OPTIMIZED PACKAGE DESIGN FOR SHELF LIFE THROUGH PERMEATION TESTING

WHITE PAPER

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Content:

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COST OF UNDER-PACKAGING OR OVER-PACKAGING

Understanding the permeation characteristics of potential packaging materials as well as the final packaging design can help optimize the package design

Introduction

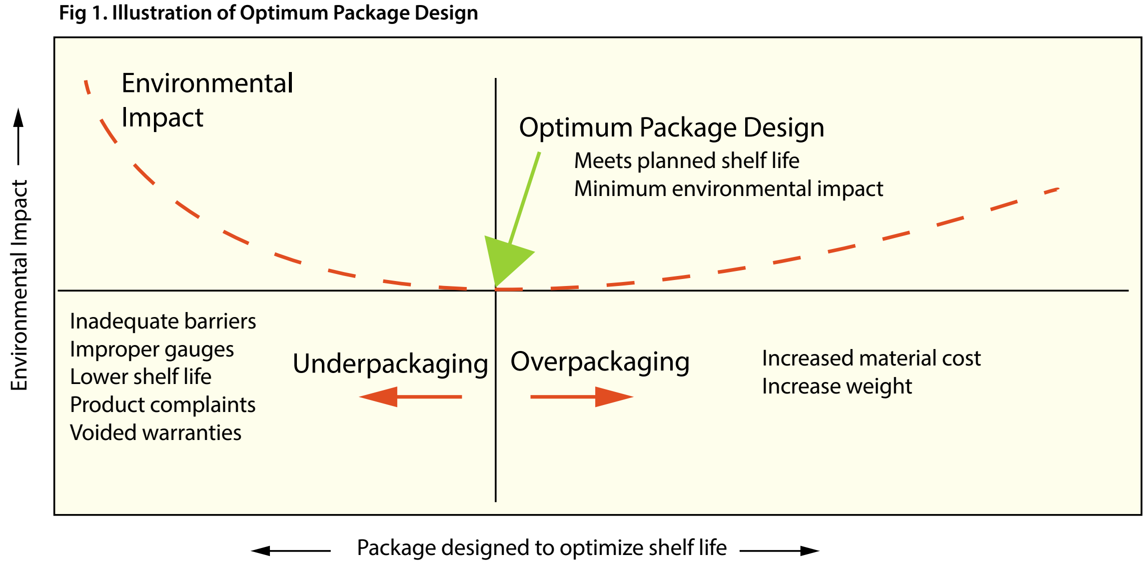
The process of designing a functional, attractive, environmentally friendly and cost-effective package is a challenging task. Often, the product protection element is overlooked in this process and has negative consequences when the product is launched.

The barrier properties of the package greatly influence the ability to achieve a desired shelf life by limiting the loss or gain of oxygen, water vapor, carbon dioxide and aromas. These permeants can alter the products' quality, nutrition and sensory attributes such as appearance, flavor, taste and texture. Understanding the permeation characteristics of potential packaging materials as well as the final packaging design can help optimize the package design to meet the objectives without overcompensating, leading to higher cost than is needed or failure to meet shelf life claims resulting in customer complaints and returned product.

- Under-packaging (inadequate barriers, improper gauges, wrong material choices, poor seams and seals etc.) allows the transmission of some compound(s) at a rate that causes product degradation faster than the desired shelf-life. Repercussions from under-packaging can range from product complaints and returns all the way potentially to voided warranties or legal action. This could cause financial loss and damage to your brand reputation.
- Over-packaging can be a significant waste of money and material resources. Oftentimes, a lack of product knowledge will lead a manufacturer to use the best package available to prevent under-packaging. A common example is using unnecessarily thicker gauge materials or multi-layered materials, which result in added cost. The extra cost could be significant over long term for mass production manufacturers. When the proper testing program is implemented in the development process, significant dollars can be saved by avoiding over-packaging.

Fig 1. Illustration shows that at either end of the spectrum, the under-packaged product goes bad causing increased complaints, higher warranty costs, increased waste and negative impact on the environment. The over-packaging results in excessive material usage creating both an increased cost as well as a negative impact on the environment with more plastic being dumped in landfills. The intersection on Fig 1. shows the optimized packaging system with effective marketing, product protection and cost. To optimize your package design, it is crucial to understand the permeation property of a package to avoid both over- and under-packaging.

Fig 1. Illustration of Optimum Package Design



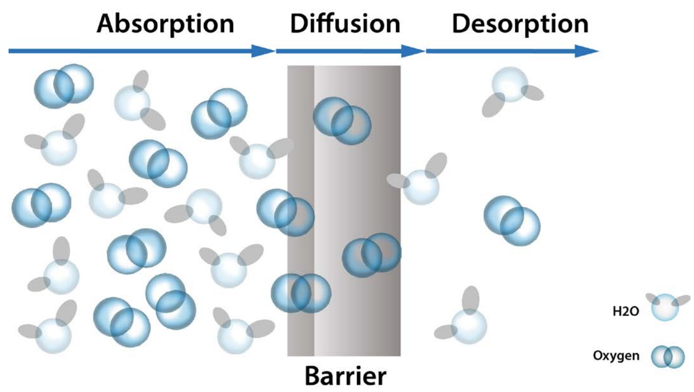
STEPS TO ACHIEVE OPTIMIZED PACKAGE DESIGN

What is Permeation and How to Measure It?

Driven by concentration difference or gradient of the interested permeant (gas or vapor), the permeation process follows the three steps of absorption-diffusion-desorption for a permeant to go through a material (Fig 2). In practical application, the transmission rate (TR), is the most common way to report the "flux" of gas moving through a polymer. The transmission rates for oxygen (OTR), water vapor (WVTR) and carbon dioxide CO_2 (CO_2TR) can be measured by permeation analyzers with different sensor technologies. For packaging films, permeation rates are typically reported as: cc/(m • day) for OTR and CO2TR, and g/(m • day) for WVTR.

To learn more about permeation basics, please refer to the following link for details: https://www.ametekmocon.com/knowledge/learnaboutpermeation

Fig 2. What is Permeation



Steps to Achieve an Optimized Packaging System

The following steps outline a recommended method for determining the optimized package design.

1. Identify Product Tolerance Level:

A key element for successful packaging design is to identify the maximum product degradation by exposure to permeant gases like oxygen and water vapor that is allowable to meet a desired shelf life target. This degradation can happen by ingress and/or egress from the package. Additionally, other gases such as carbon dioxide, odors and aromas should also be considered. The minimum exposure tolerance level of the product sets the allowable transmission rate requirement for the package.

2. Identify Candidate Barrier Materials:

To identify acceptable materials, candidate materials should be subjected to a comprehensive testing program. Begin with transmission rate testing of candidate sheet materials to confirm suppliers' data as well as narrow the candidate field. Ensure proper results by duplicate testing. When conducting these tests, candidate materials must be tested at proper test conditions (temperature and RH) to reflect realistic conditions.

3. Design Preliminary Package System:

Product requirements and candidate materials are then matched using a theoretical package size calculation to determine if the shelf life is obtainable with specific material, or to determine which material will supply a specified shelf life for a given package size. This step, as illustrated in the Case Study below, is necessary for proper material selection.

4. Test Prototype Packages

Prototype packages must then be built with the potential materials in a configuration that matches the desired package design. These preliminary package prototype with specific package dimensions, functional features, and seals are then tested to determine the overall barrier protection level.

5. Tuning and Adjusting for Optimized Package System

To optimize a package design it is common to repeat steps 3 and 4, till the optimal package system is achieved. Sometimes, depending on the nature of the product, additional method such as MAP (modified atmosphere packaging) may be introduced for prolonged shelf life without added packaging material gauge.

6. Fast and Accurate Test Methods:

Permeation Analyzers offer test results in a matter of hours or days as compared to traditional storage studies which usually take 4 to 6 months. Even if real time storage testing is not avoidable due to regulations, test results from a permeation analyzer will shorten development time by allowing you to make adjustments and improvements sooner than later. Overall, the fast and accurate test methods will lead to confidence and more success.

Case Study using Permeation Data in the Package Design Process

This case study will demonstrate how transmission rate testing can help ensure that your packaging materials will provide the desired protection to meet your shelf life target. Additionally they show how crucial it is to perform permeation analysis of not only the barrier materials but also the final finished package.

Package design for single serving of potato chips in a flexible pouch

Case Study Part 1:
Theoretical Package Design Calculation

In the early stage of a package design, where does one start? The process should always start with a good knowledge about the product to be packaged and understand the exposure limit tolerance to meet the desired shelf life.

For demonstration purpose, we will make some assumptions for the case study.

Assumption:

- The only exposure factor effecting the End of Shelf Life is oxidation

Known Elements:

- Food Quantity: 100 g
- Pouch dimensions : 5" x 7" or 13cm x 17.5cm (Surface test area 437 cm^2)
- Oxygen Tolerance: 150 mg/kg of product maximum
- Desired Shelf Life: 6 weeks

Basic Calculation:

Total volume of O_2 the product can tolerate:

- 0.1 kg x 150 mg/kg = 15.0 mg, or approx. 10.5 cm^3 (at STP)

To achieve a shelf life of 6 weeks (42 days):

- Desired package OTR level = 10.5 cm^3 ÷42 days = 0.25 cm^3/(package day)
- OTR of the packaging film (20.9 % Oxygen): 0.25 cc/(pkg day) ÷ 0.0437cm^2 = 5.72 cm^3/(m^2 day)
- Or, OTR of the packaging film (100 % Oxygen): 5.72 cm^3/(m^2 day) ÷ 0.209 = approx. 27.4 cm^3/($m^2 \cdot$ day)

So, in this example, an OTR of 27.4 cm^3/(m^2 day) is the starting point for O_2 barrier level needed to reach the desired goal. Due to safety factors for published transmission rates by suppliers it is always best to perform your own permeation testing for candidate materials. This helps to avoid expensive over-packaging and wasted material.

Case Study Part 2: Candidate Film Testing

Knowing that the intended product of potato chips are usually high in fatty oils, a good oxygen barrier is required to protect it from oxidation. It is essential to test the OTR of the metalized film samples before they are converted to pouches.

The OTR test was conducted on MOCON OX-TRAN 2/22 (Fig. 3 and Fig. 4). Then the film OTR results are used to calculate a theoretical OTR of the pouch based on the dimensions.

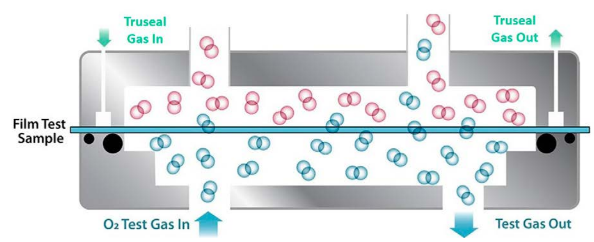
The theoretical pouch OTR results shown in Table 1 appeared to satisfy the barrier requirement for desired shelf life. Maximum package OTR level of 0.25 $cm^3/(pkg \cdot day)$ vs average OTR test results of 0.215 $cm^3/(pkg \cdot day)$

Table 1. Theoretical OTR of pouches (5" x 7" or 13cm x 17.5cm) with surface area of 437 cm^2

Sample tested	Tested Film OTR cc/(m^2 • day)	Theoretical Pouch result Estimate (with 20.9% O_2) cc/(pkg • day)
Replicate #1	23.53	0.215.
Replicate #2	23.76	0.217
Average	23.65	0.216

Fig 3. OX-TRAN 2/22 Permeation Analyzer

Fig 4. Barrier film test in cartridge



Case Study Part 3: Prototype Package Testing

To verify proper package design and material selection, sample pouches were tested using the MOCON pouch cartridge (fig. 5). OTR tests of the sealed pouches were performed on OX-TRAN 2/40 OTR Package Testing Analyzer (Fig. 6).

Table 2. Tested Pouch OTR Results with 20.9% O_2 at 23°C

Sample tested	Actual Pouch OTR Test Result cc/(m^2 • day)	OTR Difference to Theoretical Pouch OTR Estimate cc/(pkg • day)
Pouch #1	0.316	Tested Pouch OTR 46% higher
Pouch #2	0.273	Tested Pouch OTR 26% higher

Test results in Table 2 showed that the OTR of the finished pouches were 26-46% higher than the theoretical pouch OTR estimated from the results of the flat film.

Fig 5. Sample pouch packages inside OX-TRAN 2/40

CONCLUSION

In most cases, the finished packages will have higher transmission rates than the theoretical estimates due to small defects along the seams, seals and closures which negatively affected its OTR performance. This is a common reason many products on the market don't reach their anticipated shelf life.

This is a scenario of under-packaging thus leading to wasted product and unhappy customers. The package test results were above the calculated target TR which would indicate they would not provide the desired shelf life. In order to achieve the target shelf life, either better barriers or improvements to the pouch manufacturing process are required. These improvements can be only be verified by follow-up permeation testing of new samples of the package.

To ensure the proper packaging design, the finished package must be tested and proven.

Fig 6. Variety of package testing inside OX-TRAN 2/40

Conclusion

The role of permeation testing during packaging design is valuable tool towards preventing expensive over-packaging or the risk of under-packaging. Only through testing can the optimum packaging system be designed and verified to provide necessary protection for desired product shelf life and minimize the environmental impacts.

A few tips for you to takeaway:

- Identify product requirements first
- Test candidate materials at proper test conditions to best mimic realistic conditions.
- Narrow the field of candidates with theoretical OTR estimates based on package size.
- Determine optimal packaging system with testing of finished packages
- Rely on proven techniques and reliable instruments for accurate and repeatable results

Related readings:

1. Technical Note: Simplified Correlation Between OTR data and Food Shelf Life
2. Web Paper: What to Consider When Selecting Barrier Materials for Food Products: https://www.packageintegrity.com/single-post/2017/10/02/what-you-should-consider-when-selecting-barrier-materials-for-food-products
3. Application Note: New Cartridge Makes Permeation Testing of Flexible Pouches Easier https://www.ametekmocon.com/knowledge/learnaboutpermeation of finished packages

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