G U I D E

Packaging Fresh Fruit and Vegetables

Danish Technological Institute
Packaging and Transport
2008

Contents

Introduction

This guide is a product of the project: Perforation of packaging – development of new packaging and methods to control transmission of oxygen, carbon dioxide and water vapours through packaging. The project is financed by The Danish Food Industry Agency under the Innovation Act and carried out from 2006 to 2008.

Use of Packaging

The purpose of the guide is to help manufacturers and packers/fillers of fruit and vegetables to choose the optimum packaging for their products to improve shelf lift and quality of the product, and to reduce loss in the supply chain.

Basically, the right packaging coupled with the right storage temperature can contribute to create conditions in the packaging which will delay maturation and ageing of fruit and vegetables. It is therefore possible to increase shelf life and/or to harvest the product later so that the product is sold with a better quality.

Packaging can really make a difference. If both temperature and packaging is optimum, ageing of fruit and vegetables can be slowed down with up to more than 800%.

The cooling chain in the Danish distribution system – especially in retail shops – is far from perfect. In practice the packaging must then be optimised to the warmest link in the cooling chain.

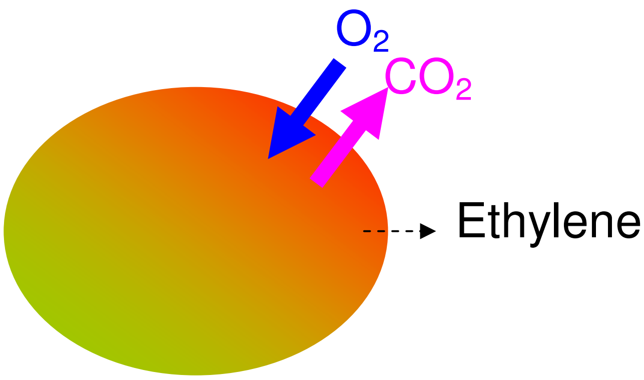
No (cooling) chain is stronger than the weakest link.

Optimum Storage of Fruit and Vegetables

The exact right storage conditions can increase the shelf life for fruit and vegetables with 300-800%. The important parameters for this shelf life extension are temperature, moisture and a modified atmosphere (oxygen, carbon dioxide and ethylene). The optimum storage conditions vary according to the product type, processing and ripening degree, time of harvest and much more. For that reason the values in the overview below are guiding.

Product	**Temp in °C**	**% relative moisture**	**% O_2**	**% CO_2**	**Ethylene**	
					Expels	Sensitive
Banana	12-15	85-100	2-5	3-5	+	+
Bean sprouts	0	90-98	5	15	+	
Mushrooms	0-5	90-98	5	10		+
Tomato (ripe/green)	12-20	90-98	3-5	5-10	+	+
Tomato (ripe)	8-12	85-98	3-5	5-10	+	+
Cauliflower/broccoli	0-5	90-95	2	5	+	++
Cucumber	8-12	90-95	3-5	0		++
Head of lettuce	0-5	95	2-5	0		++
Capsicums	8-12	90-95	3-5	2	+	+
Grape fruit	10-15	85-90	3-10	5-10		
Peach	0-5	90	1-2	5	+++	+
Apple	0-5	90	2-3	1-2	+++	+
Pear	0-5	90-95	2-3	0-1	+++	+
Plum	0-5	90-95	3	8		+
Strawberry	0-5	90-95	10	15-20		

Respiration and Ripening Process



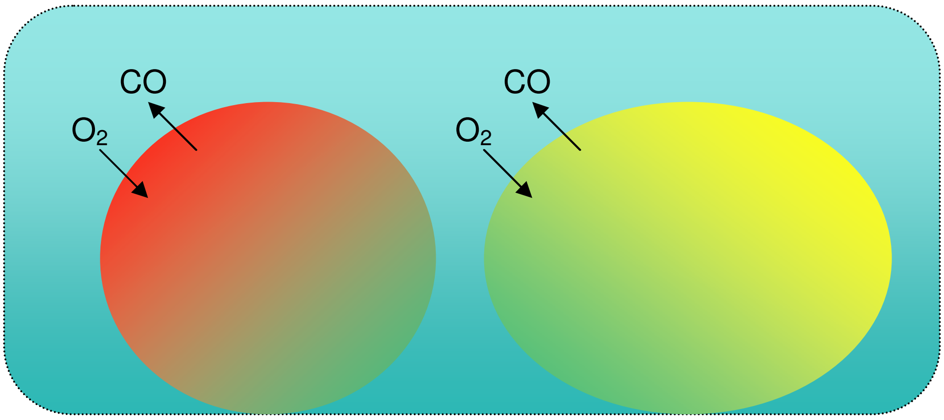
Fruit and vegetables are living products undergoing a ripening and at the end an ageing process, in which the plant tissue is broken down. The products undergo various biological processes, which also continue after the products have been harvested. The processes cause gradual changes in the quality.

An important part of the process is the product's respiration, in which the product consumes oxygen and expels carbon dioxide, water and heat. In this way, carbohydrates and other substances important to the product's freshness, taste and health quality are broken down.

Fruit and vegetables expel ethylene. Ethylene is a gas which accelerates the ripening process in fruit and vegetables, even in small quantities. The ethylene liberation and sensitivity to ethylene varies from product to product.

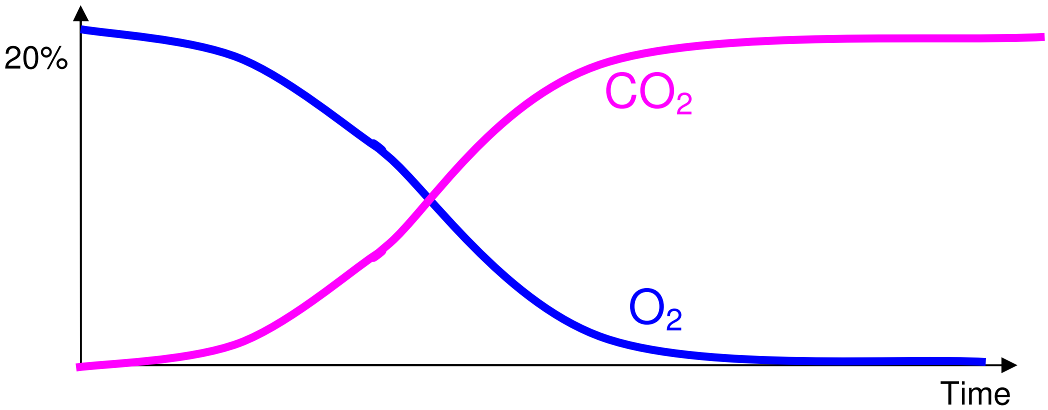
Both the respiration and the liberation of ethylene depend on the temperature. Low temperatures give a slow respiration and low ethylene liberation.

The Packaging System



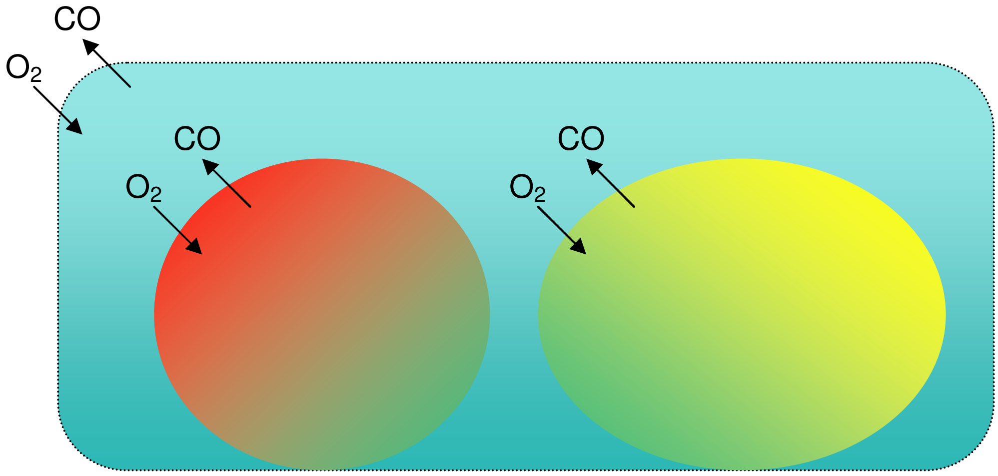
Maintaining the right temperature, gas mix and moisture in the packaging are important elements to create an efficient extension of the shelf life for fruit and vegetables.

If fruit and vegetables are kept in airtight packaging or another closed container with atmospheric air (20.9% oxygen, 78.1% nitrogen and 0.04% carbon dioxide etc.) the oxygen will be converted into carbon dioxide due to respiration.



The figure shows the oxygen and carbon dioxide concentrations in packaging with fruit and vegetables.

The respiration rate or the rate by which the oxygen is converted into carbon dioxide depends on the oxygen concentration. At low oxygen concentrations the respiration usually takes place slower than at high oxygen concentrations. This means that at low oxygen concentrations the ageing process takes place slower, and that the shelf life is extended. If the oxygen contents become very low, the product cannot breathe. Consequently, the product dies and becomes worthless.



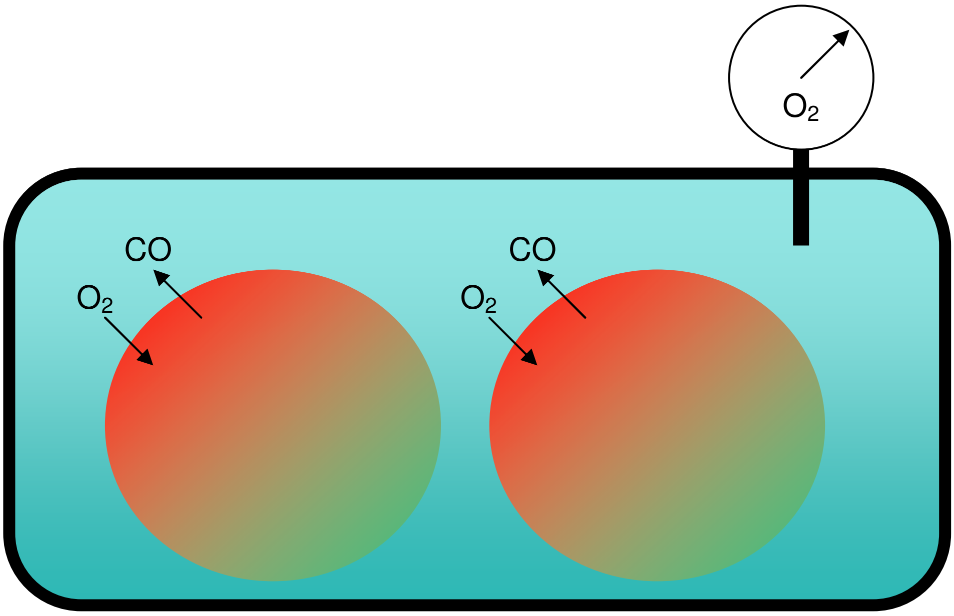
Packaging film for fruit and vegetables are never quite impervious to oxygen, carbon dioxide and water vapours. Even though the packaging film is welded quite tight, these gasses will be transported through the film (dissolved on the one side and liberated on the other). The rate depends on the type of plastic, the thickness of the film and the area, temperature and pressure differences of the gasses on each side of the film.

To obtain a sufficient mechanical strength of the packaging, a certain thickness of the packaging is necessary. For quick/rapid respiring/breathing products it is impossible to make films so thin that the permeability (the transport of gas) becomes high enough to prevent a lack of oxygen inside the packaging. If the product consumes the oxygen in the packaging faster than new oxygen is supplied, the oxygen concentration in the packaging will become so low that the product dies.

Perforation of the packaging is a solution to control the atmosphere inside the packaging, as the holes is a way of steering a continued transport of oxygen into the packaging. At the same time carbon dioxide can get out of the packaging. The size of the wholes must be adapted to the product, the packaging film and not least the distribution temperature.

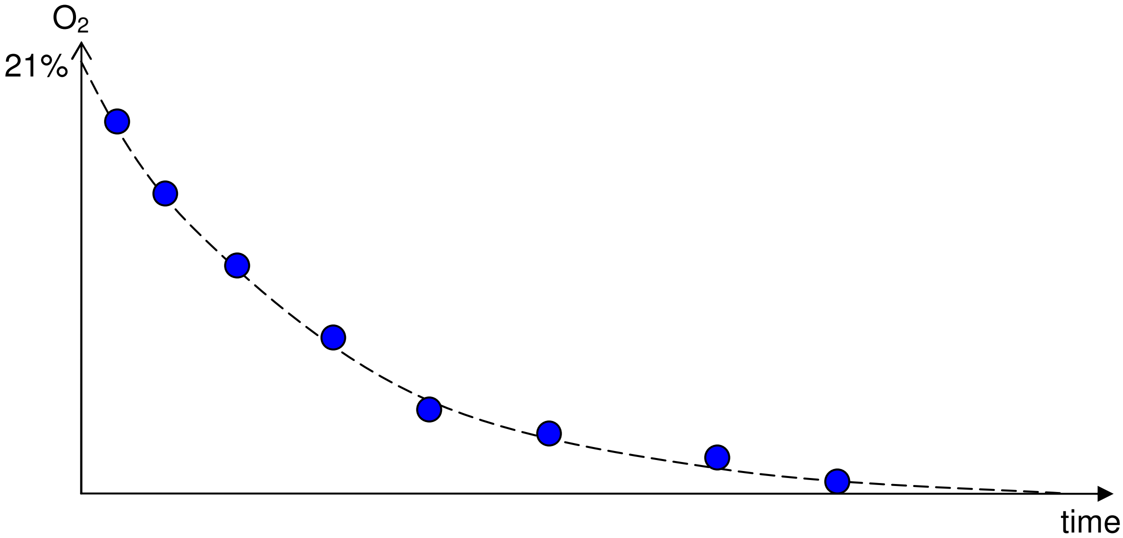
Measuring the Respiration Rate

To be able to calculate the respiration rate the product's oxygen consumption must be measured in a completely airtight container at various oxygen concentrations. In addition, when you know the volume of the container and the weight of the product inside the container, you can calculate the respiration rates at various oxygen concentrations.



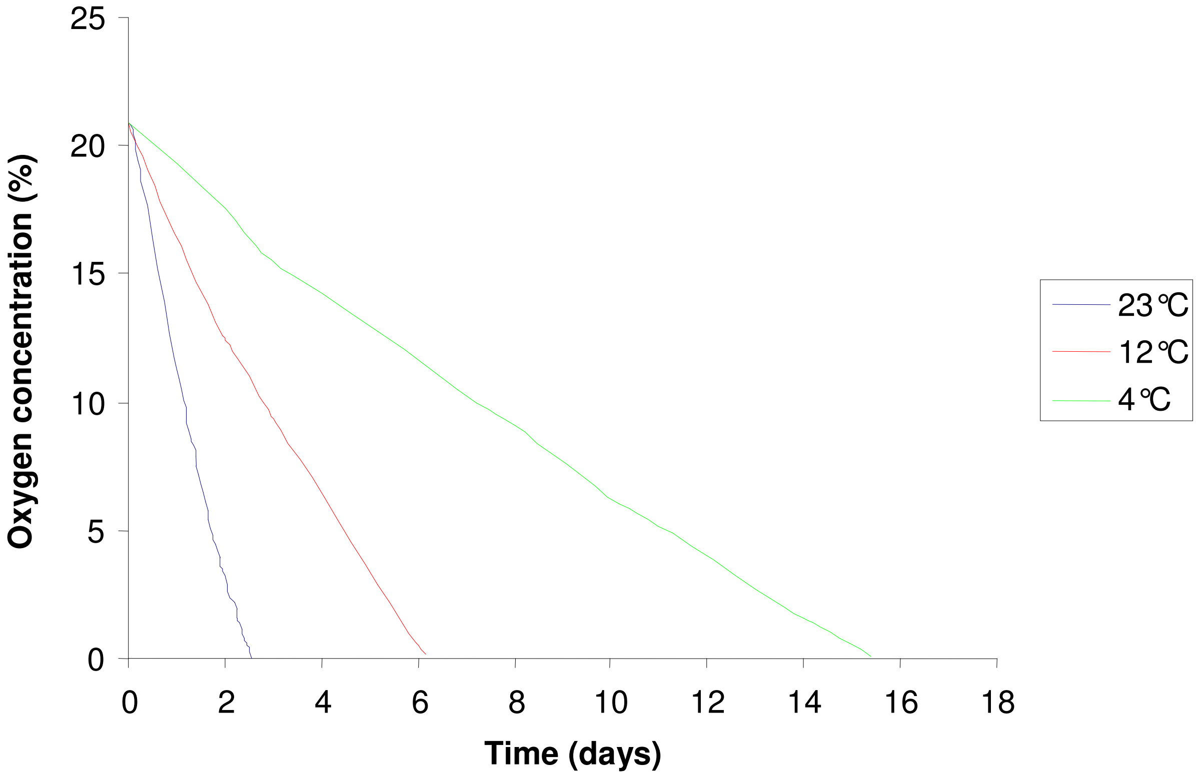
The respiration rate of a product can be determined by placing the product you wish to examine in a container with a lid. The container must be of either stainless steel or glass and have a volume of ½-5 litres, depending on the product and the quantity to be examined. Ordinary glass jars can be used. The lid must be easy to attach, and must seal completely tight. The lid must have a device for extracting gas samples. It is important that the extraction does not make the container leak. The oxygen concentration is measured over a known period of time, and the respiration rate is calculated. See the section about packaging construction.

The picture shows a set-up with respiration vessel and an instrument which measures the oxygen and carbon dioxide contents of the container.



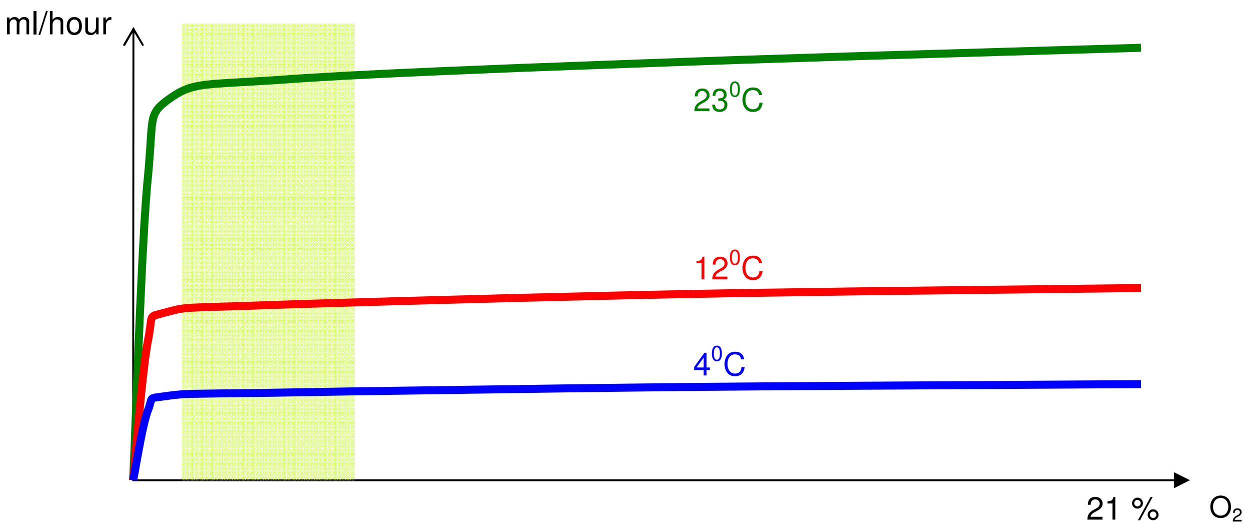
If the oxygen concentration is measured regularly until all oxygen has been consumed, a curve similar to the above can be outlined.

The Significance of Temperature to the Respiration Rate



The above curve shows the oxygen consumption of 120 grams of rocket by respiring in a 5 litre container. The measurements were taken at 4 °C, 12 °C and 23 °C, respectively. The curves show how important temperature is to respiration.

When the oxygen concentration is measured until all oxygen has been consumed, you can calculate the respiration rate of the product and relate it to the oxygen contents in the air surrounding the product.



As shown above, it is important to consider temperatures when designing packaging. For this reason test tubes and subsequently test packages must be kept at the right temperature during tests. The right temperature is the highest temperature, at which the product is kept for a longer period during distribution.

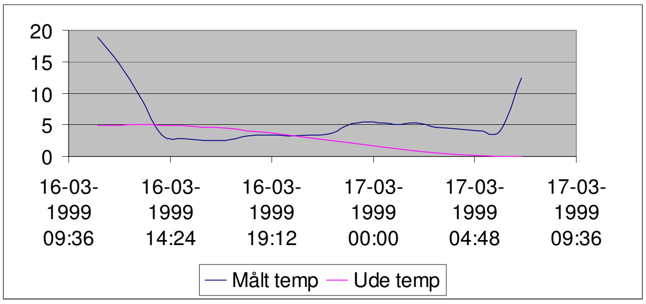
Equipment for Measuring Oxygen Concentration in the Packaging

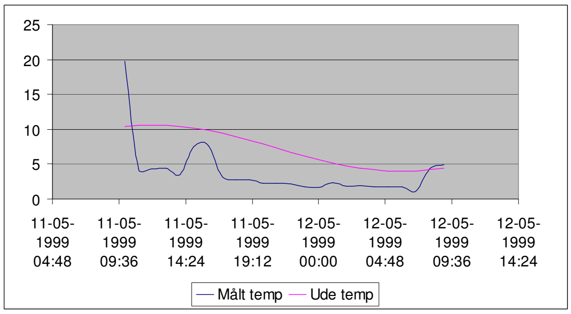
There are various measuring instruments on the market for measuring the oxygen and carbon dioxide contents in packaging. Samples are extracted with a small needle through a septum to ensure that the hole is closed after taking the sample. Prices range from 10,000 to 100,000 DKK.

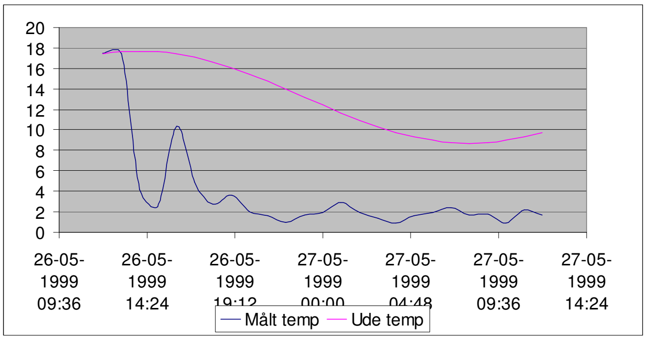
The Distribution Temperature

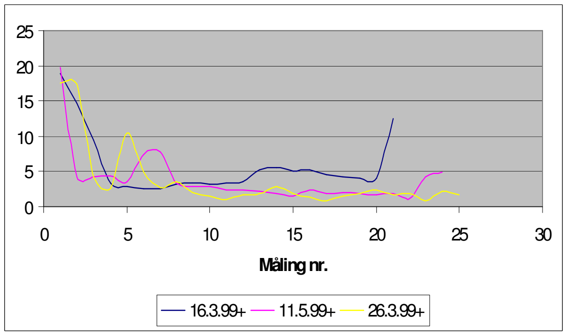
Danish Technological Institute has taken measurements of temperature development for fruit and vegetables distributed via ordinary distributors. A lot of fruit and vegetables are distributed via fresh food terminals and when the measurements were taken the transport used was often ordinary lorries with tarpaulin.

Ordinary lorry from grower/producer via distributor to shop









The above graphs show brief temperature rises during transport which must be taken into account. However, corrections must not be made with full effect because of the time it takes for the product to change temperature and the fact that the respiration is increased so much that the situation becomes critical.

Fresh-Food Terminal

Here the temperature chain is always within the range 2-4 °C.

Retail Shops

Retail shops have storerooms in the back room. Some of these storerooms have room temperature, while others have cold stores at 2-10 °C.

However, it is in the sales areas, where the product is not kept cool, that the situation becomes critical and many products are discarded. The temperature in the shops varies between 15 and 25 °C.

Ordinary Shop Presentation

Moisturisation System

On a hot summer's day, when the outside temperature was 25 °C, the Danish Technological Institute carried out measurements round a moisturisation system in a fruit and vegetable area. The results were:

> On top of fruit and vegetables: 23 °C and 67% relative moisture
>
> Approx. 5 m from the fruit and vegetable department: 23 °C and 66% relative moisture
>
> Approx. 25 m from the fruit and vegetable department: 25 °C and 57% relative moisture

Consequently, there is some indication that the moisturisation system works in a large area of the store, where it lowers the temperature with 2°C and increases the moisture with approx. 10%.

On unpackaged fruit and vegetables drops of water will completely moisturise the immediate environment close to the products, and the heat of evaporation will lower the temperature directly on the product. This was not measured.

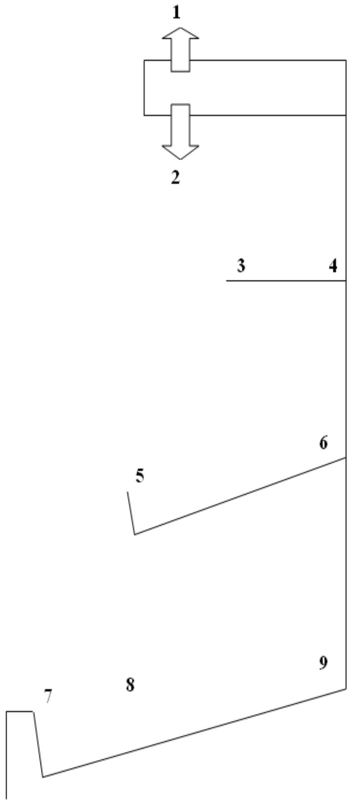
If fruit and vegetables are sold in perforated packaging in this wet environment, the perforated holes will close, which will result in a lack of oxygen in the packaging.

Cooling Shelves

Premise

Construct the packaging for the highest temperature in the distribution chain, where the products remain for more than 1-2 hours.

The data below has been measured in a cooling shelf, as outlined to the left.



Measuring Point	Temperature	Humidity
1	40-50 °C	-
2	5-8 °C	40-60 %
3	10-15 °C	50-70 %
4	12-17 °C	50-60 %
5	10-15 °C	50-60 %
6	10-15 °C	40-55 %
7	10-15 °C	50-65 %
8	10-15 °C	45-60 %
9	10-15 °C	30-50 %

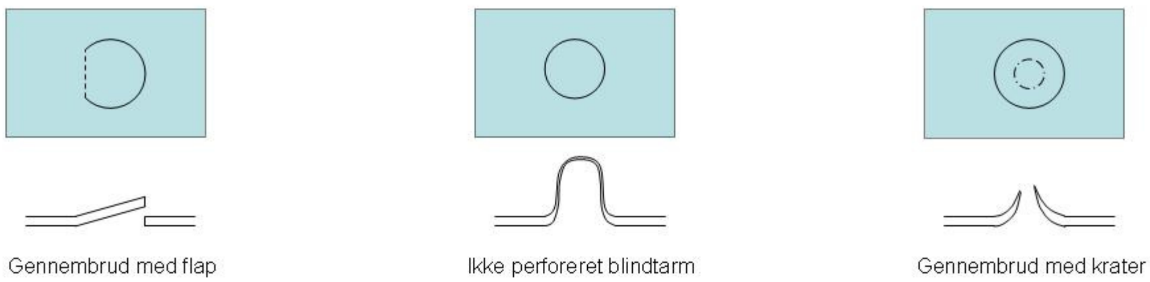
Due to the dry climate and the ventilation the products will dry out faster. The equipment should not be used for goods which are not packaged.

Even though the injection temperature is low, the temperature of the goods is relatively high.

Perforation Technology

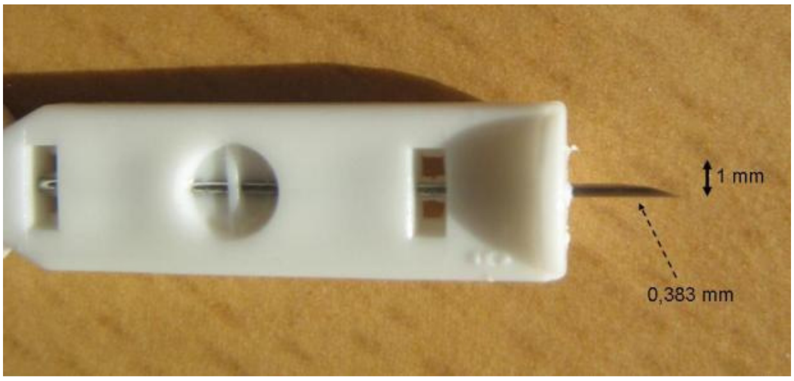
Needle Perforation

Perforation can be made with needles. These needles can be bought cheaply with diameters from 0.3-1 mm. Calculations show that a single cylinder hole of this diameter will allow far too large quantities of oxygen to pass through the hole, but needles do not make cylindrical holes in a packaging film. Packaging film is tough, so depending on the film material, the shape of the needle and the piercing technique, the whole is as follows:



Drawing texts: Piercing with flap - Non-perforated appendix - Piercing with crater

It is important to be absolutely sure that the film is pierced. If the packaging film is elastic and tough, an “appendix” may appear increasing the permeability of the film, because the area is increased and the film becomes thinner, but the film is still far too airtight. If the film is pierced, very different types of holes will appear depending on the type of needle and material. Common to these holes is that the film has withdrawn, making the hole considerably smaller than expected. At the same time a “valve” has been made which will partly close when the pressure goes against the perforating direction of the needle.

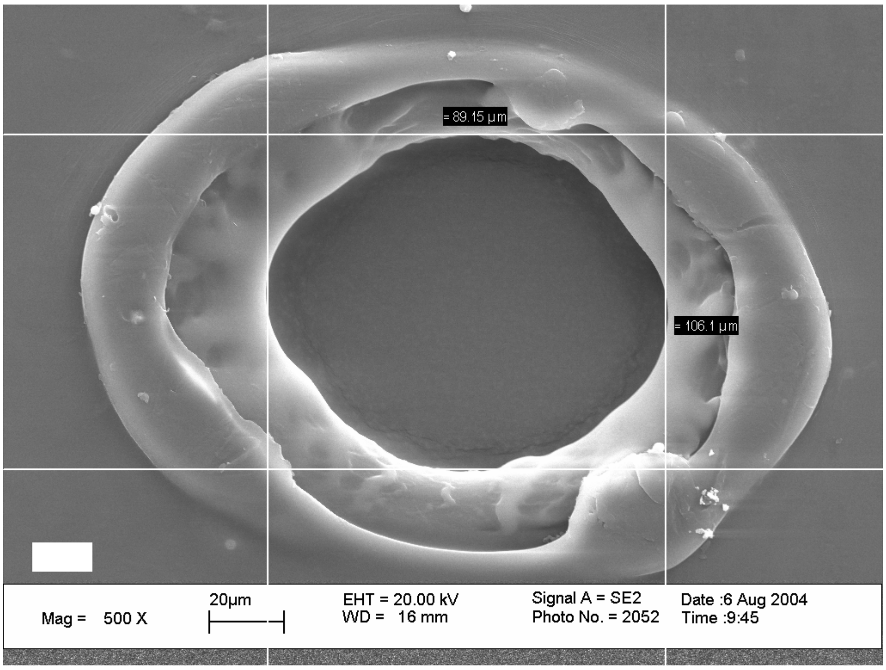


An excellent manual solution is to use a cheap medical needle, used for taking blood tests on diabetes patients.
The above applies to cold needles, but it is also possible to use heated needles. It is slightly more complicated to use heated needles, as the needle must be heated to a temperature higher than the melting point of the film. Subsequently the film is pierced with the needle, leaving a round hole. As the film melts, the needle leaves a circular hole, when it is withdrawn. The size of the hole will depend on both the diameter of the needle and the temperature of the needle.

Perforation with Electrostatic Energy

Plastic film can also be perforated with the aid of a spark. You place the film on a slab/plate or another conducting item. In a distance of 1-1.5 mm from the surface of the film you place a needle point. Between the needle point and the slab/plate, or item, below, you establish a high- frequency tension/voltage. The spark flying from the needle point and down to the film evaporates the film, and the hole appears/occurs. The size of the hole can vary by reducing or increasing the electric charge.

Laser Perforation



The ultimate solution for perforation plastic film is with a laser, but it is also the most expensive of the existing solutions, as it requires expensive specialist equipment. It is possible to make holes down to approx. 10 µm thicknesses and up to 200 µm. Laser perforation will typically make slightly oval holes. The advantage of laser perforation is that it is proportionately easy to control the size of the hole.

Always ask the supplier of perforated film for written specifications, as many films are sold as something else than they actually are.

Packaging Construction

First step is a comparative assessment of three basically different types of packaging:

1. Open or macro-perforated packaging, in which the openings are so large that the air inside the packaging is always similar to the atmosphere.
2. Completely closed packaging without physical holes.
3. Micro-perforated packaging with a number of holes of 10-200 µm.

Open or macro-perforated packaging is not relevant to this guide.

Completely Closed Packaging without Physical Holes

Many people believe that this type of packaging is completely airtight, but gasses can pass slowly through the film by a disintegration process. This transmission/diffusion is so slow that the packaging will be far too airtight for quickly respiring products, but it can be a good solution for the slowly respiring products, provided that the film is thin.

Calculation of the respiration rate

$RR_{O_2} = (C_{O_2,start} - C_{O_2,end})/(\Delta time * V)$ [ml/kg*hour]

Correlation/Relation between Oxygen Permeability and Respiration:

$P_{O_2} = (RR_{O_2} * V)/(O * (0,21 - G_{O_2}))$ [ml/m2*hour]

Micro-Perforated Packaging

For quickly respiring products it is necessary to micro-perforate the packaging film. The formulas below only apply to round perforations without a flap.

Calculation of optimum number of holes at a known respiration rate:

Required oxygen transmission packaging = permeability film + oxygen transmission hole

Required oxygen transmission packaging = $(RRO_2 * V)/(O * (0{,}21 - GO_2))$

Oxygen transmission hole = $(di * A_{hole}/(\kappa * d + t) * 3600 * 24 *$ Number of holes)

Permeability film = $PO_{2,film}$ [to be stated by supplier]

When the values below are known you can use the spreadsheet on page 25 to calculate the optimum number of holes for a packaging to a certain product.

Construction Premises/Conditions

Distribution temperature, max.	T	℃
Optimum oxygen level, mean value/average	GO_2	% divided by 100
Respiration rate (by/at T and GO_2)	RRO_2	ml/kg*hour
Product weight	V	Kg
Oxygen permeability (at current temperature)	PO_2	ml/m²/24 hours
Thickness of packaging film	t	cm
Packaging width	b	m
Length of packaging	l	m
Height of packaging	h	m
Surface area	O	(=(b*l)+(b*h)+(l*h)) ²
Diffusion coefficient	di	cm²/s
Oxygen concentration at first measurement	CO_2, start	(=%/100* V_h) ml
Oxygen concentration at last measurement	CO_2, end	(=%/100* V_h) ml
Headspace volume	V_h	
Time between the two oxygen concentration measurements	Δtime	hours
Proportionality factor	κ	
Hole diameter	d	cm
Hole area	A_{hole}	(= 3,14 * d * d/4) cm²

Diffusion coefficient and proportionality factor κ

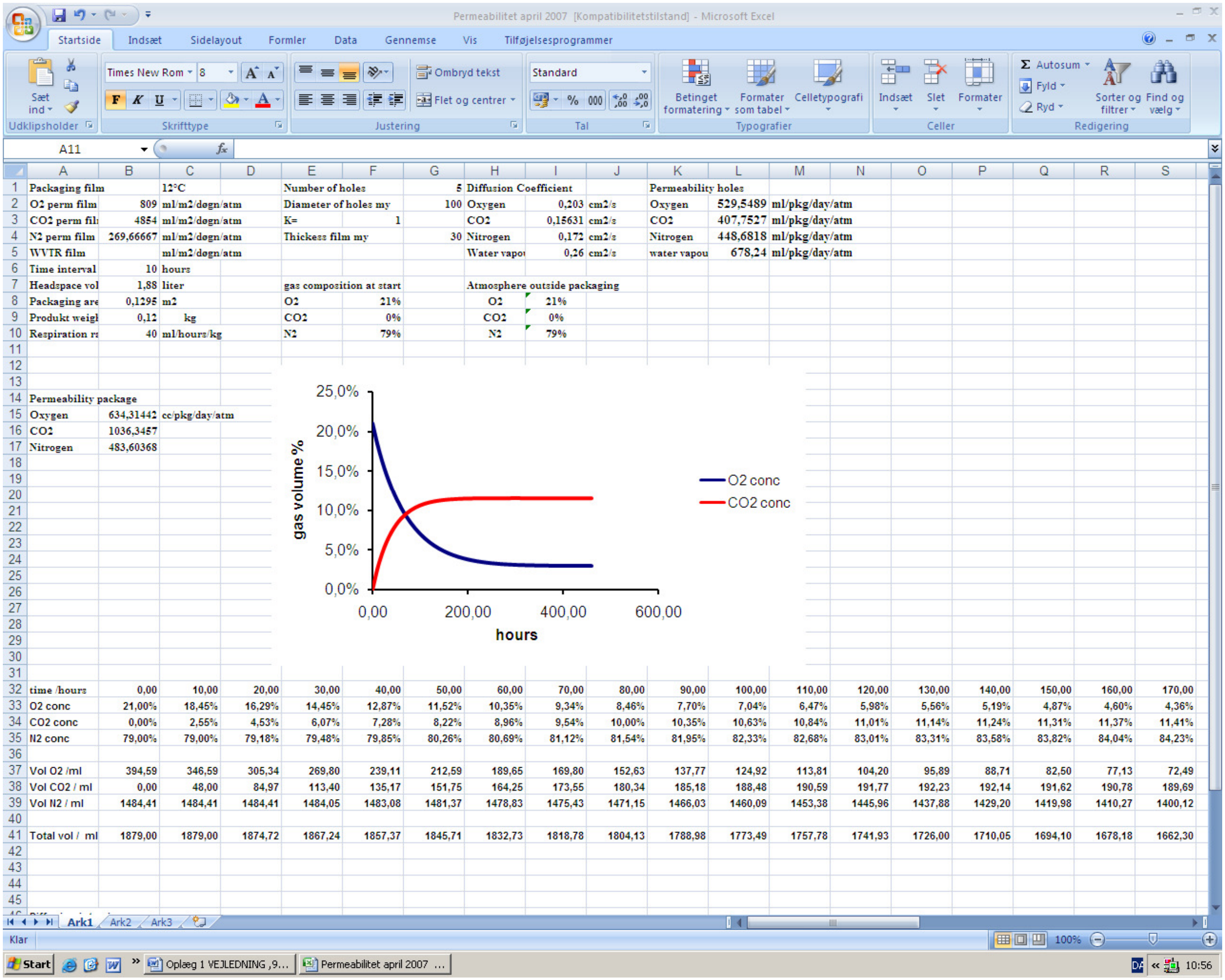
The diffusion coefficient is a variable dependent on oxygen concentration and temperature. It has no great influence on the result and is always set to be 0.2 cm^2/s.

Kappa is determined by the air rate/speed round the packaging and inside the packaging. The speed/rate inside the packaging is always low. Usually κ = 1 will be used.

κ = 1 (low air speed/rate on both sides of the film)
κ = 0.5 (high air speed/rate on one side of the film)
κ = 0 (high air speed/rate on both sides of the film)

Mathematical Modelling

Danish Technological Institute has made a mathematical model which can simulate the consequences of changing the various parameters which influence the characteristics of the packaging. Please call 72 20 31 50 for further information.



Packaging Trials

By means of respiration trials and the mathematical model you calculate the optimum number of perforated holes for a certain product, kept at a specific temperature. When the packaging has been produced you can control if the packaging performs at its best during packaging trials. A certain number of packaging is produced, e.g. 5-10, which are packed with the product and kept at the relevant temperature. Alternatively, the packaging can be kept with the product packed in existing bags or perforated bags the better to see the improvements.

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Questions and consultancy

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