ICCT

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Controlled Atmosphere and Modified Atmosphere Guidelines
Refrigerated Cargo Ships and
Refrigerated Containers

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International Cold Chain Technology has produced these guidelines to assist in understanding the principles of controlled atmosphere and modified atmosphere in the hope that this will lead to more effective use of the technology and fewer post-shipment cargo claims.

ICCT members are aware that the technologies and concepts are complex and these guidelines attempt to illustrate some of the issues.

Whilst care has been taken in the preparation of these guidelines, neither ICCT nor any of its members can be responsible for the way in which they are used, which is beyond their control. ICCT welcomes information about any perceived errors or omissions.

This document complements previous ICCT publications concerning carriage requirements notably the “ICCT Recommendations Regarding Carriage Instructions for Refrigerated Cargoes”, which includes a brief discussion on the application of controlled atmosphere carriage for perishable products.

These guidelines, guidelines on carriage conditions and further information on ICCT may be found at www.crtech.co.uk/icct.

Ian J Lawson
ICCT Chairman

Controlled Atmosphere and Modified Atmosphere Guidelines Refrigerated Cargo Ships and Refrigerated Containers

1.0 Introduction

Perishable cargoes are carried under refrigerated conditions because lowering the temperature at which they are held extends their storage life. The term “refrigerated cargo” includes both frozen and chilled cargo but only the latter may additionally benefit from controlled atmosphere or modified atmosphere carriage applications. Fresh fruit and vegetables kept under chilled conditions are transported around the globe via the cold chain using a variety of refrigerated transport equipment: by land, sea and air. The optimum carriage temperature required for each commodity will vary and depend on the produce being carried.

This document covers the principles of controlled atmosphere carriage, the benefits that can potentially be achieved, where it may be considered appropriate and the equipment available.

It must be remembered that the most important factor is to choose the correct chilled storage temperature for the produce being carried and then to maintain that temperature throughout the entire cold chain; only then can the associated benefits of the application of controlled atmosphere technology be realised. With that in mind, ICCT recommends that this document be read alongside “ICCT Recommendations regarding Carriage Instructions for Refrigerated Cargoes”.

2.0 Definition

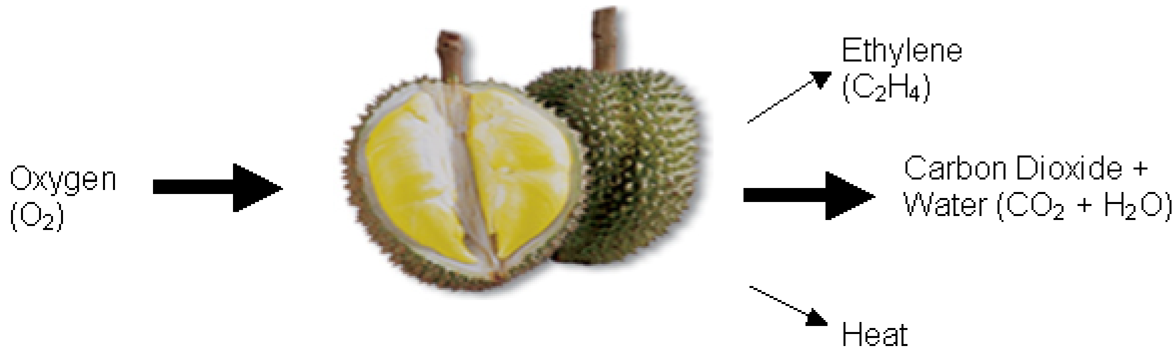
Controlled Atmosphere / Modified Atmosphere (CA / MA) is a system whereby the gas concentrations to which a cargo is exposed are different to that which normally occurs at STP (Standard Temperature and Pressure).

A glossary of CA / MA terms is given in appendix 1.

The atmosphere naturally comprises about 79% nitrogen, 20.9% oxygen, 0.03% carbon dioxide, the remainder consisting of noble gases. The aim of CA / MA is to change the ratio of these gases and control the atmosphere around a refrigerated cargo to further extend its storage life beyond that which can be achieved by refrigeration alone.

Chilled produce will still be metabolising during transport and storage using atmospheric oxygen, its own carbohydrate reserves and, whilst so doing, evolving carbon dioxide, heat, moisture and possibly ethylene gas. This is part of the ripening process for some fruits and for all produce it eventually leads to degeneration in quality and fitness for market if it continues at too fast a rate.

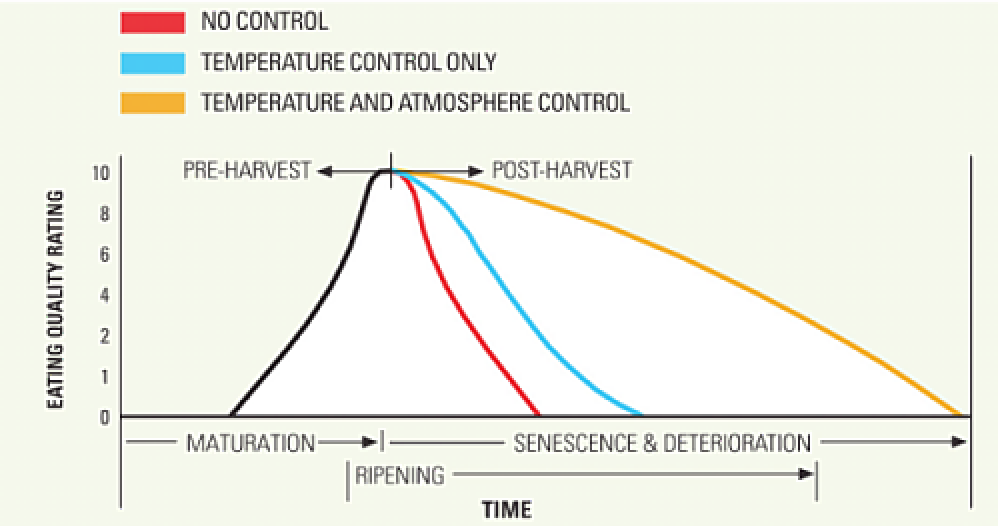
Figure 1 - Fruit Metabolism



Refrigeration slows this process down and, for those commodities which can benefit, the use of CA / MA can further control the process.

Therefore, even for chilled air-stored cargo, it is not sufficient simply to refrigerate the cargo, as carbon dioxide will build up and oxygen will become depleted; it is also necessary to remove carbon dioxide and ethylene and to supply oxygen.

Figure 2 - Ripening Control Comparisons for Fruit



3.0 Controlled Atmosphere / Modified Atmosphere

The use of CA / MA can extend storage life but it must be remembered that the final cargo outturn will be influenced by the initial quality of the produce, the temperature during transport and storage, relative humidity and gas concentration. Their relative order of importance is as follows:

- Quality: Fruit and vegetables need to be of good initial quality
- Temperature: Each 10°C reduction halves the rate of metabolism
- Relative Humidity: Just a 2% loss of water is extremely detrimental to quality
- Controlled Atmosphere: Reduction of oxygen concentration from 21% to 2% results in approximately a 30% reduction in metabolism

Where properly used, CA / MA can considerably increase the storage life of certain fruit and vegetable cargoes. Slowing down their metabolic rate delays the natural ripening of the produce without affecting its eating quality.

As well as prolonging storage life, CA / MA also improves the firmness, texture, crispness and appearance of some fruits. It further opens possibilities for the product to be harvested under partially and fully ripe conditions.

The optimum transport conditions for different perishable cargoes can, however, vary considerably and are dependent on variety and growing area and for this reason are regarded as an operational matter.

The following table gives an indication as to the response of some produce to CA / MA:

Commodity	Temp °C	O_2 %	CO_2 %	RH %	Comments
Apples	0 to 4	1 to 3	0.5 to 5	95	Very effective because it suppresses the climacteric
Asparagus	2.2	5 to 20	5 to 10	95	Effective because of the high metabolic rate which it suppresses
Avocados	7	2 to 10	4 to 10	85	Effective because of the high metabolic rate which it suppresses & CO_2 acts as a fungicide
Bananas	14 to 16	2 to 5	2 to 5	90	Effective because it suppresses the climacteric
Blueberries	0 to 2	5 to 10	15 to 20	90 to 95	Blueberries respond well to RH control, maintaining the turgidity, however, they are particularly susceptible to moulds, therefore high CO_2 levels are effective and beneficial.
Cherries	1 to 2	3 to 10	10 to 15	95	CO_2 acts as bactericide
Flowers	0.5	5	2	90	Some effect but marginal
Kiwi	1 to 2	2	5	95	Advantageous, because it inhibits effect of ethylene by the addition of CO_2
Lettuce	0	1.5	3	98	Require high humidity, can reduce browning
Mangoes	12 to 13	5	5 to 10	90	Effective, because it suppresses the high metabolic rate & CO_2 acts as a fungicide
Pears	-1 to 0	1 to 3	0 to 3	93	Very effective because it suppresses the climacteric

Redcurrants	0 to 5	2	10 to 30	90 to 95	Redcurrants respond well to RH control, maintaining the turgidity, however, they are particularly susceptible to moulds, therefore high CO_2 levels are effective and beneficial.
Strawberries	1	5 -10	15 - 20	90	Require humidity & CO_2 acts as a fungicide but CA little effect

The term “controlled atmosphere” is often used as a global term to describe the main techniques used to change the composition of air inside a refrigerated space. Properly managing the oxygen and carbon dioxide levels through atmospheric control can slow down respiration and delay ripening beyond that which can be achieved with refrigeration alone. In an enclosed space, produce can rapidly change the atmospheric levels of oxygen and carbon dioxide. Too little oxygen can lead to spoilage, too much can lead to no noticeable benefit.

Nitrogen gas is inert and has no effect on the fruit, just making up the balance of gases.

4.0 Methods to Alter Atmospheres

The main methods employed to alter atmospheres or extend storage life during shipping fall into the following categories:

- Controlled Atmosphere (CA)
- Modified Atmosphere (MA)
- Fresh Air Exchange
- Packaging Solutions

4.1 Controlled Atmosphere Gas Separation

There are controlled atmosphere systems where the user can control the exact atmospheric composition. It employs air and nitrogen injection to adjust the balance of O_2 and CO_2 inside a refrigerated space. Onboard membrane / pressure swing absorption separation units are used to obtain nitrogen from the atmosphere. It is injected to dilute the oxygen in the refrigerated air. If the concentration of oxygen becomes too low or that of carbon dioxide becomes too high, air vents or valves are opened automatically.

4.2 Modified Atmosphere Gas Injection

Used in containers. With this technique, before shipping, the container is injected with a specific composition of gases appropriate to the perishables inside. Then the container is sealed for shipping. During transit, the environment will change within the container as a result of gas evolved from the produce. To make a container suitable for modified atmosphere use, it needs to be retrofitted with a “purge port” assembly. Additionally, the container must be very well sealed and normally a door curtain is employed.

4.3 Fresh Air Exchange

A fresh air exchange system uses mechanical ventilation of the container to provide control over carbon dioxide build-up and to prevent oxygen levels from depleting too much. It relies on the metabolism of the product to vary the gas concentration. When the CO_2 or O_2 level reaches a preset point, the system activates, drawing in outside air to add O_2 and ventilate excess CO_2. As metabolism consumes oxygen and evolves carbon dioxide it is not possible for this system to simultaneously achieve low oxygen and low carbon dioxide levels unless a CO_2 absorption system is used.

4.4 Packaging Solutions

Packaging solutions can be applied to the individual product, the carton or to the pallet load. Below are 2 commonly used systems.

4.4.1 Banavac System MA Packaging of Bananas

Packing bananas in relatively thick plastic film can extend their storage life substantially. This system is well used and is called the Banavac system. By using this system, bananas can be transported for up to 50-60 days bringing the more inaccessible regions of the world to the banana trade.

4.4.2 Modified Atmosphere Pallet System

This system involves surrounding the pallet with a gas-tight film and injecting a gas. When shipping strawberries from Spain to Norway over an eight-day voyage, it has successfully been used to reduce decay at out turn from 17% to 0.6%. It is used for blueberries and redcurrants with high CO_2 levels. Usual applications are for non-climacteric fruit which are able to withstand high CO_2 levels but are susceptible to fungal attack.

5.0 Benefits and Detrimental Effects

Generally CA / MA is beneficial to the long term storage of produce though there can be some less desirable consequences.

5.1 Benefits of Controlled Atmosphere / Modified Atmosphere

The benefits of controlled atmosphere are: an increase in storage life, maintenance of firmness and crispness and the ability to store more advanced fruit. Controlled atmosphere is extremely effective on apples and pears but less effective on other fruit. In general it can be said that it gives a 50% increase in shelf life. For CA to be effective, the fruit must have a strong climacteric or a high rate of metabolism.

Atmosphere control on a non-climacteric product such as a grape or cherry is not particularly effective. In common with other non-climacteric fruits, grapes do not ripen after harvest but are allowed to reach optimum maturity on the vine. After harvest, the major obstacles to successful storage are water loss and the post harvest decay organism *Botrytis cinerea* (grey mould). Therefore high humidity and sulphur dioxide treatment are much more important than lowering the respiration rate. Similarly, weight loss and disease are more significant to cherry storage.

Carbon dioxide can be anti-bacterial: when dissolved in water it produces carbonic acid. It is also an ethylene antagonist and can negate small concentrations of ethylene. High concentrations (15%) have been shown to be beneficial in suppressing the growth of *Botrytis cinerea*.

Oxygen is required for respiration; therefore reducing the concentration can result in a reduction of the respiration rate by up to 30% thereby slowing the ripening process.

The correct amount of water vapour (RH) will minimise water loss from fruit and maintain it in good condition.

Ethylene gas is used beneficially for ripening bananas and de-greening citrus. In CA application its removal can help prevent premature ripening and softening during transport.

5.2 Detrimental Effects of Controlled Atmosphere / Modified Atmosphere

Inadequate oxygen can result in anaerobic respiration. This is a condition where the metabolic pathway is incomplete and the final product becomes alcohol resulting in alcoholic-tasting fruit. Excessive carbon dioxide can produce tissue damage, or "fizzy" fruit, in pomme fruit (apples); this can develop into a condition known as brown heart.

Sometimes bananas can turn soft while still green. Green ripe bananas can occur when they ripen in an unusual way influenced by a combination of high CO_2 levels and their metabolic activity, especially if temperature control is not maintained. Bananas with a black blotchy appearance can also develop where CO_2 levels are too high. Temperatures of 18°C to 19°C and CO_2 levels above 5% can kill the fruit.

Too much water vapour can encourage the development of fungi. However, not enough water vapour is just as bad as it promotes desiccation of fruit and vegetables.

Ethylene gas is a ripening hormone and very small quantities accumulating can promote premature ripening in fruit or de-greening and loss of leaves in green vegetables. It can also cause the abortion of embryonic flowers in bulbs.

6.0 Reefer Ships

The application of controlled atmosphere systems originated in reefer shipping using sampling systems to monitor the gas levels.

The modern specialised reefer is capable of carrying cargoes under controlled atmosphere. All new builds have a CA / MA capability incorporated.

The CA generation equipment can be either shipyard installed or installed in an ISO container or airfreight container and transported to the ship when a charter with that requirement occurs.

The reefer ship cargo hold has an advantage over its smaller cousin the reefer container in that the surface area to volume ratio is in its favour. This means that the controlled atmosphere system can use the cargo more effectively to help generate the atmosphere.

The techniques have been widely adopted by banana export companies who use CA more widely than deciduous fruit shippers.

6.1 On-Board Nitrogen Generator Units

Several companies, such as Air Products and Unitor, supply units with nitrogen outputs in the range of 100 to 1000m^3/h. The majority of the units are in containers on deck though some are also in airfreight containers. Systems supplied have been both controlled atmosphere and modified atmosphere. Below-deck gas concentrations are controlled (CA). Under deck, nitrogen is supplied to control O_2 and CO_2 while above-deck containers are flushed (MA) with between 1.6 and 2.5m^3/h of nitrogen.

Figure 3 - Unitor CA System

Holds need to be relatively airtight and need pressure testing. A guideline for air tightness might be a pressure test with a pressure decay of 350 to 150Pa in an excess of 20 minutes.

7.0 Refrigerated Containers

This section deals with the systems the container industry has developed to apply CA technology. Basically there are three systems currently in general use in refrigerated containers. These are systems that control the atmospheric content by gas injection, systems that control by utilising the metabolism of the cargo and ventilating with outside air and systems that are virtually sealed.

Examples of such systems include the Transfresh, the Thermo King AFAM+, Carrier Everfresh and MCI Star Care systems. A sealed system might be a Techtrol container, a pallet system or even the sealing of individual cartons as in the Banavac system. A non-exhaustive list of systems follows.

7.1 Transfresh System

One of the first systems to be used commercially was the Transfresh system (sometimes known as modified Techtrol) and it relies on a tightly sealed container. It has purging ports for initial development of the atmosphere, a door curtain and oxygen valve controller. Several other systems are similar in nature.

The basic hardware is provided as a kit, which is installed by the reefer manufacturer. This kit includes the purging ports, the door curtain track and the controller receptacle.

The Transfresh criteria is as follows:

- The container needs to be tightly sealed.
- Containers generally need to be less than five years old and fitted with a plastic door curtain, the best type are of fully welded construction. Riveted containers are especially prone to air leaks after a few years in service.
- Once the cargo has been stowed and the door curtain installed, the container needs to be purged to initialise the gas concentrations.
- A controller monitors the oxygen and carbon dioxide levels. If the oxygen becomes too low it opens a valve, which allows in outside air.
- Carbon dioxide control is either by fresh air ventilation (opening a valve) or where low oxygen and low carbon dioxide levels are required by absorption with hydrated lime:
  $Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$
- Sometimes the lime is in a box with a fan which only operates when the carbon dioxide is above setpoint.

Relative humidity is not generally controlled and, as the container is sealed, the refrigeration system tends to extract water, potentially creating a fairly dry environment. When using controlled atmosphere systems without humidification it is important to package products in such a way as to prevent excessive desiccation.

7.2 Thermo King Automatic Fresh Air Management System (AFAM+)

There is a development of Thermo King's automatic air freshening system (AFAM) and humidity control system known as AFAM+. This system could be described as semi-active.

The AFAM+ system has a flap positioned over the air vents connected by an arm to a stepper motor controlled by oxygen and carbon dioxide sensors. Fresh air ventilation can be completely eliminated following loading until the required level of CO_2 is generated by the cargo. The ventilation rate is reduced when the CO_2 concentration is below the set level and the ventilation rate is increased when the desired level of CO_2 is attained. Carriage temperatures and ventilation settings for a range of fresh produce are preloaded into the controller.

Figure 4 - Thermo King AFAM System

Thermo King with AFAM

Close-up of the vent and stepper motor

7.3 Carrier Everfresh System

The Carrier Everfresh system uses a membrane nitrogen generator. It can include a bottle of carbon dioxide when there is a requirement for higher levels of CO_2 than the cargo itself can generate.

Figure 5 - Carrier Everfresh System

The system can easily be recognised, as there are two controllers, one for the refrigeration system and one for the CA unit.

The system works by compressing air from outside the container and passing this air through a membrane to separate the nitrogen from the oxygen. The air compressor is mounted in the evaporator section as shown.

Figure 6 - Carrier Everfresh Air Compressor

The container needs to be sealed and have an air leakage such that the time for the pressure to decay from 2”swg (standard water gauge) to 1”swg must be in excess of 105 seconds.

The Everfresh CA system starts to generate the atmosphere following loading once the return air temperature setpoint has been reached.

It works first to control the O_2 level by injecting nitrogen-enriched air into the container thus lowering the O_2 level. It then maintains the set CO_2 level whilst still controlling the O_2 by purging with nitrogen with varying concentrations of O_2. In cases where elevated carbon dioxide is required, the gas bottle is stowed in the reefer unit in the space between the unit and the wall behind the flap. A valve connected to the controller controls discharge of the CO_2 gas.

A positive pressure is maintained inside the container.

7.4 Carrier E-Autofresh

A semi-active controlled atmosphere system developed by Carrier Transicold. The unit is a development of their automatic air freshening system (Autofresh). The E-Autofresh system is an automated control of the fresh air vents opening and closing. The control is via the Microlink controller, a stepper motor and a carbon dioxide sensor.

7.5 Maxtend RA and CA

Maxtend (of Australia) produce RA (Regulated Atmosphere) and CA systems. Their RA system is similar to the Transfresh system but said to be of lower cost. It requires a well-sealed container less than three years old and a door curtain. Flushing is not carried out and the atmosphere is generated by the cargo. Oxygen is controlled by measuring the level and operating a flushing valve. Carbon dioxide is absorbed by lime placed in a bag of pre-selected permeability appropriate to the cargo. Ethylene is absorbed by potassium permanganate. Oxygen concentration is measured and recorded, carbon dioxide is not measured but calculated based on the oxygen value.

The Maxtend CA system is virtually the same as the RA system except that the container is checked for air tightness and an initial atmosphere is developed by flushing.

7.6 MCI Star Care CA System

The Star Care system has been devised as a low cost controlled atmosphere container, specifically designed for the transport of bananas by Maersk Container Industries.

In this system the oxygen is removed by the cargo's respiration and therefore the container needs to be tightly sealed and is sensitive to air leaks. Pull-down time with an average banana cargo should be 60-90 hours.

Carbon dioxide is removed with a vacuum pump and selective membrane and can remove 130 litres/hr of carbon dioxide at an internal concentration of 5%. Oxygen can be added by a fresh air valve if it is measured to be below the setpoint.

Figure 7 - MCI Star Care

The membrane also removes water to some extent, estimated at around 1 litre/day though MCI say this should not be significant as the membrane is above the evaporator and this will merely reduce the quantity of condensate on the evaporator.

Oxygen and carbon dioxide sensors are derived from the automotive industry and use NDIR and Zirconium technology. System accuracy is ±1%.

According to MCI, in order to optimise the functionality of the Star Care system, bananas should preferably be hot stuffed, which should ensure gas levels and temperature will be brought to setpoint within 48 hours.

7.7 MCI AV+

MCI also have an automatic fresh air system called AV+. The control system monitors the concentration of O_2 and CO_2 gases inside the container. If concentrations rise beyond the set levels, the fresh air vent valve opens to allow in fresh air.

7.8 Cargofresh

Cargofresh has two CA products, a full CA system with nitrogen generation membrane and a low cost system, called Cargo Smart. This system relies on a specific cargo's metabolism to consume the oxygen (e.g. bananas) and extracts carbon dioxide and ethylene using a membrane separator. Nitrogen can also be supplied from a mother system in another variant: Cargo Switch-Smart.

7.9 Ship Nitrogen Distribution Systems

The nitrogen is generated by a mother nitrogen generator mounted in a 40' container and supplies containers by means of a system of flexible hoses.

The containers need to be sealed and have an air leakage such that the time for the pressure to decay from 3"swg to 2"swg is in excess of 240 minutes.

Figure 8 - Mother System Container

The system can have its own carbon dioxide supply from bottled gas inside the container.

Figure 9 - Nitec Control System

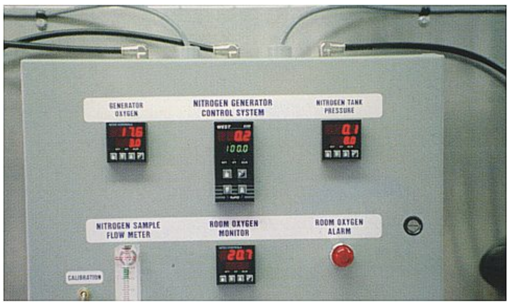


Figure 10 - Carbon Dioxide Gas Bottles

The mother container occupies a 40’ container slot and ideally should be left on the ship permanently.

Some systems do not measure the gas levels but constantly inject nitrogen with between 2 and 5% oxygen to the “child” containers.

8.0 Safety Considerations

Low oxygen atmospheres are incapable of maintaining life. Anyone entering an area during CA operation will be liable to death.

Stevedores, ship's officers and crew need to be adequately trained to understand the dangers of controlled atmosphere. Doors should be alarmed and adequate precautions taken against stowaways. Great care should be taken while entering a space that has been subject to CA or an adjacent space where the oxygen concentration may have been depleted. Anyone entering such a space should carry an oxygen detector with low-level alarm.

Symptoms of oxygen deficiency are akin to drunkenness and the subject is unaware that they are being affected. In order of severity and oxygen concentration the symptoms are as follows:

Oxygen Content %	Symptoms
21	Normal atmospheric concentration
15 - 19	Loss of coordination, impaired work ability
12 - 15	Loss of judgement, confusion and elation
10 - 12	Enhanced loss of judgement and coordination, general confusion
8 - 10	Mental incapacity, nausea and vomiting
5 - 8	Death in eight minutes, recovery possible providing exposure less than 5 minutes
< 5	Rapid unconsciousness followed by death in under 1 minute

The Carrier Everfresh system has an automatic door lock to prevent accidental entry into a low oxygen environment.

Figure 11 - Carrier Everfresh Automatic Door Lock

The nitrogen generator, if it is a membrane or a PSA system, by its very nature has an outlet of air enriched with oxygen. Oxygen is a fire hazard and this outlet should be identified and piped to a safe area.

The ISM code describes the safety measures that should be in place. Vessels should take this into consideration

9.0 Post Harvest Treatments

There are now several systems that are used either in addition to CA/MA or independently to improved post harvest quality:

These are as follows:

- Ethylene Absorbers
- Ethylene Antagonists
- Ozone Gas Enhanced Atmosphere System
- Sulphur Dioxide

9.1 Ethylene Absorbers / Removal

Ethylene gas, as is well known, has a powerful effect on fruit, vegetables and ornamentals. With fruit, small quantities in the sub ppm (parts per million) range can initiate ripening and, where applicable, the climacteric. It is also used commercially for the artificial ripening of fruit such as bananas and de-greening of citrus by loss of chlorophyll.

Vegetables also are affected by ethylene, which can cause de-greening, again by loss of chlorophyll and additionally abscission of leaves. Ornamentals are similarly affected with leaf loss and abscission of petals.

Ethylene can be removed by using proprietary product of extruded clay or alumina beads coated with potassium permanganate ($KMNO_4$).

The removal mechanism is as follows:

$$6KMnO_4 + C_2H_4 \rightarrow K_2MnO_4 + MnO_2 + 2H_2O + 2CO_2$$

Other mechanical systems exist using heated catalysts or UV light.

9.2 Ethylene Antagonists

An ethylene antagonists is in fact elevated concentrations of carbon dioxide, other are silver thiosulphate (STS) and 1-Methylcyclopropene (MCP).

STS is commonly used for ornamentals. STS contains a heavy metal, silver and can collect in groundwater and possibly pollute drinking water. The impact of STS's is being studied by environmental agencies and is already banned in Holland as a treatment for potted plants.

1-Methylcyclopropene (MCP) has been recently receiving much industry interest both at CA conferences and from many of the producer countries. MCP was discovered by North Carolina State University as an effective alternative to silver thiosulphate as a treatment for potted plants and cut flowers.

MCP is applied by mixing a powder with water which releases the gas. It is a gas of similar physical properties to ethylene and has been shown to be effective in concentrations as low as 6ppb (parts per billion).

MCP binds with the ethylene receptor sites and therefore prevents the initiation of ripening. Early reports suggested that some fruit would never ripen as the ethylene receptor sites were completely blocked and that fruit would eventually rot without ever ripening. This turned out not to be the case as new ethylene receptor sites develop.

9.3 Ozone Gas Enhanced Atmosphere Systems

Ozone has been used in refrigerated chambers for many years for sterilisation and deodorisation. Concentrations used are relative high and it was never used during storage.

Carefully controlled release enable ozone to be used during storage. Ozone has a half-life of less than 12 hours and so is continually introduced into the refrigerated storage space at levels between 100 and 300ppb. Its benefits are that it kills microorganisms and spores and breaks down ethylene gas.

9.4 Sulphur Dioxide

Used to reduce decay on grapes and dried fruit shipments. Generated by slow release pads or by direct discharge to obtain concentrations of 0.25 to 3.0ppm of SO_2.

The SO_2 is generated by the action of water on metabisulphite or directly from cylinders.

10.0 Summary

Controlled atmosphere has a place in the transport of fruit and vegetables as a supplement to refrigeration. It is most effective on apples and pears but is also effective on other climacteric fruit and vegetables with high respiration rates, for example bananas and avocados. It is less effective on non-climacteric fruit, stone fruit and slow respiration rate produce, where quite often the only benefit is the antiseptic properties of carbon dioxide.

Appendix 1 Glossary of Terms and Abbreviations used in CA / MA

CA
Controlled atmosphere usually implies the measurement and control of the normal atmospheric gases by a mechanically assisted system.

MA
Modified atmosphere usually implies the measurement and adjustment of the normal atmospheric gases by some usually passive system such as special packaging.

MAP
Modified atmosphere packaging, as used above.

CO_2
Carbon dioxide, a gas which is normally present in the atmosphere at 0.03% and is a product of metabolism. It is also used to produce plant material by the process of photosynthesis.

O_2
Oxygen, a gas which is normally present in the atmosphere at a concentration of 20.9%. It is required and consumed by metabolism producing carbon dioxide and is a product of photosynthesis.

N_2
Nitrogen is an inert gas present in the atmosphere at a concentration of 79%. It is colourless, odourless and tasteless.

C_2H_4
Ethylene, a naturally occurring chemical which acts as a plant hormone to trigger physiological changes such as ripening, de-greening and leaf loss. Because it is a hormone, its effect can be disproportionate to its concentration.

RH
Relative humidity. This is the percentage saturation of water vapour in air at any given temperature with 100% being fog. The ability of the air to hold water increases with increasing temperature and can be examined in detail by the use of a psychrometric chart.

CLIMACTERIC
A significant group of fruits show a variation from the normal respiratory pattern in that an increase in respiration coincides with ripening. This is known as a respiratory climacteric. Commercial maturity can be related to the rise in the respiration rate and/or ethylene production in climacteric fruits. As a general rule, for longest storage and optimum eating quality, fruit should be picked just prior to the climacteric rise.

METABOLISM
Metabolism represents the entirety of the many chemical activities that occur within cells. The acquisition and storage of energy and the utilisation of this stored energy are two of the central processes in the control of the overall metabolism of plants.

RESPIRATION
This is another word for metabolic activity and implies the consumption of gases by a biological process.

ANAEROBIC RESPIRATION
Respiration with insufficient oxygen present, normally producing alcohols and off flavours due to incomplete metabolic activity.