Packaging for Nonthermal Processing of Food

SECOND EDITION

Edited by
Melvin A. Pascall and Jung H. Han

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1 Packaging for nonthermal processing of food: Introduction

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Nonthermal processing technologies are food preservation methods designed to eliminate pathogenic and food spoilage microorganisms at low temperatures, when compared with commonly used thermal processes that use more heat (Min *et al*., 2005). Interests in nonthermal processing technologies have grown in food industry and academic laboratories due to the benefits associated with them. These include minimal impact on nutritional compositions, freshness and flavors, and the extension of shelf life, while diminishing the risk of pathogenic and food spoilage microorganisms. These technologies deliver convenience and efficiency of energy/water utilization when compared with conventional thermal treatments. Currently, some nonthermal processing treatments are commercially available, but others are still in the developmental stages for industrial applications.

Food products to be processed by nonthermal treatments are required to have specific characteristics when compared to similar foods that are thermally processed. Specific packaging materials and systems are required for nonthermally treated foods in order to achieve and maintain the safety and quality attributes of the products. Packaging materials selected for exposure to nonthermal processing must have good resilience and gas barrier properties in order to tolerate the physical and mechanical stresses of the process environment. Examples of nonthermal processing and preservation methods include technologies such as high pressure processing (HPP), pulsed electric fields (PEF), irradiation, light treatments, microwave sterilization, and

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active and modified atmosphere packaging. This book discusses packaging implications for these nonthermal processing techniques, mild food preservation methods and other hurdle technologies.

NONTHERMAL PROCESSING

Conventional thermal methods for food processing applications are stove-top cooking, blanching, pasteurization and retorting. These are designed to inactivate microorganisms, enzymes, and other chemical reactions, as well as achieve the expected shelf life and food safety. Chemical and physical changes taking place in foods during conventional heat treatments have been well documented in the published literature. Numerous practical applications of thermal treatments in a wide range of foods have been used from early ages to current times. Additionally, natural interactions and chemical reactions occurring in thermally processed foods and packaging materials are well known. However, in order to better understand and identify the physical, chemical and mechanical interactions taking place within foods and packaging materials exposed to nonthermal treatments, more studies are needed. These will provide data that can be used by engineers and food scientists as they seek to optimize these nonthermal technologies.

Prior to writing this book, the authors reviewed information about nonthermal processing techniques such as HPP, irradiation and PEF, that were reported in the FSTA-Food Science Technology Abstract database (https://www.ifis.org/fsta). As seen in Figure 1.1, the numbers of nonthermal processing publications have continuously increased from 2001 to 2016, especially in topics relating to HPP and irradiation. Recent studies on HPP, irradiation, and PEF technologies have extensively focused on improving the functionality, safety and fresh tasting qualities of a wide range of foods in response to consumers' demands. These publication trends also reported on recent developments and improvements to these technologies. As a result, various foods and beverages are now commercially treated by HPP and irradiation, and are in retail trade in various markets around the world.

High pressure processing is a nonthermal preservation technique that uses high pressured water or another appropriate liquid to transfer the pressure to a food product, either by itself or in its primary package. Microorganisms and enzymes are inactivated by this high pressure treatment, and this helps to maintain the safety and shelf stability of the food. The high pressure process is

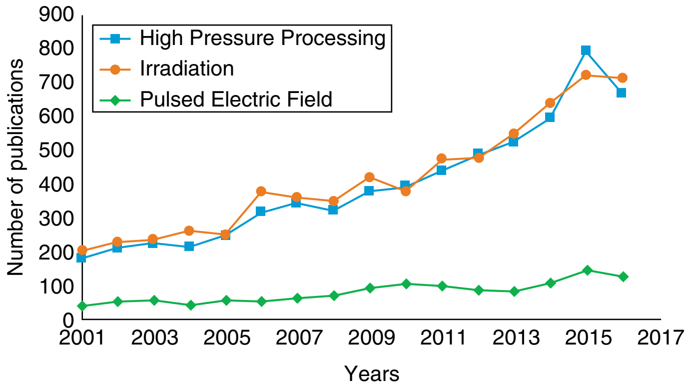

Figure 1.1 Increasing of HPP, irradiation, and pulsed electric field researches from 2001 to 2016 (https://www.ifis.org/fsta).

considered nonthermal due to its ability to inactivate pathogenic and food spoilage microorganisms without causing significant changes to the fresh-like qualities, sensory attributes or nutrients of the food. This is done without the use of heat normally generated by conventional thermal treatments such as retort processing, for example. Recent trends have shown that a growing consumer interest in HPP is due to its ability to extend the shelf life of food products without the addition of chemical preservatives. Thus, HPP provides benefits to food companies by helping them to meet the requirements for "clean label claims" for their packaged food products. The clean label claim is a recent trend driven by consumers and it relates to their concerns about too much synthetic chemicals being in processed foods.

Two types of irradiation techniques are currently used in food processing. These include ionizing and nonionizing radiations. Ionizing radiation works by using high energy to remove electrons from atoms and it produces ionization as a result. Examples of these include x-rays, alpha and beta particles, and gamma rays. Ionization can be initiated by radioactive elements such as uranium, radium, tritium, carbon-14, and polonium, or by high voltage generators that produce x-rays. Currently, beta particles and gamma rays obtained from cobalt-60 and cesium-137 are used for industrial food irradiation applications. Ionization radiation is utilized to inactivate detrimental microorganisms and reduce the rate of spoilage in selected foods. Conversely, nonionizing radiation has a much lower energy level than ionizing radiation.

However, nonionizing radiation that is used to treat food, causes atoms within the molecules to vibrate. This vibration produces heat which raises the temperature of the food. Microwave and infrared heating are examples of these. Food irradiation is associated with nonthermal processing due to its ability to inactivate microorganisms, kill insects, and other types of infestation, by using significantly lower temperatures when compared with conventional heat treatments.

Pulsed electric field is a processing technique which uses a high voltage pulse to treat a substrate positioned between two electrodes. Only pumpable liquid or semi-liquid foods which can flow between the two electrodes can be treated by this technique. During the treatment, harmful microorganisms can be inactivated by the application of micro to millisecond pulses of high voltages to the product that is pumped in the gap between the electrodes. In batch applications, a static treatment can be employed by exposure of the product to the pulsed electric field in a chamber designed with two electrodes. The PEF treatment, due to its extremely short processing time and insignificant increase in temperature, sustains freshness, sensory and nutritional qualities much better than commonly used industrial conventional heat processes such as retorting or microwave cooking.

In general, due to its relatively mild preservation methodology, nonthermally processed foods provide better nutritional and organoleptic characteristics when compared with similar conventionally heated products. Nonthermal processing techniques are also capable of producing safe and extended shelf life foods by inactivating enzymes, and killing pathogenic and spoilage microorganisms.

FACTORS TO BE CONSIDERED DURING NONTHERMAL PROCESSING

Bacilllus stearothermophilus is currently used as a microorganism indicator to estimate standard thermal treatment parameters. Other spore forming microorganisms are also used to validate other suitable thermal processes and food applications with extreme pH, water activity, and/or solute concentrations. To assist with these validation studies, food engineers have developed and used standardized data tables showing the values for D (time) and Z (temperature) for the reduction of standard microorganisms. The effectiveness of the thermal treatment on the organisms is determined by the F-value. However, the resistances of standard microorganisms to nonthermal treatments are different when compared with their responses to conventional thermal techniques. This makes the validation of nonthermal techniques a more challenging feat. Hence this is the reason why more research on nonthermal techniques is needed. In some cases, nonthermal processing can be a replacement for conventional heat treatments, at least, partially, by combining the nonthermal process with heat and or chemical treatments, and other hurdle technologies, depending on nature of the food. However, a better understanding of the effects of nonthermal techniques on chemical and physical changes and of microbiological inactivation in processed products is still needed in order to bridge the gaps between research achievements and industrial applications. Table 1.1 summarizes the process considerations, benefits, and shortcomings of nonthermal processing methods relevant to food products (Neetoo and Chen, 2014).

PACKAGING FOR NONTHERMAL PROCESSING

The main goal of food packaging is the storage, preservation and protection of the product for an extended period of time. The objective is to ensure the quality and safety of the product for convenient consumption when desired by the consumer. Besides these primary functions, other required functions are the effective marketing and distribution of the product, in addition to consumer matters such as obtaining information about the commodity, efficient and convenient handling, dispensing, and sales promotion. The significance of these packaging functions can shift from one aspect to another according to the needs of society and the lifestyle of consumers, plus the emergence of new technologies.

For nonthermally treated foods, the nature of the packaging and its design should be carefully selected in order to ensure the success of the specific technology. In addition to these, consideration must be given to the process parameters and mechanisms, the microbial growth kinetics, and the mechanical and physical properties of the packaging materials and systems. Food products treated by HPP are usually prepackaged within individual flexible or semi-rigid packaging

Table 1.1 List of process consideration, benefits, and shortcoming of alternative nonthermal processing methods (reprinted from Neetoo and Chen, 2014, pp. 145–147).

Process	Process considerations	Benefits	Shortcomings	Examples of applications
High hydrostatic pressure	Processing time	Enhances product safety	Equipment is cost-prohibitive	Fruit products
	Treatment temperature	Extends shelf life of product	Phenomenon of "tailing" during microbial inactivation	Yogurts
	Pressure level	Desirable textural changes possible	Changes in sensory quality possible	Smoothies
	Product acidity	Production of "novel" products	Not suitable for foods with air spaces	Condiments
	Water activity	Minimal effect on flavor, nutrients and pigment compounds	Not suitable for dry foods	Salad dressings
	Physiological age of target organisms	Minimal textural loss in high-moisture foods	Refrigeration needed for low-acid foods	Meats and vegetables
	Product composition	Can eliminate spores when combined with high temperature	Elevated temperatures and pressures required for spore inactivation	Sauces
	Vessel size	In-container and bulk processing possible		High-value commodities such as seafood
	Packaging material integrity	Potential for reduction or elimination of chemical preservatives		
	Processing aids	Positive consumer appeal		
		No evidence of toxicity of HHP alone		

Pulsed electric field	Electric field intensity	Effective against vegetative bacteria	Not suitable for non-liquid foods	Fruit juices
	Chamber design	Relatively short processing time	Postprocess recontamination possible	Milk
	Electrodes design	Suitable for pumpable foods	Less effective against enzymes and spores	Whole liquid egg
	Pulse width	Minimal impact on nutrients, flavor or pigment compounds	Adverse electrolytic reactions could occur	Soups
	Treatment time	No evidence of toxicity	Not currently energy efficient	Heat-sensitive foods
	Temperature		Restricted to foods with low electrical conductivity	
	Microbial species		Not suitable for product that contain bubbles	
	Microbial load		Scaling up of process difficult	
	Physiological age of organisms			
	Product acidity			
	Product conductivity			
	Presence of antimicrobials			

(*Continued*)

Table 1.1 (*Continued*)

Process	Process considerations	Benefits	Shortcomings	Examples of applications
Ultraviolet light/ pulsed UV light	Transmissivity of product	Short processing time	Shadowing effect possible with complex surfaces	Bread
	Geometric configuration of reactor	Minimal collateral effects on foods	Has low penetration power	Cakes
	Power	Low energy input	Ineffective against spores	Pizza
	Wavelength	Suitable for high-and low-moisture foods	Possible adverse sensory effects at high dosages	Fresh produce
	Physical arrangement of source	Amenable for postpackage processing	Possible adverse chemical effects	Meats
	Product shape/size	Medium cost	Reduced efficacy with high microbial load	Seafood
	Product flow profile		Possible resistance in some microbes	Cheeses
	Radiation path length		Reliability of equipment to be established	Food packages
	Combination with other hurdles			

Ultrasound	Amplitude of ultrasonic waves	Ultrasound effective against vegetative cells	Has little effect on its own	Any food that is heated
	Exposure time	TS and MTS effective against vegetative cells and spores	Challenges with scaling up	
	Microbial species	Reduced process times	Free radicals could damage product quality	
	Volume of food	Amenable to batch and continuous processing	Can induce undesirable textural changes	
	Product composition	Little adaptation required for existing processing plant	Can be damaging to eyes	
	Treatment temperature	Possible modification of food structure and texture	Can cause burns and skin cancer	
		Energy efficient	Depth of penetration affected by solids and air in product	
		Several equipment options	Potential problems with scaling up of plant	
		Effect on enzyme activity		
		Can be combined with other unit operations		

(*Continued*)

Table 1.1 (*Continued*)

Process	Process considerations	Benefits	Shortcomings	Examples of applications
Ionizing radiation	Absorbed dose	Long history of use	High capital cost	Fresh produce
	Water activity	High penetration power	Localized risks from radiation	Herbs and spices
	Freezing	Suitable for sterilization (food and packages)	Hazardous operation	Packaging materials
	Prevailing oxygen	Suitable for postpackage processing	Poor consumer acceptance	Meat and fish
	Microbial load	Suitable for nonmicrobiological applications (e.g. sprout inhibition)	Changes of flavor due to oxidation	
	Microbial species	Packaged and frozen foods can be treated	Loss of nutritional value	
	Product composition	Low operating costs	Development of radiation-resistant mutants	
	State of food	Can be scaled up	Microbial toxins could be present	
	Food thickness	Low and medium dose has minimal effect on product quality	Outgrowth of pathogens	
	Particle size	Suitable for low-and high-moisture foods		
	Combination with other hurdles	Diverse applications		

materials, or could be packaged in bulk after the treatment. The prepackaged processing method is essential during batch HPP treatments. In this process, the packaging and the material, of which it is made, will be exposed to the same HPP as the food, and must be designed with the ability to survive the pressure treatment. This means that the package must be designed to survive the water-mediated high hydrostatic pressures which typically range from 30-600 MPa, but could be as high as 800 MPa. Since the application of pressure will result in volume changes according to the laws of physics, the reversible response of the whole package to the compression/decompression process during HPP is crucial to the successful commercialization of this non-thermal processing technology. Plastics are the best choice of material for HPP food packaging because they are flexible and most have excellent water-resistant properties.

The microbicidal purpose of radiating food will be lost if the safety and the shelf life of the treated product is not maintained after the irradiation process. This is facilitated by packaging the food prior to the irradiation process. This ensures that the food remains sterile during transportation, storage and handling prior to consumption. Irradiation applied to prepackaged foods will also expose the packaging material to the radiation treatment. This means that the selection of the packaging material must be of such that minimal changes to the molecular structure are caused by the irradiation. Severe changes to the chemical or morphological composition of the material could accelerate an unsafe release of chemical additives from the package to the food. As a result, the United States Food and Drug Administration (FDA) has published a list of approved packaging materials, additives and the irradiation doses for food processing operations.

Since PEF treated products are not prepackaged before exposure to the electric field, the packaging material does not come in contact with the electrical energy. However, at the end of the PEF process, the product must be aseptically packaged for extended shelf life. To accomplish this, the packaging material must be sterilized by dry heat, steam, ultra violet light, chemicals, and/or a combination of these methods. Not only must the material survive these sterilization methods, any residual sterilant must be removed from the package prior to filling it with the PEF treated food. The packaging material must also be compatible with the product and not allow the migration of undesirable substances, odors, and flavors to the foods, in addition to maintaining its safety and quality.

CONSUMER PREFERENCE OF PACKAGING DESIGN AND REGULATION OF NONTHERMAL PROCESSING

An aesthetically appealing package influences consumers' purchasing decisions, and it serves as a strategic marketing tool. A good comprehension of consumer preferences for package design is important for the marketing success of the product. However, package design must not compromise the proper material selection because this could impact the safety and quality of the nonthermal product. Nonthermal processing operations, packaging methods, and materials in contact with the food must be used in accordance with permitted governmental regulations. As an example, the Radura logo is required on the labels of most irradiated packaged foods. Also, a list of packaging materials and the dosages approved for food irritation in the United States are shown in Table 1.2 (FDA, 2015).

Table 1.2 Packaging materials and adjuvants approved for irradiation by the U.S. Food and Drug Administration (FDA).

Maximum Radiation Dose (kGy)	Types of Packaging Materials and Adjuvants Approved for Irradiation
0.5	Kraft paper to contain only flour
7.2	Polystyrene foam tray
10	Nitrocellulose-coated cellophane; Glassine paper; Wax-coated paperboard; Polyolefin film;[a] Polystyrene film;[a] Rubber hydrochloride film;[a] Vinylidene chloride-vinyl chloride copolymer film;[a] Vinylidene chloride copolymer-coated cellophane; Nylon 11; Optional adjuvants for polyolefin films plus optional vinylidene chloride copolymer coating; PET film plus optional adjuvants, vinylidene chloride copolymer and polyethylene coatings
30	Ethylene-vinyl acetate copolymers
60	Vegetable parchments; Polyethylene film;[a] Polyethylene terephthalate film;[a] Nylon 6 film;[a] Vinyl chloride-vinyl acetate copolymer film;[a]

[a] Plus limited optional adjuvants

In summary, the packaging of a nonthermally processed food is subject to a combination of the nature of the corresponding nonthermal technology, the response of the packaging material to the nonthermal process, regulatory guidelines, consumer acceptance, and the economic analysis of the nonthermal method for the specific food product. Therefore, business studies relating to nonthermal processing and packaging methods should be both technical and socio-economical.

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2 Active packaging and nonthermal processing

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INTRODUCTION

The function of conventional food packaging is primarily to be a passive barrier that protects the contents from external environmental impacts such as water, water vapor, gases, light, odors, microorganisms, insects, dust, shock, vibration, and compression, so that the safety and quality of the contents is preserved from the time of packaging to final consumption. The packaging also serves as a way to communicate to the consumer through the label content and it provides information on issues such as the manufacturer, product, measurements, handling instructions, nutritional content, warnings, and closure applications (Robertson, 2012). The addition of active ingredient(s) to the package and its interaction with the content to keep or improve its properties during post-packaging storage and transportation converts the passive package into an active package. An active package (AP) is defined as one that performs desirable functions other than providing a passive barrier to the packaged food. The incorporated components are designed to release or absorb substances into or from the food or the surrounding environment with the intent of extending the shelf life of the product (Johansson, 2013). AP involves interactions between the food, the packaging materials and the gaseous atmosphere (ShivalkarYadav, Prabha, and Renuka, 2015). Materials or substances used in AP should be subjected to approval by the U.S. Food and Drug Administration (FDA) pursuant to Section 409(h)(6) of the Federal

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Food Drug and Cosmetic Act, for food contact substances. Systems with which AP are operated can be classified as scavenging/absorbing, emitting/releasing, or other systems.

Scavenging systems (also called also non-migrating) absorb gases such as oxygen, ethylene, moisture, carbon dioxide, or flavors from the headspace of the package. Emitting systems (called also migrating) emit/release carbon dioxide, ethanol, antioxidants, antimicrobial agents, flavors, and other types of preservatives. Examples of other systems involve temperature controllers such as isolating materials and self-heating or self-cooling containers and compensating films that have the ability to change their gas permeability to match or exceed changes in the respiration rates of fresh produce in response to ambient temperature (ShivalkarYadav, Prabha, and Renuka, 2015; Hosseinnejad, 2014; Restuccia *et al.*, 2010). The active components in these systems can be added directly to the packaging material or they can be included as a separate unit inside the package. Examples of these include sachets, cards, adhesive labels, or packaging films immobilizing the active components (Prasad and Kochhar, 2014; Rooney, 2005). A specific AP is designed for a particular food product based on its predetermined predominant deterioration mechanism(s) (Mehyar and Han, 2011). Therefore, it is important to understand the mechanism of deterioration in term of the initiation factors, the effect of the surrounding environment, and the food composition.

Nonthermal processing (NTP) is defined as using nonthermal technologies to extend the shelf life of the food by inhibiting or killing microorganisms with minimal impact on the nutritional and sensory properties of the food (Morris, Brady, and Wicker, 2007). The major advantage of nonthermal (NT) technology is that they preserve the physiochemical characteristics of the food. Examples of this include changes in nutrients such as ascorbic acid or phenolic compounds content, texture, flavor profile, color, and so on, whereas thermal processing causes irreversible loss of quality properties (Barba *et al.*, 2012). Furthermore, NTP is environmentally friendly because it acts at ambient or sub-thermal temperatures, and does not contribute in global warming, it minimizes waste water, increases water and energy savings, and results in minimal impact to the quality of foods, thus retaining “fresh-like” characteristics. The electricity savings of pulsed electrical field (PEF) can be up to 18-20% based on the assumed electricity consumption compared to existing thermal technologies (Pereira and Vicente, 2010). Some authors considered AP among NTP because both techniques are based on the same principle of delaying possible food deterioration through inactivation of causative agents without the application of heat (Morris, Brady, and Wicker, 2007).

Due to the diversity in mechanisms of inactivation for the NTP, no standard target microorganism or biochemical reaction is suggested as an efficiency index for this process. This could also change the type and requirements for a suitable AP that is to be used for efficient preservation of a nonthermally processed foods. A case study is suggested to determine the suitable combinations of NTP and AP for a particular food product before a commercial application is produced (Akbarian *et al.*, 2014). Another consideration is that the addition of an active component to the packaging should not affect the package properties and the subsequent performance of the NTP in prepackaged foods. For example, incorporating antioxidants or antimicrobial agents in the packaging materials should not affect the mechanical properties of the package if this product to be treated with high hydrostatic pressure or should not affect transparency of the package if the product to be treated by pulsed UV/white light emission process. As another example, if the NTP is to be used in foods before packaging, it should be taken into consideration that structural changes in the food may affect the performance of the AP if the production of free radicals by the ionized radiation occurs and these affect the oxygen scavenging mechanisms (Moseley, 1989; López-Rubio *et al.*, 2007).

ACTIVE PACKAGING SYSTEMS

Oxygen Scavengers

The presence of dissolved or gaseous oxygen in a food has a high detrimental effect by causing the oxidation of oils, fats, flavors, vitamins, and pigments (in plants and animal muscles) as well as the growth of molds and aerobic bacteria. These reactions decrease the shelf life of the food by causing rancidity, off odor, loss of flavors, and nutritional value as well as discoloration and an unacceptable microbial growth. The levels of residual oxygen that can be achieved by regular (MAP) technologies are too high for maintaining the desired quality and shelf life of packaged food. The use of oxygen scavenging packing systems could be used to help reduce the levels of residual oxygen dissolved or present in the headspace much lower (<0.01%) than those achievable by the MAP (0.3-3%) (Realini and

Marcos, 2014). However, some conditions must be fulfilled for oxygen scavenging systems to work properly. The packaging containers or films should be of high oxygen barrier or as a passive monolithic composite, offering a delay in the oxygen transport, caused by the high tortuosity of the material for oxygen diffusion. Otherwise, the scavenger will rapidly become saturated and lose its ability to trap oxygen (Brody *et al.*, 2008). Another consideration is that in flexible packaging, the heat sealing should be successful, so that no air leaks can occur through the seals after closing the package. Other factors that may affect choosing the appropriate type of oxygen scavenger are initial headspace oxygen level, the package surface area, biochemical reactions in the packaged food, and storage temperature (Solis and Rodgers, 2001; Benson and Payne, 2012).

The following shows the reaction for oxygen scavenger mechanisms of action:

(1) Oxidation of iron or iron salts that react with water (provided by the food) to produce stable iron oxide

$$Fe \rightarrow Fe^{+2} + 2e^-$$
$$1/2O_2 + H_2O + 2e^- \rightarrow 2OH^-$$
$$Fe^{+2} + 2(OH^-) \rightarrow Fe(OH)_2$$
$$Fe(OH)_2 + 1/2O_2 + 1/2H_2O \rightarrow Fe(OH)_3$$

In the food industry, this scavenger is available within laminates containing ferrous oxygen or it could be incorporated into the resin that is thermoformed into trays or bottles (ShivalkarYadav, Prabha, and Renuka, 2015; Prasad and Kochhar, 2014).

(2) The oxidation of nonmetallic oxygen scavengers such as ascorbic acid, ascorbate salts, and catechol. Most of these reactions are slow but can be accelerated by light or a transition metal that works as a catalyst (e.g., copper) (Cruz, Camilloto, and Pires, 2012). Celox® (used in lined crowns, aluminum ROPP, plastic caps) and Darex® (an oxygen scavenger master batch) of W.R. Grace and Co. (USA) are commercial applications on ascorbate based oxygen scavengers.

(3) The oxidation of photosensitive dye impregnated onto polymeric films. When the film is irradiated by UV light, the dye activates the oxygen to its singlet state, making the oxygen removal reaction much faster (Cruz, Camilloto, and Pires, 2012). Cryovac® OS Films are UV light–activated oxygen scavenging films developed by Cryovac Food Packaging, Sealed Air