

Permeation of Water Vapor through Polymeric Films

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INTRODUCTION

In recent years considerable research and technological activity has been directed toward investigations of materials which are pyrophoric, moisture sensitive, and/or physiologically hazardous. The necessity for the protection of personnel while employed with such materials has resulted in the establishment of a form of barrier to isolate the hazardous material from the worker and his environment. One approach to the isolation of a moisture or oxygen sensitive material from an air atmosphere as well as separation of workers from the hazards of personal contact with the material is the glovebox technique. This particular technique makes use of an enclosure containing the potentially hazardous material in an inert atmosphere. Manipulations within the glovebox are accomplished through arm-length gloves which are tightly attached to the glovebox walls. Since the gloves required for manipulation within the enclosure are manufactured from semipermeable polymeric films, they constitute a suspect area for the diffusion of water vapor into the system. This investigation was carried out to determine the role of the conditions affecting the permeability of glove materials.

MATERIALS TESTED

At the present time gloves for protective enclosures are manufactured by a dipping process. Three basic "compounds" are usually employed: neoprene (either latex or milled), butyl, and natural rubber. The most promising materials from the standpoint of minimum loss of manual dexterity and physical properties are the Neoprenes.¹ For this investigation four types of latex neoprene, all provided by different glove suppliers, three milled neoprene types, a vinyl film, and a Hycar film were tested in order to determine the effect of thickness and water vapor pressure drop across the film upon the rate of water permeation through the film.

TEST PROCEDURE

The test procedure chosen for this work was Procedure B, ASTM Designation E96-53T, "Measuring Water Vapor Transmission of Materials in Sheet Form." The dish employed was a Pyrex crystallizing dish 50 mm. in height and 70 mm. in diameter. To insure a seal between the film to be tested and the rim of the test dish, the lip of each dish was ground flat. About 25 mm. of distilled water was placed in the cup prior to testing. The film under investigation was laid over the rim of the test cup and was held in place between an aluminum flange and the ground lip of the crystallizing

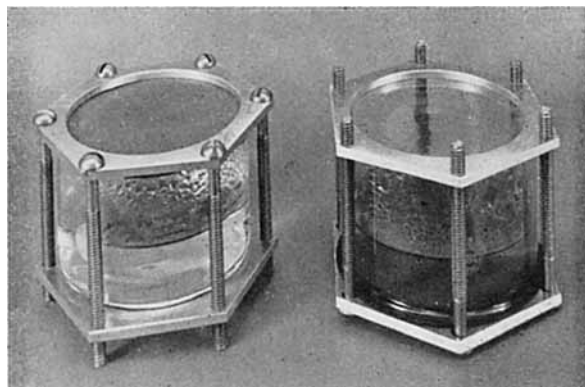


Fig. 1. Assembled test dishes for water vapor permeability tests.

dish by tension applied to six bolts. Figure 1 is a view of two assembled test dishes, one with the film uppermost and the other in the inverted position.

The test assembly was placed in a constant humidity room whose atmosphere was controlled with respect to humidity and temperature. For this investigation three levels of humidity, ambient to the test dish, were employed. These levels were: 70, 42, and 22% R.H. In each case the relative humidity was controlled to $\pm 2\%$ about the average value and the temperature was held at $24 \pm 1^\circ\text{C}$.

The room was provided with forced circulation to insure movement of air across the outside surface of the film. Weighings of the assembled test cup were made twice a week for a period of one month, the weight loss divided by the time interval between weighings being the rate of water vapor permeation through the film. A total testing time of one month was chosen to assure equilibrium permeation rates through the film and to provide relatively large weight change measurements.

A preliminary investigation was conducted to determine the effect of film and cup position. In this work a series of samples were made up into test assemblies with the films outside out and inside out. The cups were then placed upright (the film exposed to the vapor over the water) or inverted (the film in contact with the water). No difference in permeation rate was detected as a result of these test conditions. As a result of these observations all subsequent testing was carried out with no con-

TABLE I

Tabulation of Permeation Data for Polymeric Films of Varied Thickness at Constant Vapor Pressure Differential Across the Membrane^a

Material	Thickness,		Permeation rate, g./day m. ²	Rate × 10 ⁵ cc./ sec. cm. ²	Material	Thickness,		Permeation rate, g./day m. ²	Rate × 10 ⁵ cc./ sec. cm. ²	
	mils	mm.				mils	mm.			
Cadillac vinyl sheet	8	(0.203)	6.17	(0.889)	Charco latex neoprene	5	(0.127)	7.69	(1.11)	
	8	(0.203)	8.55	(0.813)		5	(0.127)	7.32	(1.05)	
	20	(0.508)	2.56	(0.367)		12	(0.305)	2.97	(0.427)	
	20	(0.508)	2.61	(0.375)		12	(0.305)	3.21	(0.461)	
Charco Pb sandwich	31	(0.787)	0.928	(0.134)		17	(0.432)	2.58	(0.370)	
	31	(0.787)	0.928	(0.134)		17	(0.432)	3.55	(0.511)	
Surety milled neoprene	22	(0.559)	1.45	(0.208)		23	(0.584)	1.96	(0.284)	
		(0.559)	1.44	(0.206)		23	(0.584)	2.18	(0.315)	
						26	(0.660)	1.96	(0.284)	
Charco milled neoprene	4	(0.102)	9.71	(1.40)		26	(0.660)	1.95	(0.281)	
		(0.102)	9.98	(1.44)		30	(0.762)	1.85	(0.266)	
		(0.254)	3.41	(0.492)		33	(0.838)	1.84	(0.266)	
		(0.254)	3.44	(0.494)		Pioneer latex neoprene	15	(0.381)	4.19	(0.605)
		(0.432)	1.90	(0.274)			15	(0.381)	4.48	(0.646)
		(0.432)	1.78	(0.256)			21	(0.533)	2.92	(0.419)
		(0.533)	1.51	(0.217)	21		(0.533)	5.40	(0.776)	
		(0.533)	1.52	(0.219)	25		(0.635)	2.63	(0.377)	
		(0.711)	1.17	(0.169)	25		(0.635)	2.95	(0.424)	
		(0.711)	1.18	(0.170)	31		(0.787)	2.68	(0.385)	
			31	(0.787)	2.68		(0.385)			
Charco Hycar	4	(0.102)	25.9	(3.73)	Surety latex neoprene		24	(0.610)	2.97	(0.427)
		(0.102)	28.6	(4.12)			25	(0.635)	2.92	(0.419)
		(0.203)	12.0	(1.73)		26	(0.660)	4.06	(0.586)	
		(0.203)	11.4	(1.64)		27	(0.686)	2.63	(0.378)	
		(0.381)	5.89	(0.848)		28	(0.711)	2.48	(0.357)	
		(0.381)	6.02	(0.867)		29	(0.737)	2.42	(0.349)	
		(0.559)	3.91	(0.564)		Seamless latex neoprene	17	(0.432)	4.48	(0.646)
		(0.559)	4.17	(0.600)			18	(0.457)	4.74	(0.682)
		(0.660)	3.41	(0.491)			18	(0.457)	5.60	(0.806)
		(0.660)	3.33	(0.480)	20		(0.508)	3.65	(0.526)	
						22	(0.559)	4.35	(0.625)	
						Butyl	10	(0.254)	0.417	(0.0599)
							17.5	(0.445)	0.130	(0.0187)

^a At constant temperature of 41°C. constant partial pressures of water: $p_1 = 22.0$ mm. Hg, $p_2 = 9.5$ mm. Hg, $\Delta p = 12.5$ mm. Hg; film area $A = 38.4$ cm.².

cern to film orientation and with the test dish in the upright position.

RESULTS

The results of an investigation of the effect of film thickness upon permeation rate appear in Table I. For this particular analysis, the mass transfer rate per unit area is designated as the permeation rate. The permeation rate is, then, the weight or volume of water vapor diffusing through the film per unit time per unit area. This quantity is presented as both weight and volume rate for purposes of comparison with other published data.

For these investigations one side of the film was always exposed to a saturated vapor p_1 while the other was exposed at varying humidity and temperature p_2 . Since the driving force for the permeation of water vapor through a film is the partial pressure of water vapor differential across the film, all data on relative humidity and temperature have been converted to partial pressure of water vapor, and the differential across the film ($p_1 - p_2$) expressed as Δp in millimeters of mercury.

A plot of permeation rate against film thickness for milled neoprene, vinyl, and Hycar films ap-

pears in Figure 2. A similar relationship is graphed for neoprene latex and appears as Figure 3. It is apparent from Figure 2 that the slope of the log-log curve is constant for all the materials tested. Mathematically, the relationship between permeation and thickness reduces to the general equation: $W/tA = M/x^m$, where W is the weight, in grams, of water which permeates the film; t is the time interval in days; A is the area in square meters through which permeation takes place; x is the film thickness in thousandths of an inch; and M and m are constants for the system. It is felt that the exponent m , which is constant for the films involved, is the result of some basic similarity between these films. Similarity is certainly not manifest in the physical or chemical nature of these copolymers. However, milled neoprene (a chloroprene rubber), vinyl (a vinyl chloride copolymer),² and Hycar (an acrylonitrile-butadiene polymer),³ though chemically dissimilar, have a common history in production, i.e., all these films are manufactured by an organic solvent-dispersion method.^{2,3} To carry this reasoning to its logical conclusion is to attribute the constant value of, m , to the dispersion system. If this were the case, then those films formed by an aqueous dispersion technique should

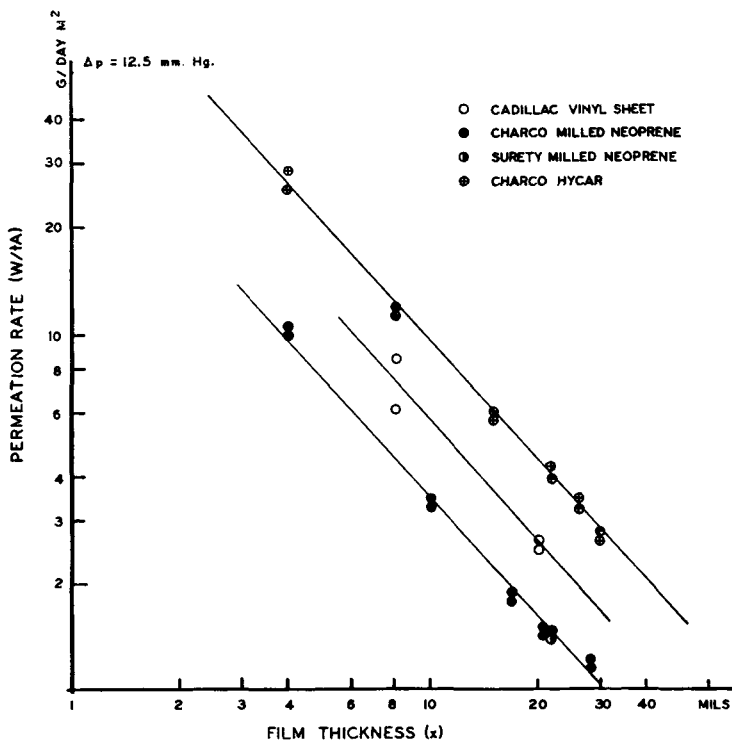


Fig. 2. Plot of permeation rate vs. film thickness at constant vapor pressure differential across films formed by an organic solvent dispersion technique.

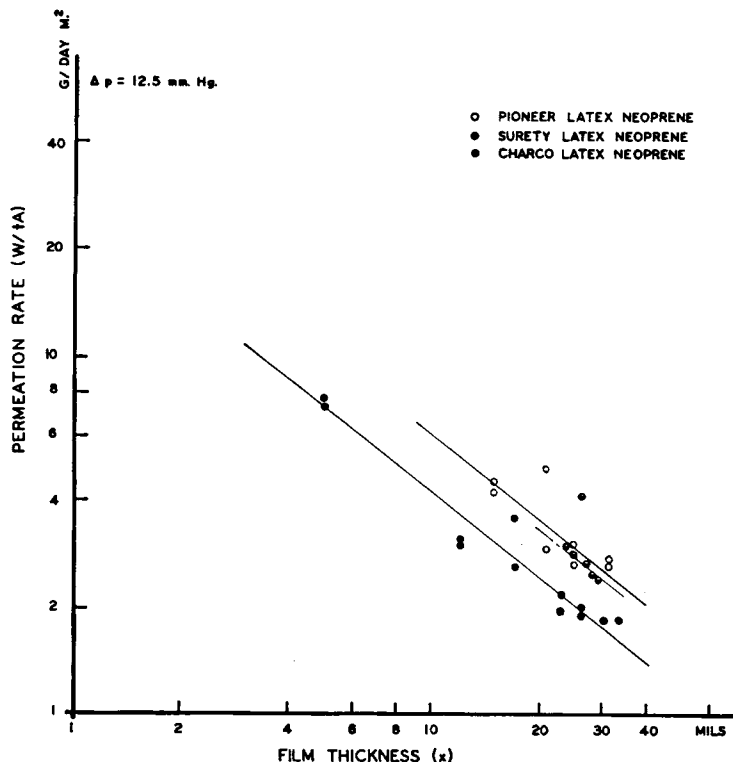


Fig. 3. Plot of permeation rate vs. film thickness at constant vapor pressure differential across films formed by an aqueous dispersion technique.

be characterized by an equivalent constant. Proof of this statement is offered in Figure 3, in which the permeation through latex neoprene films of different manufacturers is plotted against thickness. It is evident, from this figure that the relationship $W/tA = M/x^m$ holds, and that the thickness constant m has a different value than that obtained in the experiments represented by Figure 2. This fact is important when it is noted that the Charco milled neoprene and latex neoprene are chemically similar and differ only in the dispersing media. These results are also meaningful when it is recognized that the thickness coefficient may be uninfluenced by differences in compounding, as indicated by the similarity between films produced by different manufacturing concerns.

Barrer⁴ suggests that membranes which sorb little water behave according to Fick's law and the permeation rate is inversely proportional to film thickness. However, he recognizes that at high humidities the permeation constant K varies with increasing thickness. Some investigators^{5,6} have shown that, at low humidities, permeation rate is proportional to vapor pressure difference across the membrane. This phenomenon breaks down at high humidity differentials and the point of depar-

ture depends upon the hygroscopicity of the film material. Since the materials investigated usually are compounded with metallic oxides which form hydrates, it became necessary to investigate the relationship between water vapor pressure differential across the film and permeation rate.

A literature search of the subject of moisture permeability has led to the data of Rowan.⁷ Although this author offers his findings as "indicative only for presently marketed stocks" and makes no attempt at a reduction of the number of variables in the system considered, certain interesting observations are presented. If one takes the liberty of converting the temperature and relative humidity data of Rowan to partial pressure of water vapor differentials across the film, a tabulation such as that shown in Table II results.

A plot of partial pressure of water vapor differential against permeation rate for the data of Rowan yields the curve shown in Figure 4. In this figure it may be seen that for constant thickness the permeation rate is a semilogarithmic function of vapor pressure differential. Mathematical reduction of these findings results in an equation of the form: $W/tA = Ne^{n\Delta p}$, where Δp is the difference in partial pressure of water vapor across the

TABLE II^a
 Conversion and Tabulation of Data by Rowan for Polymeric Films of Constant Thickness at
 Varying Vapor Pressure Differential Across the Membrane

Material	Thickness, mils (mm.)	Partial pressure H ₂ O _v			Temp., °C.	Permeation	
		<i>p</i> ₁ mm. Hg	<i>p</i> ₂ mm. Hg	<i>p</i> ₁ - <i>p</i> ₂ , mm. Hg		rate, g./day m. ²	(Rate × 10 ⁵ cc./sec. cm. ²)
Butyl-7	32 (0.812)	13.1	0.0	13.1	24	0.0818	0.0117
	32 (0.812)	22.2		22.2	24	0.118	(0.0170)
	32 (0.812)	48.4		48.4	37	0.370	(0.0532)
Butyl-6	29 (0.737)	13.1		13.1	24	0.118	(0.0170)
	29 (0.737)	22.2		22.2	24	0.149	(0.0214)
	29 (0.737)	48.4		48.4	37	0.411	(0.0590)
Supreme-4	43 (1.09)	13.1		13.1	24	1.15	(0.165)
	43 (1.09)	22.2		22.2	24	1.51	(0.218)
	43 (1.09)	48.4		48.4	37	5.17	(0.746)
Supreme-2	25 (0.635)	13.1		13.1	24	1.49	(0.215)
	25 (0.635)	22.2		22.2	24	2.92	(0.420)
	25 (0.635)	48.4		48.4	37	14.1	(2.04)
Neoprene-3	17 (0.432)	13.1		13.1	24	1.94	(0.280)
	17 (0.432)	22.2		22.2	24	4.10	(0.590)
Surety-5	25 (0.635)	13.1		13.1	24	2.45	(0.353)
	25 (0.635)	22.2		22.2	24	5.00	(0.500)

^a Data extracted or converted from those of Rowan (ref. 7) for film of area *A* = 346 cm.².

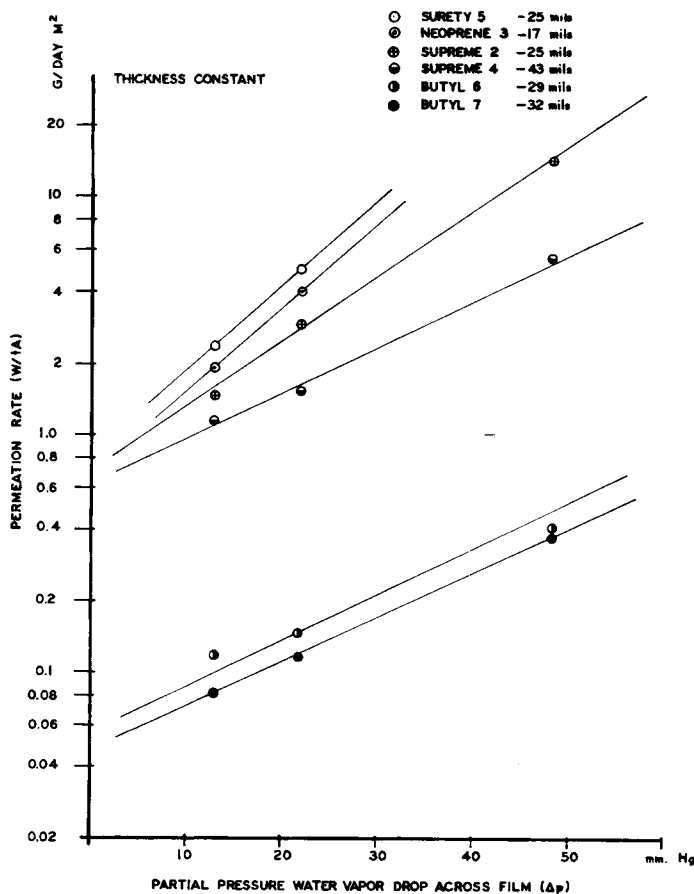


Fig. 4. Plot of permeation rate vs. partial pressure water vapor drop across various films. (Data from J. H. Rowan.)

TABLE III
 Tabulation of Data for Polymeric Films of Constant Thickness at Varying
 Vapor Pressure Differential Across the Membrane^a

Material	Thickness, mils (mm.)	Partial Pressure H ₂ O _v			Temp., °C.	Permea- tion rate, g./day m. ²	(Rate × 10 ⁶ cc./sec. cm. ²)
		<i>p</i> ₁ , mm. Hg	<i>p</i> ₂ , mm. Hg	(<i>p</i> ₁ - <i>p</i> ₂), mm. Hg			
Surety latex neoprene	25 (0.635)	22.0	5.2	16.8	24	3.41	(0.491)
	25 (0.635)		5.2	16.8		3.57	(0.513)
			9.5	12.5		2.97	(0.427)
			9.5	12.5		2.92	(0.419)
			15.9	6.1		2.24	(0.322)
			15.9	6.1		2.33	(0.335)
Charco latex neoprene	23 (0.584)		5.2	16.8		2.35	(0.337)
	23 (0.584)		5.2	16.8		2.42	(0.347)
			9.5	12.5		1.96	(0.284)
			9.5	12.5		2.18	(0.315)
			15.9	6.1		0.96	(0.138)
			15.9	6.1		1.00	(0.144)
Pioneer latex neoprene	25 (0.635)		5.2	16.8		3.70	(0.531)
	25 (0.635)		5.2	16.8		3.70	(0.531)
			9.5	12.5		2.63	(0.377)
			9.5	12.5		2.95	(0.424)
			15.9	6.1		2.22	(0.319)
			15.9	6.1		2.55	(0.366)
Cadillac vinyl	20 (0.508)		5.2	16.8		3.55	(0.510)
	(0.508)		5.2	16.8		3.57	(0.513)
			9.5	12.5		2.56	(0.367)
			9.5	12.5		2.61	(0.375)
			15.9	6.1		1.38	(0.193)
			15.9	6.1		1.38	(0.198)
Charco Milled neoprene	21 (0.533)		5.2	16.8		2.07	(0.297)
	21 (0.533)		5.2	16.8		2.08	(0.299)
			9.5	12.5		1.51	(0.217)
			9.5	12.5		1.52	(0.219)
			15.9	6.1		0.92	(0.132)
			15.9	6.1		0.94	(0.135)
Charco Hycar	26 (0.660)		5.2	16.8		4.60	(0.661)
	26 (0.660)		5.2	16.8		4.58	(0.658)
			9.5	12.5		3.41	(0.491)
			9.5	12.5		3.33	(0.480)
			15.9	6.1		2.04	(0.293)
			15.9	6.1		2.04	(0.293)

^a Constant film area $A = 38.4$ cm.². and constant temperature = 24°C.

film in millimeters of mercury and N and n are constants for the system. Here, as in the graphs of permeation rate versus thickness, it appears that a constant exponent may characterize a film with regard to the effect of controlling variables upon permeation rate.

Support for the above argument may be found in Table III and in Figure 5. Table III is an outline of the impact upon permeation rate of changes in partial pressure of water vapor differential across various films of constant thickness. Figure 5 is a

graphical representation of the above outline. These data collected by varying the humidity ambient to the film are in close agreement with those of Rowan and add support to the orderly and predictable nature of permeation phenomena in the polymeric films studied. It may be pertinent to add, at this point, that there is no known similarity between the samples of film investigated by Rowan and those used for the investigations reported herein.

It is possible mathematically to relate perme-

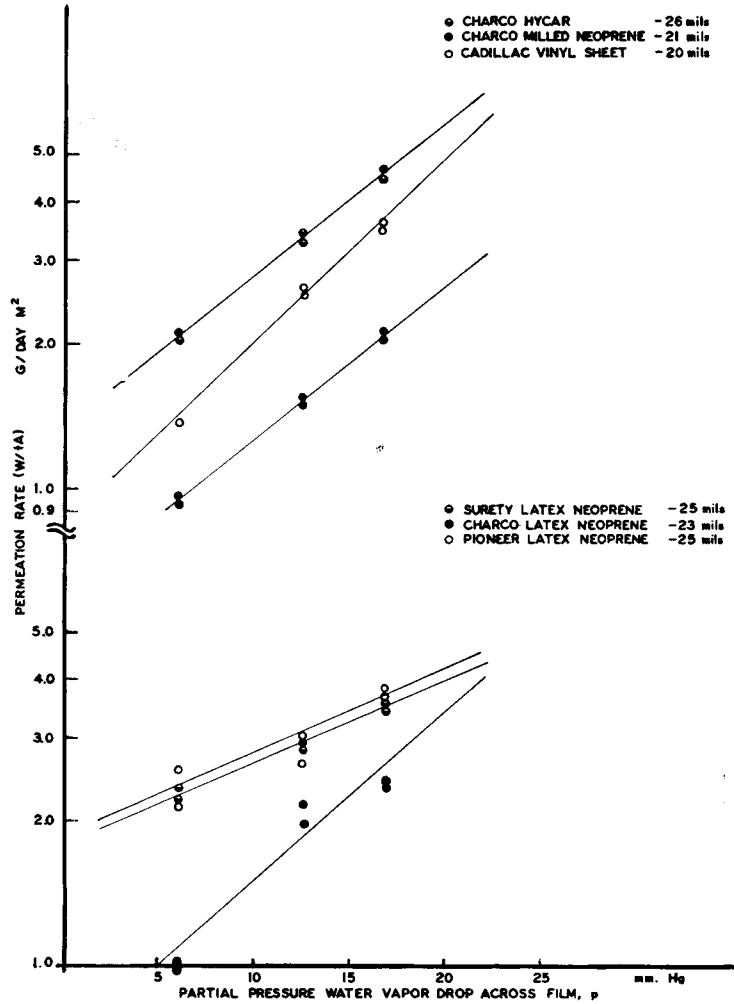


Fig. 5. Plot of permeation rate vs. partial pressure water vapor drop across films formed by both organic solvent and aqueous dispersion techniques.

ation to the controlling variables through the use of the relationship between permeation rate, thickness, and water vapor pressure differential across the membrane. Derivation of the relationship between permeation rate and the independent variables influencing this rate is as follows. Here, K is the permeability constant, and the other symbols are as defined above.

From Figures 2 and 3, we have

$$W/tA(x) = M/x^m \quad (1a)$$

From Figures 4 and 5 we have

$$W/tA(\Delta p) = Ne^{n\Delta p} \quad (1b)$$

We assume

$$M = f(\Delta p) \quad (2a)$$

$$N = f(x) \quad (2b)$$

Substitution of eq. (2a) into eq. (1a) yields

$$W/tA(x, \Delta p) = f(\Delta p)/x^m \quad (3a)$$

Similarly, substitution of eq. (2b) into eq. (1b) yields

$$W/tA(x, \Delta p) = f(x)e^{n\Delta p} \quad (3b)$$

We can then equate

$$W/tA(x, \Delta p) = f(\Delta p)/x^m = f(x)e^{n\Delta p} \quad (4)$$

On differentiation of eq. (4) we obtain

$$\frac{\partial [W/tA(\Delta p, x)]}{\partial \Delta p} \cdot \frac{\partial [f(\Delta p)]x^{-m}}{\partial \Delta p} = n[f(x)]e^{n\Delta p} \quad (5)$$

From eq. (5), we obtain

$$\partial [f(\Delta p)]/\partial \Delta p = d[f(\Delta p)]/d\Delta p = nx^me^{n\Delta p}[f(x)] \quad (6)$$

Since, from eq. (4), $f(\Delta p)/x^m = f(x)e^n \Delta^p$

$$\therefore f(\Delta p) = x^m e^{n\Delta p} [f(x)] \quad (7)$$

Substituting eq. (7) into eq. (6) yields

$$d[f(\Delta p)]/d\Delta p = nf(\Delta p) \quad (8)$$

On rearrangement to

$$d[f(\Delta p)]/f(\Delta p) = n d\Delta p$$

and integration we have

$$\ln f(\Delta p) = n\Delta p + c \quad (9)$$

Then

$$f(\Delta p) = e^{n\Delta p} + e^c = Ke^{n\Delta p} \quad (10)$$

Finally, substitution of eq. (3a) into eq. (10), yields

$$W/tA(x, \Delta p) = Ke^{n\Delta p}/x^m \quad (11)$$

The use of the above derivation will permit the calculation of a permeability constant for any membrane when the variation of permeation rate with thickness and vapor pressure differential are known. Conversely, if the permeability constant and the

TABLE IV
Calculated Permeability for Various Polymeric Films at a Normalized Thickness and Water Vapor Pressure Differential Across the Membrane

Polymer	m	n	K	$(W/tA)_c$
Butyl-7 ^a	1.1	0.043	2.1	0.12 ^b
Butyl-6 ^a	1.1	0.045	2.3	0.13 ^b
Charco milled neoprene	1.1	0.074	17	1.3 ^b
Neoprene 3 ^a	0.8	0.081	6.7	1.4 ^b
Supreme 2 ^a	0.8	0.063	9.4	1.6 ^b
Charco latex neoprene	0.8	0.082	8.1	1.7 ^b
Supreme 4 ^a	0.8	0.045	12	1.8 ^b
Cadillac vinyl	1.1	0.088	23	2.0 ^b
Surety 5 ^a	0.8	0.083	11	2.4 ^b
Surety latex neoprene	0.8	0.040	23	3.2 ^b
Pioneer latex neoprene	0.8	0.043	23	3.2 ^b
Charco Hycar	1.1	0.074	48	3.7 ^b

^a Data of Rowan⁷.

^b Calculated permeability for $p = 10$ mm Hg, $x = 22.3$ mils.

constant exponentials are known, the permeation rate for any thickness and vapor pressure drop across a film may be calculated. A tabulation of the constants and permeability at a constant level of thickness and partial pressure of water vapor differential across a series of polymeric films may be seen in Table IV.

CONCLUSIONS

Andrews and Johnston⁸ claim that the time to reach a given saturation in a membrane is approximately proportional to the square of film thickness, indicating a like variation of permeation rate with thickness. Taylor, Herrmann, and Kemp⁵ indicate a variation of permeability constant with thickness and state, further, that data obtained by constant-pressure methods show that the permeability of rubber varies inversely with the first power of thickness, while data obtained by the variable-pressure method indicates an inverse square relationship. The conflict in the findings of various investigators studying the relation between permeation and its independent variables⁹ may be resolved somewhat by differentiating the permeability constant from the diffusion constant. It might also be convenient to consider the permeability constant to have a fixed value and consider permeation rate, rather than the permeability constant, to be a function of the variable quantities in the system.

The determination of the permeability constants for the films studied is the intent of this investigation, which was carried out under constant-pressure conditions. It is evident that permeation rate is inversely proportional to thickness to a constant exponent, the value of this exponent being dependent upon the solution system employed in the manufacture of the film. It is suggested that, for a membrane formed by organic solvent dispersion system, the permeation rate is inversely proportional to the 1.1 power of thickness, that is, $W/tA \propto x^{-1.1}$. The value of this constant for an aqueous dispersion system appears to be 0.8, i.e., the rate is $W/tA \propto x^{-0.8}$.

It may be seen from Figures 4 and 5 that the variation of permeation rate with vapor pressure drop across a membrane does not appear to be as clearcut as that inferred by the thickness variation. The permeation rate varies with vapor pressure differential by an exponential value n , but the inconsistency of this value and of the permeability constant K within film type groups leads to the suggestion that the values of these two constants are functions of the nature of the polymer and of such additive materials as pigments, stabilizers, and coagulants which may be present. Since the schedule of additives within a composition will vary widely at the option of the manufacturer, no constancy of n or K should be expected within film types of different manufacturing source. The values of K and n , however, can be determined for

a particular material and these values will characterize the film with respect to its permeability.

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Synopsis

The use of gloves made of rubber or synthetically produced copolymers in protective atmosphere enclosures has focused attention upon the permeability of the film as a suspect area for the diffusion of water vapor as a contaminant into the protective gas system. This investigation was carried out to determine the role of the conditions affecting the permeability of glove materials. Particular attention was placed upon the system governing the permeation of water vapor through vinyl, Hycar, and milled and latex neoprene films. The investigation was carried out by a constant pressure technique conforming to Procedure B, ASTM Designation E96-53T. The rate at which water vapor permeates a film was studied in the light of two independent variables: film thickness and water vapor pressure differential across the film. Permeation rate was found to be inversely proportional to thickness to a constant exponent. The variation of permeation rate with vapor pressure drop across a membrane is not as sharply defined as the variation with thickness, but does vary semilogarithmically. It was found that water vapor permeation rate may be mathematically defined in terms of the controlling variables and three constants. The relationship between permeation rate and the independent variables influencing this rate can be expressed as $W/tA = Ke^{n\Delta p}/x^m$ where W is the weight of water permeating a film of area A area in time t . The film thickness is x , Δp is the difference in partial pressure of water vapor across the film, K is defined as the permeability constant, n is the partial pressure coefficient, and m is a thickness coefficient dependent upon the solution system employed for film manufacture. Characterization of a particular film with respect to its permeability is possible through the use of the permeability constants. The value of the thickness coefficient appears to be dependent upon the solution system employed in the manufacture of the film. The exponents of thickness are offered as 1.1 for an organic solvent dispersion system and 0.8 for an aqueous dispersion

system. The value of the exponential constant dependent upon the vapor pressure differential and the value of the permeability constant are suggested as dependent upon the schedule of "compounding" and not readily predictable. They appear, however, to be well defined functions and, once determined for a particular composition, may be used to predict the permeability of that material as a function of the water vapor pressure differential across the film.

Résumé

L'utilisation de gants faits de caoutchouc ou de copolymères synthétiques dans des enceintes de protection, a attiré l'attention sur la perméabilité du film comme surface susceptible de permettre la diffusion de vapeur d'eau comme agent contaminant d'un système gazeux. Ces investigations ont été effectuées en vue de déterminer le rôle des conditions affectant la perméabilité de ses matériaux. On a particulièrement étudié les systèmes perméables à la vapeur d'eau au travers de films de vinyliques, d'hycar, de films et de latex de néoprène. Les recherches ont été effectuées à pression constante conformément au procédé B, désignation ASTM E96-537. À la lumière de deux variables indépendantes on a étudié la vitesse de laquelle la vapeur d'eau imprègne un film; ces variables sont l'épaisseur du film et la tension de vapeur différentielle de l'eau au travers du film. La vitesse de perméabilisation c'est trouvé être inversement proportionnelle à l'épaisseur à un exposant constant. La variation de la vitesse de perméation avec la pression de vapeur à travers la membrane n'est pas aussi clairement tranchée qu'avec la variation d'épaisseur mais varie semilogarithmiquement. On a trouvé que la vitesse de perméation par la vapeur d'eau peut-être exprimée mathématiquement en fonction de trois variables et trois constantes. La dérivation de la relation entre la vitesse de perméation et les variables indépendante influençant cette vitesse s'exprime par expression suivante: $W/tA = Ke^{n\Delta p}/x^m$, où W est le poids d'eau imprégnant un film de surface desection A en temps t . L'épaisseur du film est x , Δp est la différence de pression partielle de la vapeur d'eau au travers du film, K est la constante de perméabilité, n est le coefficient de pression partielle et m est un coefficient d'épaisseur dépendant du système de solvant utilisé dans la manufacture du film. La caractérisation d'un film particulier en fonction de sa perméabilité est possible par l'utilisation des constantes de perméabilité. La valeur du coefficient d'épaisseur apparaît comme dépendante du système de solvant utilisé dans la manufacture du film. Les exposants de l'épaisseur valent 1,1 pour un système de solvants organiques dispersifs et 0,8 pour un système dispersif aqueux. On suggère que la valeur de la constante exponentielle dépendant de la pression de vapeur différentielle et la valeur de la constante de perméabilité sont dépendantes du processus de compounding et n'est pas entièrement prévisible. Elles apparaissent cependant comme étant des fonctions bien définies et une fois déterminées pour un composé particulier, peuvent être utilisées en vue de prévoir la perméabilité de ce matériel comme une fonction de la pression de vapeur différentielle au travers du film.

Zusammenfassung

Die Verwendung von Handschuhen, die aus Kautschuk oder aus synthetisch erzeugten Copolymeren unter einer Schutzatmosphäre hergestellt wurden, hat die Aufmerksamkeit

keit auf die Permeabilität des Films, als eines für die Diffusion von Wasserdampf als Verunreinigung in das Schutzgas in Frage kommenden Bereiches gelenkt. Die vorliegende Untersuchung wurde zur Bestimmung der Rolle der äusseren Bedingungen, die die Permeabilität von Handschuhmaterialien beeinflussten, ausgeführt. Besondere Beachtung wurde dem System gewidmet, das für die Permeation von Wasserdampf durch Vinyl-, Hycar-, und Neoprenfilme aus gemahlenem und Latex-material verantwortlich ist. Die Untersuchung wurde nach einer Methode mit konstantem Druck ausgeführt, die dem Verfahren B, ASTM Bezeichnung, E96-53T entspricht. Die Geschwindigkeit der Permeation von Wasserdampf durch einen Film wurde in Abhängigkeit von zwei unabhängigen Variablen untersucht: Filmdicke und Druckgefälle des Wasserdampfes durch den Film. Die Permeationsgeschwindigkeit war, wie gefunden wurde, einer Potent der Dicke mit konstantem Exponenten umgekehrt proportional. Die Abhängigkeit der Permeationsgeschwindigkeit vom Abfall des Dampfdruckes durch eine Membrane ist nicht so klar wie die Dickenabhängigkeit, lässt sich aber semilogarithmisch wiedergeben. Es wurde gefunden, dass die Permeationsgeschwindigkeit des Wasserdampfes mathematisch als Funktion der unabhängigen Variablen und von drei Konstanten formuliert werden kann. Die Ableitung der Beziehung zwischen der Permeationsgeschwindigkeit und den unabhängigen Variablen, die diese

Geschwindigkeit beeinflussen, führt zu folgendem Ausdruck: $W/tA = Ke^{n\Delta p}/x^m$, wo W das Gewicht des Wassers ist, das einen Film von Flächeninhalt A in Zeit t Tagen durchsetzt. Die Filmdicke ist x , Δp ist die Partialdruckdifferenz des Wasserdampfes durch den Film, K wird als Permeabilitätskonstante definiert, n ist der Partialdruckkoeffizient und m ist ein Dickekoeffizient, der davon abhängt, welches Lösungssystem bei der Herstellung des Films verwendet wurde. Eine Charakterisierung eines bestimmten Filmes in bezug auf seine Permeabilität ist durch Verwendung der Permeabilitätskonstanten möglich. Der Wert des Dickekoeffizienten scheint vom Lösungssystem, das bei der Anfertigung des Films verwendet wurde, abhängig zu sein. Die Dickeexponenten werden mit 1,1 für ein Dispersionssystem mit organischem Lösungsmittel und 0,8 für ein wässriges Dispersionssystem angegeben. Der Wert der Konstanten im Exponenten mit dem Dampfdruckunterschied sowie der Wert der Permeabilitätskonstanten scheinen vom Aufbau-schemata abzuhängen und nicht leicht vorherzusagen zu sein. Sie scheinen jedoch wohldefinierte Funktionen zu sein und können, wenn sie einmal für einen Film mit bestimmtem Aufbau ermittelt wurden zur Voraussage der Permeabilität dieses Materials als Funktion des Wasserdampfdruckgefälles durch den Film verwendet werden.

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