Controlled-Atmosphere Storage

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Engineering Considerations in the Storage of Fruits and Vegetables by the Controlled-Atmosphere Technique

THE CA (controlled-atmosphere) storage of fruits and vegetables has an important place in the food-marketing system since the storage life of some products can be considerably lengthened. At the present time, the use of the CA storage in quantity is limited to apples; however, experimental work is being carried on with the hope that in the not too distant future the CA technique can be applied to other fruits, vegetables and florist stocks.

The CA fruit storage is a refrigerated storage where the atmosphere surrounding the fruit is maintained at a level other than the normal 21 percent oxygen, 0.03 percent carbon dioxide and 79 percent nitrogen. In the CA storage, the respiration process of the fruit reduces the oxygen level and increases the carbon dioxide level. The decrease in oxygen and increase in carbon dioxide both tend to slow down the rate of respiration and extend the storage life of the fruit. The CA storage was developed in England where the first commercial CA storage (7)* was constructed in 1929. England now has over 4,000,000 bu of storage capacity. The CA storage capacity in the United States is estimated to be about 500,000 bu, all located in the Northeast.

Before a product can be commercially stored under CA conditions the individual variety of fruit or vegetable must be tested to find the specific level of oxygen and carbon dioxide that will give the desired extension of storage life without bringing on a physiological disorder. Fruits and vegetables that are susceptible to these disorders are not adaptable to CA storage. The reaction of a specific fruit to a given storage condition varies with the variety, and a variety grown in Michigan may react differently than the same variety grown in Iowa or New York. At the present time, most of the CA capacity is being used to store McIntosh apples. These apples, when stored under CA conditions of 3 per cent oxygen and 5 percent carbon dioxide at 38 F, may have twice the storage life of apples stored in air at 32 F.

There are two types of CA storage. In one type, the sum of the concentrations of oxygen and carbon dioxide is always 21 per cent. The desired combination is maintained by ventilating the storage. In the second type of CA storage, the oxygen plus carbon dioxide is less than 21 per cent. The oxygen is maintained through controlled ventilation and carbon dioxide is removed by absorption. Sodium hydroxide (caustic soda) or calcium hydroxide may be used for absorbing the carbon dioxide. An Orsat-type gas analyzer is used to measure the oxygen and carbon dioxide levels of the storage.

Fundamental data for the design of controlled-atmosphere storages are exceedingly meager considering the large number of storages that are operating successfully. The chief recommendation in the construction of the CA storage is that it be as tight as economically possible. It is unfortunate that the increased value of the product stored is not sufficient to warrant construction of truly hermetic rooms and that we must be content with rooms that are reasonably tight. Further study of the physical aspects of the problem should make it possible to ascertain in advance the relative degree of tightness necessary for a room to operate satisfactorily.

Little knowledge has been accumulated on the physical operating characteristics of CA storages in the United States. Pflug and Southwick (2) found that a breather bag speeded up the rate at which some rooms acquired the desired atmosphere. They also found that sealed rooms develop pressure cycles accompanying the temperature cycle of the room. Kidd, *et al* (1) concluded that in practice the main cause of leakage was the mass movement of the atmosphere into and out of the storage and not the escape of carbon dioxide by diffusion. Pflug and Southwick (2) arrived at similar conclusions.

The present-day CA storage can be described as being tight when compared to a refrigerated storage, but not hermetic. Pflug and Southwick (2) outlined a method of measuring the rate of leakage as a function of the differential pressure. Air will flow through the holes in a non-hermetic

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*Numbers in parentheses refer to the appended bibliography.

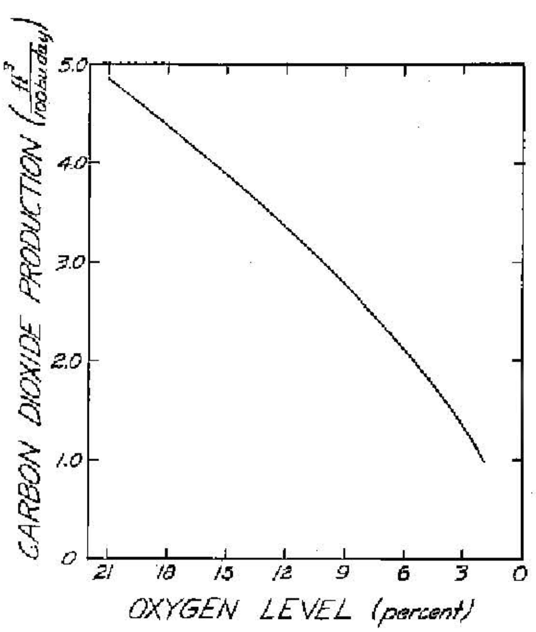

Fig. 1 Carbon dioxide production of McIntosh apples at 38 F as a function of oxygen level from data presented by VanDoren (6) and Phillips and Poapst (3)

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room whenever there is a pressure gradient. The rate of flow will be proportional to the differential pressure across the holes. The room is subject to pressure differentials arising from five sources: *(a)* changes in atmospheric pressure, *(b)* external air movements, *(c)* temperature changes in the storage, *(d)* air movement in the storage, and *(e)* the absorption or removal of gas from the storage.

It is important to consider the physiological characteristics of the stored fruit in the design of the storage since it is living and slowly carrying on respiration. Chemically the respiration process involves intercellular combining of oyxgen with stored sugars to produce water, carbon dioxide and heat.

Fig. 1 illustrates the relation of carbon dioxide production with oxygen level for McIntosh apples at 38 F. This graph was based on data from Van Doren (6) and Phillips and Poapst (3). According to these and other data, the rate of oxygen drop for a hermetic room with a given volume of total atmosphere per bushel of fruit can be determined. In Fig. 2 oxygen-reduction curves for different volumes of atmosphere per bushel are illustrated. The volume of atmosphere per bushel will be higher in the small than in the large storage and will be higher in a palletized storage than in a storage that is hand loaded. An incompletely filled storage will have a higher volume of air per bushel than a filled storage.

The data in Fig. 2 are a starting point in determining the necessary degree of tightness of the storage. The net decrease in oxygen per day for a non-hermetic storage will be the difference between the oxygen consumed in respiration and the oxygen gained through leakage. The effect of each agent causing pressure differentials must be evaluated individually. Methods and procedures that will eliminate or reduce leakage from these agents should be used where possible.

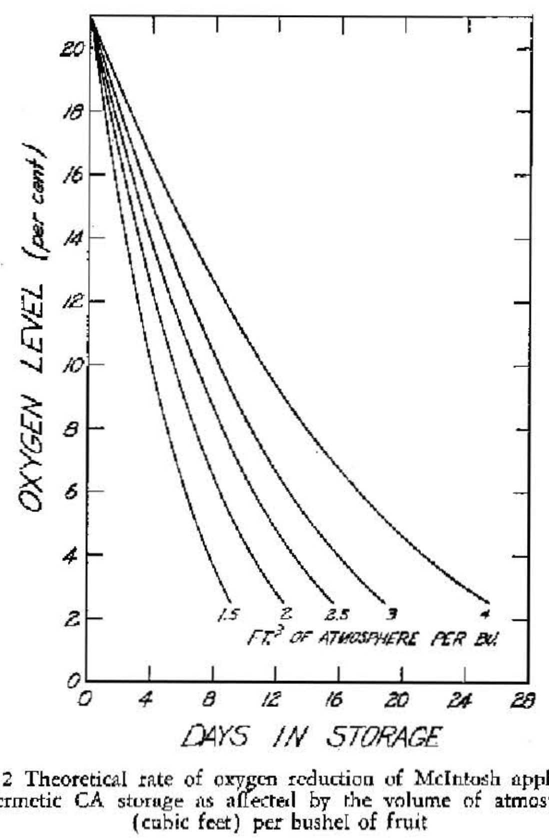

Fig. 2 Theoretical rate of oxygen reduction of McIntosh apples in a hermetic CA storage as affected by the volume of atmosphere (cubic feet) per bushel of fruit

Changes in atmospheric pressure will cause air to move into the storage as the barometer rises and out of the storage as the barometer falls. The regular cycling of the barometer may cause leaks to develop if an expansion device is not used. Pflug and Southwick (2) found that the oxygen gain from atmospheric pressure fluctuations was small compared to the leakage from other causes. Leakage from atmospheric pressure fluctuations can be approximated from weather data. The average leakage due to external air movement will be negligible, but could reach significant proportions during times of high wind. The overall effect of wind will be to create areas of positive pressure on the windward side of the building and a vacuum on the leeward side.

Temperature changes in the storage will cause the specific volume of the air in the storeroom to change. A vacuum will be formed when the temperature decreases while a positive pressure will be developed with increasing temperatures. These specific volume changes will occur whenever an off-on temperature-control system is used and the amount of leakage will be proportional, within limits, to the heat gain of the refrigerator. Since the leakage pattern due to temperature fluctuation is a cycle of great amplitude and short duration, its effect can be somewhat reduced with a breather bag. The circulation of air in the room by fans or blowers will cause pressure variations within the room. Little is known about the magnitude of these pressures in actual controlled-atmosphere storages. Sainsbury and Gerhardt (4) found a vacuum of 0.5 to 1.5 in of water near the fan inlet of some refrigerated storages. Leakage can be expected to increase with increased air velocities inside the room.

The removal of carbon dioxide or other gases by absorption will cause air to leak into the room until the volume of gas removed has been replaced. A substantial vacuum may develop in a tight room if provision has not been made for replacing the removed atmophere. The oxygen gain of a room due to the absorption of carbon dioxide will be approximately 21 per cent of the carbon dioxide removed.

The development of a sound design procedure would eliminate many of the present hazards of CA storage. The cold storage of fruits and vegetables, at best, involves considerable economic risk and this is greatly increased when controlled atmospheres are utilized. The assurance of satisfactory mechanical operation of CA rooms would be helpful in justifying the additional construction and operation costs of storage of this type.

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