AVIENT™

Understanding the Oxygen Barrier Performance of TPE Liners

Effective cap solutions to reduce oxidation and extend shelf life

INTRODUCTION

Driven by health-conscious, informed consumers who want beverages that deliver both convenience and enhanced nutritional value, ready-to-drink (RTD) beverages, protein shakes, functional drinks, and vitamin-fortified juices have become staples in the beverage industry.[1]

This change in consumer preferences is strongly influencing the beverage industry and packaging manufacturers. RTD protein beverages alone are seeing a 7.8% compound annual growth rate (CAGR) globally through 2030.[2] The industry is also experiencing a shift in how consumers purchase these types of drinks. For example, in 2024, research found that 24% of protein drinks were sold online compared to only 16% of sports drinks.[3] These growth opportunities present new challenges for preserving product quality from production to consumption. Specifically, these products are often highly sensitive to oxygen exposure because even minimal unwanted entry of oxygen into a system, known as oxygen ingress, can compromise product quality. This can include degrading flavor, nutrient content, color, or texture, resulting in reduced shelf life. Combining that with the tenuous conditions in e-commerce warehouses and last-mile delivery, it makes choosing packaging that prevents leaks and oxygen ingress even more vital to a brand's success.

Oxygen ingress is particularly problematic for beverages fortified with vitamins and bioactive compounds. Oxidation can degrade these components, forcing manufacturers to overcompensate by adding excess vitamins or other stabilizers at the time of production to help ensure label compliance throughout the serviceable life. This approach not only increases costs but also introduces variability in product quality. These adjustments can also limit the scale-up of small brands due to the needed changes in their formulation.

Alternatively, beverage packaging can be designed with high-quality components to more effectively block oxygen. Common solutions include incorporating liners into caps and using passive and active additives in the polymer bottle or closure. Each component of the packaging plays a critical role in preserving flavor, maintaining nutritional integrity, and extending shelf life — ultimately reducing waste and improving consumer satisfaction. A manufacturer may employ more than one option to meet their performance targets and achieve the overall success of the final packaging solution.

This paper examines the oxygen barrier performance of thermoplastic elastomer (TPE) liner technologies, demonstrating their effectiveness as a caps solution to help reduce oxidation and prolong shelf life by explaining the following:

TPE Liner Technology Overview
- Overview of traditional and oxygen barrier TPE materials
- Function and use cases for TPE liners in cap manufacturing

Measuring Oxygen Ingress
- Key metrics and assessment criteria for oxygen permeation

Testing Methodology and Material Evaluation
- Detailed testing protocols and framework
- Selection of advanced and traditional TPE materials

Results and Conclusions
- Performance data and findings
- Guidance for manufacturers on oxygen barrier technology selection

TPE LINER TECHNOLOGY OVERVIEW

Oxygen barrier cap liners represent a significant advancement in beverage packaging technology. TPE liners are integrated into the cap to primarily function as a physical, removable seal to prevent leakage. Traditional TPE cap liners are gas-permeable, meaning they can be ineffective over long periods of time at protecting against oxygen ingress. On the contrary, oxygen barrier TPE liners are engineered to minimize oxygen ingress. This dual functionality—leak-proof sealing and oxygen protection—makes them particularly valuable for oxygen-sensitive beverages such as meal replacements, protein drinks, and vitamin-enhanced juices.

The oxygen barrier TPEs highlighted in this paper are developed by Avient for more common polypropylene cap shells, with liners applied via compression molding for use in hot-fill processes. These materials can also be tailored to the unique oxygen barrier liner performance needs of a specific product and application.

Regulatory compliance is not only required for accurate information on your label, but the materials used in the packaging must also be compliant. Avient's oxygen barrier liners meet U.S. FDA 21 CFR and EU Food Contact standards, helping manufacturers ensure consumer safety. These TPEs have certain limitations for food types and conditions of use, including restrictions on contact with fatty foods and specific size constraints: a maximum diameter of 3.5 inches and a minimum fill volume of 12 ounces.

MEASURING OXYGEN INGRESS

There are three typical metrics used to characterize oxygen barrier performance in materials: gas transmission rate (GTR), permeance, and permeability coefficient. GTR measures the volume of gas passing through a specific area of material per unit of time; in this case, oxygen for the oxygen transmission rate (OTR).[4] Permeance involves the GTR and the partial pressure differences across the material, and the permeability coefficient is the GTR multiplied by the material thickness.

The permeability coefficient is most directly tied to the intrinsic properties of the material, allowing the direct comparison of materials. The lower the permeability coefficient, the less oxygen is transmitted over time. Plaque testing provides insight into material properties, but full-package evaluations are essential for understanding real-world performance because they account for the entire system's permeability rate. One example of full-package testing is the ambient oxygen ingress rate (AOIR) method, which mimics the packaging's actual performance. For the purposes of this paper, only material plaques were tested.

METHODOLOGY

The oxygen transmission rate (OTR) of four materials was measured using an OX-TRAN™* 2/22 Oxygen Transmission Rate System at 23 °C under a relative humidity of 0%. Two testing samples were similar oxygen barrier formulations, and two were similar standard cap liner materials. The samples were injection-molded to a thickness of close to, but no greater than, 2 mm. The samples were then cut using a metal template provided by the OTR system manufacturer to maintain a consistent test size that exactly fits the test cell. Each material was tested twice. The test area and thickness of the eight samples are summarized in Table 1.

Table 1. Sample Dimensions

Sample Plaque Codes	Thickness (mil)	Test Area (cm^2)
Barrier 1.1	68	50
Barrier 1.2	64	50
Barrier 2.1	64	50
Barrier 2.2	64	50
Standard 1.1	64	5
Standard 1.2	64	5
Standard 2.1	81	5
Standard 2.2	81	5

After the samples were loaded into the test cell, the machine's "Auto Test" setting was used to test the OTR. The "Auto Test" method can be used to determine the optimal test methodology when the properties of the barrier material are unknown. The "Auto Test" method automatically adjusts to optimize some of the test parameters as the test runs. It's important to mention that the standard formulations for comparison were well-known Avient grades. This existing material knowledge is noteworthy because when testing a material with an OTR near or exceeding 200 cc/(m^2·day), a 5 cm^2 test area is recommended to reduce the amount of oxygen sent to the sensor. The instrument will provide a warning if the sensor detects oxygen volume outside of safe operating ranges during testing. After testing all materials, the thickness of each sample was multiplied by the OTR to obtain the permeation coefficient for each sample.

*OX-TRAN is a trademark of MOCON, Inc.

AVIENT

RESULTS AND CONCLUSIONS

The average permeation coefficient for each material is shown in Figure 1. The barrier materials exhibited a 75–80% lower permeation coefficient (15,900–16,200 cc mil/m^2·day) than the standard materials (68,100–81,100 cc mil/m^2·day).

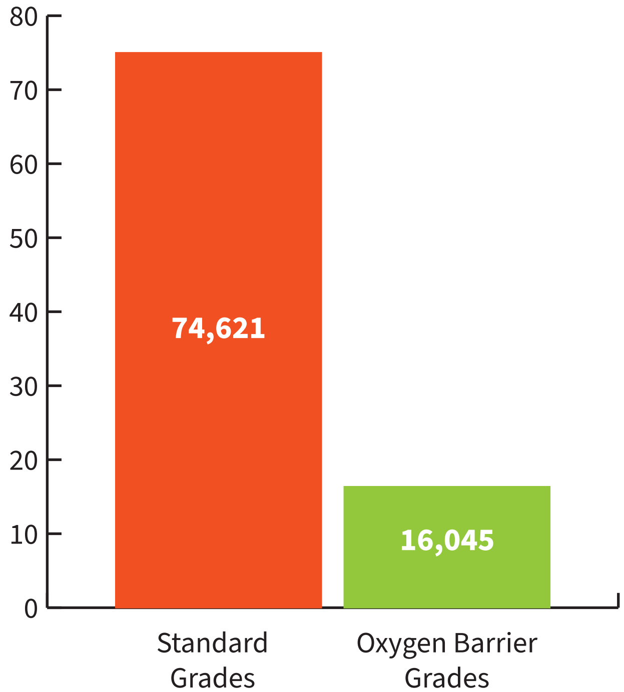

Figure 1. Average Permeation Coefficient (cc mil/m^2·day) of four tested grades of each

When compared to standard liners, the difference is clear. Oxygen barrier liners made from Avient's specialty TPE formulations significantly reduce oxygen transmission, helping safeguard product integrity throughout its shelf life. This distinction is especially critical for beverages that rely on maintaining nutrient stability and preserving flavor.

It is important to note that this data reflects only material properties, not full-package performance. Beverage companies are responsible for performing their own full-package testing, as material properties do not always scale directly in the final form factor.

While the testing data demonstrates the efficacy of oxygen barrier technologies over standard liner materials, choosing the appropriate oxygen blocking solution for beverage packaging must be carefully evaluated based on the unique regulatory, performance, sustainability, and shelf-life demands of the packaged contents. A material supplier's polymer and packaging expertise can make a significant difference in the development and success of your product. For help making an informed decision based on the unique specifications of an application, a material supplier may use a full suite of industrial, material, component, mold, and process design capabilities and recommendations.

To learn more about customizable TPE liner technologies and oxygen barrier technologies, call +1.844.4AVIENT or visit avient.com.

Sources

1. Protein beverages trends, global market overview. Market trends
2. Ready-To-Drink Protein Beverages Market - Manufacturers & Size
3. 2025 State of the Beverage Industry: Sports, protein drink market experiences growth
4. Labthink Gas Transmission Rate, Permeance and Permeability Coefficient Application Guide