Figure 1: Simple metabolism of fruit

Basics of Controlled Atmosphere Storage

Editor's Note

The contents of this article have been compiled by the editor, largely from the chapter written by D. Bishop, titled Controlled Atmosphere Storage in the book *Cold and Chilled Storage Technology* edited by C.V.J. Dellino, MD of Tempco Engineering Services, Bedford, UK and published by Blackie & Sons Ltd., Glasgow.

Controlled atmosphere (CA) technology helps to slow down the respiration of fruits and vegetables during storage inside cold stores. Hence storage life of seasonal perishable products is extended and the technique can be used for many fruits and vegetables but it is primarily used for apples and pears. With more research being carried out all over the world, many other commodities are being slowly added to the list.

Perishing is essentially over-ripening and ripening is a consequence of cell metabolism. In normal metabolism in the presence of oxygen, the products of respiration are carbon dioxide, water and heat; low levels of oxygen inhibit the rate of respiration. See *Figure 1*. The plant hormone ethylene is also produced during the ripening process and acts to promote further ripening. Extension of the storage life of fresh plant produce is dependent on applying techniques which reduce the rate of cell metabolism without causing injury to the produce itself. Refrigeration is the most important technique, but because produce can be frozen or suffer from low-temperature disorders, a compromise minimum safe temperature has to be accepted. Measures to delay the synthesis of ethylene or inhibit its action may also result in an extension of storage life for some types of fruits.

The most important supplement to refrigeration for the storage of fruit is CA storage, in which carbon dioxide produced by respiration is allowed to increase to a safe maximum level and the oxygen is decreased to the lowest safe concentration.

The precise levels of temperature, oxygen and carbon dioxide required to maximise life and minimise storage disorders are extremely varaiable. They depend on produce, cultivars, growing conditions and maturity. Optimum storage conditions can vary from farm to farm and from season to season. Because of this variability, storage conditions given in this article are only indicative and expert guidance should always be sought.

Brief History of CA

The first recorded experiments to control fruit ripening by changing the surrounding atmosphere were carried out in France by Jacques Berard in 1821. The results of his experiments won him the Grand Prix de Physique from the French Academy of Sciences, but failed to inspire any commercial application.

In the 1860s in Cleveland, Ohio a commercial storage operator called Nyce limited the oxygen available to his fruit in a sheet-metal-lined ice-cooled store. He realized the fruit generated "carbonic acid", and he reported improved storage life and increased profits!

In 1918 Kidd and West started a thorough scientific investigation at the Food Investigation Organization in Cambridge. They had many problems to solve which required the cooperation of engineers and physicists to help overcome the practical problems of making gas-tight stores. Kidd and West later moved closer to the fruit-growing industry in Kent, and helped establish the Ditton Laboratory where they continued their pioneering work. In 1969 the Ditton Laboratory was incorporated into the East Malling Research Station, which has become the world's leading CA research institution. Pioneering work was carried on there in the 1960s with Fidler, Mann and North making many improvements in storage techniques. This work has continued until the present day under the guidance of Sharples who, with the help of North, introduced the commercial use of ultra low oxygen (ULO) storage in the late 1970s.

In Europe, it was only after the second world war in 1950 that the real application of CA started by Bonomi, the father of commercial CA in Europe and the founder of the company named Bonomi System, that started to spread the technology of CA in Europe.

In Australia, Mcglasson and Wills found that at 20°C the storage life of an unripened banana could be extended from 16 days to 182 days in a CA atmosphere of 3% oxygen and 5% carbon dioxide.

Controlled Atmosphere Conditions

The first CA stores used a simple increase in the carbon dioxide levels. In this regime the carbon dioxide produced by respiration of the fruit is allowed to accumulate within the sealed store. The carbon dioxide level is measured and when it reaches a predetermined value the store is ventilated with air at a controlled rate to maintain the required concentration.

This storage system is still successfully and widely used in the UK for the storage of Bramley Seedling apples with a typical carbon dioxide level of 8%. Because high carbon dioxide levels cause injury in many varieties, the next stage of CA storage involves the

Some Definitions

Gas Storage: The storage of any product in an environment that differs from ambient air (21 % O_2, 300 ppm CO_2).

Controlled Atmosphere (CA): A low oxygen and/ or high CO_2 atmosphere is created by natural respiration or artificial means. It is then controlled by a sequence of measurements and corrections throughout the storage period. Its common use is confined to fixed storage warehouses, bulk shipment and transport containers with self contained control capacity.

Modified Atmosphere (MA): With MA an atmosphere of the required composition is created by respiration, or mixed and flushed into the product enclosure. The mixture is expected to be maintained over the storage life and no further measurement or control takes place. This definition is commonly used to describe produce in retail packing, which is usually designated Modified Atmosphere Packaging or MAP. In some systems there is an element of control by using packing materials with suitable gas exchange characteristics. MAP is an expanding technology.

ControlledVentilation: This is when CO_2 is permitted to build up naturally due to respiration and is controlled by ventilation at a chosen level. This method can be used both to enhance the level of CO_2 to improve storage life or, conversely, to prevent build-up to harmful levels of CO_2 produced by respiration.

Ultra Low Oxygen Storage (ULO): This term was used by Sharples and others in East Malling in the early 1980's when the recommended O_2 concentration for storage condition of Cox apples was reduced from 2% to l.25% oxygen. It is now commonly but incorrectly used, particularly in mainland Europe, for storage in O_2 concentrations of 2% and below.

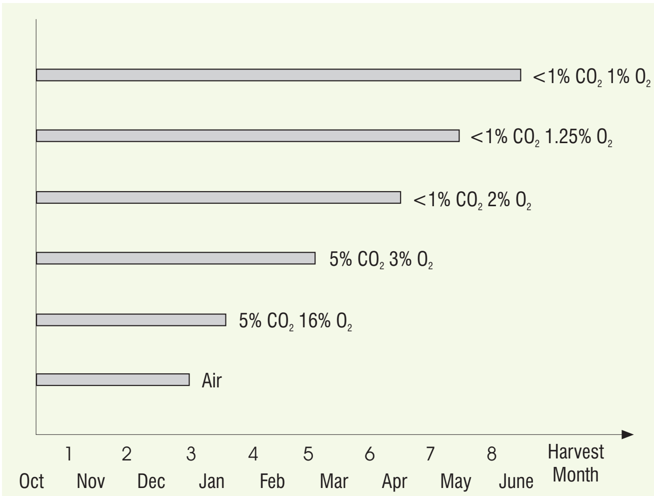

Figure 2 : Storage life of Cox Orange Pippin apples in various atmospheres.

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Country	% O_2	% CO_2	Temp. °C
Australia (Victoria)	1.5	1.0	0.0
Belgium	2.0	2.0	0.5
Brazil	1.5 ® 2.5	3.0 ® 4.5	1.0 ® 1.5
Canada (Ontario)	2.5	2.5	0.0
China	2.0 ® 4.0	4.0 ® 8.0	5.0
France	1.0 ® 1.5	2.0 ® 3.0	0.0 ® 2.0
Germany (Westphalia)	1.0 ® 2.0	3.0 ® 5.0	1.0 ® 2.0
Holland	1.2	4.0	
Israel	1.0 ® 1.5	2.0	- 0.5
Slovenia	1.0	3.0	0.0
South Africa	1.5	1.5	- 0.5
Spain	3.0	2.0 ® 4.0	0.5
USA (New York)	1.5	2.0 ® 3.0	0.0
USA (Washington)	1.0 ® 1.5	< 3.0	1.0
USA (Penn)	1.3 ® 2.3	0.0 ® 0.3	- 0.5 ® 0.5

Table 1 : Recommendations of Storage Conditions by Country for Golden Delicious Apples
Note : These storage conditions are only indicative and local guidance should always be sought.

Fruit	% O_2	% CO_2	Temp. °C	Notes
Apricot	2 ® 3	2 ® 3	0 ® 5	
Avocado	2 ® 5	3 ® 10	10 ® 13	(1)
Banana	2 ® 5	2 ® 5	12 ® 16	(1)
Blueberry	2 ® 5	12 ® 20	0 ® 5	(1)
Cherry	3 ® 10	10 ® 15	0 ® 5	(1)
Grapefruit	3 ® 10	5 ® 10	10 ® 15	(2)
Kiwifruit	1 ® 2	3 ® 5	0	(1),(3)
Lemon / Lime	5 ® 10	0 ® 10	10 ® 15	(2)
Mango	3 ® 5	5 ® 10	10 ® 15	
Orange	5 ® 10	0 ® 5	5 ® 10	(2)
Papaya	2 ® 5	5 ® 8	10 ® 15	
Peach	1 ® 2	3 ® 5	0 ® 5	
Persimmon	3 ® 5	5 ® 8	0 ® 5	
Pineapple	2 ® 5	5 ® 10	8 ® 13	(2)
Plum	1 ® 2	0 ® 5	0 ® 5	(1)
Raspberry	5 ® 10	15 ® 20	0 ® 5	(1)
Redcurrant	2 ® 5	12 ® 20	0 ® 5	(1)
Strawberry	5 ® 10	15 ® 20	0 ® 5	(1)

Table 2 : Typical CA Storage Conditions for Fruits.
Notes: (1) In regular commercial use (2) CA not considered commercially beneficial (3) very low ethylene for long term storage (4) These storage conditions are only indicative and local guidance should always be sought.

Vegetables	% O_2	% CO_2	Temp. °C	Notes
Artichokes	2 ® 5	2 ® 3	0 ® 5	
Asparagus	-	10 ® 14	0 ® 3	(2)
Broccoli	1 ® 2	5 ® 10	0 ® 5	(2)
Brussels sprouts	1 ® 2	5 ® 7	0 ® 5	
Cabbage (White)	3	5	0	(1)
Cantaloupe melon	3 ® 5	10 ® 20	2 ® 7	
Lettuce	1 ® 3	0	0 ® 5	
Onions	3	5	0	(1),(3)
Potatoes	-	-	4 ® 7	(4)
Sweet Corn	2 ® 4	5 ® 10	0 ® 5	
Tomatoes	3 ® 5	3 ® 5	10 ® 15	(2)

Table 3 : Typical CA Storage Conditions for Vegetables
Notes: (1) In regular commercial use for long term storage (2) Used in transportation (3) Stored at 65% - 75% RH (4) Considerable research with potatoes with, as yet, variable results on the potential benefit of CA storage (5) These storage conditions are only indicative and local guidance should always be sought.

removal of carbon dioxide. This is removed from the atmosphere, and the oxygen level remains low as it is depleted by the fruits' respiration. The level of carbon dioxide is controlled by adjusting the amount of removal or 'scrubbing', and the oxygen is controlled by ventilating with air. A level of 5% carbon dioxide and 3% oxygen has been widely used for many years for the storage of most common varieties.

Low-oxygen storage with oxygen levels of 2% and carbon dioxide levels less than 1% have now superseded the 5:3 levels in many stores, and ULO storage using between 1% and 1.5% oxygen with lower than 1% carbon dioxide are used (with caution) in some of the most modern automatically controlled stores.

Figure 2 shows typical storage life of Cox Orange Pippin apples in different atmospheres, showing the increase in storage potential using lower oxygen conditions. As well as prolonging life the lower oxygen levels also improve firmness, texture and the crispness of the marketed fruit. Some people consider there is a deterioration in flavour and aroma especially at ULO conditions, but this can be improved by increasing the oxygen during the last few weeks of storage.

Table 1 gives a summary of current CA recommendations for storage of Golden Delicious apples in different countries. *Tables 2 & 3* give CA storage recomentation for various other fruits and vegetables. These are only guides and expert opinion should be used for local conditions.

Ethylene

Ethylene is produced by fruit as part of the ripening process and its presence accelerates ripening. CA storage reduces ethylene production, but it can still build up to significant levels in CA rooms. It has been shown that reduction in these ethylene levels improves the storage life and reduces disorders.

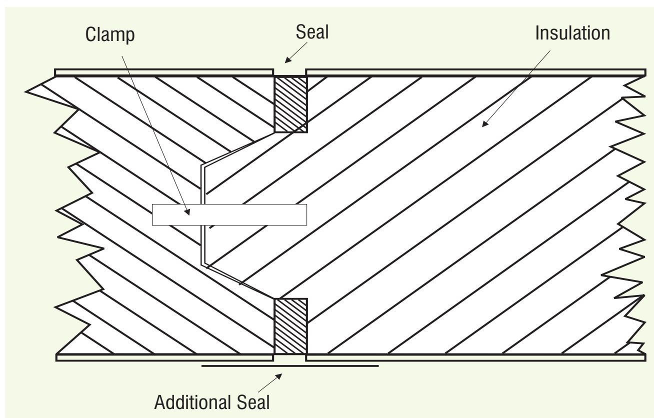

Figure 3 : Joint between interlocking insulated panels.

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Equipment is available for ethylene removal but because of its high cost this equipment is not in widespread commercial use.

Ethylene removal is also useful in the air storage of produce such as Kiwifruit and cut flowers, both of which are extremely sensitive to ethylene levels of around 0.1 ppm.

Storage Rooms

The first consideration when planning a CA store is the size. A major consideration in determining size is the speed of loading and unloading. For optimum storage conditions a store should be completely filled with fruit of the same (or a compatible) variety in a matter of one or two days. When emptying a store, the fruit should be graded and packed in 7-10 days after the store is opened. lt is therefore preferable to have the total storage capacity divided into smaller units, but of course this is more expensive and economic considerations apply. In the UK an average store size would be about 100 tonnes, with variations between 50 and 200 tonnes. In North America the stores are larger, averaging 30,000 bu (600 tonnes), whilst in continental Europe the average size is about 200 tonnes.

CA stores are constructed in a similar manner to conventional cold stores. A CA store must, however, be gas-tight and this is achieved by careful attention to detail in design and workmanship. This is usually a job best left to experts, and many problems have been incurred by inexperienced contractors trying to build new stores or convert existing cold stores for CA use.

Almost all CA stores now being built in Europe are made from metal-faced insulating panels locked together with proprietary locking systems. Gastightness of the joints is usually increased by taping and coating with a flexible plastic paint. This process is also carried out on the floor-wall joints and wall-ceiling joints. See *Figure 3*.

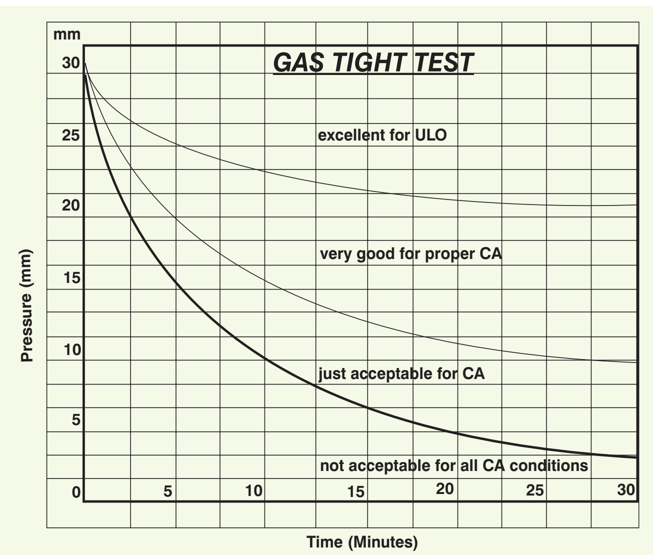

Figure 4 : Store leak testing

Doors are a common leakage area, and they have to be of very substantial construction to allow sealing with a rubber gasket around the perimeter. The doors on modern stores are almost always of the sliding variety and should be of sufficient height to allow efficient loading with fork lift trucks.

Particular care has to be taken in gas-sealing all the internal fixings and entries for pipes and cables. Drains for the removal of condensate water have to be properly designed with U-traps to ensure that water can escape without breaking the room seal.

Each store should be fitted with inspection hatches to allow access to the fruit for routine examination during the storage period. It is common practice in Europe to include double or triple glazed windows usually adjacent to the store ceiling to allow visual inspection of the condition of the fruit and to check for the ice build-up on the refrigeration coils.

In North America panel-built stores are not so common. Here it is usual to construct the stores with either timber frame and plywood boarding, or with concrete blocks or tilt-up concrete walls. The store is then sealed and insulated with foamed-in-place urethane which is then coated with a fire retardant.

To protect the store structure from damage due to excessive positive and negative pressures it is essential to install a pressure relief valve. This valve should limit the pressure on the store structure in either direction to 25 mm water.

Store Leakage Specification

To check that a CA store is capable of being properly sealed it is essential for the store to be tested for leak tightness before it is loaded with produce. This is done by pressurizing the room and measuring the rate at which the pressure falls. See *Figure 4*. The room is prepared for testing by checking that all doors, hatches, drains, valves and pipes are closed. A sensitive pressure gauge (manometer) is connected to the store; an inclined-tube water manometer is the best type to use. A dial-type bourdon tube pressure gauge must not be used, as this is nowhere near sensitive enough. After the manometer has been connected the store should be pressurized with a small air blower. A domestic vacuum cleaner can be used for this, but care is needed as these can produce enough pressure to cause structural damage even to very large stores. The store should be pressurized to 25 mm water gauge. When this is

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achieved the blower should be stopped and the air inlet to the store sealed. If 25 mm pressure cannot be achieved a large leak is indicated, and this requires rectification before continuing.

The rate at which the pressure falls is measured, and is an indication of the store leakage rate. In the UK the time taken for the pressure to fall from 20 mm water gauge to 13 mm is measured. In a store intended for storage at 2.5% oxygen and above, the minimum recommended time is 7 minutes. For stores running at 2% oxygen and lower, 10 minutes should be the minimum. It is not uncommon for well-constructed stores to take up to 30 minutes to lose 7 mm of water gauge pressure. North American operators define their tests slightly differently, and the time recorded is that required for the pressure to fall to half the starting value. For example, the time will be the same for a fall from 25.4 mm to 12.7 mm (1" to 0.5") as for 12.7 mm to 6.4 mm (0.5" to 0.25"). The acceptable time for this is 30 minutes for all low-oxygen stores with all types of scrubber, but for 3% oxygen rooms 20 minutes is acceptable. Incidently the North American '20 min' room is equivalent to 12 minutes on the UK test, and the '30 min' room to 18 minutes.

Refrigeration

CA stores are by their nature long-term stores, and therefore product weight loss is a very important consideration in the design. The refrigeration system should be designed for a very small temperature difference between the produce and cooler surface, thus maintaining high humidity and minimizing the defrosting required. Secondary refrigeration systems using pumped glycol or brine are the most satisfactory, but many successful direct expansion systems with properly designed evaporators are in use. Flooded ammonia systems are also popular in the UK, and are regularly used in the USA.

To maximize the fruit storage potential the recommended store temperatures are specified to be close to the minimum before damage occurs. It is therefore important that close temperature control is achieved and that the temperature differences throughout the store are minimized.

Good circulation of air throughout the store is essential, and the recommended rate is in the range of 30-50 empty room volumes per hour. This can be reduced after temperature pull-down to half, or less, of the initial rate. A well-designed and operated CA store will have temperature differences within the store of less than 0.5^{0}C. It is common practice to control the store temperature with an electronic thermostat with accuracies of better than 0.2^{0}C and control differentials adjustable down to less than 0.5^{0}C.

These thermostats are used to control the air temperature in the store and the probe is normally mounted in a position away from the main air stream from the cooler to reflect the average store temperature. A convenient location for this is halfway up the rear wall of the store behind the cooler ducting. A second thermostat should always be used to prevent freezing of the fruit. This is particularly important in pear stores when an override thermostat controlling the minimum temperature of the air off the cooler should be fitted.

In order to minimize the refrigeration running time, the heat input to the store must be reduced to a minimum. A major source of heat input other than the respiration of fruit itself is the air circulation fan. These are sometimes switched off to reduce power, but great care must be taken to maintain even temperature distribution within the store. Some stores now use accurate thermometers to measure the differential temperature within the store and use this to control the fans either by variable speed fans or by on/off cycling. Both these methods have proved satisfactory and have given substantial power savings and as a result, less fruit weight loss. The reduction in fruit weight loss and improved quality are generally of a greater economic benefit than savings obtained by a reduction in electricity consumption.

If ammonia is used as a refrigerant and piped directly into the store evaporator, then some means of measuring and alarming for ammonia leakage within the store is recommended. A small ammonia leak can go unnoticed in a sealed CA store and can cause severe damage to the stored fruit.

Machines for Maintaining Gas Concentration

Selection of the appropriate equipment for creating and maintaining the correct gas concentration levels in the CA stores is very important but is beyond the scope of this article. Expert opinion should be obtained for selecting the following equipment :

- Removal of ambient oxygen.
- Removal of CO_2 produced by respiration.
- Addition of air to replace oxygen consumed by respiration.
- Removal of ethylene
- Addition of CO_2.

Conclusion

Controlled atmosphere storage technology has arrived in India with a few projects that have been completed,

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some that are under installation and some that are currently being planned. Not enough experience has been gained by the new operators that can be talked and written about as yet.

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CA Storage Comes to India

Container Corporation of India, popularly known as CONCOR is India's leading multimodal logistics company.

Considering it's future growth requirements and as a part of business strategy CONCOR has identified "agri-business" for diversification and extension of it's core business. The ambitious *Cold Chain* project is an important addition to it's operation. As a part of this project, CONCOR is setting up the country's largest controlled atmosphere cold store of 12,000 MT capacity at Rai on

the Delhi-Chandigarh highway near the Delhi border.

The project is designed primarily to store apples grown in the northern regions of the country along with some other fruits. The CA storage will extend the life and preserve the quality of the fruit stored for distribution over a longer period. The complex houses 78 CA chambers, each of 150 MT capacity designed to maintain the required temperature, RH, oxygen and CO_2 levels. The complex also includes sorting, grading and packing facilities provided with controlled temperature and RH conditions.

The project is being implemented by *Infracool* on a turnkey basis and is expected to be completed in the next few months. *ACR Project Consultants of Pune* in association with *Feedback Ventures, Delhi*, are providing the design review and monitoring services for the project implementation.

(This news item on the CONCOR project along with the above photo are by courtesy of Arvind Surange of ACR Project Consultants, Pune.) ❖