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## Permeability of Shellac Coatings to Gases and Water Vapor

Robert D. Hagenmaier\* and Philip E. Shaw

U.S. Citrus and Subtropical Products Laboratory, South Atlantic Area, Agricultural Research Service,  
U.S. Department of Agriculture, P.O. Box 1909, Winter Haven, Florida 33883-1909

Shellac was coated onto highly permeable polymer films and its permeability calculated from measured values of permeance for coated and uncoated films. At 75% relative humidity and 30 °C, the O<sub>2</sub> and CO<sub>2</sub> permeability was 230 and 803 cc mil/(m<sup>2</sup> day atm), respectively, for Shellac coatings cast from ethanol. Over a wide range of relative humidities the water vapor permeability was 0.9–2.1 g mil/(m<sup>2</sup> day mmHg) for Shellac coatings cast from 2-propanol. Coatings made from water-soluble shellac were more permeable, especially at high values of relative humidity.

### 1. INTRODUCTION

Shellac has been used as a varnish since the 16th century, and it has a long history in India as a coating for wood (Hicks, 1961). Its use as an edible coating started about the beginning of this century (Martin, 1966). Edible shellac coatings have been used for pharmaceuticals and confections (Misra and Sengupta, 1970; Cockeram and Levine, 1961) and for fruits and vegetables (Martin, 1966). Shellac constitutes a major component of "waxes" used to coat fruit; for example, Martin (1972) gave a formulation that contains 27.5% shellac.

Shellac has been approved by FDA for some foods since 1939 (Fisher, 1981). In 1989, it was proposed that 21 CFR 184, Direct Food Substances Affirmed as Generally Recognized as Safe, be amended to include two new sections, 184.1705 for shellac and 184.1706 for shellac wax (Shank, 1989). Should shellac be so approved, it might become increasingly important as a food coating.

Despite the wide use of shellac as a coating, there is very little information available regarding its permeability to gases. Seaborne and Edberg (1987) reported water vapor permeability for bleached and unbleached shellac of 2.2 and 2.0 g mil/(m<sup>2</sup> day mmHg), respectively, although the conditions of the test were not stated. Pandula and Kovacs (1968) evaluated how long shellac-coated capsules stayed dry in an aqueous solution but did not relate their results to permeability.

### 2. PERMEABILITY CALCULATIONS

The calculation of gas permeability for shellac was complicated by the fact that we were unable to make

isolated shellac films that were suitable for permeance measurements. Thin films broke apart as these were removed from the drying surface, and thick films were so brittle that they cracked during handling. To solve these problems, the shellac was coated on the surface of support films of high permeance. To obtain the correct values for the permeability of shellac, it was therefore necessary to correct for the barrier properties of the support films.

For a gas diffusing through a film, its flux ( $J$ ) amounts to the product of its partial pressure drop across the film ( $\Delta p$ ) and its permeance ( $P$ ) (Crank, 1956). For a multi-layered film under steady-state conditions the flux through each layer is the same as that through the whole film. Also, the total pressure drop is the sum of the pressure drops across each layer. Thus, for a coated film (cf) made up of coating (c) and support (s)

$$J/P_{cf} = J/P_c + J/P_s \quad (1)$$

The permeability (sometimes called permeability constant) of the coating is the product of  $P_c$  and coating thickness ( $t$ ). Thus

$$\text{permeability of coating} = t/(1/P_{cf} - 1/P_s) \quad (2)$$

which is the equation used for calculation of permeability of the coating from observation of coating thickness, permeance of the coated film, and permeance of the support film.

When the diffusing gas is water vapor, it is necessary that a relative humidity gradient be maintained across the film. Since, as we will see, permeability of coating and that of support film both vary with relative humidity (RH), the result is that the water vapor encounters varying

permeability during its passage through the film. In such cases the measured value of permeability is an average, which can also be expressed by the usual integral for a mean:

$$P(\text{measured}) = (1/(RH_2 - RH_1)) \int_{RH_1}^{RH_2} P d(RH) \quad (3)$$

Crank (1956) gives a similar equation for the mean diffusion constant. Thus,  $P(\text{measured})(RH_2 - RH_1)$  is the area under a graph of permeability vs relative humidity, which is a convenient way of relating values of permeability measured under different relative humidity gradients.

Noting again that  $J^i$ , equal to  $P^i \Delta p^i$ , is the same across each of the  $i$  layers, it also follows that

$$\Delta p_s = \Delta p_{cf} P_{cf} / P_s \quad (4)$$

which is the equation used to calculate the relative humidity at the interface between the coating and the support film, taking due note of the relationship between water vapor pressure and relative humidity.

The barrier properties of coatings are expressed in terms of permeability, which is the permeance for 1 unit of thickness. Oxygen permeability and CO<sub>2</sub> permeability are expressed in units of cc mil/(m<sup>2</sup> day atm) with gas volume at standard conditions and 1 mil being 0.001 in. Unfortunately, this mixture of metric and English units is what is commonly used for permeability. In metric units, after cc's of gas are converted to density units, the units become g/cm<sup>3</sup> × cm/(cm<sup>2</sup> s dyn/cm<sup>2</sup>), which cancels to units of time (seconds). The unit 1 cc mil/(m<sup>2</sup> day atm) is equivalent for oxygen to 4.14 × 10<sup>-21</sup> s and for CO<sub>2</sub> to 5.70 × 10<sup>-21</sup> s. For water vapor the units of permeability are g mil/(m<sup>2</sup> day mmHg), equivalent to 2.21 × 10<sup>-15</sup> s. The barrier properties of the support films and also the coated films are more appropriately expressed as in units of permeance, which leaves the thickness unspecified. Oxygen and CO<sub>2</sub> permeances are expressed in units of cc/(m<sup>2</sup> day atm) and water vapor permeance in units of g/(m<sup>2</sup> day mmHg).

### 3. MATERIALS AND METHODS

Coatings of shellac were cast onto support films from solutions of 30% shellac in 95% ethanol and 28% shellac in 2-propanol, from an aqueous solution containing 20% shellac and 3.3% morpholine, and from another aqueous solution made up of 24% shellac and 2.0% NaOH.

To get uniform coverage, the film had to be kept flat and level until the solvent dried. To accomplish this, the film was held by 0.3-atm vacuum against a 0.2-mm-thick stainless steel sheet perforated with 0.4-mm-diameter holes, in turn supported by a plate with 3-mm-diameter holes.

The applicator was a small paint pad (Sur-Line, Lancaster, NY). The shellac solution was brushed onto the support film. After application, the solvent (alcohol or water) was permitted to evaporate at ambient conditions. These procedures gave coatings of 0.4–0.9-mil thickness. Before the films were used, they were hung to dry for at least 24 h.

Three different support films were used. The first was cellulose acetate, type NU9/30 from Hoechst Aktiengesellschaft, Wiesbaden, West Germany. This film has a matte finish on one side, which was the side coated. The thickness was 30.7 ± 0.4 μm, and the density was 3.76 ± 0.05 mg/cm<sup>2</sup> (95% confidence ranges).

A second film was product VQ-EVA-M, abbreviated as EVA. This film is described by Tredegar Film Products of Richmond, VA, as a copolymer of low-density polyethylene containing 3–5% vinyl acetate. Thickness was 50.5 ± 0.4 μm and the density 4.77 ± 0.08 mg/cm<sup>2</sup>. The EVA had been treated on one side to reduce surface tension, and that was the side coated with shellac. The third film was low-density polyethylene (LDPE) from Georgia Pacific, Hamlet, NC. This film had thickness of 55.1 ± 0.9 μm

and density of 5.05 ± 0.09 mg/cm<sup>2</sup>. One side had been treated to reduce surface tension, and that was the side coated.

Oxygen permeance was measured with the Ox-tran 100 oxygen permeability tester (Mocon, Minneapolis, MN). This unit was calibrated at 0% relative humidity with Standard Reference Material 1470 from the National Bureau of Standards. Samples were analyzed according to ASTM Method D-3985-81 (ASTM, 1981) except that relative humidity conditions of other than 0% were employed. To accomplish this, film samples were held overnight at the desired RH, and during the test the air and carrier gas were passed at 10 cm<sup>3</sup>/min through a bubbler maintained at the appropriate wet bulb temperature. Oxygen permeance was measured under steady-state conditions, usually 30–45 min after introduction of air into the diffusion cell.

Water vapor permeance of coated films was measured with the Permatran W1A water vapor permeability test (Mocon) according to ASTM Method F-1249-89 (ASTM, 1989). A standard calibration curve was made with aluminum foil and three reference films that spanned the flux range of the test samples—the reference films having had WVTR determined gravimetrically by ASTM Method E-96-80 (ASTM, 1987). As with oxygen transmission, the values of water permeation are for steady-state conditions, achieved after 30 min of operation with conditioned samples. Samples of film were conditioned for 2 h before the test by clamping them between two Petri dishes, one containing desiccant and the other water or salt solution.

Water vapor permeance of uncoated films was measured according to ASTM Method F-1249-89 or ASTM E-96-80. Only the gravimetric method was used for measurements with 100% vs 50% relative humidity, since the Permatran always uses 0% relative humidity on the less humid side of the film.

To define the effective area of the film, usually 5 cm<sup>2</sup>, the samples were masked with aluminum foil tape (Southeast Tape, Jacksonville, FL). Holes were cut in the tape, and the film to be measured was stuck onto the adhesive side.

Carbon dioxide permeance was measured with a gas chromatogram (Caskey, 1967). The film sample (89 cm<sup>2</sup>) was clamped between two chambers, the lower one flushed with 100% N<sub>2</sub> at 15 cm<sup>3</sup>/min and the upper with 100% CO<sub>2</sub> at 6 cc/min. Each chamber was 2 mm deep. The lower half of the cell was partly submerged in a temperature-controlled water bath. The effluent from the lower cell passed through a two-position sample injector (Valco Instruments Co., Houston, TX) with 50- and 250-μL loops and then to a GC (Hewlett-Packard Model 5890A). The GC was fitted with a 30 m × 0.53 mm GSQ fused silica capillary column (J&W Scientific, Folsom, CA). The temperatures of the column and the thermal conductivity detector were 40 and 120 °C, respectively. The He carrier gas flow rate through the column was 4.8 cm<sup>3</sup>/m. Peak areas were calculated by using a Hewlett-Packard 3345A integrator and calibrated with mixtures of N<sub>2</sub> of 0.01% (Supelco, Supelco Park, PA), 0.2%, and 3.0% CO<sub>2</sub> (Scott Medical Products, Plumsteadville, PA).

Before the flow of CO<sub>2</sub> to the top cell was begun, both top and bottom were flushed with nitrogen to measure the amount of nonpermeating CO<sub>2</sub> in the cell effluent. CO<sub>2</sub> permeance was measured at steady-state conditions, achieved about 2 h after the flow of CO<sub>2</sub> to the upper cell was begun.

Mantrolac R-49 from Mantrose-Hauser Co. (Westport, CT) was the shellac used for all samples except where otherwise indicated. This product is described by the supplier as a refined, dewaxed, bleached, food-grade shellac with maximum 0.2% wax. A second source of shellac was William Zinsser & Co., Inc., of Somerset, NJ, who described their product as refined, wax-free, vac-dry, bleached, food-grade shellac. A third source was shellac varnish (Parks Corp., Somerset, MA), described on the can as 30% shellac and 70% denatured alcohol.

The thicknesses of the shellac coatings were determined in two ways and the results averaged. First, the thickness of the coated film was measured with a micrometer to the nearest micron at eight places on the specimen, from which was subtracted the thickness of the support film. Second, the thickness was calculated from the net weight of the coating and the density of shellac (1.17 g/cm<sup>3</sup>) as determined by suspending deaerated pieces of shellac in mixtures of glycerine and water of different densities. By comparison, Misra and Sengupta (1970) reported a specific gravity of 1.1–1.2 for bleached shellac.

**Table I. Water Vapor Permeance of Cellulose Acetate at 30 °C**

RH range, %	permeance, g/(m <sup>2</sup> day mmHg)	
	measured	fitted curve <sup>a</sup>
100-50	31.2 ± 0.7	32.4
100-0	26.4 ± 0.4	26.3
75-0	24.4 ± 0.8	24.3
50-0	20.3 ± 1.4	20.2
32-0	18.8 ± 0.5	20.2
11-0	20.5 ± 0.4	20.2

<sup>a</sup> Based on eqs 5 and 6.

All reported data are the means for three or more trials. The confidence ranges were calculated for 95% significance.

#### 4. RESULTS AND DISCUSSION

**Permeance of the Support Films.** The oxygen permeance at 30 °C was 8237 ± 130 cc/(m<sup>2</sup> day atm) for EVA and 3304 ± 56 cc/(m<sup>2</sup> day atm) for cellulose acetate. Oxygen permeance of the support films was strongly dependent on temperature. The activation energy,  $E_a$ , was 12.7 ± 0.6 kcal/mol for EVA and 7.5 ± 0.9 kcal/mol for cellulose acetate. Uncoated EVA was not significantly affected by relative humidity over the range 0-100%. The oxygen permeance for LDPE treated with ethanol was 6600 ± 500 cc/(m<sup>2</sup> day atm) at 28.5 °C, the only temperature used for this film.

The water vapor permeance of cellulose acetate was dependent on relative humidity. Table I shows the moisture permeance of uncoated cellulose acetate at different relative humidity gradients. To calculate the moisture permeance of the coatings, it was found useful to fit the data of Table I with a formula that relates the measured values of permeability to the relative humidity conditions. A good fit was obtained with two straight lines intersecting at 50% relative humidity, 1010 g mil/(m<sup>2</sup> day mmHg). The slopes of the lines are 20.2 ± 0.9 and 32.4 ± 0.8. The equations for the lines are

for  $RH_1 = 0$  and  $RH_2 = 0-50$

$$P RH = 20.2RH_2 \quad (5)$$

for  $RH_1 = 0$  and  $RH_2 = 50-100$

$$P RH = 1010 + 32.4(RH_2 - 50) \quad (6)$$

where  $P$  is the mean water vapor permeance (see eq 3) in units of cc/(m<sup>2</sup> day mmHg) and RH is the relative humidity in percentage points.

Equations 5 and 6 can be used to find the permeance at 30 °C of cellulose acetate between environments of any relative humidity. For example, the mean permeance for a film situated between 0 and 75% relative humidity would be  $((50 \times 20.2) + (25 \times 32.4))/75$ , which comes to 24.27. The mean permeance for a film between 20 and 75% relative humidity chambers would be  $((75 \times 24.27) - (20 \times 20.2))/55$ , which amounts to 25.75 g/(m<sup>2</sup> day mmHg).

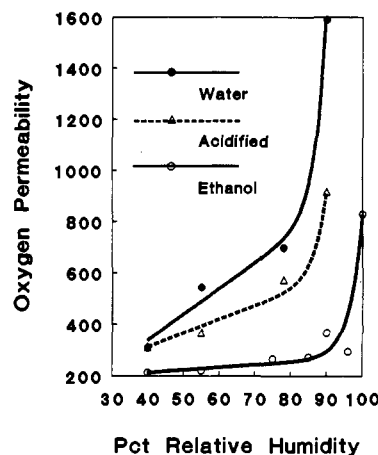
Water vapor permeability of cellulose acetate decreased somewhat with increasing temperature, indicating that  $E_a$  has a negative value. Regression analysis gave a value for  $E_a$  of -0.6 ± 1.2 kcal/mol.

The CO<sub>2</sub> permeance at 30 °C of uncoated EVA was 22 900 ± 1400 cc/(m<sup>2</sup> day atm). The measured CO<sub>2</sub> of Standard Reference Material 1470 at this same temperature was 15% less than the expected value for this standard.

**Table II. Oxygen Permeance of EVA at 55% Relative Humidity, 28.5 °C, with and without 0.7-mil Shellac Coatings**

	shellac solvent	permeance of coated film, cc/(m <sup>2</sup> day atm)	permeability of the shellac coating, cc mil/(m <sup>2</sup> day atm)
uncoated	n/a	7580 ± 125 <sup>a</sup>	NA
coated	ethanol	259 ± 17	212 ± 22
coated	2-propanol	413 ± 15	319 ± 22
coated	water/morpholine	637 ± 146	562 ± 71

<sup>a</sup> 95% confidence ranges for the means.



**Figure 1.** Oxygen permeability [cc mil/(m<sup>2</sup> day atm)] at 40-100% RH for shellac coatings cast from ethanol or water. The latter samples were treated with 1% citric acid to make the acidified samples. Each point is the average of three trials.

Oxygen and moisture vapor permeance were measured for support films treated with solvent in the same manner as the shellac-coated films. For EVA, treatment with water, ethanol, 2-propanol, or 1% citric acid did not significantly affect its oxygen permeance, nor did treatment with ethanol or water change its CO<sub>2</sub> permeance. Neither water nor 2-propanol affected the vapor permeance of cellulose acetate, although ethanol did increase its water vapor permeance by about 13%.

**O<sub>2</sub> and CO<sub>2</sub> Permeability of Shellac.** EVA films had much reduced oxygen flux when coated with shellac. Table II shows that shellac coatings of 0.75 mil reduced the oxygen permeance by 92-98%, depending on which solvent was used to prepare the coating. These same data, based on six trials each at 55% RH, show at the 95% confidence level that shellac coatings differ in oxygen permeability depending on the solvent used.

Shellac films were also coated onto other support films. With LDPE, the oxygen permeability was 184 ± 15 cc mil/(m<sup>2</sup> day atm), on the basis of three trials with a 0.6-mil coating cast from ethanol. With cellulose acetate as the support film, the permeability was 414 ± 147 cc mil/(m<sup>2</sup> day atm), on the basis of six trials with a 0.7-mil coating cast from 2-propanol. These values of permeability are not significantly different from the values shown in Table II with EVA as the support film. This similarity suggests that the same oxygen permeability also applies for shellac coatings on other surfaces, such as food products.

The oxygen permeance of coated films was routinely measured with the shellac side toward the air (20.9% O<sub>2</sub>) and the uncoated side in contact with an oxygen-free environment. However, there was no significant difference in oxygen permeance for inverted samples.

Figure 1 shows oxygen permeability at different values of relative humidity for shellac cast from ethanol and water.

**Table III. Activation Energy for Oxygen Permeability of 0.85-mil Shellac Coatings on EVA Film, at 55% Relative Humidity**

solvent	$E_a$ , kcal/mol		correl coeff <sup>b</sup>
	mean <sup>a</sup>	95% range	
ethanol	12.7	12.4–13.0	0.992
water/morpholine	15.5	14.2–16.8	0.978

<sup>a</sup> Data for ethanol are from six samples at 18–41 °C and for water from three samples at 18–35 °C. The means differ at the 99% level.

<sup>b</sup> For the Arrhenius plot.

**Table IV. Oxygen Permeability at 28.5 °C for Bleached Shellac from Two Sources**

source	permeability, cc mil/(m <sup>2</sup> day atm)
Mantrose-Haeuser	329 ± 17 <sup>a</sup>
Zinsser & Co.	316 ± 23

<sup>a</sup> The 95% confidence interval for the mean, four trials each.

ANOVA showed that oxygen permeability of all three coatings was dependent on relative humidity. Coatings cast from ethanol had lowest permeability and were least dependent on relative humidity. Over the range 40–78% relative humidity the oxygen permeability was not significantly affected by relative humidity, with an average value of 230 ± 17 cc mil/(m<sup>2</sup> day atm). By comparison, the coatings made from water-soluble shellac were much more permeable, especially at relative humidity above 50%. The higher permeability of water-soluble shellac is attributed to the addition of morpholine to neutralize the shellac, a weak acid (the pH of a 10% slurry was 4.6 ± 0.1). The pH of the morpholine-shellac solution was 8.1 ± 0.1.

To mimic what might happen when water-soluble shellac is applied to an acidic food such as citrus fruit, EVA films with dried water-soluble shellac coatings were dipped for 2 min into 1% aqueous solutions of citric acid and dried again. The oxygen permeability of these acidified coatings (see Figure 1) was intermediate between those of the water-soluble and ethanol-based shellac coatings. Thus, water-soluble shellac coatings on acidic foods are likely to have lower permeability than the values reported here for the same shellac coated onto plastic film.

Measurement of oxygen permeability at different temperatures gave the values of  $E_a$  shown in Table III. The value of 12.7 kcal/mol means the oxygen permeation doubles as the temperature was raised from 30 to 40 °C.

Bleached shellac from two different sources was compared, using oxygen permeability as the basis for comparison. The coatings were 0.8 mil thick, cast on Tredagar from 2-propanol. Relative humidity was 55%. The results from four trials each, shown in Table IV, indicate that shellac from the two sources was very similar with respect to oxygen permeability.

Shellac varnish was also evaluated for oxygen permeability. With EVA as the support film, its permeability at 28.5 °C was 440 ± 100 cc mil/(m<sup>2</sup> day atm), on the basis of four trials. This value is significantly different from the value of 259 cc mil/(m<sup>2</sup> day atm) under the same conditions for bleached shellac (data of Table II).

Carbon dioxide as well as oxygen permeability of shellac films is shown in Table V, as is their ratio. The permeability to both these gases is of some importance for water-soluble shellac used in fruit coatings, since the rate of fruit ripening can be expected to be sensitive to internal concentrations of both oxygen and carbon dioxide. The ratios reported in Table V are within the range of values reported by Lebovits (1966) for a wide range of polymers.

**Water Vapor Permeability of Shellac.** The water vapor permeability of shellac coatings was evaluated as

**Table V. O<sub>2</sub> and CO<sub>2</sub> Permeability at 75% Relative Humidity, 30 °C**

solvent	O <sub>2</sub> permeability, cc mil/(m <sup>2</sup> day atm)	CO <sub>2</sub> permeability, cc mil/(m <sup>2</sup> day atm)	ratio
	ethanol	230 ± 32	
water/morpholine	682 ± 64	4300 ± 500	0.16 ± 0.01

<sup>a</sup> The data are based on four trials.

**Table VI. Water Vapor Permeability of Shellac Coatings**

RH (coated side) <sup>a</sup>	values of permeability, <sup>b</sup> g mil/(m <sup>2</sup> day mmHg)			
	iPrOH	EtOH	morpholine <sup>b</sup>	NaOH <sup>b</sup>
100	2.1 ± 0.1	5.1 ± 0.1		
84	1.8 ± 0.4	3.8 ± 0.2	11.0 ± 2.1	
75	1.4 ± 0.1		8.8 ± 1.1	147 ± 62
51	1.2 ± 0.2		2.8 ± 0.3	3.8 ± 0.6
32	1.1 ± 0.2		1.9 ± 0.1	
11	0.86 ± 0.04			

<sup>a</sup> The uncoated side was at 0% relative humidity in all cases. <sup>b</sup> Shellac dissolved in water with morpholine or NaOH, respectively.

coatings on films of cellulose acetate. The values of permeability shown in Table VI were calculated by iteration between eqs 2, 4, 5, and 6. For example, a sample with 0.44-mil coating had a measured permeance of 3.16 g/(m<sup>2</sup> day mmHg) at 30 °C, with relative humidity of 83.6% on the coated side and 0% on the side of the support film. By use of eqs 5 and 6 or Table I as basis, a first estimate is made of the permeance of the support film. For our example suppose 25.0 g/(m<sup>2</sup> day mmHg) was this first estimate. With that value, eq 2 yields 1.59 g mil/(m<sup>2</sup> day mmHg) as the permeability of the coating. The relative humidity at the interface between coating and support film, from eq 4, amounts to 10.6%. By use of eq 5 for the second time, cellulose acetate between environments of 0 and 10.6% relative humidity has permeance of 20.2 g/(m<sup>2</sup> day mmHg). Second usage of eqs 2 and 4, respectively, gives 1.65 g mil/(m<sup>2</sup> day mmHg) for permeability and 13.1% relative humidity at the interface. Further iterations do not change this value, and in general one iteration sufficed to give stable values.

Table VI shows that for shellac cast from 2-propanol the moisture vapor permeability at 30 °C was within the range 0.9–2.1 g mil/(m<sup>2</sup> day mmHg) at all relative humidity gradients. For coatings made from water-soluble shellac the permeability was much higher, especially at relative humidities of 75% and above. We also note that at 75% relative humidity on the coated side the shellac solubilized with NaOH was about 17 times as permeable as shellac solubilized with morpholine. Thus, the choice of solvent and neutralizing agent or both of some importance in determining the amount of moisture vapor protection provided by a shellac coating.

Because the water vapor permeability was dependent on relative humidity, the permeance of the coated film depended on whether the coating or the support film was turned toward the higher humidity. The data of Table VI are for films with the shellac toward the higher humidity.

The activation energy was determined from measurement of moisture permeability at temperatures of 26, 35, and 40 °C. For three samples with 0.4-mil shellac cast from 2-propanol, measured at 100% relative humidity on the coated side, the Arrhenius plots gave 12.0 ± 1.1 kcal/mol as the activation energy. For the plots of ln PC vs reciprocal temperature the average correlation coefficient was 0.999.

For shellac varnish, the permeability was 2.1 ± 0.3 mil/(m<sup>2</sup> day mmHg), measured with 84% RH on the shellac

side of the film and 0% on the uncoated side. This is significantly different from and 40% lower than the value of 3.8 for bleached, dewaxed shellac under the same conditions (data from Table VI). It is not surprising that dewaxed shellac is more permeable, since waxes generally are good moisture barriers.

**Comparison with Other Films.** At 30 °C and relative humidities of 40–80% shellac had permeability for O<sub>2</sub> and CO<sub>2</sub> of 230–700 and 800–5800 cc mil/(m<sup>2</sup> day atm), respectively. For relative humidities not exceeding 50%, the water vapor permeability of all shellac coatings was in the range 0.9–3.8 g mil/(m<sup>2</sup> day mmHg).

Under these conditions shellac is a better barrier to CO<sub>2</sub> and O<sub>2</sub> than cellulose acetate, polyethylene (all densities), polyethylene copolymer with vinyl acetate, polypropylene, polycarbonate, or polystyrene, but not as good a barrier as nylon 6, polyester, or poly(vinylidene chloride), (Anonymous, 1988; Sacharow and Griffin, 1980). Shellac coatings cast from alcohol are better barriers to moisture vapor than cellulose, cellophane acetate, or nylon 6. However, they are poorer barriers to moisture vapor than polyester, polyethylene (all densities), polyethylene copolymer with vinyl acetate, polypropylene, or poly(vinylidene chloride).

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