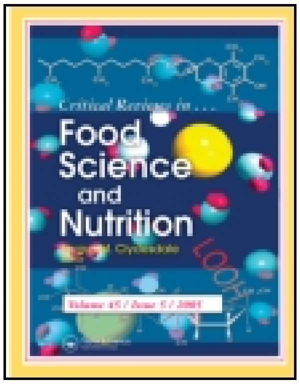

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Active Food Packaging Technologies

MURAT OZDEMIR [a] & JOHN D. FLOROS [b]
[a] Department of Food Engineering, Gebze Institute of Technology, Gebze-Kocaeli, Turkey, 41400
[b] Department of Food Science, Pennsylvania State University, University Park, PA, 16802, USA

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Active Food Packaging Technologies

MURAT OZDEMIR, PhD
Department of Food Engineering, Gebze Institute of Technology, P.O. Box 141, 41400, Gebze-Kocaeli, Turkey

JOHN D. FLOROS, PhD
Department of Food Science, Pennsylvania State University, University Park, PA 16802, USA

Active packaging technologies offer new opportunities for the food industry, in the preservation of foods. Important active packaging systems currently known to date, including oxygen scavengers, carbon dioxide emitters/absorbers, moisture absorbers, ethylene absorbers, ethanol emitters, flavor releasing/absorbing systems, time-temperature indicators, and antimicrobial containing films, are reviewed. The principle of operation of each active system is briefly explained. Recent technological advances in active packaging are discussed, and food related applications are presented. The effects of active packaging systems on food quality and safety are cited.

Keywords active packaging, food packaging, food safety, food quality, shelf life

INTRODUCTION

The use of proper packaging materials and methods to minimize food losses and provide safe and wholesome food products has always been the focus of food packaging. In addition, consumer trends for better quality, fresh-like, and convenient food products have intensified during the last decade. Therefore, a variety of active packaging technologies have been developed to provide better quality, wholesome and safe foods and also to limit package related environmental pollution and disposal problems.

Active packaging is defined as an intelligent or smart system that involves interactions between package or package components and food or internal gas atmosphere and complies with consumer demands for high quality, fresh-like, and safe products.[1–2] Active packaging extends the shelf life of foods, while maintaining their nutritional quality, inhibiting the growth of pathogenic and spoilage microorganisms, preventing and/or indicating the migration of contaminants, and displaying any package leaks present, thus ensuring food safety.[1,3] Important examples of active packaging include oxygen scavengers, carbon dioxide emitters/absorbers, moisture absorbers, ethylene absorbers, ethanol emitters, flavor releasing/absorbing systems, time-temperature indicators, and antimicrobial containing films.[1–2,4–10] Some examples of currently known active packaging systems and mode of action are presented in Table 1.

Address correspondence to Murat Ozdemir, Department of Food Engineering, Gebze Institute of Technology, PO Box 141, Gebze-Kocaeli, 41400, Turkey. E-mail: ozdemirm@penta.gyte.edu.tr

ACTIVE FOOD PACKAGING SYSTEMS

Active packaging technologies have started to receive a great deal of attention since the last decade. The market for active packaging films today is a modest $50 million worldwide, and this market is expected to grow rapidly.

Oxygen Scavengers

High levels of oxygen present in food packages may facilitate microbial growth, off-flavors and off-odors development, color change, and nutritional losses, thereby causing significant reductions in the shelf life of foods. Therefore, the control of oxygen levels in food packages is important to limit the rate of these deteriorative and spoilage reactions in foods. Oxygen absorbing systems provide an alternative to vacuum and gas flushing packaging and improve product quality and shelf life. Furthermore, they are economically viable in reducing packaging costs and increasing profitability.

Typical oxygen absorbing systems are based on the oxidation of iron powder by chemical means or scavenging of oxygen through the use of enzymes. In the former case, iron kept in a small sachet is oxidized to iron oxide. The sachet material is highly permeable to oxygen and, in some cases, to water vapor in order for the sachet to be effective. This well-known oxygen scavenging system was first developed and introduced to the food packaging market by the Mitsubishi Gas Chemical Company, known as Ageless. The type and amount of absorbent that needs to be used in a sachet is determined by the initial oxygen

Table 1 Examples of some currently known active packaging systems[39]

Type of active packaging system	Substances used and mode of action
Oxygen absorbing	Enzymatic systems (glucose oxidase-glucose, alcohol oxidase-ethanol vapor) Chemical systems (powdered iron oxide, catechol, ferrous carbonate, iron-sulfur, sulfite salt-copper sulfate, photosensitive dye oxidation, ascorbic acid oxidation, catalytic conversion of oxygen by platinum catalyst)
Carbon dioxide absorbing/ emitting	Iron powder-calcium hydroxide, ferrous carbonate-metal halide
Moisture absorbing	Silica gel, propylene glycol, polyvinyl alcohol, diatomaceous earth
Ethylene absorbing	Activated charcoal, silica gel-potassium permanganate, Kieselguhr, bentonite, Fuller's earth, silicon dioxide powder, powdered Oya stone, zeolite, ozone
Ethanol emitting	Encapsulated ethanol
Antimicrobial releasing	Sorbates, benzoates, propionates, ethanol, ozone, peroxide, sulfur dioxide, antibiotics, silver-zeolite, quaternary ammonium salts
Antioxidant releasing	BHA, BHT, TBHQ, ascorbic acid, tocopherol
Flavor absorbing	Baking soda, active charcoal
Flavor releasing	Many food flavors
Color containing	Various food colors
Anti-fogging and anti-sticking	Biaxially oriented vinylon, compression rolled oriented HDPE
Light absorbing/regulating	UV blocking agents, hydroxybenzophenone
Monitoring	Time-temperature indicators
Temperature controlling	Non-woven microperforated plastic
Gas permeable/breathable	Surface treated, perforated or microporous films
Microwave susceptors	Metallized thermoplastics
Insect repellant	Low toxicity fumigants (pyrethrins, permethrin)

level in the package, the amount of dissolved oxygen present in the food, the permeability of the packaging material, the nature (size, shape, weight, etc.), and the water activity of the food. These iron-based oxygen absorbing systems have the ability to scavenge oxygen in many foods, including high, intermediate, or low moisture foods, and foods containing lipids.[8] They can also work at refrigerated and frozen storage conditions, and they can be used as effective oxygen scavengers, even with microwaveable food products.

In enzymatic oxygen scavenging systems, an enzyme reacts with a substrate to scavenge oxygen. These systems are more expensive than iron-based systems, due to the cost of enzymes used for the oxygen scavenging purpose. Enzymatic oxidation systems are also usually very sensitive to temperature, pH, water activity, and solvent/substrate present in the sachet, thus limiting the widespread use of these enzyme-based systems.

Oxygen scavenging sachets are not appropriate for liquid foods, because the direct contact of the liquid with the sachet usually causes the spillage of sachet contents. In addition, sachets may cause accidental consumption with the food or may be ingested by children. Oxygen scavenging sachets sold in the US are required to be labeled "Do not eat," for safety reasons and regulatory purposes mandated by the Food and Drug Administration (FDA). Although sachets can be concealed using secondary packages, this practice increases packaging costs.

The incorporation of scavengers in packaging films is a better way of resolving sachet-related problems. Scavengers may either be imbedded into a solid, dispersed in the plastic, or introduced into various layers of the package, including adhesive, lacquer, or enamel layers.[7] Multi-layer oxygen scavengers more effectively absorb oxygen than one layer scavenging systems. The structure of a typical multi-layer oxygen scavenging system is shown in Figure 1. An oxygen absorbing substance imbedded in a layer very permeable to oxygen is used to absorb oxygen present in the package interior. Oxygen ingress from the outside environment to the oxygen absorbing layer is limited by a barrier layer, which is highly impermeable to oxygen. An inner layer, or a control layer, next to the oxygen absorbing layer may be used to minimize any migration of the oxygen absorbing substance into the food.

Scavengers in the form of films allow the absorption of oxygen from all surfaces of the food that are in contact with the

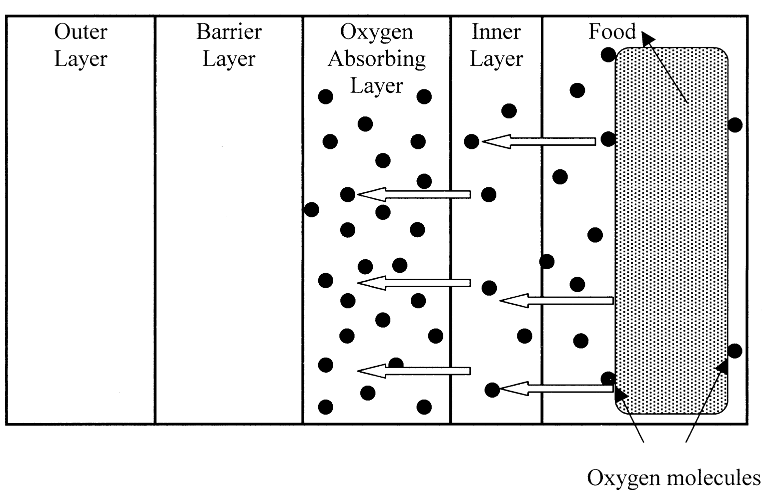

Figure 1 A structure of typical oxygen absorbing multi-layer active film.

film. Recently, Farkas[11] incorporated iron powder into a low-density polyethylene (LDPE), which effectively absorbed oxygen at significant rates, to be useful in food packaging. The rate of oxygen absorption by films changed, depending on the area and thickness of the resulting films. Although films containing iron powder are effective oxygen scavengers, they may impart undesirable flavor to foods with which are in contact. The Cryovac Corporation has recently developed a polymer-based oxygen absorbing film that can overcome the negative effects of iron-based oxygen scavenging films. This polymer-based oxygen absorbing film uses breakthrough technology that is invisible to consumers because the scavenging component is co-extruded as a layer of the package. Since oxygen absorbing material is virtually invisible in the films, these films do not alter the look of the package. They also offer shoppers a clear view of the product inside. It is equally effective with wet or dry products, because its scavenging action is initiated "on demand" on the processor's packaging line by an ultraviolet-light triggering process. Some recent US patents issued for oxygen scavenging compositions incorporated into films, packages, and containers are listed in Table 2.

Carbon Dioxide Scavengers and Emitters

High levels of carbon dioxide usually play a beneficial role in retarding microbial growth on meat and poultry surfaces and in delaying the respiration rate of fruits and vegetables. Since carbon dioxide is more permeable than oxygen through many plastic films used for the food packaging, most of the carbon dioxide inside the package usually permeates through the film. For instances where the package has a high permeability to carbon dioxide, a carbon dioxide emitting system may be necessary to reduce the rate of respiration and suppress microbial growth. The use of a dual function system consisting of an oxygen scavenger and a carbon dioxide emitter is the usual practice for increasing the shelf life of highly perishable foods.

On the contrary, dissolved carbon dioxide formed after the roasting of coffee may cause the package to burst, if the roasted coffee is packed in a can or aluminum foil pouch. This released carbon dioxide from freshly roasted coffee can be scavenged through the use of a carbon dioxide scavenger. Multiform Desiccants Incorporated has developed a CO_2 absorbing sachet that is composed of a porous envelope containing calcium oxide and a hydrating agent, such as silica gel, on which water is adsorbed. In this system, water reacts with calcium oxide and produces calcium hydroxide, which then reacts with CO_2 to form calcium carbonate.

Moisture Scavengers

The control of excess moisture in food packages is important to suppress microbial growth and prevent foggy film formation. If the package has a low permeability to water vapor, water accumulation inside the package is more pronounced. The excess water development inside a food package usually occurs due to the respiration of fresh produce, temperature fluctuations in high equilibrium relative humidity food packages or the drip of tissue fluid from cut meats, poultry, and produce.[7] The build-up of excess water inside the package promotes bacterial and mold growth, resulting in quality loss and shelf life reductions. An effective way of controlling excess water accumulation in a food package that has a high barrier to water vapor is to use a moisture scavenger, such as silica gel, molecular sieves, natural clays (e.g., montmorillonite), calcium oxide, calcium chloride and modified starch, or other moisture absorbing substances. Silica gel is the most widely used desiccant because it is non-toxic and non-corrosive.

A blanket or a pad of desiccant is usually wrapped around the food to be preserved (meat, poultry, fish, or shellfish) to absorb water. Another approach to absorb moisture from these foods is to use a superabsorbent polymeric laminate film that has a moisture absorbent layer that is formed from a polyester graft copolymer and a resin, consisting of a polyurethane resin, an acrylic

Table 2 Some recently issued US patents for oxygen scavenging systems

Company	Structure/composition	Patent year	Patent #
Advanced Oxygen Technologies, Inc.	Carrier material + salicylic acid chelate + reducing agent of an ascorbate compound	1994	5,364,555
BP Amoco Corp.	Copolymers comprising polyester segments + polyolefin oligomer segments	2000	6,083,585
Chevron Chemical Co.	Heat sealable resin + oxygen scavenger	1998	5,744,246
Continental PET Technologies, Inc.	Inner layer + core layer containing aliphatic polyketone as an oxygen scavenger + oxygen barrier layer	1999	5,952,066
Cryovac Corp.	Zeolite + an oxidizable compound and a transition metal catalyst + ethylenically unsaturated hydrocarbon	2002	6,391,403
Honeywell International Inc.	Polyamide homopolymer + copolymer + an oxidizable polydiene or oxidizable polyether	2002	6,423,776
Minnesota Mining and Manufacturing Co.	Glucose oxidaze + hydrophilic porous structure	1998	5,766,473
Mitsubishi Gas Chemical Co.	Oxygen permeating resin layer + deoxidizing resin layer containing a particulate absorbing composition + smoothing layer + gas barrier layer	2000	6,063,503
Multisorb Technologies, Inc.	Base sheet + oxygen absorbing composition + cover sheet	1997	5,667,863
Tetra Laval	Polymeric material + oxygen scavenging agent	1998	5,806,681
W.R. Grace and Co.	Ethylenically unsaturated hydrocarbon + metal salt catalyst	1997	5,648,020
W.R. Grace and Co.	Carrier material + metal loaded cationic exchange material	2000	6,086,786

resin, and a vinyl resin. Moisture absorbing systems in sachet forms are usually used to maintain low levels of moisture in dried food packages, such as chips, nuts, spices, biscuits, crackers, milk powder, and instant coffee. The sachets Desi Pak, Desi View, Sorb-It and 2-in-1 (United Desiccants, USA), MiniPax, StripPax, Natrasorb, and the moisture absorbing label Desimax (Multisorb Technologies, USA) are the most common moisture absorbing systems used to absorb and/or control moisture for water sensitive packaged foods.

Ethylene Absorbers

Ethylene is a growth-simulating hormone that accelerates ripening and senescence by increasing the respiration rate of climacteric fruits and vegetables, thereby decreasing shelf life. Ethylene also accelerates the rate of chlorophyll degradation in leafy vegetables and fruits.[12] Hence, the removal of ethylene gas from the package headspace slows senescence and prolongs shelf life.

The most well-known, inexpensive, and extensively used ethylene absorbing system consists of potassium permanganate imbedded in silica. The silica absorbs ethylene, and potassium permanganate oxidizes it to ethylene glycol. Silica is kept in a sachet highly permeable to ethylene, or it can be incorporated into a packaging film. Potassium permanganate, however, is not integrated into food contact surfaces of packaging films due to its toxicity.[13] The substrate surface area and the amount of potassium permanganate affect the performance of these systems. Another system available to absorb ethylene is based on impregnating zeolite with potassium permanganate, and then coating the impregnated zeolite with a quaternary ammonium cation. This system is not only capable of absorbing ethylene from the medium, but also other organic compounds, such as benzene, toluene, and xylene.

Ethylene scavengers have been proven to be effective in the storage of packaged fruits, including kiwifruit, bananas, avocados, and persimmons.[14] For example, an ethylene scavenging system, containing active carbon and PdCl as a catalyst, effectively reduced the rate of softening of minimally processed kiwifruits and bananas and decreased the loss of chlorophyll in spinach leaves stored at 20°C by absorbing ethylene from the medium.[15]

Ethylene scavengers are commercially available under different names, such as Evert-Fresh (Evert-Fresh Co, USA), Ethylene Control (Ethylene Control Incorporated, USA) and Peakfresh (Peak Fresh Products, Australia).

Ethanol Emitters

The spraying of ethanol on food product surfaces, such as bread, cookies, and other bakery products has been shown to be effective in extending the shelf life of these commodities by suppressing mold growth.[16] A novel application of ethanol as a microbial growth inhibitor in foods is ethanol emitting sachets or films. Sachets contain food grade ethanol absorbed or encapsulated in a carrier material. A slow or rapid release of ethanol from the carrier material to the package headspace is regulated by the permeability of the sachet material to water vapor. The ethanol in the carrier material is exchanged with the water absorbed by the carrier material. Some sachets, in addition to ethanol, may contain trace amounts of flavoring substances, such as vanilla or other flavors, to mask the alcohol odor in the package.[1] The effectiveness of an ethanol generating system primarily depends on the type and size of the carrier material, the amount of ethanol entrapped by the carrier material, the permeability of the sachet material to water vapor and ethanol, the water activity of the food, and the ethanol permeability of the packaging film.

Films containing ethanol are not as widespread as sachets in the market, due to the problems encountered in the controlled release of ethanol from the films into the package headspace. Ethanol imbedded films usually require additional layers to hold the ethanol and to release it in a controlled manner; this increases the cost of these systems.

Several advantages of ethanol emitting systems as outlined by Smith et al.[17] are:

- Ethanol vapor is directly generated from ethanol generating sachets in the package. This prevents the direct contact of ethanol with the food, thereby providing safer foods as opposed to ethanol spraying prior to packaging.
- Ethanol generating sachets eliminate the need of other preservatives, such as sorbates and benzoates, for mold inhibition.
- Sachets labeled "Do not eat" can be conveniently removed from the package and discarded.
- Ethanol emitting sachets may help delay staling of bakery products.

Absorption of ethanol vapor by the food from the package is the main disadvantage of ethanol generating systems. Although the level of ethanol can be reduced to insignificant values by heating or microwaving the product, food products consumed without being heated may contain residual ethanol. If the residual amount of ethanol is considered significant, rigorous toxicological testing may be required.

Flavor Absorbing/Releasing Systems

Food packaging materials, particularly some plastics, may interact with food flavors, resulting in loss of flavors, known as flavor scalping. Furthermore, flavors are usually lost or degraded after processing foods at high temperatures or after packaging. Therefore, there is a need to replace these lost flavor constituents when scalping or degradation occurs. Although the use of high barrier plastics holds food flavors in the package, additional flavor releasing systems may be necessary in some instances, particularly when heat seal layers of a package have high affinity to flavors. In addition, consumers always like to smell good flavors when they first open a food package. For example, most of the dry instant coffee manufacturers often fill the headspace with volatiles distilled from the dehydration process to deliver fresh coffee fragrance when the package is first opened.[18]

In contrast to flavor releasing systems, flavor absorbers scavenge undesirable flavors, aromas, and odors present in the package headspace. Some orange varieties, such as Navel after it has been pasteurized, may develop a bitter flavor when limonin concentration exceeds 12 mg/kg.[19] Internally cellulose acetate-butyrate coated plastic bottles, which act as limonin absorbers, have been shown to considerably reduce bitterness in orange juice thereby increasing shelf life.

The formation of off-flavors and off-odors in food products originates mainly from (1) the oxidation of fats and oils, leading to the formation of aldehydes; (2) the breakdown of proteins of fish muscle into amines.[7] Although aldehydes and amines can be removed from package headspaces by forming active flavor scavengers, these systems may mask or absorb off-flavors and off-odors that are indicative of spoilage.

Time-Temperature Indicators

Time-temperature indicators are another area of application in active packaging. Because temperature abuse is common during storage, transportation, and handling, these indicators are designed to monitor temperature abuses in a food product's shelf life. Temperature abuse does not only cause quality and nutritional losses, but also may lead to food poisoning and food losses. Many time-temperature indicating systems work based on a color change or color development, which is correlated with food quality loss. However, time-temperature indicators that have a response in the form of a visible mechanical deformation are also available.[20]

Time-temperature indicators must satisfy some requirements to be effective as monitoring devices[1,21]

- They must be easily activated and sensitive.
- They must provide a high degree of accuracy and precision.
- They should have tamper evident characteristics.
- Response should be irreversible, reproducible, and correlated with food quality changes.
- Physical and chemical characteristics of time-temperature indicators should be determined.
- Response should be easily readable and, should not be confusing.

Time-temperature indicators for frozen, refrigerated, modified atmosphere packaged, and thermally processed foods are commercially available. Although time-temperature indicators are still in their infancy, continued research and consumer appreciation are expected to play positive roles in the development of more reliable and sophisticated systems.

Antimicrobial Films

Since prehistoric times, people have developed methods to preserve their food supply and inhibit the growth of undesirable microorganisms. Canning, pasteurization, dehydration, freezing, refrigeration, evaporation, and fermentation are the main methods of today's food preservation. However, chemical preservatives, when used with these food preservation techniques, offer additional benefits in preventing post-process contamination and in obtaining stronger inhibitory effects against microorganisms. Sachets and films containing antimicrobials can be of great value in suppressing surface microbial growth and increasing shelf life.

Chemical preservatives that can be used in active-antimicrobial releasing systems include organic acids and their salts (primarily sorbates, benzoates, and propionates), parabens, sulfites, nitrites, chlorides, phosphates, epoxides, alcohols, ozone, hydrogen peroxide, diethyl pyrocarbonate, antibiotics, and bacteriocins.[22–24] Some chemical preservatives used in the development of non-edible antimicrobial systems are listed in Table 3.

A typical multi-layer film that exhibits antimicrobial properties usually consists of four layers, including the outer layer, barrier layer, matrix layer, and control layer (Figure 2). In this structure, an antimicrobial substance is imbedded in to the matrix layer. Its release from the matrix layer to the food surface is controlled by the control layer just next to the matrix layer. Non-edible antimicrobial films that have been used as active packages can be divided into two categories: (1) films that contain antimicrobial agents that migrate to the surface of the food; (2) those containing an antimicrobial agent, where the antimicrobial substance is bound to the surface layer of the film.[3] One of the problems encountered in antimicrobial films is that the active agent may partially or completely lose its antimicrobial activity when it is incorporated into the film. Therefore, the treatment of the polymer or the derivatization of active agents prior to their addition to the polymer may be necessary to increase the compatibility between the active agent and the polymer.

Table 3 Some recent non-edible antimicrobial systems[39]

Substance	Type	Ref.
Anhydrides	Film	40
Benomyl	Film	28
Benzoyl chloride	Film	29
Carbon dioxide	Film	7
	Sachet	1
Chlorinated phenoxy	Film	41
Chlorine dioxide	Film	41
Ethanol	Sachet	42
Grapefruit seed extract	Film	43
Hinokitiol	Film	42
Imazalil	Film	5, 27
Potassium sorbate	Film	30
Silver ion	Film	4
Silver-zeolite	Film	6
Sulfur dioxide	Film	10

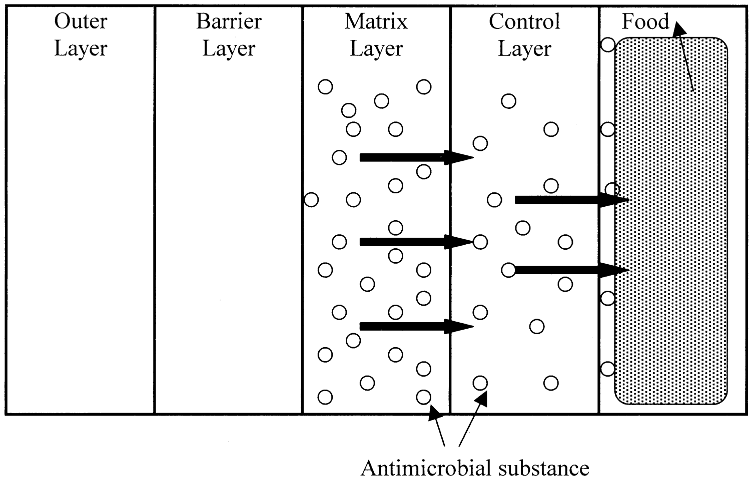

Figure 2 A structure of typical antimicrobial multi-layer active film.

Smith and Rollin[25] demonstrated that a moisture proof cellophane film containing sorbic acid could be produced by a thermoplastic coating process. Although sorbic acid was only dusted on the inside waxed cellophane film surface and not incorporated into the film, it was effective in prolonging the shelf life of natural and processed cheeses by retarding surface mold growth. This first application of active-antimicrobial film opened new frontiers in the development of more sophisticated active films containing preservatives.

A coating solution of calcium sorbate and carboxymethyl cellulose was used to manufacture a fungistatic wrapper by Ghosh et al.[26] An antimycotic agent, imazalil, was incorporated into LDPE for wrapping fruits and vegetables.[27] Imazalil-impregnated LDPE films were also shown to be effective in preventing the mold growth development on cheese surfaces.[5] Halek and Garg[28] chemically coupled a fungicide (benomyl) onto an ionomer film (Suryln). Although the film showed the characteristics good microbial growth inhibition, benomyl is not a legal food preservative and is not allowed for food use.

More recently, acid or base treated ionomer films reacted with benzoyl chloride to manufacture antimicrobial releasing films by Weng et al.[29] Han and Floros[30] incorporated potassium sorbate in several plastic films to develop an antimicrobial releasing film. They also tested the effectiveness of potassium sorbate impregnated films in real food systems, including American processed cheese and Mozzarella cheese. Another example of an antimicrobial film is a silver substituted zeolite film, which slowly releases silver ions from the plastic film to the food.[6] Because silver-zeolite films are expensive, they are produced in the form of thin layers, which are usually laminated on the inner-surface of a food contact film. These silver-zeolite films are effective against a broad range of bacteria, yeast, and molds.

Antimicrobial films that show an antimicrobial effect without the migration of the antimicrobial substance(s) are revolutionary films in which antimicrobial activity showing peptides could be attached to the film surface, or the surface of the film could be treated by an appropriate surface treatment method, so that the film would show antimicrobial activity.[31–32] Haynie et al.[33] immobilized peptides exhibiting antimicrobial activity on the surface of polymer films by modifying their surface characteristics with chemical methods. This application prevented the transfer or migration of antimicrobial substances from the polymer to the food.

Modifying the surface composition of polymers by electron irradiation, so that the surface would contain amine groups, has been shown to exhibit antimicrobial activity that kills microorganisms on contact.[34] A more sophisticated method of producing an antimicrobial film on food polymer surfaces recently has been developed by using a UV excimer laser at the proper wavelength. Nylon (6,6) films irradiated with a UV excimer laser irradiation at 193 nm in air possess antimicrobial activity that results in the conversion of amide groups at the nylon surface to amines, which are still bound to the polymer chain.[35] Microbial tests showed that these films were capable of providing up to a 99.999% (5D) reduction of *Klebsiella pneumoniae* in one hour.

Other Active Packaging Systems

Other active packaging applications that are expected to find increased attention in the future include antioxidant releasing films, color containing films, light absorbing/regulating systems, anti-fogging and anti-sticking films, susceptors for microwave heating, gas permeable/breathable films, and insect repellant packages. For example, antioxidant incorporated films can be used to prevent the oxidation of fats and oils that lead to rancidity. They can also be used to prevent the formation of off-odors and off-flavors in foods. Han et al.[36] demonstrated that plastic films containing antioxidants could successfully be used to prevent the oxidation of packaged oat flakes. Labuza and Breene[1] reported commercial applications of antioxidant releasing systems in cereals.

Food grade color imbedded films can supply coloring compounds to foods that have an adversely affected color due to storage conditions. One application of color releasing systems is in the storage of surimi (artificial crab meat). An edible red color pigment migrates from the surimi wrapper to the product to give the surimi the desirable red crab color. Even if color releasing systems contain food grade colors, their use must be regulated by legal standards.

Light absorbing or regulating systems protect light sensitive foods from harmful effects of light, especially UV light, by decreasing UV transmittance, thus slowing the rate of oxidation and enzymatic degradation reactions. Anti-fogging films prevent fog formation inside food packages, such as fresh fruit, vegetable, and meat packages. Anti-fogging films also let customers see packaged foods clearly. The use of anti-sticking films reduces the sticking tendency of soft candies and sliced cheeses to packaging films. Microwave susceptors convert sufficient microwave energy into heat that provides a high temperature increase in a very short time compared to conventional heating.[37] These high temperatures yield drying, crisping, and browning effects that are desirable for some food products, including pastries, bread, pizza crust, french fries, and popcorn.

Gas permeable or breathable packages provide gas exchange between package interior and exterior, resulting in an increase in the shelf life of respiring fruits and vegetables. The most important commercial application of breathable packages is in ready-to-eat salads. The inclusion of low toxicity fumigants, such as pyrethrins or permethrin, to the outer layer of food packages is an interesting application of forming an active package against insect attacks during warehousing and transportation.[7]

Active Packaging Systems With Dual Functionality

A more sophisticated way of extending the shelf life of packaged foods with active packaging systems is to use multiple function active systems. For example, the combination of oxygen scavengers with carbon dioxide and/or antimicrobial releasing systems significantly improves the storage stability of packaged foods. Self-working systems, which absorb oxygen and generate an equal volume of carbon dioxide, are very promising in extending the shelf life of snack foods, nuts, cakes, and similar products. A dual function sachet containing a mixture of iron powder and calcium hydroxide has been used to delay flavor changes in fresh ground coffee due to oxygen and to prevent the package from bursting due to the accumulation of carbon dioxide inside the package.[10]

Oxygen scavengers containing ethanol or antimicrobial releasing systems inhibit microbial growth more effectively than an oxygen absorber alone. A similar application in this area combines oxygen scavenging with the antimicrobial action of a silver-zeolite. Fresh fruits and vegetables, marine products, cheeses, bakery products, cakes, cookies, pizza crusts, and fresh pasta can benefit from packaging in a dual function oxygen absorbing and antimicrobial releasing system.

Dual function active packaging systems developed to scavenge both oxygen and ethylene from packages of fresh produce are of great value not only in reducing the growth of spoilage microorganisms, but also in limiting the rate of respiration. Oya stone, a naturally occurring stone first discovered in a cave in Japan, has the ability to absorb ethylene gas produced by respiring fruits and vegetables. Oya stone-impregnated plastic bags for fresh produce are commercially produced in the US.[37] These bags are microperforated, thus preventing the moisture accumulation inside the package. These bags are also capable of controlling oxygen and carbon dioxide levels inside the package. In addition to ethylene absorbing plastic bags, sachets of potassium permanganate-based ethylene scavengers are also available and are commercially used in the US and Japan.[13] Table 4 presents some applications of active packaging technologies in various food commodities.

Table 4 Applications of active packaging technologies[39]

Type of application	Foods
Oxygen scavengers	Ground coffee, tea, roasted nuts, potato chips, chocolate, fat powdered milk, powdered drinks, bread, tortillas, pizza, pizza crust, refrigerated fresh pasta, fruit tortes, cakes, cookies, beer, deli meats, smoke and cured meats, fish, cheese
Carbon dioxide absorbers	Ground coffee
Carbon dioxide emitters	Meat, fish
Moisture absorbers	Dry and dehydrated products, meat, poultry, fish
Ethylene scavengers	Kiwifruit, banana, avocados, persimmons
Ethanol emitters	Bread, cakes, fish
Antimicrobial releasing films	Dry apricots
Antioxidant releasing films	Cereals
Flavor absorbing films	Navel orange juice
Flavor releasing films	Ground coffee
Color containing films	Surimi
Anti-fogging films	Some fresh fruit and vegetable packages
Anti-sticking films	Soft candies, cheese slices
Light absorbers	Pizza, milk
Time-temperature indicators	Microwaveable pancake syrup, refrigerated pasta, deli items
Gas permeable/breathable films	Ready-to-eat salads
Microwave susceptors	Ready-to-eat meals

A PROMISING FUTURE

Oxygen scavengers, carbon dioxide absorbing/releasing systems, and antimicrobial films are promising form of active food packages.[38] Most of the active packaging applications are concentrated on fresh produce. Although passive packaging has been used to minimize microbial growth and the rate of deteriorative reactions in fresh fruits and vegetables, active packaging offers new opportunities in preserving fresh produce and prolonging shelf life.

The accomplishment and attainment of optimum levels of oxygen, carbon dioxide and water vapor concentrations inside a package is almost impossible to achieve using passive plastic films alone. However, using active packaging technologies help achieve optimal gas atmospheres and moisture levels in food packages for maximum shelf life.

Currently, used active packaging technologies are mainly based on sachet technologies. Sachets suffer from inadequate consumer acceptance due to fears of ingestion by children and accidental consumption with package contents. The development and use of active packaging systems in the form of thin films can be expected to increase in the next decade.

Active packaging is useful in extending the shelf life of many food products. Recognition of the benefits of active packaging technologies by the food industry, development of economically viable active packaging systems, and increased consumer acceptance open new frontiers for active packaging. Active packaging is an evolving technology; it is always open to improvements and further developments. Continued innovations in active packaging are expected to lead to further improvements in food quality, safety, and stability.

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