1

Active Packaging of Food

Brian P. F. Day

1.1 Introduction and Background Information

Active packaging has been variously classified in the literature by a number of differing definitions. Some of these definitions are either so broad as to include many packages that are clearly not active, or so narrow as to exclude important subsets of active packaging (Robertson, 2006). According to previous reviews, active packaging has been classified as a subset of smart packaging and referred to as the incorporation of certain additives into packaging film or within packaging containers with the aim of maintaining and extending product shelf-life (Day, 2001; 2003). However, as pointed out by Robertson (2006), this definition focuses on the additives that make a package active and hence excludes certain categories such as temperature compensating polymeric films for fresh fruit and vegetables. Another definition states that packaging may be termed active when it performs some desired role in food preservation other than providing an inert barrier to external conditions (Rooney, 1995). Robertson (2006) correctly identifies ‘desired’ and ‘inert’ as the key words in this definition, since all packaging materials, except glass, are not totally inert and can contribute undesirable components to food or absorb desirable components from food. Consequently, for the purposes of this chapter, active packaging is defined as ‘packaging in which subsidiary constituents have been deliberately included in or on either the packaging material or the package headspace to enhance the performance of the package system’ (Robertson, 2006). The key words here are ‘deliberately’ and ‘enhance’, and implicit in this definition is that performance of the package system includes maintaining the sensory, safety and quality aspects of the food.

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Hence, active packaging includes components of packaging systems that are capable of scavenging oxygen; absorbing carbon dioxide, moisture, ethylene and/or flavour/odour taints; releasing carbon dioxide, ethanol, antioxidants and/or other preservatives; and/or maintaining temperature control and/or compensating for temperature changes. Pira International Ltd estimated the global value of the total active packaging market in 2005 to be worth $1.558 billion and has forecasted this market in 2010 to be worth $2.649 billion (Anon., 2005e). Table 1.1 lists examples of active packaging systems, some of which may offer extended shelf-life opportunities for new categories of food products (Day, 2003; Rooney, 1995; Brody, 2005; Robertson, 2006).

Active packaging has been used with many food products and is being tested with numerous others. Table 1.1 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 and biological structure) and extrinsic factors (e.g. storage temperature, relative humidity and the surrounding gaseous composition). These factors will directly influence the chemical, biochemical, physical and microbiological spoilage mechanisms of individual food products and their achievable shelf-lives. 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 (Day, 2001).

Active packaging is not synonymous with intelligent packaging, which simplistically refers to packaging that senses and informs (Day, 2003). Robertson (2006) defines intelligent packaging as packaging that contains an external or internal indicator to provide information about aspects of the history of the package and/or quality of the food. 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. Intelligent packaging devices include time–temperature indicators, gas sensing dyes, microwave doneness indicators, microbial growth indicators, physical shock indicators, and numerous examples of tamper proof, anti-counterfeiting and anti-theft technologies (Day, 2001; Robertson, 2006).

It should be noted that there is a certain grey area with regards to what constitutes active and/or intelligent packaging (Brody, 2005; Robertson, 2006). The vast majority of consumers could not tell the difference and probably do not care so long as the packaging is safe and functional (Kerry, personal communication). Smart packaging can be considered an all-embracing term used to encompass both active and intelligent packaging, as well functional and emotional packaging in addition to clever packaging design (Kerry and Butler, foreword of this book; Robertson, 2006).

The intention of this chapter is to provide an overview of active packaging and to describe briefly the different types of device, the scientific principles behind them, the principal food applications and some of the food safety and regulatory issues that need to be considered by potential users. The major focus of this chapter 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 some of the other chapters in this book as well as the references listed.
Table 1.1  Selected examples of active packaging systems

<table>
<thead>
<tr>
<th>Active packaging system</th>
<th>Mechanisms</th>
<th>Food applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen scavengers</td>
<td>Iron based</td>
<td>Bread, cakes, cooked rice, fish, coffee, snack foods,</td>
</tr>
<tr>
<td></td>
<td>Metal/acid</td>
<td>dried foods and beverages</td>
</tr>
<tr>
<td></td>
<td>Metal (e.g. platinum) catalyst</td>
<td></td>
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<tr>
<td></td>
<td>Ascorbate/metabolic salts</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Enzyme based</td>
<td></td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>Iron oxide/calcium hydroxide/ferrous carbonate</td>
<td>Coffee, fresh meats and fish, nuts and other snack food</td>
</tr>
<tr>
<td>scavengers/emitters</td>
<td>metal halide</td>
<td>products and sponge cakes</td>
</tr>
<tr>
<td></td>
<td>Calcium oxide/activated charcoal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ascorbate/sodium bicarbonate</td>
<td></td>
</tr>
<tr>
<td>Ethylene scavengers</td>
<td>potassium permanganate</td>
<td>Fruit, vegetables and other horticultural products</td>
</tr>
<tr>
<td></td>
<td>Activated carbon</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Activated clays/zeolites</td>
<td></td>
</tr>
<tr>
<td>Preservative</td>
<td>Organic acids</td>
<td>Cereals, meats, fish, bread, cheese, snack foods,</td>
</tr>
<tr>
<td>releasers</td>
<td>Silver zeolite</td>
<td>fruit and vegetables</td>
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<tr>
<td></td>
<td>Spice and herb extracts</td>
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<tr>
<td></td>
<td>BHA/BHT antioxidants</td>
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<td></td>
<td>Vitamin E antioxidant</td>
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<td></td>
<td>Chlorine dioxide/sulphur dioxide</td>
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<tr>
<td>Ethanol emitters</td>
<td>Encapsulated ethanol</td>
<td>Pizza crusts, cakes, bread, biscuits, fish and bakery</td>
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<tr>
<td></td>
<td></td>
<td>products</td>
</tr>
<tr>
<td>Moisture absorbers</td>
<td>PVA blanket</td>
<td>Fish, meats, poultry, snack foods, cereals, dried</td>
</tr>
<tr>
<td></td>
<td>Activated clays and minerals</td>
<td>foods, sandwiches, fruit and vegetables</td>
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<tr>
<td></td>
<td>Silica gel</td>
<td></td>
</tr>
<tr>
<td>Flavour/odour</td>
<td>Cellulose triacetate</td>
<td>Fruit juices, fried snack foods, fish, cereals,</td>
</tr>
<tr>
<td>absorbers</td>
<td>Acetylated paper</td>
<td>poultry, dairy products and fruit</td>
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<tr>
<td></td>
<td>Citric acid</td>
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<td></td>
<td>Ferrous salt/ascorbate</td>
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<tr>
<td></td>
<td>Activated carbon/clays/zeolites</td>
<td></td>
</tr>
<tr>
<td>Temperature control</td>
<td>Non-woven plastics</td>
<td>Ready meals, meats, fish, poultry and beverages</td>
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<tr>
<td>packaging</td>
<td></td>
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<td></td>
<td>Double-walled containers</td>
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<td></td>
<td>Hydrofluorocarbon gas</td>
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<td></td>
<td>Quicklime/water</td>
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<td></td>
<td>Ammonium nitrate/water</td>
<td></td>
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<tr>
<td></td>
<td>Calcium chloride/water</td>
<td></td>
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<td></td>
<td>Super corroding alloys/salt water</td>
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<tr>
<td></td>
<td>Potassium permanganate/glycerine</td>
<td></td>
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<tr>
<td>Temperature</td>
<td>Side chain crystallisable polymers</td>
<td>Fruit, vegetables and other horticultural products</td>
</tr>
<tr>
<td>compensating films</td>
<td></td>
<td></td>
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1.2 Oxygen Scavengers

Oxygen can have considerable detrimental effects on foods. Oxygen scavengers (also referred to as oxygen absorbers) 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 (Day, 2001; Rooney, 1995, 2005).

Oxygen scavengers are becoming increasingly attractive to food manufacturers and retailers and the growth outlook for the global market is bullish. Pira International Ltd estimated the global oxygen scavenger market to be 12 billion units in Japan, 500 million in the USA and 300 million in Western Europe in 2001. This market was forecast to grow to 14.4 billion in Japan, 4.5 billion in the USA and 5.7 billion in Western Europe in 2007 (Anon., 2004a). In addition, Pira International Ltd. estimated the global value of this market in 2005 to be worth $888 million and has forecast this market to be worth $924 million in 2010 (Anon., 2005e). The increasing popularity of oxygen scavenging polyethylene terephthalate (PET) bottles, bottle caps and crowns for beers and other beverages has greatly contributed to this impressive growth (Anon., 2005e).

Oxygen scavengers are the most commercially important sub-category of active packaging for food products and the most well known 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’ and includes a diagram illustrating this warning. 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 (Day, 2003; Robertson, 2006).

Non-metallic oxygen scavengers have also been developed to alleviate the potential for metallic taints being imparted to food products. The problem of inadvertently setting off in-line 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 non-ferrous metallic contaminants. Non-metallic 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 (Day, 2003).

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 (Rooney, 1995; 2005). 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. As pointed out by Robertson (2006), the acceptance of innovative packaging is the most likely reason why oxygen scavengers have been a commercial success in Japan. In contrast to the Japanese market, the acceptance of oxygen scavengers in North America and Europe has been relatively slow, although several manufacturers and distributors of oxygen scavengers are now established in both these continents (Rooney, 1995, 2005; Brody, 2005). Table 1.2 lists selected manufacturers and trade names of oxygen scavengers, including some that are still under development or have been suspended because of regulatory controls (Day, 2003; Rooney, 1995; 1998; 2005).

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 will help the commercial acceptance of this technology. For example, Marks & Spencer Ltd was 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 (Day, 2001). Other UK retailers, distributors and caterers are using these labels for the above food products as well as for coffee, pizzas, speciality bakery goods and dried food ingredients (Hirst, 1998). 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. (Day, 2001). In Japan, Toyo Seikan Kaisha Ltd has marketed a laminate containing an iron based oxygen scavenger which can be thermoformed into an Oxyguard™ tray that has been used commercially for cooked rice.

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 water activity \( (a_w) \) foods because when wet, their oxygen scavenging capability is rapidly lost. Instead, various non-metallic reagents and organo-metallic compounds that have an affinity for oxygen have been incorporated into bottle closures, crown and caps or blended into polymer [usually polyester (PET)] materials so that oxygen is scavenged from the bottle headspace and any ingressing oxygen is also scavenged. The PureSeal™ oxygen scavenging bottle crowns (produced by W.R. Grace Co., Inc. USA), oxygen scavenging plastic (PET) beer bottles (manufactured by Continental PET Technologies, USA), OS2000® cobalt catalysed oxygen scavenger films (produced by Cryovac Sealed Air Corporation, USA) and light activated ZerO₂® oxygen scavenger materials (developed by Food Science Australia, North Ryde, NSW, Australia) are just four of many oxygen scavenger developments aimed at the beverage market but which are also applicable to other food applications (Rooney, 1995; 1998; 2000; 2005; Scully and Horsham, 2005). However, it should be noted that the speed and capacity of oxygen scavenging plastic films and laminated trays are considerably lower compared with iron-based oxygen scavenger sachets or labels (Hirst, 1998).

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
6 Smart Packaging Technologies for Fast Moving Consumer Goods

Table 1.2 Selected oxygen scavenger systems

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Country</th>
<th>Trade name</th>
<th>Scavenger mechanism</th>
<th>Packaging form</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitsubishi Gas Chemical Co. Ltd</td>
<td>Japan</td>
<td>Ageless</td>
<td>Iron based</td>
<td>Sachets and labels</td>
</tr>
<tr>
<td>Toppan Printing Co. Ltd</td>
<td>Japan</td>
<td>Freshilizer</td>
<td>Iron based</td>
<td>Sachets</td>
</tr>
<tr>
<td>Toagosei Chem. Industry Co. Ltd</td>
<td>Japan</td>
<td>Vitalon</td>
<td>Iron based</td>
<td>Sachets</td>
</tr>
<tr>
<td>Nippon Soda Co. Ltd</td>
<td>Japan</td>
<td>Seagul</td>
<td>Iron based</td>
<td>Sachets</td>
</tr>
<tr>
<td>Finetec Co. Ltd</td>
<td>Japan</td>
<td>Sanso-Cut</td>
<td>Iron based</td>
<td>Sachets</td>
</tr>
<tr>
<td>Toyo Seikan Kaisha Ltd.</td>
<td>Japan</td>
<td>Oxyguard</td>
<td>Iron based</td>
<td>Plastic trays</td>
</tr>
<tr>
<td>Ueno Seiyaku Co. Ltd.</td>
<td>Japan</td>
<td>Oxyeater</td>
<td>Iron based</td>
<td>Sachets and labels</td>
</tr>
<tr>
<td>Multisorb Technologies, Inc.</td>
<td>USA</td>
<td>FreshMax</td>
<td>Iron based</td>
<td>Labels</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FreshPax</td>
<td>Iron based</td>
<td>Labels</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fresh Pack</td>
<td>Iron based</td>
<td>Labels</td>
</tr>
<tr>
<td>M&amp;G</td>
<td>Italy</td>
<td>ActiTUF</td>
<td>Iron based</td>
<td>Polyester bottles</td>
</tr>
<tr>
<td>Ciba Speciality Chemicals</td>
<td>Switzerland</td>
<td>Shellplus O₂</td>
<td>PET copolyester</td>
<td>Plastic film, bottles and containers</td>
</tr>
<tr>
<td>Chevron Chemicals</td>
<td>USA</td>
<td>N/A</td>
<td>Benzyl acrylate</td>
<td>Plastic film</td>
</tr>
<tr>
<td>W.R. Grace Co. Ltd</td>
<td>USA</td>
<td>PureSeal</td>
<td>Ascorbate/Metallic salts</td>
<td>Bottle crowns</td>
</tr>
<tr>
<td>Grace Darex Packaging Technologies</td>
<td>USA</td>
<td>DarExtend</td>
<td>Ascorbate</td>
<td>Bottle crowns</td>
</tr>
<tr>
<td>Food Science Australia</td>
<td>Australia</td>
<td>ZerO₂</td>
<td>Photosensitive dye/organic compound</td>
<td>Plastic film, bottles and containers</td>
</tr>
<tr>
<td>CMB Technologies</td>
<td>France</td>
<td>Oxbar</td>
<td>Cobalt catalysed polymer oxidation</td>
<td>Plastic bottles</td>
</tr>
<tr>
<td>Cryovac Sealed Air Corporation</td>
<td>USA</td>
<td>OS2000</td>
<td>Cobalt catalysed polymer oxidation</td>
<td>Plastic films</td>
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<td>Standa Industrie</td>
<td>France</td>
<td>ATCO</td>
<td>Iron based</td>
<td>Sachets</td>
</tr>
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<td>EMCO Packaging Systems</td>
<td>UK</td>
<td>ATCO</td>
<td>Iron based</td>
<td>Bottle crowns</td>
</tr>
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<td>Johnson Matthey Plc</td>
<td>UK</td>
<td>N/A</td>
<td>Platinum group metal catalyst</td>
<td>Labels</td>
</tr>
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<td>Bioka Ltd</td>
<td>Finland</td>
<td>Bioka</td>
<td>Enzyme based</td>
<td>Sachets</td>
</tr>
<tr>
<td>Alcoa CSI Europe</td>
<td>UK</td>
<td>O₂-Displacer System</td>
<td>Unknown</td>
<td>Bottle crowns</td>
</tr>
</tbody>
</table>

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and necessary packaging criteria) of the different types of oxygen scavenger can be obtained from the manufacturers and suppliers, as well as Rooney (1995; 1998; 2000), Labuza and Breene (1989) and Brody (2005).

1.2.1 ZerO₂® Oxygen Scavenging Materials

As a case study, brief details of the ZerO₂® oxygen scavenging development are described here (Rooney, 2000; Scully and Horsham, 2005). ZerO₂® is the registered trade name for a range of oxygen scavenging plastic packaging materials that are inactive until activated and thus can be subjected to conventional extrusion-based converting processes in the manufacture of packaging such as film, sheet, coatings, adhesives, lacquers, bottles, closure liners and can coatings. This patented technology is based on research undertaken at Food Science Australia (North Ryde, NSW, Australia).

Packaging problems involving the need for oxygen scavenging may be divided into two classes based on the origin of the oxygen that needs to be removed. Firstly, headspace and dissolved oxygen is present at the time of sealing of most packages of food and beverages. Removal of some or all of this oxygen is required to inhibit the various food degradation processes that occur in such food. A headspace oxygen scavenger is required in this case. Secondly, the oxygen that enters a package by permeation or leakage after package sealing needs to removed, preferably before contacting the food. The oxygen scavenger required in this case is a chemically enhanced barrier. Prototype ZerO₂® headspace scavenging polymer compositions to meet these two requirements have been synthesised from food-grade commercial polymers and extruded into film. Oxygen scavenging from the gas phase can be made to occur within minutes at retort temperatures and within several hours to one or two days at room temperature. Oxygen scavenging to very low levels under refrigeration temperatures can require two or more days, as expected when gas diffusion into the polymer is slowed.

Beverages are particularly susceptible to quality degradation due to oxidation or, in some cases, due to microbial growth. Distribution can require shelf-lives of up to a year under ambient conditions in some cases, resulting in a need for an enhanced oxygen barrier for plastics. The conditions found in liquid paperboard cartons, laminate pouches or multilayer barrier bottles were studied (Rooney, 2000; Zerdin et al., 2003) in collaboration with TNO Food Science and Nutrition (Zeist, The Netherlands). Experimental conditions were chosen using pouches of a laminate including an ethylene vinyl alcohol (EVOH) layer with an experimental ZerO₂® layer on the inside (with an EVOH/polyethylene laminate as control). The test beverage was orange juice and, in the control packs, the dissolved oxygen concentration decreased from 8 to 0 ppm, due to reaction with the ascorbic acid (vitamin C), over a month at 25°C and 75 days at 4°C. At both temperatures, the ZerO₂® laminate removed the oxygen in less than three days and halved the loss of the vitamin C over a storage period of one year. Browning was also reduced by one third after one year at 25°C (Rooney, 2000; Scully and Horsham, 2005).

Alcoholic beverages, such as beer and white wine, are also susceptible to rapid oxidative degradation. Using ZerO₂® materials, shelf life extensions of at least 33% have been demonstrated for bag-in-box wine. Cheese and processed meats are examples of refrigerated foods that are normally packaged under modified atmospheres. It is the headspace oxygen that severely limits the storage life of these products. Cheese normally requires the
presence of carbon dioxide as well as an oxygen level below 1%. Results of packaging in laminates with and without a ZerO₂® layer have demonstrated that the common spoilage moulds can be inhibited completely with little or no carbon dioxide. Also, discolouring of sliced smoked ham can be inhibited under refrigerated cabinet lighting conditions when the packaging laminate scavenges the initial oxygen concentration of 4% to very low levels. Development of ZerO₂® polymers with ‘glass-like’ barrier properties is aimed at inhibiting the widest range of oxygen-mediated food degradation processes. Examples studied so far have demonstrated that some fast oxidative degradation reactions can be successfully inhibited. It is likely that the use of such oxygen scavenging packaging materials will influence the consumer trend away from glass and metals towards plastic containers for the packaging of oxygen-sensitive beverages such as beer, wine and juices (Rooney, 2000; Scully and Horsham, 2005).

1.3 Carbon Dioxide Scavengers/Emitters

Many commercial sachet and label devices can be used either to scavenge or emit carbon dioxide. The use of carbon dioxide scavengers is particularly applicable for fresh roasted or ground coffees, which produce significant volumes of carbon dioxide. Fresh roasted or ground coffees cannot be left unpackaged since they will 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 will build up within the packs and eventually cause them to burst. To circumvent this problem, two solutions are currently used. The first is to use packaging with patented one-way valves that will 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-lined 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 (Day, 2003; Rooney, 1995). 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 (Rooney, 1995). Commercially available dual-action oxygen and carbon dioxide scavengers are available from Japanese manufacturers, e.g. Mitsubishi Gas Chemical Co. Ltd (Ageless™ type E and Fresh Lock™) and Toppan Printing Co. Ltd (Freshilizer™ type CV). An innovative dual action carbon dioxide scavenger and oxygen emitter sachet has been developed by EMCO Packaging Systems Ltd (Worth, Kent, UK) to counteract respiration in high oxygen MAP of fresh-cut produce (Anon., 2003e; Hirst, 1998; Parker, 2002).

Carbon dioxide emitting sachet and label devices can either be used alone or combined with an oxygen scavenger. An example of the former is the Verifrais™ package that has been manufactured by SARL Codimer (Paris, France) and used for extending the shelf-life of fresh meats and fish. This innovative package consists of a standard MAP tray that has a perforated false bottom under which a porous sachet containing sodium bicarbonate/ascorbate is positioned. When juice exudate from MA packed meat or fish drips onto the sachet, carbon dioxide is emitted and this antimicrobial gas can replace the carbon dioxide already absorbed by the fresh food, so avoiding pack collapse (Rooney, 1995).
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 that absorb oxygen and generate an equal volume of carbon dioxide. These sachets and labels usually contain ferrous carbonate and a metal halide catalyst although non-ferrous variants, such as ascorbate and sodium hydrogen carbonate, 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 (Rooney, 1995; Day, 2003).

Carbon dioxide scavengers and emitters represent a relatively small but growing area of the active packaging market. Pira International Ltd estimated the total global market to be worth $121 million in 2005 and forecast this market to increase to $182 million in 2010 (Anon., 2005e). Dual-action combination lines account for the majority of sales. The growth and development of this market is likely to revolve around the development of films that incorporate carbon dioxide scavenger/emitter functionality, although research into this is still in its early stages (Anon., 2003e).

1.4 Ethylene Scavengers

Ethylene 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 (Rooney, 1995; Day, 2003; Scully and Horsham, 2005). Nevertheless, Pira International Ltd estimated the global value of the ethylene scavenging market in 2005 to be worth $62 million and has forecast this market in 2010 to be worth $121 million (Anon., 2005e).

Table 1.3 lists selected ethylene scavenger systems. Effective systems utilise potassium permanganate immobilised on an inert mineral substrate such as alumina or silica gel. Potassium permanganate oxidises ethylene to acetate and ethanol and in the process changes colour from purple to brown, and hence indicates its remaining ethylene scavenging capacity. Potassium permanganate-based ethylene scavengers are available in sachets to be placed inside blankets or tubes that can be placed in produce storage warehouses (Rooney, 1995; Labuza and Breene, 1989; Day, 2003).

Activated carbon-based scavengers with various metal catalysts can also effectively remove ethylene. They have been used to scavenge ethylene from produce warehouses or are incorporated into sachets for inclusion into produce pack, and 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 (Rooney, 1995; Labuza and Breene, 1989; Day, 2003).
In recent years, numerous produce packaging films and bags have appeared on the market place that are based on the putative ability of certain finely ground minerals to scavenge 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 minerals are embedded or blended into polyethylene film bags which are then used to package fresh produce. Manufacturers of such bags claim extended shelf-life for fresh produce partly due to the three-dimensional absorption or two-dimensional surface 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 absorption or adsorption. In fact, almost any powdered mineral can confer such effects without relying on expensive Oya stone or other speciality minerals (Rooney, 1995; Labuza and Breene, 1989; Day, 2003).

1.5 Ethanol Emitters

Ostensibly, ethanol emitters are a sub-set of preservative releasing technologies although ethanol emitters are usually in sachet forms as opposed to impregnated preservative releasing films. 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. 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% (v/v) in the products. However, a more practical and safer method of generating ethanol is through the use of ethanol emitting sachets (Rooney, 1995; Labuza and Breene, 1989; Day, 2003; Anon., 2003f).

Many applications of ethanol emitting sachets have been patented, primarily by Japanese manufacturers. These include Ethicap™, Antimold 102™ and Negamold™ (Freund Industrial Co. Ltd), Oitech™ (Nippon Kayaku Co. Ltd), ET Pack™ (Ueno Seiyaku Co. Ltd), Oytech L (Ohe Chemicals 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%) absorbed 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’ 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 (Rooney, 1995; Labuza and Breene, 1989; Day, 2003; Anon., 2003f).

The size and capacity of the ethanol emitting sachet used depends on the weight of food, the w of the food and the desired 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% (Rooney, 1995; Day, 2003). 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 (Rooney, 1995; Day, 2003).

Ethanol emitting sachets are relatively expensive compared with other active packaging technologies and hence their use tends to focus on premium food items. Nevertheless, ethanol emitters represent a relatively small but growing area of the active packaging market. Pira International Ltd estimated the total global market (almost exclusively in Japan currently) to be worth $37 million in 2005 and forecast this market to increase to $65 million in 2010 (Anon., 2005e). Developments in this area are likely to involve the incorporation of encapsulated ethanol emitters into closures and packaging films and containers. However, these developments are set to be targeted at consumers in Asia-Pacific markets, given the concerns about product taints and regulatory controls in Europe and the USA (Anon., 2003f).

1.6 Preservative Releasers

In recent years, 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
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,
adverse secondary effects, narrow spectrum of activity, economic factors and/or regulatory
constraints (Rooney, 1995; Day, 2003; Brody, 2005).

The commercial use of antimicrobial films is controversial due to concerns arising from
their ability to mask natural spoilage reactions and hence mislead consumers about the
condition of packaged food. In addition, the use of antimicrobial additives in packaging
films and contact surfaces may give food manufacturers and consumers a false sense of
security and undermine traditional cleaning and disinfection practices and possibly lead
to the development of resistant microbial strains (Anon., 2003b). Notwithstanding, Pira
International Ltd estimated the global value of the antibacterial packaging market in 2005
to be worth $99 million and has forecast this market in 2010 to be worth $169 million
(Anon., 2005e).

Some commercial antimicrobial films and materials have been introduced, primarily in
Japan which is by far the largest market (Anon., 2003a). 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 antimicro-
bial 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 plast-
ic and edible films. These include organic acids (e.g. propionate, benzoate and sorbate),
aromatic chloro-organic compounds (e.g. triclosan, the active ingredient in food contact ap-
proved Microban™), bacteriocins (e.g. nisin), spice and herb extracts (e.g. from rosemary,
basil, cloves, horseradish, mustard, cinnamon, wintergreen oil and thyme), enzymes (e.g.
peroxidase, lysozyme and glucose oxidase), chelating agents (e.g. EDTA), volatile inor-
ganic acids (e.g. sulphur dioxide and chlorine dioxide) and antifungal agents (e.g. imaza-
lil and benomyl). The major potential food applications for antimicrobial films include meats,
fish, bread, cheese, fruit and vegetables (Rooney, 1995; Day, 2003; Anon., 2003a; 2004b;
2005d; Brody, 2005; Robertson, 2006).

Interest in the use of antioxidant packaging films has been stimulated by two influences.
The first of these is the consumer demand for reduced antioxidants and other additives in
foods. The second is the interest of plastics manufacturers in using natural and approved
food antioxidants (e.g. vitamin E) for polymer stabilisation instead of synthetic antioxidants
developed specifically for plastics (Rooney, 1995). The potential for evaporative migration
of antioxidants into foods from packaging films has been extensively researched and com-
ercialised 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
(Labuza and Breene, 1989). Recently there has been interest in the use of vitamin E as a vi-
able alternative to BHT/BHA-impregnated packaging films since there have been questions
raised regarding BHT and BHA’s safety (Day, 2003). Hence, the use of packaging films
incorporating vitamin E can confer benefits to both film manufacturers and the food indus-
try. 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 development of rancid odours
and flavours is often the shelf-life limiting spoilage mechanism (Rooney, 1995; Labuza and Breene, 1989; Day, 2003).

1.7 Moisture Absorbers

A major cause of food spoilage is excess moisture. 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 (Rooney, 1995). The use of moisture absorber sachets is common place in Japan where popular foods feature a number of dried products that need to be protected from moisture and 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 has used silica gel-based moisture absorbers sachets for maintaining the crispness of filled ciabatta bread rolls (Day, 2003).

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 non-woven 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 polycrylate salts, carboxymethyl cellulose (CMC) and starch copolymers, which have a very strong affinity for water (Day, 2003; Anon., 2003g; Reynolds, 2007). 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 air freight transportation or for controlling transpiration of horticultural produce (Rooney, 1995). Commercial moisture absorber sheets, blankets and trays include Toppan Sheet™ (Toppan Printing Co. Ltd, Japan), Thermarite™ (Thermarite Pty Ltd, Australia), Luquasorb™ (BASF, Germany) and Fresh-R-Pax™ (Maxwell Chase, Inc., Douglasville, GA, USA).

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. This can be done by placing one or more humectants between two layers of water permeable plastic film. For example, the Japanese company Showa Denko Co. Ltd has developed 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 (Rooney, 1995; Labuza and Breene, 1989). Another example of this approach has been applied in the distribution of horticultural produce. Microporous sachets of desiccant inorganic salts such as sodium chloride have been used for the distribution of tomatoes in the USA (Rooney, 1995). Yet another example is an innovative fibreboard box that 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, patented by CSIRO Plant Industries, Australia, 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 (Day, 1993; Scully and Horsham, 2005).

Moisture absorbers are the best selling active packaging technology for all applications but oxygen scavengers are commercially more valuable for strictly food applications. Pira International Ltd estimated the global value of the moisture absorber market in 2005 to be worth $722 million ($454 million for desiccants and $268 for moisture drip pads) and has forecast this market in 2010 to be worth $1,286 million ($823 million for desiccants and $463 for moisture drip pads) (Anon., 2005e).

1.8 Flavour/Odour Absorbers and Releasers

The commercial use of flavour/odour absorbers and releasers is controversial due to concerns arising from their ability to mask natural spoilage reactions and hence mislead consumers about the condition of packaged food. For this reason, flavour/odour absorbers and releasers have been effectively banned in Europe and the USA (Anon., 2005e; 2006b; 2003c; Brody, 2005). Nevertheless, flavour/odour absorbers and flavour-releasing films are commercially used in Japan and have a number of legitimate applications that cannot be easily dismissed (2003c). For example, in the USA, ScentSational® Technologies has developed aroma-releasing packs that have been trialled by the US army to make ready-to-eat meals more appetising (Anon., 2003h). Pira International Ltd estimated the global value of the flavour/odour absorber market in 2005 to be worth $46 million and has forecast this market in 2010 to be worth $68 million (Anon., 2005e).

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 two weeks storage in aseptic packs of orange juice (Rooney, 1995). Commercially, very few active packaging techniques have been used selectively to 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 limonin that 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. A possible active packaging solution would be to include limonin absorbers
Active Packaging of Food

Active Packaging of Food

*e.g. cellulose triacetate or acetylated paper* into orange juice packaging material (Rooney, 1995).

Two types of taints amenable to removal by active packaging are amines, which are formed from the breakdown of fish muscle proteins, and aldehydes, which are formed from the autoxidation of fats and oils. Unpleasant smelling volatile amines, such as trimethylamine, associated with fish protein breakdown, are alkaline and can be neutralised by various acidic compounds. In Japan, Anico Co. Ltd has 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 as they are absorbed by the polymer film (Rooney, 1995).

Removal of aldehydes such as hexanal and heptanal from package headspaces is claimed by Dupont’s Odour and Taste Control (OTC) technology that is based upon a molecular sieve with pore sizes of around 5 nanometres. Dupont claims that their OTC technology removes or neutralises aldehydes although evidence for this is lacking. The claimed food applications for this technology are snack foods, cereals, dairy products, fish, poultry and fish (Day, 2003). A similar claim of aldehyde removal has been reported by Swedish company EKA Noble, in collaboration with the Dutch company Akzo, who developed a range of synthetic aluminosilicate zeolites which they claim, absorb 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 absorbed in the pore interstices of the powder (Day, 2003).

1.9 Temperature Control Packaging

According to market research by Pira International Ltd, global sales for temperature control packaging was estimated to be a meagre €15.1 million in 2001 but has been predicted to reach €42.4 million in 2007 (Anon., 2002). Self-heating and self-cooling technologies and their associated markers are described in detail by Butler (2005). As with most active packaging markets, Japan’s market for temperature control packaging is the largest in the world.

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) which is a special non-woven 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™ which consists of a double walled PET container in which an insulating gel is deposited in between the walls (Labuza and Breene, 1989).

Self-heating cans and containers have been commercially available for decades and are particularly popular in Japan (Day, 2003; Anon., 2002; 2003d; 2005b; 2006c). Self-heating aluminium and steel cans and containers for sake, coffee, tea and ready meals are heated by an exothermic reaction when quicklime and water positioned in the base are mixed. During 2001 in the UK, Nestlé introduced a range of Nescafé coffees in self-heating insulated cans that used the quicklime and water exothermic reaction. These self-heating cans were
manufactured by Thermotic Developments (UK) but were withdrawn from the market in 2002 because the coffee didn’t get hot enough during the winter months. However, Thermotic Developments has revamped its self-heating concept and design and are in further negotiations with interested food manufacturers (Anon., 2005b). Other self-heating technologies, manufacturers and users on the market include HotCan™ (UK), Vitcho (France), Sonoco (USA), Steam to Go™ (UK), KPS Technologies (Korea), Caldo Caldo (Italy), PressTo™ (USA) and Tempra Technologies (USA). The self-heating mechanisms used are most commonly quicklime/water but also include calcium chloride/water, potassium permanganate/glycerol and super corroding alloys/salt water (Anon., 2006c).

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 was introduced briefly into the market was the Chill Can™ (The Joseph Company, USA), which relied on a hydrofluorocarbon (HRC) gas refrigerant. The release of HRC gas was triggered by a button set into the can’s base and could cool a drink by 10 °C in 2 minutes. However, concerns about the environmental impact of HRCs curtailed the commercial success of the Chill Can™ (Day, 2003; Anon., 2003d). Another self-cooling can concept that doesn’t have the environmental concerns associated with the Chill Can™, has been developed by Tempra Technology in partnership with Crown Cork & Seal (USA). The IC™ (Instant Cool) can relies on the ammonium nitrate/salt water endothermic reaction and can reduce the temperature of ambient drinks by 15 °C within 3 minutes (Anon., 2002).

1.10 Temperature Compensating Films

Commercially available temperature compensating films are manufactured by Landec Corporation (Menlo Park, California, USA). Their patented Intellipac® technology is based on unusual side-chain crystallisable Intellimer® polymers that respond to temperature in a controllable and predictable way. Intellimer® polymers can abruptly change their permeability, adhesion or viscosity when heated or cooled by just a few degrees. These changes are triggered by a built-in temperature switch, which can be set within temperature ranges compatible with most biological applications, particularly the respiration rate of fresh-cut horticultural produce. Moreover, since the process of change involves a physical, and not a chemical change, it can be repeatedly reversed (Robertson, 2006; Scully and Horsham, 2005; Brody, 2005; Anon., 2005a).

Intellimer® polymers help maintain optimal atmospheres within sealed packs of fresh-cut and whole produce during the fluctuations of temperature that can occur during chilled storage and distribution. At elevated temperatures, when respiring produce needs more oxygen, the polymer becomes more permeable, but at lower temperatures, the polymer permeability automatically decreases. Despite their relatively high cost, commercialisation has taken place with Chiquita Brands using Landec’s Intellipac® technology for the packaging of single-serve bananas to convenience stores in the USA. Other commercial fresh produce applications include fresh-cut mixed vegetables, broccoli, cauliflower, asparagus and strawberries (Robertson, 2006; Anon., 2005c).
1.11 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 (Ahvenainen and Hurme, 1997). 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. However, ultimately, active packaging must benefit and be accepted by consumers before it is more widely adopted (Lahteenmäki and Arvola, 2003). Also, active packaging must not be driven by technological possibilities but rather by meeting real market needs (Anon., 2006a).

Oxygen scavengers and moisture absorbers are by far the most commercially important sub-categories of active packaging and the market has been growing steadily for the last ten years and is predicted to grow even further by 2010 (Anon., 2005e). The introduction of oxygen scavenging films and bottle caps will also help stimulate the market in future years and the unit costs of oxygen scavenging technology will drop. All other active packaging technologies are also predicted to be used more in the future, particularly ethylene scavengers, carbon dioxide scavengers and emitters, moisture absorbers and temperature control packaging. Food safety and regulatory issues in the European Union and USA are likely to restrict the use of certain preservative releasers and flavour/odour absorber active packaging technologies (Vermeiren et al., 1999; Brody, 2005). Nevertheless, the use of active packaging is becoming increasingly popular and many new opportunities in the food and non-food industries will open up for utilising this technology in the future.

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18  Smart Packaging Technologies for Fast Moving Consumer Goods

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