INTERNATIONAL STANDARD

ISO 6949

First edition
1988-11-01

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION
ORGANISATION INTERNATIONALE DE NORMALISATION
МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ

Fruits and vegetables — Principles and techniques of the controlled atmosphere method of storage

Fruits et légumes — Principes et techniques de la méthode d'entreposage en atmosphère contrôlée

Reference number
ISO 6949 : 1988 (E)

Foreword

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Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 6949 was prepared by Technical Committee ISO/TC 34, *Agricultural food products*.

Annex A of this International Standard is for information only.

Introduction

The extension of the keeping period for fruits and vegetables, with minimum loss, to the long term is closely linked to the rate of the metabolic processes occurring in the products and the rate of development of pathogenic micro-organisms and physiological diseases.

The use of cold storage, with control of the relative humidity of the air in the store, results in the reduction of the respiration rate and of transpiration, as well as of the development of some diseases.

Better results may be obtained, however, by the storage of fruits and vegetables in controlled atmospheres, which is based on the maintenance of the temperature and of the relative humidity at optimal values, and also involves the regulation of the gas composition in the store.

Storage in controlled atmospheres, combining the effects of three basic factors (temperature, relative humidity and gas composition), leads generally to a reduction in metabolic activity and, in the case of climacteric products (such as apples, pears, bananas and tomatoes), possibly to a delay in the appearance of the onset of the climacteric period.

The low-oxygen atmosphere reduces ethylene production and the combination of the low oxygen and high carbon dioxide levels reduces the effects of ethylene. Consequently, there is a delay in ripening, the nutritive value and the appearance for sale are maintained and the keeping period of the product can be extended.

Further, as a result of the reduction in oxygen content and increase in carbon dioxide content, the development of pathogenic micro-organisms and the appearance of some physiological disorders may be retarded.

The products stored in controlled atmospheres shall be of varieties and quality different from those of products stored under normal conditions.

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Fruits and vegetables — Principles and techniques of the controlled atmosphere method of storage

1 Scope

This International Standard specifies the principles and techniques of controlled atmosphere storage for fruits and vegetables.

It applies to various kinds of fruits and vegetables (notably apples, pears and bananas). The application of this method is specific to each product; in addition to maintaining the optimum limits of temperature and of relative humidity, the oxygen content should also be reduced from 21 % (*V/V*) (the normal level); this means that the partial pressure of this gas is also reduced.

However, oxygen contents below 1,5 % (*V/V*) are not recommended since, in the absence of sufficient oxygen, fermentation processes take place (intracellular respiration) and a brownish discoloration of the fruits and vegetables may appear.

At the same time, the atmosphere is enriched in carbon dioxide; however, too high a carbon dioxide content [for example exceeding 8 % (*V/V*) to 10 % (*V/V*)] can in most cases cause various physiological diseases (carbon dioxide injuries) resulting in a reduction in quality as well as quantitative losses.

2 Types of controlled atmosphere

In practice two types of controlled atmosphere can be distinguished.

2.1 Type 1

Atmosphere with slightly reduced oxygen content [from 18 % (*V/V*) to 11 % (*V/V*)] and more or less enriched in carbon dioxide [from 3 % (*V/V*) to 10 % (*V/V*)] in such a way that the sum of the oxygen and carbon dioxide contents is 21 % (*V/V*).

EXAMPLE

8 % (*V/V*) CO_2; 13 % (*V/V*) O_2; 79 % (*V/V*) N_2

This type of atmosphere, also called a modified atmosphere, is brought about by the increase in the carbon dioxide content during the natural respiration of the product and is thus not preferred. The level of carbon dioxide can only be decreased by ventilation with outside air, with a consequential increase in the oxygen level.

This type of controlled atmosphere is recommended for apples and may be beneficial in the tropics for short-term storage of fruits such as bananas.

2.2 Type 2

Atmosphere with

— an oxygen content of 2 % (*V/V*) to 4 % (*V/V*) [mean, 3 % (*V/V*)] and a carbon dioxide content of 3 % (*V/V*) to 5 % (*V/V*),

or with

— a greatly reduced oxygen content [1 % (*V/V*) to 2 % (*V/V*)] and a carbon dioxide content of 1 % (*V/V*) to 2 % (*V/V*),

so that the sum of the oxygen and the carbon dioxide contents is below 21 % (*V/V*).

EXAMPLE

3 % (*V/V*) CO_2; 3 % (*V/V*) O_2; 94 % (*V/V*) N_2

Special equipment is necessary to obtain these concentrations.

This is the type of controlled atmosphere most often used. In general, it is necessary to vary the gas mixture according to the type of product to allow for

— sensitivity to carbon dioxide concentrations which are too high or to lack of oxygen;

— the degree of ripening;

— the storage period.

3 Method of regulation of atmospheres

Atmospheres of composition different to that of the normal atmosphere can be prepared in specially fitted-out storage chambers, or exceptionally in so-called physiological packing-cases, the permeability of which is designed to give an oxygen-carbon dioxide mixture of specified composition.

The storage of products in sacks or in chambers provided with semi-permeable membranes made of silicone plastics of the Marcellin and Letenturier types represents an application of this system.

The specially fitted-out storage chambers and the use of adequate equipment and installations allows a controlled atmosphere of characteristic oxygen and carbon dioxide contents to be produced for the products to be stored.

Short-term high-carbon-dioxide treatments may be applied to specific products (e.g. Golden Delicious).

4 Chambers for controlled atmosphere storage

4.1 Capacity

The capacity of the chambers is in general from several hundred tonnes up to 1 000 t of the product.

4.2 Gas-tightness

The construction of chambers for controlled atmosphere storage is designed to obtain an appropriate gas-tightness to allow the composition of the desired atmosphere inside to be maintained. In practice, it is not possible to make chambers absolutely gas-tight; gas exchange between the interior and the exterior is unavoidable. However, the chamber should be sufficiently gas-tight that control of the oxygen and carbon dioxide levels is possible.

Therefore, it is important to know the maximum permissible leakage rate and to have available a method to check whether the construction satisfies this criterion. (The rate of entry of oxygen into the chamber is directly proportional to the leakage rate.)

4.2.1 Minimum gas-tightness

In theory, the inflow of oxygen into the chamber has to remain lower than the respiratory consumption by the products stored.

Thus the acceptable inflow depends on the product stored, its temperature, the gas mixture sought and the ancillary equipment which may be deployed to control it (e.g. oxygen absorbers or expansion sacks).

The actual inflow into the chamber in operation is caused by diffusion, resulting from the difference in concentration of the gases, and by convection, resulting from the difference in pressure.

It is particularly the exchange by convection which should be eliminated. During storage, the controlled atmosphere chambers should function under the most difficult circumstances, e.g. storage of apples, at 0 °C, in an atmosphere of type 2. Therefore, the criteria of gas-tightness are defined for this case, but are suitable for other uses.

4.2.2 Construction

The gas-tightness of the chambers is achieved by covering the walls, the floor and the ceiling with aluminium sheathing, prefabricated steel sheathing, polyester resins, epoxy resins or polyamide resins, reinforced with glass fibre, etc. The thickness of insulation required depends, amongst other things, on the exterior temperature, the storage period and cost factors.

An advantageous and technically better solution is the use of sandwich panels mounted on metal frames which ensure simultaneously thermal insulation and gas-tightness. The sandwich panels are constructed of a metal, wooden or plastic plate on the outside, a polyurethane layer in the middle and a layer of polyester resin on the interior (a total thickness up to about 10 cm is advisable).

In the case of constructions with concrete walls, as in the case of the use of sandwich panels, the gas-tight layer serves equally as a barrier against vapours. In order to make repairs easier, for example if cracks appear, the gas-tight layer is generally applied on the internal surface of the wall. In order to ensure gas-tightness, plastic-resin-based paints, pitch, asphalt-lined paper, etc. can also be used. In all cases, the materials for gas-tightness should

- be gas-tight,
- not give off odours,
- be resistant to the action of micro-organisms and humidity,
- be easy to install and repair,
- be resistant to mechanical shock,
- be fire-proof,
- retain their properties during variations in temperature, relative humidity and pressure within the chamber.

The gas-tightness is considered to be suitable when the ratio between the quantity of oxygen getting into the chamber and that consumed by the products stored is approximately unity.

It is necessary to improve the gas-tightness of a chamber when

- it is used at a lower temperature,
- it is partially loaded with products,
- it contains products whose respiration rate is particularly low.

The closure of the storage chambers is ensured by thermo-insulating doors with rubber trimming, and with a sliding hermetic closure or other hermetic systems.

The doors are fastened by means of bolts or any other system of closure which ensures that the trimming on the door touches the metal frame in the wall, thus forming a gas-tight seal. The doors may be fitted with portholes allowing the inside of the chamber to be seen and with smaller doors giving access to the chamber.

However, inspection windows placed at a level above that of the contents of the store may be more useful. They are hinged to allow entrance above the level of the contents for inspection of the product, evaporators and cooling apparatus.

A warning sign signalling the presence of a low-oxygen atmosphere should be placed at the entrance of the chamber and at other appropriate places.

4.3 Equalization of pressure

Between the chamber and the exterior, differences in pressure are created by fans, cooling equipment, appliances for regulating the composition of the atmosphere, as well as fluctuations in exterior atmospheric pressure. A sudden drop in the gas pressure in the chamber can cause the gas-tight layer on the walls and ceiling to become detached, thereby destroying the gas-tightness of the chamber. It follows that drops in pressure should be not greater than 1 mm H_2O (9,8 Pa). In order to avoid great fluctuations in pressure, the doors of controlled atmosphere chambers should be hermetically sealed only when the storage temperature has been attained.

To the same end, pressure valves are fixed in each controlled atmosphere chamber. These consist of pipes of appropriate diameter which link the interior of the chamber to the exterior. The exterior part is bent and penetrates about 4 mm into a vessel containing water and possibly antifreeze. For example, for a storage chamber of capacity 2 000 m^3, it is necessary to have two valves having a tube of diameter 15 cm.

Siphon-type pressure valves ensure equalization of pressure. If the exterior pressure is lower, some of the gas mixture leaves the chamber without modifying the composition of the atmosphere inside, while, if the exterior pressure is higher, air enters the chamber until equilibrium is reached, modifying the composition of the atmosphere in the chamber.

To avoid pressure fluctuations in small stores, impermeable plastic sacks (breather bags) of gas having a volume of 5 % to 7 % of the volume of the free gas in the chamber (or a corresponding percentage of the volume of the chamber) may be used. The sacks, which are connected to the chamber by a pipe of large diameter, expand with increasing pressure and contract with decreasing pressure thereby regulating the pressure in the chamber.

Sacks require a great deal of space and they may deteriorate, producing an additional source of leakage.

Pipes for refrigeration, for sampling the air, for regulation of the gas-composition, for electric circuits, etc. pass through the walls of the chamber. The points where cables and pipes pierce the gas seal must be sealed very carefully.

4.4 Testing for gas-tightness

Checking of the gas-tightness of the chambers is carried out when the chambers are first put into service and then every year, before the start of storage, to discover any cracks.

The following methods (4.4.1 and 4.4.2) may be used to test for gas-tightness.

4.4.1 Convection method based on the study of pressure variation

The test is carried out in an empty chamber at constant temperature, with the fans not operating.

Close the doors hermetically and increase the pressure to 15 mm H_2O to 25 mm H_2O (147 Pa to 245 Pa) above atmospheric, using independent air pumps or air pumps built into the installation for regulating the composition of the atmosphere. Measure the time necessary to obtain this pressure.

This time gives an indication of whether the gas-tightness of the chambers is very good, good or insufficient.

A variant of this method is to estimate the gas-tightness as a function of the minimum time necessary for the excess pressure created to dissipate. The time varies between 10 min and 70 min as a function of the dimensions of the chamber and the product stored.

Another variant of this method is to measure the time necessary for the initial excess pressure in the chamber to fall by half. This time (under appropriate constant temperature conditions) should exceed 10 min to 12 min for the chamber to be acceptable.

In practice, it is recommended that the gas-tightness be estimated as a function of the pressure reached after 30 min from an initial pressure of 10 mm H_2O (98,1 Pa).

The result of the estimate may be used to classify the chamber as

— very good [increase in pressure of 3,4 mm H_2O (33,3 Pa)]

— good [increase in pressure of 1 mm H_2O to 3,4 mm H_2O (9,8 Pa to 33,3 Pa)]

— insufficient [increase in pressure of 1 mm H_2O (9,8 Pa)].

The convection method can also be used for measuring the gas-tightness of chambers employing gas-filled sacks if the gas-filled sacks can be shut off with a valve.

4.4.2 Diffusion method based on the diffusion of carbon dioxide from a previously cooled chamber

This method is particularly appropriate to chambers with gas-filled sacks where the convection method cannot be used. A known carbon dioxide content is established in the chamber. The changes in the levels of carbon dioxide and oxygen are then determined continuously.

For example, a carbon dioxide content of 15 % (V/V) is produced in the chamber [giving an oxygen content of 6 % (V/V) in the chamber].

If, in the course of 24 h, the carbon dioxide content does not decrease by more than 1 % (V/V) and the oxygen content does not increase more than 0,25 % (V/V) with the fans operating, the gas-tightness is considered to be suitable.

4.5 Detection of faults in gas-tightness

In order to detect cracks or areas of insufficient gas-tightness, proceed as follows.

Increase or decrease the pressure in the chamber by about 10 mm H_2O (98,1 Pa) with the doors hermetically sealed and the fans not operating. Instruct a person inside or outside the chamber to locate the point through which the gas is moving by observing whether

— smoke generated in the chamber flows in a particular direction,

— there is any whistling noise indicating air movement into or out of the chamber,

— when a solution of soapy water is applied with a paint brush to suspicious areas, air bubbles are formed,

— when a lighted candle is placed in the suspicious area, the passage of air makes the flame longer.

4.6 Repair

Chambers having unsatisfactory gas-tightness should be repaired before any products are stored in them.

In the areas having gas-tightness faults, apply silicone or polyurethane mastics.

Eliminate the faults by replacing the sheathing which lines the walls (steel, aluminium, etc.). When polyester resins are used for insulation, stick together webs of glass-fibre and apply two or three coats of resin on top.

After reparation, it is recommended that the gas-tightness of the chamber be checked again.

5 Regulation of the temperature and the atmosphere

5.1 Regulation of temperature

Precool the product immediately after harvest.

The time of filling and the rate of cooling determine the maximum size of the controlled atmosphere chamber.

5.2 Regulation of the atmosphere

The regulation of the atmosphere follows immediately the regulation of the temperature.

In order to produce, maintain and check the controlled atmosphere in the storage chambers, different methods may be used according to the equipment available (converters, scrubbers, controlled atmosphere generators, analysers, etc.).

5.2.1 Regulation of the oxygen content

The oxygen content of the atmosphere [21 % (V/V)] may be reduced because of the respiration of the product, or by using special installations, in controlled atmosphere storage chambers.

5.2.1.1 Reduction in the oxygen content by respiration

During respiration, oxygen is consumed and carbon dioxide, water and heat are given off. The reduction in the oxygen content is therefore determined, in this case, by the respiration rate of the products stored, the capacity of the storage chamber, its degree of loading, etc. In a chamber of capacity 300 t of apples, an oxygen level of 2 % (V/V) to 3 % (V/V) can be obtained in about 20 days. During the storage period, the opening of the doors is not advisable, given that a longer period of time would be necessary to reattain the oxygen content and that variations in the chemical composition of the gas would be unfavourable to the products stored.

5.2.1.2 Reduction in the oxygen content by means of converters

Converters are used to reduce the oxygen content to 2 % (V/V) to 4 % (V/V) in 2 days to 3 days. They work on the principle of consumption of oxygen by combustion of hydrocarbons or by combination of the oxygen with hydrogen which is produced by the decomposition of ammonia (NH_3) (reduction of the oxygen takes 2 days or 3 days).

The consumption of oxygen by the combustion of hydrocarbons takes place according to the reaction

$$C_3H_8 + 5\ O_2 \rightarrow 3\ CO_2 + 4\ H_2O$$

The combustion takes place at high temperature, then the atmosphere enriched in carbon dioxide is cooled and passed through a carbon dioxide absorber or is introduced directly into the chamber.

These installations function generally in closed or open cycle; atmosphere taken from the chamber or from the exterior is passed over the heated catalyst and, now impoverished in oxygen, is pumped back into the interior.

In practice, different types of converters are used.

5.2.2 Regulation of the carbon dioxide content

During the keeping period, as a result of the respiration process of the products, carbon dioxide accumulates in the chambers. To maintain this content constant at an optimum value, different types of apparatus named "adsorbers" or "scrubbers" allowing the carbon dioxide content to be reduced to the desired value are used.

These appliances work on the principle of physical adsorption or chemical absorption of carbon dioxide.

5.2.2.1 Physical adsorption

For physical adsorption, active carbon, zeolites, etc., whose effectiveness depends on the capillarity, the porosity and the nature of the adsorbent and on the activation method, are used as adsorbents.

The adsorbers work in two stages, i.e.

— adsorption: The atmosphere taken from the chamber is fed through a space where the carbon dioxide is retained by the adsorbent. After diminution of the carbon dioxide content, the atmosphere is returned to the storage chamber.

— regeneration: Regeneration of the adsorbent is carried out by passing a current of air, through the adsorbent, which picks up the carbon dioxide and drives it out to the exterior.

These two stages take place during well-determined periods; the passage from one to the other is controlled by a temporizing relay.

Some zeolite adsorbers have a molecular sieve.

5.2.2.2 Chemical absorption

Various chemical substances (potassium carbonate, sodium hydroxide, ethanolamine, calcium hydroxide, etc.) are used to remove carbon dioxide. However, their limited effectiveness and precision restrict their use.

The following types can be distinguished:

— (mono-, bi-, or tri-) ethanolamine scrubber: The absorption of carbon dioxide is achieved by chemical as well as physical processes. Solutions of carbonates and hydrogen carbonates are obtained, which on heating release carbon dioxide and regenerate themselves.

— potassium carbonate scrubbers, based on the principle of the reversibility of the reaction of the product with carbon dioxide: In a first compartment, the formation of potassium hydrogencarbonate is carried out by the capture of carbon dioxide from the gas passing through the chamber, then the solution is regenerated in another compartment by liberation of carbon dioxide to the exterior. The process is continuous.

— scrubber in which dry calcium hydroxide reacts with carbon dioxide to produce calcium carbonate or bicarbonate: When the calcium hydroxide no longer reacts, it is replaced with fresh material.

5.2.3 Gas generators

These are installations made up of an oxygen converter and a scrubber. These devices work simultaneously during the keeping period; a carbon dioxide scrubber alone can also be used.

The catalytic combustion of oxygen takes place in the converter and the gas mixture obtained (rich in nitrogen and carbon dioxide) is cooled and then sent on to the scrubber which absorbs the carbon dioxide. The gas mixture which results is pumped into the chamber.

NOTE — The catalytic combustion of oxygen may also result in a decrease in the ethylene content of the atmosphere.

The atmosphere generated contains 1 % (V/V) to 1,5 % (V/V) oxygen, 2 % (V/V) to 5 % (V/V) carbon dioxide, the rest being nitrogen. The carbon dioxide and oxygen contents can be regulated, if necessary.

There are two types of generators:

a) open-cycle generators use air from the exterior; after the combustion and fixation of the carbon dioxide, the gas mixture is pumped by a fan into the chamber, which creates a pressure excess thereby displacing some of the atmosphere in the chamber;

b) closed-cycle generators which recycle the air in the storage chamber, lower the oxygen content gradually, remove the carbon dioxide and circulate the effluent through the chamber until the desired composition is obtained.

5.2.4 Production of controlled atmospheres by exchanger-diffusers

Exchanger-diffusers may be used for the regulation of the composition of the atmosphere, based on the principle of the difference in the diffusion speeds of oxygen, carbon dioxide and nitrogen across a silicone plastic membrane with selective properties for the gases.

The passage of air through the exchanger-diffuser favours diffusion and automatically allows fixed proportions of carbon dioxide and oxygen concentrations to be obtained according to the silicone plastic membrane used [for example 5 % (V/V) carbon dioxide, 2 % (V/V) to 3 % (V/V) oxygen, and 92 % (V/V) to 93 % (V/V) nitrogen].

In this case, the desired concentrations in the atmosphere are obtained after a longer period of time as a consequence of normal metabolic processes.

These membranes are bags of various capacity which can be fitted inside or outside the chambers, or linked to the exterior by means of pipes.

The surface area of the membrane depends on the volume of the gas in the chamber.

6 Maintenance of the composition of the controlled atmosphere

Once the required oxygen or carbon dioxide contents have been obtained, recourse has to be made to various procedures to maintain the composition constant.

Owing to the different factors causing variation in the oxygen and carbon dioxide contents (delivery of carbon dioxide gas during ventilation, diffusion of oxygen) specific intervals are needed to control and maintain the required level of each of the gas components.

Stabilization systems for controlled atmospheres are as follows:

— a periodic and careful input of gas for atmospheres of type 1;

— a periodic and careful input of fresh air and removal of carbon dioxide combined with the use of scrubbing and diffusion equipment for atmospheres of type 2.

7 Checks during the keeping period

Check the keeping factors (temperature, relative humidity and gas composition) twice-daily initially and then every day, using direct reading or recording equipment.

Check the quality of the products stored periodically.

8 Operations at the end of controlled storage

When it is desired to end controlled atmosphere storage, open the doors of the cells and leave the fans operating for 1 h or 2 h. Excess carbon dioxide is thus dispersed and the oxygen content is equilibrated with the ambient levels, making it safe for workers to enter without a protective mask.