Permeation and its Impact on Films and Packages

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Content:

- Permeation Basics
- Measurement Techniques
- Package Testing
- Fickian Behaviour
- Case Study: Metalized Film
- Summary
Permeation Basics

Solution-Diffusion Mechanism

- The gas absorbs at the entering face and dissolves in the material at the high-pressure side of the material
- Diffuses through the polymer
- Desorbs or outgases at the low-pressure side
Permeation Basics
Driving Force & Partial Pressure Gradient
Permeation Basics

Package Design versus environmental impact

![Diagram showing the relationship between package design and environmental impact, highlighting the optimum package design that meets planned shelf life with minimum environmental impact.](image)
Permeation Basics

Transmission Rate versus Time

Time

Transmission Rate
Measurement Techniques

- Principle of a Test Cell
Measurement Techniques

- Right Condition
  - Temperature
  - relative Humidity
- Partial Pressure
Measurement Techniques

Right Condition: Temperature

Film O₂ Permeation vs Temp

P (cc 25µm)/ (m² day atm)

Temp (°C)
Measurement Techniques

Right Condition: Temperature

Generally: For every 10°C increase in Temp, the Permeation Rate Doubles

Table 7. Transmission Rate (g\text{*}mm/m^2/day) of selected organic compounds through low density polyethylene. (adapted from Robertson, 1993)

<table>
<thead>
<tr>
<th>Permeant</th>
<th>0°C</th>
<th>21.1°C</th>
<th>54.4°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetic acid</td>
<td>0.14</td>
<td>1.22</td>
<td>25.9</td>
</tr>
<tr>
<td>Benzaldehyde</td>
<td>0.15</td>
<td>2.67</td>
<td>81.0</td>
</tr>
<tr>
<td>Ethyl alcohol</td>
<td>0.75</td>
<td>6.5</td>
<td>149</td>
</tr>
<tr>
<td>Phenol</td>
<td>0.04</td>
<td>0.2</td>
<td>9.4</td>
</tr>
<tr>
<td>Propyl Alcohol</td>
<td>0.03</td>
<td>0.2</td>
<td>8.8</td>
</tr>
<tr>
<td>Toluene</td>
<td>22.7</td>
<td>199</td>
<td>2270</td>
</tr>
<tr>
<td>Xylene</td>
<td>14.2</td>
<td>101</td>
<td>1420</td>
</tr>
</tbody>
</table>

*K. Cooksey, IMPORTANT FACTORS FOR SELECTING FOOD PACKAGING MATERIALS BASED ON PERMEABILITY*
Measurement Techniques

Right Condition: Relative Humidity

740 mm Hg, 100% O₂, 30°C
1 mil (25μm) EVOH
Measurement Techniques

Right Condition: Relative Humidity

RH (%)  OTR (cc/100 in²-day)

Nylon 6
SELAR
44% EVOH
Nylon MXD6
30% EVOH
SELAR OH Plus
Measurement Techniques

Right Condition: Relative Humidity

Oxygen | Nitrogen
---|---
90% RH | 90% RH

Oxygen | Nitrogen
---|---
50% RH | 70% RH
Measurement Techniques

Right Condition: Partial/Ambient Pressure
Measurement Techniques

Right Condition: Combined Influence

- RH is RELATIVE to Temperature

- Vp of water at 50°C is 92.5 mmHg and 50%RH at 50°C corresponds to 46.25 mmHg.

- The Vp of water at 53°C is 107.2 mm Hg and 50%RH at 53°C is 53.6 mm Hg.
Package Testing
## Package Testing

<table>
<thead>
<tr>
<th>ID</th>
<th>OTR (cm³/day)</th>
<th>OTR- Film (cm³/m² day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.011</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>B</td>
<td>0.032</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>C</td>
<td>0.040</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>D</td>
<td>0.036</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>E</td>
<td>0.052</td>
<td>&lt;0.005</td>
</tr>
</tbody>
</table>
Package Testing

Room O₂ (20.9%)

Package Sample

Epoxy or Hot-Melt Adhesive

N₂ In

N₂ + O₂ Out
Fickian Behaviour

Permeation Rate

NON-FICKIAN

FICKIAN

Permeant Concentration
Fickian Behaviour

Fickian Behavior:
Permeation, of most polymer materials, is linear with test gas concentration.

\[ \text{O}_2 \text{ through PET}; \quad \text{H}_2\text{O} \text{ through OPP} \]

Non-Fickian Behavior:
Permeation is non-linear with test gas concentration -
a structural change occurs when polymer is exposed to RH or certain chemicals….

\[ \text{H}_2\text{O} \text{ through EVOH, Nylon}…. \]
Case Study: Metalized Film

- Test method: ASTM F-1249, isostatic method
- WVTR testing at 37.8°C, 50%RH, 75%RH, 90%RH and 100%RH
- Started testing at a lower RH level for 48 hours, then proceed to higher RH levels
- Repeat 50%RH analysis after 100%RH is done
Case Study: Metalized Film

Tested Film: 75gauge OPP/Print & Adhesive/48gauge met-PET, corona treatment under the metal

<table>
<thead>
<tr>
<th>Driving Force</th>
<th>WVTR g/(m²-day)</th>
<th>Calculated Fickian Behavior g/(m²-day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cell A</td>
<td>Cell B</td>
</tr>
<tr>
<td>%RH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>0.14</td>
<td>0.15</td>
</tr>
<tr>
<td>75</td>
<td>0.41</td>
<td>0.48</td>
</tr>
<tr>
<td>90</td>
<td>1.11</td>
<td>1.09</td>
</tr>
<tr>
<td>100</td>
<td>2.03</td>
<td>2.01</td>
</tr>
<tr>
<td>Repeat 50%RH</td>
<td>0.79</td>
<td>0.77</td>
</tr>
</tbody>
</table>
Case Study: Metalized Film

Multi-layer Metalized film - WVTR

- Actual WVTR
- Fickian Behavior
Case Study: Metalized Film

- Results exhibited Non-Fickian behavior
- It is not suitable to factor WVTR values from one RH to other RH conditions
- Higher level humidity impact to a greater degree on the film barrier property
- After exposure to higher humidity (100%RH), moisture barrier was not recoverable when humidity was reduced back to 50%RH
Summary

- Permeation Measurement is critical for finding right material
- Many parameters influencing test results=> Taking care on them
- Transmission rate of film and finished package do not necessarily correlate
- Metalized films show that calculation or correlation will not work for every material

=> Think about your measurements!
Questions??