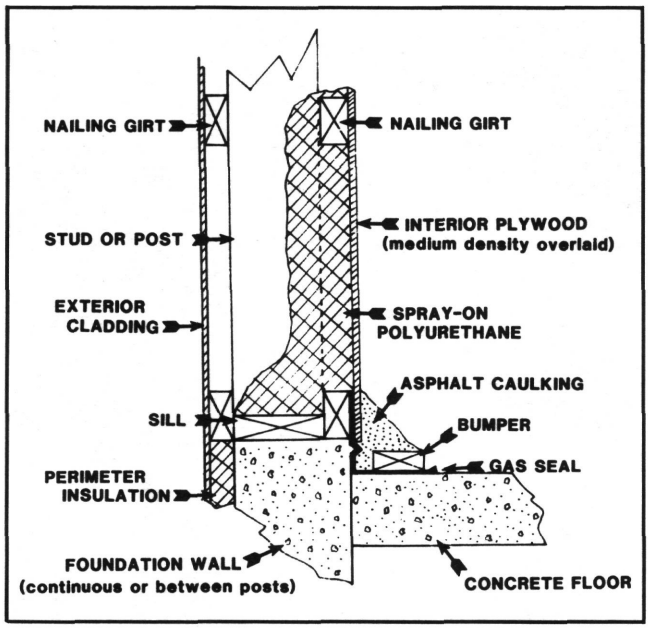


Fig. 1. Detail of partial wall-floor section employing the "inside-outside" method of construction of a CA storage building.

whereas the insulated service door is opened and closed frequently during loading and unloading.

A relief valve or box (see Figs. 4 and 5) is essential to avoid damage to the sealed room caused by excessive pressures or vacuums developing in the room as a result of scrubbing, defrosting and possibly marked changes in barometric pressure. Pressure variations in excess of ± 1 inch water gauge can damage the structure and markedly reduce its airtightness.

Special Equipment

Inside thermometers that are visible through windows or the sensors of distant-reading temperature indicators should be located in the coldest (usually in front of the evaporator) and warmest (usually near the floor beneath the evaporator) parts of the storage room. An externally adjustable thermostat that responds to temperature changes of ± 0.5° is essential for good temperature regulation. Locate the sensor in an area of good air movement so as to respond immediately to changes in room temperature.

Scrubbers that utilize chemical reaction, absorption or adsorption for removing carbon dioxide from the room atmosphere are employed in Michigan storages. Fresh hydrated lime, $Ca(OH)_2$, is the most commonly employed chemical agent. Place it directly in the storage room in nonplastic lined bags so that the full quantity of lime is constantly exposed to the atmosphere or in an outside chamber connected to the storage room through which a small portion of

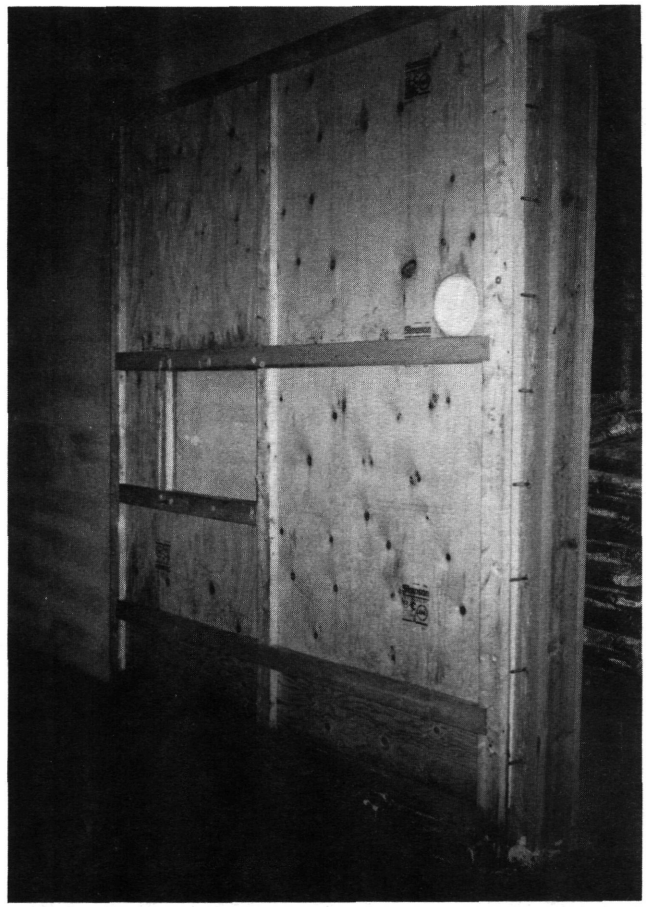


Fig. 2. Airtight door constructed of plywood bolted in place against the door frame after the room is filled.

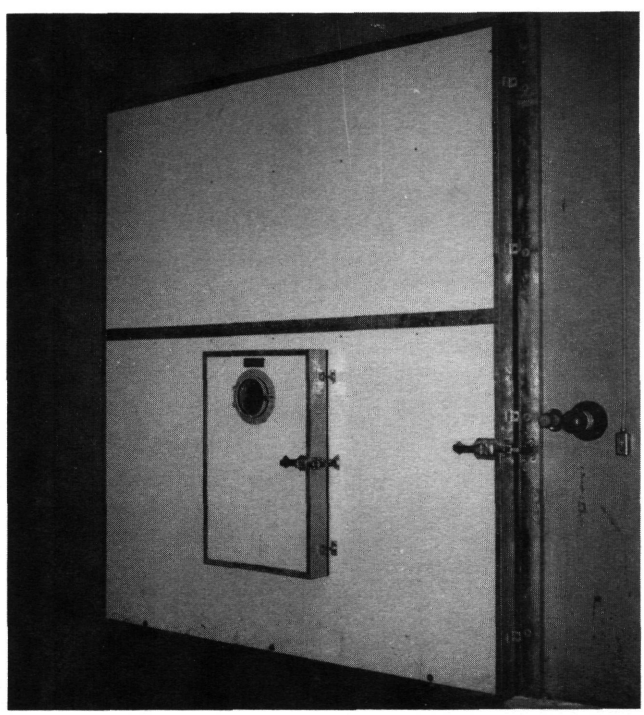
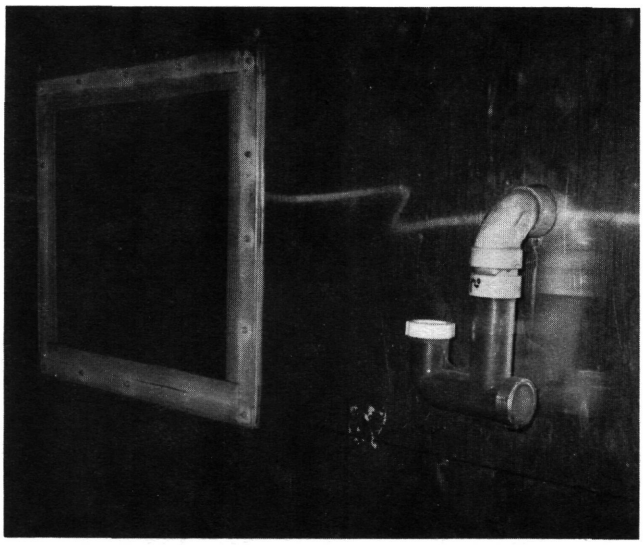


Fig. 3. Combination airtight, insulated storage room door with a smaller observation door containing a porthole.



Fog. 4. Portion of airtight plywood door showing observation window (left) and a pressure relief value (right) to prevent the occurrence of excessive positive or negative pressure of atmosphere within the room.

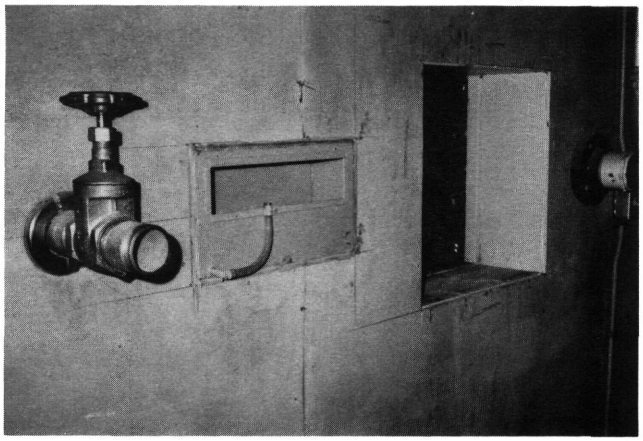


Fig. 5. CA room accessories of air vent with gate valve (left), pressure release box (center) and window (right) for observing thermometers and fan operation in the room.

the storage room atmosphere is circulated. When lime is placed in the room, the carbon dioxide will remain low, usually at 0.5 to 1.5%, until most of the lime has reacted. With an outside lime chamber, the carbon dioxide can be adjusted to the desired level by regulating the flow of the storage room atmosphere through the chamber. The spent lime is sometimes utilized as a soil additive; however, it is difficult to crush and distribute uniformly on the soil. As a general rule, 1/2 to 1 pound of lime is recommended for each bushel of fruit stored for 6 months when the lime is placed within the room, depending upon the space available and how often the operator changes the lime during the storage season.

Absorption of carbon dioxide by passing the room atmosphere through a flow of aerated water in a packed tower is another common means of scrubbing (Fig. 6). Water scrubbers are economical to operate, suitable for automation and help maintain high relative humidity. Their major disadvantages are a fairly high original cost and difficulty in maintaining carbon dioxide levels below 3% without the scrubber adding back too much oxygen to the room atmosphere.

Absorption scrubbers containing activated charcoal (Fig. 7) that operate in a manner similar to water scrubbers are being used to a limited extent. The carbon dioxide removed from the room atmosphere is released by aerating or sometimes by heating the absorption bed of activated carbon. It is claimed by manufacturers that operating costs are more reasonable than for water scrubbers.

CA Generators

Combustion units for artificially creating and maintaining a low oxygen atmosphere, instead of depending on the naturally occurring respiration process of the stored product, have been used since the mid 1960's. Some generators flush the room with the desired atmosphere created by external combustion of natural or propane gas with outside air in the presence of a catalyst. The excess carbon dioxide is removed by carbon scrubbers. A less sophisticated version for flushing the room atmosphere to establish CA rapidly is the open flame generator. It requires careful adjustment of the gas flame, which burns in the absence of a catalyst, in order to facilitate nearly complete combustion of the fuel and avoid excessive amounts of undersirable combustion products such as carbon monoxide and ethylene entering the room. These generators are portable, inexpensive in initial and operating costs, and quite useful for small scale storage operations. A catalytic gas combustion generator suitable for removing the excess oxygen by recirculating the storage room atmosphere is widely used. Since generators are used frequently without an attached scrubber, the excess carbon dioxide enters the room and must be removed by the regular room scrubber.

All combustion generators are potentially hazardous and must be operated cautiously. Gasses toxic to fruit and human beings may be produced as a result of incomplete combustion; even worse, explosive concentrations of natural or propane gas may accumulate in the storage room. Closely follow directions and precautions furnished with the equipment; monitor the equipment and its products frequently during operation; and handle the fuel safely.

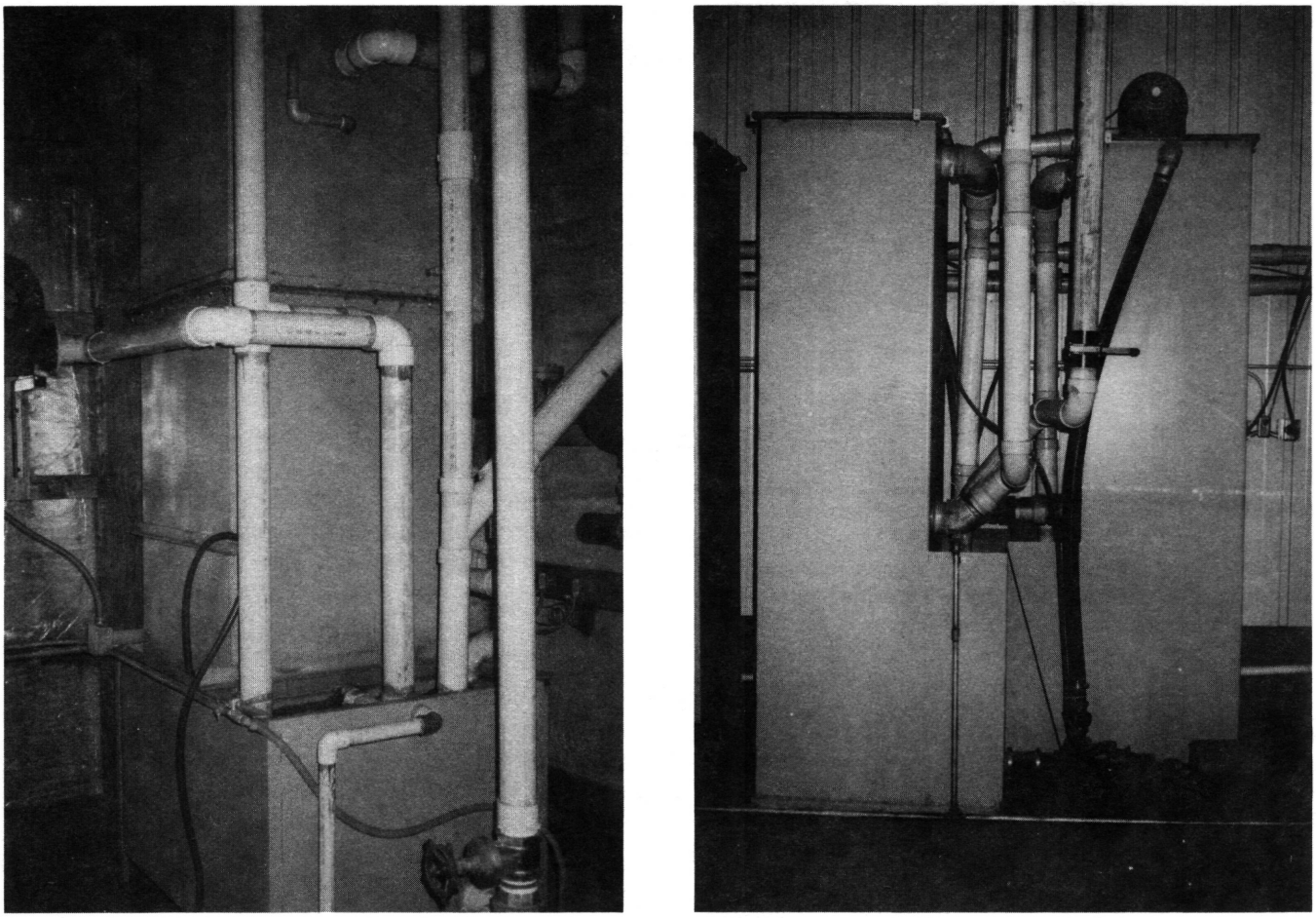


Fig. 6. Two types of water scrubbers for carbon dioxide removal: left, tandem tower; right, side-by-side tower.

Room Operation

The chemical absorption gas analyzer (see Fig. 8) employing solutions of potassium hydroxide for carbon dioxide and alkaline pyrogallol for oxygen is widely used for analysis of CA room atmospheres. A gas sample is taken from the room through airtight tubing, preferably by a pressure delivery system from within the room rather than by suction from outside the room, so as to avoid contamination of the room atmosphere with ambient air. Each analysis takes several minutes, which may seem like a lengthy period if a number of rooms are in operation, yet the time can be advantageously utilized by the operator for considering the adjustments to be made to reach and maintain the desired gas levels.

Several types of electronic gas analysis systems can provide rapid operation and automation if desired. They have proven satisfactory provided they are routinely calibrated with standard gasses. It is normal to analyze a room atmosphere several times daily during the initial 20 to 30 days of room operation and then once a day after the desired levels of oxygen and carbon dioxide are reached. Any determinations that seem somewhat questionable should be re-run.

Scrubber operation for re-establishing the desired carbon dioxide level and the adding of outside air through a vent or by a blower to restore oxygen are determined on the basis of the daily gas analysis plus the previous experiences with a room. Obviously, previous records help to simplify decisions about reaching or maintaining a desired atmosphere in a room.

Precautions

The supply of oxygen in a CA room is inadequate to support human life. If someone must enter a room in order to make equipment repairs or adjustments, and the oxygen level is below 17%, a suitable breathing apparatus is essential. A better and safer procedure is to open the room and thoroughly ventilate it prior to entry. The atmosphere can be quickly re-established by use of a generator or with nitrogen gas without harm to the fruit or loss of CA label qualifications.

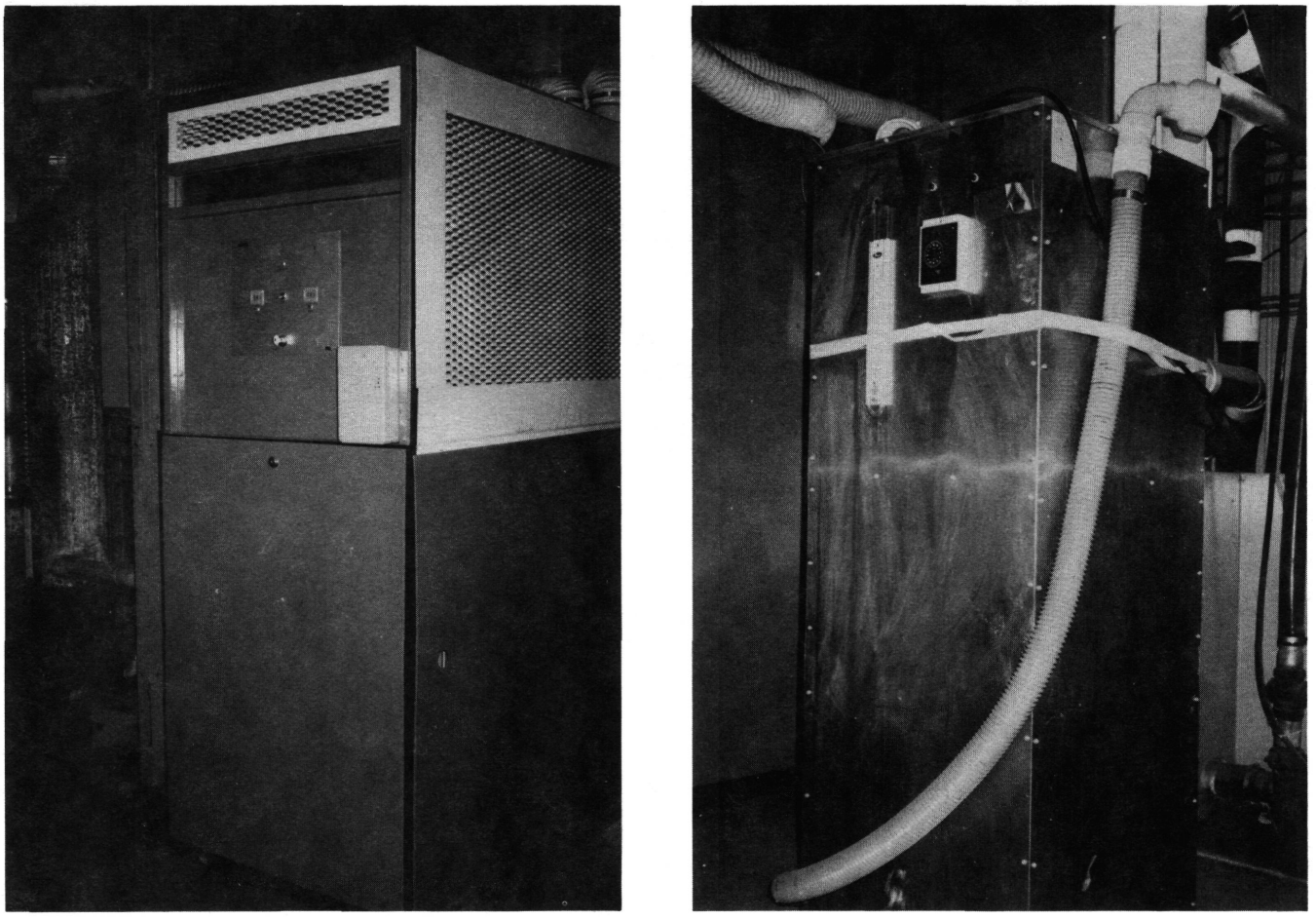


Fig. 7. Carbon scrubbers suitable for removing carbon dioxide.

CA Regulations

Apples marketed as CA fruit must be stored and labelled according to the requirements of Michigan Act No. 228 (Public Acts of 1959) and Regulation No. 530 which specifies that the fruit has been held in an atmosphere of not more than 5% oxygen for at least 60 days for the Jonathan variety and 90 days for all other varieties. Qualified CA rooms must be licensed and certified by the Michigan Department of Agriculture on a yearly basis, and the fruit must be packed, marketed, and identified by permit. Although there are no legal quality requirements for CA fruit, it is obvious that the apples must be of suitable market value in order to justify the extra costs of storage and possibly command a premium price.

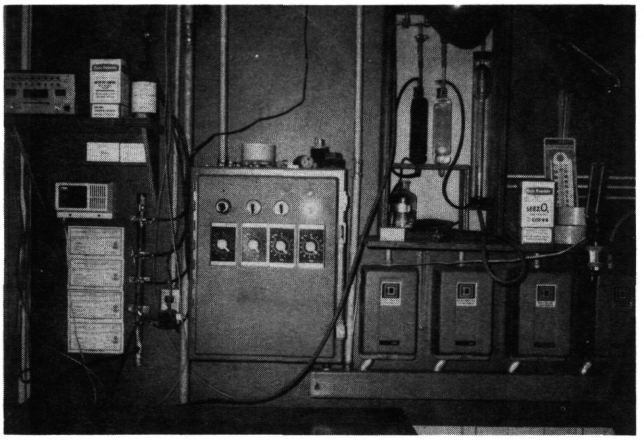


Fig. 8. Operating panel for regulating room atmospheres, operating scrubbers and monitoring temperatures. A chemical analyzer (right center) is employed for atmosphere analysis.

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