CONTROLLED ATMOSPHERE STORAGE: FRESH PRODUCE

by Pawanexh Kohli
June 2013

The concept "Controlling the atmosphere"

Cold stores alter the temperature inside an enclosed chamber through the use of refrigeration. To save operating costs of the refrigerating equipment, insulation as a thermal barrier is used during construction to minimise external heat ingress. Depending on the product types stored, the cooling is distributed inside the chambers using fans which circulate cool air – in case of frozen temperature goods, the cold air need only shield the cargo, to isolate it from exterior peripheral walls and other heat ingress. In the case of living fresh produce, the cold air must additionally envelope each individual piece and penetrate interstitial space in storage to evacuate other gases & heat produced due to respiration. This is ordinary storage and does not involve any change to the base atmospheric composition.

Controlled atmospheres are essentially those which deviate from the normal air composition of 21% oxygen, 78% nitrogen and 380ppm of carbon dioxide. Other gases are also present but normally in too small a concentration to have a prime effect on stored produce.

Controlled Atmosphere cold stores are understood as cold storages designed and fitted with additional equipment such as to actively control the atmospheric content inside the closed chamber.

The concept involves forcibly purging the mass of air in a closed room with other 'inert' gas, to quickly obtain a low level of oxygen inside the chamber. Low oxygen levels (in tandem with controlled temperature) have been observed to further reduce the physiological rates of living tissue stored in such an environment. Controlled atmosphere technology benefits by reducing produce respiration, slowing ethylene production, inhibiting pathogen reproduction, and killing insects.

The most common inerting gas used is natural Nitrogen (abundant in plenty in earth's air). Special generator units are employed to extract the atmospheric Nitrogen (reducing O^2 content). The resulting air mixture is then pumped into the cold store chamber, purging the existing mass of air. The atmosphere content in the chamber is controlled to preset levels (depending on produce) and CA requirements complied with.

The main added cost component for building a controlled atmosphere store is the nitrogen generator with controls and associated fan blowers. The equipment regularly samples air parameters inside the target chamber to stop the system and to replenish with fresh air when needed.

Globally a lot of research has been conducted in quantifying the benefits from controlling the atmosphere when storing fruits and vegetables. The most commonly beneficial products accepted for commercial storage in CA are apples, pears, kiwifruits for long term and for temporary storage or transport of strawberries, cherries, bananas and lettuce. Research has continued on various other produce types.

Modified Atmosphere

Conversely, modified atmosphere storage involves the passive inducement of atmospheric parameters inside any enclosed space or package.

This can be compared to modern office buildings where human occupancy & activity self-induces changes to atmosphere content and raising the CO^2 and humidity levels beyond optimal working levels. These levels are monitored and controlled ventilation of fresh air is accordingly undertaken.

In case of long term storage of fruits & vegetables, the goods would continually manifest their presence by creating their own atmosphere through normal respiration. All cold stores monitor such parameters and maintain a living atmosphere over extended period by vent regulation. All modern cold store designs would qualify as MA stores.

Since, Modified atmospheres are self-induced due to normal respiratory activity, advantages to shelf life is exploited through MAP (modified air packaging), where semi-permeable packaging is used to sustain a localised MA condition inside the package itself.

In either case, the intent of CA storage is to extend the shelf life of fresh produce, wherein price realisation is possible through sale in their original non-processed condition.

When used for long term storage, CA storage is deployed as farm-gate infrastructure and designed to suit batch wise dispatch as per market requirement.

It is notable that CA conditions (low oxygen contents) are harmful to living produce when delayed after harvest, cannot be tolerated by produce which is in later stage of shelf life and must be enforced within first few days of harvest. If CA conditions cannot be operationally achieved within first 36 to 96 hours of initiation, the process is annulled and normal cold storage parameters are to be maintained. Once a produce has been removed from CA environment, it reverts to normal physiological activity and reintroducing into CA is harmful and causes tissue demise.

Cold storage Status in India

The Indian government promotes the development of cold-chain infrastructure. This includes cold storage infrastructure, transport infrastructure and point of production infrastructure. Development so far has manifested in the storage space, largely stemming from earlier successes with storing potato on an annual basis. For other horticultural crops, point of production infrastructure in form of pre-coolers and packhouses are required to serve as the base initiators of cold-chain movement. It is noted that food processing units as a point of production for food items have been successfully implemented. Without such production units, the goods cannot enter the cold-chain and hence instead of domestic produce transiting through our cold storages, we have imported produce that is effectively serviced.

In case of cold storages, two primary types persist. The first is farm gate infrastructure that is deployed close to producing regions for long term storage of farm produce. These storage types are designed for single commodity bulk storage where the produce is intended for subsequent sale over an extended period over its marketable life. These stores are predominated by potato stores and those for spices and specific crops like carrots, apples, oranges, onions, etc. CA stores, due to their base intent of extending shelf life over long term, fall under this category. Produce stored in such cold storage is not intended for repetitive handling and these stores can serve as initiating points for subsequent market links.

The second type of cold stores, are more transient in their nature of service. These are the distribution hubs close to market, those that are at point of consumption (retail outlets and fridges at homes), consolidation hubs (eg. for grapes and those appended to pack-houses), etc. The integrity of the cold-chain largely depends on this transit infrastructure including logistics. The goods handled in these stores are those with shorter shelf life, those that have exited bulk storage, and those that are enroute to market or final consumption. The majority of horticultural crops have a limited shelf life even when in the cold-chain and cannot be stored across seasons. Additionally, all products towards the end of their storage life, need to transit to market through such cold-chain facilities. Such storage infrastructure has only recently been developed in India.

Amongst laymen all cold storages seem to be the same but farm gate cold storage infrastructure must not be confused with the other types of cold storage, especially when correlating with the integrated cold supply chain that links farm to markets.

As per recent reports there are approximately 6000 cold stores in India, predominantly the farm gate long term storage type, designed originally for single commodity storage. In the last decade, more of the market linked transit type storage facilities have developed. Without these facilities, the chain breaks as soon as the produce exits farm-gate production units if there is no close to market facilities.

Pack-houses with pre-coolers with appended staging stores are not sufficiently present in India. Reefer transportation that links the primary processing units to the cold-chain service facilities are present to service existing trade in the must-have category (ice-creams, dairy, meats and imports in the cold-chain).

Use of Controlled Atmosphere (CA) Cold Storage

Apples are the major commodity stored in Controlled Atmosphere (CA) cold stores worldwide. The reason for limited commercial use of CA to relatively few products, despite experimented benefits on quality of many others, is related to cost benefit ratios. Like ordinary cold stores, CA structures must not only be air tight and refrigerated, but require added investment in equipment to modify and maintain the desired atmospheres. The volumetric size of these storage rooms is also optimised to maximize the value of the added equipment. Typically, adding CA equipment can increase the cost of a cold store by x1.8 to x3.0 times depending on various factors.

Therefore, the return on investment requires long lived horticultural products that are stored for months and not days or even weeks. In addition, the extension of storage life is often too small to warrant added investment. If the storage potential of a particular product is a week, for example, then adding on a few days extra, is often not commercially significant.

However, newer tent-based CA based cold storage systems, with lower cost oxygen and carbon dioxide control monitors, are now available, and maybe more useful for shorter lived products. The tents and controllers are placed in cold storage rooms and have been used successfully for local market strawberries for example. Similarly, Modified Air Packaging which allows the produce's own respiration to alter the air composition inside the package, is considered more viable in case of short storage life products. CA is also used for long term storage of dry grains. Ripening rooms are examples of short term controlled atmosphere storage – in this case ethylene and CO_2 are the parameters controlled.

Since nitrogen is the most commonly used gas in controlling the atmosphere, special human safety aspects must also be deployed in CA cold stores. These include personnel O_2 monitoring instruments to safeguard inadvertent asphyxiation and nitrogen related hazards (one whiff of pure nitrogen can cause brain death). Nitrogen is generated by separating it from normal atmospheric air (78% Nitrogen) through special equipment. Alternately, gas injection from cylinders and CO_2 generators are also used in some facilities.

Additionally, since the internal atmosphere of a chamber is forcibly flushed, the chambers are fitted with pressure relief valves to avoid excess pressure build up inside the chamber which can cause the insulating walls to bulge outwards. CA cold stores maintain a positive internal pressure to avoid ingress of external air which is detrimental to controlled status. Monitoring equipment to record and control the CA conditions are also installed. Usually, once CA parameters are achieved – usually within 5 days of harvest – the gas generator can be switched off as natural respiration then continues to lower the oxygen level and effect CO_2 and other gases. At predetermined limits, outside air is then vented into the rooms to effectively maintain the desired levels – feed and bleed approach. Such cold stores also deploy CO_2 scrubbers and optionally ethylene scrubbers. Before sale of the stored produce, the entire chamber is flushed with fresh air with venting blowers to bring the atmosphere back to normal conditions and to make it safe for human access.

The most capital intensive component added to a cold store (with CA facility) is the Nitrogen generator with associated controls. The common N^2 generators are swing adsorption type and pressure membrane type (like reverse osmosis tubes). The capacity of the CA generator (in M^3 or litres per hour), is matched to ensure that the entire broken space in the cold store can be purged in 36 to 72 hours. If CO_2/O_2 parameters cannot be achieved in this critical initial duration, the space must be reverted to normal atmosphere condition and the produce should be maintained as in an ordinary cold store.

CA Cold Storage in India

Controlled Atmosphere storage in India has been well developed in case of apples, a model that is one of the most commercially accepted globally. In India, the single season produce, apple is selectively stored in CA cold stores with the intention to safely store the crop, while drip feeding the consuming market for the whole year, until the next harvest comes due, when the cycle is repeated.

The costs involved for building a controlled atmosphere Cold store are highly subjective and will depend on a variety of factors – source of equipment, design parameters, number of chambers under controlled atmosphere, type of utility, capacity etc. CA cold stores are used for storing of fresh produce over extended duration but in some cases, food processors may use CA stores to safeguard produce like peaches intended for canning purpose over short durations to counter canning line capacity restraints. Reference to NHB Guidelines and Standards (CS3); these also refer guidance to WFLO for use of CA storage, which is notably only for Apples and Pears.

Components: differentiating technology of a cold storage

1. The Normal component costs applicable to a cold store, such as-
    a. Thermal structural barriers (Insulating wall, ceiling, floor, doors, air curtains)
    b. Refrigeration designed to produce type and capacity.
        i. Evaporators/Air handlers
        ii. Compressors/Condensers
    c. Humidifiers
    d. Energy efficiency controls
        i. PLC controls
        ii. Temperature monitors
        iii. RH monitors
        iv. Air Ventilation systems.
    e. Safety and structural components
        i. Emergency door release
        ii. Gas leak detectors
        iii. Fire Detection, fighting equipment
        iv. Effluent and waste treatment
    f. Handling and Storage components
        i. Docks – staging and receiving
        ii. Ante-rooms
        iii. Racking, bins, crates
        iv. Material handling equipment (Forklifts, pallet lifts, conveyor, etc.)

2. Add-on cost components specific to Controlled Atmosphere components-
    a. Gas generator – nitrogen generator – by unit capacity.
    b. Additional piping to supply gas to chambers
    c. Pressure relief valves or pressure equalisers
    d. Gas analysing/sensing instruments
    e. Added air ventilation systems
    f. CO^2 & ethylene scrubbers (where needed)
    g. Human safety – oxygen analysers
    h. Gas tightening walls etc with resin, coating/cladding
    i. Specialised Gas tight doors
    j. Storage Bins and special high reach trucks

While the CA components are an added cost to capital, the overall cost of these additional components is not a direct factor to the storable ton capacity of a cold storage. This is more so, in cases where only some compartments and chambers are designed for CA use. The remaining cold chamber space created is for use as normal temperature controlled storage.

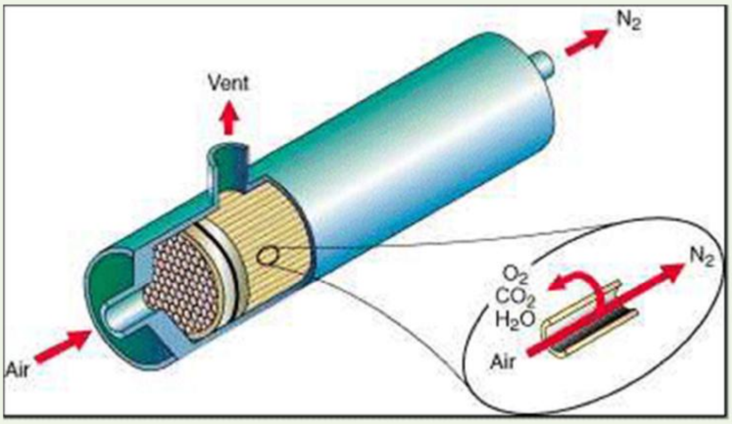
Not understanding the technology or its application, many projects are reported with nominative compliance with technical CA parameters from regions far distant from the established commercially tested norm (in desert regions, more than 8 hours distance from farms, in ports with intent to store imported produce, etc).

In such cases, where target intent is not the prevalent or commercially established norm, partial capacity for CA may be considered for trial pilot projects.

Nitrogen Generators

Reference 1

What is MEMBRANE TECHNOLOGY



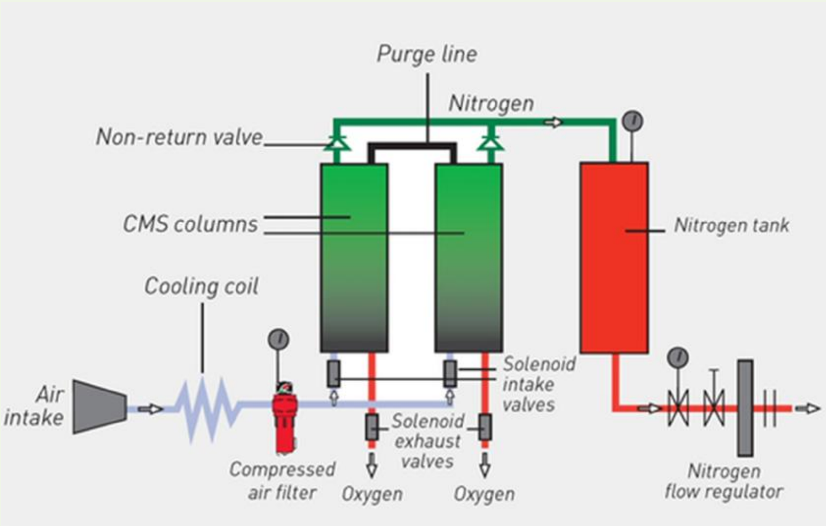
Compressed air enters one end of a permeable membrane. The membrane is comprised of many hollow fibres. The N² travels the length of the fibres and exits at the other end of the membrane. The O² in the air passes through the sidewall of the fibres and exits the side of the membrane.

Prior this basic process, the air mixture is treated to remove contaminants, moisture, etc. Nitrogen generated on demand and is directly pumped into enclosed chambers.

This technology is more modular for expansion, is mobile and similar to membrane sieve technology used in water purification (reverse osmosis) designs. It has a much reduced foot-print (a 10 feet by 20 feet container can house capacity to serve 15000MT of produce).

What is PSA TECHNOLOGY

Compressed air enters one end of two absorber tubes . . . filled with carbon molecular sieve (CMS). While the smaller oxygen molecules are absorbed by the CMS, the larger nitrogen molecules pass through and are stored. Upon saturation, the first adsorber releases the oxygen, which the second adsorber repeats the process over again for further purification for N2 levels.



After about one minute adsorption in one adsorption tower the process controller is switching over to the second tower and the first one is regenerated. Nitrogen generated is stored in tanks for subsequent use.

This technology is more commonly used in India and requires larger area to install.

Other methods involve stored nitrogen in cylinders (usually used for air transport) or in case of small storage options.

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 CO^2 and O^2 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 color.
8. CA is also used for long term grain storage where it reduces wastage due to infestation by pests, insects, etc.

These benefits manifest commercially when storage span is longer than 3 months or where quality benefits are similarly realised in consumption markets. Partial in-transit benefits are also targeted as in case of cross continent ocean transport where an added week in special CA transport containers allows for longer times to new markets at added distances.

Commercial viability from controlling the atmosphere, either actively or passively ranges from product to product. In storage it is mostly used for long term storage at production end. For produce with short term storage it is used in transportation in specially designed refrigerated modes and by use of Modified Air packaging.

Modified Air Packing

Modified Atmosphere Packaging is a way of extending the shelf life of fresh and other food products. The technology allows modification to the atmospheric air inside a package.

The simplest form of this technology is the application of a wax coat to the surface of the fruit. Similarly, selectively permeable plastics can be used to package fresh produce. In effect, the packaging serves like a molecular sieve and allows for normal respiratory process of fruit to alter the atmosphere inside the packaging within specified limits.

In some cases including meat, fish and processed foods, forcible flushing of the package with gas can be used to counter microbial build up and preserve the product longer. CO^2 in carbonated drinks is the most common example.

References:

- *Proc. Fla. State Hort. Soc. USDA, Agriculture Research Service Subtropical Horticulture Research Station*
- *Controlled Atmosphere Storage, Prof Kadel, University of California, Davis, CA*
- *Controlled Atmosphere and Modified Atmosphere Guidelines, ICCT*
- *Controlled Atmosphere Reefer vessels, CrossTree techno-visors*
- *NYS IPM Publication No. 10, Cornell University*
- *FAO Corporate Document Repository*
- *UNIDO Documents repository*
- *Inputs from stakeholder and user industry*