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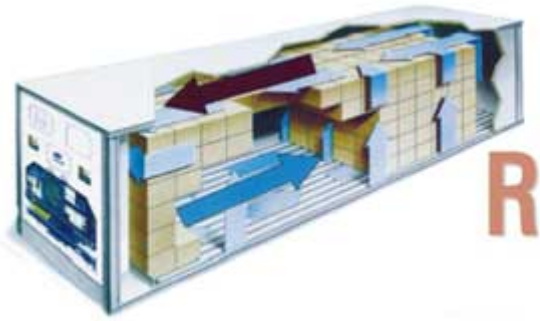

CONTAINER REFRIGERATION

Controlled Atmosphere Systems

(Part 3)

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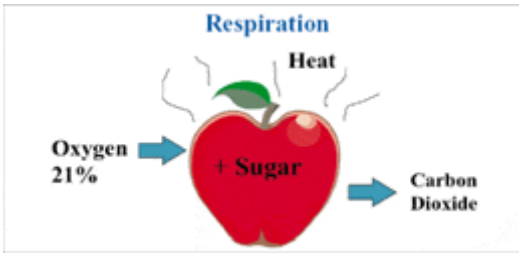
In this issue, we examine the evolution of CA as a system, how it is different from Modified Atmosphere systems, various forms of Controlled Atmosphere systems available in the current reefer market and the various additional components involved.

Basic Concepts

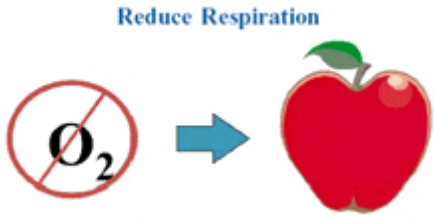
When a fruit or vegetable is harvested from the tree, it is still living. Chemical reactions are going one within it, with liberation of gases and heat. In other words, it is still respiring. This respiration process contributes to aging or senescence of the fruit.



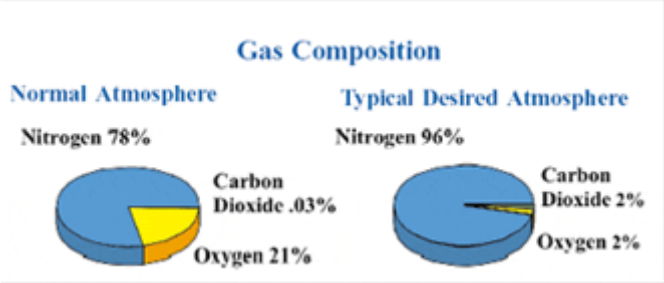
Respiration of fruit :

$C_6H_{12}O_6 + 6\ O_2 = 6\ CO_2 + 6\ H_2O + Heat$

If we are able to reduce the respiration rate, we can reduce the speed of chemical reactions going on within the fruit and can delay the aging of the fruit.



The idea of CA is to ensure conservation of perishables not only by refrigeration but also by changing the gas concentration of the air inside the refrigerated chamber. For the purpose of conservation the oxygen level is reduced to approx. 2-3% (normal air 21%) and the carbon dioxide level is increased to 5-15 % (normal air 0.03 %). The gas mixtures that provide the best conservation depend on the crop but may vary with variety, origin and harvest date. The most common fruits that are stored under CA on shore are apples and pears. It is to be remembered that CA is an additional feature provided to supplement refrigeration.



By changing the atmosphere in the correct way, the respiration of the fruit is reduced and preservation is better. The transit times can therefore be longer, so that fruit, normally transported by air, can be shipped by sea or truck. Another possibility is to harvest riper fruit in order to transport it in better quality than earlier.

The rate of respiration falls rapidly below 9% of Oxygen content in the atmosphere. At 2% Oxygen level, the rate of respiration is as low as 25%. Most of the products require Oxygen content close to 2% for better preservation in addition to refrigeration.

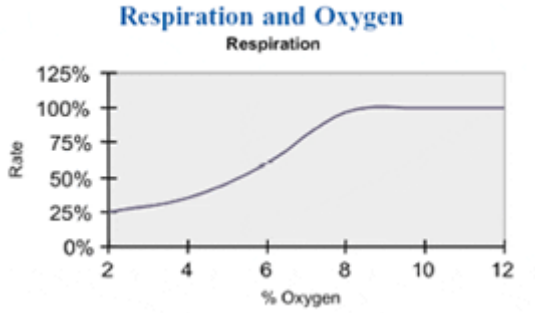
Atmosphere changes must however be made with care as oxygen levels that are too low, as well as carbon dioxide levels that are too high, can result in damage to the fruit. Ethylene, which is a gas that is produced by many fruits, but which also accelerates the ripening process, also has to be removed from the atmosphere (green bananas for example are treated with ethylene in the ripening stores to get them ready for sale).

What is Controlled Atmosphere? How is it Different from Modified Atmosphere?

- Controlled Atmosphere
  – The control of the chemical composition of the atmosphere surrounding a commodity by the *continual* addition or removal of gases.
- Modified Atmosphere
  – The *one time* surrounding of a commodity with a mixture of calibrated gases prior to shipment.

Applications of Controlled Atmosphere

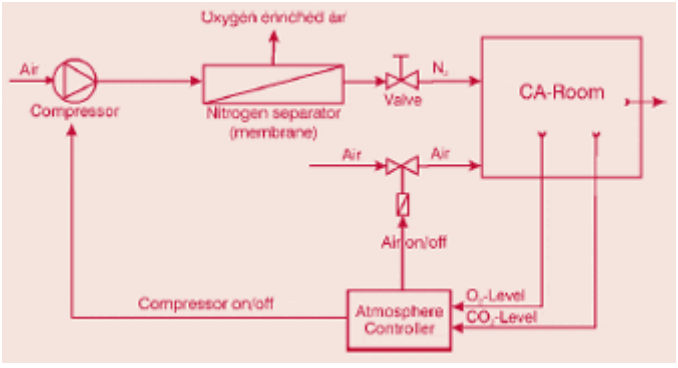
For several years now, Controlled Atmosphere (CA) has become more and more important in the refrigerated transportation of perishables. While in the beginning CA was almost unknown, it has now become a quite common addition to normal refrigeration in several fruit trades. In the reefer vessel market CA is mostly used by banana companies like Chiquita and Dole for the transport of bananas and other fruits from Latin America to Europe. Apples from New Zealand to Europe and stone fruit (e. g. peaches, nectarines) from Chile to the US are also shipped in reefer containers under CA. Each product has its own requirement of Oxygen and Carbondi- oxide percentages ranging from 1 to 10% with varying degree of potential benefit, ranging from slight to very good.



Various Makes & Models of CA Systems

The first applications of CA on shore simply used the respiration of the fruit to lower the oxygen level and increase the carbon dioxide level. The fruit was placed in the gastight store, and the atmosphere changed by itself. With a normal CA store for apples it took several weeks to bring down the oxygen level to the desired 2%. To limit the carbon dioxide level, lime was simply placed inside the CA room. To increase the oxygen level if necessary, fresh air was supplied to the room.

Nowadays the pull-down of the atmosphere is usually achieved by flushing the room with nitrogen (normal air 78 % N_2). The nitrogen is either separated from ambient air (**Figure 1**) or is delivered in tanks or trucks for an initial filling. Nitrogen separators can be of the membrane type or Pressure-Swing-Adsorption (PSA) systems. In the case of membrane separators, a membrane which has different permeability for oxygen and nitrogen is used to separate nitrogen from compressed air. In PSA systems, activated carbon is used to adsorb oxygen at high pressure and is reactivated at low pressure. Two adsorbers are combined with one adsorbing and the other reactivating in exchange.



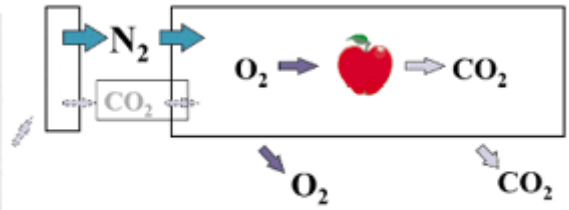


Figure 1: Simple CA system with nitrogen separator for controlling oxygen and carbon dioxide.

For the limitation of carbon dioxide levels two different principles are used:

- flushing with nitrogen and
- carbon dioxide scrubbers.

The flushing system is normally used when a nitrogen separator is present. Due to the fact that the nitrogen produced by these separators still has oxygen content of approximately 2–3 %, the oxygen level cannot be reduced significantly lower than this level when carbon dioxide is flushed out of the room (**Figure 1**).

Carbon dioxide scrubbers are mainly PSA systems, but lime scrubbers are also used. When carbon dioxide scrubbers are used, attention must be paid to the ethylene level, which might increase in this case. Ethylene is not a problem for flushing systems, as both the ethylene and the carbon dioxide are flushed out of the room. The disadvantages of nitrogen flushing are the high-energy consumption of nitrogen separators and the fact that the capacity of the separator has to be designed for carbon dioxide limitation, where often more nitrogen is necessary than for atmosphere pull-down.

Some manufacturers offer ethylene scrubbers on a PSA base. Catalytic ethylene burners are also available.

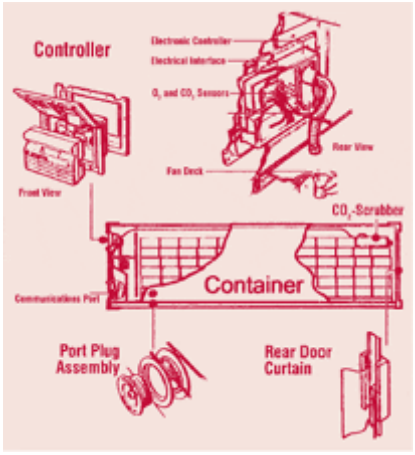
The CA room has to be as gastight as possible in order to prevent ambient air (oxygen) from entering. Due to the injection of nitrogen for atmosphere pull-down or carbon dioxide flushing there has to be a pressure relief valve, otherwise the room would be blown up and destroyed.

TransFRESH

California based TransFRESH Corporation has been the biggest provider of CA services for some years. The Tectrol CA system came into the market at the end of 1990. Tectrol CA is used primarily with avocados and deciduous fruit. Other cargoes include asparagus, mangoes, melons and mixed vegetable shipments.

The Tectrol system is not able to build up its own atmosphere. An initial gas mixture is injected into the container after loading. The Tectrol system is designed to maintain this

atmosphere by supplying fresh air and carbon dioxide scrubbing. This requires containers which are extremely gas tight with minimal leakage.



The main advantage of the Tectrol system is the low investment cost. Only an investment of about US $ 700 is necessary to fit a container with the basic installations. These include:

- Two port assemblies which are built into opposite ends of the container sidewalls. These plugs are temporarily removed to allow injection of the initial specified atmosphere.
- An extruded aluminium door track is built into the container door frame. In case of a transport, a large plastic curtain seals the rear container door opening. The curtain is snap-sealed into the track with a stiff plastic ribbon.
- Casing and wiring for the controller. The controller records atmosphere and other performance information during transit. It is only mounted to the container in case of a CA transport. Once the container has reached its destination the controller is removed and returned to TransFRESH for data retrieval.
- Facilities for fitting a lime based carbon dioxide scrubber

The disadvantage of the Tectrol system is that it is based on fruit respiration and therefore is not a standalone system. A TransFRESH station is needed at the loading port to supply the container with the necessary equipment and the initial atmosphere. On the other hand, this has turned out to be an advantage, as the containers as well as the cargo are inspected carefully before shipment commences. This results in a very good quality of transported goods and very few losses.

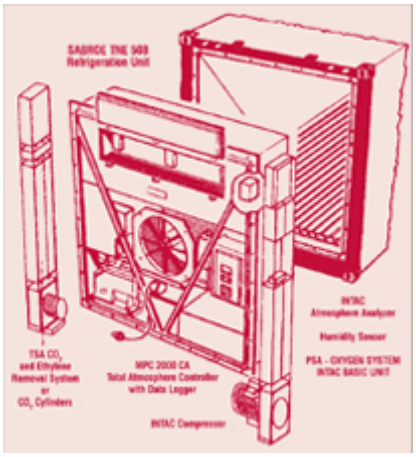
Freshtainer

Freshtainer, which is a part of the Austrian Welz group offers one of the more sophisticated CA systems that was available till recently: the INTAC IV. The system features a PSA nitrogen seperator, a carbon-di-oxide scrubber and an ethylene scrubber. Humidification and dehumidification are also available. Now, Freshtainer does not operate the INTAC IV containers itself anymore, but gives them on lease to large customers. Before introducing the INTAC IV system, the company already had an older INTAC III system in operation, which was based on carrying nitrogen and carbon dioxide in cylinders. Since the beginning of 1995 Freshtainer and Sabroe Reefer Cool have started to collaborate. The original Freshtainer's INTAC IV system has been redesigned to fit into a Sabroe TNE 508 refrigeration unit (formerly Klinge).

There are three options available:

- The basic option is designed for oxygen control and moderate carbon dioxide control by using a PSA nitrogen separator. The humidity level can also be modified. The unit is placed beside the reefer unit, so that no cargo space is lost.
- Option two offers the supply of carbon dioxide from two or four cylinders, which are placed just opposite the nitrogen separator.
- Alternatively option three adds a carbon dioxide and an ethylene scrubber instead of the CO_2 cylinders. Depending on the installed option, the system weights 150 - 320 kg.

In order to guarantee the air tightness of the container, Freshtainer's own containers use a special one wing door instead of the normal two wing door. In case of the Freshtainer/Sabroe system, provisions concerning air tightness must be taken by the container manufacturer/ operator, for example, by using a plastic curtain.



With all options installed, the Freshtainer/Sabroe unit is able to build up and keep the inside atmosphere down to 1% of oxygen, between 0 % and 80 % of carbon dioxide at a

humidity of 60 % to 98 %.

Carrier Transicold

In November 1994, Carrier Transicold unveiled its own CA system is based on Carrier's NT reefer machinery and fitted completely into it. The additional weight is 70 kg. The system consists of a membrane type nitrogen separator including the necessary oil-less air compressor. The membrane itself was developed in conjunction with Medal (DuPont). The controller for atmosphere control is of the same type as for temperature control, so that the two controllers can even be interchanged. The data logger records oxygen and carbon dioxide levels as well as the air humidity inside the container, in addition to the temperature setpoint, supply air and return air temperatures.

System Operation

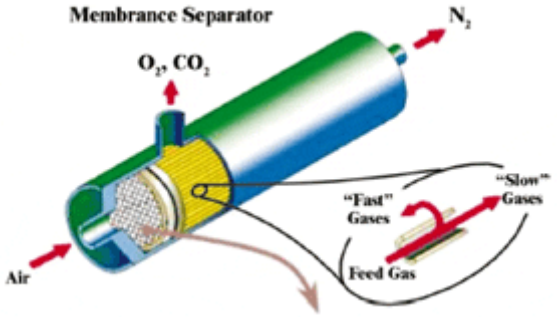
Atmospheric air is drawn through an air intake filter to remove contaminants before entering an oil-less air compressor. Once it is compressed, air is feed into a condensing line where moisture is removed. It then passes through a filter assembly where the moisture is drained away. To enhance the efficiency of seperation, it is passed through an air heater before entering the membrane seperator. In the membrane seperator, nitrogen is separated from the other gases and delivered inside the container while the other separated gases are simply vented to the outside atmosphere.

Principle of Seperation

The membrane seperator contains thousands of small hollow-fibres, approximately twice the diameter of human hairs that make up a semi-permeable membrane bundle. Similar to the shell and tube heat exchanger, the membrane bundle is housed in a cylindrical shell with a feed inlet port at one end and two vent ports- one each at the opposite end and on the side of the housing. Compressed air used as a supply gas is fed at the inlet of the seperator and flows inside the hollow fibres towards the opposite end vent port. Each of the air components has its own permeation rate that is a function of its ability to dissolve and diffuse through a porous medium. This characteristic permeation rate allows fast gases like oxygen to separate out from slow gases like nitrogen.

The ability of a membrane to separate gases is determined by the rate of permeation of each feed gas component, which is a function of the individual components' solubility in the membrane material and the rate of diffusion through the membrane wall. Gases with a higher solubility in the membrane material and are small in molecular size, permeate faster than large, less soluble gases. The higher the solubility, the more efficient is the

seperation process is. The driving force behind the seperation process is the difference between the gas components' partial pressures that make up the feed gas.



Both oxygen and carbon dioxide levels are controlled by flushing with nitrogen. An automatic purity control guarantees the proper function of the system.

It is also possible to connect a CO_2 source to the container (cylinders inside and outside the container). The controller is already designed for CO_2 supply, and a magnetic valve is installed to which the CO_2 source can be connected.

Graaff

The German container manufacturer Graaff was known to have developed the "Pacas" container in conjunction with Permea Inc.

Graaff now offers a modular CA system. The simplest option provides only an uncontrolled nitrogen separator without data logging. By adding a controller, a data logger, a carbon dioxide scrubber and/or a humidification/ dehumidification unit, the CA system can be adapted exactly to customer's requirements.

Freshcon eshcon

Hamburg based Freshcon, a company belonging to the Sietas shipyard, also developed a CA unit in cooperation with Isolcell Italia (CA) and Noske-Kaeser (refrigeration). The system provides a membrane based nitrogen separator, a PSA carbon dioxide scrubber and a catalytic ethylene scrubber.

Isolcel

Isolcell is one of the biggest manufacturers of CA equipment and CA stores in Europe. Beside the Freshcon container, which uses Isolcell equipment for atmosphere control, the company offers its own CA container.

The CA system consists of a permeable membrane nitrogen separator, a carbon dioxide scrubber and an ethylene converter. The components are installed inside the container

beside the reefer machinery casing, so no cargo space is lost. A controller and data logger are installed and are accessible from outside.

To increase the air tightness of the container, a plastic curtain is fitted magnetically into the door opening. This aims to reduce leakage to 600 l/h at 20 mm WG.

CONAIR plus

G+H Montage, who are known for building CONAIR stacks for cold air supply to porthole containers on vessels, offer a CA system for porthole containers. The CA equipment consists of a nitrogen separator producing 30 m^3/h N_2 at a purity of 97%, a carbon dioxide scrubber and a catalytic ethylene converter. This system is connected to the CONAIR stack, which has been specially sealed in order to improve gas tightness.

The main problem with this system is the air tightness of the containers, which are normal porthole containers without additional sealings. The capacity of the nitrogen separator is sufficient to lower the oxygen concentration to approx. 3 % even with not fully air tight containers, but high carbon dioxide levels will not be reached due to permanent nitrogen flushing.

Analysis

The most successful system at the moment, the TransFRESH Tectrol system, is the one with the lowest initial investment cost, but with the highest operating cost.

The different CA systems for container application show a wide range of different approaches. These relate to the technical equipment of the containers as well as the price. They range from the simple TransFRESH Tectrol system, which needs an initial atmosphere filling after loading, to Freshtainer's sophisticated INTAC IV system, which offers almost all opportunities for atmosphere control.

All in all, it can be found, that prices for well equipped CA containers like Freshtainer or Freshcon are still too high to be accepted on the market. The most successful TransFRESH Tectrol system is the simplest one with the lowest initial investment. Due to decreasing prices for stand-alone CA containers, it is expected that more of these units will get into operation in the future.

Safety

Since we are dealing with atmospheres which are deficient in oxygen, we need to be very cautious whenever we are working on Controlled Atmosphere systems. Awareness of the ill

effects of exposure to Oxygen-deficient atmospheres is crucial.

The following are the effects of various degrees of reducing oxygen content in the atmosphere and the affects on human beings.

- 15 - 19% O_2 – Co-ordination impaired
- 12 - 14% O_2 – Perception and judgement impaired
- 10 - 12% O_2 – Performance failure, poor judgement, onset of Cyanosis
- 8 - 10% O_2 – Mental failure, unconsciousness
- 6 - 8% O_2 – 100% fatal after 8 minutes exposure
- 4% O_2 – Coma in 40secs, convulsions, death The following precautions are recommended when working on Controlled and Modified Atmospheres:
- Never assume the atmosphere is safe
- Vent before entering
  – 20 minutes minimum
  – Remain clear of open doors
  – Remain clear of air vents
  – Even if safe yesterday
- Work in pairs when entering Modified/Controlled Atmosphere Units

Most of the containers are now equipped with a safety door lock which allows the rear doors of the container to be opened only after the oxygen content in the container has reached 20.3% and locks the container at oxygen percentage below 19.8%. The locking and unlocking is achieved through a solenoid valve which pushes out a locking lever and the signal for the same is obtained from the controller based on the sensed value of the oxygen percentage inside the container.

Pre-Trip Kit

Prior to every loaded trip of the reefer container using CA System, the following items comprising the Pre-Trip Kit must be replaced.

- Rear Door Curtain
- Ribbon
- Air Filter Element
- Sample Air filter Element
- Safety Precautions Label (Decal)

Benefits of Controlled Atmosphere

- Reduces respiration
  – Ethylene production retarded
  – higher natural sugar content.
- Retards senescence (ripening / aging)
  – associated softening and compositional changes
- Alleviates certain physiological storage disorders.
- Retards some pathogens and consequential decay.
- Provides insect control.
- Permits longer tree ripening
- Better product quality at final destination
- Less spoilage during transport
- Broader range of cargo can be shipped
- Permits extended post harvest shipping and storage times.

Controlled Atmosphere - A Panacea!

Controlled Atmosphere System is not a panacea. Temperature control is of paramount importance. Each product has its own requirement of oxygen and carbondi- oxide content to be maintained which needs to be known beforehand. All products are not equal. The product has to be of good quality at the time of loading inside the refrigerated chamber. Correct product quality is maintained by adoption of correct handling practices all through the product's post-harvest life - from the field to the consumer. Controlled Atmosphere Systems cannot improve the product quality. It can only maintain the product quality by prolonging the life of the product and retaining the freshness.

Individual pieces of fruit cargoes should be packed in cardboard boxes with holes all around so as to allow ingress of cold air inside the box and touch the individual pieces of cargo. Similarly each individual piece of fruit cargo should be properly protected to prevent any mechanical injury by wrapping with a suitable material. The ideal material of packing each individual fruit is thin porous paper which allows passage of cold air through the pores and touch the cargo. Alternatively, plastic nets may be used. Totally enclosed plastic bags should not be used, plastic being a non-conductor of heat does not allow passage of cold air to touch the individual pieces of cargo. As a result, heat accumulation and gas accumulation takes place inside the plastic bag causing deterioration and damage. If

plastic bags are used, there must be sufficient number of holes to allow cold air to pass through.

Proper loading procedures should be followed along with the necessary precautions. Cargo pallets or crates should be evenly stacked with uniform space all around the boxes. Formation of hot pockets should be prevented. Proper lashing of stacked cargo should be done. Suitable separating dunnage should be used to obviate any possibility of shifting of cargo during transportation causing formation of hot pockets. Packing material should have sufficient stacking strength to withstand the weight of the upper tiers of cargo. This is particularly important if the cargo is to be transported across oceans in a refrigerated container, where it is subjected to severe weather conditions and mechanical movement due to rolling, pitching, pounding, panting, yawing and heaving.

If the product is of inferior quality at the time of harvesting or not packed in the right manner or not stowed in the right manner inside the refrigerated chamber or if the temperature is not maintained accurately within a narrow range, even Controlled Atmosphere System cannot prevent the cargo from deterioration or damage. GARBAGE IN – GARBAGE OUT!

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