PERMEABILITY TO MOISTURE OF SYNTHETIC RESIN FINISHES FOR AIRCRAFT

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ABSTRACT

The permeability to moisture and some related properties of various synthetic resin finishes used on aircraft are reported. The glyceryl-phthalate enamels are less permeable to moisture under relatively dry conditions than are the enamels made with a phenol-formaldehyde resin. This order is reversed, however, under wet conditions. This corresponds with the service uses to which these finishes have been found to be best adapted. The aircraft finish made with a cellulose nitrate base is much more permeable to water vapor under both wet and dry conditions than are the resinous materials. The permeability of these finishes is not directly proportional to the vapor-pressure difference. The rate of passage of moisture per unit difference in vapor pressure increases with rising temperature. A given type of aircraft finish transmits moisture at the same rate whether in contact with liquid water or with saturated water vapor. The mechanism of penetration is, therefore, probably the same in the two cases. The film probably behaves as a typical colloidal, permeable membrane, and the water vapor is adsorbed by it and transmitted through the film by a process of chemical diffusion. Some observations on the absorption of moisture by resinous films and the effect of carnauba wax on permeability are presented. Results of measurements of the permeability to moisture of gas-cell fabrics of varying gelatin content and amount of paraffin coating are also given.

CONTENTS

I. INTRODUCTION

The permeability to moisture of a protective coating is now recognized as a fundamental property of practical importance in connection with its use over metals. The presence of moisture is necessary for the common types of metal corrosion. The problem of protecting

the metal is not merely one of waterproofing, since a sound coating does not normally allow the passage of water by diffusion through holes or capillary spaces. The films behave rather as typical colloidal, permeable membranes, according to the data obtained in this investigation. Water vapor is adsorbed by them and transmitted through the films by a process of chemical diffusion.

This process is closely analogous to the passages of gases through films of rubber, which was the subject of a previous investigation at the National Bureau of Standards [12].[1] Gases are adsorbed on one surface of the rubber, diffuse through it, and evaporate from the other side. Water vapor, which is of greater density than gaseous hydrogen, passes through it about fifty times as fast. Likewise, water vapor is adsorbed to a much greater extent by rubber than is hydrogen. The rate of passage of a gas through rubber is proportional to the difference in pressure or partial pressure of the gas on the two sides of the film. The rate also increases with increase in temperature and decreases with increase in thickness of the film.

Organic film-forming materials, such as synthetic resins, drying oils, and cellulose derivatives, differ markedly in their affinity for water. Regenerated cellulose and gelatin are known to be very hygroscopic, and films prepared from these substances are characterized by high rates of passage of moisture through them. On the other hand, the hydrocarbon waxes, such as the paraffins, have very little attraction for water, and act as moisture-proofing coatings for many commercial purposes. The synthetic resins differ among themselves in hygroscopicity. The styrene and vinyl types, which are essentially hydrocarbons, absorb only negligible amounts of water; the glyceryl phthalates, which are of the ester type and oxygen-bearing compounds, will absorb considerable amounts of moisture. Paints prepared with resinous vehicles of various types will yield films which show different rates of absorption and diffusion of moisture.

This paper describes the results of a study of the permeability to moisture and some related properties of various aircraft finishes used by the Navy Department.

II. EXPERIMENTAL PROCEDURE

1. PREPARATION OF THE FILMS

Films were prepared for this work by dipping amalgamated tin-plate panels in the respective aircraft finishes, the compositions of which are described in table 1. The tin plate, 0.016 inch thick, was cleaned with toluene, dried, and covered with mercury. The surface was rubbed gently with a silk cloth to obtain complete amalgamation. Clean mercury was then poured over the surface of the plate and the excess allowed to drain off. In this way a plate having a smooth, polished appearance was produced. This amalgamated plate was dipped within 1 hour of its preparation into the coating material and supported in a vertical position to allow the excess of liquid to flow off. The first coat was dried 1 week before application of further coats because of a tendency for the films to creep if insufficiently dry. This is caused by the lack of adhesion to the amalgamated tin. Three-day intervals between any additional coats were found to be ample to assure against creeping. After the desired number of coats

1 Figures in brackets refer to literature citations listed at the end of this paper.

TABLE 1.—*Composition by weight of aircraft finishes studied*

Specification	Product on wet basis		Nonvolatiles			Volatiles	
	Nonvolatile (minimum)	Volatile (maximum)	Resinous vehicle		Pigment	Type	Amount
			Type	Amount			
	%	%		%	%		%
V–11B	44	56	Glyceryl-phthalate	Min 40	None	Aliphatic and terpene hydrocarbons.	100.
			Modifying agents	Max 60			
E–5 (gray)	50	50	Same as above	Approx 50	Approx 50	do	100.
E–6B (black; type I)	33	67	Same as above	Min 90	Max 10	do	100.
V–10A	60	40	(33 gallon length)		None	Butyl alcohol	Min 5.
			Bakelite XR254	Min 28		Turpentine	Min 10.
			China wood oil	Min 45		Dipentine	Min 10.
			Castor oil	Min 2		Mineral spirits	Max 75.
			Linseed oil	Max 25			
			Drier	As required			
E–4A (orange yellow)	60	40	Same as above	Min 48	Min 48	Same as above	Same as above.
M–67D (gray)	60	40	Same as above	Min 48	Min 48	Same as above	Same as above.
P–23B	65	35	Same as above	Max 42	Min 58	Same as above	Same as above.
P–24A	40	60	Bakelite XR3962	Max 67	Min 33	Toluene	100.
P–27	60	40	Bakelite XR3962	Max 45	Min 55	Butyl alcohol	Min 10.
			Glyceryl-phthalate			Hydrocarbons	Max 90.
L–8D (gray)	41	59	Cellulose nitrate	Approx 24.4	Approx 39.0	Esters (as Et. Ac.)	Min 40.
			Glycol sebacate	Approx 24.4		Alcohols (bp. above 115°)	Min 14.
			Glyceryl-phthalate	Approx 12.2		Alcohols (bp. below 115°)	Max 6.
						Aromatic hydrocarbons	Max 40.

had been applied, the films were loosened at the edge with a razor blade and stripped from the panel with the aid of a steel spatula. Disks approximately 72 mm in diameter were cut from the films for the permeability tests, and their average thickness was determined with a dial gage.

2. MEASUREMENT OF PERMEABILITY TO MOISTURE

The rate of transfer of moisture through paint films, wrapping materials, and other membranes has been measured by a number of investigators. Selected literature references on this subject are appended. The method has been gravimetric in nearly every case, but the procedures have varied considerably. The following method
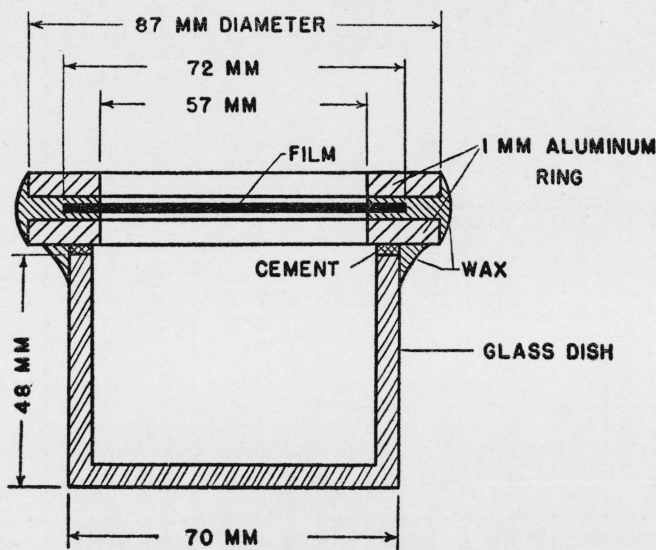

FIG. 1.—*Diagram of cell used for measurement of permeability to moisture.*

is a convenient one and gives results which are comparable with many of the published data.

The film to be tested is sealed on a glass dish, containing phosphorus pentoxide, water, or a saturated salt solution which will produce the desired relative humidity inside the cell (fig. 1). The chemicals used are shown in table 2, together with the calculated vapor-pressure differences between the two sides of the films in the tests. The cells are placed in a cabinet in which the temperature and relative humidity are controlled and are then weighed on a Chainomatic analytical balance at approximately 3-day intervals until a constant for the moisture permeability has been established. Glass crystallizing dishes known as Tanners Special were used for the cells. These dishes are 70 mm in outside diameter, 50 mm deep, and weigh approximately 35 g. A rough-ground rather than a fire-polished edge is to be preferred on these dishes. An aluminum ring of 57 mm inside diameter and 87 mm outside diameter was fastened to the rim of the dish with Cementyte of hard grade. A melted mixture of equal parts of beeswax and rosin was used to seal the outer edge of the dish

to the metal and to close any cracks between them. The disk cut from the film was attached to another aluminum ring with the beeswax-rosin mixture and subsequently sealed to the aluminum ring on the cell with the same material. This served to limit the exposed area of the film between the two rings to 25.5 cm ^{2} and to prevent edge leakages.

TABLE 2.—*Reagents used to obtain various relative humidities*

Chemical	Temperature	Relative humidity	Vapor pressure	Vapor-pressure difference between cell and cabinet
	°F	Percent	mm Hg	mm Hg
H₂O	70	100	18.77	6.6
KNO₃	70	94	17.6	5.4
NH₄H₂PO₄	70	93	17.5	5.3
NaCl	70	76	14.3	2.1
Cabinet	70	65	12.2	
MgCl₂	70	33	6.2	6.0
P₂O₅	70	0	0	12.2
H₂O	85	100	30.75⁻	8.9
KNO₃	85	92	28.3	6.5
NH₄H₂PO₄	85	93	28.6	6.8
NaCl	85	75	23.1	1.3
Cabinet	85	71	21.8	
MgCl₂	85	32	9.8	12.0
P₂O₅	85	0	0	21.8
H₂O	100	100	49.16	14.3
KNO₃	100	90	44.2	9.3
NH₄H₂PO₄	100	93	45.7	10.8
NaCl	100	75	36.9	2.0
Cabinet	100	71	34.9	
MgCl₂	100	31	15.2	19.7
P₂O₅	100	0	0	34.9

III. PERMEABILITY TO MOISTURE OF FILMS OF VARIOUS AIRCRAFT FINISHES

The amounts of moisture transmitted by the aircraft finishes listed in table 1 were determined for different film thicknesses at various temperatures and relative humidities. The variation in the thickness of a film was about ±0.1 mil. The values obtained for permeability in grams per hour, as determined by weighing the cells at intervals of 3 to 4 days, varied within approximately ±2.5 percent of the average; the reproducibility with different films was approximately ±5 percent. In order to readily compare the results obtained with the different materials, the rate of transmission of moisture for 1 mil thickness was calculated. The assumption was made that the permeability is inversely proportional to the thickness. These calculated values are presented in table 3. The materials are listed in the table in the approximate order of increasing permeability as determined at the three different temperatures.

The exposure environment in which the cell contains water-saturated air on the inside will be referred to as the wet condition; when the air in the cell is dried with phosphorus pentoxide and moisture is transferred through the film from the outside air, which is 65 to 71 percent saturated, the exposure environment will be designated as the dry condition. It will be noted that two of the three primers studied, namely, *P-27* and *P-24*, are less permeable to moisture under both wet and dry conditions than are the remaining finishes. The

glyceryl-phthalate enamels are less permeable to moisture under dry conditions than are the enamels made with a phenol-formaldehyde resin (Bakelite *XR–254*); this order is reversed, however, under wet conditions, the three phenol-formaldehyde films becoming less permeable than the glyceryl-phthalate type. This corresponds with the service uses to which these finishes have been found to be best adapted. Thus, the phenol-formaldehyde finishes are used on parts which come in contact with water, such as hulls, fuselages, etc., whereas the glyceryl-phthalate materials are applied to the external superstructure which is above the water line. The aircraft finish made with a cellulose nitrate base, *L–8*, is very permeable to water vapor under both wet and dry conditions. In service this material is used only for insignia overdoped surfaces.

TABLE 3.—*Permeability to moistuɾe of aircraft finishes calculated to films 1 mil thick and listed in the approximate order of increasing permeability*

Material	Relative humidity in cell	Permeability at—					
		70° F and 65-percent relative humidity		85° F and 71-percent relative humidity		100° F and 71-percent relative humidity	
	Percent	g/hr/m²	g/hr/m²/ mm Hg	g/hr/m²	g/hr/m²/ mm Hg	g/hr/m²	g/hr/m²/ mm Hg
P–27	0	0.41	0.03	0.93	0.04	1.46	0.04
P–24	0	.70	.06	1.40	.06	2.40	.07
E–6	0	.67	.05			3.22	.09
E–5	0	.90	.07	1.75	.08	2.59	.07
M–67	0	1.06	.09	2.09	.10	3.28	.09
P–23	0	.86	.07	2.11	.10	4.08	.12
E–4	0	.98	.08	2.29	.11	4.74	.14
V–11	0	1.40	.11	3.29	.15	6.82	.20
V–10	0	1.47	.12	3.39	.16	7.11	.20
L–8	0	2.37	.19	5.30	.24	17.14	.49
P–24	100	.44	.07	.83	.09	2.36	.17
P–27	100	.73	.11	1.33	.15	3.45	.24
E–4	100	.79	.12	1.44	.16	3.46	.24
P–23	100	.88	.13	1.59	.18	3.26	.23
M–67	100	.94	.14	1.62	.18	3.50	.24
E–6	100	1.07	.16			4.90	.34
V–10	100	1.10	.17	2.01	.23	4.85	.34
V–11	100	1.41	.21	2.46	.28	5.75	.40
E–5	100	1.89	.29	3.15	.35	6.19	.43
L–8	100	4.53	.69	7.68	.86	15.32	1.07

The clear varnishes, phenol-formaldehyde base *V–10* and glyceryl-phthalate base *V–11*, showed the same reversal of permeability under wet and dry conditions, respectively, as the pigmented finishes prepared from them. Films with aluminum powder added to these varnishes were not studied, but the effect of this pigment has been determined and reported in a series of papers from the Aluminum Research Laboratories. They report that the permeability decreases regularly with increase in the concentration of aluminum powder and that in aluminum paints of the same pigment concentration the moisture permeability decreases as the mesh size of the powder decreases or the number of flakes per unit volume of film increases, until the moisture-proofing effect of the flakes eventually approximates that of a granular pigment. They attribute the beneficial effect of aluminum powder to the structure presented by overlapping flakes, which greatly increases the diffusion path.

IV. FACTORS INFLUENCING THE RATE OF PASSAGE OF MOISTURE THROUGH THE FILMS

1. VAPOR-PRESSURE DIFFERENCE

The vapor-pressure difference is determined from the temperature and relative humidity of the atmospheres on the two sides of the film. It can be varied experimentally either by raising or lowering the temperature or by using various reagents to obtain a range of relative humidities. The effect of vapor-pressure difference on moisture transmission of the various coating materials is shown in tables 3 and 4, in which the permeability, expressed as grams per hour per square meter, have been converted to grams per hour per square meter per millimeter of mercury by dividing by the differences in vapor pressure recorded in table 2. It was found that when the temperature is constant and the relative humidity varied, the permeability is not directly proportional to the vapor-pressure difference. In the case of the materials which have low permeabilities, the values found at relative humidities below 75 percent are approximately constant; likewise those from 75 to 100 percent give a constant which, however, is somewhat greater than for the lower relative humidities. For films of cellulose nitrate lacquer which are much more permeable to moisture, the rates of transmission are not at all proportional to vapor-pressure differences, but increase more rapidly than the vapor-pressure difference as the relative humidity is raised. These results partially confirm the conclusions reached by Charch and Scroggie in an investigation of the permeability to water vapor of cellulose wrapping materials. They found that the permeability of a given type of sheet is directly proportional to the vapor-pressure difference existing during the test only when the materials are reasonably impermeable and then only at a relative humidity well below saturation.

2. TEMPERATURE

The effect of raising the temperature at which the test cell is exposed is shown in tables 3 and 4. The permeability in grams per hour per square meter is, of course, greater, since the vapor-pressure difference is increased. Moreover, the permeability per unit-pressure difference is also increased with rising temperature. It will be noted that a greater spread exists between the experimental results obtained with the various types of films at 100° F than at the lower temperatures. For this reason it is preferable to study the various materials at the higher temperature, which is not in excess of conditions to be met in service. This temperature is not sufficient to cause the resinous films to break down during the period of the test, as was shown by determinations of moisture permeability at 70° F after conclusion of the 100° F exposures. The rates measured at such time duplicated those measured initially at 70° F on the same films.

3. TIME

A certain length of time is required for water vapor to diffuse uniformly through the film and set up a steady state of emission from the drier side. This equilibrium was very quickly attained with the materials investigated. However, the cells were kept at least 48 hours under the test conditions before the first weighing was made.

TABLE 4.—*Effect of varying vapor-pressure difference on the permeability to moisture of films of aircraft finishes*

COATING V-11

Relative humidity in cell	Permeability at—					
	70° F and 65-percent relative humidity, calculated for 1 mil thickness		85° F and 71-percent relative humidity, calculated for 1 mil thickness		100° F and 71-percent relative humidity, calculated for 1 mil thickness	
Percent	g/hr/m²	g/hr/m²/ mm Hg	g/hr/m¹	g/hr/m²/ mm Hg	g/hr/m⁷	g/hr/m²/ mm Hg
0	1.20	0.10	2.97	0.14	6.26	0.18
32 to 33	.72	.12	1.74	.15	3.51	.18
75 to 76	.38	.18	.34	.26	.83	.41
93	1.10	.21	1.68	.25	3.72	.35
90 to 94	1.04	.19	1.62	.25	3.14	.34
100	1.37	.21	2.47	.28	5.86	.41

COATING V-10

0	1.29	.11	3.02	.14	7.00	.20
32 to 33	.72	.12	1.67	.14	3.39	.17
75 to 76	.34	.16	.28	.22	.65	.32
93	.81	.15	1.20	.18	2.32	.22
90 to 94	.79	.15	1.25	.19	2.51	.27
100	.96	.15	1.87	.21	5.26	.37

COATING E-4

0	1.05	.09	2.44	.11	5.12	.15
32 to 33	.59	.10	1.38	.12	2.72	.14
75 to 76	.22	.10	.22	.17	----------	----------
93	.73	.14	1.09	.16	2.17	.20
100	.74	.11	1.36	.15	3.17	.22

COATING E-6

0	.66	.05	----------	----------	2.75	.08
32 to 33	.28	.05	----------	----------	1.56	.08
75 to 76	.29	.14	----------	----------	1.34	.67
93	.50	.09	----------	----------	2.45	.23
100	.86	.13	----------	----------	4.30	.30

COATING L-8

0	1.75	.14	4.43	.20	----------	----------
32 to 33	1.03	.17	2.49	.21	6.45	.33
75 to 76	.54	.26	.50	.38	1.37	.69
93	2.41	.45	3.66	.54	7.28	.67
100	4.19	.64	6.85	.77	12.22	.86

The age of the film has been found by Edwards and Wray to have an important bearing on the moisture permeability. The results recorded herein were obtained on films which had been air-dried approximately 30 days before starting the tests.

4. COMPARATIVE BEHAVIOR OF LIQUID WATER AND AIR SATURATED WITH MOISTURE

A large number of tests were made to determine whether water in contact with the films would be transmitted at the same rate when in the vapor and the liquid state. The latter condition was obtained by turning the cell upside down. In most cases the rates were observed to be the same within the experimental error, as indicated in table 5.

TABLE 5.—*Comparative permeability of films of aircraft finishes to liquid water and to saturated water vapor*

COATING V-11

Film thickness	Exposure environment in cell S=saturated water vapor; W=liquid water	Permeability at—		
		70° F and 65-percent relative humidity	85° F and 71-percent relative humidity	100° F and 71-percent relative humidity
mils		g/hr/m²	g/hr/m²	g/hr/m²
2.5	S	0.50	0.96	2.52
2.5	W	.49	.91	2.29
5.3	S	.26	.47	1.09
5.2	W	.25	.45	1.02
7.7	S	.18	.34	.80
7.7	W	.22	.36	.81
COATING E-6				
2.0	S	.43	--------------	2.15
2.0	W	.43	--------------	1.92
3.8	S	.27	--------------	1.33
3.5	W	.31	--------------	1.41
5.7	S	.23	--------------	.94
5.6	W	.20	--------------	.86
COATING V-10				
3.0	S	.32	.62	1.75
3.0	W	.36	.77	1.43
5.9	S	.20	.34	.78
6.0	W	.18	.33	.74
9.0	S	.13	.24	.54
8.9	W	.13	.23	.54
COATING E-4				
2.0	S	.35	.66	1.63
2.1	W	.35	.61	1.59
4.0	S	.18	.34	.79
3.9	W	.21	.36	.83
6.3	S	.15	.26	.61
6.3	W	.15	.26	.58
COATING L-8				
3.2	S	1.31	2.14	3.82
3.4	W	1.26	2.21	3.69
8.2	S	.60	1.04	1.94
8.2	W	.64	1.08	--------------
11.8	S	.38	.65	1.51
11.9	W	.38	.67	--------------

5. EFFECT OF WAX FINISH ON THE PERMEABILITY TO MOISTURE OF THE FILMS

Wax is much less permeable to water than the varnishes. This property of waxes is utilized commercially in the coatings of wrapping papers and for the protection of automobile finishes. It has also been found that the leaves and fruits of many plants are covered with a layer of wax which retards the loss of moisture.

The effect of a coating of carnauba wax on the permeability to moisture of aircraft finishes was determined in the course of the present study. Films prepared on amalgamated tin-plate were dipped in an aqueous ammonia solution of this wax and allowed to drain and dry. They were stripped from the plate and tested for moisture perme-

ability by the process outlined above. The results are shown in table 6. The films used were 2 to 3 mils thick and each coating of wax was about 0.2 mil. The additional protection afforded by the thin film of wax against passage of moisture was found to be considerable, being in some cases equivalent to doubling the thickness of the original film.

Carnauba wax is one of the vegetable type and consists largely of fatty acid esters of mono- and dihydric alcohols mixed with the related free acids, alcohols and hydrocarbons. It contains oxygen in the form of hydroxyl groups and ester linkages and has a greater affinity for water, therefore, than the paraffin waxes. These latter materials are nonsaponifiable and consist of mixtures of saturated hydrocarbons.

TABLE 6.—*Effect of wax coating on the permeability to moisture of films of aircraft finishes*

COATING V-11

Film thickness	Coats of wax	Relative humidity in cell	Permeability at—		
			70° F and 65-percent relative humidity	85° F and 71-percent relative humidity	100° F and 71-percent relative humidity
mils		%	g/hr/m^2	g/hr/m^2	g/hr/m^2
2.5	0	100	0.50	0.96	2.52
2.7	1	100	.37	.68	1.49
2.8	2	100	.30	.48	1.21

COATING V-10

3.1	0	0	.42	.97	2.26
3.2	1	0	.32	.69	1.49
3.0	2	0	.25	.55	1.19
3.0	0	100	.32	.62	1.75
3.3	1	100	.29	.49	1.16
3.1	2	100	.23	.42	----------

COATING E-4

2.0	0	0	.35	.91	1.88
2.2	1	0	.36	.83	1.65
2.7	2	0	.27	.62	1.25
2.0	0	100	.35	.66	1.63
2.3	1	100	.34	.54	1.13
2.5	2	100	.26	.41	.81

COATING L-8

3.2	0	100	1.31	2.14	3.82
3.0	1	100	1.14	1.85	3.37
3.6	2	100	.84	1.69	3.07

V. ABSORPTION OF MOISTURE BY RESINOUS FILMS

The amount of moisture absorbed at various relative humidities by films of glyceryl-phthalate enamel *E-6* and phenol-formaldehyde primer *P-23* was determined by the same method previously used in a study of aircraft fabrics. The results are shown in tables 7 and 8.

TABLE 7.—*Change in weight of glyceryl-phthalate films (E-6) which have been conditioned in air at 21° C and 65-percent relative humidity when they are exposed at other relative humidities*

Relative humidity	Thickness of film	Percentage change in weight on exposure for various periods—								6 months
		Hours			Days		Weeks			
		1	3	6	1	4	1	2	4	
%	mils	%	%	%	%	%	%	%	%	%
0	6	−0.5	−0.9	−1.1	−1.4	−1.5	−1.5	−1.5	−1.5	−1.6
6	6	−.5	−.8	−1.1	−1.2	−1.3	−1.3	−1.3	−1.3	−1.4
33	6	−.2	−.5	−0.6	−0.7	−0.8	−0.8	−0.8	−0.8	−1.0
65	6					−.1	−.2		−.2	−0.3
86	4	.4	.6	.8	.9	.9	.9	.8	.7	.4
94	4	.5	.9	1.1	1.4	1.5	1.5	1.5	1.5	1.0
97	6	.5	.8	1.2	1.7	2.0	2.2	2.7	3.2	4.1
97	4	.7	1.1	1.5	2.0	2.2	2.4	2.9	3.4	4.6
97	2	.9	1.4	1.6	2.1	2.4	2.4	2.9	3.4	4.4
100	4	1.0	1.7	2.2	3.6	5.5	6.0	8.2	11.9	a 41.7

a Moisture condensed on film.

TABLE 8.—*Change in weight of phenol-formaldehyde films (P-23) which have been conditioned in air at 21° C and 65-percent relative humidity when they are exposed at other relative humidities*

Relative humidity	Thickness of film	Percentage change in weight on exposure for various periods—								6 months
		hours			days		weeks			
		1	3	6	1	4	1	2	4	
%	mils	%	%	%	%	%	%	%	%	%
0	8	−0.3	−0.4	−0.5	−0.7	−0.8	−0.8	−0.8	−0.8	−0.8
6	8	−.3	−.4	−.5	−.6	−.6	−.6	−.6	−.6	−.8
33	8	−.1	−.2	−.3	−.4	−.4	−.4	−.4	−.4	−.6
65	8					.1	−.1		−.1	−.1
86	8	.1	.2	.3	.4	.4	.4	.4	.3	−.1
94	8	.2	.3	.5	.9	.9	1.0	1.0	1.0	.5
97	8	.2	.5	.7	1.3	1.8	2.1	2.6	3.1	4.8
97	5	.3	.6	.8	1.4	1.9	2.2	2.6	3.1	4.6
97	3	.4	.6	.8	1.3	1.8	2.0	2.4	2.9	4.8
100	8	.3	.6	.9	1.8	3.4	4.2	6.1	9.6	a 34.7

a Moisture condensed on films.

It will be noted that the percentage change in weight for both materials at relative humidities of 94 percent or less is practically negligible, being not more than 1.5 percent in any case. Furthermore, equilibrium is practically attained under such conditions after 24 hours. At relative humidities of 97 and 100 percent the absorption of moisture continues over long periods, although in the former case it does not exceed 5 percent. The experiments at 97-percent relative humidity with various thicknesses of films indicate that the final percentage absorption is the same, but that the rate of absorption is somewhat slower for the thicker films.

VI. PERMEABILITY TO MOISTURE OF GELATIN-LATEX GAS-CELL FABRICS

Some observations on the absorption of moisture by gas-cell fabrics were previously reported in this journal.[2,3] It was believed that information on the permeability of some of these same fabrics would be of value in estimating the amount of moisture which would be transmitted into the cells during periods of high relative humidity.

The gas-cell fabrics which were tested for permeability to moisture are described in table 9, which, except for thickness measurements, is taken from the reference in footnote 3. The fabric designated as *Q39-A-10* contains less gelatin than the standard light-weight fabric *Q39-A-2*, and is hereafter referred to as "improved fabric."

Disks of 72 mm diameter were cut out and sealed to the glass cells by the method previously described. The films were attached with the normally "outside" surface of the fabric exposed to the interior of the cell.

The results obtained at various temperatures and relative humidities are presented in table 10. In order to show a ready comparison between permeability and the amount of paraffin on the fabric, the materials have been listed in table 10 in their order of increasing permeability to moisture. It will be noted that for gas-cell fabrics coated with paraffin, the improved fabric is in every case less permeable to moisture than the standard material. Likewise the paraffin-coated materials are, in general, superior to the fabrics coated with aluminum varnish; this is particularly true for tests at low relative humidity. Under the wet conditions, the painted fabrics were less permeable than certain of the paraffined fabrics; however, the threefold to sixfold greater weight of the paint film corresponding to an increased thickness of coating material must be considered.

TABLE 9.—*Description of gas-cell fabrics studied*

Fabric sample no.	Type of coating	Thickness of coated fabric	Weight of coated fabric	Amount of coating indicated by manufacturer		Total paraffin found
				Inside	Outside	
GOODYEAR CODE *Q39-A-2* FABRIC						
		mils	oz/yd²	oz/yd²	oz/yd²	oz/yd²
1	Paraffin	7.0	5.41		0.2	0.3
2	___do___	7.1	5.66		.4	.6
3	___do___	7.4	5.83	0.2	.2	.7
4	___do___	7.4	5.96	.2	.4	.8
5	Paraffin and Goodyear code 755C aluminum paint a	7.5	5.94	.2	{ 0.2 paraffin 0.2 Al paint }	c.6
6	Aluminum powder in flexible spar varnish b	8.4	7.30			
GOODYEAR CODE *Q39-A-10* FABRIC						
7	Paraffin	7.1	5.58		0.2	0.35
8	___do___	7.2	5.82		.4	.6
9	___do___	7.9	6.00	0.2	.2	.8
10	___do___	7.8	5.96	.2	.4	.8
11	Paraffin and Goodyear code 755C aluminum paint a	8.0	6.07	.2	{ 0.2 paraffin 0.2 Al paint }	c.7
12	Aluminum powder in flexible spar varnish b	8.4	6.95			

a The aluminum paint and the flexible spar varnish are apparently of different compositions.
b Flexible spar varnish containing aluminum dust is applied to both surfaces. Total weight of coating for sample 6 is 2.2 oz/yd²; for sample 12 is 1.8 oz/yd².
c Value may be slightly high as a result of breakdown of the paint coating.

2 G. M. Kline, J. Research NBS 14, 67–84 (1935) RP758.
3 D. F. Houston, J. Research NBS 15, 163–172 (1935) RP818.

TABLE 10.—*Permeability to moisture of gas-cell fabrics listed in the approximate order of increasing permeability*

Fabric sample no.	Paraffin on fabric	Relative humidity in cell	Permeability at—					
			70° F and 65-percent relative humidity		85° F and 71-per cent relative humidity		100° F and 71-per cent relative humidity	
	oz/yd²	%	g/hr/m²	g/hr/m²/ mm Hg	g/hr/m²	g/hr/m²/ mm Hg	g/hr/m²	g/hr/m²/ mm Hg
9	0.8	0	0.047	0.004	0.114	0.005	0.47	0.013
11	.7	0	.059	.005	.133	.006	.39	.011
3	.7	0	.063	.005	.141	.006	.55	.016
10	.8	0	.067	.005	.153	.007	.55	.016
4	.8	0	.067	.005	.157	.007	.59	.017
8	ª.6	0	.086	.007	.200	.009	.63	.018
5	.6	0	.106	.009	.255	.012	.86	.025
7	ª.35	0	.110	.009	.263	.012	1.14	.033
2	ª.6	0	.165	.014	.392	.018	1.10	.032
12	0	0	.270	.022	.564	.026	1.37	.039
1	.3	0	.239	.020	.568	.026	1.92	.055
6	0	0	.317	.026	.674	.031	1.10	.032
9	.8	100	.031	.005	.071	.008	.20	.014
10	.8	100	.031	.005	.086	.010	.39	.027
11	.7	100	.039	.006	.090	.010	.24	.017
4	.8	100	.071	.011	.165	.019	.27	.019
5	.6	100	.094	.014	.168	.019	.51	.036
3	.7	100	.102	.015	.212	.024	.39	.027
8	ª.6	100	.188	.028	.341	.038	.86	.060
6	0	100	.235	.036	.404	.045	1.18	.083
12	0	100	.345	.052	.596	.067	1.18	.083
7	ª.35	100	.294	.045	.604	.068	1.45	.101
1	ª.3	100	.353	.053	.819	.092	2.39	.167
2	ª.6	100	.435	.066	.948	.107	1.96	.137

ª Paraffin on only 1 side of fabric.

Insofar as the effects of temperature and relative humidity on the rate of transmission of moisture through gas-cell fabrics are concerned, the directions of the changes are the same as were observed with paint films. The data in tables 10 and 11 indicate that raising the

TABLE 11.—*Effect of varying relative humidity on the permeability to moisture of paraffined gas-cell fabric*

Fabric sample no.	Relative humidity in cell	Permeability at—			
		70° F and 65-percent relative humidity		100° F and 71-percent relative humidity	
	%	g/hr/m²	g/hr/m²/mm Hg	g/hr/m²	g/hr/m²/mm Hg
3	0	0.063	0.005	0.55	0.016
3	31 to 33	.031	.005	.31	.016
3	75 to 76	.008	.004	.08	.040
3	93	.024	.005	.20	.019
3	100	.102	.015	.39	.027

temperature causes the permeability per unit difference in vapor pressure to increase under both wet and dry conditions, the increase being even greater for the paraffined fabrics than for the paint films. For the fabrics exposed at the lower relative humidity, there is a considerable percentage increase only when the temperature is raised from 85 to 100° F, whereas in saturated water vapor the percentage increase between 70 and 85° F is fairly comparable to that between 85 and 100° F. The anomalous behavior under the dry conditions

cannot be attributed to increase in moisture content of the air, since the percentage increase in moisture content per unit volume in going from 70° F and 65-percent relative humidity to 85° and 71-percent relative humidity is greater than that in going from the latter condition to 100° F and 71-percent relative humidity. It is probable that the difference in the amount of moisture held by the gelatin-latex fabric at the high and low relative humidities is an important factor in the influence of temperature on the moisture permeability.

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