The Construction of a Diffusion Cell and the Determination of Oxygen and Carbon Dioxide Permeability of Films for Flexible Food Packages

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Abstract

Flexible food packages should be characterized by an adequate permeability for water vapor and gases. In this work we have constructed a diffusion cell for the measurement of gas permeability and have determined $O_2$ ($P_{O_2}$), $CO_2$ ($P_{CO_2}$) and water vapor ($P_{H_2O}$) permeability of 92 flexible packages used commercially in Mexico in a variety of foods, but only those on fruits and vegetables are reported here. The diffusion cell was constructed from acrylic plates and was conditioned with 4 valves and a manometer for pressure control. It is composed of 2 compartments separated by the film to be evaluated. The values of $P_{CO_2}$ and $P_{O_2}$ were found to be in the range of those reported for similar packages, indicating that the constructed diffusion cell is reliable. The cost of the construction of this cell was very low, and the time required for analysis is shorter compared to standard methods.

INTRODUCTION

Significant food losses occur as a consequence of inadequate packaging. Polymeric flexible films are commonly used for food packaging, and their value and quality rely on adequate gas and water permeability values for specific applications. It is therefore essential to be able to determine permeability values for proposed new film materials to predict the response of the packed food. The availability of these tools is not yet common in many developing countries because of high cost and long measurement time. Hence, permeability data on films used for food packaging is permanently lacking. Therefore, there is an urgent need to develop instruments for this purpose that are inexpensive and with fast response.

Several approaches have been described for permeability measurements. Karel et al. (1963) used the method of increased concentration to determine the $O_2$ and $CO_2$ permeability ($P_{O_2}$ and $P_{CO_2}$) in flexible films. Beaudry et al. (1992) determined $P_{O_2}$ and $P_{CO_2}$ in low density polyethylene films using a sequential combination of detectors that made the system rather costly. There are 2 standard methods (ASTM, 1988a, b) based on volumetric and manometric evaluations, where the permeability is determined by the difference in volume and pressure, respectively. In both methods, the film to be characterized is usually localized between 2 chambers that constitute the diffusion cell, one chamber usually contains the gas to be determined and the other, at low pressure, receives the permanent gas. Regardless of its simplicity these techniques normally perform with a low sensitivity. $P_{H_2O}$ is commonly determined gravimetrically, using a desiccant agent (such as $CaCl_2$) inside a container sealed with the film.

This article describes the construction of an inexpensive diffusion cell, along with
a rapid and effective means of measuring gas permeability of polymeric films. To illustrate its usefulness, we have determined the permeability of O₂ and CO₂ of the films used in 92 packages of a variety of commercial food products found in the shelf of supermarkets in Mexico. Water vapor permeability of these packages was also determined.

MATERIALS AND METHODS

Ninety two packages used for different food products in Mexico were collected and divided into 17 groups according to the type of food. The thickness of the films was measured with a Starret micrometer (L.S. Starret Co., LTD, Jedburg, Scotland). Four readings were taken at random positions around the film, and the results were averaged and expressed in cm.

The diffusion cell was constructed with acrylic plates with a square base of 12 x12 cm and an interior chamber of 5 x 5 cm. Figures 1 and 2 show the pieces that conform the cell. Each one of the plates was fixed with a special adhesive to form the two chambers of 25 ml each, separated by the film to be characterized. The film and chambers were sealed together with a neoprene o-ring (piece cut to size) and secured with 4 stainless steel screws. The injection and extraction of gases from the chambers consisted of a system of tubes and valves as shown in Figure 2. The metal-acrylic unions were sealed with epoxy-resin. The air tightness of the system was evaluated by water-immersion of the cell pressurized with air. The inner pressure was measured in each one of the chambers with a gauge.

P₀₂ and P₅CO₂ were determined in duplicates. High purity N₂, dry O₂, and CO₂ were obtained from AGA, Mexico. The tested gas was directed into one chamber, and pure nitrogen gas was directed into the other. Pressure in the chambers was equilibrated and maintained at atmospheric pressure. Oxygen and CO₂ were analyzed continuously using a Nitec Model GA-20 portable O₂/CO₂ analyzer (Nitec Inc., Cincinnati, OH). The oxygen sensor is an electrochemical fuel cell with a range of 0–100 kPa and accuracy of ±0.5 kPa of full scale. The carbon dioxide sensor is a non-dispersing infrared sensor with a range of 0–100 kPa and accuracy of ±0.2 kPa of full scale. The maximum time required for permeability determination was 30 minutes.

Water vapor permeability was determined according to ASTM (1988b). Petri dishes of 9 cm of diameter and 1.8 cm deep and containing 25 ml of distilled water were used. The film was sealed on top of the petri dish. Water loss through the film was determined by weight loss with an electronic scale (Model Explorer, with a sensitivity of +10 mg, OHAUS, USA).

RESULTS AND DISCUSSION

Figures 1 and 2 show diagrams and photos of the constructed diffusion cell. The cell is divided in two chambers by the film. One of the chambers is to contain N₂ and the other one the test gas (CO₂ or O₂). Both chambers are set to one atmosphere of pressure, which facilitates the calculation and handling of the system. Beaudry et al. (1992) proposed the dimensions of a cylindrical cell with two chambers with a diameter of 8 cm and 0.5 cm deep. The two chambers of 25 ml are separated by the film, with 50 cm of exposed area in both chambers and sealed by packing. Figure 3 illustrates the diffusion cell.

Six packages used for fresh and processed vegetables were analyzed, including 4 for processed and 2 for fresh vegetables (Table 1). Fresh vegetables were salad mix of mostly lettuce, and processed vegetables included a mix of peas and carrots. The films used for these products were made of high density polyethylene and had a thickness of 6.35 to 7.62 x 10⁻³ cm, P₅CO₂ of 58.10 to 76.70 x 10⁻¹⁶ mol cm⁻² s⁻¹ Pa⁻¹, P₀₂ of 31.60 to 38.00 x 10⁻¹⁶ mol cm⁻² s⁻¹ Pa⁻¹, and P₅H₂O of 1.26 to 1.51 x 10⁻¹⁳ mol cm⁻² s⁻¹ Pa⁻¹. Films used for the packaging of fresh vegetables were thinner and had lower P₅CO₂, P₀₂, and P₅H₂O values compared to those used for processed vegetables. There were significant differences in thickness, P₅CO₂, P₀₂ and P₅H₂O between the different packages. Both P₀₂ and
P<sub>CO</sub><sub>2</sub> for films used for fresh vegetables were low, which can generate anaerobic conditions inside the package. It has been reported that P<sub>O</sub><sub>2</sub> and P<sub>CO</sub><sub>2</sub> for fresh fruits and vegetables should be high (Rizvi, 1981; Yahia, 1998). The accumulation of CO<sub>2</sub> in the packages of fresh lettuce can cause injury. P<sub>H</sub><sub>2</sub>O was low compared to other films used for other types of foods, which can be adequate for frozen vegetable products, but inappropriate for fresh products such as lettuce.

CONCLUSIONS

The constructed diffusion cell functions adequately as a device for the determination of O<sub>2</sub> and CO<sub>2</sub> permeabilities with a short measurement time and with low cost. Aside from the fact that reported values correspond to products commercially used in Mexico, the packages are used in other countries. It is then important to base the selection of packages on permeability data as obtained in this work. This should help to guarantee a genuine conservation of food products by the package.

Literature Cited


Tables

Table 1. Thickness (μm), O<sub>2</sub>, CO<sub>2</sub> and water vapor permeability (mol·cm·cm<sup>-2</sup>·s<sup>-1</sup>·Pa<sup>-1</sup>) of flexible package films used for a variety of commercial products. Thickness and permeability data are the average of 4 points. LSD = least significant difference. NS = No significant differences.

<table>
<thead>
<tr>
<th>Vegetables</th>
<th>Film parameters</th>
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<tbody>
<tr>
<td></td>
<td>Thickness</td>
</tr>
<tr>
<td>1 (processed)</td>
<td>76.2</td>
</tr>
<tr>
<td>2 (processed)</td>
<td>76.2</td>
</tr>
<tr>
<td>3 (processed)</td>
<td>63.5</td>
</tr>
<tr>
<td>4 (processed)</td>
<td>63.5</td>
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<tr>
<td>5 (fresh)</td>
<td>47.6</td>
</tr>
<tr>
<td>6 (fresh)</td>
<td>32.1</td>
</tr>
<tr>
<td>LSD&lt;sub&gt;A&lt;/sub&gt;</td>
<td>0.75</td>
</tr>
<tr>
<td>LSD&lt;sub&gt;B&lt;/sub&gt;</td>
<td>10.7</td>
</tr>
</tbody>
</table>
Fig. 1. Description of the system of the diffusion cell.
Fig. 2. Description of the diffusion cell. 1=Chamber, 2=Ferrule, 3=Copper tube, 4=Connection, 5=Control valve, 6=Connection.
Fig. 3. Diffusion cell a) Coupled to the manometer, b) Coupled to the detector, c) Upper view, d) Lateral view.