

20) CONTROLLED ATMOSPHERE STORAGE

Controlled atmosphere storage is a system for holding produce in an atmosphere that differs substantially from normal air in respect to CO₂ and O₂ levels. Controlled atmosphere storage refers to the constant monitoring and adjustment of the CO₂ and O₂ levels within gas tight stores or containers. The gas mixture will constantly change due to metabolic activity of the respiring fruits and vegetables in the store and leakage of gases through doors and walls. The gases are therefore measured periodically and adjusted to the predetermined level by the introduction of fresh air or nitrogen or passing the store atmosphere through a chemical to remove CO₂.

There are different types of controlled atmosphere storage depending mainly on the method or degree of control of the gases. Some researchers prefer to use the terms "static controlled atmosphere storage" and "flushed controlled atmosphere storage" to define the two most commonly used systems. "Static" is where the product generates the atmosphere and "flushed" is where the atmosphere is supplied from a flowing gas stream, which purges the store continuously. Systems may be designed which utilize flushing initially to reduce the O₂ content then either injecting CO₂ or allowing it to build up through respiration, and then maintenance of this atmosphere by ventilation and scrubbing.

IMPORTANCE OF CONTROLLED ATMOSPHERE

CA storage has been the subject of an enormous number of biochemical, physiological and technological studies, in spite of which it is still not known precisely why it works. The actual effects that varying the levels of O₂ and CO₂ in the atmosphere have on crops varies with such factors as:

- a. The species of crop
- b. The cultivars of crop
- c. The concentration of the gases in the store
- d. The crop temperature
- e. The state of maturity of the crop at harvest
- f. The degree of ripeness of the climacteric fruit
- g. The growing conditions before harvest
- h. The presence of ethylene in the store

There are also interactive effects of the two gases, so that the effects of the CO₂ and O₂ in extending the storage life of a crop may be increased when they are combined. The practical advantages of storage under CA can be summarized as follows:

1. A considerable decrease in respiration rate, with a reduction in climacteric maximum, accompanied by an expansion of both pre-climacteric and post-climacteric periods
2. A reduction in the effect of ethylene on metabolism due to the interaction of O₂ with ethylene, with a consequent delay of appearance of senescence symptoms
3. An extension in storage life, which can even be doubled, in as much as the over ripening is delayed
4. The preservation of an excellent firmness of flesh, due to effect of CO₂ concentration on the enzymes acting on cellular membranes
5. A high turgidity is achieved, such that fruits are more juicy and crisp
6. A smaller loss of acidity, sugars and vitamin C, so that the nutritional and sensory quality is higher
7. A limited degradation of chlorophyll, with a consequent higher stability of colour

8. Some physiological alterations, such as chill injuries, spot, decay, browning, water core and scald are prevented, or greatly limited
9. Moulds can be reduced, in particular under low O₂, high CO₂ atmospheres
10. A longer shelf life in the post storage trading, which can even be trebled thanks to the protraction of the effects on respiration and on the other metabolic activities.

FRUITS AND VEGETABLES STORAGE UNDER CA

The storability of fruits and vegetables is strictly related to their respiration rate, which is an expression of metabolic activity. Aerobic respiration requires O₂, and results in CO₂ and heat release. More than 95% of the energy released is lost as heat. The temperature decrease, in particular if helped by modification of the atmosphere leads to a reduction in respiration rate, and therefore to an increase in storage life in fruits with climacteric respiration.

Selection of the most suitable atmosphere depends on cultivars, stage of maturity, environmental and cultivation parameters. No one atmosphere is best for all produce, specific recommendations and cautions must be determined for each crop over the range of storage temperature and periods.

Some examples of CA atmospheres can be seen in Table 1 and 2.

Table 1. Controlled atmosphere conditions for some fruit species (from Gormley, T.R., 1985)

Species	Temper. °C	RH (%)	O ₂ (%)	CO ₂ (%)	Time
Avocado ⁽¹⁾	7/12	90	2-3	3-10	2 months
Cherry ⁽²⁾	0	95	3-10	10-12	30 days
Kiwi ⁽³⁾	0	98	2	4-5	7 months
Nectarine ⁽⁴⁾	-0.5/0	95	2	5	50 days
Peach ⁽⁴⁾	-0.5/0	95	2	4-5	40 days
Plum ⁽⁵⁾	0	95	2	5	45 days

1. In avocado, CA reduces chilling injury and delays softening
2. Pre-cooling is necessary
3. Kiwi is damaged by high CO₂, and low O₂. Small amounts of ethylene must be eliminated for a long storage life
4. Pre-cooling is necessary, also rapid attainment of a Ca is useful
5. Different varieties behave differently in CA storage; some varieties are susceptible to internal breakdown.

Table 2. Controlled atmosphere conditions for some vegetable species (from Gormley, T.R., 1985)

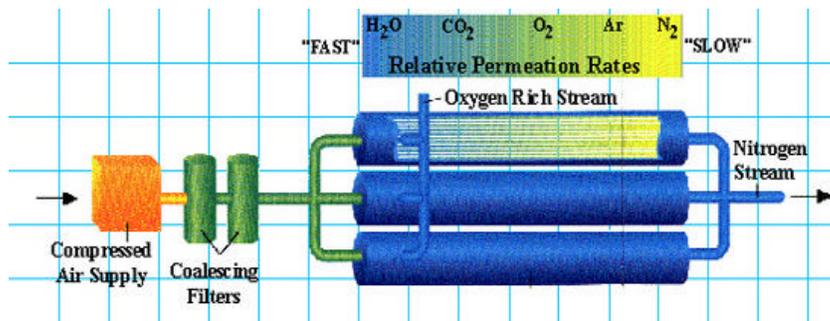
Species	Temper. °C	O ₂ (%)	CO ₂ (%)	Time
Asparagus	1-4	10-16	10-14	10-15 days
Artichokes	0-1	2-4	2-3	20-25 days
Broccoli	0	2-3	5-10	10 days
Cabbage	0	2-3	4-5	3-4 months
Cauliflower	0	3-4	5-7	40-50 days
Cucumber	12	1-4	0	20 days
Garlic	-1	3	5	7 months
Green beans	7	3-4	4-5	10 days
Leeks	0	2-4	5-10	5 months
Onions	0	1-2	0-1	9 months
Tomatoes	2	3-4	2-3	30-40 days

ATMOSPHERE CONDITIONING

The reduction of O₂ level inside the storage rooms can be biologically achieved by means of fruit respiration, or by O₂ burning, or by replacing air by feeding nitrogen. In first case, the reduction in O₂ down to a steady state level takes place within 15-25 days, with a slow and progressive decrease thereof. When a non-biological system is used, O₂ can be reduced to levels of 68% within 24 h and the subsequent lowering to the desired levels for storage can take place via respiration.

The reduction in O₂ level can be rapid only if the fruits have reached a temperature lower than 5°C. However, waiting for some days for the fruit to be cooled is better, in order not to cause asphyxia, with browning developing at the surface, or inside the first layers of fruit flesh, or hollows being formed inside the tissues of the core.

Fast cooling, in order to enable the storage room to be rapidly scaled, is only possible by hydrocooling. Otherwise it is essential to transfer the product from room to room. The fastest reduction in O₂ level in the atmosphere is obtained by using nitrogen generators (by now, a widely used system), or by feeding liquid N₂. Lowering O₂ down to steady state controlled atmosphere levels by means of non-biological techniques is disadvantageous from a financial standpoint, due to the high consumption of fuel or of nitrogen. Nitrogen generators selectively separate air to produce an enriched nitrogen system.



Nitrogen separation from the compressed air supply



Nitrogen generator systems using membrane separators

CA STORAGE ROOMS

A gas tight room is an obvious prerequisite for achieving a good controlled atmosphere. Thus it is necessary to make room walls gas-tight. In order to ensure that the walls were gas tight to CA storage they were lined with sheets of galvanized steel.



Doors may be mounted on a sliding rail, as pictured to the left. Or, they may be mounted to open vertically on overhead rails, as pictured to the right.

The bottoms and tops of the steel sheets were embedded in mastic (a kind of mortar composed of finely ground limestone, sand, litherage and linseed oil) and, where sheets abutted on the walls and ceiling, a coating of mastic was also applied. Modern controlled atmospheres stores are made from metal-faced insulated panels (usually polyurethane foam), which are fitted together with gas tight-patented locking devices. The joints between panels are usually taped with gas tight tape or painted with flexible plastic paint to ensure that they are gas tight.

Major areas of the store where leaks can occur are the doors. Having rubber gaskets around the perimeter, which correspond to another rubber gasket around the doorjamb or frame so that when the door is closed the two meet to seal the door, usually seals these.

Sealed CA rooms go through many pressure changes during the storage season. There is a danger of damaging the walls or ceiling of the rooms if proper measures are not taken to absorb the pressure changes. Pressure/vacuum relief valve is a simple solution to the problem. With this valve mounted externally to a 4" pipe penetrating one wall of the room, a non-threatening pressure level can be kept in the room. Where there is a pressure difference between the store air and the outside air there can be a difficulty in retaining the store in completely gas tight condition. Stores are therefore fitted with pressure release valves, but these can make the maintenance of the precise gas level difficult, especially the O₂ level in the ultra low O₂ store.



Pressure release valve is pictured to the left, expansion bag is pictured to right

An expansion bag may be fitted to the store to overcome this problem of pressure differences. The bags are gas tight and partially inflated and are placed outside the store with the to the bag inside the store. If the store air volume increases then this will automatically further inflate the bag and when the pressure in the store is reduced then air will flow from the bag to the store. The inlet of the expansion bag should be situated before the cooling coils of the refrigeration unit in order to ensure the air from expansion bag is cooled before being returned to the store. With an increasing need for Ultra-lo Oxygen (ULO) storage of fruit, the use of air bags is growing in popularity. The air bag can be used in conjunction with a balance/cascading air line on a series of CA rooms to help absorb pressure changes without changing the oxygen content of the rooms.

Temperature Control

The main way of preserving fruits and vegetables in storage or during long distance transport is by refrigeration, and controlled atmospheres are considered a supplement to increase or enhance the effect of refrigeration. CA storage is only successful when applied at low temperatures. Standard refrigeration units are therefore integral components of CA stores. Temperature control is achieved by having pipes containing a refrigerant inside the store. Ammonia or chlorofluorocarbons are common refrigerants. These pipes pass out of the store; the liquid is cooled and passed over the cooled pipes. All temperature measurement systems depend fundamentally on the quality of the measuring sensor. In commercial practice for CA stores the store temperature is initially reduced to 0 °C for a week or so whatever the subsequent storage temperature will be. Also, CA stores are normally designed to a capacity, which can be filled in 1 day, so fruit are loaded directly into store and cooled the same day.

Humidity Control

Most fruits and vegetables, which are kept in CA storage, require a high relative humidity, generally the closer to saturation the better, so long as moisture does not condense on the crop. The amount of heat absorbed by the cooling coils of the refrigeration unit is related to the temperature of the refrigerant they contain and the surface area of the coils. If the refrigerant temperature is low compared to the store air temperature then water will condense on the evaporator. This removal of moisture from the store air reduces its relative humidity, which results in the stored crop losing moisture by evapo-transpiration. In order to reduce crop desiccation the refrigerant temperature should be kept close to the store air temperature.

A whole range of humidifying devices can also be used to replace the moisture in the air, which has been condensed out on the cooling coils of refrigeration units. These include

spinning disc humidifiers where water is forced at high velocity onto a rapidly spinning disc. A technique, which retains high humidity within the store, is via secondary cooling so that the cooling coils do not come into direct contact with the store air. Ice blank cooling is also a method of secondary cooling where the refrigerant pipes are immersed in a tank of water so that the water is frozen. The ice is then used to cool water and the water is converted to a fine mist, which is used to cool and humidify the store air.

Gas Control

The atmosphere in a modern CA store is constantly analysed for CO₂ and O₂ levels using an infrared gas analyser to measure the gas content in the store constantly. They need to be calibrated with mixtures of known volume of gases.



Portable dual gas analyzer capable of measuring oxygen (0-25%) and carbon dioxide (0-10%) and ethylene analyzer

There are also ethylene analyzers that continuously measure ethylene concentration in the store. In storage rooms where low ethylene is essential, checks can be made that the ventilation and ethylene removal systems are operating correctly. The minimum resolution of 0.2 ppm makes this instrument very useful for most products and for the ultra ethylene sensitive products such as Kiwi Fruit, a reading on this machine will indicate severe storage atmosphere problems.

There are many gas control systems in CA rooms. Carbon dioxide and oxygen sensors are located in the store atmosphere, and send a low voltage signal back to the controller which may be mounted outside the store. This eliminates the need for sample tubing or pumps, and gives continuous real time readings. Gas control systems can extend from 6 to 62 rooms. It provides individual settings in each room, for any gas and temperature storage regime.





Gas control systems

Two miniature display/controllers, one each for oxygen and carbon dioxide, make up the CA store controller. It features the following control functions: control output for store ventilation when oxygen is low; control output for nitrogen purge when oxygen is high, or if selected, when carbon dioxide is high; control output for scrubbers when carbon dioxide is high; and an optional control output for adding CO₂ when carbon dioxide is low.

Scrubbers

The composition of the gas mixture inside the storage rooms undergoes continuous change as a function of the metabolic activity of the stored product and scrubbers are necessary to absorb excess CO₂. Scrubbers are generally classified according to the absorbent material: Ca(OH)₂, NaOH, H₂O, zeolites, activated charcoals. They are classified according to the mode of absorption (i.e. chemical or physical), or to the mode of air passage through the absorbing agent. Scrubbers using activated charcoal are currently the most popular. Gas removal with this type of equipment is based on the fixing of CO₂ in a particular way, and releasing it again on contact with atmospheric air, even at room temperature.



Scrubber: The unit consists of an activated carbon filter chamber, a low-pressure ventilator, an air-transport system, a control unit, and a buffer or lung system.

Scrubbers use advanced electronic PLC control and a panel mounted Carbon Dioxide Analyzer to constantly monitor the status of the carbon beds. Through careful monitoring of CO₂ levels, the scrubber switches cycles only when needed, keeping the cycles to a minimum and efficiency to a maximum. By filtering in the scrub air and the fresh purge air, carbon life is also kept to a maximum.

CARBON DIOXIDE AND OXYGEN DAMAGE

CA storage have also adverse effects, at O₂ levels below 1%, in the absence of CO₂, anaerobic conditions can prevail with the consequent formation of alcohol and physiological changes. Also high CO₂ and low O₂ may cause abnormality in metabolism. The level of CO₂, which

can cause damage to fruit and vegetables, varies between cultivars of the same crop. Variability in plant material prevents precise control of intercellular atmosphere; recommendations can be designed only to avoid complete anaerobic conditions and a harmful level of CO₂ in the centre of the permeable individual fruit and vegetable. Some examples of CA injury can be seen in Table 3.

Table 3. Examples of CA injury (from Thompson A.K, 1998)

Crop and cultivars	CO ₂ injury level	CO ₂ injury symptoms	O ₂ injury level	O ₂ injury symptoms
Apple, red delicious	>3%	Internal browning	<1%	Alcoholic taste
Apple, Fuji	>5%	CO ₂ injury	<2%	Alcoholic taint
Apple, Gala	>1.5%	CO ₂ injury	<1.5%	Ribbon scald
Apricot	>5%	Loss of flavour	<1%	Of-flavour
Banana	>7%	Green fruit softening	<1%	Brown skin, discoloration
Green beans	>7%	Off flavour	<55	Off-flavour
Cabbage	>10%	Discoloration of inner leaves	<25	Off-flavour
Cherry	>30%	Brown, discoloration	<1%	Skin pitting, off-flavour
Mango	>10%	softening	<2%	Skin discoloration

CA DEVELOPMENT

The direction suggested by studies carried out in the past as to the most suitable gas composition has changed progressively on the basis of the new experiences gained, on the development of new support equipment, and of new structural technologies. From atmospheres where O₂ and CO₂, generated by fruit respiration, were in equilibrium (O₂ 11-16%; CO₂ 5-10%), the studies have progressively turned to atmospheres with limited concentrations of O₂ and CO₂, accomplished by means of air cleaners (O₂ 2-3%; CO₂ 2-5%). More recently, lower O₂ and CO₂ levels (respectively 1-1.5% and 0-1%) were investigated.

This concept of the progressive reduction of O₂ and CO₂ in the atmosphere, in order to limit the respiratory activity and thus more or less extend the storage life of the product, led to the adoption of the so-called ULO (Ultra low oxygen) system. The advantages of ULO are particularly evident when the temperature and O₂ concentration are simultaneously quickly reduced in the atmosphere inside the storage rooms. This is called RCA, rapid controlled atmosphere. High CO₂ treatment (10-15% for 10-15 days) and initial O₂ stress have also been proposed to enhance the effects of CA storage.

Further developmental proposals for CA modification are dynamics CAs, in which O₂ and CO₂ levels are changed during storage according to previously programmed patterns, or as a function of physiological parameters of stored fruit, or with an intermittent enrichment with high-dosage CO₂ for a few days.

CA TRANSPORT

A large and increasing amount of fresh fruit and vegetables is transported by sea freight (reefer) containers. Controlling the levels of some of the gases in reefer containers has been

used for many years to increase the marketable life of fresh produce. CA containers have some mechanism for measuring the changes in gases and adjusting them to a pre-set level. The degree of control over the gases in container is affected by how gas tight the container is, some early systems had a leakage rate of 5m³/h or more, but current systems can be below 1 m³. The systems used to generate the atmosphere in the containers falls into three categories:

1. The gases that are required to control the atmosphere are carried with the container in either a liquid or solid form
2. Membrane technology is used to generate the gases by separation
3. The gases are generated in the container and recycled with pressure absorption technology and swing absorption technology

The first method involves injecting nitrogen into the container to reduce the level of O₂ with often some enhancement of CO₂. The gases are carried in the compressed liquid form in steel cylinders at the front of the container, with access from the outside.

In containers, which use membrane technology, the CO₂ is generated by the respiration of the crop and nitrogen is injected to reduce the O₂ level. The nitrogen is produced by passing the air through fine porous tubes, made from polyamides, at a pressure of about 56 bar. These will divert most of the oxygen through the tube walls leaving mainly nitrogen, which is injected, into the store.

The containers use ventilation to control O₂ levels and a patented molecular sieve to control CO₂. The molecular sieve will also absorb ethylene and has two distinct circuits which are switched at predetermined intervals so that while one circuit is absorbing, the other is being generated. The regeneration of the molecular sieve beds can be achieved when they are warmed to 100 °C to drive off the CO₂ and ethylene. This system of regeneration is referred to as temperature swing where the gases are absorbed at low temperature and released at high temperature. Regeneration can also be achieved by reducing the pressure around the molecular sieve, which is called pressure swing. A computer controls all the level of gas, temperature and humidity within the container, which is an integral part of the container. It monitors the levels of oxygen from a paramagnetic analyser and the CO₂ from an infrared gas analyser and adjusts the levels to those, which have been preset in the computer.

REFERENCES

- Thompson, A.K. 1998. Controlled Atmosphere Storage of Fruit and Vegetables, CAB International, UK.
- Gormley, T.R., 1985, Chilled Foods, the State of the Art, Elsevier App. Sci. , London, New York.
- Proudlove R.K, 1989, The Science and Technology of Foods, Forbes Publications, England. Storage Control Systems Inc. Web page, www.storagecontrol.com