Modified Atmosphere Packaging (MAP) White Paper

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Introduction of MAP for Produce

Modified Atmosphere Packaging (MAP) has been a technology pillar of the fresh cut produce industry for more than twenty years. Properly designed and utilized it has the potential to optimize shelf life, quality and convenience, thus contributing to the economic and safe global distribution of fresh cut produce. Due to these advantageous attributes MAP is now being evaluated in a whole host of new applications and segments of the marketplace. Additional functionality attributes are being researched and evaluated including, antimicrobial, RH, free liquid, and ethylene management.

Historically, MAP has been used primarily in the fresh cut market segment and from the fresh cut processor thru to the consumer. Recently new segments of the supply chain are being actively investigated to determine if they, too, can reap the benefits of MAP. Field pack, whole produce for both food service and retail, the global air and sea shipment of produce are all now being actively evaluated and developed. In addition, now more than ever, companies are utilizing MAP not only as a technology platform but as a marketing sales and even social media platform.

In this paper we will recap the fundamental science and technology that supports and drives Modified Atmosphere Packaging as well as the transition of MAP to a technology and marketing platform. We will detail what MAP can do, and under what conditions. In addition, and just as important, what it cannot do. We will explore the difference between optimizing quality and extending shelf life along with the impact that MAP can have on food safety.

We will, in short, provide a picture of the current state of the science technology and marketing of Modified Atmosphere Packaging along with what is next coming down the road.

The Science and Technology of MAP

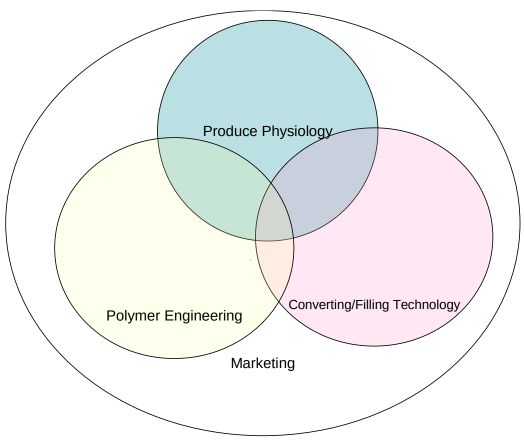
By definition, Modified Atmosphere Packaging is when the internal atmosphere of a package is something other than ambient atmosphere. In the food packaging industry, this type of packaging falls into two broad categories: Modified Atmosphere Packaging (MAP) and Controlled Atmosphere Packaging (CAP). For barrier packaging of products such as meat, cheese, snack food, etc., MAP refers to enclosing a product within a barrier package and modifying the internal atmosphere, either by or a combination of drawing a vacuum or filling it with a gas(es). MAP barrier packaging allows meat to bloom, extends shelf life, prevents soft products from being crushed, and retains moisture. CAP is a process where gases are added or removed to actively maintain a desired set point and balance. MAP for fresh produce is more complex than other food packaging markets because the produce continues to respire, consuming O_2 and giving off CO_2.

Quantifying Produce Physiology

Modified Atmosphere Packaging in one of the key technologies associated with the shelf-life extension and quality optimization of fresh produce. For many years, especially in the early uses of MAP, the industry was focused on shelf-life extension, almost to the exclusion of quality. This was in large part due to the distribution challenges of leafy greens from the West coast to the balance of the country. The practice of the North American consumer of using a large amount of salad dressing allowed this focus solely on shelf-life extension to move forward. Given enough salad dressing, leafy greens (where MAP was first used) became strictly a texture as their flavor was overpowered by the dressing. As North American's diets and tastes changed and less dressing was utilized, it was realized that we as an industry had compromised quality for shelf life. Now, when designing MAP structures, the goal is not maximum shelf life but rather optimizing quality and flavor throughout a given shelf life.

When designing Modified Atmosphere Packaging for fresh produce the convergence of three unique and separate sciences must take place, namely produce physiology, polymer engineering and converting technology (see **Figure 1**). Since the intersection of these three sciences is where the Modified Atmosphere Packaging design process must take place, a full and complete understanding of each science is necessary in combination with the surrounding disciplines of marketing and consumer preferences.

Figure 1 Sciences Impacting Modified Atmosphere Package Design



In any discussion of MAP for the fresh produce industry, it is important to understand MAP does have limitations: First and foremost, MAP is only effective if there is consistent temperature management throughout the entire life cycle of the produce product. This includes processing as well as the entire distribution channel. Lack of temperature control will result in produce physiological variations, particularly respiration, which will impact the effectiveness of the packaging system. For example, if MAP is designed for 10°C but held at 5°C, then it will take longer to achieve an effective atmosphere because the respiration rate is lower. If it is stored at 20°C then the respiration rate increases and the product can go anaerobic, which affects quality, causes off flavors and decreases shelf life.

In addition, Modified Atmosphere Packaging (MAP) will never improve the quality of the incoming raw material product. Under ideal circumstances, the best that can be achieved is to maintain the existing quality level throughout the desired shelf life. The need for optimal incoming quality is the primary driving force behind the investigation of MAP further up the supply chain. In real world applications, often MAP will maintain quality for the majority of the targeted shelf life but due to parameter variations during distribution, quality will suffer at the very end of the desired shelf life. Since modified atmosphere packaging will never improve incoming product quality, the need for optimal post-harvest handling procedures is paramount.

If the package leaks, then the target modified atmosphere cannot be achieved and/or maintained. In effect, a package with a leaker will no longer be in control; therefore, Modified Atmosphere Packaging must be designed to minimize and ultimately eliminate leakers. This can be accomplished through proper polymer and film selection as well as packaging equipment parameters.

Effects of MAP on Product Physiology and Safety

Reducing O_2 concentrations below about 10% around many fresh fruits and vegetables slows their respiration rate and indirectly slows the rates at which they ripen, age and decay. Reducing the O_2 concentration can, in some cases, reduce oxidative browning reactions which can be of particular concern in precut leafy vegetables. Reduced O_2 can delay compositional changes such as fruit softening, pigment development, toughening of some vegetables (such as asparagus and broccoli), and development of flavor (Kader, 1986). However, O_2 is required for normal metabolism to proceed. O_2 concentrations below about 1–2% can lead to anaerobic (sometimes called fermentative) metabolism and associated production of ethanol and acetaldehyde resulting in off flavors, off odors and loss of quality. Of even greater concern is the potential growth of anaerobic bacteria, some of which are pathogenic to humans, under these low oxygen conditions. The proper O_2 concentration will depend upon the fruit or vegetable and its tolerance to low O_2, the temperature (which will affect the product's tolerance to low O_2) and the time that the product will be exposed to low O_2.

Elevated CO_2 can, like reduced O_2, slow respiration thereby extending shelf life. High CO_2 and low O_2 together can, in some cases, reduce respiration more than either gas alone (Kader, Zagory, & Kerbel, 1988). CO_2 at relatively high concentration (> 10%) has been shown to suppress the growth of a number of decay-causing fungi and bacteria. Carbon dioxide is also very soluble in water, especially in cold water, (179.7 cm3/100 ml @ 0°C) and will, thus, be absorbed by high moisture foods. When CO_2 dissolves in water it produces carbonic acid, which will cause a drop in pH and have an acidifying effect. This acidification, as well as direct antimicrobial effects, can suppress the growth of many spoilage microorganisms and for this reason is essential in many extended shelf-life packages. However, too much CO_2 can be damaging to plant tissues, and individual fruits and vegetables differ in their tolerance to CO_2.

What makes fresh produce Modified Atmosphere Packaging unique is the significant impact and requirement of the produce physiology. In other words, there is a symbiotic relationship between the packaging and the produce and the importance of produce physiology when specifying packaging systems cannot be overstated. Unlike almost all other packaging applications, produce Modified Atmosphere Packaging involves packaging a living product.

MAP depends upon the respiratory activity of the enclosed product as a driving force for atmosphere modification and the permeability of the packaging material to maintain atmospheres within desired limits. It is the continued depletion of O_2 and/or the release of CO_2 (and water vapor) by the product that enables the modified atmosphere to become established within a sealed package. Factors that must be controlled or incorporated include film permeability, film area, film thickness, temperature and the respiratory behavior (responses to O_2 and temperature) of the product.

The processes of altering the atmosphere within the package generally takes a number of days to reach the target atmosphere and equilibrium. For produce items that are prone to enzymatic browning reactions (pinking), which can be exacerbated by O_2 levels above 3%, this gradual decent may be too long. Gas flushing of fresh cut Modified Atmosphere Packaging establishes an initial low alternative atmosphere within the package, which can be beneficial in reducing enzymatic browning reactions (pinking). Gas flushing, however, is not a substitute for proper package design or to mask the effect of leakers. Gas flushing is only optimized when it is employed in combination with proper package design and a leak-free package. Since the primary goal of gas flushing is to reduce the initial O_2 level within the package, N_2 is the most effective and economic gas.

Quantifying Produce Physiology

Using published respiration rates, although a good starting point, is not as effective as measuring the respiration rate of your product. This is due to the differences between growing regions, cultivars handling and growing conditions. Ultimately, the proper design of MAP requires a quantitative understanding of the respiration of specific fresh produce. Produce respiration is determined through testing. The condition, age and temperature of the raw material product significantly impact the outcome of the respiration test. There are a number of independent resources for product respiration calculations, including University of California Davis (http://postharvest.ucdavis.edu/) and The JSB Group, LLC. (www.jsbgroup.com).

Well-designed respiration rate (RR) test methods should have the following components:

- Ability to perform tests at either customer or our own facilities
- Testing RR on multiple produce raw materials simultaneously
- Testing RR of complex produce blends
- Testing RR on ready to eat meals
- Data collection spreadsheets directly linked to package design and shelf life determination system
- Be transparent so that the customer is able to access the calculated respiration rate data

Once the respiration rate is calculated, then one can determine the target package oxygen transmission rate (OTR). The primary method for determining the required Modified Atmosphere Package oxygen transmission rate is seen in the following equation. Parameters in addition to respiration rate include package surface area, product weight, structure thickness and target final modified atmosphere. A thorough understanding of the equation and how each parameter can affect the package OTR is critical for optimal package design. It is the interplay of these parameters that mandates that there is no one package that fits all uses. Modified Atmosphere Packaging must be designed on an individual application basis. Once the produce respiration is quantified and the balance of parameters are determined, the target OTR can be calculated. Establishment of the target OTR allows the package design process to move from physiological science into the polymer and converting science.

OTR for a target atmosphere is:

OTR= RRO_2 • t • W/A • (O_2 air- O_2 pkg)

Where:

OTR = Film O_2 Permeability (Oxygen Transmission Rate) per mil

RR = Respiration Rate (O_2 Consumption rate in ml/kg-hr)

t = Film Thickness (mils)

W = Product Weight (kg)

A = Film Surface Area (cm2)

O_2 pkg = Desired O_2 Concentration in the Package (% O_2 Target Atmosphere)

NOTE: OTR in this example is calculated on a per mil basis. Therefore, when a 2 mil thickness film is used, the OTR on a per mil basis must double to achieve the equivalent package OTR.

Polymer Engineering

In order to achieve the target modified atmosphere, the packaging films must be permeable to gases. Specifically, they must have the required gas transmission properties to achieve the targeted oxygen transmission rate. The movement of gases across films depends on several physical factors that are related through Fick's Law as follows:

Where:

Jgas = Total flux of gas (cm3/s)

A = Surface area of the film (cm2)

Cgas = Concentration gradient across the film

R = Resistance of the film to gas diffusion (s/cm)

The gas flow across a film increases with increasing surface area and with increasing concentration gradient across the film. The gas flow across the film decreases with increasing film resistance to gas diffusion. Gases diffuse through polymeric films at different rates. Carbon dioxide diffuses between two to five times faster than oxygen. The ratio, within a polymer, film or structure of CO_2 transmission rate to oxygen transmission rate is termed the Beta value. Polymeric films, therefore, have a Beta value of 2–5:1, with an average of 3:1. The Beta value of a Modified Atmosphere Package will have a direct bearing on the final modified atmosphere achieved within the package. For example, in polymer films it is possible to achieve a low (2%) O_2 level in combination with a mid-level (7%) CO_2. The impact of the Beta value is dependent on the specific ideal modified atmosphere for each individual product.

Polymers

There is a transmission rate ceiling with non-perforated films and a lower level transmission rate limit with perforated films. It is, therefore, important to understand the different properties of the two types of packaging transmission technologies so that the optimal technology can be used.

There are a variety of polymers used in fresh-cut produce Modified Atmosphere Packaging. A portion of these polymers are used in primarily flexible packaging structures, a portion are used in primarily rigid packaging structures and a portion are found in both applications. Each specific polymer has physical, chemical and gas transmission rate properties that are unique to that polymer. Design of a packaging structure entails matching the specific polymer properties to the requirements of the MAP application. **Table 1** lists many of the common polymers used in produce Modified Atmosphere Packaging.

As with most food packaging, produce modified atmosphere packaging contains not only individual polymers but combinations of polymers in the form of films and structures (see **Figure 2**).

Figure 2 Multilayer Lamination Example

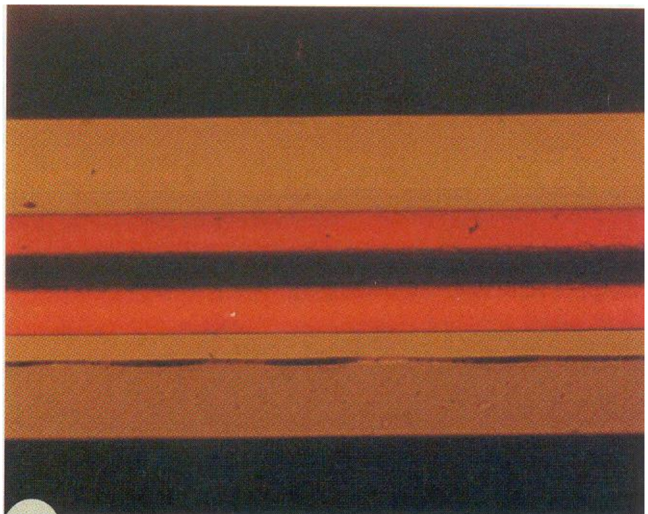
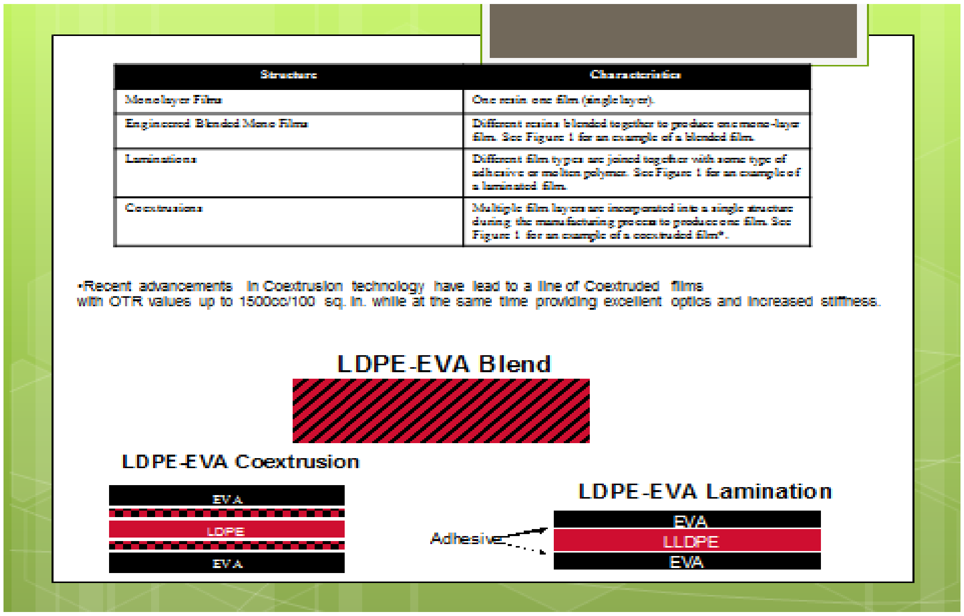


Fig. 1—Cross-section of a 7-layer barrier material photographed using 200× magnification

These films can consist of blended monolayer films, coextruded films or combinations of both laminated together. See **Figure 3** for film types. Determination of the gas transmission rate, therefore, requires knowledge of not only the individual polymers but also how they are combined. A blend of polymers within a single layer of plastic film, referred to as a blend, will yield an OTR that is the weighted average of the OTR of the individual polymer components. Individual distinct layers of pure polymers (or blends) created within a single total structure are referred to as a coextrusion. Coextrusions can be used as-is or combined with additional coextrusions or polymer films to create a lamination.

Figure 3 Film Types



Structure	Characteristics
Monolayer Films	One resin one film (single layer).
Engineered Blended Mono Films	Different resins blended together to produce one mono-layer film. See Figure 1 for an example of a blended film.
Laminations	Different film types are joined together with some type of adhesive or molten polymer. See Figure 1 for an example of a laminated film.
Coextrusions	Multiple film layers are incorporated into a single structure during the manufacturing process to produce one film. See Figure 1 for an example of a coextruded film*.

Since gases will move through each independent layer sequentially, the OTR of each independent layer of polymer must be determined and inserted into the following equation to calculate the overall structure oxygen transmission rate (see **Figure 4**).

Figure 4 OTR Calculations on Multi-Layer Coextruded Films and Structures

Calculating the OTR

$$OTR = \frac{1}{\frac{t1}{OTR1} + \frac{t2}{OTR2} + \frac{t3}{OTR3}}$$

Where:

t = Thickness of the individual layer

OTR = Oxygen transmission rate of the individual layer at 1 mil

Based upon this equation the total structure OTR can never be higher than the lowest individual layer OTR. This limiting factor establishes a practical ceiling for polymer Modified Atmosphere Packaging. Depending on the type of structure and all of the converting and marketing requirements, this ceiling may be as low as 175 cc/100 in^2/mil/atm/day (2713 cc/m2/mil/atm/day) or as high as 900–1000 cc/100 in^2/mil/atm/day (13,950–15,500 cc/m2/mil/atm/day).

The specific combination of polymers, blends, coextrusions and laminations are governed by numerous parameters, in addition to the physiological requirements mandated by the product being packaged. These additional functional requirements often act in an opposing manor. Therefore, to effectively design a Modified Atmosphere Package, it is necessary to have a full understanding all of the desired features of the package. Requirements impacting polymer and film choice can include stiffness, sealability, aesthetics clarity, graphics, dimensions, economics, sustainability, runnability, packaging format, COF, antimicrobial additives and thickness.

As is listed in Table 1, polymers that exhibit increased stiffness properties also exhibit lower gas transmission rate properties.

Table 1 List of Common Polymers

Polymer	Abbreviation	Characteristic	Typical OTR(cc/100 in²/mil/atm/day)	Application Most Commonly Used
Low density polyethylene	LDPE	General purpose polymer	450–500	Both
Linear low density polyethylene	LLDPE	Increased stiffness	480–500	Both
Linear medium density polyethylene	MDPE	Increased stiffness, lower OTR, decreased clarity	300–350	Both
High density polyethylene	HDPE	Relatively stiff, opaque	150	Rigid
Ultra low density polyethylene	ULDPE	High OTR, decreased stiffness	900	Flexible
Plastomer metallocenes	-	Very high OTR, soft	1100	Flexible
Amorphous polyethylene terapthalate	APET	Clear, rigid	5	Rigid
Poly vinyl chloride	PVC	Clear, rigid	10	Rigid
Polypropylene	PP	Decreased clarity	300	Both
Ethylene vinyl acetate	EVA	Sealability	600–900	Flexible

Perforations

The increase in demand for higher respiring fresh produce, including fruit, herbs and specialty baby leaf greens has meant a significant increase in Modified Atmosphere Packaging gas transmission rates. A method for achieving high oxygen transmission rate packaging structures that are not limited by the upper end of polymer gas transmission rates and stiffness constraints is microperforation technology. This technology employs the science of placing micro holes in the packaging structure. With microperforation technology, the gas transmission rate of the Modified Atmosphere Package is governed by the configuration of holes and their individual geometry and size. The hole size and configuration can vary with the specific perforation method but, in general, microperforations are not visible to the naked eye and range from 40–200µm in diameter. It is essential to have a complete understanding of the package geometry so that holes are not blocked or obstructed in any way. This is critical to the success and control of gas transmissions. Microperforations also have transmission rate limitations, however, for microperforation technology the limitations are at the lower end of the range. Typical oxygen transmission rates for microperforated packaging are from 200 cc/100 in^2/mil/atm/day and above. Gas transmission rates of microperforated structures are determined by the gas diffusion properties through the combined effect of the individual micro holes, their corresponding placement and, in certain cases, the OTR of the perforated structure. As the targeted OTR requirements are lower, the number of holes decreases. Since microperforated structures cannot have less than one hole, the gas transmission rate through a single hole dictates the lower transmission rate level. Modified atmosphere microperforation packaging with only one hole can be problematic. With two or more holes there is less risk from hole blockage as well as there is more uniform gas flow throughout the package. In order to avoid only one microperforated hole, alterations to the other key OTR control parameters, such as product weight or package dimension, should be considered.

The diffusion rates of various gases through microperforations are very similar. In effect the diffusion rates of CO_2 and O_2 are virtually the same; a Beta value of 1. Therefore, for a targeted 2% O_2, a 19% CO_2 level will be achieved. The Beta value difference between polymeric and microperforated structures create significantly different final modified atmospheres. It is not possible with a microperforated film to achieve a modified atmosphere consisting of low O_2 concentrations and low to moderate CO_2 concentrations. Conversely, if low O_2 concentrations in combination with high CO_2 concentrations are required, then packaging comprising of engineered polymers is not suitable. This parameter needs to be accounted for in the packaging design process.

When using microperforations, it is critical to ensure that the hole is both consistent and uniform throughout the package as well as from package to package. In addition, as the structure to be perforated increases in thickness so too must the diameter of the microperforation. This ensures that the microperforated hole is completely through the structure.

Macroperforations, which are visible to the naked eye, should not be mistaken for microperforations. The gas movement through the larger visible holes utilized in macroperforation technology is too great to consistently modify and control the gas level within the package. Therefore, attempting to create a low O_2 modified atmosphere is not feasible. This does not mean, however, there is not a function and need for macroperforated structures. Since the gas transmission is so high, a macroperforated structure will virtually never become anaerobic, O_2 levels falling below 0%, even under temperature abuse situations. If having a fresh-cut produce package not become anaerobic under any circumstances is the highest priority and atmospheric levels of O_2 do not significantly impact shelf life, then macroperforation technology may be applicable. Historically, this has been the technology of choice for mushroom packaging. Recent advances in microperforation technology have provided mushroom growers and processors alternatives.

Converting and Packaging Format

Choosing the correct packaging format is an integral step in Modified Atmosphere Package design. The process of determining the correct packaging format must include input from all stake holders, including fresh-cut processor, packaging manufacturer, raw material suppliers and the consumer. The choice of the optimal packaging is dependent on a complete understanding of the entire physiological, polymer, manufacturing, marketing, environmental and economic considerations. Issues such as package configuration, package stiffness, graphics, filling method, economics, environmental impact as well as ancillary requirements such as cook-in, antimist/antifog, resealability and compostability all impact the design and make-up of the Modified Atmosphere Package. In general, there are three types of formats that are most commonly used in fresh-cut produce Modified Atmosphere Packaging: flexible packaging, rigid packaging and active/intelligent packaging. Within each of these broader categories there are numerous variations and permeations.

The science of converting technology combines the raw material polymers, films, adhesives, inks and additives in the proper sequence to create the desired package. Improvements in converting technology, including printing, laminating and perforation technology has created more viable options than ever before. Depending upon the format, packaging can be developed separate or in combination with automatic filling equipment. The result of these various converting requirements is the development of a wide variety of packaging formats or geometries. There is no right or wrong format. Rather, it is important to choose the format with optimum suitability based on all of the outlined requirements. Packaging formats can range from the very basic monolayer pre-formed side weld bag to the very complex multilayer coextruded reverse print lamination and thermoformed multilayer tray with peelable lidding structure. **Table 2** lists some of the more common packaging formats. It is important to note that this is not an all-inclusive list since there are many variations to these common formats, which optimize specific desired properties to the specific produce packaged.

Table 2 Common Packaging Formats

Package Format	Suitable for MAP	Natural Aspiration	Prone to Leakers if Properly Manufactures	Common Products Packaged
Side weld premade bag	Somewhat	Somewhat	Yes	Carrots
Pre made pouch	Yes	No	No	
VFFS pag	Yes	No	Structure dependent	Leafy greens
Pre made SUP	Yes	No	No	
VFFS SUP	Yes	No	No	
Thermoformed tray with attachable lid	No	Yes	N/A	In-store fresh-cut fruit
Clamshell tray	No	Yes	N/A	Berries
Thermoformed tray with sealable lid	Yes	No	Lidding dependent	
Tray with overwrap	Package dependent	Yes	Yes	Cut squash
Macroperforations	No	Yes	N/A	Mushrooms

Flexible Versus Rigid Packaging

As the names imply, the fundamental difference between flexible versus rigid packaging relates to the stiffness of the respective packaging configuration. The relative stiffness of a given package is controlled by the choice of polymers and their respective stiffness properties as well as the thickness of the structure and geometry. In Modified Atmosphere Packaging there is another significant difference between traditional rigid and flexible packaging. This relates to the effective surface area available to gas diffusion. In traditional rigid packaging the polymers required to maintain the rigid form of the package exhibit low gas transmission rates. These low transmission rates, in combination with the thickness required to maintain the package form, effectively create a gas barrier structure. This dictates that when determining the effective “breathable” surface area of the package, the rigid portion of the package cannot be included in the calculations. This means that the flexible lidding material sealed to the top of the tray must take on the entire burden of gas transmission. Therefore, when comparing a flexible package with a rigid tray type package, the gas transmission level of the effective surface area of the flexible package can have a significantly lower overall transmission rate.

When a traditional rigid tray is used in combination with a rigid lid, both components of the package are effective gas barriers. Therefore, if a hermetic seal is created between lid and tray, effective gas transmission will not take place and depending upon the type and quantity of produce anaerobic conditions will rapidly develop.

Often, a rigid tray and lid combination are not designed to create a complete seal. In this situation the package is not a true engineered Modified Atmosphere Package but rather a “natural aspiration” package meaning that, depending on how effective the seal, the atmosphere inside could range from anaerobic to ambient. When designing packaging for the produce market it is important to decide if you are designing a Modified Atmosphere Package or a “natural aspiration” package. Both can be effective packaging formats, depending on the initial requirements and desired outcome. It is important to remember that quality and self-life optimization can only be achieved through engineered Modified Atmosphere Packaging technology.

One area of rigid packaging that is gaining alot of attention is the concept of a breathable tray. Although this has been looked at for many years, recent research is getting the technology much closer to realization. The benefits of a breathable tray are many, including:

- Ability to have gas transmission rates uniformly throughout the rigid package
- Engineer specific transmission rates of a rigid package
- Significant reduction in amount of produce that goes anaerobic
- Potential shelf-life extension
- Allow produce items restricted by current technology to be packaged in a rigid tray format

No matter which format (flexible or rigid) is chosen, if proper Modified Atmosphere Packaging is desired then the controlled and quantifiable transmission of gases through the package in concert with the physiological characteristics of the produce being packaged is necessary. If there is no control or quantification of gas transmission rates, then optimal modified atmospheres cannot be guaranteed and the packaging system is thereby out of control. There are a number of reasons for an out-of-control packaging system, including improperly quantified produce physiological properties, an improperly specified package and out of specification raw materials. However, the most common reason is due to a leaking package. If the package does not have a leak-free seal, then gases will immediately begin to pass through the leak. Depending upon the size of the leak, the impact could range from missing the optimal target modified atmosphere to allowing the package to remain at ambient conditions. In either case, optimal shelf life and quality will not be achievable.

Therefore, one of the most important packaging parameters that must be considered is the selection of the sealant layer polymer and configuration. Choice of the correct sealing polymer and format is dependent upon operating parameters, including package machine type, filling speed, package configuration, seal configuration as well as product type and weight. Each polymer has its own sealing characteristics, including ultimate seal strength, hot tack strength, seal initiation temperature, ability to seal through contamination and oxygen transmission rate. Careful consideration should be given in order to optimize the specific polymers characteristics to the specific requirements of the package necessary properties.

In certain circumstances, a peelable seal is desired. This can be in both a bag or tray configuration, however, it is much more common in a tray configuration. There are a number of technologies that can be employed to achieve an optimal peelable seal. As Gorny and Brandenburg (2003) point out, peelable lidding stock technologies are generally complex; therefore, a dialogue with a packaging expert is recommended. The three most commonly available peelable technologies are controlled contamination, dissimilar resins and controlled delamination, with each having its own advantages and disadvantages.

Rigid packaging does provide a number of distinct offerings over flexible packaging including:

- Greater physical protection for sensitive produce
- Rigid bowl or tray may be used as the serving vessel for the consumer
- Rigid packaging can be made stackable, which can significantly reduce the store shelf footprint. Note: This option may greatly decrease lidding film gas transmission effectiveness

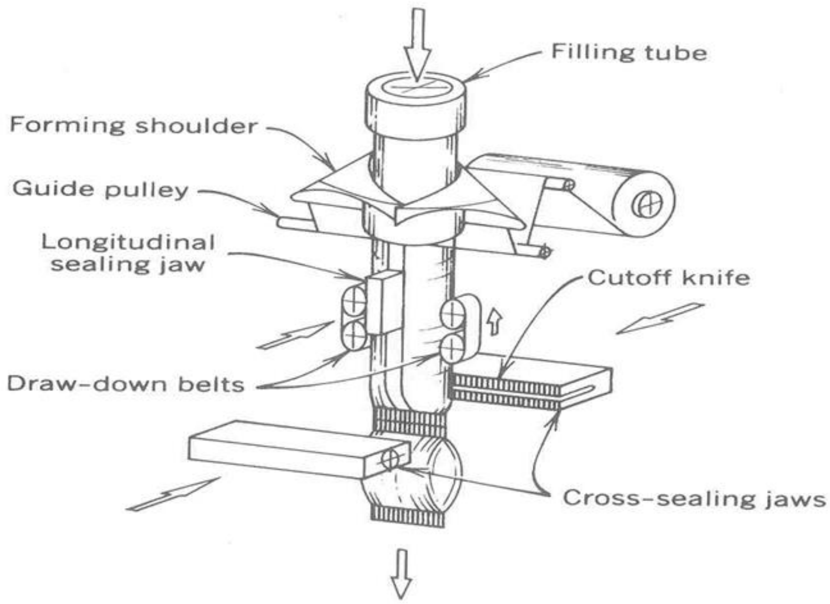
Stand-Up Pouches

Stand-up pouches can be obtained either in a preformed or roll stock format. The distinguishing features are that at least one side of the bag is gusseted, and stiffer polymers are utilized allowing the pouch to stand on its own. This stand-up feature allows for product differentiation and smaller footprint on the store shelf. Although stand-up pouches can be designed and manufactured with either engineered polymer or microperforation technology, generally they are microperforated due to the low OTR of the stiffer polymers required to achieve the stand-up feature.

Packaging Equipment

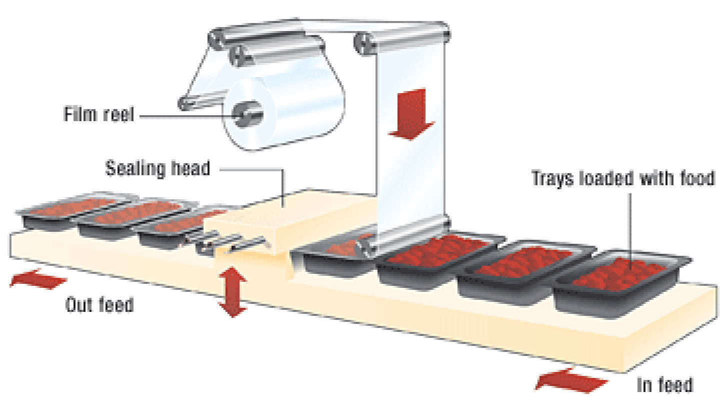
Packaging equipment used for Modified Atmosphere Packaging is as varied as the packaging types themselves. Packaging equipment can range from the basic handheld impulse sealer to processor-controlled automatic form fill and seal lines. Within this plethora of options, however, are two fundamental categories; vertical and horizontal. **Figure 5** and **Figure 6** are examples respectively of a vertical and horizontal filling line. Both styles of packaging equipment can be configured for either manual or automatic operation.

Figure 5 Vertical Filling Line



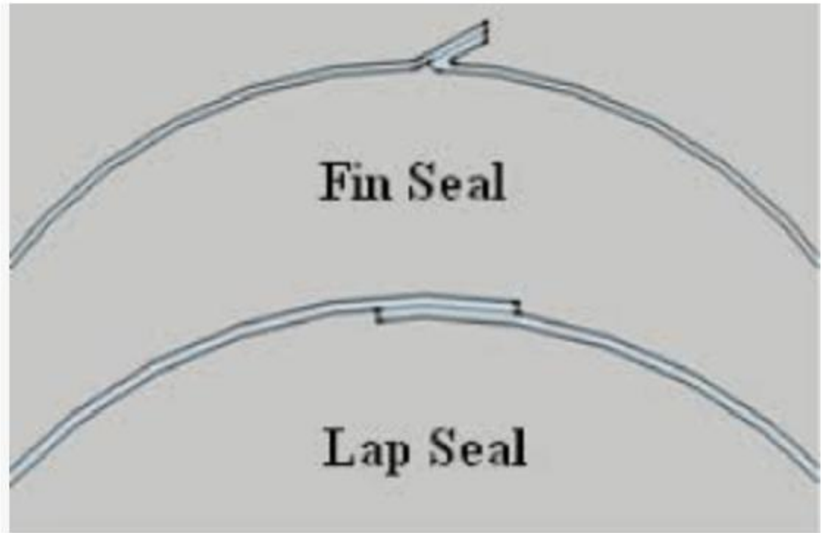
From Gorny, J.R., & Brandenburg, J. (1997). Packaging design for fresh-cut produce. In A.L. Brody, & K.S. Marsh (Eds.), *The Wiley encyclopedia of packaging technology* (2nd ed). Wiley.

Figure 6 Horizontal Filling Line



Although there are exceptions, generally, vertical packaging machines are designed to run flexible style packaging and horizontal machines are designed to run rigid style packaging. Within the vertical configuration, there are two seal configurations: fin and lap as seen in **Figure 7**. Determining which seal type will be used is a critical step in the package design since the seal type can impact polymer selection, graphics and material usage. The most significant difference between the two types is that the fin seal configuration seals only the inside of the package whereas the lap seals the inside to the outside of the package. Therefore, when a lap seal configuration is used, the polymers on both the inside and outside of the package must be sealable.

Figure 7 Fin Versus Lap Seal



MAP as a Technology Platform: Active and Intelligent Packaging

Packaging engineers and designers have for many years been working on ways to engineer packaging such that Modified Atmosphere Packaging takes an even more active role in protecting and maintaining the quality of fresh-cut produce. Common examples of active packaging include antimicrobial, temperature switches, moisture absorbent, antifog and cook-in packaging. In addition, new technologies such as RH, ethylene, and ripeness detection and control are also being evaluated. With the advent of these new technologies Modified Atmosphere Packaging is transitioning from a purely packaging role to that of a technology platform. In other words, MAP becomes not only a packaging application but also a vehicle by which other beneficial attributes can be realized.

In all additive applications, careful consideration must be given when considering the incorporation of any new technology into a Modified Atmosphere Package. Although the addition may enhance or add certain desirable features or properties they will almost surely detract or negatively impact other properties or functions. The key property in fresh produce applications that is most likely to be negatively affected will be the overall gas transmission rate properties of the packaging system.

Antifog

Antifog technology is often incorporated into produce packaging to prevent water condensation on the inside of the package, which would obscure a potential purchaser's view of the product. Antifog technologies functionality is accomplished by coating or impregnating the polymer/film used for the interior surface of the flexible packaging material with compounds that reduce water surface tension or reduce the ability of the water to adhere to the packaging material and thus cause the condensed water to run off the interior surface of the package.

There are two categories of antifog technology: applied coatings and sealant layer incorporation, with each yielding distinct advantages and disadvantages. The main disadvantage with applied coatings is cost and that the coatings are applied to the non-treated surface, and most applied coatings require a surface treatment to guarantee strong adhesion to the packaging structure. Therefore, antifog coating pick off may occur. Coordination and good communication with both the antifog supplier and the converter is critical when planning to use this type of antifog coating.

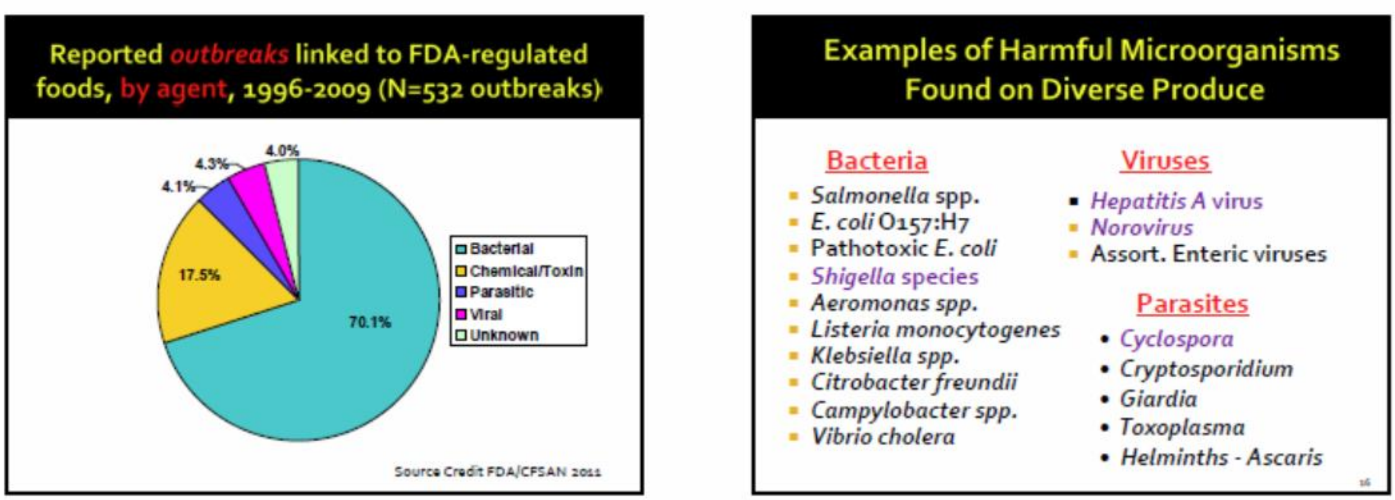
Antifog sealant layer blends incorporates or blends an antifog compound into the sealant layer during the film manufacturing process. This system significantly reduces the cost of adding antifog technology to produce packages since no specialized converting equipment is needed and, thus, has advantages both for the converter and end-user. The major disadvantage to antifog sealant layer blends is that the antifog is, by default, in the sealing area of the bag; therefore, weaker seals and potentially package leakers are a greater possibility. The optics and performance of this type of antifog technology may also be inferior to coated antifog. In addition, in order to properly function, the incorporated antifog must “bloom” to the service and, thus, can cause a significant reduction in the gas transmission rates of the package.

Antimicrobial Packaging

The U.S. Centers for Disease Control and Prevention (CDC) summarizes that each year, 1 in 6 Americans get sick from and 3,000 die of foodborne diseases (see **Figure 8**). Reducing foodborne illness by 10% would keep 5 million Americans from getting sick each year. Preventing a single fatal case of E. coli O157 infection would save an estimated $7 million.

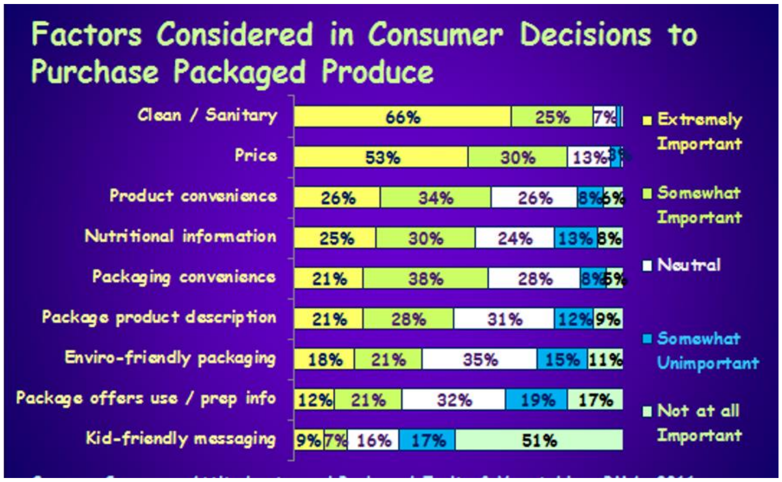
Finally, according to a new report by the CDC, at least 2 million people in the United States develop serious bacterial infections that are resistant to one or more types of antibiotics each year, and at least 23,000 die from the infections. The United States is not alone in raising the alarm over antibiotic drug resistance. Last March the chief medical officer for England said antibiotic resistance poses a "catastrophic health threat." That followed a report last year from the World Health Organization (WHO) that found a "superbug" strain of gonorrhoea had spread to several European countries.

Figure 8 Pathogenic Microorganisms



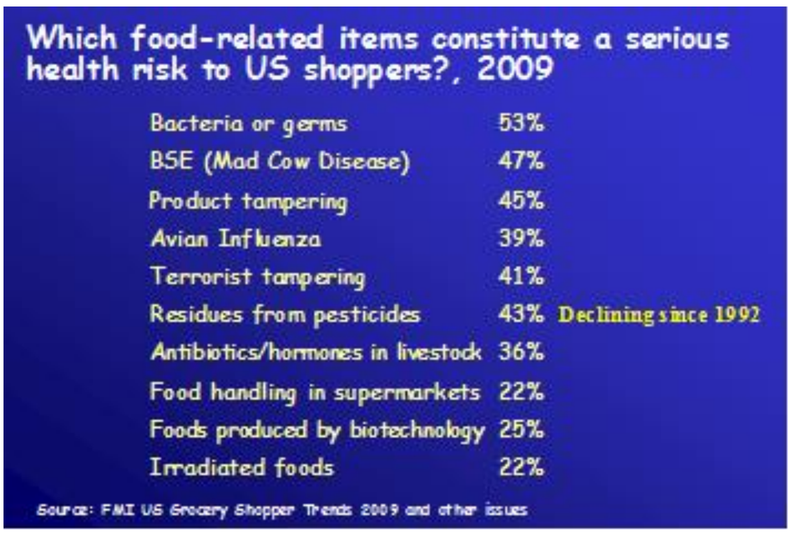
We can also see that Clean Sanitary (Safe) produce is a leading factor in the consumers buying decision process (see **Figure 9**).

Figure 9 Consumer Purchasing Data



In **Figure 10**, we can see that bacteria is the leading health risk for shoppers in the U.S. This remains true in 2022.

Figure 10 Food Health Risk Data



Note: While this table was published in 2009, the data remains relevant in 2022.

(Additional details courtesy of Dr. Roberta Cook UC Davis detail the specific types of bacteria as the details on both outbreaks and illnesses.)

State of the Existing Antimicrobial Technology

Many antimicrobial additives are either coated or bloom to the surface of the inside layer of the package. Therefore, the issues of gas transmission rate reduction and sealing ability are equally present. Their method of operation is by contact of the antimicrobial component to the packaged product. Although common place in protein Modified Atmosphere Packaging, they are not widely employed in produce MAP. This is due to the relatively high amount of product surface area in relation to package surface area in fresh produce applications. This ratio imbalance prevents the majority of the product to come in contact with the microbial agent thus making these systems relatively ineffective (see **Table 3**).

New technologies are currently under development with potentially exciting results and effectiveness, including technologies which have a controlled release within the package. With controlled release antimicrobials the efficacy of the antimicrobial is greatly released as the volatile antimicrobial is in contact with the vast majority of the produce surface area. The challenges with controlled release relate to methods of incorporation and release, dose levels, consistency and regulatory approval. Compounds being evaluated include:

- CO_2
- ClO_2
- SO_2
- O3
- Natural antimicrobials

Table 3 Antimicrobials

Existing Solutions	Cost	Efficacy	Regulatory	Commercial	Advantages	Disadvantages	Technology
Conventional silver coatings	-	0	+	+	Well established	Cost	Ag
Natural antimicrobials	0	0	+	0	Natural	Efficacy and consistency	Natural
Controlled release technologies	-	+	-	-	Efficacy	Regulatory approval	ClO_2, SO4 CO_2

Combinations of Produce, Protein and Carbohydrates

The growth of varietal blends and novel combinations is a direct result of processors continually searching and investigating ways to differentiate their product line. This need to differentiate has led to an explosion of vegetable and leafy green combinations, vegetable stew and soup mixes, varieties and combinations of tropical fruits. These new opportunities place additional challenges and requirements on the technology of Modified Atmosphere Packaging. Specifically, each separate and unique raw material has its own physiological properties combined with its own individual optimal target atmosphere. Therefore, not all fresh-cut fruit and vegetables are computable. In other words, what may be an optimal target for one product may be very detrimental to another. Compromises in atmosphere targets will most likely be required; however, it is critical to minimize the compromises. Instead, companies are quantifying the physiological properties of their individual raw materials and then grouping like products in order to create desirable blends and combinations without having to sacrifice quality and shelf life.

The combination of produce, protein and carbohydrate into a fresh-ready-meal format has also increased significantly over the past few years. A technology that is still more widespread in Europe than in other world markets is rapidly gaining mainstream popularity. One of the main driving forces for this change is the desire of non-traditional “fresh items” to be associated with fresh produce due to its health benefits. This type of packaging requires different types of modified atmosphere technology for each type of food category. Hence these applications generally require multi compartment trays to separate each food product with unique target atmospheres in each compartment. Since within a single package there are different and unique food groups, effective package design must cross over and combine often competing requirements. Coordination between the packaging designer and food scientists from each of the participating food groups is essential.

Ethylene Management

Absorbent packaging describes the packaging’s ability to absorb liquids or gases produced by fresh-cut produce. Buildup of gases such as ethylene, the ripening hormone, can significantly reduce shelf life. Technologies incorporated into Modified Atmosphere Packaging include the development of high ethylene transmission polymers as well as absorption. Gas absorption technologies include sachets placed inside the package and additives within the inner polymer layer. Unlike gas transmission technology, which allows gases to leave the package entirely, gas absorption technology absorbs and traps it within the package. The net effect of the two technologies can be similar. Additives incorporated or placed within the package will need to meet all applicable FDA direct food contact regulations. Gas absorption technology is applicable in all types of packaging formats.

Moisture Management

Liquid absorption or liquid control has grown with the introduction and growth of the fresh-cut fruit market. Liquid absorption technologies work by trapping or venting free moisture or purge. If trapping the free liquid within the package, then the technology transports the liquid into another portion of the package and holds it there. If a venting technology is employed, then the free liquid is expelled or vented out of the package. Technologies can include absorbent pads, absorbent gels, high water vapor transmission rate WVTR, films, in combination with compartmentalized packaging. Removal of the liquid from the fresh-cut produce can extend shelf life and trap microorganisms as well as prevent cross contamination from the liquid. Although most commonly found in combination with rigid packaging, the technology can be adapted to flexible packaging. Moisture, humidity and free liquid management are several of the technology hurdles with evaluation MAP for whole produce. This will be discussed in greater detail in the section entitled Next generation MAP.

Microwaveability

Historically, one of the fastest growing segments of fresh-cut produce packaging is the use of microwaveable and steam-in microwaveable packages. This trend has grown beyond the fresh cut leafy green portion of the market, spinach, where it originated. The growth of this market segment has been especially strong in the new baby potato market. As Lisa Cork explained at Produce Marketing Association's (PMA) Fresh Summit convention in Anaheim (2012), one of the trends seen at the recent PMA was the trend toward microwavable baby potatoes. Whereas in 2011, there were three or four companies with a microwave potato range; in 2012, just about all potato packers exhibiting had a microwave offer.

In addition to potatoes, brussels sprouts, broccoli, asparagus, peas, cauliflower, carrots, beets and green beans can all be found in microwave MAP packages.

In order for microwave packaging to function properly there must be a method by which the internal pressure, steam, which is created within the bag during the cooking process, can be vented. There are a number of steam venting technologies including:

- Pressure release labels
- One-way valves
- Microperforations and scoring
- Pressure release through the seal area

It is critical to insure not only proper venting but also optimal MAP design that the two technologies remain separate while, at the same time, working together. In other words, the technology that is utilized for the venting cannot at the same time be used for modified atmosphere control.

With respect to the technology of microwave packaging, it is necessary to evaluate both the functional as well as regulatory requirements, specifically migratory compliance. Polymers that are direct contact food compliant and act as "functional barriers" at ambient temperatures may or may not remain so under elevated temperatures. In addition, as the internal package temperature rises, fewer and fewer polymers remain both functionally and regulatorily compliant. It is, therefore, critical to engage in a detailed dialogue with the packaging supplier and to make sure that all applicable conditions of use regulations have been identified. The following sections of the U.S. Code of Federal Regulations (CFR’s) may be applicable when dealing with microwave and steam-in microwave applications.

- 21CFR § 177.1350
- 21CFR § 177.1390
- 21CFR § 177.1395
- 21CFR § 177.1520

It is important to assure that, before developing a microwave product, you conduct in-depth discussions with your packaging supplier to assure that the above-mentioned issues have been addressed and that you are in full regulatory compliance. Not all packaging materials are suitable for all microwave applications.

MAP and Sustainability

Sustainability is one of the most active areas in package design not only from a technical perspective but a marketing and merchandizing perspective as well. Sustainability is a very broad concept, which can mean many things to many people. With respect to MAP, it is most commonly, by consumers at least, associated with the recyclability, compostability and degradability of packaging materials. Although, in the background, source reduction is a very active and effective component in packaging sustainability.

Sustainability is also a concept where, often, perception becomes reality. That said, the science behind Modified Atmosphere Packaging sustainability includes a variety of options, each displaying positive and negative traits. As with the other incorporated packaging platform technologies previously highlighted, it is important to quantify the impact of any sustainability option on the functionality of the MAP system.

Compostable and degradable technologies are additive technologies, where an additive allows the packaging to become more easily composted or degraded. The conditions of use, efficacy and impact, especially package OTR, of these additives are critical in determining their fit for use. When evaluating these technologies, it wise to ask the supplier to provide quantitative evidence of efficacy and under what specific conditions of use.

Recycling of many current produce MAP packages is tricky since the packages are blended polymer packaging and must then be given a 7 recycle code. The most significant exception is PET and PP rigid trays.

Source reduction, as the name implies, is reducing the amount of packaging used for a specific application through the use of thinner films and structures produced by stronger polymers. As the Flexible Packaging Association states “Less Waste in the First Place.”

Renewability is the use of raw materials that come from renewable resources. This is a challenge for fresh produce as many of the packages made for these sources are opaque (i.e., fiberboard). The most common example of a renewable product in the produce market is PLA, Poly lactic acid, which is a polymer that is derived from corn. The associated film produced from PLA has certain very desirable attributes including clarity and stiffness. There are also polymers that can be derived from a variety of vegetables and plants. As previously mentioned, it is necessary to quantify the efficacy of the packaging and under what specific conditions of use.

Common Sustainability Packaging Options

- Recyclable
    - Post industrial
    - Post-consumer
- Renewable
- Compostable
    - Industrial
    - Consumer
- Degradable
    - Oxy
    - Bio
    - Photo
- Source reduction

Next Generation of MAP Products
As previously mentioned, Modified Atmosphere Packaging is becoming more and more commonplace in the whole produce retail and foodservice market as well as up and down the global fresh produce supply chain. The market pressures that are fuelling this trend include COOL legislation, inventory control, the global shipment of produce and theft reduction.

The technical challenges as this trend continues deal in large part with:

- Free liquid
- Water vapor
- Relative humidity
- Temperature impact and control
- Pressure venting during vacuum cooling

Currently, the packaging primarily used in whole produce and global distribution channels is not Modified Atmosphere Packaging although it certainly may have the same appearance. The packaging generally used, whether in the form of a rigid clamshell, vented crate or macroperforated stand-up pouch, is vented such that the internal atmosphere of the package remains the same mixture and pressure as the ambient atmosphere. In other words, the internal atmosphere is not modified. Historically, this has been necessary to:

- Deal with the significant temperature changes within the supply chain
- Minimize the buildup of free liquid
- Minimize internal relative humidity fluctuations

In order for these markets to fully utilize the benefits of optimizing quality, shelf life and protection that MAP offers, these challenges will need to be fully overcome.
Currently, polymers with significantly increased WVTR are being developed and commercialized along with technologies that can more effectively deal with humidity, temperature pressure and free liquid fluctuations. In addition, work is being done to combine competing packaging technologies in order to reap the benefits of each technology while at the same time downplaying the disadvantages.

As MAP is evaluated up and down the global supply chain the definition of a package is even being challenged. Commercial refrigerators, storage rooms, trucks, rail cars, air and sea freight containers are all being evaluated to see if the science and technology of MAP can be brought to bear to improve incoming quality shelf life and ultimately global distribution.

MAP as a Marketing and Sales Tool

Packaging has always played an important role in drawing in consumers. In addition to the functionality that packaging provides, there is the marketing, advertising and merchandising aspect of packaging. Packaging can not only provide functionality, it can impart the sense of convenience, shelf appeal freshness and safety. “Most [fresh producers] underutilize packaging to drive down costs. But what if we could use packaging to drive sales and to drive value?” asks Lisa Cork at the Produce Marketing Association’s (PMA) Fresh Connections: Southern Africa event in Cape Town.
“If you’re already packaging your produce, you can create a sales opportunity at almost no additional cost. It’s all about packaging optimization.”

As retail space becomes more competitive and costly, the need to have packaging participle in the advertising and marketing of not only the product but social messages will only increase. This, coupled with the advancements in printing technologies, makes packaging the ideal marketing media. Whether you have the package itself printed, which is advantageous for larger volume, more mature product lines or you use a printed label, which is more cost effective for smaller, newer items, the printed package can get your message to the target audience. As Lisa concludes, “Remember, your pack is your in-store mini billboard. It can help capture shopper attention and help you sell your products, but only if you optimize the message on-pack.” Ultimately, the combination of high-quality graphics with new packaging technologies and geometries will continue to redefine and expand the look and placement of the traditional produce retail space.

Future Trends

It is an exciting time within the modified packaging industry. There are immerging technologies and opportunities, which will have far-reaching impact on the marketplace. Issues such as sustainability in packaging, country of origin labelling, supply chain challenges and the impact of packaging on food safety issues are already providing both tremendous challenges and opportunities. The challenge will be how to incorporate all of the desired requirements into Modified Atmosphere Packaging without diluting its fundamental purpose. When packaging becomes all things to all applications, it runs the risk of becoming mediocre at best with respect to any one requirement.

It is an exciting time and an exciting future with the ongoing need to focus. At the end of the day, what are the true customer requirements and what creative technologies can be brought to bear to address those requirements. We must remember that packaging is a technology platform, technical delivery technology and marketing tool built into a package. At the end of the day, packaging must be an integral part of the entire new product development process.

The Technology and Supply of Packaging is a Global Effort in a Global Market.

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General Glossary Of Terms

- Adhesive: Two Component: Adhesive and Catalyst two component system combined in specific ratio
- Antiblock: Antiblock concentrates prevent polyolefin films from adhering both to themselves and to processing take equipment. These concentrates achieve this effect through a dispersion of inorganic solids that "roughen" the film surface
- Antifog: Antifog agents, also known as anti-fogging agents and treatments, prevent the condensation of water on a surface in the form of small droplets which resemble fog
- Coextrusion: A film containing specific resins in individual layers within the film
- APET: Amorphous Polyester
- CAP: Controlled Atmosphere Packaging
- COF: Coefficient of Friction High COF less slippery; Low COF more slippery
- CPET: Crystalline Polyester
- EVA: Ethylene Vinyl Acetate
- Ga. Gauge: Thickness measurement 100 gauge equals 1 mil
- Gm, gms; grams
- LDPE: Low Density Polyethylene
- LLDPE: Linear Low Density Polyethylene
- MAP: Modified Atmosphere Packaging
- Mil Thickness measurement: 1 mil is 1 thousandth of an inch
- OPP: Oriented Polypropylene
- OTR: Oxygen Transmission Rate
- Polyolefin: Polyethylene type resin
- PA: Nylon
- PET: Polyester
- Plastomer Metallocenes: ULLDPE resins manufactured using the single site Metallocene catalyst
- PLA: Poly Lactic Acid corn based sustainable polymer resin
- PP: Polypropylene
- PS: Polystyrene
- PVC: Poly Vinyl Chloride
- RPET Recycled Polyester
- Slip Additives: Slip concentrates provide surface lubrication to facilitate rapid processing of polyolefin films and molded articles. The fatty amide active ingredient blooms to the surface and lowers the coefficient of friction.
- Treatment: Method for either chemically or electronically oxidizing/roughening the surface of plastic film: Treatment allows for ink, adhesive and coating adhesion.
- ULLDPE: Ultra Low Linear Density Polyethylene, Plastomer Metallocenes
- VLLDPE: Very Low Linear Density Polyethylene