FRUIT & VEGETABLE PACKAGING GUIDE

How package testing solutions help maximize the quality and shelf life of fresh produce

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UNDERSTANDING STAKEHOLDER CHALLENGES

Packaging for fresh fruit and vegetables plays a critical role not only in protecting produce but also in preserving freshness, maintaining visual appeal and reducing waste throughout the supply chain. To design and implement effective packaging solutions, it is essential to understand the needs and expectations of the key stakeholders involved: wholesalers, retailers and consumers. Each group approaches packaging with distinct priorities, but all share the common goal of maximizing the quality and shelf life of fresh produce.

As a **wholesaler**, effective packaging minimizes your losses, supports your compliance with food safety regulations, and helps uphold your reputation in the supply chain. Your main priority is to ensure that fruit and vegetables arrive at their next destination in optimal condition. This means packaging must:

- Protect against mechanical damage during handling and transportation
- Maintain temperature and humidity control to prevent spoilage
- Be stackable and efficient for palletization and storage
- Reinforce brand values, such as sustainability

UNDERSTANDING STAKEHOLDER CHALLENGES (CONT'D)

As a **retailer**, your focus is on how packaging influences consumer behavior and product turnover. Your objectives include:

- Extending shelf life to reduce waste
- Optimizing display by using packaging that fits well within shelving systems and allows clear visibility of the produce
- Maintaining visual appeal to attract customers and encourage purchases

As a **consumer**, you are concerned with what you see, feel and experience, and packaging can influence your perception and purchase decisions as much as the produce itself. Your expectations include:

- Visual cues of freshness, such as vibrant color and minimal blemishes
- Convenient, easy-to-open packaging that protects the contents but doesn't overcomplicate access
- Sustainable materials that align with growing environmental awareness
- Clear labeling to provide reassurance about origin, quality and safety.

It is important for wholesalers and retailers to understand consumers' needs and biases and to be aware of consumer trends. It can be a good idea to educate your employees about the advantages of packaging, so they can provide informed answers to consumers' questions and concerns about plastic and over-packaging.

THE IMPACT OF RESPIRATION

To meet the diverse needs of wholesalers and retailers, as well as the preferences of consumers, packaging must do more than simply contain the fresh produce. It also plays a crucial role in managing the natural physiological processes of fruit and vegetables after harvest, and the most impactful of these is respiration.

Even after being harvested, fruit and vegetables continue aerobic respiration, consuming oxygen (O_2) and producing carbon dioxide (CO_2), water and energy. This energy powers vital cellular functions, maintaining membrane integrity, color, texture and ongoing metabolism, but also leads to the gradual deterioration of the produce. As the carbohydrates and other organic compounds that support the product's freshness, flavor and nutritional value are broken down, this affects its overall quality and shelf life.

The respiration process continues until carbohydrate reserves are depleted, which can last from a few days to weeks, depending on the crop and conditions. Produce with high respiration rates, such as lettuce and asparagus, exhaust reserves quickly, while low-respiration items, such as apples and potatoes, last longer. It should be noted that temperature plays a key role. For example, a 10 °Celsius increase can double or even triple the respiration rate, shortening the shelf life of the produce accordingly.

THE IMPACT OF RESPIRATION (CONT'D)

CONSEQUENCES

The consequences of continued respiration in fresh fruit and vegetable products include:

- **Weight loss and shriveling** – Water evaporates (transpiration), and CO_2 is released, which can lead to weight loss, shriveling and textural degradation, reducing the visual appeal and texture of the produce and its market value.
- **Heat generation** – The heat created by respiration can raise internal package temperature, destabilizing cold storage.
- **Condensation and decay** – Heat and high moisture from respiration lead to moisture condensing inside packaging. Condensation encourages microbial growth (yeasts, molds and pathogens), accelerating decay, especially in high-humidity items such as lettuce.
- **Fermentation and off-flavors** – Insufficient O_2 in sealed packaging triggers fermentation, producing off-flavors, odors and tissue damage.

Understanding respiration is therefore essential to designing packaging that supports freshness throughout the supply chain.

MAINTAINING FRESHNESS & MINIMIZING WASTE

To maintain the freshness of fruit and vegetables, respiration can be controlled by modifying the microenvironment around the produce. This is achieved through a combination of suitable food packaging and a temperature controlled supply chain that keeps the produce at a constant temperature from harvest through to consumption. Different types of produce have specific temperature requirements during transportation and storage, so in each case it is important to maintain the correct temperature to prevent spoilage. Effective communication and coordination among all parties involved in the supply chain is also important, to ensure that produce is always handled correctly.

Proper storage conditions can substantially extend the shelf life of fruit and vegetables. Key factors influencing this extension include temperature, humidity and a modified atmosphere – specifically the levels of oxygen, carbon dioxide and ethylene. The ideal storage environment depends on several variables such as the type of produce, its stage of ripeness, processing methods, harvest time, and other specific characteristics.

Product	Temp in °C	% relative moisture	% O_2	% CO_2
Apple	0-5	90	2-3	1-2
Banana	12-15	85-100	2-5	3-5
Bean sprouts	0	90-98	5	15
Broccoli/cauliflower	0-5	90-95	2	5
Cucumber	8-12	90-95	3-5	0
Lettuce head	0-5	95	2-5	0
Mushrooms	0-5	90-98	5	10
Plum	0-5	90-95	3	8
Strawberry	0-5	90-95	10	15-20
Tomato (ripe)	8-12	85-98	3-5	5-10

Optimum storage of fruit and vegetables. Source: Danish Technological Institute.

MAINTAINING FRESHNESS & MINIMIZING WASTE (CONT'D)

Reducing food waste is a critical goal for economic, environmental and ethical reasons. To minimize food waste, it is important to protect produce from physical damage such as bruising, which occurs when it is subjected to pressure or impact. This damage not only affects the visual appeal of the produce – reducing its chances of being sold and risking financial losses for producers and retailers – but also diminishes its nutritional value through loss of vitamins, oxidation, moisture loss, microbial growth and accelerated decay. Improper packaging and handling – not only during transportation but also in-store by potential customers – are the leading causes of bruise damage in fresh produce.

There are further instances where consumer behavior can contribute to increased food waste. For example, some consumers opt to buy fruit and vegetables in bulk to keep costs down, but the large quantities often exceed what they can realistically eat before the food begins to spoil. As a result, much of it can go to waste, despite their good intentions. It is therefore important to increase awareness of the best methods of preserving produce. There is also a growing consumer trend to avoid plastic packaging because of environmental and sustainability concerns. However, plastic packaging can help in extending the shelf life of the produce by slowing spoilage and providing protection from bruising and contamination, thereby reducing food waste.

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TYPES OF PACKAGING

There is no 'one size fits all' solution for packaging fresh fruit and vegetables. A wide range of options is available, each designed to meet specific needs related to shelf life, product freshness, protection, sustainability and consumer preference. From high-tech systems that control internal gas composition to eco-friendly alternatives that reduce environmental impact, packaging plays a vital role in protecting produce and ensuring quality from farm to consumer. Let's look at some of the most widely used and innovative packaging types.

MODIFIED ATMOSPHERE PACKAGING

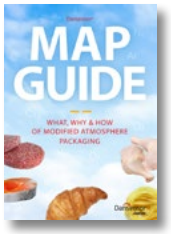
When fruit and vegetables are in sealed packaging, there is a certain amount of 'empty' space that is not occupied by the produce. This is known as the headspace. In modified atmosphere packaging (MAP), a specified mixture of O_2, CO_2 and nitrogen (N_2) are inserted into the headspace to help preserve the produce. After the fruit and vegetables have been placed in their packaging, the package is flushed with a tailored gas mixture to replace the ambient air, allowing the produce to be preserved as effectively as possible. The package is then hermetically sealed, to maintain the internal atmosphere and extend shelf life.

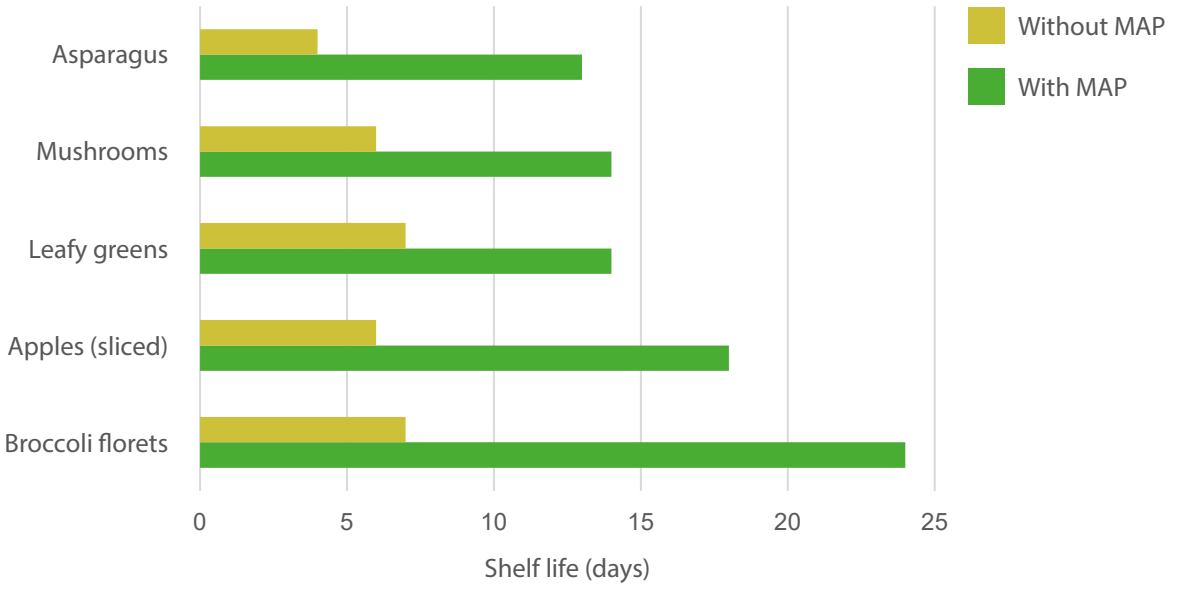
TYPES OF PACKAGING (CONT'D)

MAP slows the respiration rate of the produce, thereby reducing microbial growth and oxidation, and delaying ripening and aging. This extends the shelf life of the produce and helps to reduce food waste, supporting sustainability goals. For example, broccoli, lettuce, sliced apples, mushrooms, pre-chopped mixed vegetables for stir fry, ready-to-eat salads, cauliflower rice and asparagus all benefit from MAP, typically doubling or even tripling their refrigerated shelf life through controlled gas levels. Tailoring gas levels within the packaging to the respiration rate of the produce is essential for maximum shelf life extension.

MAP also preserves the color, flavor, nutritional value and texture of the produce, helping to create a positive experience for consumers and enhance the reputation of the producer. In addition, MAP provides significant benefits in the supply chain, as it enables produce to be stored for longer and transported further, while remaining fresh. It should be noted, though, that MAP does not slow the growth of all harmful bacteria, so refrigeration may still also be required in some instances.

You can learn more about MAP in our MAP Guide.
Download here ➔





Examples of how MAP extends the shelf life of fresh produce. Source: Sciencedirect.com.

TYPES OF PACKAGING (CONT'D)

PERFORATED PACKAGING

Perforated packaging is commonly used for produce such as berries, leafy greens, tomatoes, cucumbers and grapes because

it helps to balance gas exchange, control humidity and reduce spoilage without fully sealing the produce. By managing produce respiration and allowing excess gases to escape and fresh air to circulate, perforated packaging maintains freshness by preventing the anaerobic conditions that cause spoilage and off-odors. High humidity inside sealed packaging can lead to condensation, promoting mold and decay, but the small holes in perforated packaging vent excess moisture, reducing the risk of microbial growth. Perforated packaging is easy to open, allowing consumers to tear the packaging cleanly and predictably. Furthermore, perforated films help to improve the appearance of the produce by preventing condensation and fogging within the packaging.

Micro-perforations can be used in MAP packaging as a means of providing a passive rather than active MAP system. In active MAP, the atmosphere is actively created by flushing the package with a specific gas mixture before sealing. The desired gas levels are reached immediately. In passive MAP, with micro-perforations, the package is sealed without gas flushing. The micro-perforations added to the packaging film fine-tune the gas exchange between the inside and outside of the package, and the modified atmosphere develops naturally over time as the produce respires. The size, number and placement of the micro-perforations are designed to match the specific respiration rate of each fruit or vegetable.

TYPES OF PACKAGING (CONT'D)

ACTIVE PACKAGING

Active packaging solutions for fruit and vegetables go beyond traditional passive barriers by actively interacting with the packaged environment to enhance freshness, extend shelf life and reduce waste. Types of active packaging include:

- **Oxygen scavengers** – These are materials incorporated into packaging to absorb residual oxygen, thereby reducing oxidation and inhibiting the growth of aerobic microorganisms. Common scavengers include powdered iron or ascorbic acid. These are especially beneficial for products sensitive to oxygen-induced spoilage.
- **Ethylene absorbers** – Fruit and vegetables emit ethylene gas, which accelerates ripening. Ethylene scavengers, such as potassium permanganate or activated carbon with metal catalysts, are used to absorb this gas, slowing down the ripening process and extending shelf life.
- **Moisture absorbers** – These are materials or components specifically designed to control excess humidity inside the packaging. Their main purpose is to absorb free moisture, which can otherwise lead to condensation, mold growth or microbial spoilage, and accelerated decay or texture degradation. Common types of moisture absorbers include desiccant sachets or pads, absorbent liners or sheets, and humidity-regulating films.

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TYPES OF PACKAGING (CONT'D)

BIODEGRADABLE PACKAGING

A combination of environmental, regulatory and consumer-driven factors is seeing a growing shift towards biodegradable packaging for fruit and vegetables. Typical examples of biodegradable packaging include:

- **Polylactic acid (PLA)** – This is a biodegradable polymer made from fermented plant starches, such as corn or sugarcane. It is widely used in food packaging due to its transparency, compostability and suitability for thermoforming. It is commonly used for clamshell containers, films and trays for fresh produce, and can be blended with other materials, such as starch, to enhance flexibility and reduce costs.
- **Cellulose films** – These films are produced from plant-derived cellulose, offering a biodegradable and compostable alternative to conventional plastics. They are employed as wraps or coatings for fruit and vegetables, and provide good barrier properties against oils and greases, as well as excellent transparency and gloss, enhancing product visibility.
- **Mushroom-based packaging** – Mycelium, the root structure of fungi, can be utilized to create biodegradable packaging materials, providing a sustainable alternative to traditional plastics. These compostable materials are grown by combining mycelium with agricultural waste, forming a foam-like structure that is ideal for protective packaging applications, such as cushioning for delicate produce. The packaging can be molded into various shapes to fit specific product requirements.

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TESTING SOLUTIONS

PERMEATION TESTING

Accurate permeation testing is crucial when packaging fruit and vegetables correctly, as it enables producers to select the right packaging material for each type of produce. Because different types of fruits and vegetables have unique respiration rates and sensitivities to O_2, CO_2 and moisture, it is essential to understand and select packaging materials that maintain the optimal balance of gases and moisture in each specific case, to prevent spoilage, preserve freshness and extend shelf life.

Permeation tests are performed to assess the barrier properties of packaging materials and ensure that they provide the appropriate level of breathability.

These tests include:

- **Oxygen Transmission Rate (OTR)**
- **Water Vapor Transmission Rate (WVTR)**
- **Carbon Dioxide Transmission Rate (CO_2TR)**

Highly accurate advanced permeation analyzers perform these tests on different packaging barrier types and whole packages – including recyclable films, pouches, trays and lids – under controlled environmental conditions to simulate real-world storage and transportation conditions. Analyzers should comply with international testing standards, such as ASTM D3985 and F1307 for OTR measurements and ASTM F1249 for WVTR, to ensure reliable and standardized results.

Learn more

Knowing the permeation rates of different packaging materials helps food manufacturers select well-suited packaging solutions and define safe shelf life times for their products.

With its high precision and wide testing range, OX-TRAN 2/22 offers both the accurate, repeatable results required for packaging development, and it can keep up with the high-quality control demands of manufacturers by evaluating their new packaging materials.

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TESTING SOLUTIONS

GAS MIXING AND ANALYSIS

Precise gas mixing is crucial in fruit and vegetables packaging, as it helps to maintain the appearance, freshness, taste and quality of the produce, extend its shelf life and, ultimately, reduce food waste. To achieve this, high-capacity gas mixers and on-line gas analyzers work in tandem in a closed-loop system to ensure accurate, consistent gas compositions within MAP.

Gas mixers are responsible for blending the O_2, CO_2 and N_2 in ratios tailored for specific produce. Input gases from cylinders or central lines are fed into the mixer, which then precisely blends either two or three gases, depending on the set recipe. The mixer maintains a steady flow rate and constant gas composition, even if upstream pressure fluctuates. The output is fed directly into a flow-pack machine or tray-sealing equipment.

RECOMMENDED GAS MIX FOR SELECTED FRESH PRODUCE

Apples

O_2	CO_2	N_2
2-3%	1-2%	95-97%

Broccoli

O_2	CO_2	N_2
1-2%	1-2%	88-94%

Mango

O_2	CO_2	N_2
3-5%	5-10%	85-92%

Peppers (Capsicum)

O_2	CO_2	N_2
3-5%	1-2%	92-95%

Spinach

O_2	CO_2	N_2
5-10%	5-10%	80-90%

Strawberries

O_2	CO_2	N_2
5-15%	15-60%	25-80%

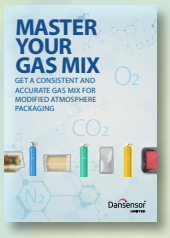
Source: Simona Colli, AMETEK Italy

TESTING SOLUTIONS

On-line gas analyzers monitor the gas composition being delivered into each package, in real time. The analyzer is placed on the packaging line and continuously samples the gases inside the tray sealer or flow packer just before sealing takes place, checking if the actual gas composition matches the target mix. If any deviation is detected – too much O_2, for example – the analyzer sends feedback to the gas mixer, which then auto-adjusts valve settings to bring the gas mix back to specification.

Combining these two systems in an integrated approach not only ensures product integrity but also optimizes gas usage, reduces waste and enhances overall production efficiency.

To learn more about gas mixing, you can download our guide, Master Your Gas Mix
Download here ➔



MONEY-SAVING ON-LINE SOLUTIONS

An optional GasSave functionality is available on ***Dansensor® MAP Check 3*** *continuous gas analyzer. By precisely monitoring and adjusting the gas content on flow packaging machines, GasSave can significantly reduce gas consumption – often by 20-50% – providing major cost savings without compromising package quality.*

Precisely blend, customize gas mixtures on-site with ***Dansensor MAP Mix Provectus®.*** *Save money and increase flexibility compared to using pre-mixed gases. Supply adjustable mixtures directly to the packaging line (for flow packers) or to a buffer tank (for thermoformers or tray sealers).*

Learn more

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TESTING SOLUTIONS

HEADSPACE GAS TESTING

Even if you are using a gas mixer and a continuous gas analyzer to ensure that the correct gas composition is being delivered to your fruit and vegetable packaging process, it is still necessary to perform headspace gas testing. There are several reasons for this. Firstly, although the gas mixer ensures that the input gas is correct, it does not account for a loss of packaging integrity – for example, seal failures, leaks, or incorrect or incomplete gas flushing – which can cause the final headspace composition to differ from the intended mix. There may also be variations in the packaging process itself, machine inconsistencies, operator error or equipment malfunction, all of which can affect how much of the target gas composition ends up inside the final package. Headspace gas testing provides critical feedback for controlling and validating the packaging process, ensuring that the correct gas composition is consistently achieved inside the final package.

Headspace testing is required by many food safety and quality assurance standards (for example, the BRCGS Food Safety Global Standard and the IFS Food Standard) as part of verification procedures, regardless of process control measures. It is the final validation that the correct atmosphere is present inside the sealed pack, and therefore ensures the efficacy of the packaging process, product quality and regulatory compliance.

High-precision headspace gas analyzers can be used to measure the concentrations of gases within a sealed package and ensure that the internal atmosphere remains within the desired parameters over time. A needle or probe extracts a sample of the headspace gas from the package, and the sample is then analyzed using O_2 and CO_2 sensors. The analyzer processes the sensor data to determine gas concentrations, ensuring that they meet predefined specifications. Regular monitoring of the headspace atmosphere ensures that the conditions remain consistent, providing reliable quality for consumers.

Headspace gas analyzers, like ***Dansensor CheckPoint® 4****, play an important role in the quality control processes for MAP products by finding inconsistencies in internal gas composition, such as elevated oxygen levels, which could compromise the product's shelf life.*

Learn more

To learn more about testing headspace gas in MAP, you can download our Headspace Guide.
Download here ➔

TESTING SOLUTIONS

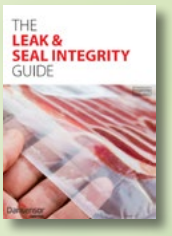
LEAK DETECTION

Airtight packaging is essential for the effectiveness of MAP. Even minor leaks can allow O_2 ingress, disrupting the intended gas composition and leading to spoilage, nutrient degradation, reduced shelf life and increased food waste. To ensure the integrity of fruit and vegetables packaging, it is necessary to employ robust leak detection solutions that will identify any breaches in the MAP that could alter the package's internal gas composition.

Leak testing devices have been developed to provide quality control of packages at the packaging line, helping to ensure that sealing settings are correct, inconsistencies are caught early, recalls are avoided, and consumer trust is maintained. These testers detect leaks in sealed packaging, especially in the MAP used for fresh produce. The most common method for testing packages is in a water bath, but more producers are moving towards non-destructive leak testing methods.

Effective leak detection helps in meeting industry standards for food safety and packaging integrity, and non-destructive testing enables the product to remain sellable if no leaks are detected. In addition, the prompt identification of leaks minimizes product recalls and waste due to compromised packaging, thereby reducing costs.

To learn more, you can download our Leak & Seal Integrity Guide.
Download here ➔



Conduct non-destructive leak tests with ***Dansensor LeakPointer® 3*** *to make sure products remain fresh and appealing for as long as possible. Ensuring products can stay fresh until their best before date is important for maintaining good relations with retailers and consumers and for protecting brand integrity.*

Learn more

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SUMMARY

Keeping fruit and vegetables fresh for longer is a complex challenge that requires a combination of scientific understanding, technological innovation and coordinated handling across the supply chain. Respiration leads to spoilage, so managing this process through temperature control and protective packaging is essential to preserving freshness and minimizing food waste. However, produce freshness is also affected by factors such as physical damage, inconsistent storage conditions, and even consumer behavior.

Advanced packaging solutions such as MAP, perforated packaging, active packaging technologies and biodegradable materials offer tailored approaches to extend shelf life, maintain quality and support sustainability goals.

Each method plays a unique role in preserving color, flavor, texture and nutritional value, while helping producers and retailers reduce product waste and financial losses.

Equally critical are testing and monitoring solutions. Accurate permeation analysis, precise gas mixing and headspace gas testing, along with robust leak detection, ensure that packaging systems perform effectively from production through to retail. With the right combination of packaging technologies and quality control tools, fresh produce can reach consumers in optimal condition, helping to reduce food waste, meet regulatory standards and deliver a better overall experience.

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REFERENCES

Guide: Packaging Fresh Fruit and Vegetables - Danish Technological Institute Packaging and Transport 2008

Plastemart.com: Active packaging technologies for fruits and vegetables important to prevent wastage.

Essential Food & Beverage Industry News for Professionals: Top 10 Mushroom Packaging Innovations & Industry Leaders.

Sciencedirect.com: Modified atmosphere packaging of fresh produce: Current status and future needs

Sciencedirect.com: Modelling respiration rate of fresh fruits and vegetables for modified atmosphere packages: a review

Kader, A. A. (2002). *Postharvest Technology of Horticultural Crops (3rd ed.)*. University of California, Agriculture and Natural Resources.

Jacxsens, L., Devlieghere, F., & Debevere, J. (2002). *Temperature dependence of shelf-life as affected by microbial proliferation and sensory quality of MAP vegetables.*

ABOUT US

At AMETEK MOCON, we prioritize understanding our customers and their challenges. Through four decades of experience and close collaborations, we have aimed to deliver excellence in every aspect of our work. With our wide range of quality control and permeation instruments, we empower companies to ensure longer shelf life for their products, reduce packaging waste, and develop sustainable packaging solutions. When you include AMETEK MOCON instruments in your packaging development and quality control processes, you can be assured that your test results are accurate, traceable and compliant. We can help improve the packaging of your products and protect your brand integrity.

Contact us and learn more

MOCON, Inc.
7500 Mendelssohn Ave. N.
Minneapolis. MN 55428 USA
Tel +1 763 493-6370
info.mocon@ametek.com
www.ametekmocon.com

MOCON Europe A/S
Rønnedevej 18
4100 Ringsted, Denmark
Tel +45 57 66 00 88
sales.dk.mocon@ametek.com
www.ametekmocon.com

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