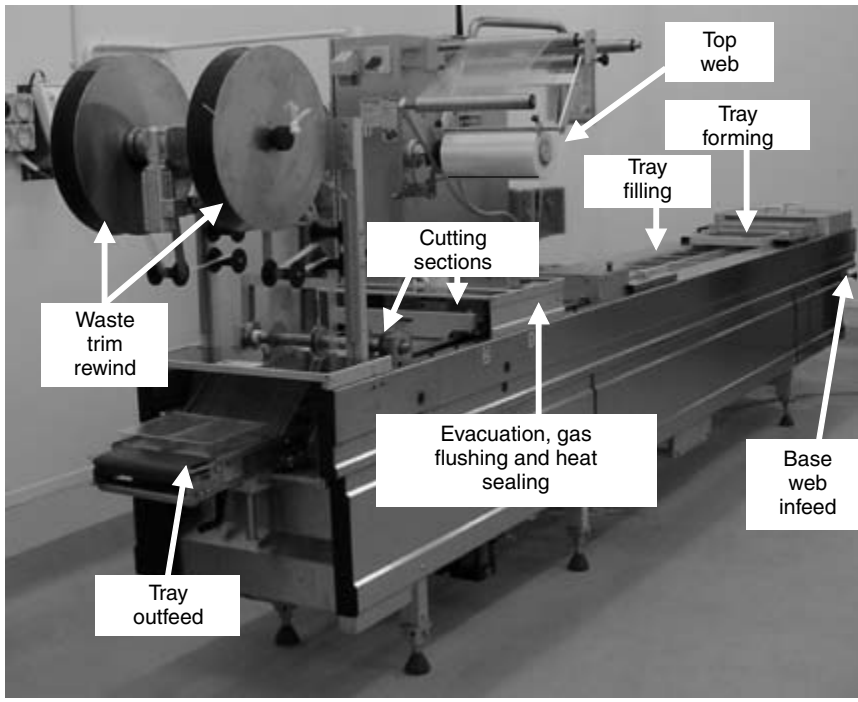

Figure 10.7 Multivac R230 thermoform fill seal machine.

10.A5 Quality assurance of MAP

Examples of instruments used in quality assurance of MAP are discussed in this section. These are provided by way of example and are not intended to be recommendations by the authors.

10.A5.1 Heat seal integrity

The majority of MAP form-fill-seal retail packs are heat sealed. The quality and safety of MAP food will be compromised if the seal integrity is lost during the required life of the pack. A breach of the heat seal will result in a rapid loss of the modified atmosphere in the pack. Therefore, the sealing operation constitutes a critical control point and must be monitored during production as part of the quality assurance procedure. It is of key importance that sealing bar temperature, pressure and dwell time are set according to machine manufacturer and packaging supplier specifications and conditions are monitored during machine operation.

Figure 10.8 Lower web unwind and infeed section on the Multivac R230.

Seal and pack integrity can be assessed by either destructive or nondestructive tests. Destructive tests are based on immersing packs in water and checking for escaping gas bubbles from around the seal. Other test methods measure seal strength by pressurising packs using compressed air until the seal fails. Non-destructive tests are based on measuring changes in pressure generated by packs under vacuum in sealed chambers. Some examples of seal integrity equipment are discussed below.

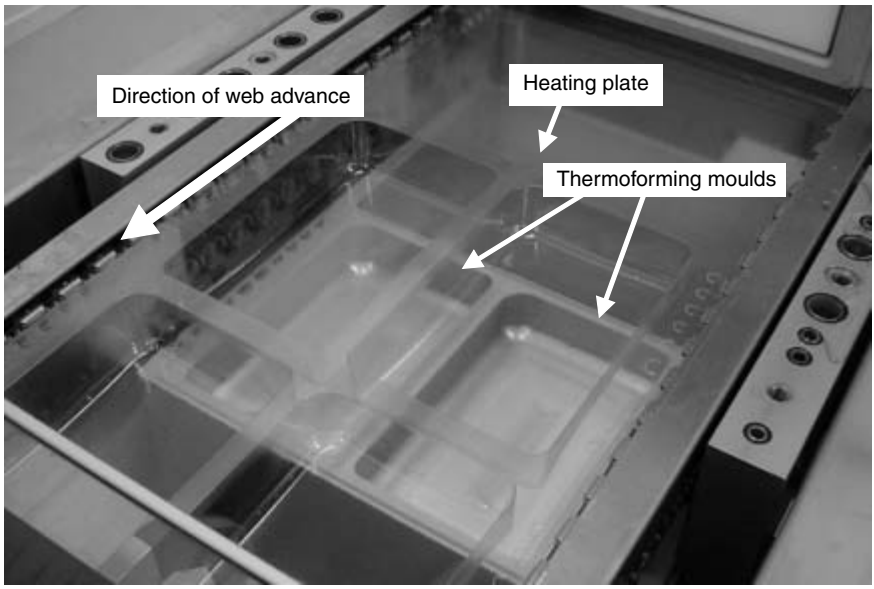

Figure 10.9 Base web thermoforming section on the Multivac R230.

10.A5.1.1 Nondestructive pack testing equipment

Ai Qualitech manufactures a range of vacuum leak testers (Q700 series) designed for the use in production or laboratory environments for MAP tray packs, pouches and pillow packs. When the vacuum is pulled, the pack expands, causing the top web to dome. A pressure sensor in contact with the top of the pack will detect pressure drop due to a leaking pack. Ease of use and objective and quantifiable measurement are possible benefits. The instrument can be supplied with pick and place equipment to enable online automatic operation. The instrument is capable of detecting holes of 10 μm or greater.

10.A5.1.2 Destructive pack testing equipment

An example of equipment which measures the heat seal strength of complete packs is LIPPKE 2500 SL Package Test System. The equipment can be used to measure seal rupture and also pack atmosphere leakage through pinholes or faulty seals. In the leak test mode, the pack is pressurised to a predetermined maximum and internal pack pressure monitored. Leaks are evident as a decrease in pack pressure. In the seal strength mode, a linear pressure increase is applied internally in the package. The pressure achieved at burst indicates the strength of the seal. Needle probe minimum penetration is 1 mm, which makes this instrument suitable for most types of pack.

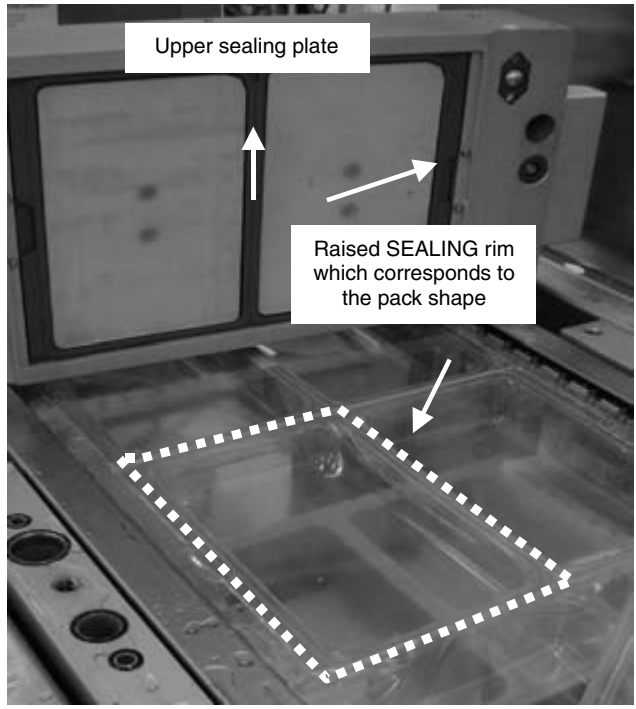

Figure 10.10 Top web heat sealing on the Multivac R230.

10.A5.2 Measurement of transmission rate and permeability in packaging films

Accurate determination of the oxygen, CO_2 and water vapour permeabilities of plastic-based film is important for MAP applications. Several methods exist for measuring transmission rate and permeability of gases and vapours across a packaging film. The most common test procedure is based on the isostatic method. In this method, both sides of the test film are maintained at the same total pressure but a constant partial pressure difference is maintained by passing test gas continuously on one side of the film while inert carrier gas continuously removes permeant from the other side of the film. This maintains a very low partial pressure of permeated test gas and establishes a constant gas concentration difference across the film. This is also referred to as the *concentration increase* method.

10.A5.2.1 Water vapour transmission rate and measurement

Water vapour transmission rate is defined as the time rate of water vapour flow, normal to the two surfaces, under steady-state conditions through unit

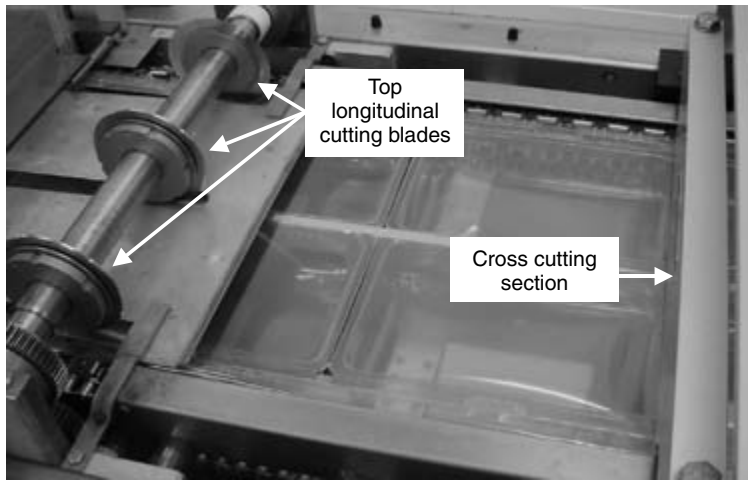

Figure 10.11 Cutting section on the Multivac R230.

area of a test film. There are several methods for measuring WVTR and water vapour permeability. Earlier methods were based on ASTM E96: Standard Test Methods for Water Vapor Transmission of Materials. This gravimetric procedure measured the weight increase by a desiccant sealed in an aluminium cup by the test film, with the apparatus being held in an environment of known and controlled temperature and RH. The weight increase of the dish occurs as a result of moisture uptake by the dessicant and is due to the water permeating through the test film from the surrounding environment into the sealed cup. The corresponding WVTR could be calculated from the weight increase. For high-barrier films, the test can take several days, if not weeks.

In 1990, ASTM introduced a test standard (ASTM F 1249: Standard Test Method for Water Vapor Transmission Rate Through Plastic Film and Sheeting Using a Modulated Infrared Sensor) based on the isostatic method and employing solid-state electronics with pulse-modulated infrared sensors which can detect water vapour from 1 part per million. MOCON (Modern Controls Inc.) supply equipment to measure WVTR based on this standard. Test temperatures can be controlled from 10 to 40°C (±0.5°C) and RH from 35 to 90% RH (±3%). The instrument can test at 100% RH by inserting water-saturated sponges in the test cell.

Water vapour permeating across the test film is transported by dry N_2 gas to an infrared detection system intended for operation over a 5–50°C temperature range. The infrared photodetector produces a low-level electrical signal in response to the change in transmitted infrared radiation. The amplifier produces a filtered DC signal in direct proportion to the water vapour in the test cell and therefore proportional to the water vapour transmission of the test film. The WVTR of high-barrier materials can be determined within 2 days. Test measurements are reported in the units: $g\,m^2\,day^{-1}$.

10.A5.2.2 Measurement of oxygen transmission rate

Oxygen transmission rate is defined as the time rate of gaseous oxygen flow, normal to the two film surfaces, under steady-state conditions through a unit area of a test film material.

MOCON Oxtran (Modern Controls, Inc.) measures the transmission rate of oxygen across flat films by a method based on the isostatic procedure. A coulometric sensor detects permeated oxygen and provides parts per billion sensitivity.

10.A5.2.3 Measurement of carbon dioxide transmission rate

The PERMATRAN C-IV, manufactured and marketed by MOCON (Modern Controls, Inc.), is an instrument for measuring the rate at which gaseous CO_2 diffuses through a flat film. Test films are clamped in a diffusion cell, and one half of the cell is flushed continuously with CO_2 gas. Permeated gas is carried to an infrared sensor where a response is generated proportional to the amount of CO_2 present. In cases where the test film offers a very low barrier to CO_2, the test film may be mounted on an aluminium foil mask to reduce the test surface area from 50 to 5 cm^2.

10.A5.3 Determination of headspace gas composition

10.A5.3.1 Oxygen determination

Oxygen promotes many food spoilage reactions as discussed in Section 10.A 2.3. Certain foods can be damaged by exposure to oxygen concentrations of 1–2%. The level of residual oxygen in the pack headspace is therefore of concern to food processors and forms part of the quality procedures for the manufacture and packing of oxygen-sensitive products. An example of the type of equipment which measures the concentration of headspace oxygen is the TORAY LC 750F Oxygen headspace analyser. This instrument determines residual oxygen by probing and sampling headspace gases in MAP packs and is suitable for production and laboratory use, with a response time of approximately 2 s.

10.A5.3.2 Carbon dioxide determination

Similar in operation to the TORAY LC 750F, the TORAY PG100 Carbon dioxide headspace analyser measures CO_2 in flexible, semi-rigid and rigid packages.

SECTION B MAIN FOOD TYPES

10.B1 Raw red meat

Microbial growth and oxidation of the red oxymyoglobin pigment are the main spoilage mechanisms that limit the shelf life of raw red meats. The packaging

technologist has to maintain the desirable red colour of the oxymyoglobin pigment, by having an appropriate O_2 concentration in the pack atmosphere, and at the same time minimise the growth of aerobic microorganisms. Highly pigmented red meats, such as venison and wild boar, require higher concentrations of O_2.

Aerobic spoilage bacteria, such as *Pseudomonas* species, normally constitute the major flora on red meats. Since these bacteria are inhibited by CO_2, it is possible to achieve both red colour stability and microbial inhibition by using gas mixtures containing 20–30% CO_2 and 70–80% O_2. These mixtures can extend the chilled shelf life of red meats from 2–4 days to 5–8 days. A gas/product ratio of 2:1 is recommended.

Red meats provide an ideal medium for the growth of a wide range of spoilage and food poisoning microorganisms including *E. coli*. Because raw red meats are cooked before consumption, the risk of food poisoning can be greatly reduced by proper cooking. The maintenance of recommended chilled temperatures and good hygiene and handling practices throughout the butchery, MAP, distribution and retailing chain is of critical importance in ensuring both the safety and extended shelf life of red meat products.

10.B2 Raw poultry

Microbial growth, particularly growth of *Pseudomonas* and *Achromobacter* species, is the major factor limiting the shelf life of raw poultry. These Gram-negative aerobic spoilage bacteria are effectively inhibited by CO_2. Consequently, the inclusion of CO_2 in MAP at a concentration in excess of 20% can significantly extend the shelf life of raw poultry products. CO_2 concentrations higher than 35% in the gas mixture of retail packs are not recommended because of the risks of pack collapse and excessive drip. Nitrogen is used as an inert filler gas, and a gas/product ratio of 2:1 is recommended. Since pack collapse is not a problem for bulk MAP master packs, gas atmospheres of 100% CO_2 are frequently used.

Since poultry meat provides a good medium for the growth of pathogenic microorganisms, including some that are not inhibited by CO_2, it is critical that recommended chilled temperatures and good hygiene and handling practices throughout the supply chain are adhered to and that products are properly cooked prior to consumption.

Early research into gas mixes for MAP of poultry meat reported discolouration of the meat at CO_2 concentrations higher than 25%. Even at 15%, the authors sometimes observed a loss of *bloom* (Ogilvy & Ayres, 1951). This research is at variance with the lack of problems reported from the commercial use of relatively high levels of CO_2 with meat products, with up to 100% in some products. Gas compositions of 25–50% CO_2 and 50–75% N_2 are used routinely.

It would appear that the problems that have been occasionally encountered with high levels of CO_2, e.g. development of greyish tinges on meat, may simply be due to high residual levels of O_2 rather than the concentration of CO_2 (Gill, 1990).

It is recommended that research into the optimal gas composition and package type and size should be conducted for individual food products. Furthermore, headspace gas composition will change during storage due to microbial respiration and gas exchange between the pack headspace and the environment. Therefore, processors should conduct trials to determine the extent to which gas composition changes through the shelf life of the product. The ratio of headspace pack volume to food product volume is also important, as is the types and thickness of the package material and the package design. Shelf life evaluations must reflect the conditions from manufacture to consumption of the product. It may also be necessary to consider the effect of pack opening on the subsequent shelf life of the product.

10.B3 Cooked, cured and processed meat products

The principal spoilage mechanisms that limit the shelf life of cooked, cured and processed meat products are microbial growth, colour change and oxidative rancidity. For cooked meat products, the heating process should kill vegetative bacterial cells, inactivate degradative enzymes and fix the colour. Consequently, spoilage of cooked meat products is primarily due to post-process contamination by microorganisms, as a result of poor hygiene and handling practices. The colour of cooked meats is susceptible to oxidation, and it is important to have only low levels of residual O_2 in packs. MAP using CO_2/N_2 mixes (gas compositions of 25–50% CO_2 and 50–75% N_2) along with a gas/product ratio of 2:1 is widely used to maximise the shelf life and inhibit the development of oxidative off-flavours and rancidity. Raw cured meat products, e.g. bacon, owe their characteristic pink reddish colour to nitrosylmyoglobin. This pigment is more stable than oxymyoglobin and is unaffected by high levels of CO_2 but is slowly converted to brown metmyoglobin in air. During cooking, nitrosylmyoglobin is converted to pink denatured nitrosohemochrome pigments that are unstable in air.

Processed meat products such as sausages, frankfurters and beef burgers generally contain sodium metabisulphite, which is an effective preservative against a wide range of spoilage microorganisms and pathogens. Cooked, cured and processed meat products containing high levels of unsaturated fat are liable to be spoiled by oxidative rancidity, but MAP with CO_2/N_2 mixtures is effective at inhibiting this undesirable reaction.

Potential food poisoning hazards are primarily due to microbial contamination or growth resulting from post-cooking, curing or processing contamination.

These can be minimised by using recommended chilled temperatures, good hygiene and handling practices. The low water activity (a_w) and addition of nitrite in cooked, cured and processed meat products inhibit the growth of many food poisoning bacteria, particularly *C. botulinum*. This inhibition may be compromised in products formulated with lower concentrations of chemical preservatives than those used in traditional foods. The potential effects of any changes in product formulation on the growth and survival of pathogens should always be considered. Cooked meats stored without any added preservatives will be at risk from growth of *C. botulinum* under anaerobic MAP conditions, particularly when held at elevated storage temperatures. It should be noted that many sliced, cooked, cured and processed meat products are vacuum packed for retail sale. However, the shelf life of such products in MAP is similar to that achieved in vacuum packs, and additionally, MAP allows for easier separation of meat slices.

10.B4 Fish and fish products

There has been a very significant increase in the sale of MAP fish products in Europe and particularly in the UK. Nevertheless, packaging technologists should be aware of a major concern limiting the development of MAP, namely *C. botulinum*. There is also debate about the cost benefits of MAP, since in some applications only relatively small increases in safe shelf life have been reported. Spoilage of fish results in the production of low molecular weight volatile compounds, therefore, packaging technologists need to consider the odour barrier properties of packaging films and select appropriate high-barrier materials for packaging strong flavoured fresh, smoked and brined fish and fish products.

Spoilage of fish and shellfish results from changes caused by three major mechanisms: (i) the breakdown of tissue by the fish's own enzymes (autolysis of cells), (ii) growth of microorganisms, and (iii) oxidative reactions. MAP can be used to control mechanisms (ii) and (iii) but has no direct effect on autolysis. Because autolysis is the major cause of spoilage of fish and shellfish stored at temperatures close to 0°C compared with the activities of bacteria, this may explain the reduction in benefits achieved from MAP of fish compared to other flesh products. MAP, while potentially inhibiting oxidative reactions, may be more effective at inhibiting microbial growth.

Oxidative reactions are much more important as shelf life limiters in fish compared with other flesh meat, because seafood has a higher content of polyunsaturated lipids. Storage temperature has a major effect on fat oxidation that occurs even at frozen temperatures. Note that salt addition can accelerate oxidative processes.

Generally, the major spoilage bacteria found on processed fish are aerobes including *Pseudomonas*, *Moraxella*, *Acinetobacter*, *Flavobacterium* and

Cytophaga species. There are several microorganisms that are of particular importance when dealing with MAP fish products, these include *C. botulinum*. Use of CO_2 can effectively inhibit the growth of some of these species, see Table 10.2. The aerobic spoilage organisms tend to be replaced by slower growing, and less odour producing, bacteria, particularly lactic acid bacteria such as lactobacilli, during storage.

Because fish and shellfish contain much lower concentrations of myoglobin, the oxidation status of this pigment is less important than that in other meats. Consequently, there is potential to use higher levels of CO_2, e.g. 40%. Because of the high moisture content and the lipid content of some species, N_2 is used to prevent pack collapse.

One of the concerns about MAP of fish is that removal of O_2 and its replacement by either N_2 or N_2/CO_2 results in anaerobic conditions that are conducive to the growth of protease-negative strains of *C. botulinum*. Because these bacteria can grow at temperatures as low as 3°C and do not significantly alter the sensory properties of the fish, there is the potential for food poisoning that can lead to fatalities. While there is no evidence that CO_2 promotes the growth of psychotropic strains of *C. botulinum*, there are, as discussed previously, some concerns about CO_2 promoting the germination of spores of this organism.

Considerable research has been undertaken to assess, and to control, the risks associated with the growth of *C. botulinum* in MAP of fish and other products. The Advisory Committee on the Microbiological Safety of Food (ACMSF) (Anon, 1992) have recommended controlling factors that should be used singly or in combination to prevent the growth of, and toxin production in prepared chilled food by, psychotropic *C. botulinum*. As far as MAP of raw fish products is concerned, risk can be effectively eliminated if storage temperature is held at 3°C or below and if the shelf life is limited to no more than 10 days.

Some fish processors include O_2 in their MAP to further reduce the risk of growth of clostridia. Gas mixtures of 30% O_2, 40% CO_2 and 30% N_2 are used for white non-processed fish, i.e. nonfatty fish. While this will increase the shelf life of some fish and fish products, it would not significantly enhance the shelf life of oily or fatty fish. High, 40%, CO_2 mixes along with 60% N_2 are generally used for smoked and fatty fish. Because of the risks already discussed, it would appear reasonable to aim for a target shelf life of 10–14 days at 3°C.

10.B5 Fruits and vegetables

Consumers now expect fresh fruit and vegetable produce throughout the year. MAP has the potential to extend the safe shelf life of many fruits and

vegetables. Packaging fresh and unprocessed fruits and vegetables poses many challenges for packaging technologists. As with all products, it is essential to work with the highest quality raw materials, and this is especially true for this product group, often referred to as *fresh produce*. The quality of fresh produce is markedly dependent on growing conditions, minimising bruising and other damage during harvesting and processing, adherence to good hygienic practices, controlling humidity to prevent desiccation while avoiding condensation to prevent mould growth, and maintaining optimum storage temperatures. Unlike other chilled perishable foods, fresh produce continues to respire after harvesting. The products of aerobic respiration include CO_2 and water vapour. In addition, respiring fruits and vegetables produce C_2H_4 that promotes ripening and softening of tissues. The latter if not controlled will limit shelf life.

Respiration is affected by the intrinsic properties of fresh produce as well as various extrinsic factors, including ambient temperature. It is accepted that the potential shelf life of packed produce is inversely proportional to respiration rate. Respiration rate increases by a factor of 3–4 for every 10°C increase in temperature. Hence, the goal of MAP for fruits and vegetables is to reduce respiration to extend shelf life while maintaining quality. Respiration can be reduced by lowering the temperature, lowering the O_2 concentration, increasing the CO_2 concentration and by the combined use of O_2 depletion and CO_2 enhancement of pack atmospheres. If the O_2 concentration is reduced beyond a critical concentration, which is dependent on the species and cultivar, then anaerobic respiration will be initiated. The products of anaerobic respiration include ethanol, acetaldehyde and organic acids. Anaerobic respiration, or anaerobiosis, is usually associated with undesirable odours and flavours and a marked deterioration in product quality. While increasing the CO_2 concentration will also inhibit respiration, high concentrations may cause damage in some species and cultivars.

Reducing O_2 concentrations below 5% will slow the respiration rate of many fruits and vegetables. Kader *et al.* (1989) have tabulated the minimum O_2 concentration tolerated by a range of fresh produce; while some cultivars of apples and pears can tolerate O_2 concentrations as low as 0.5%, potatoes undergo anaerobic respiration at around 5% O_2. In general, O_2 concentrations below about 3% can induce anaerobic respiration in many species of fresh produce.

Elevated CO_2 can also inhibit respiration. If the gas concentration is too high, then anaerobic respiration is induced with consequent quality problems. CO_2 sensitivity is both species and cultivar dependant; strawberries are able to tolerate 15% CO_2 whereas celery is stressed by CO_2 concentrations above 2% (Kader *et al.*, 1989). The tolerance of strawberries to CO_2 can be used to inhibit the growth of the mould *Botrytis cinerea*.

The use of low concentrations of O_2 and elevated levels of CO_2 can have a synergistic effect on slowing down respiration and, indirectly, ripening. While

the mechanisms whereby MAP can extend the shelf life of fresh produce are not fully understood, it is known that the low O_2/high CO_2 conditions reduce the conversion of chlorophyll to pheophytin, decrease the sensitivity of plant tissue to C_2H_4, inhibit the synthesis of carotenoids, reduce oxidative browning and discolouration and inhibit the growth of microorganisms. These mechanisms are all temperature dependent. The effects of MAP on the physiology of fruits and vegetables have been the subject of extensive research by many groups and have been well reviewed, e.g. Kader (1986).

Packaging technologists should be aware of several major pathogens as far as MAP fresh produce is concerned, in particular *L. monocytogenes* and *C. botulinum*. As previously discussed, *L. monocytogenes* can grow under reduced O_2 levels and is not markedly inhibited by CO_2. This combined with its ability to grow at temperatures close to 0°C helps explain the concern.

The use of MAP atmospheres containing low concentrations of O_2 and elevated CO_2 concentrations may permit the growth of psychotropic protease-negative strains of *C. botulinum*. However, provided packs are stored at 3°C or below for not more than 10 days, there is unlikely to be a problem with clostridia. Temperature control is critical, since temperature abuse could lead to pack contents becoming toxic.

The environment in which fruits and vegetables are grown may harbour pathogens including *Salmonella* species, enterotoxigenic *E. coli* and viruses. While these microorganisms may not grow in MAP packs, particularly if the storage temperature is maintained around 3°C, they may survive throughout storage and could cause food poisoning through cross-contamination in the home or due to the consumption of raw or under-processed product. Hygienic preparation, sanitation in chilled-chlorinated water, rinsing and dewatering prior to MAP are now considered as essential treatments to fruits and vegetables prior to packaging to ensure low microbial counts and assure safety. Since there is a risk of anaerobic pathogens, such as *C. botulinum*, growing in MAP packs, a minimum level of O_2 (e.g. 2–3%) is usually recommended to ensure that potentially hazardous conditions are not created.

Equilibrium MAP (refer to Chapter 2) has been used for fresh produce. Essentially, this involves using knowledge of the permeability characteristics of particular packaging films, along with the respiration characteristics of the product to balance the gas transfer rates of O_2 and CO_2 through the package with the respiration rate of the particular product.

Increasingly, gas packing fresh produce along with $CO_2/O_2/N_2$ gas mixtures is being used. This approach may have benefit in reducing enzymic browning reactions before a passively generated equilibrium modified atmosphere has been established.

10.B6 Dairy products

MAP has the potential to increase the shelf life of a number of dairy products. These include fat-filled milk powders, cheeses and fat spreads. In general, these products spoil due to the development of oxidative rancidity in the case of powders and/or the growth of microorganisms, particularly yeasts and moulds, in the case of cheese.

Whole milk powder is particularly susceptible to the development of off-flavours due to fat oxidation. Commercially, the air is removed under vacuum and replaced with 100% N_2 or N_2/CO_2 mixes and the powder is hermetically sealed in metal cans. Due to the spray drying process, air tends to be absorbed inside the powder particles and will diffuse into the container over a period of ten days or so. This typically will raise the residual headspace O_2 content to 1–5% or higher (Evans, Mullan and Pearce, unpublished results). Because some markets require product with low levels of residual O_2 (<1%), some manufacturers re-pack the cans after ten days of storage. Obviously, this is both expensive and inconvenient. We have found that use of N_2/CO_2 mixes (Evans, Mullan and Pearce, unpublished results) can be helpful. Use of O_2 scavenging may also be useful. Refer to Chapter 9 for a more detailed discussion of O_2 scavengers.

English territorial cheeses, e.g. Cheddar, have traditionally been vacuum packed. Increasingly MAP is being used with high CO_2 concentration gas mixes. This has the advantage of obtaining a low residual O_2 content and a tight pack due to the CO_2 going into solution. It is important to balance this process using the correct N_2 level in the gas mix so as to avoid excessive pressure being put on the pack seal.

Use of N_2/CO_2 atmospheres has significant potential for extending the shelf life of cottage cheese. The cottage cheese is a high-moisture, low-fat product that is susceptible to a number of spoilage organisms including *Pseudomonas* spp. Use of gas mixtures containing 40% CO_2 balanced with 60% N_2 can increase the shelf life significantly.

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