9
Packaging

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9.1
Introduction

The main functions of a package are to contain the product and protect it against a range of hazards which might adversely affect its quality during handling, distribution and storage. The package also plays an important role in marketing and selling the product. In this chapter only the protective role of the package will be considered. In this context the following definition may apply: 'Packaging is the protection of materials by means of containers designed to isolate the contents, to some predetermined degree, from outside influences. In this way, the product is contained in a suitable environment within the package'. The qualification 'to some predetermined degree' is included in the definition as it is not always desirable to completely isolate the contents from the external environment.

Today most food materials are supplied to the consumer in a packaged form. Even foods which are sold unpackaged, such as some fruits and vegetables, will have been bagged, boxed or otherwise crudely packaged at some stage in their distribution. A wide range of packaging materials is used for packaging foods including: papers, paperboards, fibreboards, regenerated cellulose films, polymer films, semirigid and rigid containers made from polymer materials, metal foil, rigid metals, glass, timber, textiles and earthenware. Very often a combination of two or more materials is employed to package one product. It is important to look on packaging as an integral part of food processing and preservation. The success of most preservation methods depends on appropriate packaging, e.g. to prevent microbiological contamination of heat-processed foods or moisture pick up by dehydrated foods. It is essential to consider packaging at an early stage in any product development exercise, not only for its technical importance, but also because of its cost implications. Packaging should not give rise to any health hazard to the consumer. No harmful substances should leach from the packaging material into the food. Packaging should not lead to the growth of pathogenic microorganisms when anaerobic conditions are created within the package.

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Packages should be convenient to use. They should be easy to open and resealable, if appropriate. The contents should be readily dispensed from the container. Other examples of convenient packaging are ‘boil in the bag’ products and microwavable packaging.

There are many environmental implications to packaging. In the manufacture of packaging materials, the energy requirements and the release of undesirable compounds into the atmosphere, have environment implications. The use of multitrip containers and recycling of packaging materials can have positive influences on the environment. The disposal of waste packaging materials, particularly those that are not biodegradable, is a huge problem. These topics are outside the scope of this chapter but are covered elsewhere in the literature [1–5].

9.2 Factors Affecting the Choice of a Packaging Material and/or Container for a Particular Duty

9.2.1 Mechanical Damage

Fresh, processed and manufactured foods are susceptible to mechanical damage. The bruising of soft fruits, the break up of heat processed vegetables and the cracking of biscuits are examples. Such damage may result from sudden impacts or shocks during handling and transport, vibration during transport by road, rail and air and compression loads imposed when packages are stacked in warehouses or large transport vehicles. Appropriate packaging can reduce the incidence and extent of such mechanical damage. Packaging alone is not the whole answer. Good handling and transport procedures and equipment are also necessary.

The selection of a packaging material of sufficient strength and rigidity can reduce damage due to compression loads. Metal, glass and rigid plastic materials may be used for primary or consumer packages. Fibreboard and timber materials are used for secondary or outer packages. The incorporation of cushioning materials into the packaging can protect against impacts, shock and vibration. Corrugated papers and boards, pulpboard and foamed plastics are examples of such cushioning materials. Restricting movement of the product within the package may also reduce damage. This may be achieved by tight-wrapping or shrink-wrapping. Inserts in boxes or cases or thermoformed trays may be used to provide compartments for individual items such as eggs and fruits.

9.2.2 Permeability Characteristics

The rate of permeation of water vapour, gases (O_2, CO_2, N_2, ethylene) and volatile odour compounds into or out of the package is an important consideration, in the case of packaging films, laminates and coated papers. Foods with relatively high moisture contents tend to lose water to the atmosphere. This results in a loss of weight and deterioration in appearance and texture. Meat and cheese are typical examples of such foods. Products with relatively low moisture contents will tend to pick up moisture, particularly when exposed to a high humidity atmosphere. Dry powders such as cake mixes and custard powders may cake and lose their freeflowing characteristics. Biscuits and snack foods may lose their crispness. If the water activity of a dehydrated product is allowed to rise above a certain critical level, microbiological spoilage may occur. In such cases a packaging material with a low permeability to water vapour, effectively sealed, is required. In contrast, fresh fruit and vegetables continue to respire after harvesting. They use up oxygen and produce water vapour, carbon dioxide and ethylene. As a result, the humidity inside the package increases. If a high humidity develops, condensation may occur within the package when the temperature fluctuates. In such cases, it is necessary to allow for the passage of water vapour out of the package. A packaging material which is semipermeable to water vapour is required in this case.

The shelf life of many foods may be extended by creating an atmosphere in the package which is low in oxygen. This can be achieved by vacuum packaging or by replacing the air in the package with carbon dioxide and/or nitrogen. Cheese, cooked and cured meat products, dried meats, egg and coffee powders are examples of such foods. In such cases, the packaging material should have a low permeability to gases and be effectively sealed. This applies also when modified atmosphere packaging (MAP) is used (see Section 9.4).

If a respiring food is sealed in a gastight container, the oxygen will be used up and replaced with carbon dioxide. The rate at which this occurs depends on the rate of respiration of the food, the amount in the package and the temperature. Over a period of time, an anaerobic atmosphere will develop inside the container. If the oxygen content falls below 2%, anaerobic respiration will set in and the food will spoil rapidly. The influence of the level of carbon dioxide in the package varies from product to product. Some fruits and vegetables can tolerate, and may even benefit from, high levels of carbon dioxide while others do not. In such cases, it is necessary to select a packaging material which permits the movement of oxygen into and carbon dioxide out of the package, at a rate which is optimum for the contents. Ethylene is produced by respiring fruits. Even when present in low concentrations, this can accelerate the ripening of the fruit. The packaging material must have an adequate permeability to ethylene to avoid this problem.

To retain the pleasant odour associated with many foods, such as coffee, it is necessary to select a packaging material that is a good barrier to the volatile compounds which contribute to that odour. Such materials may also prevent the contents from developing taints due to the absorption of foreign odours. It is worth noting here that films that are good barriers to water vapour may be permeable to volatiles.

In those cases where the movement of gases and vapours is to be minimised, metal and glass containers, suitably sealed, may be used. Many flexible film materials, particularly if used in laminates, are also good barriers to vapours and gases. Where some movement of vapours and/or gases is desirable, films that are semipermeable to them may be used. For products with high respiration rates the packaging material may be perforated. A range of microperforated films is available for such applications.

In the case of an intact polymer film, the rate at which vapours and gases pass through it is specified by its 'permeability' or 'permeability constant', P, defined by the following relationship:

$$P = \frac{ql}{A(p_1 - p_2)} \tag{9.1}$$

where q is the quantity of vapour or gas passing through A, an area of the film in unit time, l is the thickness of the film and p_1, p_2 are the partial pressures of the vapour or gas in equilibrium with the film at its two faces. The permeability of a film to water vapour is usually expressed as x g m^{-2} day^{-1} (i.e. per 24 h) and is also known as the water vapour transfer rate (WVTR). Highly permeable films have values of WVTR in the range from 200 g m^{-2} day^{-1} to >800 g m^{-2} day^{-1}, while those with low permeability have values of 10 g m^{-2} day^{-1} or below. The permeability of a film to gases is usually expressed as x cm^3 m^{-2} day^{-1}. Highly permeable films have P values from 1000 cm^3 m^{-2} day^{-1} to >25 000 cm^3 m^{-2} day^{-1}, while those with low permeability have values of 10 cm^3 m^{-2} day^{-1} or below. When stating the P value of a film, the thickness of the film and the conditions under which it was measured, mainly the temperature and (p_1, p_2), must be given.

9.2.3 Greaseproofness

In the case of fatty foods, it is necessary to prevent egress of grease or oil to the outside of the package, where it would spoil its appearance and possibly interfere with the printing and decoration. Greaseproof and parchment papers (see Section 9.3.1) may give adequate protection to dry fatty foods, such as chocolate and milk powder, while hydrophilic films or laminates are used with wet foods, such as meat or fish.

9.2.4 Temperature

A package must be able to withstand the changes in temperature which it is likely to encounter, without any reduction in performance or undesirable change in appearance. This is of particular importance when foods are heated or cooled in the package. For many decades metal and glass containers were used for foods which were retorted in the package. It is only in relatively recent times that heat resistant laminates were developed for this purpose. Some packaging films become brittle when exposed to low temperatures and are not suitable for packaging frozen foods. The rate of change of temperature may be important. For example, glass containers have to be heated and cooled slowly to avoid breakage. The method of heating may influence the choice of packaging. Many new packaging materials have been developed for foods which are to be processed or heated by microwaves.

9.2.5 Light

Many food components are sensitive to light, particularly at the blue and ultraviolet end of the spectrum. Vitamins may be destroyed, colours may fade and fats may develop rancidity when exposed to such light waves. The use of packaging materials which are opaque to light will prevent these changes. If it is desirable that the contents be visible, for example to check the clarity of a liquid, coloured materials which filter out short wavelength light may be used. Amber glass bottles, commonly used for beer in the UK, perform this function. Pigmented plastic bottles are used for some health drinks.

9.2.6 Chemical Compatibility of the Packaging Material and the Contents of the Package

It is essential in food packaging that no health hazard to the consumer should arise as a result of toxic substances, present in the packaging material, leaching into the contents. In the case of flexible packaging films, such substances may be residual monomers from the polymerisation process or additives such as stabilisers, plasticisers, colouring materials etc. To establish the safety of such packaging materials two questions need to be answered: (a) are there any toxic substances present in the packaging material and (b) will they leach into the product? Toxicological testing of just one chemical compound is lengthy, complicated and expensive, usually involving extensive animal feeding trials and requiring expert interpretation of the results. Such undertakings are outside the scope of all but very large food companies. In most countries there are specialist organisations to carry out such this type of investigation, e.g. the British Industrial Biological Research Association (BIBRA) in the UK. Such work may be commissioned by governments, manufacturers of packaging materials and food companies.

To establish the extent of migration of a chemical compound from a packaging material into a food product is also quite complex. The obvious procedure would be to store the food in contact with the packaging material for a specified time under controlled conditions and then to analyse the food to determine the amount of the specific compound present in it. However, detecting a very small amount of a specific compound in a food is a difficult analytical problem. It is now common practice to use simulants instead of real foods for this purpose. These are liquids or simple solutions which represent different types of foods in migration testing. For example the EC specifies the following simulants:

- Simulant A: distilled water or equivalent (to represent low acid, aqueous foods);
- Simulant B: 3% (w/v) acetic acid in aqueous solution (to represent acid foods);
- Simulant C: 15% (w/v) ethanol in aqueous solution (to represent foods containing alcohol);
- Simulant D: rectified olive oil (to represent fatty foods).

The EC also specifies which simulants are to be used when testing specific foods. More than one simulant may be used with some foods. After been held in contact with the packaging material, under specified conditions, the simulant is analysed to determine how much of the component under test it contains. Migration testing is seldom carried out by food companies. Specialist organisations mostly do this type of work, e.g. in the UK Pira International.

Most countries have extensive legislation in place controlling the safety of flexible plastic packaging materials for food use. These include limits on the amount of monomer in the packaging material. There is particular concern over the amount of vinyl chloride monomer (VCM) in polyvinylchloride (PVC). The legislation may also include: lists of permitted additives which may be incorporated into different materials, limits on the total migration from the packaging material into the food and limits on the migration of specific substances, such as VCM. The types of simulants to be used in migration tests on different foods and the methods to be used for analysing the simulants may also be specified. While the discussion above is concerned only with flexible films, other materials used for food packaging may result in undesirable chemicals migrating into foods. These include semirigid and rigid plastic packaging materials, lacquers and sealing compounds used in metal cans, materials used in the closures for glass containers, additives and coatings applied to paper, board and regenerated cellulose films, wood, ceramics and textiles.

Apart from causing a health hazard to the consumer, interaction between the packaging material and the food may affect the quality and shelf life of the food and/or the integrity of the package; and it should be avoided. An example of this is the reaction between acid fruits and tinplate cans. This results in the solution of tin in the syrup and the production of hydrogen gas. The appearance of the syrup may deteriorate and coloured fruits may be bleached. In extreme cases, swelling of the can (hydrogen swelling) and even perforation may occur. The solution to this problem is to apply an acid resistant lacquer to the inside of the can. Packaging materials, which are likely to react adversely with the contents, should be avoided, or another barrier substance should be interposed between the packaging material and the food [6–9].

9.2.7
Protection Against Microbial Contamination

Another role of the package may be to prevent or limit the contamination of the contents by microorganisms from sources outside the package. This is most important in the case of foods that are heat-sterilised in the package, where it is essential that postprocess contamination does not occur. The metal can has dominated this field for decades and still does. The reliability of the double seam (see Section 9.3.8) in preventing contamination is one reason for this dominance. Some closures for glass containers are also effective barriers to contamination. It is only in relatively recent times that plastic containers have been developed, which not only withstand the rigours of heat processing, but also whose heat seals are effective in preventing postprocess contamination. Effective seals are also necessary on cartons, cups and other containers which are aseptically filled with UHT products. The sealing requirements for containers for pasteurised products and foods preserved by drying, freezing, curing, etc. are not so rigorous. However, they should still provide a high level of protection against microbial contamination.

9.2.8
In-Package Microflora

The permeability of the packaging material to gases and the packaging procedure employed can influence the type of microorganisms that grow within the package. Packaging foods in materials that are highly permeable to gases is not likely to bring about any significant change in the microflora, compared to unpackaged foods. However, when a fresh or mildly processed food is packaged in a material that has a low permeability to gases and when an anaerobic atmosphere is created within the package, as a result of respiration of the product or because of vacuum or gas packaging, the type of microorganisms that grow inside the package are likely to be different to those that would grow in the unpackaged food. There is a danger that pathogenic microorganisms could flourish under these conditions and result in food poisoning. Such packaging procedures should not be used without a detailed study of the microbiological implications, taking into account the type of food, the treatment it receives before packaging, the hygienic conditions under which it is packaged and the temperature at which the packaged product is to be stored, transported, displayed in the retail outlet and kept in the home of the consumer.

9.2.9
Protection Against Insect and Rodent Infestation

In temperate climates, moths, beetles and mites are the insects that mainly infest foods. Control of insect infestation is largely a question of good housekeeping. Dry, cool, clean storage conditions, good ventilation, adequate turnaround of warehouse stocks and the controlled use of fumigants or contact insecticides can all help to limit insect infestation. Packaging can also contribute, but an insectproof package is not normally economically feasible, with the exception of metal and glass containers. Some insects are classified as penetrators, as they can gnaw their way through some packaging materials. Paper, paperboard and regenerated cellulose materials offer little resistance to such insects. Packaging films vary in the resistance they offer. In general, the thicker the film the more resistant it is to penetrating insects. Oriented films are usually more resistant that unoriented forms of the same materials. Some laminates, particularly those containing foil, offer good resistance to penetrating insects. Other insects are classified as invaders as they enter through openings in the package. Good design of containers to eliminate as far as possible cracks, crevices and pinholes in corners and seals can limit the ingress of invading insects. The use of adhesive tape to seal any such openings can help. The application of insecticides to some packaging materials is practised to a limited extent, e.g. to the outer layers of multiwall paper sacks. They may be incorporated into adhesives. However, this can only be done if regulations allow it [10, 11].

Packaging does not make a significant contribution to the prevention of infestation by rodents. Only robust metal containers offer resistance to rats and mice. Good, clean storekeeping, provision of barriers to infestation and controlled use of poisons, gassing and trapping are the usual preventive measures taken to limit such infestation.

9.2.10
Taint

Many packaging materials contain volatile compounds which give rise to characteristic odours. The contents of a package may become tainted by absorption or solution of such compounds when in direct contact with the packaging materials. Food not in direct contact with the packaging material may absorb odorous compounds present in the free space within the package. Paper, paperboard and fibreboard give off odours which may contaminate food. The cheaper forms of these papers and boards, which contain recycled material, are more likely to cause tainting of the contents. Clay, wax and plastic coatings applied to such materials may also cause tainting. Storage of these packaging materials in clean, dry and well ventilated stores can reduce the problem. Some varieties of wood, such as cedar and cypress, have very strong odours which could contaminate foods. Most polymers are relatively odour-free, but care must be taken in the selection of additives used. Lacquers and sealing compounds used in metal and glass containers are possible sources of odour contamination. Some printing inks and adhesives give off volatile compounds, when drying, which may give rise to tainting of foods. Careful selection of such materials is necessary to lessen the risk of contamination of foods in this way [9].

9.2.11 Tamper-Evident/Resistant Packages

There have been many reports in recent years of food packages being deliberately contaminated with toxic substances, metal or glass fragments. The motive for this dangerous practise is often blackmail or revenge against companies. Another less serious, but none the less undesirable activity, is the opening of packages to inspect, or even taste, the contents and returning them to the shelf in the supermarket. This habit is known as grazing. There is no such thing as a tamper-proof package. However, tamper-resistant and/or tamper-evident features can be incorporated into packages. Reclosable glass or plastic bottles and jars are most vulnerable to tampering. Examples of tamper-evident features include: a membrane heat-sealed to the mouth of the container, beneath the cap, roll-on closures (see Section 9.3.9), polymer sleeves heat-shrunk over the necks and caps, breakable caps which are connected to a band by means of frangible bridges that break when the cap is opened and leave the band on the neck of the container [12–14].

9.2.12 Other Factors

There are many other factors to be considered when selecting a package for a particular duty. The package must have a size and shape which makes it easy to handle, store and display on the supermarket shelf. Equipment must be available to form, fill and seal the containers at an acceptable speed and with an adequately low failure rate. The package must be aesthetically compatible with the contents. For example, the consumer tends to associate a particular type of package with a given food or drink. Good quality wines are packaged in glass, whereas cheaper ones may be packaged in 'bag in box' containers or plastic bottles. The decoration on the package must be attractive. A look around a supermarket confirms the role of the well designed package in attracting the consumer to purchase that product. The labelling must clearly convey all the information required to the consumer and comply with relevant regulations.

Detailed discussion of these factors is not included in this chapter but further information is available in the literature [13–20].

9.3
Materials and Containers Used for Packaging Foods

9.3.1
Papers, Paperboards and Fibreboards

9.3.1.1 Papers

While paper may be manufactured from a wide range of raw materials, almost all paper used for food packaging is made from wood. Some papers and boards are made from repulped waste paper. Such materials are not used in direct contact with foods. The first stage in the manufacture of papers and boards is pulping. Groundwood pulp is produced by mechanical grinding of wood and contains all the ingredients present in the wood (cellulose, lignin, carbohydrates, resins, gums). Paper made from this type of pulp is relatively weak and dull compared to the alternative chemical pulp. Chemical pulp is produced by digesting wood chips in an alkaline (sulphate pulp) or acid (sulphite pulp) solution, followed by washing. This pulp is a purer form of cellulose, as the other ingredients are dissolved during the digestion and removed by washing. Some mechanical pulp may be added to chemical pulp for paper manufacture, but such paper is not usually used in direct contact with foods. The first step in the paper making process itself is known as beating or refining. A dilute suspension of pulp in water is subjected to controlled mechanical treatment in order to split the fibres longitudinally and produce a mass of thin fibrils. This enables them to hold together when the paper is manufactured thus increasing the strength of the paper. The structure and density of the finished paper is mainly determined by the extent of this mechanical treatment. Additives such as mineral fillers and sizing agents are included at this stage to impart particular properties to the paper. The paper pulp is subjected to a series of refining operations before being converted into paper. There are two types of equipment used to produce paper from pulp. In the *Fourdrinier machine*, a dilute suspension of the refined pulp is deposited on to a fine woven, moving and vibrating mesh belt. By a sequence of draining, vacuum filtration, pressing and drying, the water content is reduced to 4–8% and the network of fibres on the belt is formed into paper. In the alternative *cylinder machine*, six or more wire mesh cylinders rotate partly immersed in a suspension of cellulose fibres. They pick up fibres and deposit them in layers onto a moving felt blanket. Water is removed by a sequence of operations similar to those described above. This method is mainly used for the manufacture of boards where combinations of different pulps are used.

Types of papers used for packaging foods include:

- Kraft paper, which is made form sulphate pulp. It is available unbleached (brown) or bleached. It is a strong multipurpose paper used for wrapping individual items or parcelling a number of items together. It may also be fabricated into bags and multiwall sacks.
- Sulphite paper, which is made from pulp produced by acid digestion. It is again a general purpose paper, not as strong as Kraft. It is used in the form of sachets and bags.

- Greaseproof paper, which is made from sulphite pulp, which is given a severe mechanical treatment at the beating stage. It is a close-textured paper with greaseproof properties under dry conditions.
- Glassine paper, which is produced by polishing the surface of greaseproof paper. It has some resistance to moisture penetration.
- Vegetable parchment, which is produced by passing paper made from chemical pulp through a bath of sulphuric acid, after which it is washed, neutralised and dried. The acid dissolves the surface layers of the paper, decreasing its porosity. It has good greaseproof characteristics and retains its strength when wet better than greaseproof paper.
- Tissue paper, which is light and has an open structure. It is used to protect the surface of fruits and provide some cushioning.
- Wet-strength papers, which have chemicals added which are crosslinked during the manufacturing process. They retain more of their strength when wet, compared to untreated papers. They are not used in direct contact with food, but mainly for outside packaging.
- Wax-coated papers, which are heat-sealable and offer moderate resistance to water and water vapour transfer. However, the heat seals are relatively weak and the wax coating may be damaged by creasing and abrasion.
- Other coatings may be applied to papers to improve their functionality. These include many of the polymer materials discussed in Section 9.3.2. They may be used to increase the strength of paper, make it heat-sealable and/or improve its barrier properties.

These various types of papers may be used to wrap individual items or portions. Examples include waxed paper wraps for toffees and vegetable parchment paper wraps for butter and margarine. They may be made into small sachets or bags. Examples include sulphite papers sachets for custard powders or cake mixes and bags for sugar and flour. Kraft papers may be fabricated into multiwall papers sacks containing from two to six plies. They are used for fruits, vegetables, grains, sugar and salt in quantities up to 25 kg. Where extra protection is required against water vapour, one or more plies maybe wax- or polyethylene-coated. The outer layer may consist of wet-strength paper.

9.3.1.2 **Paperboards**

Paperboards are made from the same raw materials as papers. They normally are made on the cylinder machine and consist of two or more layers of different quality pulps with a total thickness in the range 300–1100 μm. The types of paperboard used in food packaging include:

- Chipboard, which is made from a mixture of repulped waste with chemical and mechanical pulp. It is dull grey in colour and relatively weak. It is available lined on one side with unbleached, semi or fully bleached chemical pulp. A range of such paperboards are available, with different quality liners. Chipboards are seldom used in direct contact with foods, but are used as outer car-

tons when the food is already contained in a film pouch or bag e.g. breakfast cereals.
- Duplex board, which is made from a mixture of chemical and mechanical pulp, usually lined on both sides with chemical pulp. It is used for some frozen foods, biscuits and similar products.
- Solid white board, in which all plies are made from fully, bleached chemical pulp. It is used for some frozen foods, food liquids and other products requiring special protection.
- Paperboards are available which are coated with wax or polymer materials such as polyethylene, polyvinylidene chloride and polyamides. These are mainly used for packaging wet or fatty foods.

Paperboards are mainly used in the form of cartons. Cartons are fed to the filling machine in a flat or collapsed form where they are erected, filled and sealed. The thicker grades of paperboards are used for set-up boxes which come to the filling machine already erected. These are more rigid than cartons and provide additional mechanical protection.

9.3.1.3 **Moulded Pulp**

Moulded pulp containers are made from a waterborne suspension of mechanical, chemical or waste pulps or mixtures of same. The suspension is moulded into shape either under pressure (pressure injection moulding) or vacuum (suction moulding) and the resulting containers are dried. Such containers have good cushioning properties and limit in-pack movement, thus providing good mechanical protection to the contents. Trays for eggs and fruits are typical examples.

9.3.1.4 **Fibreboards**

Fibreboard is available in solid or corrugated forms. Solid fibreboard consists of a layer of paperboard, usually chipboard, lined on one or both faces with Kraft paper. Solid fibreboard is rigid and resistant to puncturing. Corrugated fibreboard consists of one or more layers of corrugated material (medium) sandwiched between flat sheets of paperboard (linerboard), held in place by adhesive. The medium may be chipboard, strawboard or board made from mixtures of chemical and mechanical pulp. The completed board may have one (single wall) two (double wall) or three (triple wall) layers of corrugations with linerboard in between. Four different flute sizes are available:
- A (104–125 flutes m^{-1}) is described as coarse and has good cushioning characteristics and rigidity.
- B (150–184 flutes m^{-1}) is designated as fine and has good crush resistance.
- C (120–145 flutes m^{-1}) is a compromise between these properties.
- E (275–310 flutes m^{-1}) is classed as very fine and is used for small boxes and cartons, when some cushioning is required.

Wax and polymer coated fibreboards are available. Fibreboards are usually fabricated into cases which are used as outer containers, to provide mechanical protection to the contents. Unpackaged products such as fruits, vegetables and eggs are packaged in such containers. Inserts within the case reduce in-pack movement. Fibreboard cases are also used for goods already packaged in pouches, cartons, cans and glass containers.

9.3.1.5 Composite Containers

So called composite containers usually consist of cylindrical bodies made of paperboard or fibreboard with metal or plastic ends. Where good barrier properties are required, coated or laminated board may be used for the body or aluminium foil may be incorporated into it. Small containers, less than 200 mm in diameter, are referred to as tubes or cans and are used for foods such as salt, pepper, spices, custard powders, chocolate beverages and frozen fruit juices. Larger containers, known as fibreboard drums, are used as alternatives to paper or plastic sacks or metal drums for products such as milk powder, emulsifying agents and cooking fats [13, 16–22].

9.3.2 Wooden Containers

Outer wooden containers are used when a high degree of mechanical protection is required during storage and transport. They take the form of crates and cases. Wooden drums and barrels are used for liquid products. The role of crates has largely been replaced by shipping containers. Open cases find limited use for fish, fruits and vegetables, although plastic cases are now widely used. Casks, kegs and barrels are used for storage of wines and spirits. Oak casks are used for high quality wines and spirits. Lower quality wines and spirits are stored in chestnut casks [13].

9.3.3 Textiles

Jute and cotton are woven materials which have been used for packaging foods. Sacks made of jute are used, to a limited extent, for fresh fruit and vegetables, grains and dried legumes. However, multiwall paper sacks and plastic sacks have largely replaced them for such products. Cotton bags have been used in the past for flour, sugar, salt and similar products. Again, paper and plastic bags are now mainly used for these foods. Cotton scrims are used to pack fresh meat. However, synthetic materials are increasingly used for this purpose [13].

9.3.4
Flexible Films

Nonfibrous materials in continuous sheet form, up to 0.25 mm thick, are termed packaging films. They are flexible, usually transparent, unless deliberately pigmented and, with the exception of regenerated cellulose, thermoplastic to some extent. This latter property enables many of them to be heat-sealed. With the exception of regenerated cellulose, most films consist of a polymer, or a mixture of two or more polymers, to which are added other materials to give them particular functional properties, alter their appearance or improve their handling characteristics. Such additives may include plasticisers, stabilisers, colouring materials, antioxidants, antiblocking and slip agents.

- Extrusion is the method most commonly used to produce polymer films. The mixture of polymer and additives is fed into the extruder, which consists of a screw revolving inside a close-fitting, heated barrel. The combination of the heat applied to the barrel and that generated by friction, melts the mixture, which is then forced through a die in the form of a tube or flat film. The extrudate is stretched to control the thickness of the film and rapidly cooled. By using special adaptors, it is possible to extrude two or more different polymers, simultaneously. They fuse together to form a single web. This is known as coextrusion.
- Calendering is another techniques used to produce polymer films and sheets. The heated mixture of polymer and additives is squeezed between a series of heated rollers with a progressively decreasing clearance. The film formed then passes over cooled rollers. Some polyvinylchloride, ethylene-vinyl acetate and ethylene-propylene copolymers are calendered.
- Solution casting is also used to a limited extent. The plastic material, with additives, is dissolved in a solvent, filtered and the solution cast through a slot onto a stainless steel belt. The solvent is driven off by heating. The resulting film is removed from the belt. Films produced in this way have a clear, sparkling appearance. Cellulose acetate and ethyl cellulose films are among those that are produced by solvent casting.
- Orientation is a process applied to some films in order to increase their strength and durability. It involves stretching the film in one (uniaxial orientation) or two directions at right angles to each other (biaxial orientation). This causes the polymer chains to line up in a particular direction. In addition to their improved strength, oriented films have better flexibility and clarity and, in some cases, lower permeability to water vapour and gases, compared to nonoriented forms of the same polymer film. Oriented films tear easily and are difficult to heat-seal. The process involves heating the film to a temperature at which it is soft before stretching it. Flat films are passed between heated rollers and then stretched on a machine known as a tenter, after which they are passed over a cooling roller. Films in the form of tubes are flattened by passing through nip rollers, heated to the appropriate temperature and stretched by increasing the air pressure within the tube. When stretched to

the correct extent they are cooled on rollers. Polyester, polypropylene, low-density polyethylene and polyamide are the films that are mainly available in oriented form.
- Irradiation of some thermoplastic films can bring about crosslinking of the C-C bonds, which can increase their tensile strength, broaden their heating-sealing range and improve their shrink characteristics. Polyethylene is the film most widely irradiated, using an electron beam accelerator.

The following are brief details of the packaging films which are commonly used to package food.

9.3.4.1 **Regenerated Cellulose**

Regenerated cellulose (cellophane) differs from the polymer films in that it is made from wood pulp. Good quality, bleached sulphite pulp is treated with sodium hydroxide and carbon disulphide to produce sodium cellulose xanthate. This is dispersed in sodium hydroxide to produce viscose. The viscose is passed through an acid-salt bath which salts out the viscose and neutralises the alkali. The continuous sheet of cellulose hydrate produced in this way is desulphured, bleached and passed through a bath of softener solution to give it flexibility. It is then dried in an oven. This is known as plain (P) regenerated cellulose. It is clear, transparent, not heat-sealable and has been described as a transparent paper. It provides general protect against dust and dirt, some mechanical protection and is greaseproof. When dry it is a good barrier to gases, but becomes highly permeable when wet. Plain cellulose is little used in food packaging. Plain regenerated cellulose is mainly used coated with various materials which improve its functional properties. The most common coating material is referred to as 'nitrocellulose' but is actually a mixture of nitrocellulose, waxes, resins, plasticisers and some other agents. The following code letters are used to reflect the properties of coated regenerated cellulose films:
- A: anchored coating i.e. lacquer coating
- D: coated on one side only
- M: moistureproof
- P: uncoated
- Q: semimoistureproof
- S: heat-sealable
- T: transparent
- X or XD: copolymer coated on one side only
- XX: copolymer coated on both sides.

The types of film most often used for food packaging include:
- MSAT: nitrocellulose-coated on both sides, a good barrier to water vapour, gases and volatiles and heat-sealable;
- QSAT: nitrocellulose-coated on both sides, more permeable to water vapour than MSAT and heat-sealable;

- DMS: nitrocellulose-coated on one side only;
- MXXT: copolymer coated on both sides, very good barrier to water vapour, gases and volatiles, strong heat-seal;
- MXDT: copolymer coated on one side only.

The copolymer used in the X and XX films is a mixture of polyvinyl chloride (PVC) and polyvinylidene chloride (PVdC). The various coated films are used in the form of pouches and bags and as a component in laminates.

9.3.4.2 **Cellulose Acetate**

Cellulose acetate is made from waste cotton fibres which are acetylated and partially hydrolysed. The film is made by casting from a solvent or extrusion. It is clear, transparent and has a sparkling appearance. It is highly permeable to water vapour, gases and volatiles. It is not much used in food packaging except as window material in cartons. It can be thermoformed into semirigid containers or as blister packaging.

9.3.4.3 **Polyethylene**

Polyethylene (PE), commonly called polythene, is made in one of two ways. Ethylene is polymerised at high temperature and pressure, in the presence of a little oxygen and the polymer converted into a film by extrusion. Alternatively, lower temperatures and pressures may be used to produce the polymer if certain alkyl metals are used as catalysts. The film is available in low (LDPE), medium (MDPE) and high (HDPE) density grades. The lower density grades are most widely used in food packaging. The main functional properties of LDPE are its strength, low permeability to water vapour and it forms a very strong heat seal. It is not a good barrier to gases, oils or volatiles. It is used on its own in the form of pouches, bags and sacks. It is also used for coating papers, boards and plain regenerated cellulose and as a component in laminates. HDPE has a higher tensile strength and stiffness than LDPE. Its permeability to gases is lower and it can withstand higher temperatures. It is used for foods which are heated in the package, so called 'boil in the bag' items.

9.3.4.4 **Polyvinyl Chloride**

Polyvinyl chloride (PVC) is made by chlorination of acetylene or ethylene followed by polymerisation under pressure in the presence of a catalyst. The film can be formed by extrusion or calendering. It is a clear, transparent film which on its own is brittle. The addition of plasticizers and stabilisers to the polymer are necessary to give it flexibility. It is essential that PVC film used in food packaging contains only permitted additives to avoid any hazard to the consumer (see Section 9.2.6). It has good mechanical properties. Its permeability to water vapour, gases and volatiles depends on the type and amount of plasticizers added to the polymer. The most common grade used for food packaging is slightly more permeable to water vapour than LDPE, but less permeable to gases and volatiles. It is a good grease barrier. It can be sealed by high-frequency welding. It can be orientated and as such is heat-shrinkable. Highly plasticised grades are available with stretch and cling properties. This is one form of 'cling film' which is used for stretch-wrapping foods in industry and in the home.

9.3.4.5 **Polyvinylidene Chloride**

Polyvinylidene chloride (PVdC) is made by further chlorination of vinyl chloride in the presence of a catalyst, followed by polymerisation. The polymer itself is stiff and brittle and unsuitable for use as a flexible film. Consequently, it is a copolymer of PVdC with PVC that is used for food packaging. Typically, 20% of VC is used in the copolymer, although other ratios are available. The film is usually produced by extrusion of the copolymer. The properties of the copolymer film depend on the degree of polymerisation, the properties of the monomers used and the proportion of each one used. The copolymer film most widely used for food packaging has good mechanical properties, is a very good barrier to the passage of water vapour, gases and volatiles and is greaseproof and heat-sealable. It can withstand relatively high temperatures such as those encountered during hot filling and retorting. It is available in oriented form which has improved strength and barrier properties and is highly heat-shrinkable. PVdC/PVC copolymer film is used for shrink-wrapping foods such as meat and poultry products and as a component in laminates.

9.3.4.6 **Polypropylene**

Polypropylene (PP) is produced by low-pressure polymerisation of propylene in the presence of a catalyst. The film is normally extruded onto chilled rollers and is known as cast polypropylene. Its mechanical properties are good except at low temperature, when it becomes brittle. The permeability of cast PP to water vapour and gases is relatively low, comparable with high-density polyethylene. It is heat-sealable, but at a very high temperature, 170 °C. It is usually coated with PE or PVdC/PVC copolymer to facilitate heat-sealing. Cast PP is used in the form of bags or overwraps for applications similar to PE. Oriented polypropylene (OPP) has better mechanical properties than cast PP, particularly at low temperature, and is used in thinner gauges. It is a good barrier to water vapour but not gases. It is often coated with PP or PVdC/PVC copolymer to improve its barrier properties and to make it heat-sealable. It is normally heat-shrinkable. It is used in coated or laminated form to package a wide range of food products, including biscuits, cheese, meat and coffee. It is stable at relatively high temperature and is used for in-package heat processing. A white opaque form of OPP, known as pearlised film, is also available. Copolymers of PP and PE are also available. Their functional properties tend to be in a range between PP and HDPE.

9.3.4.7 **Polyester**

Polyester (PET) film used in food packaging is polyethylene terephthalate, which is usually produced by a condensation reaction between terephthalic acid and ethylene glycol and extruded. There is little use of the nonoriented form of PET but it widely used in the biaxially oriented form. Oriented PET has good tensile strength and can be used in relatively thin gauges. It is often used coated with PE or PVdC/PVC copolymer to increase its barrier properties and facilitate heat-sealing. It is stable over a wide temperature range and can be used for 'boil in the bag' applications. Metallised PET is also available and has a very low permeability to gases and volatiles. Metallised, coextruded PE/PET is used for packaging snack foods.

9.3.4.8 **Polystyrene**

Polystyrene (PS) is produced by reacting ethylene with benzene to form ethylbenzene. This is dehydrogenated to give styrene which is polymerised at a relatively low temperature, in the presence of catalysts, to form polystyrene. PS film is produced by extrusion. It is stiff and brittle with a clear sparkling appearance. In this form it is not useful as a food packaging film. Biaxially oriented polystyrene (BOPS) is less brittle and has an increased tensile strength, compared to the non-oriented film. BOPS has a relatively high permeability to vapours and gases and is greaseproof. It softens at ca. 80–85 °C, but is stable at low temperature, below 0 °C. It shrinks on heating and may be heat-sealed by impulse sealers. The film has few applications in food packaging, apart from wrapping of fresh produce. PS is widely used in the form of thermoformed semirigid containers and blow-moulded bottle. For these applications it is coextruded with ethylene-vinyl alcohol (EVOH) or PVdC/PVC copolymer. PS is also used in the form of a foam for containers such as egg cartons, fruit trays and containers for takeaway meals.

9.3.4.9 **Polyamides**

Polyamides (PAs) known generally as Nylons, are produced by two different reactions. Nylon 6,6 and 6,10 are formed by condensation of diamines and dibasic acids. The numbers indicate the number of carbon atoms in the diamine molecules followed by the number in the acid. Nylon 11 and 12 are formed by condensation of ω-amino acids. Here, the numbers indicate the total number of carbon atoms involved. The film may be extruded or solution cast. PA films are clear and attractive in appearance. As a group they are mechanically strong, but the different types do vary in strength. The permeability to water vapour varies from high, Nylon 6, to low, Nylon 12. They are good barriers to gases, particularly under dry conditions, volatiles and greases. They are stable over a very wide temperature range. They can be heat-sealed but at a high temperature, 240 °C. They do absorb moisture and their dimensions can change by 1–2% as a result. Nylon films may be combined with other materials, by coating, coextrusion or lamination, in order to facilitate heat-sealing and/or improve their mechanical and barrier properties. Polyethylene, ionomers, EVA and EAA (see below) are among such other materials. Different types of Nylon may be combined as copolymers e.g. Nylon 6/6,6 or 6/12. Biaxially oriented Nylon films are also available. Their functional properties may be further modified by vacuum-metallising. Applications for Nylon films include packaging of meat products, cheese and condiments.

9.3.4.10 **Polycarbonate**

Polycarbonate (PC) is made by the reaction of phosgene or diphenyl carbonate with bisphenol A. The film is produced by extrusion or casting. It is mechanically strong and grease-resistant. It has a relatively high permeability to vapours and gases. It is stable over a wide temperature range, from –70 °C to 130 °C. It is not widely used for food packaging but could be used for 'boil in the bag' packages, retortable pouches and frozen foods.

9.3.4.11 **Polytetrafluoroethylene**

Polytetrafluoroethylene (PTFE) is made by the reaction of hydrofluoric acid with chloroform followed by pyrolysis and polymerisation. The film is usually produced by extrusion. It is strong, has a relatively low permeability to vapours and gases and is grease-resistant. It is stable over a wide temperature range, –190 °C to 190 °C and has a very low coefficient of friction. It is not widely used in film form for packaging of foods but could be used for retortable packages and where a high resistance to the transfer of vapours and gases is required e.g. for freeze-dried foods. It is best known for its nonstick property and is used on heat sealers and for coating cooking utensils.

9.3.4.12 **Ionomers**

'Ionomers' are formed by introducing ionic bonds as well as the covalent bonds normally present in polymers such as PE. This is achieved by reacting with metal ions. Compared to LDPE, they are stiffer and more resistant to puncturing and have a higher permeability to water vapour and good grease resistance. They are most widely used as components in laminates with other films, such as PC or PET, for packaging cheese and meat products.

9.3.4.13 **Ethylene-vinyl Acetate Copolymers**

Ethylene-vinyl acetate copolymers (EVAs) are made by the polymerisation of polyethylene with vinyl acetate. Compared to LDPE, they have higher impact strength, higher permeability to water vapour and gases and are heat-sealable over a wider temperature range. EVA with other polymers such as ethylene-ethyl acrylate (EEA) and ethylene-acrylic acid (EAA) form a family of materials that may be used, usually in laminates with PE, PP and other films, for food packaging. Care must be taken in selecting these materials as there are limitations on the quantity of the minor components which should be used for particular food applications. EVA itself has very good stretch and cling characteristics and can be used, as an alternative to PVC for cling-wrap applications [13, 16, 17, 23, 24].

9.3.5 Metallised Films

Many flexible packaging films can have a thin coating, less than 1 μm thick, of metal applied to them. This was originally introduced for decorative purposes. However, it emerged that metallising certain films increased their resistance to the passage of water vapour and gases, by up to 100%. Today metallised films are used extensively to package snack foods. The process involves heating the metal, usually aluminium, to temperatures of 1500–1800 °C in a vacuum chamber maintained at a very low pressure, ca. 10^{-4} Torr (0.13 Pa). The metal vaporises and deposits onto the film which passes through the vapour on a chilled roller. PET, PP, PA, PS, PVC, PVdC and regenerated cellulose are available in metallised form [17, 24, 25].

9.3.6 Flexible Laminates

When a single paper or film does not provide adequate protection to the product, two or more flexible materials may be combined together in the form of a laminate. In this form the functional properties of the individual components complement each other to suit the requirements of a particular food product. The materials involved may include papers or paperboards, films and aluminium foil (see Section 10.3.8). The paper or paperboard provides stiffness, protects the foil against mechanical damage and has a surface suitable for printing. The film(s) contributes to the barrier properties of the laminate, provides a heat-sealable surface and strengthens the laminate. The foil acts as a barrier material and has an attractive appearance. Laminates may be formed from paper-paper, paper-film, film-film, paper-foil, film-foil and paper-film- foil combinations. The layers of a laminate may be bonded together by adhesive. When one or more of the layers is permeable to water vapour, an aqueous adhesive may be used. Otherwise, nonaqueous adhesives must be used. If one or more of the components is thermoplastic, it may be bonded to the other layer by passing them between heated rollers. A freshly extruded thermoplastic material, still in molten form, may be applied directly to another layer and thus bonded to it. Two or more thermoplastic materials may be combined to together by coextrusion (see Section 9.3.4). There are hundreds of combinations of different materials available. Examples include:

- vegetable parchment-foil for wrapping butter and margarine;
- MXXT regenerated cellulose-PE for vacuum packed cheese, cooked and cured meats;
- PET-PE for coffee, paperboard-foil-PE for milk and fruit juice cartons.

Retortable pouches may be made of a threeply laminate typically consisting of PET-foil-PP or PET- foil-HDPE [13, 16, 17, 24].

9.3.7
Heat-Sealing Equipment

Many flexible polymer films are thermoplastic and heat sealable. Nonthermoplastic materials may be coated with or laminated to thermoplastic material to facilitate heat-sealing. Heat-sealing equipment must be selected to suit the type of material being sealed. Nonthermoplastic materials such as papers, regenerated cellulose and foil, which are coated with heat-sealable material, are best sealed with a *hot bar* or *resistance* sealer. The two layers of material are clamped between two electrically heated metal bars. The temperature of the bars, the pressure exerted by them and the contact time all influence the sealing. Metal jaws with matching serrations are often used for coated regenerated cellulose films. The serrations stretch out wrinkles and improve the seal. In the case of laminates, smooth jaws meeting uniformly along their length are used. Alternatively, one of the jaws is made of resilient material, often silicone elastomer, which is not heated.

For continuous heat-sealing of coated material, heated rollers are used. Heated plates are used to seal wrapped items. For unsupported, thermoplastic materials, *impulse sealers* are used. In such sealers, the layers of film are clamped between jaws of resilient material, one or both of which has a narrow metal strip running the length of the jaw. An accurately timed pulse of low-voltage electricity is passed through the strip(s), heating it and fusing the two layers of material together. The jaws are held apart by unmelted material each side of the strip. This minimises the thinning of the sealed area, which would weaken the seal. The jaws remain closed until the melted material solidifies. The jaws are coated with PTFE to prevent the film sticking to them. For continuous sealing of unsupported thermoplastic material a *band sealer* may be used. A pair of moving, endless metal belts or bands is heated by stationary, heated shoes. The shoes are so shaped that they touch the centre of the bands only. This minimises thinning of the seal. After passing between the heated shoes, the layers of material pass between pressure rollers and then between cooled shoes to solidify the melted film. A heated wire may be used to simultaneously cut and seal unsupported thermoplastic films. *Electronic sealing* is used on relatively thick layers of polymer material with suitable electrical properties, mainly PVC and PVC/PVdC copolymers. The layers of film are placed between shaped electrodes and subjected to a high-frequency electric field. This welds the layers of material together. *Ultrasonic sealing* may be used to seal layers of film or foil together. This is particularly suited to uncoated, oriented materials that are difficult to seal by other methods [15–17, 24].

9.3.8
Packaging in Flexible Films and Laminates

Flexible films may be used to overwrap items of food such as portions of meat. The meat is usually positioned on a tray made of paperboard or foamed plastic, with an absorbent pad between it and the tray. The film is stretched over the meat and under the tray. It may be heat sealed on a heated plate or held in position by clinging to itself. Films may also be made into preformed bags which are filled by hand or machine and sealed by heat or other means. Heavy gauge material, such as PE, may be made into shipping sacks for handling large amounts, 25–50 kg, of foods such as grains or milk powder.

However, films and laminates are most widely used in the form of sachets or pillow packs. A sachet is a small square or rectangular pouch heat-sealed on all four edges (see Figs. 9.1, 9.3). A pillow pack is a pouch with a longitudinal heat seal and two end seals (see Figs. 9.2, 9.4). These are formed, filled and sealed by a sequential operation, known as a form-fill-seal (FFS) system. Form-fill-seal machines may operate vertically or horizontally. The principle of one vertical FFS machine, for making sachets, is shown in Fig. 9.1.

Vertical FFS machines can also make pillow packs (see Fig. 9.2).

Vertically formed pillow and sachet packs may be used for liquids and solids. The principle of one horizontal FFS for sachets is shown in Fig. 9.3.

Such a system is used for both solid and liquid products. Horizontal FFS machines can also produce pillow packs (see Fig. 9.4).

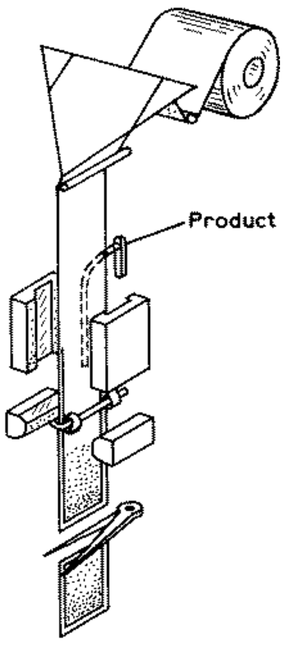

Fig. 9.1 Vertical form-fill-seal machine for sachets; adapted from [16] with permission.

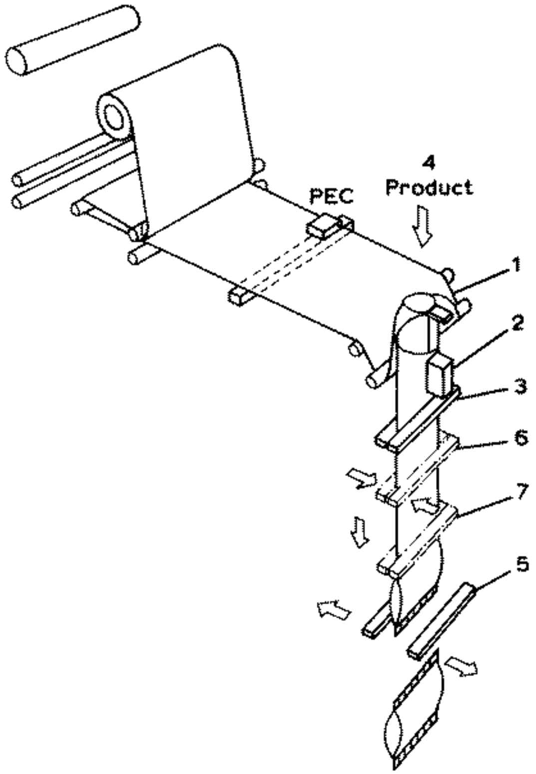

Fig. 9.2 Vertical form-fill-seal machine for pillow packs. 1. Film from reel made into a tube over forming shoulder. 2. Longtitudinal seal made. 3. Bottom of tube closed by heat crimped jaws which move downwards drawing film from reel. 4. Predetermined quantity of product falls through collar into pouch. 5. Jaws open and return on top of stroke. 6. Jaws partially close and 'scrape' product into pouch out of seal area. 7. Jaws close, crimp seal top of previous pouch and bottom of new one. Crimp-sealed container cut-off with knife. Adapted from [16] with permission.

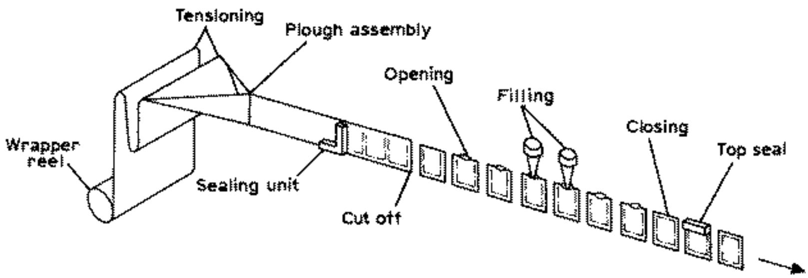

Fig. 9.3 Horizontal form-fill-seal machine for sachets; adapted from [16] with permission.

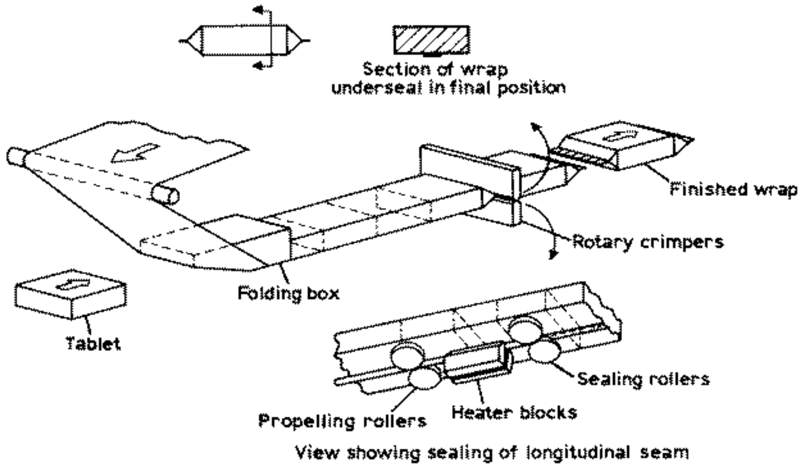

Fig. 9.4 Horizontal form-fill-seal machine for pillow packs. Film is drawn from reel and formed into horizontal tube around product with continuous seal underneath formed by heater blocks and crimping rollers. Then, rotary heaters make the crimped end seals and cut-off produces individual packs. Adapted from [16] with permission.

Systems like these are used for solid items such as candy bars or biscuits.

Pillow packs are more economical than sachets in the use of packaging material. The packaging materials must be thin and flexible, have good slip characteristics and form a strong seal, even before cooling. Sachets are made from stiffer material and can be used for a wider range of product types. They are usually used in relatively small sizes, e.g. for individual portions of sauce or salad dressing [13, 15–17, 24, 26].

9.3.9 Rigid and Semirigid Plastic Containers

Many of the thermoplastic materials described above can be formed into rigid and semirigid containers, the most common being LDPE, HDPE, PVC, PP, PET and PS, singly or in combinations. Acrylic plastics are also used for this purpose, including polyacrylonitrile and acrylonitrile-butadiene-styrene (ABS). Urea formaldehyde, a thermosetting material, is used to make screwcap closures for glass and plastic containers.

The following methods are used to convert these materials into containers:

9.3.9.1 Thermoforming

In thermoforming, a plastic sheet is clamped in position above a mould. The sheet is heated until it softens and then made to take up the shape of the mould by either (a) having an air pressure greater than atmospheric applied above the sheet, (b) having a vacuum created below the sheet or (c) sandwiching the sheet between a male and female mould. The sheet cools through contact with the mould, hardens and is ejected from the mould. Plastic materials that are thermoformed include PS, PP, PVC, HDPE and ABS. Thermoforming is used to produce opentopped or widemouthed containers such as cups and tubs for yoghurt, cottage cheese or margarine, trays for eggs or fresh fruit and inserts in biscuit tins or chocolate boxes.

9.3.9.2 Blow Moulding

In blow moulding, a mass of molten plastic is introduced into a mould and compressed air is used to make it take up the shape of the mould. The plastic cools, hardens and is ejected from the mould. Blow moulding is mainly used to produce narrownecked containers. LDPE is the main material used for blow moulding, but PVC, PS and PP may also be processed in this way. Food applications include bottles for oils, fruit juices and milk and squeezable bottles for sauces and syrups.

9.3.9.3 Injection Moulding

In injection moulding, the molten plastic from an extruder is injected directly into a mould, taking up the shape of the mould. On cooling, the material hardens and is ejected from the mould. Injection moulding is mainly used to produce widemouthed containers, but, narrownecked containers can be injection-moulded in two parts which are joined together by a solvent or welding. PS is the main material used for injection moulding, but PP and PET may also be processed in this way. Food applications include cups and tubs for cream, yoghurt, mousses as well as phials and jars for a variety of uses.

9.3.9.4 Compression Moulding

Compression moulding is used from thermosetting plastics, such as urea formaldehyde. The plastic powder is held under pressure between heated male and female moulds. It melts and takes up the shape of the mould after which it is cooled, the mould opened and the item ejected. The main application for this method is to produce screw caps [13, 16, 17, 24, 27–29].

9.3.10 Metal Materials and Containers

The metal materials used in food packaging are aluminium, tinplate and electrolytic chromium-coated steel (ECCS). Aluminium is used in the form of foil or rigid metal.

9.3.10.1 **Aluminium Foil**

Aluminium foil is produced from aluminium ingots by a series of rolling operations down to a thickness in the range 0.15–0.008 mm. Most foil used in packaging contains not less than 99.0% aluminium, with traces of silicon, iron, copper and, in some cases, chromium and zinc. Foil used in semirigid containers also contains up to 1.5% manganese. After rolling, foil is annealed in an oven to control its ductility. This enables foils of different tempers to be produced from fully annealed (dead folding) to hard, rigid material. Foil is a bright, attractive material, tasteless, odourless and inert with respect to most food materials. For contact with acid or salty products, it is coated with nitrocellulose or some polymer material. It is mechanically weak, easily punctured, torn or abraded. Coating or laminating it with polymer materials will increase its resistance to such damage. Relatively thin foil, less than 0.03 mm thick, will contain perforations and will be permeable to vapours and gases. Again, coating or laminating it with polymer material will improve its barrier properties. Foil is stable over a wide temperature range. Relatively thin, fully annealed foil is used for wrapping chocolate and processed cheese portions. Foil is used as a component in laminates, together with polymer materials and, in some cases, paper. These laminates are formed into sachets or pillow packs on FFS equipment (see Section 9.3.6). Examples of foods packaged in this way include dried soups, sauce mixes, salad dressings and jams. Foil is included in laminates used for retortable pouches and rigid plastic containers for ready meals. It is also a component in cartons for UHT milk and fruit juices. Foil in the range 0.040–0.065 mm thick is used for capping glass and rigid plastic containers. Plates, trays, dishes and other relatively shallow containers are made from foil in the thickness range 0.03–0.15 mm and containing up to 1.5% manganese. These are used for frozen pies, ready meals and desserts, which can be heated in the container.

9.3.10.2 **Tinplate**

Tinplate is the most common metal material used for food cans. It consists of a low-carbon, mild steel sheet or strip, 0.50–0.15 mm thick, coated on both sides with a layer of tin. This coating seldom exceeds 1% of the total thickness of the tinplate. The structure of tinplate is more complex than would appear from this simple description and several detectable layers exist (see Fig. 9.5).

The mechanical strength and fabrication characteristics of tinplate depend on the type of steel and its thickness. The minor constituents of steel are carbon, manganese, phosphorous, silicon, sulphur and copper. At least four types of steel, with different levels of these constituents, are used for food cans. The corrosion resistance and appearance of tinplate depend on the tin coating. The stages in the manufacture of tinplate are shown in Fig. 9.6. These result in two types of tinplate, i.e. single (or cold) reduced electroplate (CR) and double reduced electroplate (DR). DR electroplate is stronger in one direction than CR plate and can be used in thinner gauges than the latter for certain applications.

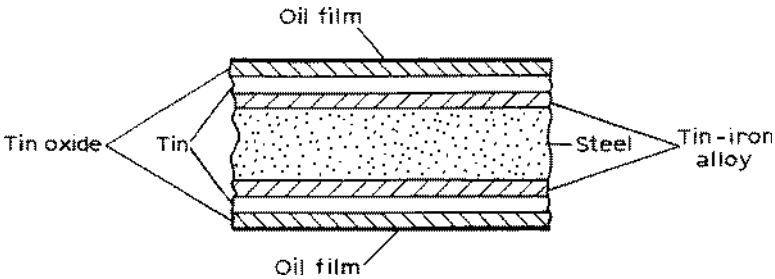

Fig. 9.5 Structure of tinplate.

The thickness of tinplate used for food can manufacture is at the lower end of the range given above. CR plate thickness may be as low as 0.17 mm and DR plate 0.15 mm. The amount of tin coating is now usually expressed as x g m^{-2}. This may be the same on both sides of the plate or a different coating weight may be applied to each side. The latter is known as differentially coated plate. In general, the more corrosive the product the higher the coating weight used. Coating weights range over 11.2–1.1 g m^{-2} (represented as E.11.2/11.2 to E.1.1/1.1) if the same weight is applied to both sides. Differentially coated plate is identified by the letter D followed by the coating weights on each side. For example, D.5.6/2.8 plate has 5.6 g m^{-2} of tin on one side and 2.8 g m^{-2} on the other. Usually, the higher coating weight is applied to the side that will form the inside of the can. Lacquer (enamel)

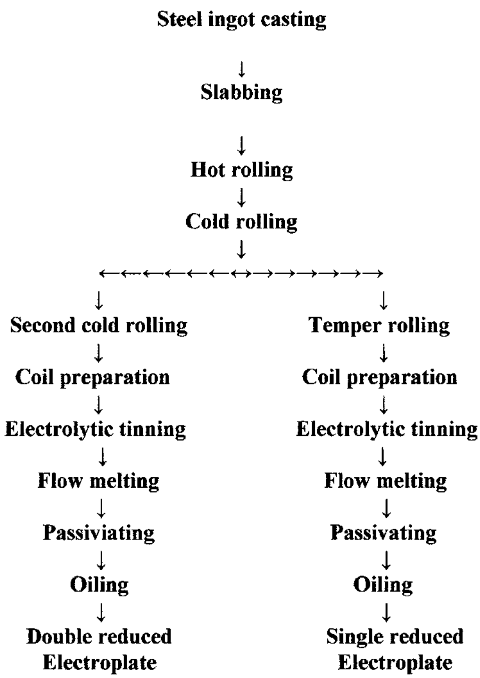

Fig. 9.6 Stages in the manufacture of tinplate.

Table 9.1 Main types of internal can lacquer (enamel); extracted from [32].

General type of resin and compounds blended to produce it	Sulphide stain resistance	Typical uses	Comments
Oleo-resinous	Poor	Acid fruits	Good general purpose natural range at relatively low cost
Sulfur-resistant oleoresinous with added zinc oxide	Good	Vegetables, soups	Not for use with acid products
Phenolic (phenol or relatively low-substituded phenol with vegetables formaldehyde)	Very good	Meat, fish, soups	Good at cost but film thickness restricted by flexibility
Epoxy-phenolic (epoxy resins with phenolic resins)	Poor	Meat, fish, soups vegetables, beer, beverages (top coat)	Wide range of properties may be obtained by modifications
Epoxy-phenolic with zinc oxide	Good	Vegetables, soups (especially can ends)	Not for use with acid products; possible colour change with green vegetables
Aluminized epoxy-phenolic (metallic aluminium powder added)	Very good	Meat products	Clean but dull appearance
Vinyl solution (vinyl chloride-vinyl acetate copolymers)	Not applicable	Spray on can bodies, roller coating on ends, as topcoat for beer and beverages	Free from flavour taints; not usually suitable for direct application to tinplate
Vinyl organosol or plastisol (high MW vinyl resins suspended in a solvent)	Not applicable	Beer and beverage topcoat on ends, drawn cans	As for vinyl solutions, but giving a thicker, tougher layer
Acrylic (acrylic resin usually pigmented white)	Very good when pigmented	Vegetables, soups, prepared foods containing sulphide stainers	Clean appearance
Polybutadiene (hydrocarbon resins)	Very good if zinc oxide added	Beer and beverage first coat, vegetables and soups with ZnO	Costs depend on country

may be applied to tinplate to prevent undesirable interaction between the product and the container. Such interactions arise with: (a) acid foods which may interact with tin dissolving it into the syrup and, in some cases, causing a loss in colour in the product, (b) some strongly coloured products where anthocyanin colour compounds react with the tin, causing a loss of colour, (c) sulphur-containing foods where the sulphur reacts with the tin, causing a blue-black stain on the inside of the can, (d) products sensitive to small traces of tin, such as beer. Lacquers can provide certain functional properties, such as a nonstick surface to facilitate the release of the contents of the can e.g. solid meats packs. A number of such lacquers are available, including natural, oleoresinous materials and synthetic materials. Information on some of these lacquers is presented in Table 9.1. Cans may be made from prelacquered plate or the lacquer may be applied to the made-up can.

9.3.10.3 **Electrolytic Chromium-Coated Steel**

Electrolytic chromium-coated steel (ECCS), sometimes described as tinfree steel, is finding increasing use for food cans. It consists of low-carbon, mild CR or DR steel coated on both sides with a layer of metallic chromium and chromium sesqueoxide, applied electrolytically. It is manufactured by a similar process to that shown in Fig. 9.6, but the flow melting and chemical passivation stages are omitted. A typical coating weight is $0.15\ g\ m^{-2}$, much lower than that on tinplate. ECCS is less resistant to corrosion than tinplate and is normally lacquered on both sides. It is more resistant to weak acids and sulphur staining than tinplate. It exhibits good lacquer adhesion and a range of lacquers, suitable for ECCS, is available. The structure of ECCS is shown in Fig. 9.7.

9.3.10.4 **Aluminium Alloy**

Hard-temper aluminium alloy, containing 1.5–5.0% magnesium, is used in food can manufacture. Gauge for gauge, it is lighter but mechanically weaker than tinplate. It is manufactured in a similar manner to aluminium foil. It is less re-

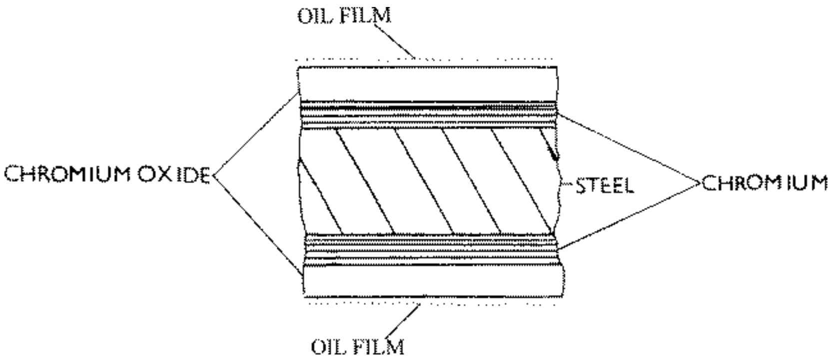

Fig. 9.7 Structure of ECCS plate (tin-free steel).

sistant to corrosion than tinplate and needs to be lacquered for most applications. A range of lacquers suitable for aluminium alloy is available, but the surface of the metal needs to be treated to improve lacquer adhesion.

9.3.10.5 **Metal Containers**

Metal cans are the most common metal containers used for food packaging. The traditional *three-piece can* (open or sanitary) is still very widely used for heat-processed foods. The cylindrical can body and two ends are made separately. One end is applied to the can body by the can maker, the other (the canners end) by the food processor after the can has been filled with product. The ends are stamped out of sheet metal, the edges curled in and a sealing compound injected into the curl. The body blank is cut from the metal sheet, formed into a cylinder and the lapped, side seam sealed by welding or by polyamide adhesive. Both ends of the cylindrical body are flanged in preparation for the application of the can end (Fig. 9.8 a).

The can end is applied to the body by means of double-seaming (Fig. 9.9). The can body and end are clamped tightly between a chuck and a base plate.

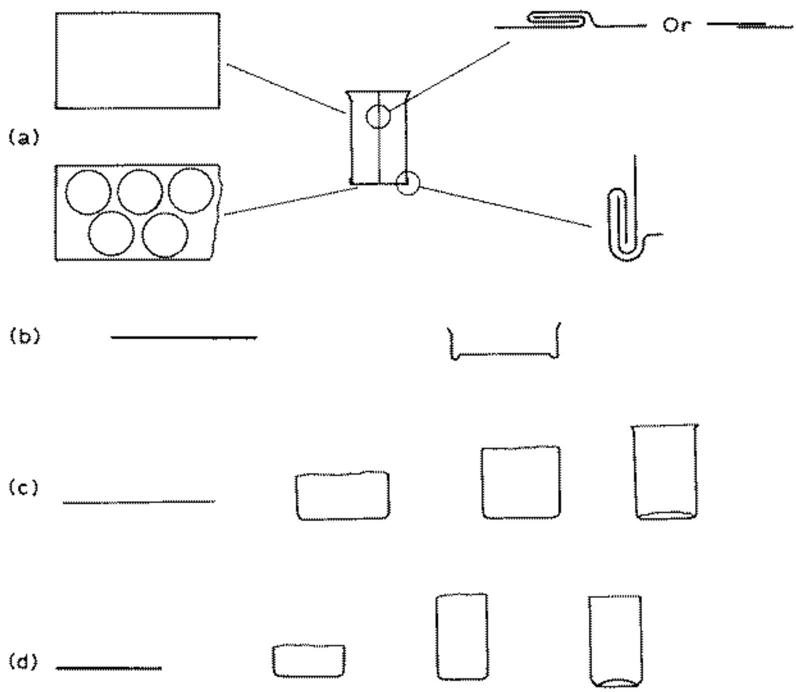

Fig. 9.8 Schematic representation of the manufacture of: (a) three-piece can, (b) drawn can, (c) drawn and redrawn can, (d) drawn and wall-ironed can; from [15] with permission of the authors.

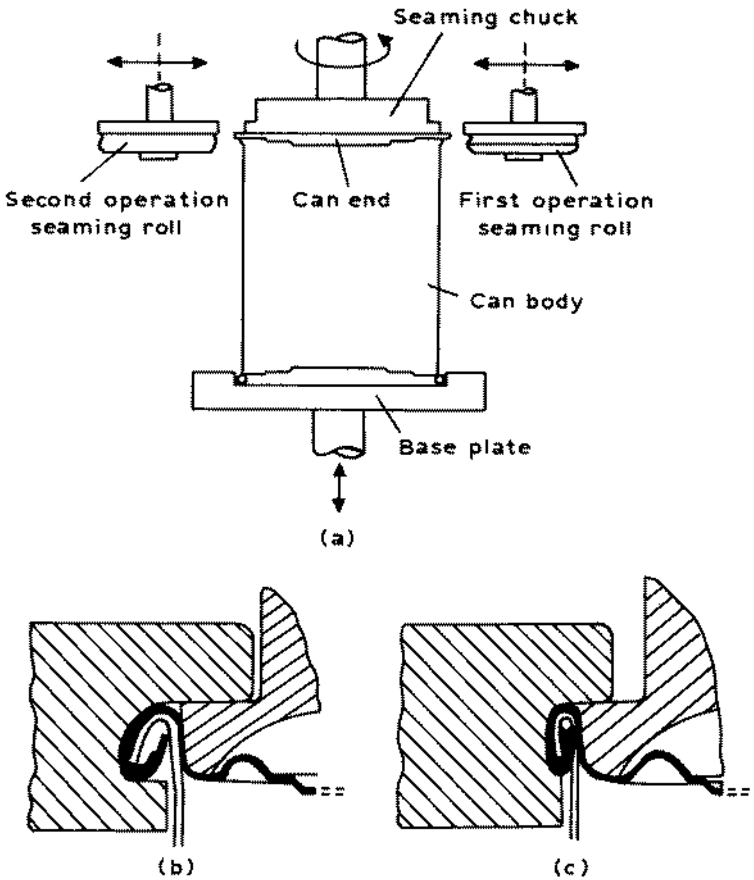

Fig. 9.9 Double-seaming of cans: (a) view of seamer, (b) seam after completion of first operation, (c) seam after completion of second operation; adapted from [15] with permission of the authors.

The chuck is made to rotate rapidly; and the can body and base rotate with the chuck. The first seaming roller moves in and engages with the chuck, forming mating hooks on the can body and end. The first seaming roller moves out and a second roller moves in, tightens the hooks and completes the seam. In some high-speed seaming machines and those used for noncylindrical cans, the can body, end and chuck remain stationary and the seaming rollers rotate on a carriage around them.

The *drawn can* (DR can) is a type of two-piece container. The can body and base are made in one operation from a blank metal sheet by being pressed out with a suitable die. The open end of the body is flanged. The can end, manufactured as described above, is applied to the body by double-seaming after the can is filled with product. Because of the strain on the metal, DR cans are shallow with a maximum height:diameter ratio of 1:2 (Fig. 9.8b). The *drawn and re-drawn can* (DRD) is another type of two-piece can. It is made by drawing a cup to a smaller diameter in a series of stages to produce a deeper container than the DR can. The can end is applied to the filled can by double-seaming. DRD cans are usually relatively small, cylindrical and have a height:diameter ratio of up to 1.2:1.0 (Fig. 9.8c). The *drawn and wall-ironed* can (DWI) is made from a disc of metal 0.30–0.42 mm thick. This is drawn into a shallow cup which is forced through a series of ironing rings of reducing internal diameter so that the wall of the cup gets thinner and higher. The top of the body is trimmed, flanged and the end applied by double-seaming after filling the can (Fig. 9.8d). Because of the very thin body wall, typically 0.10 mm thick, DWI cans are mainly used for packaging carbonated beverages. The internal pressure supports the thin wall.

The dimensions of cylindrical cans are usually specified in diameter and height, in that order. In many countries the units of diameter and height are millimetres. In the UK and USA inches and 16ths of an inch are used. Thus a can specified as 401/411 has a diameter of $4\,^{1}/_{16}$ inches and a height of $4\,^{11}/_{16}$ inches. In the case of rectangular or oval cans, two horizontal dimensions must be given.

Other metal containers used for packaging foods include:

- cylindrical cans with a friction plug closure at the canners end, used for dry powders such as coffee and custard powders or for liquids such as syrups and jams;
- rectangular or cylindrical containers with push-on lids, often sealed with adhesive tape, used for biscuits and sweets;
- rectangular or cylindrical containers, incorporating apertures sealed with screwcaps, used for liquids such as cooking oils and syrups;
- metal drums used for beer and other carbonated drinks [13, 14, 16, 17, 30–36].

9.3.11 Glass and Glass Containers

In spite of the many developments in plastic containers, glass is still widely used for food packaging. Glass is inert with respect to foods, transparent and impermeable to vapours, gases and oils. Because of the smooth internal surface of glass containers, they can be washed and sterilised and used as multitrip containers, e.g. milk and beer bottles. However, glass containers are relatively heavy compared to their metal or plastic counterparts, susceptible to mechanical damage and cannot tolerate rapid changes in temperature (low thermal shock resistance). Broken glass in a food area is an obvious hazard. The composition of a typical UK glass is shown in Table 9.2.

These ingredients, together with up to 30% recycled glass or cullet, are melted in a furnace at temperatures in the range 1350–1600 °C. The viscous mass passes into another chamber which acts as a reservoir for the forming machines. Two forming methods are used, i.e. the blow and blow (B & B) process,

Table 9.2 Composition of a typical British glass.

Silica (from sand)	72.0%
Lime (from limestone)	11.0%
Soda (from synthetic sodium carbonate)	14.0%
Alumina (from aluminium minerals)	1.7%
Potash (as impurity)	0.3%

which is used for narrownecked containers, and the press and blow (P & B) process, which is used for widemouthed containers (see Fig. 9.10).

After forming, the containers are carried on a conveyor belt through a cooling tunnel, known as an annealing lehr. In this lehr, they are heated to just below the softening temperature of the glass, held at that temperature for about 5 min and then cooled in a controlled manner. This is done to remove any stresses in the glass that may have developed during forming and handling. These stresses would weaken the containers and make them less resistant to mechanical damage. As the containers leave the lehr, they are inspected for faults. To produce coloured containers, colouring compounds such as metal oxides, sulphides or selenides are included in the formulation. It is important that the dimensions and capacities of glass containers only vary within specified tolerance limits. Otherwise, breakages and hold ups may occur in the bottling plant and customer complaints may arise. When a delivery of new glass containers is received at the bottling plant, samples should be removed on a statistical basis and their di-

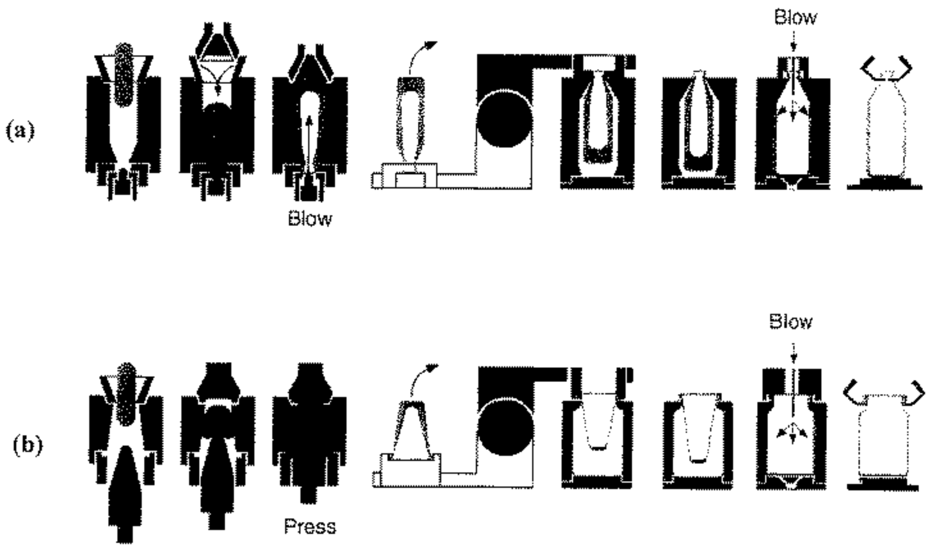

Fig. 9.10 Methods of forming glass containers: (a) blow and blow forming, (b) press and blow forming for wide-mouthed containers; by courtesy of Rockware Glass Ltd.

mensions and capacities measured and checked against specifications. In the case of cylindrical containers, the dimensions that are usually measured are the height, diameter, verticality (how truly vertical the container is) and ovality (how truly cylindrical it is). In the case of noncylindrical containers, other dimensions may be measured. The mechanical strength of glass containers, i.e. their resistance to internal pressure, vertical loads and impacts, increases with increasing thickness of the glass in the bodies and bases. The design of the container also influences its strength. Cylindrical containers are more durable than more complex shapes featuring sharp corners. The greater the radius of curvature of the shoulder, the more resistant the container is to vertical loads (Fig. 9.11). The thickness of the glass in the base is usually greater than that in the body. The

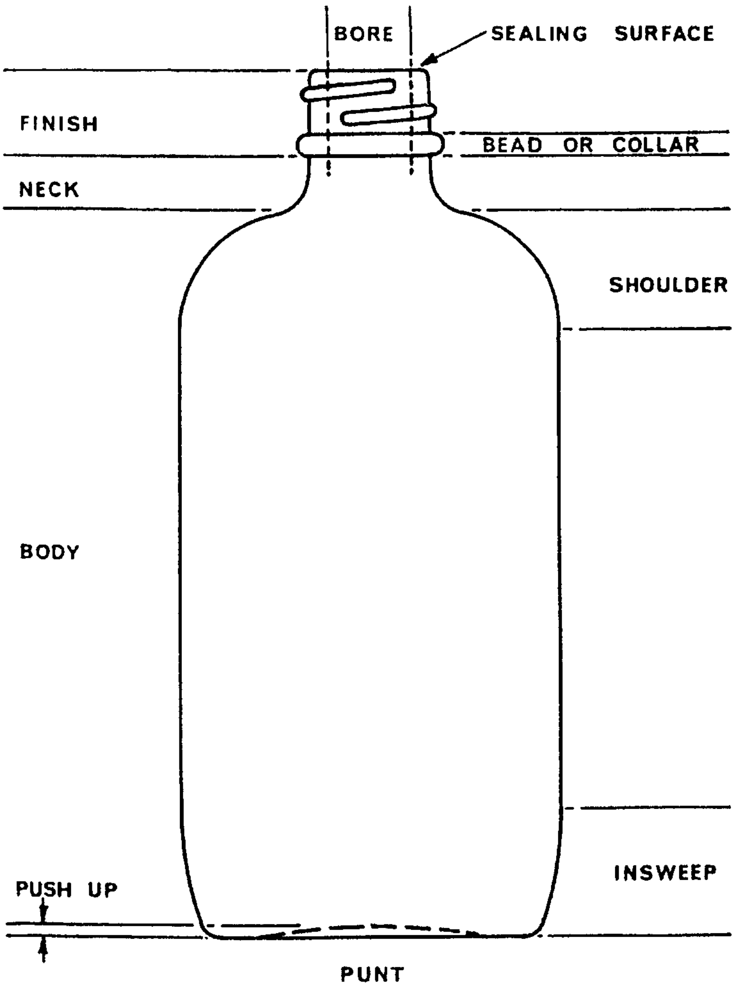

Fig. 9.11 Important features of glass containers.

circle where the body joins the base is weak due to the change in thickness. The insweep (Fig. 9.11) minimises container to container contact in this weak area.

Glass containers become weaker with use, due to abrasion of the outer surface as a result of container to container contact or contact with other surfaces. Treating the surface with compounds of titanium or tin and replacement of the sodium ions at the surface with potassium ions can reduce this problem. The resistance of glass containers to sudden changes in temperature is reduced as the thickness of the glass increases. Thus, when designing glass containers which are to be subjected to heating or cooling, e.g. when the product is to be sterilised or pasteurised in its bottle or jar, or if the container is to be hot-filled with product, a compromise has to be achieved between their mechanical strength and thermal shock resistance. Heating and cooling should be carried out relatively slowly to avoid thermal damage to glass containers.

Glass containers are sealed by compressing a resilient disc, ring or plug against the sealing surface of the container and maintaining it in the compressed condition by means of a retaining cap. The resilient material may be cork, rubber or plastic. The cap is made of metal or plastic. The cap may be screwed on, crimped on or pushed in or onto the finish of the container. Roll-on caps are used as tamper-evident closures. Different closures are effective when: (a) the pressure inside the container is close to atmospheric pressure (normal seal), (b) the pressure inside the container is less than that outside (vacuum seal), (c) the pressure inside the container is higher than that outside (pressure seal). Pressure seals are necessary when packaging carbonated drinks.

Singletrip glass containers are used for liquids such as some beers, soft drinks, wines, sauces, salad dressings and vinegars and for dry foods such as coffee and milk powders. Multitrip containers are used for pasteurised milk, some beers and soft drinks. Products heated in glass containers include sterilised milk, beer, fruit juices and pickled vegetables [13, 16, 17, 37–40].

9.4 Modified Atmosphere Packaging

Modified atmosphere packaging (MAP) is a procedure which involves replacing air inside a package with a predetermined mixture of gases prior to sealing it. Once the package is sealed, no further control is exercised over the composition of the in-package atmosphere. However, this composition may change during storage as a result of respiration of the contents and/or solution of some of the gas in the product.

Vacuum packaging is a procedure in which air is drawn out of the package prior to sealing but no other gases are introduced. This technique has been used for many years for products such as cured meats and cheese. It is not usually regarded as a form of MAP.

In MAP proper, the modified atmosphere is created by one of two methods. In the case of trays, the air is removed by a vacuum pump and the appropriate mixture of gases introduced prior to sealing. In the case of flexible packages, such as pouches, the air is displaced from the package by flushing it through with the gas mixture before sealing. In the case of horticultural products, a modified in-package atmosphere may develop as a result of respiration of the food. The concentration of oxygen inside the package will fall and that of carbon dioxide will rise. The equilibrium composition attained inside the package will largely depend on the rate of respiration of the food and the permeability of the packaging material to gases (see Section 9.2.2).

The gases involved in modified atmosphere packaging, as applied commercially today, are carbon dioxide, nitrogen and oxygen.

Carbon dioxide reacts with water in the product to form carbonic acid which lowers the pH of the food. It also inhibits the growth of certain microorganisms, mainly moulds and some aerobic bacteria. Lactic acid bacteria are resistant to the gas and may replace aerobic spoilage bacteria in modified atmosphere packaged meat. Most yeasts are also resistant to carbon dioxide. Anaerobic bacteria, including food poisoning organisms, are little affected by carbon dioxide. Consequently, there is a potential health hazard in MAP products from these microorganisms. Strict temperature control is essential to ensure the safety of MAP foods. Moulds and some gram negative, aerobic bacteria, such as *Pseudomonas* spp, are inhibited by carbon dioxide concentrations in the range 5–50%. In general, the higher the concentration of the gas, the greater is its inhibitory power. The inhibition of bacteria by carbon dioxide increases as the temperature decreases. Bacteria in the lag phase of growth are most affected by the gas.

Nitrogen has no direct effect on microorganisms or foods, other than to replace oxygen, which can inhibit the oxidation of fats. As its solubility in water is low, it is used as a bulking material to prevent the collapse of MAP packages when the carbon dioxide dissolves in the food. This is also useful in packages of sliced or ground food materials, such as cheese, which may consolidate under vacuum.

Oxygen is included in MAP packages of red meat to maintain the red colour, which is due to the oxygenation of the myoglobin pigments. It is also included in MAP packages of white fish, to reduce the risk of botulism.

Other gases have antimicrobial effects. Carbon monoxide will inhibit the growth of many bacteria, yeasts and moulds, in concentrations as low as 1%. However, due to its toxicity and explosive nature, it is not used commercially. Sulphur dioxide has been used to inhibit the growth of moulds and bacteria in some soft fruits and fruit juices. In recent years, there has been concern that some people may be hypersensitive to sulphur dioxide.

So called noble gases, such as argon, helium, xenon and neon, have also been used in MAP of some foods. However, apart from being relatively inert, it is not clear what particular benefits they bring to this technology.

MAP packages are either thermoformed trays with heat-sealed lids or pouches. With the exception of packages for fresh produce, these trays and pouches need to be made of materials with low permeability to gases (CO_2, N_2, O_2). Laminates are used, made of various combinations of polyester (PET), polyvinylidene chloride (PVdC), polyethylene (PE) and polyamide (PA, Nylons; see Section 9.3.4). The oxygen permeability of these laminates should be less than 15 $cm^3\ m^{-2}\ day^{-1}$ at a pressure of 1 atm (101 kPa). The following are some examples of MAP (see Fig. 9.12) [41–50].

- Meat products: fresh red meat packaged in an atmosphere consisting of 80% oxygen and 20% carbon dioxide or 70% oxygen, 20% carbon dioxide and 10% nitrogen should have a shelf life of 7–12 days at $2 \pm 1\,^{\circ}C$. The meat is usually placed on an absorbent pad, contained in a deep tray with a heat-sealed lid. Poultry can be MA-packaged in a mixture of nitrogen and carbon dioxide. However, this is not widely practised because of cost considerations. Cooked and cured meats may be packaged in a mixture of nitrogen and carbon dioxide.
- Fish: fresh white fish, packaged in a mixture of 30% oxygen, 30% nitrogen and 40% carbon dioxide, should have a shelf life of 10–14 days at a temperature of $0\,^{\circ}C$. Such packages should not be exposed to a temperature above $5\,^{\circ}C$, because of the risk of botulism. Fatty fish are packaged in mixtures of carbon dioxide and nitrogen.
- Fruits and vegetables: respiration in such products leads to a build-up of carbon dioxide and a reduction in the oxygen content (see Section 9.2.2). Some build up of carbon dioxide may reduce the rate of respiration and help to prolong the shelf life of the product. However, if the oxygen level is reduced to 2% or less, anaerobic respiration will set in and the product will spoil. The effect of the build up of carbon dioxide varies from product to product. Some fruits and vegetables can tolerate high levels of this gas while others cannot. Each fruit or vegetable will have an optimum in-package gas composition which will result in a maximum shelf life. Selection of a packaging film with an appropriate permeability to water vapour and gases can lead to the development of this optimum composition. For fruits with very high respiration rates, the package may need to be perforated. A range of microperforated films are available for such applications.
- Cheese: portions of hard cheese may be packaged by flushing with carbon dioxide before sealing. The gas will be absorbed by the cheese, creating a vacuum. Cheese packaged in this way may have a shelf life of up to 60 days. To avoid collapse of the package, some nitrogen may be included with the carbon dioxide. Mould ripened cheese may be packaging in nitrogen.
- Bakery products and snack foods: the shelf life of bread rolls, crumpets and pita bread may be significantly increased by packaging in carbon dioxide or nitrogen/carbon dioxide mixtures. Nuts and potato crisps benefit by being MA-packaged in nitrogen.
- Pasta: Fresh pasta may be MA-packaged in nitrogen or carbon dioxide.
- Other foods: pizza, quiche, lasagne, and many other prepared foods may benefit from MAP. It is very important to take into account the microbiological implications of MA-packaging such products. Maintenance of low temperatures during storage, distribution, in the retail outlet and in the home is essential.

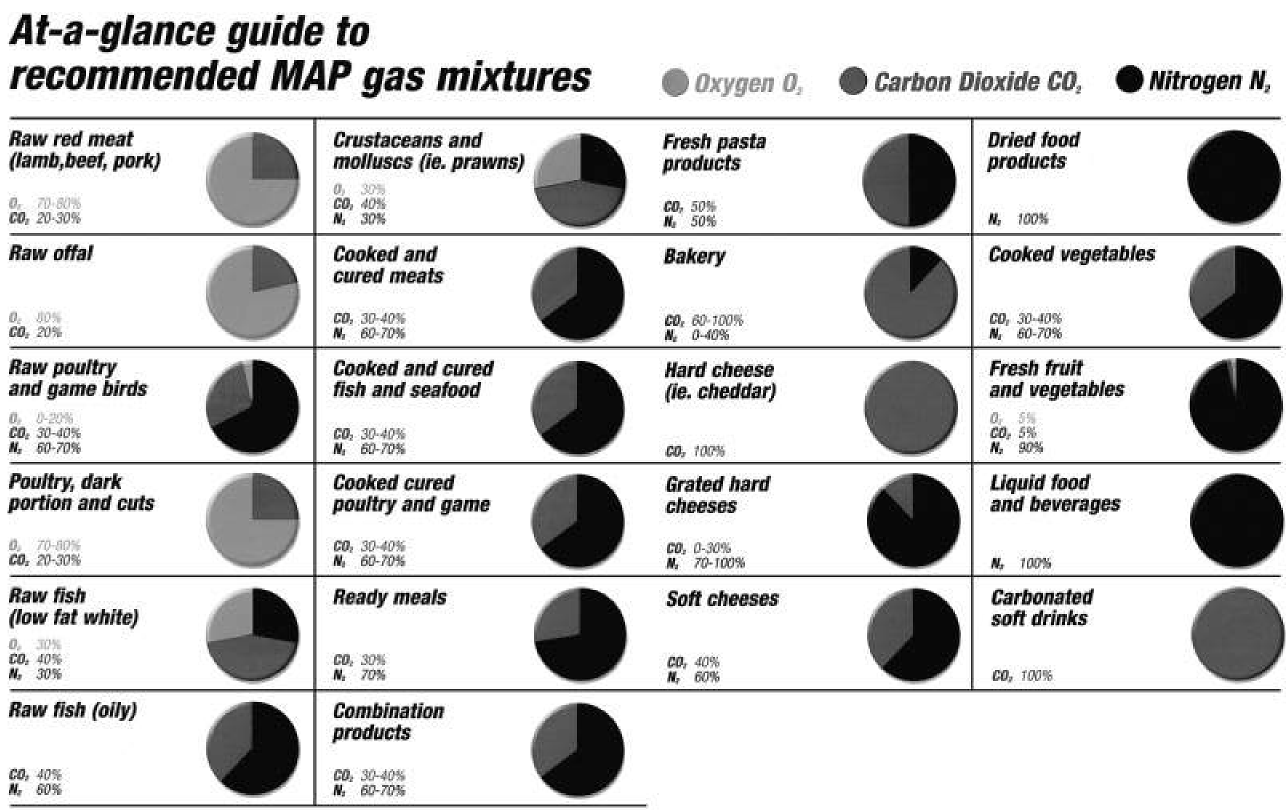

Fig. 9.12 Gas compositions commonly used in MAP food containers; by courtesy of Air Products.

9.5
Aseptic Packaging

Chapter 2 discussed the advantages, in terms of product quality, to be gained by heat processing foods in bulk prior to packaging (UHT treatment) as compared with heat treating the packaged product. UHT-treated products have to be packaged under conditions which prevent microbiological contamination, i.e. aseptically packaged. With some high-acid foods ($pH<4.5$), it may be sufficient to cool the product after UHT treatment to just below $100\,^{\circ}C$, fill it into a clean container, seal the container and hold it at that temperature for some minutes before cooling it. This procedure will inactivate microorganisms that may have been in the container or entered during the filling operation and which might grow in the product. The filled container may need to be inverted for some or all of the holding period. However, in the case of low-acid foods ($pH>4.5$) this procedure would not be adequate to ensure the sterility of the product. Consequently for such products, aseptic filling must involve sterilising the empty container or the material from which the container is made, filling it with the UHT-treated product and sealing it without it being contaminated with microorganisms.

In the case of rigid metal containers, superheated steam may be used to sterilise the empty containers and maintain a sterile atmosphere during the filling and sealing operations. Empty cans are carried on a stainless steel conveyor through a stainless steel tunnel. Superheated steam, at a temperature of approximately $260\,^{\circ}C$, is introduced into the tunnel to sterilise the cans. They then move into an enclosed filling section, maintained sterile by superheated steam. They are sprayed on the outside with cool sterile water before being filled with the cooled UHT product. The filled cans move into an enclosed seaming section, which is also maintained in a sterile condition with superheated steam. The can ends are also sterilised with superheated steam and double-seamed onto the filled cans in the sterile seaming section. The filled and seamed cans then exit from the tunnel. The whole system has to be presterilised and the temperatures adjusted to the appropriate levels before filling commences. This aseptic filling procedure is known as the *Dole process* [51]. Glass containers and some plastic and composite containers may be aseptically filled by this method. Cartons made from a laminate of paper/aluminium foil/polyethylene are widely used for UHT products such as liquid milk and fruit juices. This type of packaging material cannot be sterilised by heat alone. A combination of heat and chemical sterilant is used. Treatments with hydrogen peroxide, peracetic acid, ethylene oxide, ionising radiation, ultraviolet radiation and sterile air have all been investigated. Hydrogen peroxide at a concentration of 35% in water and $90\,^{\circ}C$ is very effective against heat-resistant, sporeforming microorganisms and is widely used commercially as a sterilant in aseptic packaging in laminates. Form-fill-seal systems are available, an example being the Tetra Brik system, offered by Tetra Pak Ltd. (Fig. 9.13).

The packaging material, a polyethylene/paper/polyethylene/foil/polyethylene laminate, is unwound from a reel and a plastic strip is attached to one edge,

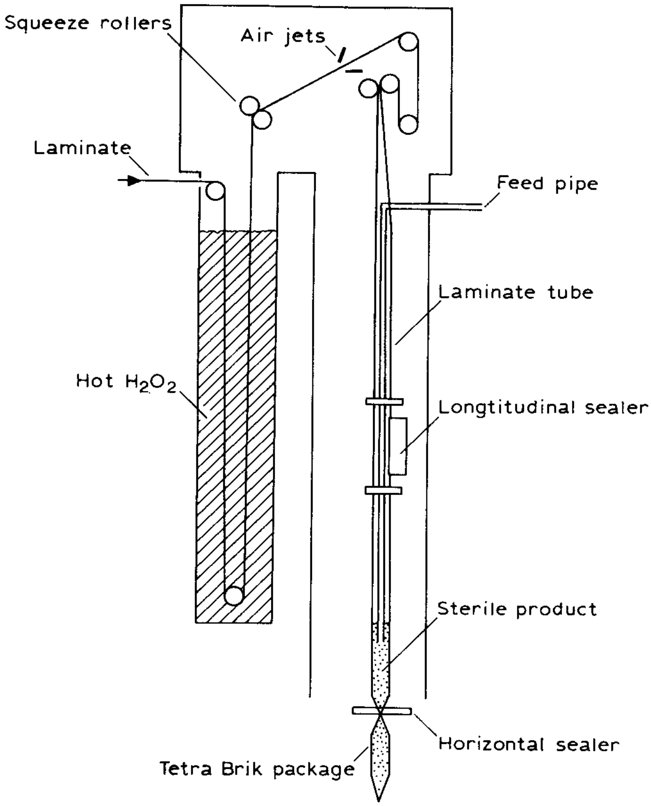

Fig. 9.13 Principle of the Tetra Brik aseptic packaging system; from [15] with permission.

which will eventually overlap the internal longitudinal seal in the carton. It then passes through a deep bath of hot hydrogen peroxide, which wets the laminate. As it emerges from the bath, the laminate passes between squeeze rollers, which express liquid hydrogen peroxide for return to the bath. Next, a high-velocity jet of hot sterile air is directed onto both sides of the laminate to remove residual hydrogen peroxide, as a vapour. The laminate, which is now sterile and dry, is formed into a tube with a longitudinal seal in an enclosed section which is maintained sterile by means of hot, sterile air under pressure. The product filling tube is located down the centre of the laminate tube. The presterilised product is fed into the sterile zone near the bottom of the tube, which is heat-sealed. The air containing the vaporised hydrogen peroxide is collected in a cover and directed to a compressor where it is mixed with water, which washes out the residual hydrogen peroxide. The air is sterilised by heat and returned to the filling zone. In another system, the laminate is in the form of carton blanks which are erected and then sterilised by a downward spray of hydrogen peroxide followed by hot sterile air. This completes the sterilisation and removes residual hydrogen peroxide. The presterilised product is filled into the cartons and the top sealed within a sterile zone. Similar systems are available to aseptically fill into preformed plastic cups. The lidding material is sterilised with hydrogen peroxide or infrared radiation before being heat-sealed onto the cups within a sterile zone. Thermoform filling systems are available to aseptically fill into polymer laminates. The web of laminate passes through a bath of hydrogen peroxide and then is contacted by hot sterile air which completes the sterilisation, removes residual hydrogen peroxide and softens the laminate. The laminate is then thermoformed into cups and filled with presterilised product within a sterile zone. The sterilised lidding material is applied before the cups leave the sterile zone. Thermoforming systems are usually used to fill small containers e.g. for individual portions of milk, cream and whiteners [52–58].

9.6 Active Packaging

9.6.1 Background Information

Active packaging refers to the incorporation of certain additives into packaging film or within packaging containers with the aim of maintaining and extending product shelf life [59]. Packaging may be termed active when it performs some desired role in food preservation other than providing an inert barrier to external conditions [60, 61]. Active packaging includes additives or 'freshness enhancers' that are capable of scavenging oxygen, adsorbing carbon dioxide, moisture, ethylene and/or flavour/odour taints, releasing ethanol, sorbates, antioxidants and/or other preservatives and/or maintaining temperature control. Table 9.3 lists examples of active packaging systems, some of which may offer extended shelf life opportunities for new categories of food products [59].

Active packaging has been used with many food products and is being tested with numerous others. Table 9.3 lists some of the food applications that have benefited from active packaging technology. It should be noted that all food products have a unique deterioration mechanism that must be understood before applying this technology. The shelf life of packaged food is dependent on numerous factors, such as the intrinsic nature of the food (e.g. pH, water activity, nutrient content, occurrence of antimicrobial compounds, redox potential, respiration rate, biological structure) and extrinsic factors (e.g. storage temperature, relative humidity, surrounding gaseous composition). These factors directly influence the chemical, biochemical, physical and microbiological spoilage mechanisms of individual food products and their achievable shelf life. By carefully considering all of these factors, it is possible to evaluate existing and developing active packaging technologies and apply them for maintaining the quality and extending the shelf life of different food products [59].

Table 9.3 Selected examples of active packaging systems.

Systems	Mechanisms	Food applications
Oxygen scavengers	1. Iron-based 2. Metal/acid 3. Metal (e.g. platinum) catalyst 4. Ascorbate/metallic salts 5. Enzyme-based	Bread, cakes, cooked rice, biscuits, pizza, pasta, cheese, cured meats, cured fish, coffee, snack foods, dried foods and beverages
Carbon dioxide scavengers/ emitters	1. Iron oxide/calcium hydroxide 2. Ferrous carbonate/metal halide 3. Calcium oxide/activated charcoal 4. Ascorbate/sodium bicarbonate	Coffee, fresh meats, fresh fish, nuts, other snack food products and sponge cakes
Ethylene scavengers	1. Potassium permanganate 2. Activated carbon 3. Activated clays/zeolites	Fruit, vegetables and other horticultural products
Preservative releasers	1. Organic acids 2. Silver zeolite 3. Spice and herb extracts 4. BHA/BHT antioxidants 5. Vitamin E antioxidant 6. Volatile chlorine dioxide/ sulphur dioxide	Cereals, meats, fish, bread, cheese, snack foods, fruit and vegetables
Ethanol emitters	1. Alcohol spray 2. Encapsulated ethanol	Pizza crusts, cakes, bread, biscuits, fish and bakery products
Moisture absorbers	1. PVA blanket 2. Activated clays and minerals 3. Silica gel	Fish, meats, poultry, snack foods, cereals, dried foods, sandwiches, fruit and vegetables
Flavour/odour adsorbers	1. Cellulose triacetate 2. Acetylated paper 3. Citric acid 4. Ferrous salt/ascorbate 5. Activated carbon/clays/ zeolites	Fruit juices, fried snack foods, fish, cereals, poultry, dairy products and fruit
Temperature control packaging	1. Non-woven plastics 2. Double-walled containers 3. Hydrofluorocarbon gas 4. Lime/water 5. Ammonium nitrate/water	Ready meals, meats, fish, poultry and beverages

Table 9.4 Selected commercial oxygen scavenger systems.

Manufacturer	Country	Trade name	Scavenger mechanism	Packaging form
Mitsubishi Gas Chemical Co. Ltd	Japan	Ageless	Iron-based	Sachets and labels
Toppan Printing Co. Ltd	Japan	Freshilizer	Iron-based	Sachets
Toagosei Chemical Industry Co. Ltd	Japan	Vitalon	Iron-based	Sachets
Nippon Soda Co. Ltd	Japan	Seagul	Iron-based	Sachets
Finetec Co. Ltd	Japan	Sanso-Cut	Iron-based	Sachets
Toyo Seikan Kaisha Ltd	Japan	Oxyguard	Iron-based	Plastic trays
Multisorb Technologies Inc.	USA	FreshMax FreshPax Fresh Pack	Iron-based Iron-based Iron-based	Labels Labels Labels
Ciba Speciality Chemicals	USA	Shelf-plus	PET copolyester	Plastic film
Chevron Chemicals	USA	N/A	Benzyl acrylate	Plastic film
W.R. Grace Co. Ltd	USA	PureSeal	Ascorbate/ metallic salts	Bottle crowns
Food Science Australia	Australia	ZERO$_2$	Photosensitive dye/organic compound	Plastic film
CMB Technologies	France	Oxbar	Cobalt catalyst	Plastic bottles
Standa Industrie	France	ATCO Oxycap	Iron-based Iron-based	Sachets Bottle crowns
EMCO Packaging Systems	UK	ATCO	Iron-based	Labels
Johnson Matthey Plc	UK	N/A	Platinum group metal catalyst	Labels
Bioka Ltd	Finland	Bioka	Enzyme-based	Sachets
Alcoa CSI Europe	UK	O_2-displacer system	Unknown Trade name	Bottle crowns Scavenger mechanism

Active packaging is not synonymous with intelligent or smart packaging, which refers to packaging which senses and informs [62, 63]. Intelligent packaging devices are capable of sensing and providing information about the function and properties of packaged food and can provide assurances of pack integrity, tamper evidence, product safety and quality, as well as being utilised in applications such as product authenticity, anti-theft and product traceability [62, 63]. Intelligent packaging devices include time-temperature indicators, gas-sensing dyes, microbial growth indicators, physical shock indicators and numerous examples of tamper-proof, anti-counterfeiting and anti-theft technologies. Information on intelligent packaging technology can be obtained from other reference sources [62–64].

It is not the intention of this section to extensively review all active packaging technologies but rather to describe the different types of devices, the scientific principles behind them, the principal food applications and the food safety and regulatory issues that need to be considered by potential users. The major focus of this section is on oxygen scavengers but other active packaging technologies are described and some recent developments are highlighted. More detailed information on active packaging can be obtained from the numerous references listed.

9.6.2 Oxygen Scavengers

Oxygen can have considerable detrimental effects on foods. Oxygen scavengers can therefore help maintain food product quality by decreasing food metabolism, reducing oxidative rancidity, inhibiting undesirable oxidation of labile pigments and vitamins, controlling enzymic discoloration and inhibiting the growth of aerobic microorganisms [59, 60, 62].

Oxygen scavengers are by far the most commercially important subcategory of active packaging. The global market per annum for oxygen scavengers was estimated to exceed ten billion units in Japan, several hundred million in the USA and tens of millions in Europe in 1996 [65, 66]. The global value of this market was estimated to exceed $200 million in 1996 and to top $1 billion by 2002, particularly since the recent introduction of oxygen-scavenging PET bottles, bottle caps and crowns for beers and other beverages is now fully commercialised [62, 65, 66]. More recent market information has estimated that the global market per annum for oxygen scavengers was $480 million in 2001, with 12 billion units sold in Japan and 300 million units sold in Europe [67].

The most common oxygen scavengers take the form of small sachets containing various iron-based powders containing an assortment of catalysts. These chemical systems often react with water supplied by the food to produce a reactive hydrated metallic reducing agent that scavenges oxygen within the food package and irreversibly converts it to a stable oxide. The iron powder is separated from the food by keeping it in a small, highly oxygen permeable sachet that is labelled “Do not eat”. The main advantage of using such oxygen scavengers is that they are capable of reducing oxygen levels to less than 0.01%, which is much lower that the typical 0.3–3.0% residual oxygen levels achievable by modified atmosphere packaging (MAP). Oxygen scavengers can be used alone or in combination with MAP. Their use alone eliminates the need for MAP machinery and can increase packaging speeds. However, it is usually more common commercially to remove most of the atmospheric oxygen by MAP and then use a relatively small and inexpensive scavenger to mop up the residual oxygen remaining within the food package.

Nonmetallic oxygen scavengers have also been developed to alleviate the potential for metallic taints being imparted to food products. The problem of inadvertently setting off inline metal detectors is also alleviated even though some modern detectors can now be tuned to phase out the scavenger signal whilst retaining high sensitivity for ferrous and nonferrous metallic contaminants [68]. Nonmetallic scavengers include those that use organic reducing agents such as ascorbic acid, ascorbate salts or catechol. They also include enzymic oxygen scavenger systems using either glucose oxidase or ethanol oxidase which could be incorporated into sachets, adhesive labels or immobilised onto packaging film surfaces [69].

Oxygen scavengers were first marketed in Japan in 1976 by the Mitsubishi Gas Chemical Co. Ltd. under the trade name 'Ageless'. Since then, several other Japanese companies, including Toppan Printing Co. Ltd. and Toyo Seikan Kaisha Ltd., have entered the market but Mitsubishi still dominates the oxygen scavenger business in Japan with a market share of 73% [60]. Oxygen scavenger technology has been successful in Japan for a variety of reasons, including the acceptance by Japanese consumers of innovative packaging and the hot and humid climate in Japan during the summer months, which is conducive to mould spoilage of food products. In contrast to the Japanese market, the acceptance of oxygen scavengers in North America and Europe has been slow, although several manufacturers and distributors of oxygen scavengers are now established in both these continents and sales have been estimated to be growing at a rate of 20% annually [60]. Table 9.4 lists selected manufacturers and trade names of oxygen scavengers, including some which are still under development or have been suspended because of regulatory controls [60, 66, 70, 71].

It should be noted that discrete oxygen-scavenging sachets suffer from the disadvantage of possible accidental ingestion of the contents by the consumer; and this has hampered their commercial success, particularly in North America and Europe. However, in the last few years, the development of oxygen-scavenging adhesive labels that can be adhered to the inside of packages and the incorporation of oxygen-scavenging materials into laminated trays and plastic films have enhanced and help the commercial acceptance of this technology. For example, Marks & Spencer Ltd were the first UK retailer to use oxygen-scavenging adhesive labels for a range of sliced cooked and cured meat and poultry products which are particularly sensitive to deleterious light and oxygen-induced colour changes [62]. Other UK retailers, distributors and caterers are now using these labels for the above food products as well as for coffee, pizzas, speciality

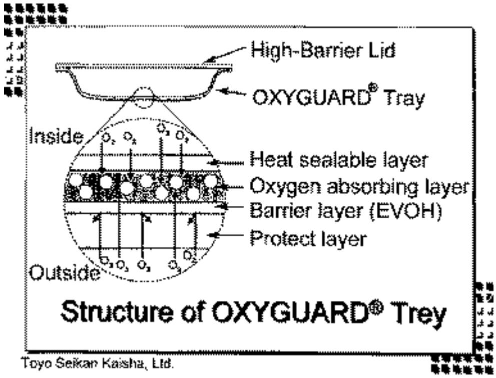

Fig. 9.14 Structure of the Oxyguard tray.

bakery goods and dried food ingredients [72]. Other common food applications for oxygen scavenger labels and sachets include cakes, breads, biscuits, croissants, fresh pastas, cured fish, tea, powdered milk, dried egg, spices, herbs, confectionery and snack food [62]. In Japan, Toyo Seikan Kaisha Ltd. have marketed a laminate containing a ferrous oxygen scavenger, which can be thermoformed into an 'Oxyguard' tray, which has been used commercially for cooked rice, see Fig. 9.14.

The use of oxygen scavengers for beer, wine and other beverages is potentially a huge market that has only recently begun to be exploited. Iron-based label and sachet scavengers cannot be used for beverages or high a_w foods because, when wet, their oxygen-scavenging capability is rapidly lost. Instead, various nonmetallic reagents and organometallic compounds which have an affinity for oxygen have been incorporated into bottle closures, crown and caps or blended into polymer materials so that oxygen is scavenged from the bottle headspace and any ingressing oxygen is also scavenged too. The 'PureSeal' oxygen-scavenging bottle crowns (marketed by W.R. Grace Co. Ltd. and ZapatA Technologies Inc., USA), oxygen-scavenging plastic (PET) beer bottles (manufactured by Continental PET Technologies, Toledo, USA) and light-activated 'ZERO2' oxygen scavenger materials (developed by Food Science Australia, North Ryde, NSW, Australia) are just three of many oxygen scavenger developments aimed at the beverage market but also applicable to other food applications [60, 66, 70, 73]. It should be noted that the speed and capacity of oxygen-scavenging plastic films and laminated trays are considerably lower than iron-based oxygen scavenger sachets or labels [72].

More detailed information on the technical requirements (i.e. for low, medium and high a_w foods and beverages, speed of reaction, storage temperature, oxygen scavenging capacity, necessary packaging criteria) of the different types of oxygen scavengers can be obtained from Rooney [60, 66, 69, 73, 74].

9.6.3 Carbon Dioxide Scavengers/Emitters

There are many commercial sachet and label devices that can be used to either scavenge or emit carbon dioxide. The use of carbon dioxide scavengers is particularly applicable for fresh roasted or ground coffees that produce significant volumes of carbon dioxide. Fresh roasted or ground coffees cannot be left unpackaged since they absorb moisture and oxygen and lose desirable volatile aromas and flavours. However, if coffee is hermetically sealed in packs directly after roasting, the carbon dioxide released builds up within the packs and eventually causes them to burst [50]. To circumvent this problem, two solutions are currently used. The first is to use packaging with patented oneway valves that allow excess carbon dioxide to escape. The second solution is to use a carbon dioxide scavenger or a dual-action oxygen and carbon dioxide scavenger system. A mixture of calcium oxide and activated charcoal has been used in polyethylene coffee pouches to scavenge carbon dioxide but dual-action oxygen and carbon dioxide scavenger sachets and labels are more common and are commercially used for canned and foil pouched coffees in Japan and the USA [59, 60, 75]. These dual-action sachets and labels typically contain iron powder for scavenging oxygen and calcium hydroxide which scavenges carbon dioxide when it is converted to calcium carbonate under sufficiently high humidity conditions [60]. Commercially available dual-action oxygen and carbon dioxide scavengers are available from Japanese manufacturers, e.g. Mitsubishi Gas Chemical Co. Ltd. ('Ageless' type E, 'Fresh Lock') and Toppan Printing Co. Ltd. ('Freshilizer' type CV).

Pack collapse or the development of a partial vacuum can also be a problem for foods packed with an oxygen scavenger. To overcome this problem, dual-action oxygen scavenger/carbon dioxide emitter sachets and labels have been developed which absorb oxygen and generate an equal volume of carbon dioxide. These sachets and labels usually contain ferrous carbonate and a metal halide catalyst although nonferrous variants are available. Commercial manufacturers include Mitsubishi Gas Chemical Co. Ltd. ('Ageless' type G), and Multisorb Technologies Inc. ('Freshpax' type M). The main food applications for these dual-action oxygen scavenger/carbon dioxide emitter sachets and labels have been with snack food products, e.g. nuts, and sponge cakes [60, 76].

9.6.4 Ethylene Scavengers

Ethylene (C_2H_4) is a plant hormone that accelerates the respiration rate and subsequent senescence of horticultural products such as fruit, vegetables and flowers. Many of the effects of ethylene are necessary, e.g. induction of flowering in pineapples and colour development in citrus fruits, bananas and tomatoes, but in most horticultural situations it is desirable to remove ethylene or to suppress its effects. Consequently, much research effort has been undertaken to incorporate ethylene scavengers into fresh produce packaging and storage areas.

Some of this effort has met with commercial success, but much of it has not [60, 77].

Table 9.5 lists selected commercial ethylene scavenger systems. Effective systems utilise potassium permanganate ($KMnO_4$) immobilised on an inert mineral substrate such as alumina or silica gel. $KMnO_4$ oxidises ethylene to acetate and ethanol and in the process changes colour from purple to brown and hence indicates its remaining ethylene-scavenging capacity. $KMnO_4$-based ethylene scavengers are available in sachets to be placed inside produce packages or inside blankets or tubes that can be placed in produce storage warehouses [60, 74, 77].

Activated carbon-based scavengers with various metal catalysts can also effectively remove ethylene. They have been used to scavenge ethylene from produce warehouses or incorporated into sachets for inclusion into produce packs or embedded into paper bags or corrugated board boxes for produce storage. A dual-action ethylene scavenger and moisture absorber has been marketed in Japan by Sekisui Jushi Limited. 'Neupalon' sachets contain activated carbon, a metal catalyst and silica gel and are capable of scavenging ethylene as well as acting as a moisture absorber [60, 77].

In recent years, numerous produce packaging films and bags have appeared on the market place which are based on the putative ability of certain finely ground minerals to adsorb ethylene and to emit antimicrobial far-infrared radiation. However, little direct evidence for these effects has been published in peer-reviewed scientific journals. Typically these activated earth-type minerals include clays, pumice, zeolites, coral, ceramics and even Japanese Oya stone. These

Table 9.5 Selected commercial ethylene scavenger systems.

Manufacturer	Country	Trade name	Scavenger mechanism	Packaging form
Air Repair Products Inc.	USA	N/A	$KMnO_4$	Sachets/blankets
Ethylene Control Inc.	USA	N/A	$KMnO_4$	Sachets/blankets
Extenda Life Systems	USA	N/A	$KMnO_4$	Sachets/blankets
Kes Irrigations Systems	USA	Bio-Kleen	Titanium dioxide catalyst	Not known
Sekisui Jushi Ltd	Japan	Neupalon	Activated carbon	Sachet
Honshu Paper Ltd	Japan	Hatofresh	Activated carbon	Paper/board
Mitsubishi Gas Chemical Co. Ltd	Japan	Sendo-Mate	Activated carbon	Sachets
Cho Yang Heung San Co. Ltd	Korea	Orega	Activated clays/ zeolites	Plastic film
Evert-Fresh Corp.	USA	Evert-Fresh	Activated zeolites	Plastic film
Odja Shoji Co. Ltd	Japan	BO Film	Crysburite ceramic	Plastic film
PEAKfresh Products Ltd	Australia	PEAKfresh	Activated clays/ zeolites	Plastic film

minerals are embedded or blended into polyethylene film bags that are then used to package fresh produce. Manufacturers of such bags claim extended shelf life for fresh produce partly due to the adsorption of ethylene by the minerals dispersed within the bags. The evidence offered in support of this claim is generally based on the extended shelf life of produce and reduction of headspace ethylene in mineral-filled bags in comparison with common polyethylene bags. However, independent research has shown that the gas permeability of mineral-filled polyethylene bags is much greater and consequently ethylene will diffuse out of these bags much faster, as is also the case for commercially available microperforated film bags. In addition, a more favourable equilibrium modified atmosphere is likely to develop within these bags compared with common polyethylene bags, especially if the produce has a high respiration rate. Therefore, these effects can improve produce shelf life and reduce headspace ethylene independently of any ethylene adsorption. In fact, almost any powdered mineral can confer such effects without relying on expensive Oya stone or other speciality minerals [60, 77].

9.6.5
Ethanol Emitters

The use of ethanol as an antimicrobial agent is well documented. It is particularly effective against mould but can also inhibit the growth of yeasts and bacteria. Ethanol can be sprayed directly onto food products just prior to packaging. Several reports have demonstrated that the mould-free shelf life of bakery products can be significantly extended after spraying with 95% ethanol to give concentrations of 0.5–1.5% (w/w) in the products. However, a more practical and safer method of generating ethanol is through the use of ethanol-emitting films and sachets [60].

Primarily Japanese manufacturers have patented many applications of ethanol-emitting films and sachets. These include Ethicap, Antimold 102 and Negamold (Freund Industrial Co. Ltd.), Oitech (Nippon Kayaku Co. Ltd.), ET Pack (Ueno Seiyaku Co. Ltd.) and Ageless type SE (Mitsubishi Gas Chemical Co. Ltd.). All of these films and sachets contain absorbed or encapsulated ethanol in a carrier material that allows the controlled release of ethanol vapour. For example, Ethicap, which is the most commercially popular ethanol emitter in Japan, consists of food grade alcohol (55%) and water (10%) adsorbed onto silicon dioxide powder (35%) and contained in a sachet made of a paper and ethyl vinyl acetate (EVA) copolymer laminate. To mask the odour of alcohol, some sachets contain traces of vanilla or other flavours. The sachets are labelled “Do not eat contents” and include a diagram illustrating this warning. Other ethanol emitters such as Negamould and Ageless type SE are dual-action sachets that scavenge oxygen as well as emitting ethanol vapour [60].

The size and capacity of the ethanol-emitting sachet used depends on the weight of food, the a_w of the food and the shelf life required. When food is packed with an ethanol-emitting sachet, moisture is absorbed by the food and ethanol vapour is released and diffuses into the package headspace. Ethanol emitters are used extensively in Japan to extend the mould-free shelf life of high ratio cakes and other high moisture bakery products by up to 2000% [60, 78]. Research has also shown that such bakery products packed with ethanol-emitting sachets did not get as hard as the controls and results were better than those using an oxygen scavenger alone to inhibit mould growth. Hence, ethanol vapour also appears to exert an anti-staling effect in addition to its anti-mould properties. Ethanol-emitting sachets are also widely used in Japan for extending the shelf life of semi-moist and dry fish products [60].

9.6.6 Preservative Releasers

Recently there has been great interest in the potential use of antimicrobial and antioxidant packaging films that have preservative properties for extending the shelf life of a wide range of food products. As with other categories of active packaging, many patents exist and some antimicrobial and antioxidant films have been marketed but the majority have so far failed to be commercialised because of doubts about their effectiveness, economic factors and/or regulatory constraints [60].

Some commercial antimicrobial films and materials have been introduced, primarily in Japan. For example, one widely reported product is a synthetic silver zeolite that has been directly incorporated into food contact packaging film. The purpose of the zeolite is apparently to allow slow release of antimicrobial silver ions into the surface of food products. Many other synthetic and naturally occurring preservatives have been proposed and/or tested for antimicrobial activity in plastic and edible films [60, 79–81]. These include organic acids, e.g. propionate, benzoate and sorbate, bacteriocins, e.g. nisin„ spice and herb extracts, e.g. from rosemary, cloves, horseradish, mustard, cinnamon and thyme, enzymes, e.g. peroxidase, lysozyme and glucose oxidase, chelating agents, e.g. EDTA, inorganic acids, e.g. sulphur dioxide and chlorine dioxide, and anti-fungal agents, e.g. imazalil and benomyl. The major potential food applications for antimicrobial films include meats, fish, bread, cheese, fruit and vegetables.

An interesting commercial development in the UK is the recent exclusive marketing of food contact approved Microban (Microban International, Huntersville, USA) kitchen products such as chopping boards, dish cloths and bin bags by J. Sainsbury Plc. These Microban products contain triclosan, an antibacterial aromatic chloroorganic compound, which is also used in soaps, shampoos, lotions, toothpaste and mouth washes [82-84]. Another interesting development is the incorporation of methyl salicylate (a synthetic version of wintergreen oil) into RepelKote paperboard boxes by Tenneco Packaging (Lake Forest, Illinois, USA). Methyl salicylate has antimicrobial properties, but RepelKote is primarily being marketed as an insect repellent and its main food applications are dried foods that are very susceptible to insect infestations [85].

Two influences have stimulated interest in the use of antioxidant packaging films. The first of these is the consumer demand for reduced antioxidants and other additives in foods. The second is the interest of plastic manufacturers in using natural approved food antioxidants, e.g. vitamin E, for polymer stabilisation instead of synthetic antioxidants developed specifically for plastics [60]. The potential for evaporative migration of antioxidants into foods from packaging films has been extensively researched and commercialised in some instances. For example, the cereal industry in the USA has used this approach for the release of butylated hydroxytoluene (BHT) and butylated hydroxyanisole (BHA) antioxidants from waxed paper liners into breakfast cereal and snack food products [74]. Recently there has been a lot of interest in the use of α-tocopherol (vitamin E) as a viable alternative to BHT/BHA-impregnated packaging films [86]. The use of packaging films incorporating natural vitamin E can confer benefits to both film manufacturers and the food industry. There have been questions raised regarding the safety of BHT and BHA and hence using vitamin E is a safer alternative. Research has shown vitamin E to be as effective as an antioxidant compared with BHT, BHA or other synthetic polymer antioxidants for inhibiting packaging film degradation during film extrusion or blow moulding. Vitamin E is also a safe and effective antioxidant for low to medium a_w cereal and snack food products where the development of rancid odours and flavours is often the spoilage mechanism limiting shelf life [60, 74, 86].

9.6.7 Moisture Absorbers

Excess moisture is a major cause of food spoilage. Soaking up moisture by using various absorbers or desiccants is very effective at maintaining food quality and extending shelf life by inhibiting microbial growth and moisture-related degradation of texture and flavour. Several companies manufacture moisture absorbers in the form of sachets, pads, sheets or blankets. For packaged dried food applications, desiccants such as silica gel, calcium oxide and activated clays and minerals are typically contained within Tyvek (Dupont Chemicals, Wilmington, Delaware, USA) tear-resistant permeable plastic sachets. For dual-action purposes, these sachets may also contain activated carbon for odour adsorption or iron powder for oxygen scavenging [60, 87]. The use of moisture absorber sachets is commonplace in Japan where popular foods feature a number of dried products which need to be protected from humidity damage. The use of moisture absorber sachets is also quite common in the USA where the major suppliers include Multisorb Technologies Inc. (Buffalo, New York), United Desiccants (Louisville, Kentucky) and Baltimore Chemicals (Baltimore, Maryland). These sachets are not only utilised for dried snack foods and cereals but also for a wide array of pharmaceutical, electrical and electronic goods. In the UK, Marks & Spencer Plc have used silica gel-based moisture absorber sachets for maintaining the crispness of filled ciabatta bread rolls.

In addition to moisture absorber sachets for humidity control in packaged dried foods, several companies manufacture moisture drip absorbent pads, sheets and blankets for liquid water control in high a_w foods such as meats, fish, poultry, fruit and vegetables. Basically they consist of two layers of a microporous nonwoven plastic film, such as polyethylene or polypropylene, between which is placed a superabsorbent polymer that is capable of absorbing up to 500 times its own weight with water. Typical superabsorbent polymers include polyacrylate salts, carboxymethyl cellulose (CMC) and starch copolymers which both have a very strong affinity for water. Moisture drip absorber pads are commonly placed under packaged fresh meats, fish and poultry to absorb unsightly tissue drip exudate. Larger sheets and blankets are used for absorption of melted ice from chilled seafood during airfreight transportation or for controlling transpiration of horticultural produce [60]. Commercial moisture absorber sheets, blankets and trays include Toppan Sheet (Toppan Printing Co. Ltd., Japan), Thermarite (Thermarite Pty Ltd., Australia) and Fresh-R-Pax (Maxwell Chase Inc., Douglasville, Georgia).

Another approach for the control of excess moisture in high a_w foods, is to intercept the moisture in the vapour phase. This approach allows food packers or even householders to decrease the water activity on the surface of foods by reducing in-pack relative humidity. Placing one or more humectants between two layers of water-permeable plastic film can do this. For example, the Japanese company Showa Denko Co. Ltd has developed a Pitchit film which consists of a layer of humectant, carbohydrate and propylene glycol, sandwiched between two layers of polyvinyl alcohol (PVA) plastic film. Pitchit film is marketed for home use in a roll or single sheet form for wrapping fresh meats, fish and poultry. After wrapping in this film, the surface of the food is dehydrated by osmotic pressure, resulting in microbial inhibition and shelf life extension of 3–4 days under chilled storage [60, 74]. Another example of this approach has been applied in the distribution of horticultural produce. In recent years, microporous sachets of desiccant inorganic salts such as sodium chloride have been used for the distribution of tomatoes in the USA [60]. Yet another example is an innovative fibreboard box which functions as a humidity buffer on its own without relying on a desiccant insert. It consists of an integral water vapour barrier on the inner surface of the fibreboard, a paper-like material bonded to the barrier which acts as a wick and an unwettable but highly permeable to water vapour layer next to the fruit or vegetables. This multilayered box is able to take up water in the vapour state when the temperature drops and the relative humidity rises. Conversely, when the temperature rises, the multilayered box can release water vapour back in response to a lowering of the relative humidity [88].

9.6.8 Flavour/Odour Adsorbers

The interaction of packaging with food flavours and aromas has long been recognised, especially through the undesirable flavour scalping of desirable food components. For example, the scalping of a considerable proportion of desirable limonene has been demonstrated after only 2 weeks storage in aseptic packs of orange juice [60]. Commercially, very few active packaging techniques have been used to selectively remove undesirable flavours and taints, but many potential opportunities exist. An example of such an opportunity is the debittering of pasteurised orange juices. Some varieties of orange, such as Navel, are particularly prone to bitter flavours caused by limonine, a tetraterpenoid which is liberated into the juice after orange pressing and subsequent pasteurisation. Processes have been developed for debittering such juices by passing them through columns of cellulose triacetate or Nylon beads [60]. A possible active packaging solution would be to include limonine adsorbers, e.g. cellulose triacetate or acetylated paper, into orange juice packaging material.

Two types of taints amenable to removal by active packaging are amines, which are formed from the breakdown of fish muscle proteins, and aldehydes that are formed from the autooxidation of fats and oils. Volatile amines with an unpleasant smell, such as trimethylamine, associated with fish protein breakdown are alkaline and can be neutralised by various acidic compounds [89]. In Japan, Anico Co. Ltd have marketed Anico bags that are made from film containing a ferrous salt and an organic acid such as citrate or ascorbate. These bags are claimed to oxidise amines when they are adsorbed by the polymer film [60].

Removal of aldehydes, such as hexanal and heptanal, from package headspaces is claimed by Dupont's Odour and Taste Control (OTC) technology [90]. This technology is based upon a molecular sieve with pore sizes of around 5 nm and Dupont claim that their OTC removes or neutralises aldehydes, although evidence for this is lacking. The claimed food applications for this technology are snack foods, cereals, dairy products, fish and poultry [90]. A similar claim of aldehyde removal has been reported recently [91]. Swedish company EKA Noble in cooperation with Dutch company Akzo, have developed a range of synthetic aluminosilicate zeolites which they claim adsorb odorous gases within their highly porous structure. Their BMH powder can be incorporated into packaging materials, especially those that are paper-based, and apparently odorous aldehydes are adsorbed in the pore interstices of the powder [91].

9.6.9
Temperature Control Packaging

Temperature control active packaging includes the use of innovative insulating materials, self-heating and self-cooling cans. For example, to guard against undue temperature abuse during storage and distribution of chilled foods, special insulating materials have been developed. One such material is Thinsulate (3M Company, USA) that is a special nonwoven plastic with many air pore spaces. Another approach for maintaining chilled temperatures is to increase the thermal mass of the food package so that it is capable of withstanding temperature rises. The Adenko Company of Japan has developed and marketed a Cool Bowl that consists of a double-walled PET container in which an insulating gel is deposited in between the walls [74].

Self-heating cans and containers have been commercially available for decades and are particularly popular in Japan. Self-heating aluminium and steel cans and containers for sake, coffee, tea and ready meals are heated by an exothermic reaction when lime and water positioned in the base are mixed. In the UK, Nestlé recently introduced a range of Nescafé coffees in self-heating insulated cans that use the lime and water exothermic reaction. Self-cooling cans have also been marketed in Japan for raw sake. The endothermic dissolution of ammonium nitrate and chloride in water is used to cool the product. Another self-cooling can that has recently been introduced is the Chill Can (The Joseph Company, USA) that relies on a hydrofluorocarbon (HRC) gas refrigerant. The release of HRC gas is triggered by a button set into the can's base and can cool a drink by 10 °C in 2 min. However, concerns about the environmental impact of HRCs are likely to curtail the commercial success of the Chill Can [92].

9.6.10 Food Safety, Consumer Acceptability and Regulatory Issues

At least four types of food safety and regulatory issues related to active packaging of foods need to be addressed. First, any need for food contact approval must be established before any form of active packaging is used. Second, it is important to consider environmental regulations covering active packaging materials. Third, there may be a need for labelling in cases where active packaging may give rise to consumer confusion. Fourth, it is pertinent to consider the effects of active packaging on the microbial ecology and safety of foods [60]. All of these issues are currently being addressed in an EC-funded 'Actipack' project which aims to evaluate the safety, effectiveness, economic and environmental impact and consumer acceptance of active and intelligent packaging [93].

Food contact approval will often be required because active packaging may affect foods in two ways. Active packaging substances may migrate into the food or may be removed from it. Migrants may be intended or unintended. Intended migrants include antioxidants, ethanol and antimicrobial preservatives which would require regulatory approval in terms of their identity, concentration and possible toxicological effects. Unintended migrants include various metal compounds that achieve their active purpose inside packaging materials but do not need to or should not enter foods. Food additive regulations require identification and quantification of any such unintended migration.

Environmental regulations covering reuse, recycling, identification to assist in recycling or the recovery of energy from active packaging materials needs to be addressed on a case by case basis. European Union companies using active packaging as well as other packaging need to meet the requirements of the Packaging Waste Directive (1994) and consider the environmental impact of their packaging operations.

Food labelling is currently required to reduce the risk of consumers ingesting the contents of oxygen scavenger sachets or other in-pack active packaging devices. Some active packages may look different from their passive counterparts. Therefore it may be advisable to use appropriate labelling to explain this difference to the consumer even in the absence of regulations.

Finally, it is very important for food manufacturers using certain type of active packaging to consider the effects this will have on the microbial ecology and safety of foods. For example, removing all the oxygen from within packs of high a_w chilled perishable food products may stimulate the growth of anaerobic pathogenic bacteria such as *Clostridium botulinum*. Specific guidance is available to minimise the microbial safety risks of foods packed under reduced oxygen atmospheres [94]. Regarding the use of antimicrobial films, it is important to consider what spectrum of microorganisms will be inhibited. Antimicrobial films that only inhibit spoilage microorganisms without affecting the growth of pathogenic bacteria will raise food safety concerns.

In the USA, Japan and Australia, active packaging concepts are already being successfully applied. In Europe, the development and application of active packaging is limited because of legislative restrictions, fear of consumer resistance, lack of knowledge about effectiveness, economic and environmental impact of concepts [95]. No specific regulations exist on the use of active packaging in Europe. Active packaging is subjected to traditional packaging legislation, which requires that compounds are registered on positive lists and that the overall and specific migration limits are respected. This is more or less contradictory to the concept of some active packaging systems in which packaging releases substances to extend shelf life or improve quality [93]. The food industry's main concern about introducing active components to packaging seems to be that consumers may consider the components harmful and may not accept them. In Finland a consumer survey conducted in order to determine consumer attitudes towards oxygen scavengers revealed that the new concepts would be accepted if consumers are well informed by using reliable information channels [96]. More information is needed about the chemical, microbiological and physiological effects of various active concepts on the packaged food, i.e. in regard to its quality and safety. So far research has mainly concentrated on development of various methods and their testing in a model system, but not so much on functioning in food preservation with real food products. Furthermore, the benefits of active packaging need to be considered in a holistic approach to environmental impact assessment. The environmental effect of plastics-based active packaging will vary with the nature of the product/package combination and additional additives need to be evaluated for their environmental impact [95].

9.6.11
Conclusions

Active packaging is an emerging and exciting area of food technology that can confer many preservation benefits on a wide range of food products. Active packaging is a technology developing a new trust because of recent advances in packaging, material science, biotechnology and new consumer demands. The objectives of this technology are to maintain sensory quality and extend the shelf life of foods whilst at the same time maintaining nutritional quality and ensuring microbial safety.

Oxygen scavengers are by far the most commercially important subcategory of active packaging and the market has been growing steadily for the last 10 years. It is predicted that the recent introduction of oxygen scavenging films and bottle caps will further help stimulate the market in future years and the unit costs of oxygen scavenging technology will drop. Other active packaging technologies are also predicted to be used more in the future, particularly carbon dioxide scavengers and emitters, moisture absorbers and temperature control packaging. Food safety and regulatory issues in the EU are likely to restrict the use of certain preservative releasers and flavour/odour adsorber active packaging technologies. Nevertheless, the use of active packaging is becoming increasingly popular and many new opportunities in the food and nonfood industries will open up for utilising this technology in the future.

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