Air Leakage in Controlled-Atmosphere Storage

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IN the CA (controlled-atmosphere) McIntosh apple storage it is desirable to obtain an atmosphere of 3 percent oxygen and 5 percent carbon dioxide as rapidly as possible after storing the fruit. In such rooms a level of 3 percent oxygen is obtained by allowing the respiring fruit to utilize and thereby reduce the oxygen level in the room. Any delay in acquiring the 3 percent oxygen level will tend to shorten the potential storage life of the fruit. Since no sealed CA storage room is 100 percent gastight, any movement of air through small leaks may be expected to influence the rate at which the oxygen level is reduced. The movement of air through small leaks in such storage rooms, the effect of this leakage in terms of added oxygen, and a method of reducing the influx of oxygen are discussed below.

During the 1952 apple storage season, observations made on a 3300-bu-capacity CA room indicated that a pressure fluctuation occurred. It was thought that the temperature cycling of the room could cause the specific volume of the atmosphere in the room to change and thereby create negative and positive pressures during the cooling off and warming portions of the temperature cycle. Since the structure is rigid but not hermetic, the room would "breathe" with each temperature cycle. It was concluded that, if the atmosphere did expand and contract, an appropriate contraction and expansion chamber might be used to reduce the amount of breathing and thereby increase the rate at which the oxygen level dropped after closing the room. A project was set up to study the problem during the 1953 storage season.

Experimental

The study reported in this paper was made at the farm storage of a Massachusetts apple grower who had two similar CA storage rooms. These rooms were built in 1952 according to the general specifications given by Smock (3)*. The rooms were lined with aluminum sheeting and equipped with a sheet metal door in addition to a standard refrigerator door. The aluminum sheets were overlapped, and all joints caulked. The refrigeration system used F-12 as the refrigerant. One refrigeration system served both rooms; the temperature in each room was controlled by a remote bulb thermostat that operated the liquid line solenoid valve to that room. Each room was equipped with a scrubber constructed according to plans outlined by Smock and Van Doren (5).

The first phase of the project was measuring the rate of leakage of the rooms. A method was devised using a small air compressor for supplying air under pressure, a rotometer for measuring air flow, a valve for regulating air flow, and a micromanometer for measuring the difference between room and atmospheric pressure. This apparatus is illustrated in Fig. 1. The rotometer was calibrated for air flows of 25 to 200 cfh. The first step in the testing procedure was to seal the room and allow it to equilibrate in temperature with the surroundings. Air was then metered into the room at the rate of 25 cfh until the differential pressure reached a constant value. At this point the air was leaking out of the room at the same rate it was being added; therefore, the manometer reading was the differential pressure causing 25 cfh of leakage. The rate of flow was then increased to the next higher value, and the entire procedure repeated. The result is a graph relating pressure differential with rate of

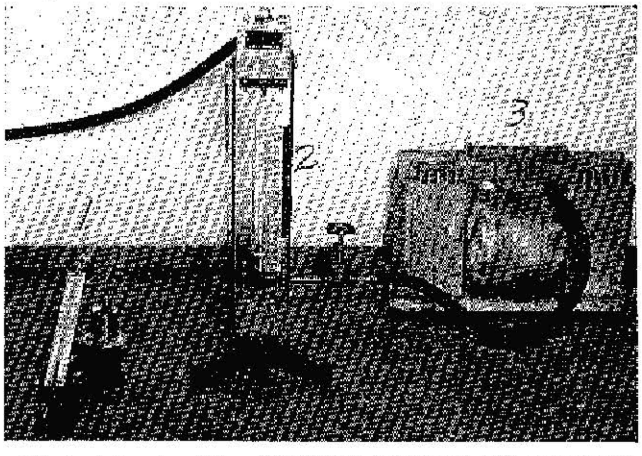

Fig. 1 Apparatus for measuring rate of leakage: (1) micromanometer, (2) flow meter, and (3) air compressor

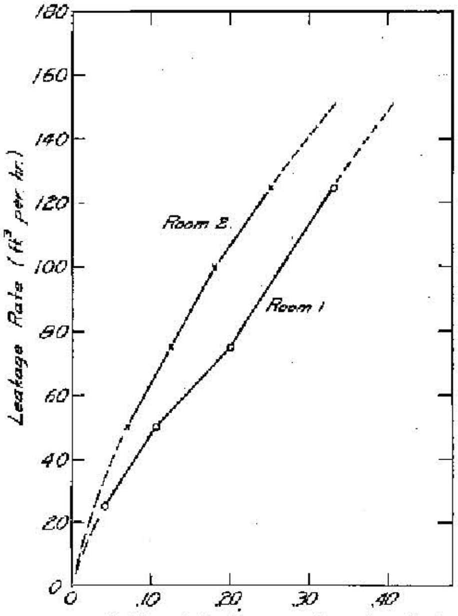

Fig. 2 Leakage rate graph

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*Numbers in parentheses refer to the appended bibliography.

Paper prepared expressly for AGRICULTURAL ENGINEERING. Approved as Contribution No. 954 of the Massachusetts Agricultural Experiment Station, Amherst.

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Acknowledgment: The authors express appreciation for the assistance of G. S. Gay, Three Rivers, Mass., in whose storage the tests reported were carried on, and his foreman, L. Jacek; R. M. Smock, Cornell University, and W. B. Esselen, University of Massachusetts, both of whom gave valuable advice on several occasions and reviewed this manuscript.

This article is reprinted from AGRICULTURAL ENGINEERING (vol. 35, no. 9, pp. 635-637, September, 1954),
the Journal of the American Society of Agricultural Engineers, Saint Joseph, Michigan

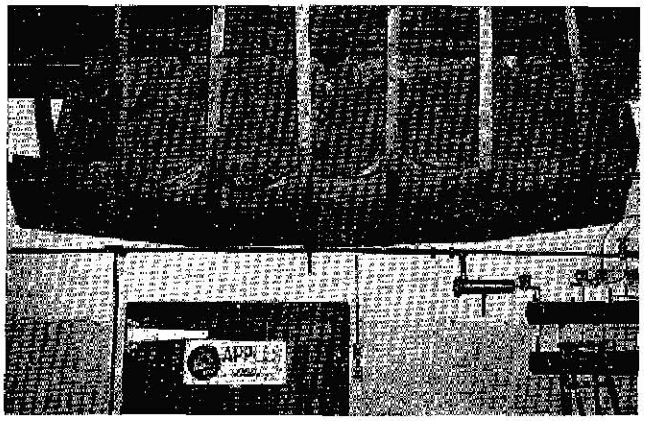


Fig. 3 Expansion bag connected to room

leakage; in Fig. 2 the leakage rate graph for the two rooms under study is illustrated. The maximum pressure put on the room was relatively low because it was felt that high pressure would serve no useful purpose in this test and might cause more leaks in the room.

Since pressure differentials were to be studied, two recording differential manometers were obtained, and one was connected to each room. A temperature-sensing element was located in each room and connected to a multiple-point recorder so that a continuous record of temperature in the room would be available. The empty rooms were refrigerated at this time and several tests made to determine the pressure fluctuations. Empty room tests showed definite pressure fluctuations accompanying temperature changes.

A bag 12 by 16 ft (flat size) made of vinylite plastic sheeting was attached to room No. 2 as shown in Fig. 3 as a means of reducing pressure differentials. Initially the bag was connected to the room with 1⅜ I.D. hose and 1¼ Am. Std. pipe. In March, 1954, some 2⅝ I.D. flexible metal hose was obtained; this was used to connect the bag to the room for a 3-day test period.

The bag was hung from the ceiling as illustrated in Fig. 3. The bottom of the bag was supported by straps about 6 ft below the ceiling in an effort to reduce the pressure required to move and hold air in the bag. It was found that supporting the bottom of the bag was not enough; so a few weeks after installation one side of the bag was tied back to maintain more air in the bag at equilibrium pressure. Room No. 1 was not equipped with a bag and therefore would serve as a control in the evaluation of the breather bag.

The rooms were filled to capacity with apples during the latter part of September. The recording thermometers and manometers were operated the entire length of the storage season giving a complete pressure and temperature record for both rooms. In addition the operator of the storage measured the oxygen and carbon dioxide levels twice daily.

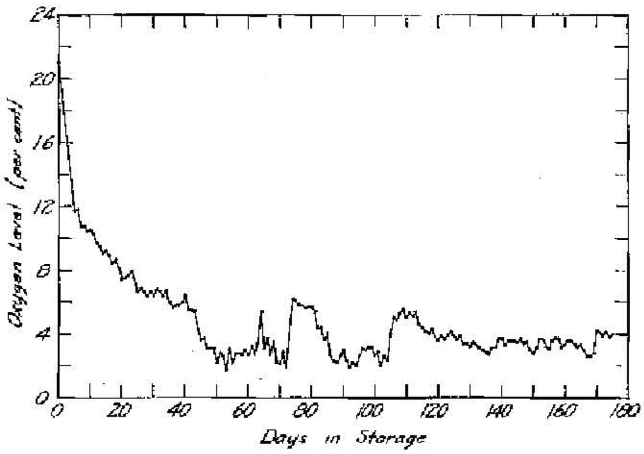
Results and Discussion

The breather bag appears to have had a marked effect in reducing the oxygen level in the rooms under study, as illustrated in Figs. 4 and 5. The oxygen levels plotted on the graph in Figs. 4 and 5 are an average of the two daily readings. The oxygen level in the No. 2 room (initially connected to the breather bag) was reduced to 2.7 percent in 23 days. The No. 1 room (initially without the bag) had an oxygen level between 7 and 8 percent, 22 days after sealing; about 6 percent, 40 days after sealing. A breather bag was connected to the No. 2 room on October 31, 42 days after the room was sealed. Eight days after the bag was connected to the No. 1 room the oxygen level was reduced to 2.2 percent. A serious F-12 leak developed in room No. 2 and required that the door be removed and the leak repaired. Although the door was off for only an hour, the oxygen level the following day (January 5, 1954) was 15.4 percent. The oxygen level was reduced to 3.1 percent in 22 days as illustrated in Fig. 5; during this period the room was connected to the bag.

The pressure variations of room No. 2 are illustrated on the recorder charts shown in Figs. 6, 7, and 8. It is obvious when the pressure differentials of Figs. 7 and 8 are compared that the 1⅜-in I.D. hose and pipe are too small.

When the rooms were connected to the breather bag, it was difficult to keep the oxygen level up to between 2 and 3 percent. It was found that, if the bag was disconnected or shut off, the rooms would maintain an almost constant oxygen level without adding any ventilating air. On several occasions the CA oxygen content went above the desired level; at these times the bag was connected to the room and the oxygen level was brought down in a few days.

One of our breather bags was used by Smock and Branton (4) for a few weeks during December, 1953, and January, 1954. Their results indicated that the bag helped to reduce the oxygen level of the room. The bag plus nitrogen gas had more effect than the bag alone.



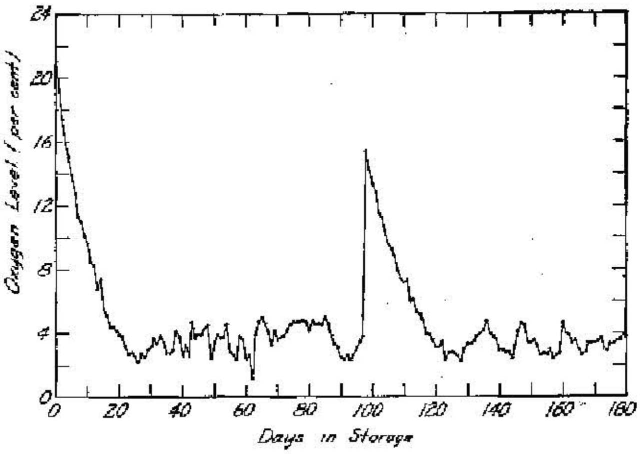


Fig. 4 *(Left)* Oxygen level in storage room No. 1 during storage season • Fig. 5 *(Right)* Oxygen level in storage room No. 2 during storage season

An analysis was made of the variables affecting the oxygen level of the CA storage in an attempt to rationalize the results obtained. The quantity of air drawn into the storage during each temperature cycle was obtained by using the differential pressure data illustrated in Figs. 6, 7, and 8 to find the rate of leakage from Fig. 2. A curve of leakage rate as a function of time was then plotted, and the area under the curve, leakage per cycle in cubic feet, was obtained by measuring the area under the curve with a planimeter and multiplying by the unit area factor. The average of a number of these analyses gave the leakage through cracks per temperature cycle as 4.27 cu ft without the breather bag, 1.72 cu ft when the bag was connected with the 1⅜-in hose and 0.65 cu ft when the 2⅝-in hose was used.

The average temperature cycle of the storage room under study was about 0.5 F. The volume change calculated by the general gas law $PV/T - P'V'/T'$ for a room containing 4330 cu ft of atmosphere, for a 0.5 F temperature change assuming the pressure is constant is 4.4 cu ft. Using the same equation and temperature condition, the pressure change for a rigid hermetic room would be 0.4 in of water. The behavior of the room therefore can be explained by physical laws.

The flexible breather bag, theoretically as part of the room, permits the volume of the room to change as the volume of the atmosphere in the room changes with temperature and pressure. From a practical standpoint, we can only approach this ideal situation because of the weight of the bag and the pressure drop in the elements connecting the expansion chamber with the room.

The oxygen used by the fruit under CA conditions of 3.5 percent O_2 and 5 percent CO_2 calculated from data presented by Van Doren (6) is 46.5 cu ft per day. The air leakage of room No. 2 (the product of the number of temperature cycles, average of 70 per day, and the leakage rate per cycle, 4.26 cu ft) is 303.2 cu ft per day when the room is not connected to the breather bag. Using a modification of the formula presented by Sainsbury and Gerhardt (2), the calculated oxygen gain under the condition illustrated in Fig. 7 is 52.3 cu ft per day. With the bag connected under conditions illustrated in Fig. 8 the oxygen gain is only 21.0 cu ft per day.

An analysis of the refrigeration loads of the rooms under study showed that over 80 percent of the cooling load, after removal of field heat, was due to the motors and fans of the unit coolers and a carbon air purifier. The unit cooler and air purifier fans were operated continuously.

Kidd and West (1) point out that barometric pressure changes can affect the time required to obtain the desired atmosphere. A study was made of cycles of the barometric pressure at Amherst, Mass., between October 1, 1953, and March 1, 1954. It was found that the average major cycle required six days and had a range of 0.63 in of mercury (8.58 in of water). The effect of these barometric pressure changes on the storage rooms in this study is to increase the oxygen level by about 15.7 cu ft per barometer cycle, or 2.6 cu ft per day. It appears that the oxygen gain from barometric pressure changes is small compared to the oxygen gain of a room without a breather bag.

In general, this study indicates that a breather bag will probably increase the rate of oxygen reduction of a CA storage that has off-on temperature control and is 92 to 95 percent tight according to Smock (3). The greatest benefit will probably be in small rooms with unit coolers.

It is doubtful if the breather bag aids in reducing the oxygen gain from barometric pressure cycles. Oxygen gain due to scrubbing out carbon dioxide also seems to be beyond control with the breather bag, since the volume of CO_2 scrubbed out must be replaced by air from outside the storage if equilibrium is to be maintained. The bag will improve the operation of a tight room but will do little for a leaky room.

Summary

Observations made during a one-year study of pressure, temperature, and volume relationships of a CA apple storage have been outlined. A method of testing a CA storage for rate of leakage has been described and test data presented. Results from the use of a breather bag to increase the rate of oxygen reduction have been discussed.

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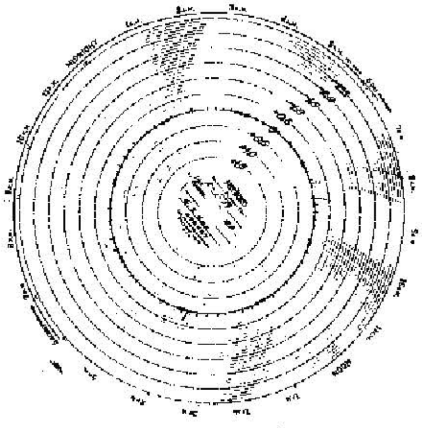

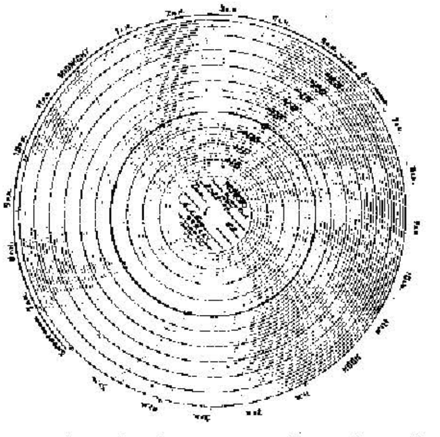

Fig. 6 *(Left)* Chart showing pressure fluctuations of storage room without bag • Fig. 7 *(Center)* Chart showing pressure fluctuations of storage room connected to breather bag with 1⅜-in elements • Fig. 8 *(Right)* Chart showing pressure fluctuations of storage room connected to breather bag with 2⅝-in elements (Pressures in Figs. 6, 7 and 8 are in inches of water)